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Also, the ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering, Tome XVI [2023], Fascicule 1 [January–March], includes scientific papers presented in the sections of:

- IRMES 2022 – 10th International Conference on Research and Development of Mechanical Elements and Systems: "Machine design in the context of Industry 4.0 – Intelligent products", organized under the auspices of the Association for Design, Elements and Constructions (ADEKO) and University of Belgrade, Faculty of Mechanical Engineering, Department of General Machine Design, in 26 May 2022, Belgrade (SERBIA). The current identification numbers of the selected papers are the #01–04, according to the present contents list.
- ISB–INMA TEH' 2022 – International Symposium (Agricultural and Mechanical Engineering), organized by Politehnica University of Bucharest – Faculty of Biotechnical Systems Engineering (ISB), National Institute of Research–Development for Machines and Installations Designed to Agriculture and Food Industry (INMA Bucharest), Romanian Agricultural Mechanical Engineers Society (SIMAR), National Research & Development Institute for Food Bioresources (IBA Bucharest), National Institute for Research and Development in Environmental Protection (INCDPM), Research–Development Institute for Plant Protection (ICDPP), Research and Development Institute for Processing and Marketing of the Horticultural Products (HORTING), Hydraulics and Pneumatics Research Institute (INOE 2000 IHP) and "Food for Life Technological Platform", in Bucharest, ROMANIA, between 06–07 October, 2022. The current identification numbers of the selected papers are the #11–13, according to the present contents list.
- IIZS 2021 – XI International Conference on Industrial Engineering and Environmental Protection, organized by Department of Mechanical Engineering, Department of Environmental Protection and Department of Industrial Engineering in Exploitation of Oil and Gas, Technical Faculty Mihajlo Pupin Zrenjanin, University of Novi Sad (SERBIA), in cooperation with partners University Politehnica Timisoara, Faculty of Engineering, Hunedoara (ROMANIA), University St. Kliment Ohridski, Technical Faculty, Bitola (MACEDONIA), Aurel Vlaicu University of Arad, Faculty of Engineering, Arad (ROMANIA), University of East Sarajevo, Faculty of Mechanical Engineering East Sarajevo (BOSNIA & HERZEGOVINA) and University of Giresun, Faculty of Engineering, Giresun (TURKEY), in Zrenjanin, SERBIA, in 06–07 October, 2022. The current identification numbers of the selected papers are the #16–18, according to the present contents list.

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ACTA TECHNICA CORVINIENSIS – BULLETIN OF ENGINEERING
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[1.] Isak KARABEGOVIĆ

SENSORY TECHNOLOGY IS ONE OF THE BASIC TECHNOLOGIES OF INDUSTRY 4.0 AND THE FOURTH INDUSTRIAL REVOLUTION

[1.] Academy of Sciences and Arts of Bosnia & Herzegovina, Sarajevo, BOSNIA & HERZEGOVINA

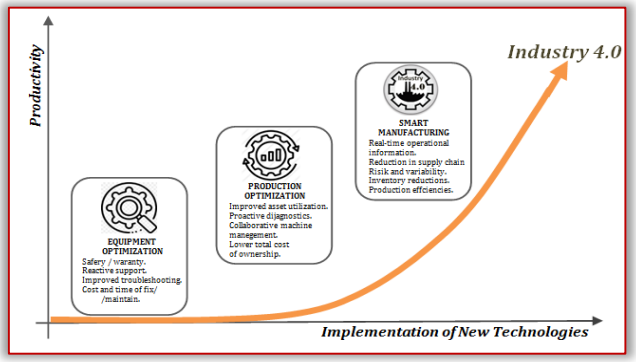
Abstract: Digital transformation of the production process or the entire value chain, from component to system and from supplier to customer, is the key to hidden value that can contribute to the company's productivity, compliance, profitability, and quality of the finished product. Connected production processes in the company are realized by converging information technology (IT) and operational technology into a single one, which results in the introduction of flexible industrial automation of production processes. These technologies connect the physical and virtual worlds with the Internet of Things (IoT) in order to better collect and analyze data, turning it into information that reach the decision–makers. All of the above cannot be achieved without the implementation of smart sensors that provide information at all times. Industry 4.0 can be implemented in production processes only by using smart sensors, and they, along with other technologies, are responsible for fully flexible automation of production processes, which brings a number of advantages such as shortening product development time and reducing manufacturing costs. The application of smart sensors makes production processes more efficient, and we have the ability to optimize them. The paper presents the basics of smart sensors, their role in Industry 4.0 as well as examples of their implementation in production processes.

Keywords: smart sensors, Industry 4.0, implementation, production system

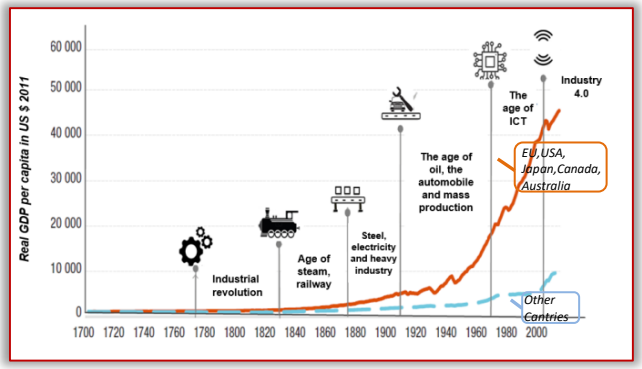
INTRODUCTION

All companies in the world as facing global competition, and in order to keep up with the competition and meet the growing demands of the market, it is necessary to use new technologies in production processes, i.e. implement Industry 4.0. In other words, digital transformation is needed to make a connected company that enables production processes to discover new ways to increase productivity and improve overall business performance. Industry 4.0 helps to increase productivity as well as improve the company's overall business performance [1,2,3]. To ensure this, it is necessary to have a secure connection between the various production systems and processes throughout the company. The new way of managing production processes aims to improve performance, make better use of data that already exist, and use a combination of tools that can improve the system or production process. The digitalization performed throughout the company, integration of processes, serial and discrete, drives, and movement into one connected infrastructure increases efficiency and productivity in all segments of companies. The access to production data in the production process at any time in real time allows us to monitor and improve the performance of the production process itself. Many companies around the world have developed different sensor designs to measure different physical sizes [1,7,8,9]. Currently, great changes are happening every day in all industries, including the transformation of production processes, increasing flexible automation of production processes, new form of delivery of finished products, and a new way of consumption, all thanks to the implementation of Industry 4.0. The basic technologies on which Industry 4.0 is based are: robotics and automation, smart sensors, Big Data, Internet of Things (IoT), 3D printing, radio frequency identification (RFID), virtual and augmented reality (AR), artificial intelligence (AI), advanced security systems, etc. [10–13]. The application of Industry 4.0 brings a number of advantages such as flexible automation, and bridging the physical and digital world through cyber physical systems (CPS). Greater and more open integration in manufacturing companies is enabled by cyber physical system (CPS) and Internet of Things (IoT) through horizontal integration (reflected in the exchange of information and data, networking of production processes, communication integration: procurement–production–logistics, and inclusion of customers in the production process), and vertical integration (connectivity in the company from the operational level to the production itself). The implementation of base technologies can optimize the following: equipment in the production process so that we have greater safety, improved problem–solving, equipment safety, improved maintenance, self–production so that we improve the use of tools, proactive diagnostics, collaboration and management machines, and lower total costs [14–19]. The goal of implementation of Industry 4.0 core technologies is smart manufacturing where we have real–time operational information, reduce supply chain risk, reduce inventory, achieve the efficient production (Figure 1.a), as well as growth of GDP (Figure 1.b). It is necessary

to build a set of skills both inside and out. An illustration of how to achieve smart manufacturing using Industry 4.0 implementation in companies is shown in Figure 1.



a – application of base technologies of Industry 4.0 increases productivity



b – the impact of technological change on GDP growth

Figure 1. Implementation of base technologies of Industry 4.0 –a, and their impact on GDP growth – b [6]

A graphical representation of the implementation of base technologies in Industry 4.0, their impact on technological change and inequality over the centuries, and GDP growth are shown in Figure 1. The analysis of Figure 1.b) has shown that the biggest jump in living standards due to investment in research, development and the implementation of advanced technologies happened in the last fifty years. Worldwide, many leading companies are investing and implementing advanced technologies that are key Industry 4.0 technologies. These companies have made significant progress thanks to artificial intelligence, machine learning, and an increase in available data growing exponentially, as well as the improvement of statistical methods and advanced data analysis in digitization and automation in production processes. All this has been happening in the last ten years.The accelerated implementation of advanced technologies in Industry 4.0 has been significant since 2016, when the Fourth industrial revolution was announced at the World Economic Forum. In order to survive and be present in the global market, it is necessary for companies to optimize equipment, which must be reliable and safe, minimize equipment downtime, and improve problem solving. It is necessary to optimize the production processes (as shown in Figure 1–a) that are active in companies through improving the use of devices and machines, collaborative management of machines, proactive diagnostics, and reduction of overall costs. By introducing the technologies that form the foundation of Industry 4.0, we have real–time operational information and can act instantly which makes production efficient, reduces risk and supply chain variability, thus reducing inventory. The implementation of advanced Industry 4.0 technologies would not be possible without the use of smart sensors, defined by the IEEE 1451 Standard. The enhanced development of robotic and sensor technology, supported by information and communication technologies, is moving in the direction of communication between robots and humans, and the machines themselves.

SMART SENSORS AND THEIR CAPABILITIES IN PRODUCTION PROCESSES

Companies in the world engaged in the research, development and production of sensors for measuring different physical quantities have developed different sensor designs. Today, companies are in the phase of transformation of production processes, because they want to achieve greater automation of production processes with greater flexibility due to the higher customer requirements and survival in the global market. The implementation of advanced Industry 4.0 technologies such as: Internet of Things (IoT), Big Data, 3D printing, robotics, smart sensors, artificial intelligence (AI), virtual and augmented reality (AR), etc., provided a new way of consumption and a new form of delivery to the customer, since the customer wants to be involved in the production process. The implementation of Industry 4.0 cannot be achieved without the implementation of all the above mentioned advanced technologies. However, we must single out the basic sensor technology, because without the implementation of various smart sensors we could not monitored parameters in real time [1,3,17,18,20,21,22].Since there has been a development in all segments of society in all technologies, there has also been a historical development of sensors. The schematic representation of the development of sensor technology over time is given in Figure 2.

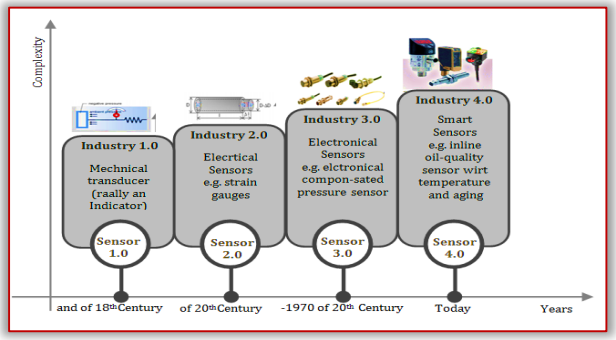


Figure 2. Schematic representation of the development of sensor technology over time

Based on Figure 2, we can conclude that sensor technology has had continuous development from the

first mechanical sensors, electrical sensors, and electronic sensors. Today smart sensors are being researched, developed and implemented to support the implementation of Industry 4.0 in production processes. By implementing smart sensors in all processes, as well as in production processes, we can monitor and obtain a large amount of data on the basis of which we make decisions.

Given that the world's leading companies are in the process of implementing Industry 4.0, and they are trying to follow other companies in the world to remain in the global market, the possibility of increasing the use of sensors, and thus improving the manufacture of products is reflected in the following [1,3]:

- Sensors help to detect defects, allowing quick adjustment of settings and change of parameters to prevent downtime in future production processes.
- Based on data provided by smart sensors and insights gained from production to the delivery process, the entire supply chain is managed much more efficiently.
- Scheduled machine maintenance allows companies to more effectively plan downtime and prevent downtime or breakdowns during the manufacturing process.
- Increases efficiency and productivity by integrating smart sensors.
- We are able to quickly change the production process of one product to the production of another product.
- Adaptation of the production process for another product is simulated practically before it is physically implemented in order to adequately assess the impact and reduce the chances of errors.
- Implementation of smart sensors leads to smart machines and devices.
- Analysis of data obtained through smart sensors helps to identify and prevent dangerous situations, and thus improves the health and safety of workers.
- Their implementation ensures planned maintenance and quality control.
- Energy consumption can be optimized by using advanced analytics, because we can monitor energy consumption and make decisions by using smart sensors.

We can maintain optimal productivity and efficiency at all times if we have information about what is happening on machines that are installed in production processes minute by minute. We are also able to avoid unplanned downtime and losses that occur in the production process. The integration of smart sensors provides us with all the necessary data to create a comprehensive image of the production process at every moment. The implementation of smart sensors enables the introduction and operation of smart machines that increase the productivity and efficiency of the production process. Their installation in the production process enables all possible parameter: temperature, pressure, flow level, movement to distance, control of the accuracy of the performed operation, monitoring of the production process, and many other parameters that we have not listed. We are able to have a comprehensive overview of the production process. By knowing the current situation in the production system and the state of the sensor, we can ensure and timely identify any type of potential malfunction in the production process, as well as the sensor itself. The installation of smart sensors in the production process with other necessary equipment is shown in Figure 3 [3]

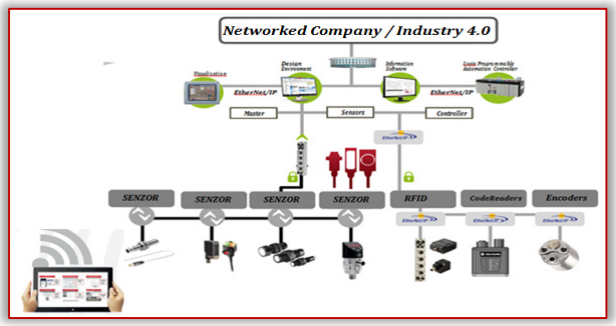


Figure3. Scheme of installation of smart sensors in the production process with accompanying equipment

The continuous flow of valuable process and diagnostic data, and the visualization system are enabled by smart sensors with informative software and programmable controllers, as shown in the configuration diagram in Figure 1. In this way, the company is connected, which provides efficiency and other advantages. Creating a connected company using smart sensors and smart machines reduces the complexity of production processes and errors [23,24,25].

They simplify access to available data that can help achieve overall equipment efficiency and average time between failures. Real–time diagnostics optimizes preventive maintenance and problem–solving that arises in the production process, which enables us to reduce the solution time by about 90 % [28]. The change time for each sensor is reduced, and there is the possibility of automatic device configuration to reduce the error when replacing the sensor. Within each production process there are many operations such as: material handling, material transport, execution of certain operations, assembly, packaging, varnishing, sorting, etc., which require smart sensor so that we can have data on the smooth performance of the operation.

When implementing sensors, we must identify key operations within the production system and define the area of focus in which we need to verify the conditions. We need to know what the system is doing or what we want it to do, such as counting products, performing quality checks, orienting parts, etc.[28,29,30]. We need to

know what the feedback is for each function, as well as what conditions must be met after each function to confirm that the function was performed correctly. When we have identified the areas in which the action takes place in the production process, it is necessary to make an analysis of whether each area is so important from the point of view of automation of the production process and monitoring data important in the production process. As we have seen, the application of smart sensors can occur in any production process. We need to choose the parameters to be monitored, make the right decision to install the appropriate smart sensor with other selected technology and continue to monitor the performance of appropriate tasks in the production process on mobile devices, as shown in the example in Figure 4.

Figure4. Implementation of smart sensors for collecting information in the production process

As Figure 4 shows, we are able to obtain information about performing operations on a mobile device. For the sake of illustration, Figure 4 shows the production process in which real–time data is monitored. The machine works normally (Figure 4.a)) and is monitored by mobile devices using smart sensors. Data is processed and monitored including activated output and measured data, the accuracy of the sensor, the state of communications, as well as data flow. It is observed that the sensor detects dust accumulation (Figure 4.b)). The operator has information about the type of sensor and where it is placed in the production process (Figure 4.c)). He provides information for maintenance, which act in a timely manner and eliminate the malfunction (Figure 4.d)), thus returning safe operating parameters (Figure 4.e)). Therefore, the monitoring of the production process can continue (Figure 4.f)). In this way, we can monitor the operation of all parameters of the production process that are important for that process at any time, so that we can take necessary measures and eliminate the shortcomings and allow the production process to work without errors. By implementing smart sensors in the production process, we are able to quickly adjust the production process for the production of another product, i.e., the transition from the production of one product to the production of another is very simple, as shown in Figure 5.

If the production process is set to manufacture one product, e.g., product (A) which we monitor using smart sensors, the setting of all parametersis defined for product (A), as shown in Figures 5.a and b). If we want to stop the product (A) and switch to the production of the product (B), we must give the command for that product on the mobile device, as shown in Figure 5.c).

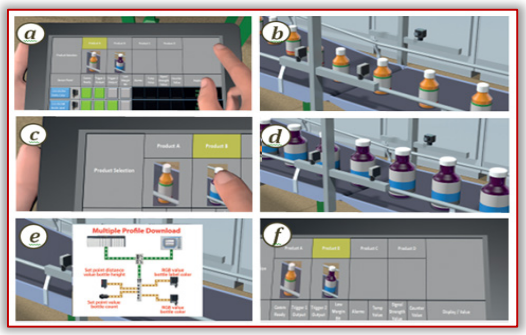


Figure5. Adjusting the production process to manufacture another product using smart sensors

The production of product (B) is initiated (Figure 5.d)) and profiles for four sensors that monitor the parameters in the production process (Figure 5.e) are downloaded. Smart sensors set new parameters for product (B) so that the machine is ready to manufacture another product. By implementing smart sensors in the production process, we can supervise, monitor, and control certain parameters when performing tasksat any time, all depending on which parameters are necessary for the production of the finished product to run smoothly. For the sake of illustration, an example is given in Figure 6.a). If we want to have information on which product is currently on the production line,we can obtain this information by implementing a radio frequency identification RFID sensor, since it is connected to PLC Logix controllers (Figure 6.b)) through a set network [30,31,32]. The control, information and monitoring of the current product packaging on the packaging section is shown in Figure 6. c, d), whereas the monitoring of products and raw materials at each stage from entry, production and shipment to the end customer isshown in Figure 6.e, f). We can achieve increased productivity and production efficiency by implementing smart sensors. We can also achieve detailed monitoring of products, as well as the visibility of the supply chain in order to make the right decisions on time. An example of monitoring certain positions in the production process by implementing smart sensors is shown in Figure 7. Depending on the production process, there are different positions for the application of smart sensors. In addition, the choice of information we are interested in will influence the choice of smart sensor that will be placed to monitor and obtain information [31,32].

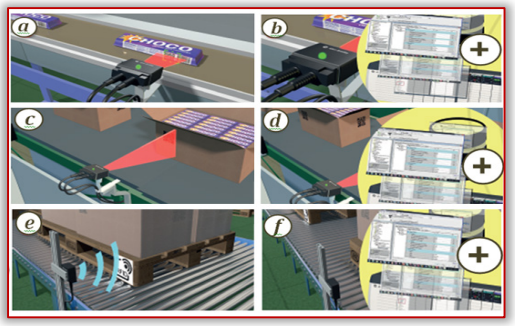


Figure 6. Monitoring of certain parameters with smart sensors in the production process

Figure 7 shows an illustrative example in which the temperature is monitored in the production process. There is a sensor that shows that the temperature is 45 °C, while the second position displays the application of pressure sensor which shows a pressure of 50 bars. In the third position, there is a proximity sensor that registers the positioning of the product on the 750 mm conveyor belt, while the power signal is 500 units. At the end of the production process, a sensor for counting parts was installed, which is now active and providing information that there are 1284 units of elements.

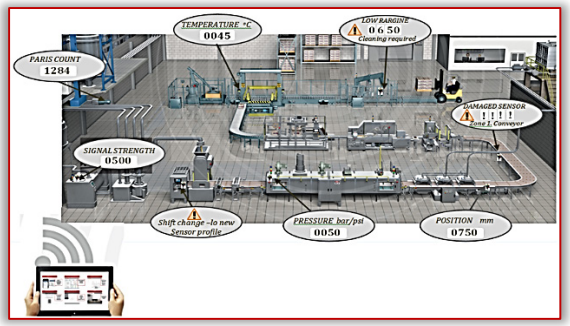


Figure 7. Mobile monitoring of production process parameters using smart sensors

Monitoring of the production process can take place on different devices, static screen or mobile device. In this particular example on the mobile device we have information about the problem on three sensors that we need to eliminate. The sensor in zone 1 is loaded on the conveyor belt, the second sensor needs cleaning, and the third sensor shows a warning that we have to change the sensor profile, i.e., we have to adjust the new sensor profile. When we have complete information given to us by smart sensors from the production process, we can act in time and eliminate errors so that the production process works normally. As we have seen in the concrete example on mobile devices in Figure 7, we can monitor the information in the production process, as well as problems on sensors that we need to eliminate. After analysing the obtained information, we can make a decision on what actions need to be performed, such as cleaning or changing the sensor profile. In other words, we need to adjust the new sensor profile. When we have complete information given to us by smart sensors from the production process, we can act in time and eliminate errors so that the production process works normally.

CONCLUSIONS

Industry 4.0 is the one that provides relevant answers to the fourth industrial revolution. It is already present in all industries, from production to sales of finished products. By introducing technologies that form the basis of the fourth industrial revolution or Industry 4.0 such as: smart sensors, robotics and automation, big data (Big Data), Internet of Things (IoT), 3D printing, radio frequency identification (RFID), virtual and augmented reality, artificial intelligence (AI), advanced security systems, etc., we can change processes and technologies as well as the organization of production and sales. The fourth industrial revolution brings disruption to almost every industry in the world, because it has a greater impact than we think. The impact is reflected on all sectors and companies, including large, medium and small companies. Industry 4.0 relies on advances in the use and sharing of information, and has such potential to connect almost anything and everything on the web, thus drastically improving the company's business performance. Small and medium enterprises can benefit from what Industry 4.0 has to offer, because by using the technologies mentioned in this chapter, they can more efficiently process and store data, and improve the way they design, manufacture and deliver their products. Currently, small companies can compete with big companies in a way they never could before. It is impossible to implement Industry 4.0 without smart sensors. They are the ones that give the first information about monitoring parameters in the production process. Their implementation provides the company with advantages, some of which are:

- lower operating costs
- improved business communication processes
- increased productivity of companies
- access to the world economic market is expanding (wide user base)
- provides companies of all sizes with greater outsourcing opportunities (external associates)
- thanks to the availability of new communication tools the cooperation of company departments and individuals is easier
- advanced achievements, such as blockchain technology, greatly increase the security of business and personal data
- reduced downtime in the production process,
- rapid adaptation of the production process to the production of another product

As we have seen, advanced technologies that include: IoT (Internet of Things), robotics, cloud computing, smart sensors, radio frequency identification, cyber–physical systems and big data, are key in the application of the Industry 4.0 concept, because they imply full digitalization

of all production processes, as well as creating an idea about a product, product engineering, production organization, process control, and the provision of industrial services. Based on all this, we can conclude that new constructions of smart sensors will be developed in the future, and their implementation in production processes, as well as in all segments of the human environment, will increase on a daily basis.

References

[1] Karabegović Isak, Karabegović Edina, Smart Sensors: Support for the Implementation of Industry 4.0 in Production Processes, Chapter 7. Handbook of Research on Integrating Industry 4.0 in Business and Manufacturing, IGI Global, USA, pp.147–163, (2020)
[2] Schwab, K.: The Fourth Industrial Revolution, World Economic Forum, Geneva, Switzerland, (2016)
[3] Karabegović, I., Kovačević, A., Banjanović–Mehmedović,L.,Dašić,P.:Integrating Industry 4.0 in Busniess and Manufacturing, IGI Global,Hershey, PA, USA, (2020)
[4] Chryssolouris, G., Mavrikios, D., Papakostas, N., Mourtzis, D., Michalos, G., Georgoulias, K.: Digital manufacturing: History, perspectives, and outlook, Journal of Engineering Manufacture, Proceedings of the Institution of Mechanical Engineers, Part B, pp.451–462(2009)
[5] Karabegović Isak and Karabegović E., The Role of Collaborative Service Robots in the Implementation of Industry 4.0,International Journal of Robotics and Automation Technology,Vol.6., 40–46, (2019)
[6] UNCTAD (2018) Technology and innovation report 2021, United Nations conference on Trade and Development; based on data from Maddison Project Database, version 2018, Bolt et al. (2018), Perez (2002), and Schwab (2013)
[7] Muller, J.M., Buliga, O., Voigt, K.I.: Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. Technological Forecasting and Social Change, Vol.132,Iss.C, pp.2–7 (2018)
[8] Isak Karabegović, The Role of Industrial and Service Robots in Fourth Industrial Revolution with Focus on China ,Journal of Engineering and Architecture ,Vol. 5, No. 2, pp. 110–117 , (2017)
[9] Edina Karabegovic, Isak Karabegovic, Edit Hadzalic (2012),Industrial Robot Application Trend in World's Metal Industry Inzinerine Ekonomika–Engineering Economics, , 23(4), 368–378
[10] Hermann, M.; Pentek, T.; Otto, B. Design principles for industry 4.0 scenarios. In Proceedings of the IEEE 2016, 49th Hawaii International Conference on System Sciences (HICSS), Koloa, HI, USA, pp. 3928–3937 (2016),
[11] Thoben, K.D.; Wiesner, S.; Wuest, T. Industrie 4.0 and smart manufacturing–a review of research issues and application examples. International Journal Automation Technology , Vol.11, pp.4–16 (2017)
[12] Karabegović, I.: The Role of Industrial and Service Robots in the Fourt Industrial Revolution, ACTE Technica Corviniensis–Bulletin of Engineering, University Politehnica Timisoara, Tome XI, Fascicule 2. April 2018. Hunedoara, Romania, pp.11–16 (2018)
[13] Karabegović. I., Karabegović, E., Mahmić, M., Husak, E.: The application of service robots for logistics in manufacturing processes, Advances in Production Engineering & Management, Vol. 10. No. 4. 2015,Maribor, Slovenia, EU, pp. 185–194 (2015)
[14] Karabegović, I., Karabegović, E., Mahmić, M., Husak, E.: Implementation of Industry 4.0 and Industrial Robots in Production Processes In: Isak Karabegović (eds) New Technologies, Development and Application II 2019. Lecture Notes in Networks and Systems. Springer Nature Switzerland AG 76, pp.96–102 (2020)
[15] Karabegović, I., Husak, E.: Industry 4.0 based on Industrial and Service Robots with Application in China, Journal Mobility and Vehicle, 44(4), pp.59–71 (2018)
[16] Karabegović, I.: The Role of Industrial and Service Robots in Fourth Industrial Revolution with Focus on China,Journal of Engineering and Architecture, 5(2), pp.110–117 (2017)
[17] Byeong, W.A. , Jung, H. S., So–Yun, K., Joohee, K., Sangyoon, J., Jihun, P., Youngjin, L., Jiuk, J., Young–Geun, P., Eunjin, C., Subin, J. & Jang–Ung, P. (2017). Smart Sensor Systems for Wearable Electronic Devices, Journal Polymers, 9(303),1–32
[18] Johan, H.H.,Frank R.R. & Gertvan H. (1994). Developments in integrated smart sensors, Sensors and Actuators A: Physical, 43(1–3), 276–288
[19] Karabegović I., Husak E.,Predrag D.:The Role of Service Robots in Industry 4.0 – Smart Automation of Transport, International Scientific Journal Industry 4.0, Vo.4. Iss.6. pp.290.292 (2019)
[20] Andreas, S., Nikolai, H., & Tizian, S. (2018). Sensors 4.0 – smart sensors and measurement technology enable Industry 4.0, Published by Copernicus Publications on behalf of the AMA Association for Sensor Technology,359–371.
[21] Gary, W. H., Joseph, R. S., Peter, J. H., & Chung–Chiun L. (2010). Smart Sensor Systems, The Electrochemical Society Interface, Winter 2010, 29–34.
[22] Karabegović Isak, Karabegović Edina, Mahmić Mehmed, Husak Ermin, The Implementation of Industry 4.0 by Using Industrial and Service Robots in the Production Processes, Chapter 1. Handbook of Research on Integrating Industry 4.0 in Business and Manufacturing, IGI Global, USA, pp.1–30, (2020), DOI: 10.4018/978–1–7998–2725–2.ch001
[23] Randy, F. (2013). Smart Sensors, Series: Artech House Remote Sensing Library, Massachusetts, Publisher–Artech House,
[24] Clarence, W.S. (2017). Sensor and Actuators, Engineering System Instrumentation, Second Edition, 2nd Edition, Florida, CRC Press.
[25] Bunse, B., Kagermann, H., & Wahlster, W. (2017). Industrie 4.0: Smart Manufacturing for the Future, Brochure, 20750. Germany Trade and Invest, Gesellschaft für Außenwirtschaft und Standortmarketing mbH, Berlin, Germany.
[26] Karabegović, I., Karabegović, E., Mahmić, M., & Husak, E. (2015). The application of service robots for logistics in manufacturing processes, Advances in Production Engineering & Management, 10(4); 185–194.
[27] Karabegović I., & Husak, E. (2018) Industry 4.0 based on Industrial and Service Robots with Application in China, Journal Mobility and Vehicle,44(4), 59–71
[28] Rockwel Aotomation. (2016). Condition Sensors and Switches, Publication 836E–BR001C–EN–P ,USA.
[29] Rockwel Aotomation. (2017). Get Smart, Key considerations for developing smart machines and equipment, Publication: OEM–SP019B–EN–P,USA.
[30] Rockwel Aotomation. (2016). Smart Sensors, Enabling Smart Machines for The Connected Enterprise, Publication IOLINK–BR001B–EN–P, USA.
[31] Rockwel Aotomation. (2011). Sensor Application Guide, Publication SENS–AT001B–EN–P–May2011, USA.
[32] Rockwel Aotomation. (2016). Integrated Smart Sensors, Publication SENSOR–BR002A–EN–P, USA.

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MACHINE SIMULATION OF ADDITIVE MANUFACTURING TOOL PATH

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Abstract: Additive technology (AT) has emerged as a key enabling technology, with its ability to shorten product design and development time. The paper presents the programming and program verification using machine simulation of additive manufacturing tool path in CAD/CAM and Vericut environment. A procedure for configuring and preparing of a virtual machine for several additive process simulations has been proposed. The paper analyses the available programming software for generating G code from the STL file as well as the possibility of simulating the virtual machine when working according to the generated program.
Keywords: additive manufacturing, machine simulation, CAD/CAM

INTRODUCTION

Industry 4.0 has an initiative that aims to digitalize industrial manufacturing via the exploitation of innovative technologies [1]. In this regard, this paper will present the possibilities of applying the machine simulation of additive manufacturing processes in the era of Industry 4.0. The machine simulation of the additive manufacturing tool path aims to configure the digital twin of the machine for additive processes and simulate its work. Whatever happens on screen during simulation, will also occur identically on the real machine for additive processes.

Additive technology (AT) has emerged as a key enabling technology, with its ability to shorten product design and development time. AT is used for quick fabrication of physical models, functional prototypes and small series of parts directly from CAD models [2,3]. Rapid prototyping is used in a variety of industries to fast fabrication of parts, and representation before final realization or commercialization [4]. The main advantage of rapid prototyping technologies is that almost any shape can be produced.

The application of new additive technologies is based on models STL models of prototypes that will be build. This paper discusses two additive technologies: Fused Deposition Modeling – FDM and Laser Metal Directed Energy Deposition – Laser DED in terms of program preparation and its verification by simulation of material addition, i.e. machine simulation for these procedures.

Simulation is a key technology for program verification. Machine simulation and digital twin are the primary simulation–based approaches in the context of the Industry 4.0.

OUTLINE OF CONSIDERED ADDITIVE MANUFACTURING PROCESSES

Within this paper, the machine simulation of additive manufacturing machines based on the FDM (Fused Deposition Modelling) and Laser DED (Direct Energy Deposition) methods will be considered.

— Fused Deposition Modeling – FDM

Fused deposition modeling (FDM) is one of the most widely used additive fabrication technologies. FDM is the same as fused filament fabrication (FFF), but the term "Fused deposition modeling" and the abbreviated "FDM" were trademarked by Stratasys in 1991, creating the need for a second name [5].

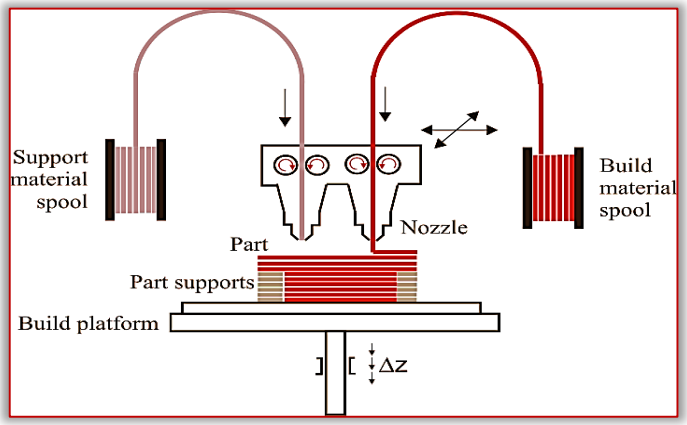


Figure 1. Schematic of FDM system

A plastic filament is unwound from a coil and supplied as a material to an extrusion nozzle, which moves along the programmed path of material addition. The possible movements of the nozzle are defined by the machine's own kinematic configuration. The nozzle is heated to melt the plastic, has closed–loop temperature control and is coupled with a mechanism which allows the deposition of the melted plastic to be turned on and off. As the nozzle is moved over the table in the active layer, following the

programmed path, it deposits extruded plastic, thus forming each layer. FDM approach demands fully controlled extrusion of material through a nozzle. Two extrusion heads are often used so that support structures can be fabricated from a different material to facilitate part clean–up and removal, Figure 1.

FDM 3D additive machine is a type of a CNC machine that has 3 axes of movement and usually implements Cartesian (serial) or DELTA (parallel) mechanisms, although machines with hybrid kinematics are also possible. This paper considers Velleman Vertex K8400 additive manufacturing machine – 3D printer with 3–axis Cartesian serial kinematics.

— Laser Metal Directed Energy Deposition (DED)

Directed energy deposition (DED) is a group of AM processes that adds material alongside the heat input simultaneously. The heat input can either be a laser, electron beam, or plasma arc, while the material feedstock is either metal powder or wire [6]. This paper discusses laser and powder DED processes. A schematic of the laser powder DED process is shown in Figure 2.

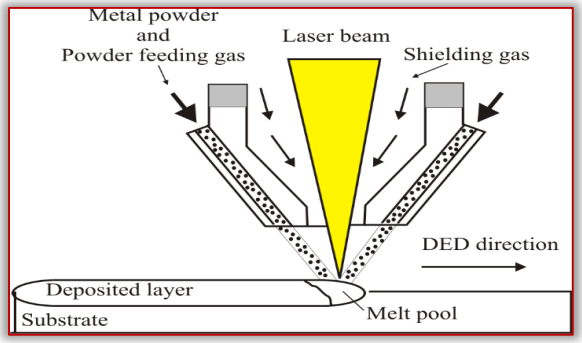


Figure 2. Schematic of a Laser powder DED process

Powder DED machines often have powder–feeding gas blown together with the powder from the nozzles, thereby sheathing the melted region, and reducing the oxidization rate. Powder DED systems can use single or multiple nozzles to eject the metal powders [6].

Figure 3. Laser DED extruder in a testing setup in a Haas VF series CNC machine [8]

Phillips has taken the innovative laser metal deposition technology of Meltio, and integrated it with the Haas CNC vertical machining centres, bringing the best value of additive hybrid machines to the market [7]. Supported Haas Machine Models are Haas VF Series, Haas UMC Series and Haas TM series. These machines can combine benefits from both additive and subtractive technologies. In this regard, the real challenge is the simulation of their work, which can be realized in the Vericut environment.

This opens the access to hybrid manufacturing processes that include additive and subtractive operations. Additive processes allow increased design flexibility, customization and part complexity, while subtractive processes enable higher production speeds, improved accuracy and surface finish [8]. Figure 3 shows a metal powder directed energy deposition (DED) process which can be combined with a multi–axis CNC milling process.

CONFIGURING VIRTUAL MACHINES FOR ADDITIVE MANUFACTURING

The simulation of additive manufacturing machines and processes, in the era of Industry 4.0, is one of the most important verification steps prior to the actual production. This section will show procedures and examples of configuring virtual machines for additive manufacturing using available software environments (PTC Creo and Vericut).

— PTC Creo

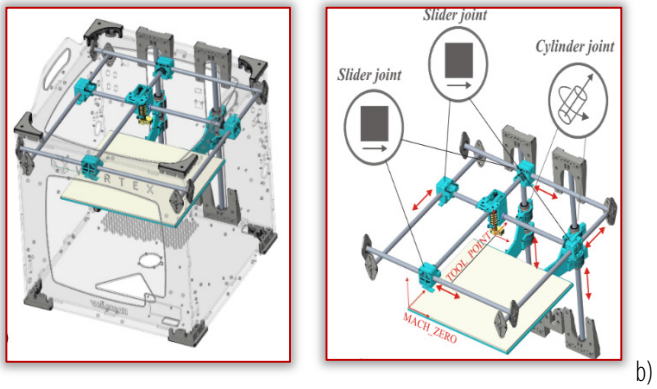
Most CAD/CAM systems are used for the simulation of the subtractive technologies, simulating virtual machine tool along a given tool path, while offering no similar alternatives for additive manufacturing.

In contrast, CAD /CAM system PTC Creo has a module for Additive Manufacturing, but it must be used in an indirect way, by configuring the machine for additive manufacturing as an equivalent milling machine with the same kinematics [9].

This paper presents the configuration of an additive manufacturing machine Velleman Vertex K8400 [10,11]. The configured virtual machine offers a virtual prototype with graphic structural elements that move as a rigid body system, aiming to be used in the simulation of the tool path [12]. All kinematic connections between structural elements of the virtual prototype must be defined in accordance with the real machine. The required kinematic connections for the considered 3–axis Velleman Vertex K8400 are three translations with slider and/or cylinder connection type, Figure 4.

During configuring of the complete virtual model of the machine, based on the available machine components [11], it is necessary to define the kinematic connections for all the moving parts. Next, need connect the coordinate systems of the workpiece, the tool with coordinate systems on virtual machine within the used PTC Creo 8.0. On virtual machine tool need to define the coordinate

system MACH_ZERO, on the machine table and TOOL_POINT on top of the nozzle (Figure 4b). Also, workpiece and tool have the same coordinate systems. By matching the appropriate coordinate systems of tool and workpiece with coordinate systems on virtual machine is prepare a set–up for simulation [12,16]. The virtual machine prepared in this way is ready for the needs of simulation according to the programmed tool path within the layer, which will be specified in section 5.



a) b)

Figure 4. Virtual machine Velleman Vertex K8400 with defined kinematic connections and coordinate systems

— Vericut

Vericut provides CNC machine simulation according to a given program, program verification and process visualization. Vericut now offers the Additive module that provides CNC machine simulation for directed energy deposition (DED), laser sintering, 3D printer and powder bed layups from their build files, wire–fed additives, thermo–plastic composite additives, welding, and other layup processes that add material [13].

A very important advantage of the simulation is collision detection between the expensive machine elements and the additive part being built [13].

Vericut uses G–code as one of its basic inputs, so to simulate an additive technology operation, one of the existing machines from the Vericut library that supports additive technologies can be selected, or a new machine can be configured.

To configure a new virtual machine in the Vericut environment, it is necessary to define the machine's kinematics – type and order of joints/axes according to the structural formula. For example, the Haas VF3 machine has a kinematic structure (X'Y'OZ), Figure 5.

The basic structure of the machine tool in Vericut consists of a BASE, TOOL, and STOCK. The configuration of the virtual machine starts from the base (O), as a fixed component. The vertical translational axis Z (Z Linear) was first added to the base, on the tool side. The horizontal translational axis Y '(Y Linear) was first added to the base in order, and then the horizontal translational axis X' (X Linear) was added to it, on the workpiece side.

On the spindle that moves along the Z–axis, there is the main spindle (Spindle) and a tool (Tool), which completes the kinematic structure of the machine. The hierarchical tree structure of the Haas VF3 machine is shown in Figure 5. The machine has the name *haas_vf3_tc20* with control *haascnc*. This machine supports additive technologies and will be used as an example for simulation of additive technology in section 5.2.

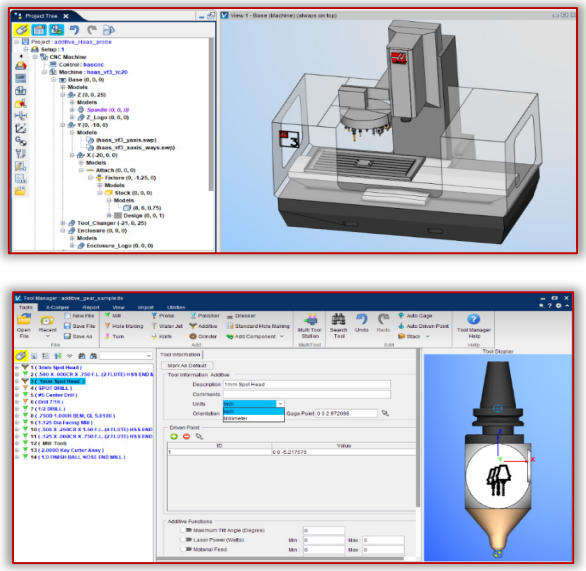


Figure 5. Selected virtual machine Haas vF3 and Laser DED extruder

PROGRAMMING OF MACHINES FOR ADDITIVE MANUFACTURING

Programming of machines for additive manufacturing can be realized using various specialized software, such as Slic3r, Replicator G, Catalyst EX, Repetier–Host, and others. These programs represent an interface for communication with additive manufacturing machines. The input into these programs is a 3D model file, upon which we prepare additive layers and the required paths for material addition. Such programs usually allow [10]: (i) 3D model display; (ii) model scaling to the desired size; (iii) model orientation in the workspace; (iv) automatic or manual basing of the model when several parts are produced at once; (v) slicing and forming of additive layers; (vi) layer addition simulation and display of each layer; (vii) G– code generation for the specified machine.

In this paper, the Slic3r software was tested as a programming software of the considered machines for additive processes. Slic3r translates digital 3D models into instructions that are understood by a 3D printer (G–code). It slices the model into horizontal layers and generates suitable paths to fill them. Slic3r accepts the following 3D model files types: STL (Stereo Lithography), OBJ, Additive Manufacturing File Format (AMF), while 3MF is an XML–based file format, similar to AMF [14].

A typical procedure for additive manufacturing includes the following stages: (1) obtain the model in STL format, (2) load model into software, (3) set the parameters for 3D additive manufacturing (print, filament, printer), (4)

export to G–code (5) simulate 3D additive manufacturing, (6) build prototype on the machine.

The first example for programming additive processes was tested on the example of the Champions League Cup model in pendant form, given in STL format, Figure 6.

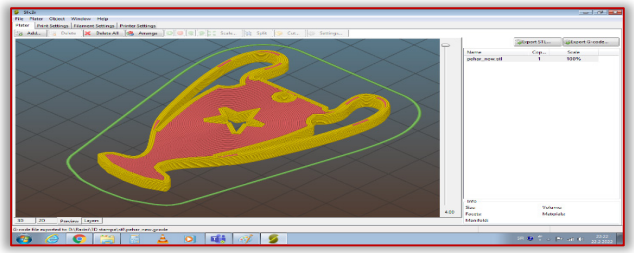


Figure 6. The example of the Champions League Cup in pendant form in slic3r environment

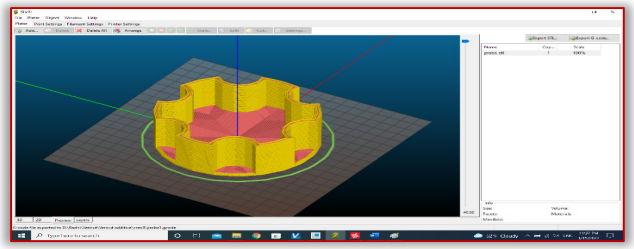


Figure 7. The second example of CNC machine simulation for laser directed energy deposition

For this example, machine simulation was prepared in CAD/CAM system PTC Creo (section 5.1), and finally this part was made on Velleman Vertex K8400 machine for additive manufacturing using FDM. Model for the first example is prepared in PTC Creo 8.0 and exported in the STL format that was loaded into Slic3r, where G–code is obtained for additive manufacturing. Prior to generating the G–code – print, filament and printer settings are adjusted. After generating the G–code, options are available for simulating the addition of material with the possibility of displaying toolpath for each individual layer.

The second example of programming additive processes, utilizing laser directed energy deposition (DED), is prepared for CNC machine simulation, Figure 7. Here also, the model is produced in PTC Creo, exported in STL and loaded into Slic3r, where the G–code is obtained for additive manufacturing. This example was checked in Vericut environment.

MACHINE SIMULATION AND TOOL PATH VERIFICATION

This section presents a machine simulation of additive manufacturing for two considered methods: FDM and DED in two different environments (PTC Creo and Vericut).

— Machine Simulation of Additive Manufacturing in Creo

An example of programming additive processes for FDM was tested on the example of the Champions League Cup in pendant form and printed on Velleman Vertex K8400.

CAD/CAM system PTC Creo can simulate additive manufacturing in an indirect way. The configuration of the considered additive machine Velleman Vertex K8400 is shown in section 3.1. The configured machine can move along the tool path for each individual layer. The simulation of the last layer was chosen for the illustration.

To obtain the toolpath (nozzle path) in additive processes, it is necessary to convert the nozzle path into G code, using appropriate software, Slic3r in this case, Figure 8. Obtained G–code can be converted into DXF file using CIMCO software. After that, the DXF is loaded into PTC Creo, where it is saved as a part, including nozzle path as a curve. This part is used in the CAM Manufacturing module (CAM–MFG), where the nozzle path serves to generate tool paths for simulation. During the simulation, the CAD model of the complete virtual machine can be loaded in PTC Creo environment, as shown in Figure 8, and Figure 9.

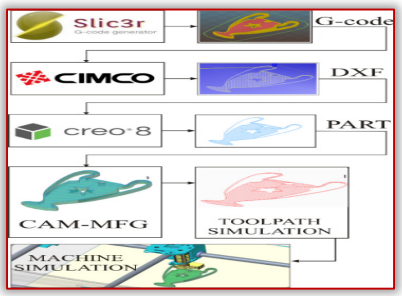


Figure 8. Procedure for indirect machine simulation of additive tool path on each layer

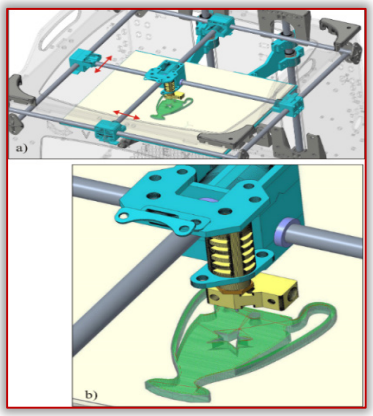


Figure 9. Machine simulation according to the given tool path within the last layer in PTC Creo environment

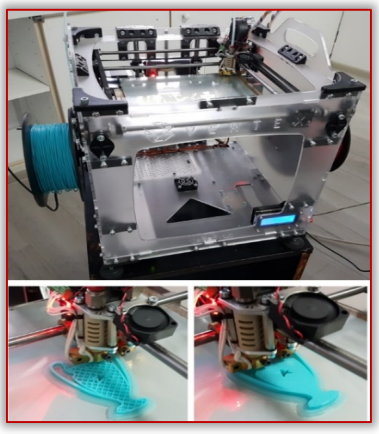


Figure 10. Velleman Vertex K84000 during the printing of model champion league cup in pendant form in STL format

An illustration of the work done on Velleman Vertex K8400 during 3D printing of the first example is shown in Figure 10.

— Machine Simulation of Additive Manufacturing in Vericut

Simulation of the virtual machine tool in the VERICUT environment, according to the given program, allows the simulation of the operation of the machine based on G–code [15]. Virtual machines can be loaded from the available library or configured from scratch by the user, as explained in Section 3.2. The following is a procedure for additive technology simulation based on G–code with an example of adding material by directed energy deposition (DED). The project hierarchical tree of Vericut has already been discussed in the description of the virtual machine configuration, and now the other parts it contains are presented, referring to the basic tools needed to prepare a simulation project according to the given program, Figure 11, with specifics that are characteristic for additive technology.

At the beginning, it is necessary to choose the control system and the virtual machine to perform the simulation. For example, in this paper, the chosen machine is haas_vf3_tc20 with its control haascnc.

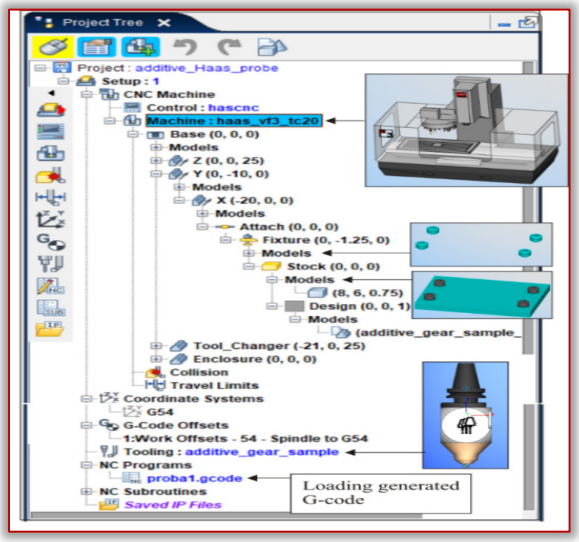


Figure 11. VERICUT project hierarchical tree, an example of for additive technology

To continue with the definition of the simulation project, in this case, for additive technology, it is necessary to define: (i) stock as the platform on which the model will be based, and which is here connected to the worktable by means of a fixture; (ii) coordinate system (Program Zero Point), here G54, (iii) zero–point position adjustment on the virtual machine (G–code Offsets), (iv) tools which are used for additive technology (Laser DED extruder) and (v) G–code for additive technology.

In order to connect the virtual machine to the zero point of the program, it is necessary to select the appropriate offset of the G–code. Work offset was chosen from Spindle to CSYS Origin–G54.

G–code is prepared in software for additive manufacturing (Slic3r), and loaded in Vericut environment for simulation. When all the previously mentioned stages for the preparation of the simulation project are completed, the G–code is loaded and the additive technology is simulated, Figure 12.

The simulation display of the virtual machine operation can be organized in several views, namely: Stock (workpiece)–view, where we can see the material being added layer by layer; Machine Base (Machine) – view, where the simulation of adding material can be followed on the virtual machine.

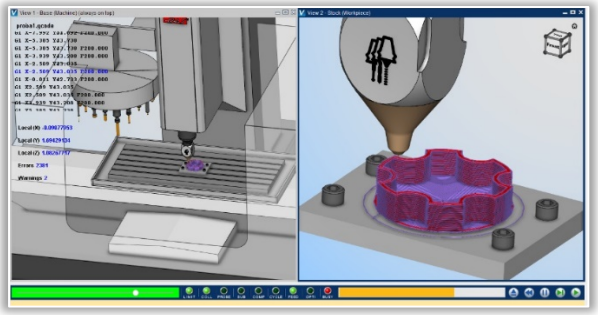


Figure 12. Machine simulation of Haas vF3 virtual vertical machining center operation on example of additive technology

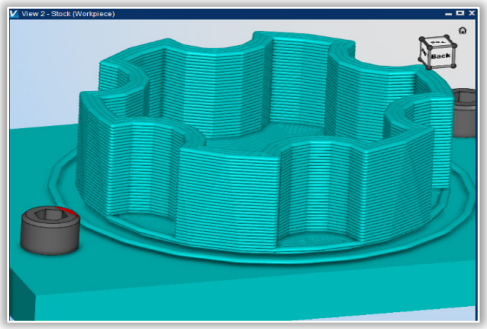


Figure 13. Finished simulation example of additive technology

During simulation, its speed can be controlled using the slider on the bottom–left of the screen. Also, the display of the G–code can be included, that also marks the line being executed. The final result of the simulation and the look of the obtained part is shown in Figure 13.

CONCLUSIONS

This paper provides an overview of programming and program verification using machine simulation in two environments for additive technology. Two methods for rapid prototyping by adding material were considered: fused deposition modelling and laser direct energy deposition.

In the age of Industry 4.0, an important research direction is digitization and virtualization of processes, enabling better verification and process monitoring.

Currently, there is ongoing research in the field of adding metallic materials in combination with milling, the so–called hybrid manufacturing, uniting additive and subtractive technology.

The importance of machine simulation for additive processes refers to the detection of possible collisions of various extruders with machine parts or the part to be made, thus gaining a higher degree of safety for people and equipment.

Our further research relates to the configuration of new virtual machines that combine additive and subtractive technologies – virtual hybrid manufacturing.

Acknowledgment

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References

[1] Zivanovic, S., Slavkovic, N.: Programming of machine tools and robots for machining using STEP–NC in the era of Industry 4.0, Keynote Lecture, Proceedings of the 15th International Conference on Accomplishments in Mechanical and Industrial Engineering DEMI 2021, 28–29 May, University of Banjaluka, Faculty of Mechanical Engineering, pp. 3–26, 2021.

[2] Pham, D., Dimov, S.: Rapid Manufacturing: The Technologies and Applications of Rapid Prototyping and Rapid Tooling, Springer Verlag, London, 2001.

[3] Pham, D., Dimov, S.: Rapid prototyping and rapid tooling– the key enablers for rapid manufacturing, Proceedings of the Institution of Mechanical Engineers, Part C, 217, pp 1–23, 2003.

[4] Gibson, I., Rosen, D. and Stucker, B.: Additive Manufacturing Technologies, 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing, 2nd Edition, Springer New York Heidelberg Dordrecht London, 2010.

[5] https://all3dp.com/2/fused–deposition–modeling–fdm–3d–printing–simply–explained/, Craftcloud, Accessed on 2022–03–27.

[6] Harbaugh, K., McClain, A.: 3D printing of metals in rapid prototyping of biomaterials: Techniques in additive manufacturing, In: Rapid Prototyping of Biomaterials, Editor Roger Narayan, pp.17–40, Elsevier Ltd, 2020.

[7] https://meltio3d.com/phillips–additive–hybrid–haas–cnc–meltio/, Phillips Additive Hybrid integrates Haas CNC with Meltio, Accessed on 2022–03–22.

[8] Weaver, J., Jones, J.: Characterization of high–deposition polymer extrusion in hybrid manufacturing, Proceedings of the 29th Annual International Solid Freeform Fabrication Symposium – An Additive Manufacturing Conference, August 13–15, The University of Texas at Austin, Austin, Texas, USA, 2018.

[9] Zivanovic, S.: Rapid prototyping and manufacturing for model of human head, Proceedings of the 8th International Scientific Conference IRMES 2017– Machine elements and systems in energy sector Development of power production systems, 07–09. September, Trebinje, Bosnia and Herzegovina, pp. 271–276, 2017.

[10] https://vertex3dprinter.eu/downloads/vertex–downloads/, VERTEX ORIGINAL (K8400), Accessed on 2022–03–26.

[11] https://github.com/Velleman/Vertex–CAD, Velleman Vertex–CAD, Accessed on 2022–03–26.

[12] Tabakovic, S., Zivanovic, S., Dimic, Z., Zeljkovic. M.: Programming of 3–Axis Hybrid Kinematics CNC Machine for Rapid Prototyping Using Subtractive and Additive Processes. Journal of Mechatronics, Automation and Identification Technology, Vol. 6, No. 4, pp. 16 – 21, 2021.

[13] https://www.cgtech.com/products/product–line/85–additive.html, VERICUT's Additive module simulates both additive and traditional machining (milling or turning) capabilities of new hybrid CNC machines, Accessed on 2022–03–22.

[14] https://slic3r.org/about/, Slic3r – Open–source 3D printing toolbox, Accessed on 2022–03–22.

[15] Zeljković, M., Tabaković, S., Živković, A., Živanović, S., Mlađenović, C., Knežev, M.: Basics of CAD/CAE/CAM, University of Novi Sad, Faculty of Technical Sciences, ISBN 978–86–6022–120–1, 2018.

[16] Živanović S., Slavković, N., Kokotović, B., Milutinović, D.: Machining simulation of virtual reconfigurable 5 axis machine tool, Annals of Faculty Engineering Hunedoara, International Journal of Engineering, Tome XV, Fascicule 2 , pp.189–194, May 2017.

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EXPERIMENTAL AND NUMERICAL ANALYSIS OF MECHANICAL PROPERTIES OF CARBON FIBER-REINFORCED POLYMER GEARS

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Abstract: Composite materials emerge as better alternatives for replacing metallic gears in gear drive applications. Because composites have better mechanical properties, such as resistance to abrasion, don't require lubrication, produce less noise, and have high strength/weight ratios. It is considered that using composites in gears, which are an important machine element, will be extremely advantageous. This research aims to identify the mechanical properties of carbon fiber-reinforced polymer (CFRP) gears. To this end, a composite plate was created by vacuum infusion employing twill woven carbon fiber cloth as a reinforcing element and epoxy resin as a matrix element. This manufactured plate was used to cut the gear profile, which was then put through its paces. The tensile test was carried out to determine the strength of the samples cut from the plate. The modulus of elasticity and the tensile strength was found to be 62.85 GPa and 616.085 MPa, respectively, as a result of the test. After the strength tests, numerical analysis of the gear sample produced by the finite element method was performed. The results showed that composite gears would offer a good alternative to metal gears.

Keywords: CFRP gears; composite materials; vacuum infusion; finite element method; mechanical testing

INTRODUCTION

The increasing need for rigid and lightweight structures has led researchers and industry to composite materials. Composite materials have gained momentum in recent years as a viable alternative to traditional materials such as steel or aluminium alloys, in aerospace, automotive and other industrial applications. However, due to its advantages over metal gears, the use of polymer materials in gear transmissions is increasing. Polymer gears have been widely used in recent years, where the use of metal gears would not be very economical and typically with lower load requirements. Polymer gear transmissions are significantly less in weight than metal gears because the material properties of composites are very attractive for weight improvements. In addition, polymer materials have better noise, vibration, and stiffness (NVH) behaviour due to good damping effects. New environmental regulations have mandated different designs that focus on the global efficiency of the system to reduce greenhouse gas emissions and fuel consumption. One of the strategies developed due to such constraints is to reduce gear transmissions. High-speed fatigue behaviour of autoclave-cured carbon fiber reinforced polymer (CFRP) composite gears researched by "The mechanical properties of fiber-reinforced polymer composites are highly dependent on the strength of the fibers and the matrix and the adhesion between the two." It is important to investigate the performance of woven CFRP gears because of their potential to further increase load bearing capacity and wear resistance compared to short fiber reinforced polymer gears [1-2]. The thermal and mechanical properties of laminated CFRP composites are affected by the properties of their key components, such as the polymer matrix and reinforcing fibers, as well as the method of preparation of the laminate. Zhang et al (2016) performed quasi-static and dynamic tensile tests on unidirectional woven CFRP samples. While a characteristic effect of strain rate on tensile modulus and strength was observed in dynamic load tests, the significance of this correlation decreased in quasi-static tests [3]. Gear performance depends on the tribological behaviour of the gear pair at the contact interface. Bijwe and Sharma studied the effect of carbon fiber (CF) content ratio on the mechanical and tribological properties of CFRP with polyetherimide (PEI) thermoplastic matrix. With a fiber content of 65%, it has reached optimum results in mechanical and tribological properties [4]. As noted above, many possibilities exist to further improve the thermomechanical and tribological properties of composite gears. CFRPs can provide high mechanical strength, good thermal stability, high thermal conductivity and favourable tribological properties if a suitable manufacturing technique is used. This makes them ideal candidates for gears and other power transmission components. The purpose of this study is to make a comparison between metal and CFRP gears. It is

aimed to fill the gap between the two gear types by using vacuum infusion cured, laminated CFRP gears. It is known that the use of polymer materials in gear transmissions is increasing due to their advantages over metal gears. Nevertheless, the subject contains gaps that are worth investigating and examining.

MATERIAL AND METHOD

In this section, design of spur gear is realized with programming mathematical equations. The parameters of rack cutter that generates spur gear are illustrated in Figure 1.

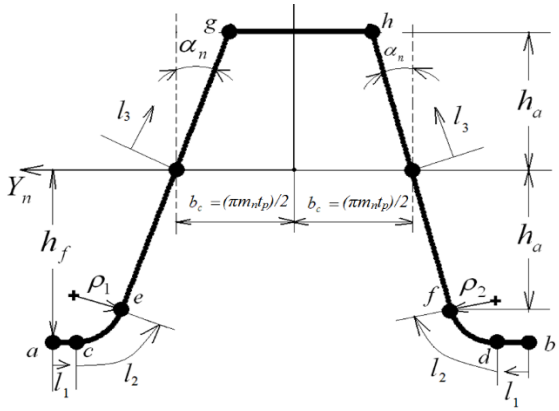


Figure 1. Parameters of rack

The equation of rack regions are given as matrix form in the following expressions;

ac-bd region

$$R_n^1=\begin{bmatrix} -h_f \\ \pm\left(\frac{\pi m}{2}-l_1\right) \\ 0 \\ 1 \end{bmatrix} \quad (1)$$

$$0<l_1<b_c-h_f\tan\alpha_n+\rho_{1,2}\tan\alpha_n-\rho_{1,2}\sec\alpha_n \quad (2)$$

ce-df region

$$R_n^2=\begin{bmatrix} -h_f+\rho_{1,2}-\rho_{1,2}\cos l_2 \\ \pm(b_c+h_f\tan\alpha_n-\rho_{1,2}\tan\alpha_n+\rho_{1,2}\sec\alpha_n-\rho_{1,2}\sin(l_2)) \\ 0 \\ 1 \end{bmatrix} \quad (3)$$

$$0<l_2<\left(\frac{\pi}{2}-\alpha_n\right) \quad (4)$$

eg-fh region

$$R_n^3=\begin{bmatrix} l_3\cos\alpha_n \\ \pm(b_c-l_3\sin\alpha_n) \\ 0 \\ 1 \end{bmatrix} \quad (5)$$

$$\frac{-h_a}{\cos\alpha_n}\leq l_3\leq\frac{h_a}{\cos\alpha_n} \quad (6)$$

Where, m is the module, z is the teeth number, $\alpha_{n1,2}$ is the pressure angle on sides, h_f is the dedendum, h_a is the addendum, $\rho_{1,2}$ are the tip radii, $l_{1,2,3}$ is the design parameter of cutter, b_c is half thickness of rack on pitch line.

$$n_n^i=\frac{\frac{\partial R_n^i}{\partial l_i}xk_n}{\left|\frac{\partial R_n^i}{\partial l_i}xk_n\right|} \qquad i=1\text{-}3 \quad (7)$$

where k_n unit normal vector of Z direction.

According the gearing theory, direction of sliding velocity vector between pinion and gear is parallel with tangent vector of common meshing point. Of course, it is always perpendicular to common normal vector. This expression is presented in Eq. (8).

$$n_n^i.v_{relative}=0 \qquad i=1\text{-}3 \quad (8)$$

During the generating process, the rack cutter makes a linear motion as $r_{p1}\times\phi_1$ whilst the gear as workpiece revolves as $\emptyset_1$. $S_1(X_1,Y_1)$ is the coordinate system of workpiece. Relationship between cutter and workpiece is shown in Figure 2.

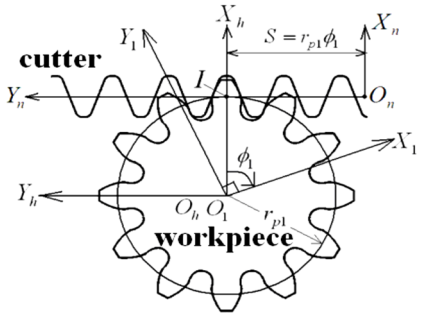


Figure 2. Relation between cutter and gear

Coordinate transformation matrix between rack cutter and workpiece is presented in the following equations.

$$M_{1n}=\begin{bmatrix} \cos(\emptyset_1) & -\sin(\emptyset_1) & 0 & r_{p1}\emptyset_1\sin(\emptyset_1)+r_{p1}\cos(\emptyset_1) \\ \sin(\emptyset_1) & \cos(\emptyset_1) & 0 & -r_{p1}\emptyset_1\cos(\emptyset_1)+r_{p1}\sin(\emptyset_1) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (9)$$

$$R_1^i=M_{1n}{}^iR_n{}^i \qquad i=1\text{-}3 \quad (10)$$

Where M_{1n} is the coordinate transformation matrix and R_1 is matrix of involute spur gear, r_{p1} is pitch diameter.

With programming Eq.(1-10) in MATLAB program, the design points of involute spur gears are obtained. These points are exported to CAD to generate FE model. In Figure 3, design phases are given.

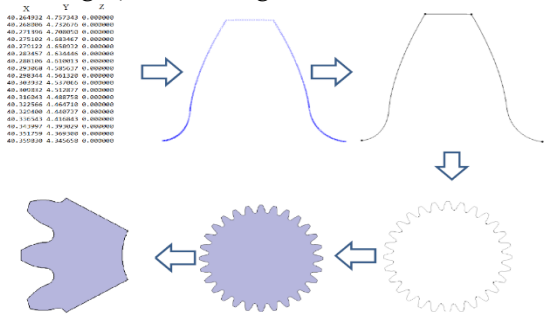


Figure 3. Design phases

First, sample plates were produced using epoxy resin with the fiber planned to be used. The carbon fiber fabric used in the study was 3K twill woven with a density of 245 gr/cm² and the epoxy used had the Duratek brand DTE 1200/DTS 2110 code. After determining the fabrics, resin, and vacuum values to be used, sample plates of 45*50 cm were produced by applying the steps of the vacuum infusion method. Glass plate was used as a mold during production. The composite sheet was removed from the

mold after the infusion process and the necessary curing time, and the sample was cut in line with the TS EN ISO 527-4 tensile test standard. End-tab was adhered to the cut samples with epoxy adhesive and made ready for the tensile test (Figure 4).

Figure 4. CFRP samples prepared for tensile testing

After the above-mentioned processes, tensile tests were applied. These tests were carried out on the Besmak universal tensile/compression test device. According to the results obtained, the modulus of elasticity was 62.85 GPa and the tensile strength was 616,085 MPa for the CFRP sample.

FINITE ELEMENT ANALYSIS

In this section, finite element analyses were conducted for specific gear parameters. In Table 1, the parameter of case studies are illustrated.

Table 1. Gear parameters

Parameters	Case I	Case II	Case III
Module-m (mm)	2	2	2
Teeth number(z)	20	20	20
Pressure angle-α_n (°)	20	20	20
Addendum-h_a (×m)	1	1	1
Dedendum-h_f (×m)	1.25	1.25	1.25
Cutter tip radius- $\rho_{1,2}$ (×m)	0.38	0.38	0.38
Facewidth- b (mm)	1	1	1
Rim status	Solid	Thin	Solid
Material	Steel	Steel	CFRP

3 teeth model is prepared for finite element analyses. Meshing force (100 N) was applied at tip of tooth. Fixed support was given lateral sides and shaft hole. Boundary condition and mesh structure are presented in Figure 5.

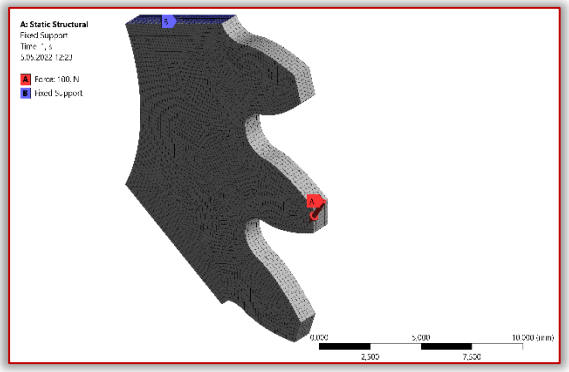
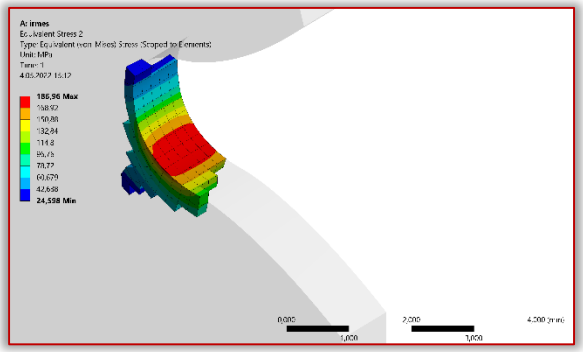


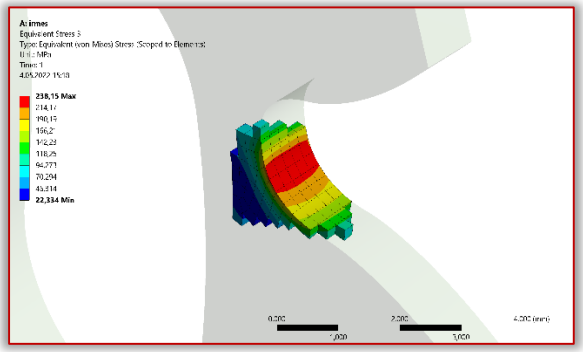
Figure 5. Mesh and boundary conditions

Hexahedral mesh type is used for discrete FE body with 0.2 mm edge length. For Case I and II, Young modulus and Poisson's ratio of material is taken as 210 GPa and 0.3, respectively. For Case III, CFRP material is modelled as isotropic material. Young modulus of CFRP is obtained as 62.85 GPa in the tensile test. For this reason, this value is taken as directly in numerical modelling.

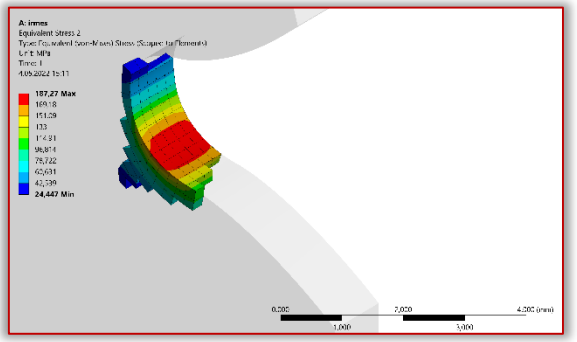
In Figure 6, the root stress results are given.



Case I



Case II



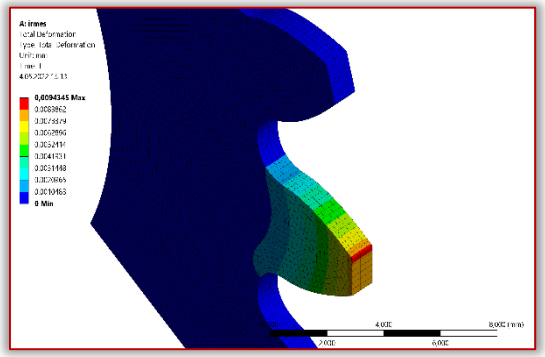
Case III

Figure 6. Root stress results

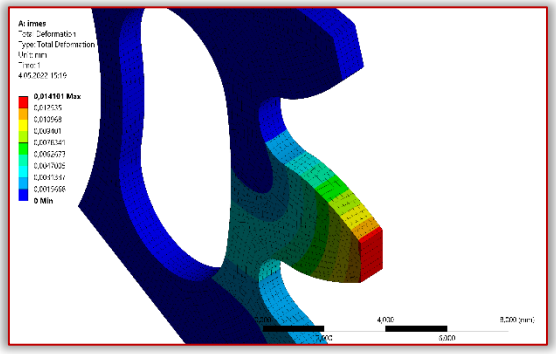
According to results, the material change slightly makes differences in root stress when the root stress results is examined for Case I and Case II (<1%). On the other side root stress of thin rimmed steel spur gear is approximately 30% higher than CFRP gear. Tooth deformation is another key parameter for spur gear performance. For this reason, tooth deformation values should be investigated. In Figure 7, deformation results are given for each cases.

According to results, the Case I is found as the best option in terms of tooth deformation. CFRP gear deformation

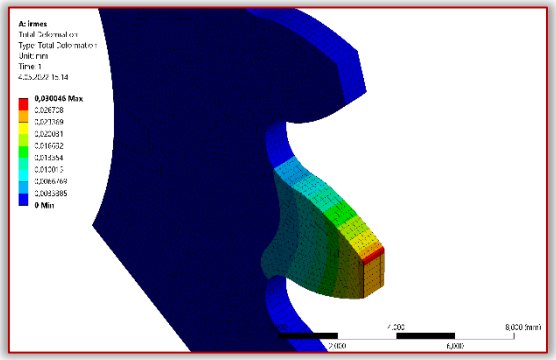
value is double of thin rimmed lightweight steel gear. Deformation is closely related with Young modulus. For this reason, these results are expected.



Case I



Case II



Case III

Figure 7. Tooth deformation results

CONCLUSIONS

In this study, the CFRP gear was compared with steel and light steel gear in terms of stress and deformation. For this aim, the 3D gear model was prepared for finite element analyses. To obtain the Young's modulus of composite material, tensile test was conducted. According to finite element analyses, the following points were obtained.

- CFRP gear is better than thin rimmed lightweight steel gear in terms of root stress. The root stress difference between solid rim steel gear and CFRP gear is found as rather low.
- CFRP gear is found as worst option in view of tooth deformation. Yet, when taken into consideration of the whole gear weight status, CFRP gear (1.40 gr) can be more advantageous than steel (6.6 gr) and lightweight steel gear (5 gr). Based on this fact, the tooth deformation of CFRP gear can be decreased with increase the face width.

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References

[1] Zorko D, Tavear J, Bizjak M, Sturm R, Bergant Z. High cycle fatigue behaviour of autoclave-cured woven carbon fibre-reinforced polymer composite gears. Polymer Testing; 102:107339, 2021.

[2] Cerne, B., Bergant, Z., Sturm, R., Tavcar, J., Zorko, D. Experimental and numerical analysis of laminated carbon fiber-reinforced polymer gears with implicit model for coefficient-of-friction evaluation. Journal of Computational Design and Engineering, 00(0), 1–18, 2021

[3] Zhang, X., Hao, H., Shi, Y., Cui, J., & Zhang, X. Static and dynamic material properties of CFRP/epoxy laminates. Construction and Building Materials, 114, 638–649, 2016.

[4] Bijwe, J., & Sharma, M. Carbon fabric- reinforced polymer composites and parameters controlling tribological performance. In J. P. Davim (Ed.), Wear of Advanced Materials (Chap.1, pp. 1–60). John Wiley & Sons, Ltd. ISO number of standard (incl. year), Standard Title, 2013.

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APPLICATION OF WELDING FOR THE PRODUCTION OF BALLISTIC PROTECTIVE STRUCTURES

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Abstract: In the common industry and especially in military industry there is a growing need for production of highly effective protective structures. For that purposes the most used materials are armor steels. They belong into a group of the fine-grained, increased strength steels, which are manufactured by intensive thermo-mechanical treatment at high temperatures and later quenching and low-tempering. Combination of the heat and mechanical treatments provides for the fine grains and exceptionally good properties of these steels, while the low-tempering enables relatively high hardness and good ballistic properties. However, sometimes there is a need to weld these steels in order to manufacture some specific assemblies. Since the way these steels are produced this is why the welding can negatively affect the material properties in specific zones of the welded joint, what could lead to worsening of the material's ballistic properties, as well. The aim of this paper was to determine influence of the welding procedure on that mechanical and ballistic properties. In that order the model plates were welded with the specially prescribed technology in three types of the joints: the but-joint, corner joint and the corner joint with the shielding plate. After the welding the test plates were subjected to the ballistic tests which consisted of shooting with three types of live ammunition at different types of the welded joints. At the end the comparative analysis of the results is given.
Keywords: protective structure, welding, armor steels; ballistic properties

INTRODUCTION

The combat vehicles for the infantry were created from the tendency to increase the efficiency of the tanks and possibilities for their survival on the combat field. The problem that appeared was how to develop the armor, which would guarantee the safety to the personnel by preventing the penetration of the projectile from the anti-armor ammunition into the vehicle, while simultaneously realizing as good as possible its tactical-technical and combat-exploitation characteristics. Taking into account these requirements, it was inevitable to develop the special group of the high-strength steels, known as the armor steels that are being improved [1].

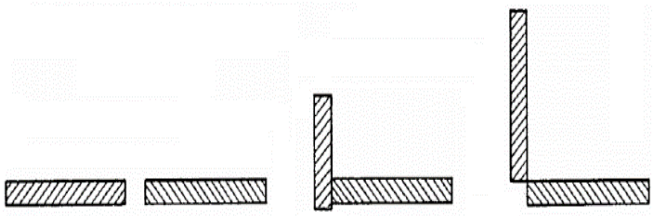
The Swedish company SSAB Oxelösund [2] has the high-strength steels in its production program, where the especially interesting is a group of armor steels, known under the commercial brand ARMOX, which are produced according to the strictly defined manufacturing procedures, [3]. Their excellent properties are resulting from the manufacturing process. They possess a very low content of carbon what positively affects their weldability, while the strength is being achieved by application of the thermo-mechanical processing (TMP) [1, 3]. However, despite their exceptional properties, when the armor is being welded, the worsening of those properties occurs, locally, due to the entered heat. Such spots represent the critical places on the structure and the objective of this paper is to show how those places (various types of the welded joints) behave in the conditions when being hit by the projectiles of different types [4, 5].

WELDING OF SAMPLES

The welded joints on combat vehicles, made of this or some other steel, represent the most vulnerable places of the whole structure. The reason for that is the fact that in welding of the armor steels the filler metals must be applied, which produce the weld metal of the significantly lower strength with respect to the base metal. Thus, the appearance of the cold cracks can happen, since the armor steels are very prone to hardening. Besides that, this steel belongs into a group of the conditionally weldable steels, which implies that adequate measures must be taken during the welding. One of the most important measures is to control the heat input, what is explicitly presented by SSAB in specifications of this steel. The heat input is limited to 200°C, since at the higher temperatures the excessive annealing occurs and thus the loss of all the positive properties induced by the TMP. In this paper are given recommendations that are mandatory to be followed in order to obtain as high quality welded joints as possible. The welding technologies are also proposed, all based on recommendations by the steel manufacturer, as well as the experts that have already dealt with this problem.

The experimental samples, needed for the ballistic tests of the basic zones of the welded joint, were made in the form of the butt, corner and corner-edge joints (Figure 1). The plates' dimensions of the ARMOX 500T steel were 200 × 200 × 8.6 mm and they were cut by the laser (Figure 2).

The welding was done using MMA welding procedure. The welding parameters are given in Table 1 while in Figure 3 are shown the plates' appearances after the welding, for all the three cases.



a) b) c)

Figure 1. Schematic presentation of the welded joint: a) butt, b) corner and c) corner-edge

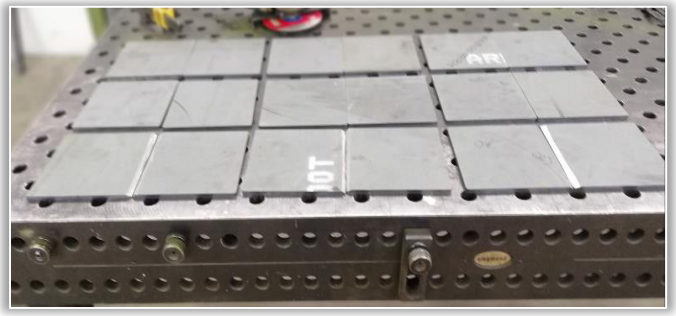
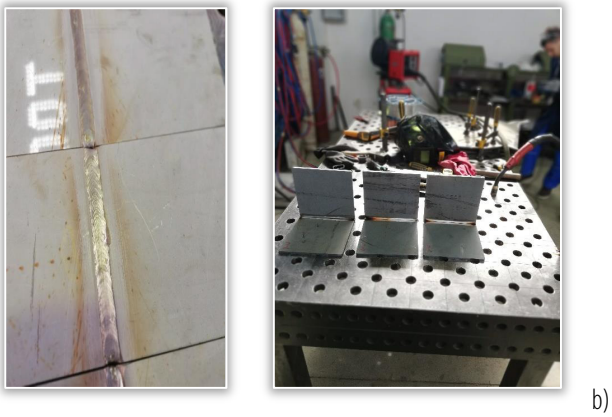


Figure 2. Plates prepared for welding



a) b)

c)

Figure 3. Welded plates: a) butt, b) corner and c) corner-edge joint.

TESTING OF THE WELDED JOINT BASIC ZONES BALLISTIC RESISTANCE

Many countries have prescribed standards regarding the levels of the ballistic protection; the most used by the ARMOX manufacturers are STANAG 4569 (Table 2) prescribed by the NATO and EN 1522, prescribed by the UN, primarily due to the customers' requests [4]. The STANAG 4569 standard refers to degrees of the protection for logistic and light armored vehicles.

Table 1. Used welding parameters

1.	Groove type	V
	Way of preparation	grinding
2.	Wire diameter	1.0 mm
	Type	
	Protective gas type	Ar + 2.5
3.	Preheating temperature	125-175°C
	Interpass temperature	150-175°C
	Measurement procedure	Thermo-chalks
	Preheating device	Gas flame
4.	Welding procedure	135 (MMA)
	Welding position	PA
	Welding technology	To the left/75°
	Power	190-210 A
	Arc voltage	24.5 V
	Current type	DC
	Polarity	+
	Wire feeding rate	6 m/min
	Welding rate	21 cm/min
	Gas flow	18 l/min
	Number of passes	2
	Driving energy	≈ 11000 J/cm

The standard includes threats by the ballistic projectiles, of the small and medium caliber, as well as the fragments simulating the penetrators, in order to simulate the artillery actions. It is aimed for the repeatable testing procedures for estimate of the ballistic protection of the armored vehicles' parts and for determination of the critical zones on those vehicles. The threats are divided into five levels, where the first level is related to civilian threats, while the other levels are related for various military threats.

Table 2. Standard STANAG 4569 NATO

Level	Weapon type	Caliber	Distance, m	Velocity, m/s
I	Rifle	7.62×51-NATO Ball	30	833
		5.56×45-NATO SS109		900
		5.56×45-M193		937
II	Infantry rifle	7.62×39-API BZ	30	695
III	Sniper rifle	7.62×51-AP (WC core)	30	930
		7.62×54R-B32 API		854
IV	Machine gun	14.5×114AP-/B32	200	911
V	Auto-matic cannon	25 mm APDS-TM-791	500	1258

RESULTS OF THE BALLISTIC TEST

Though the three samples were made for each type of joints (the butt, corner and corner-edge), the ballistic tests were done at one sample from each group, only. That was done primarily due to the complexity of the experiment and since the obtained data were sufficient to estimate the ballistic resistance. The objective of the

experiment was to estimate the degree of damage, namely the type of penetration of the basic zones of the welded joint (the base metal – BM, the heat affected zone – HAZ, the joining zone – JZ and the weld metal – WM) by ammunition of the 7.62 × 39 type: M67 Ball, 7.62 × 51 NATO Ball (Ball M80) and armor bullet 7.62 × 54R B32 API (Dragoon's). The 7.62 × 39 M67 Ball bullet is not prescribed by the NATO standards, but by the Russian standards of the ballistic protection, which is not guaranteed by the SSAB.

The experiment was performed on the test field of the "Prvi Partizan DOO" company in Užice, Serbia, which has decades' long experience in producing the ammunition and the tests of this kind. The finishing, verification and homologation (approval) tests of ammunition are being conducted on this test field. The experiment was executed by the expert staff, according to adequate safety standards. The testing equipment included:

- Test barrel with the cover for measuring the velocity, of caliber 7.62 × 39 mm,
- Test barrel with the cover for measuring the velocity, of caliber 7.62 × 51 mm,
- Test barrel with the cover for measuring the velocity, of caliber 7.62 × 54 mm,
- Stand for the test barrel
- Ammunition 7.62x39 M67 Ball, velocity at v25=725 m/s,
- Ammunition 7.62 x 51 NATO Ball (Ball M80), velocity at v25 = 830 m/s,
- Ammunition 7.62x54R B32API, velocity at v25=790 m/s.

The samples of the armor steel, prior to the commencing of the experiment, were firmly positioned in the wooden frames, to prevent the loss of energy due to motion of the plates when hit by the bullet. The distance from the exit hole of the test barrel to the sample was 10 m. According to the experimental plan, the welded joints were positioned in such a way that the weldment was perpendicular to the bullet motion direction, what at the corner and corner-edge joints should present the behavior of the base metal and the heat affected zone at the bullet impact at an angle.

Appearance of the butt joint after the bullet impacts is presented in Figure 4. Total of 10 projectiles were fired of the three calibers [4].

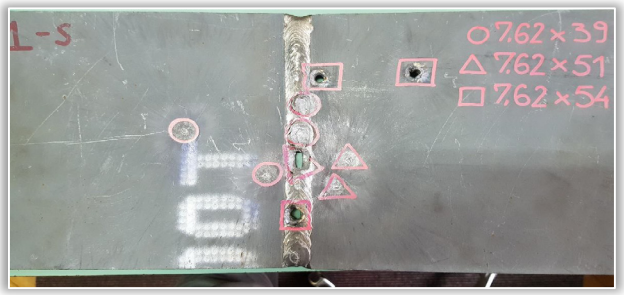


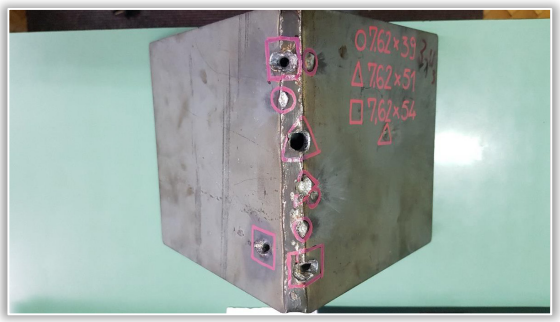
Figure 4. Appearance of the tested sample of the butt joint from the entrance side

After the tests on the butt joint, the tests of the corner joint were performed, with the samples fixed as described earlier. The total of 9 bullets was fired of the three calibers. The entrance side of the corner joint is presented in Figure 5 [5].

Figure 5. Appearance of the tested sample of the corner joint from the entrance side.

The penetrated spots – perforations were of the type characteristic for an impact by the sharp pointed projectiles into the armors of the small thickness. In some cases they also appear for the flat bullets' impacts at velocities that are close to the limiting velocities of penetration. Consequences of penetrations of this type are characteristic since the shape of the hole at the exit side resembles the flower petals.

At the end, the corner-edge joint was tested, which on the inside has little platelets made of the same material. The idea is that they should act as a protection in the case that the weld metal and its vicinity have been penetrated. The total of 8 bullets were fired of the three different calibers, into the characteristic zones of the welded joint. Results are presented in Figure 6 [4, 5].



a)

b)

Figure 6. Appearance of the corner-edge joint with protection: a) at the entrance side, b) at the exit side.

CONCLUSIONS

In this paper the ballistic check the penetration resistance of three types of welded joints' zones were performed. Ammunition used was 7.62 x 39 M67 Ball, 7.62 x 51 NATO Ball, and 7.62 x 54R B32 API. Besides, the whole welding technology of the samples was presented.

Obtained results led to the following conclusions:

- The base metal, the heat affected zone and the weld metal are all bullet proof for the caliber 7.62 × 39.
- Test by the 7.62 × 51 caliber bullets showed that only the base metal is resistant to penetration.
- For the armor ammunition of the 7.62 × 54R caliber there are no obstacles, i.e. all the zones of the welded joint are threaten, even the protective plates in the corner-edge joint case.

Based on these results, one must recommend that vehicles constructions made of this steel must be so designed that all the zones of the welded joint should be well protected against penetration by any caliber projectiles. The weld metal should be hidden whenever possible, while the butt joints should be strictly avoided in any case. If these recommendations were not followed to the letter, the safety of the personnel in the vehicle, against the projectile penetrating the armour, cannot be guaranteed.

The reason that the welded joint is the weakest place at the structure can be the heat input during welding. Namely, the heat generated during welding leads to worsening of the properties of the material in the welded zone (softening of the steel). Although, the steel producer forbid the heating of the steel over 200°C in order to preserve the good mechanical properties, during the welding that cannot be achieved. Since the welding has to be used for joining that is the reason why we tested different types of joints in order to determine the most favourable option.

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References

[1] Arsić, D., Nikolić, R., Lazić, V., Hadzima, B., Aleksandrović, S., Djordjević, M., 2014. Weldability estimates of some high strength steels, Proceedings of 42. International Conference "Zvaranie 2014", Tatranská Lomnica, Slovakia, ISBN 978-80-89296-17-0, pp. 11-21, 2014.

[2] https://www.ssab.com/products/brands/armox, accessed on 12. 04. 2022.

[3] Lazić, V., Arsić, D., Nikolić, R. R., Djordjević, D., Prokić-Cvetković, R., Popović, O., Application of the high strength steel HARDOX 450 for manufacturing of assemblies in the military industry, Key Engineering Materials, ISSN 1013-9826, Vol. 755, pp. 96-105, 2017.

[4] Rakičević, M., 2018. Estimation of weldability and selection of optimal welding technology of bulletproof steel ARMOX 500T, MSc thesis, Faculty of Engineering, University of Kragujevac, Kragujevac, Serbia. (In Serbian)

[5] Lazić, V., Arsić, D., Rakičević, M., Aleksandrović, S., Đorđević, M., Marinković, P., Ratković, N., Uticaj vrste zavarenog spoja na balistička svojstva pancirnog čelika ARMOX 500T, Zbornik radova sa 37. Savetovanja proizvodnog mašinstva Srbije, Kragujevac, 2018, 25-26 Oktobar, ISBN 978-86-6335-057-1, pp. 173-177.

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INVESTIGATION ON THE BUCKLING OF AEROSOL CANS DURING THE BOTTOM FORMING PROCESS

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Abstract: In this paper, the mechanical analysis of the bottom forming process of aluminium aerosol cans is presented. Our main objective is to investigate the buckling of the shaping process. The commercial finite element software Abaqus is used to solve the problem. The can geometry is mapped by thin three-dimensional shell element. The problem is highly nonlinear, Riks and displacement based methods are used to trace the equilibrium path and calculate the reaction force - displacement diagram with the buckling load, at which the loss of stability occurs. The effect of different features of the can geometry is investigated on the buckling load, such as the fillet radii of the bottom of the can, the thickness of the shell. We included the effects of the imperfections in the geometry, the mesh and the friction between the tool and the can.
Keywords: Aerosol cans, bottom forming, shells, FEM, Abaqus, buckling

INTRODUCTION

In recent years aerosol cans craft from aluminium are reporting mounting growth rates all over the world. Aerosol cans may also be made from a process known as extrusion or impact extrusion using 99.5 % pure aluminium sheet or in some cases steel. In an impact extrusion process, a hydraulic ram punches an aluminum slug to begin forming the can, which creates the initial geometry for the further forming steps. The first phase of the forming process of aerosol cans is the bottom forming process which is the topic of this paper.

It is well-known, that the behavior of thin shells is highly nonlinear. There are several textbooks devoted to the mechanics and finite element modelling of thin shell structures, such as [1], [2] or [3]. Patten [4], Hardy and Abdusslam [5] investigated the back extrusion of cans. Belblidia et. al. [6], [7] developed finite element techniques to determine the stress state and burst pressure of thin aerosol cans. Paper [8] investigated various technological parameters of the forming process using experimental data, while Takeutshi [9] presented a few basic problems in the forming process of aerosol aluminum cans. Several works [11-15] deal with the mechanical and experimental analysis of the necking process (reaction forces) for thin shells and the buckling limit with the determination of the crushing force during these last shaping steps.

In this study, the main objective is to investigate the forming process of the bottom part, in which a spherical or conical surface is created. These features are important, because these help the cans to withstand the internal pressure coming from different filling media and strengthen the can (increase burst pressure), furthermore these ensure the stable standing of the cans. The efficiency of the finite element method and Abaqus is presented for the design process and analysis of thin-walled cans.

AIMS AND DATA

The forming process of thin shell structures is a highly nonlinear problem, which involves geometric and material nonlinearities with contact equations. It is a large deformation problem, in which the material is a strain hardened aluminium Al99.5 (EN AW 1050). Our aim is to calculate the reaction force – displacement diagram, then to determine the crushing force, which is the reaction force, at which the loss of stability occurs. Different aspects of the forming technology are going to be analysed. The effect of the geometry of different features of the aerosol cans is investigated on the reaction forces and on the crushing forces.

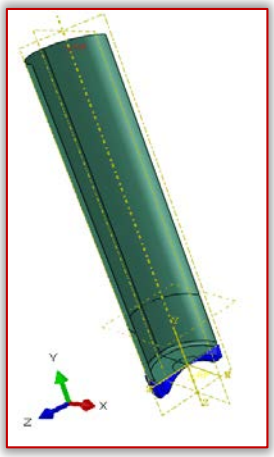

Figure 1. The sketch of the geometry

According to experiments, the Young modulus of the aluminium is 75 GPa, the Poisson's ratio is 0.4, the yield stress is 120 MPa and a bilinear plasticity law is used with 230 MPa stress at φ=4 plastic strain level. The friction coefficient between the can and the steel tool is 0.05. The initial geometry of the can and the tool can be seen in Figure 1. The diameter of the can is 44 mm, the length of the can is 200 mm, the wall thickness of the bottom part (base of the cylinder) is 0.9 mm, the thickness of the mantle of the cylinder is 0.36 mm. The piece is constrained at its side of 35 mm height against radial motion. The radius of the steel tool is 20.2 mm.

MODELLING TECHNIQUE

Due to the nature of buckling, three-dimensional geometry with shell elements is used to solve the problem. The aluminium piece is considered a solid body (elasto-plastic shell), while the steel tool is modeled as a discrete rigid part. One of the main sources of the numerical difficulties comes from the contact equations between the can and the tool, so linear elements are used to create the mesh of the can. This cylinder is constrained at its side against radial motion, while there is a kinematic coupling at the top edge of the shell using a reference point (Figure 1 - RP) as a control point to pin the nodes there. Another reference point controls the motion and position of the rigid tool.

To include the effect of the imperfections, a linear perturbation/frequency analysis was carried out. Then the eigenshapes are determined and mapped to the initial geometry using different scale factor. According to measurements, this scale factor is around one tenth of the shell thickness, so we used the value 0.04.

To crush the can, a prescribed displacement is applied at the reference point of the rigid tool in the direction *y*.

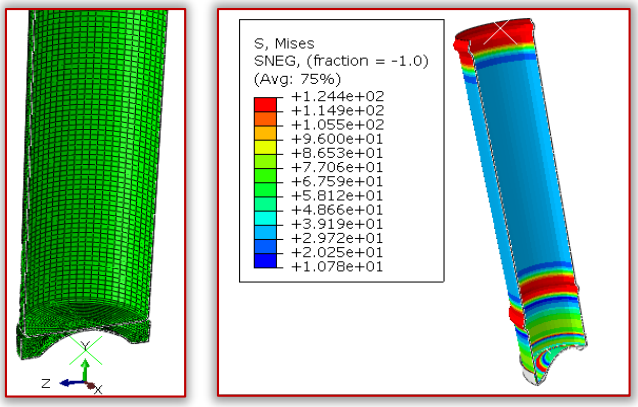

Figure 2. The mesh of the problem and the deformed state of the ideal geometry with the von Mises stress distribution (in MPa)

At first, the effect of the mesh is investigated on the ideal geometry during Static/general and Riks methods. Linear and quadratic element were used with different mesh densities. The latter led to significantly increased solution time, while the results were approximately the same, the crushing force (that belonged to the element size 2 mm) was 5928 N. The crushing force coming from linear elements with the average size of 2 mm was 5927 N, while with the element size of 1 mm the loss of stability occurred at 5924 N. The chosen mesh with linear elements (average size 2 mm) can be seen is Figure 2. To facilitate the contact calculations and to improve the accuracy, a finer mesh was created at the contact region and at the radius of the base of the cylinder.

A diverse combination of the eigenshapes can be used and multiple disturbed geometries can be mapped within a specified tolerance range. During experiments, the can deformed above the radially constrained side area. The eigenshapes of Figure 3 were applied to the ideal geometry, the result can be seen is Figure 4.

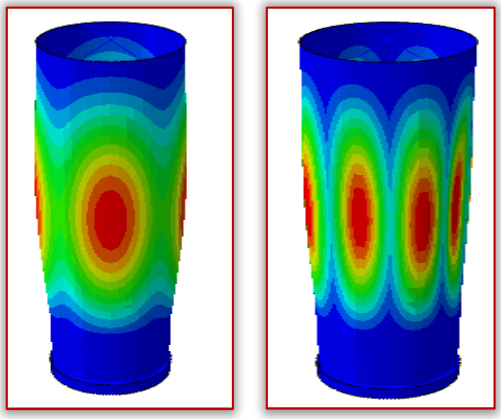

Figure 3. Some of the eigenshapes of the can

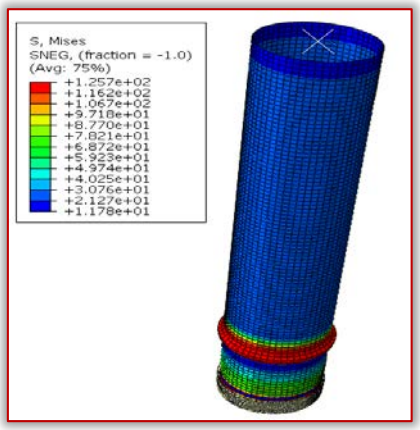

Figure 4. The deformed state of the disturbed geometry

In this case the maximum reaction force was 5910 N, which is in good agreement with the experimental results. We are going to use these imperfections for our further investigations.

THE EFFECT OF THE GEOMETRY OF THE CAN

There are multiple features that affect the shaping forces and may affect the buckling load. At first, let us investigate the effect of the fillet radius at the base of the can. Consider three different radii: 0.7 mm, 2 mm and 4 mm. The reaction force – displacement curves can be seen in Figure 5. The results show, that the maximum reaction forces are the same, but the force requirements of different deformations differ.

In the next step, the effect of the shell thickness at the base of the cylinder is investigated. Seven different values are considered: 0.36 mm, 0.6 mm, 0.8 mm, the original 0.9 mm, 1 mm, 1.2 mm and 1.7 mm. Figure 6 shows the results. Here we can see, that at a certain value, the crushing forces are the same, but when the thickness of the base is greater, than this value (in our case it is approximately 1.05 mm), the buckling load decreases. It is clear, that with the increase of the base thickness the reaction forces increase too.

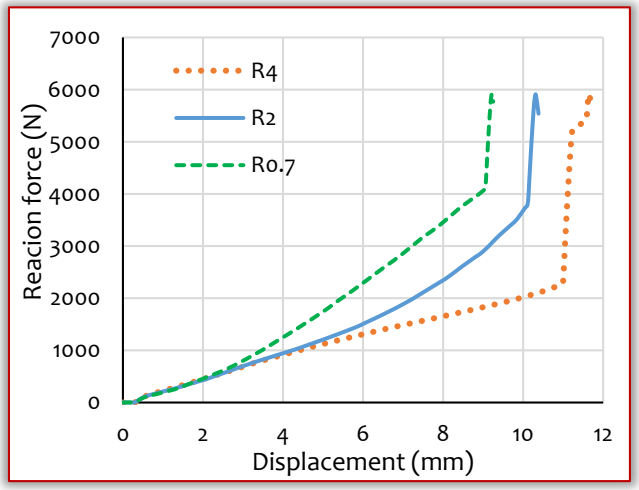

Figure 5. The reaction force – displacement diagrams for different fillets between the base and the side of the cylinder

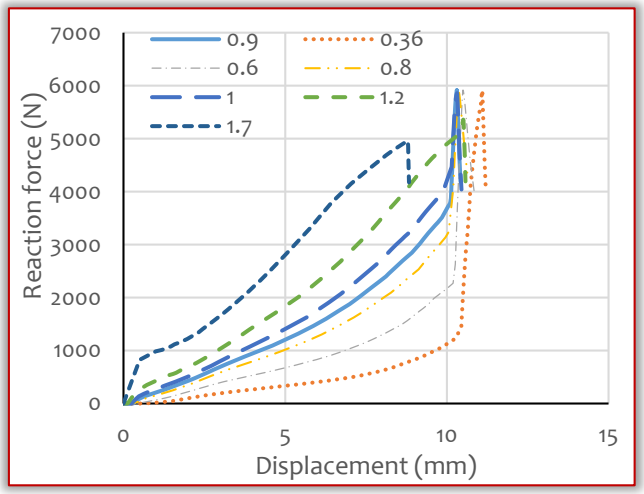

Figure 6. The effect of the shell thickness at the base of the cylinder.

In the following case, the thickness of the base is constant (0.9 mm), the thickness of the side of the cylinder changes. The investigated values and the results for the loss of stability are shown in Figure 7. It is clear, that the reaction forces are similar at a significant range of the thickness values, but the buckling loads differ. Here we note, that the software had some numerical issues with smaller values, especially below 0.22 mm and canceled the simulation with an error. Furthermore with these diagrams, we can determine the limits of the geometry, because we get the maximum deformation (until the buckling) for different values, and then these can be paired up with the appropriate factor of safety. In our current example, the maximum displacement of the can with 0.22 mm side thickness is 9.7 mm (excluding the effect of springback, which can be easily calculated by adding an extra deload step in our model).

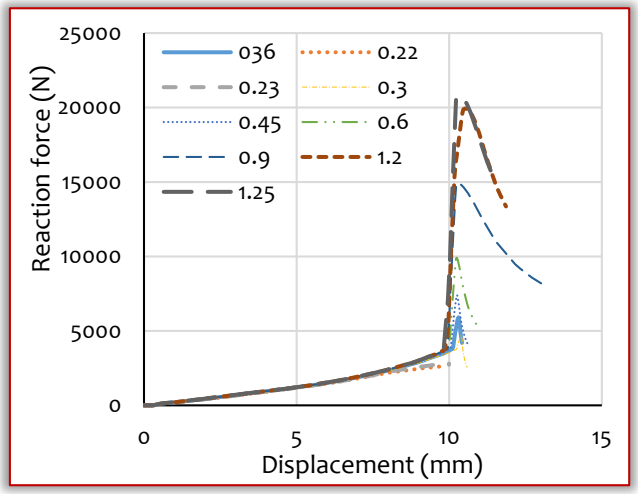

Figure 7. The effect of the thickness of the side on the reaction forces.

THE EFFECT OF GEOMETRY OF THE TOOL AND FRICTION

Let us consider the original can geometry with different tool radii. Figure 8 shows the reaction force – displacement curves for different values. The crushing forces are approximately the same, but the reaction forces during the forming process increase with the increase of the tool radii. To take into account the springback effect, 8.25 mm axial displacement is required to form an 8 mm deep spherical feature. To achieve this, the following reaction forces are required: 14 mm – 2101 N; 16 mm – 2230 N; 18.5 mm – 2375 N; 20.2 mm – 2480 N; 23 mm – 2640 N; 26 mm – 2810 N.

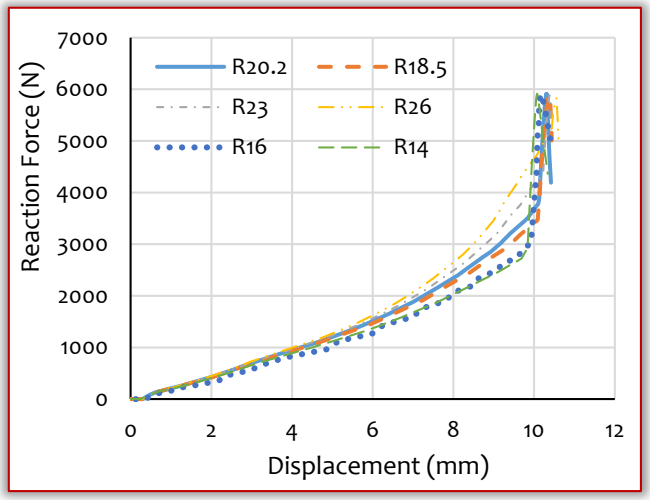

Figure 8. The effect of the radius of the tool on the reaction forces

Finally, the effect of the friction coefficient between the tool and the can is investigated on the reaction forces. Six different values were considered, the results can be seen in Figure 9. I turned out, that the friction coefficient do not significantly affects the reaction forces in this case.

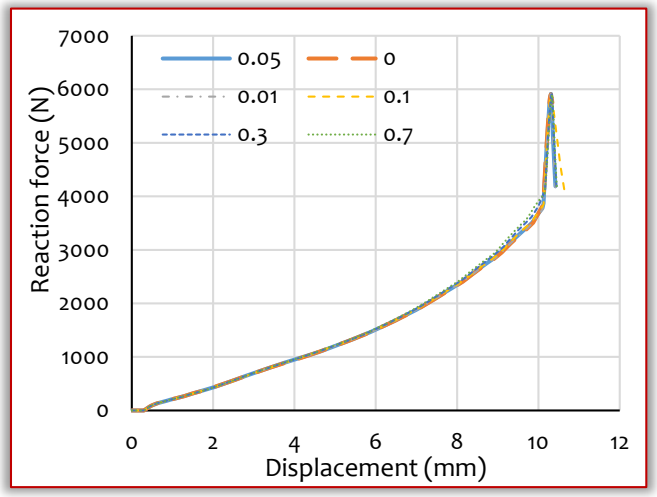

Figure 9. The effect of the friction coefficient

CONCLUSIONS

This paper presents a numerical method to determine the reaction forces during the bottom forming step of thin aerosol cans with the commercial finite element software Abaqus. The three-dimensional geometry was mapped by shell elements introducing imperfections and nonlinearities. It is important to investigate the loss of stability to reduce the number of waste products and to make the mass production more efficient. Multiple features of the geometry were investigated. We could outline the features, that significantly influence the reaction forces required to form the can, thus can be used in the design process to determine the limits of the geometry when compared to the crushing forces. The main contributing factors were the shell thickness of the base of the cylinder, then the different radii in the geometry. An efficient method is presented to calculate the crushing force of the can, at which the loss of stability occurs. The main factor that influenced the stability of the can was the thickness of the side of the can. We found, that the effect of the imperfections on the reaction forces is rather small in this case, although it is necessary to investigate further cases, geometries and parameters, because if the least favorable values occur at the same time for multiple parameters, the buckling load can be significantly lower.

References

[1] Reddy J.N.: Theory and Analysis of Elastic Plates and Shells. CRC Press, 2006.
[2] Chapelle D., Bathe C.J.: The Finite Element Analysis of Shells - Fundamentals. 2nd edition, Springer, 2011.
[3] Radwanska M., Stankiewicz A., Wosatko A., Pamin J..: Plate and Shell Structures: Selected Analytical and Finite Element Solutions. John Wiley and Sons Ltd., 2016.
[4] Patten S.: Design and optimisation of aluminium aerosol cans produced by the back extrusion process. MPhil thesis, University of Wales, Swansea, 2001.
[5] Hardy S.J., Abdusslam R.M.: Finite element modelling of the extrusion process for aluminium aerosol cans. Proc. IMechE, Part L, J. Materials: Design and Applications, 221, pp. 265-274, 2007.
[6] Belblidia, F., Corft, N., Hardy, S. J., Shakespeare, V., Chambers, R.: Simulation based aerosol can design under pressure and buckling loads and comparison with experimental trials, Materials and Design, 52, pp. 214-224, 2013.
[7] Belblidia, F., Corft, N., Hardy, S.J. , Bould, D.C. , Sienz, J.: Aerosol cans under pressure and buckling loads, Sustainable Design and Manufacturing, 1, pp. 13-17, 2014.
[8] Folle, L.F., Netto, S.E.S., Schaeffer, L.: Analysis of the manufacturing process of beverage cans using aluminum alloy, Journal of Material Processing Technology, 205, pp. 347-352, 2008.
[9] Takeutshi, H.: Numerical simulation technology for lightweight aluminium can. Journal of Material Processing Technology, 38, pp. 675-687, 1993.
[10] Ceretti, E., Attanasio, A., Fiorentino, A., Giorleo, L., Giardini, C.: Aluminium can shaping by hydroforming: simulative feasibility study and prototype production, The International Journal of Advanced Manufacturing Technology, 68, pp. 1797-1807, 2013.
[11] Hegadekatte, V., Shi, Y.: Buckling of beverage cans under axial loading, Simulia India Regional Users Meeting, pp. 1-16, 2011.
[12] Sawant, D.A., Venkatesh, M. A.: Buckling and crushing analysis of cylindrical aluminium cans & optimizing the parameters effecting crush strength using FEM, International Research Journal of Engineering and Technology, 3(6), pp. 32081-3085, 2016.
[13] Kiss L.P.: The effect of various imperfections ont he buckling of aluminium shells. Acta Technica Corviniensis – Bulletin of Engineering. 13(1), pp. 49- 52, 2020.
[14] Gönczi D.: Finite element investigation in the forming process of aluminium aerosol cans. ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering, 13(4), pp. 19-22., 2020.
[15] Dessie J.E., Lukács Zs.: Necking limit analysis of thin wall aerosol can. Pollack Periodica. 17(2), pp. 48-53, 2022.

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A PROTOTYPE OF AUTOMATIC ASSEMBLY OF BOLTS AND NUTS

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Abstract: Assembling is one of the essential manufacturing processes, and is typically the final step in producing the final product. The most common assembly in machine building technology, the bolt and nut assembly is highly efficient and simple to replace and maintain. This research involved the prototyping of automatic assembly and classify of bolts and nuts. The Machine elements were designed on Inventor software and then fabricated by 3D printing method. Experiments have demonstrated that the proposed model and the mechanism performed as anticipated. The obtained products are simple in construction, user-friendly, and less expensive than those currently available on the market.

Keywords: classify, assembly, prototype, 3D printing, bolts and nuts

INTRODUCTION

Assembling is one of the essential manufacturing processes, and is typically the final step in producing the final product [1-5]. Assembly encompasses the processes of completing a product from its components or parts. Assembly is a fundamental type of manufacturing in which components are permanently or semi-permanently joined [6-10]. These permanent techniques may include adhesive bonding or welding. Using a combination of mechanical actions and components, such as screws, bolts, and other threaded fasteners, the semi-permanent method of assembling components is accomplished. These conventional mechanical assemblies facilitate assembly and removal when necessary. Assemblies of bolts and nuts are frequently used in machines and structures to facilitate assembly and disassembly. The most common assembly in machine building technology, the bolt and nut assembly is highly efficient and simple to replace and maintain [11-15]. A low-cost automated bolt-nut assembly and classification system is presented in this paper. In the workshop, the traditional bolt-nut assembly procedure is frequently repeated. This is an extremely monotonous and repetitive task that degrades the quality of the work. The proposed system mimics human product sorting and assembly, but is entirely automated. This paper focuses on the design and manufacture of a low-cost, simple-to-operate, and easy-to-maintain system for sorting and assembling bolts and nuts.

OVERALL STRUCTURE OF MACHINE

The overall structure assembly model of the machine designed in this paper is shown in Figure 1. The machine consists of four main parts, as shown in Figure 1: (1): Bolt tray; (2): Groove rail track; (3): Nut- washer tray; (4): Assembly zone

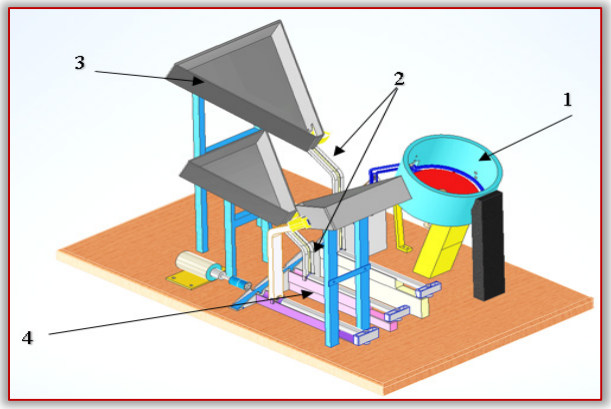
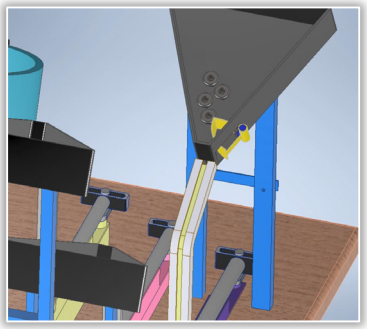


Figure 1. Overview of the machine



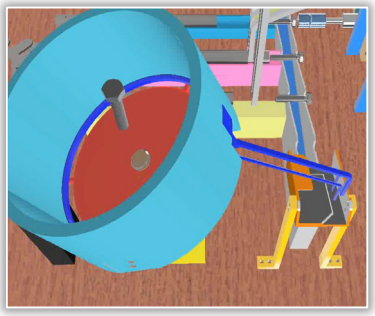


Figure 2. Bolt and nuts tray

Working principle: Bolts are placed haphazardly in the mechanism as shown in Figure 2, the mechanism rotates continuously in combination with the inclined plane, and gravity causes the bolt to roll towards the split groove. The head of the bolt will be directed downwards due to gravity and the clearance of the split groove. At this gap, there are jigs to hold the bolts. The bolt is then pushed by the joists and in the direction of the split groove to move down the assembly, as shown in the Figure 3.

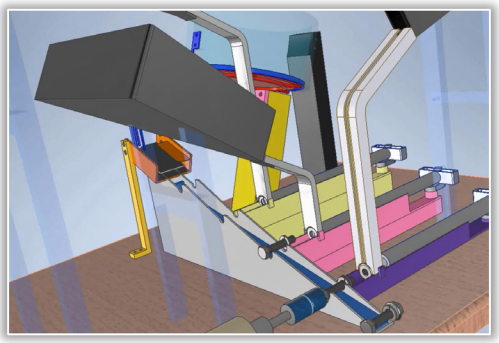
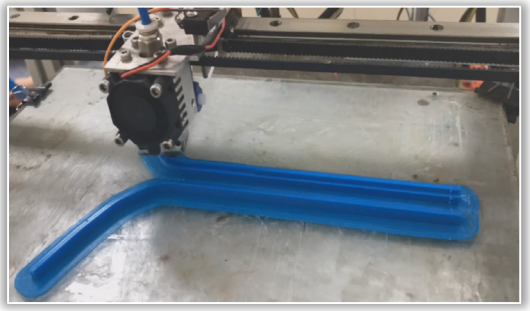


Figure 3. Assembly system

FABRICATION OF A PROTOTYPE MACHINE

Machine elements are designed on Inventor software and then fabricated by 3D printing method, as shown in Figure 4. Most of the machine's parts are manufactured and assembled at the Faculty of Engineering Mechanics and Automation (FEMA) - University of Engineering and Technology, VNU Hanoi. FDM (Fused Deposition Modeling) was the 3D printing technique used, and models are designed in Inventor software before being transferred to Cura software for setting the 3D printing parameters [16]. The printing temperature is 200°C and the layer height is 0.2 mm, it takes from 1 to 2 hours are required to print each parts.



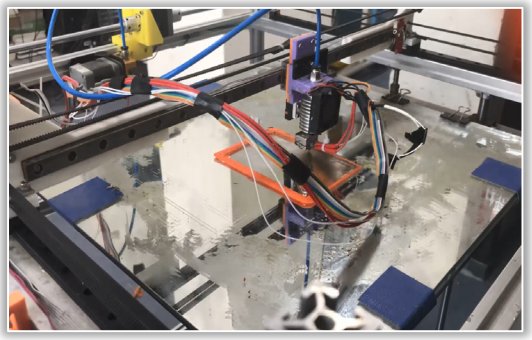


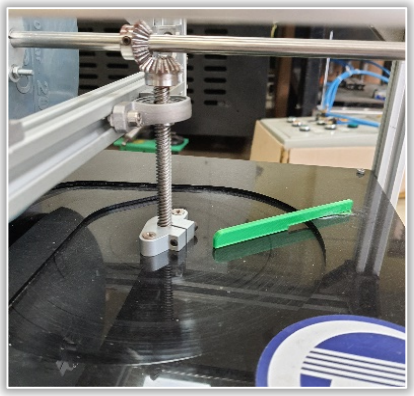
Figure 4. 3D printing technology

RESULT AND DISCUSSION

Figure 5 shows the complete manufactured prototype proposed in this study. The machine's dimensions in length, width, height correspond to 750 mm, 405 mm, and 412 mm, respectively.

Figure 5. A prototype of assembly bolts and nuts machine

Other components, such as screw, bearings and shafts, are selected as standard parts and made available on the market to facilitate repair and maintenance. To evaluate the efficiency of the machine, a large number of bolts and nuts are arranged in trays and subjected to numerous experiments. Experiments indicate that the movements of product sorting, parts sliding on tracks, and assembly completion are executed with great precision.



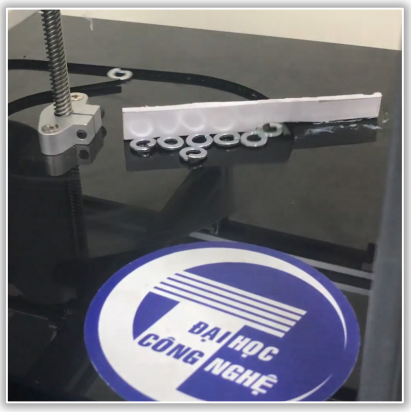
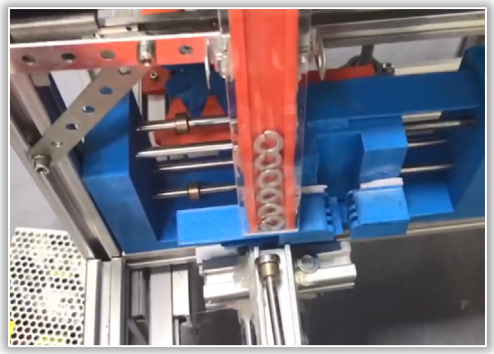


Figure 6. Classification mechanism for washers



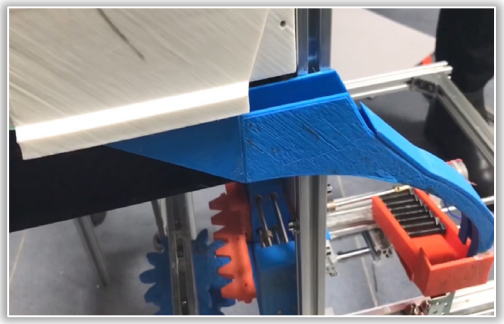


Figure 7. Groove rail track for bolt and nut

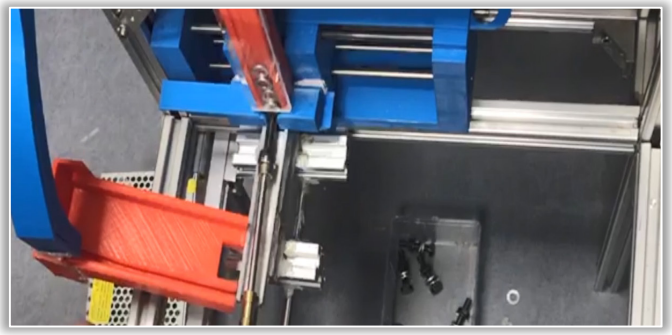


Figure 8. Bolt and nut assembly zone

During operation, components such as bolts, nuts, and washers are moved through the sorting mechanism and then lowered to the assembly area in accordance with their respective grooves, as shown in Figure 6 and 7. Then, these machine element components will be assembled using a hydraulic system in assembly zone as shown in Figure 8.

Table 1. Experimental results

No	Operation steps	Time sequences (s)
1	Push the component down to the assembly area	1
2	Push spring washer for the first bolt	5
3	Push washer for the first bolt Push spring washer for the second bolt	6
4	Push nut for the first bolt Push washer for the second bolt Push spring washer for the third bolt	8
5	Rotate nut for the first bolt	10
6	Rotate nut for the second bolt	12
7	Rotate nut for the third bolt	14
Total (3 complete sets)		15 s

Table 1 shown that assembly time for 3 sets of samples is about 15s. There are fifteen operational steps in the machine system, ranging from part placement to sorting and assembly. Experiments have demonstrated that the proposed model and the mechanism performed as anticipated. Therefore, it is demonstrated that the machine model is intended to achieve the stated objective, thereby improving the precision and efficiency of automatic bolt and nut assembly.

CONCLUSION

This paper describes a procedure for designing and fabricating a machine for sorting and assembling bolts and nuts. A model of a low-cost machine has been proposed. Simple construction and operation, with straightforward maintenance. The obtained products are simple in construction, user-friendly, and less expensive than those currently available on the market.

References

[1] Shai Chereshnia, Sigal Berman. Automatic identification of the assembly base component for robotic manufacturing. IFAC-PapersOnLine, Volume 55, Issue 2,2022

[2] Ding Zhang, Jiewu Leng, Min Xie, Hong Yan, Qiang Liu. Digital twin enabled optimal reconfiguration of the semi-automatic electronic assembly line with frequent changeovers. Robotics and Computer-Integrated Manufacturing, Volume 77, 2022

[3] M. Bortolini, E. Ferrari, M. Gamberi, F. Pilati, M. Faccio. Assembly system design in the industry 4.0 era: a general framework. IFAC-PapersOnLine, 50 (1) (2017), pp. 5700-5705

[4] A. Miqueo, M. Torralba, J.A. Yagüe-Fabra Lean manual assembly 4.0: A systematic review. Applied Sciences, 10 (23) (2020), p. 8555

[5] Paul Jose Madappilly, Ola Jon Mork. Review and modification of DFA2 methodology to support design for automatic assembly (DFAA) in the maritime industry.Procedia CIRP, Volume 100, 2021

[6] Alexandre Dolgui, Fabio Sgarbossa & Marco Simonetto (2022) Design and management of assembly systems 4.0: systematic literature review and research agenda, International Journal of Production Research, 60:1, 184-210,

[7] Bhuvnesh Bharti, Gerhard H. Findenegg, and Orlin D. Velev. Analysis of the Field-Assisted Permanent Assembly of Oppositely Charged Particles. Langmuir 2014 30 (22), 6577-6587. DOI: 10.1021/la5009335

[8] Liu S., Xu D., Zhang D., Zhang Z. (2016) High precision automatic assembly based on microscopic vision and force information. IEEE T. Autom. Sci. Eng., 13(1), 382–393.

[9] Lacey A.W., Chen W., Hao H., Bi, K. (2019) Review of bolted inter-module connections in modular steel buildings. J. Build. Eng., 23, 207–219

[10] J. Matuszek, T. Seneta, D. Plinta, D. Więcek. Manufacturability assessment in assembly processes. IFAC-PapersOnLine, Volume 53, Issue 2, 2020

[11] Christian Denkert, David Kühne, Dietmar Süße, Ralf Glienke, Melanie Fiedler, Maik Dörre, Markus Kästner, Knuth-Michael Henkel. Numerical and experimental studies on press-bolt joints for sheet metal applications - Static strength assessment. Journal of Advanced Joining Processes. Volume 6. 2022

[12] Rachel R. Kroe, Thomas M. Laue. NUTS and BOLTS: Applications of fluorescence-detected sedimentation. Analytical Biochemistry. Volume 390, Issue 1. 2009

[13] Jin-Hee Ahn, Jun Min You, Jungwon Huh, In-Tae Kim, Young-Soo Jeong. Residual clamping force of bolt connections caused by sectional damage of nuts. Journal of Constructional Steel Research, Volume 136,2017
[14] Nishant Ranjan. Dimensional and roughness analysis of ABS polymer-based 3D printed nuts and bolts. Materials Today: Proceedings. Volume 48, Part 5, 2022
[15] Naoki Hosoya, Takanori Niikura, Shinji Hashimura, Itsuro Kajiwara, Francesco Giorgio-Serchi. Axial force measurement of the bolt/nut assemblies based on the bending mode shape frequency of the protruding thread part using ultrasonic modal analysis. Measurement, Volume 162, 2020
[16] Ultimaker Cura, https://ultimaker.com/software/ultimaker-cura (Access 30 May 2021)

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BEST MANAGEMENT PRACTICES ON SOIL ORGANIC MATTER CONSERVATION AND RAINFALL RUNOFF REDUCTION: A TECHNICAL NOTE

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Abstract: The loss of soil degrades arable land and eventually renders it unproductive. Appropriate land management is very important in an area like Uyo, South-South Nigeria, which is characterized by frequent rainfall and high intensity of rainfall in order to reduce the impact of soil erosion consequent upon runoff to a great extent. There have been numerous attempts to avert the menace of soil erosion in the agro-ecological region of Uyo, especially through the large-scale engineering projects funded by World Bank as well as the Federal and State Governments. However, little awareness has been created on the use of cheap and reliable management practices such as growing vegetation strip cropping, crop rotation and mulching, which are capable of protecting the soil surface against the direct impact of rain drop by kinetic energy. These methods also help to increase soil organic matter level and / or vegetal cover, thereby ensuring the stability of the soil aggregates (structure), increases infiltration capacity, while vegetal cover intercepts the ain drops on the soil direction, thus averting intense surface runoff and erosion. The study is intended to provide profound information on cheap and simple methods of soil conservation and erosion control, named best management practices (BMPs). These management practices are expected to be implemented by farmers, soil and water conservation engineers, soil scientists, environmental scientists, crop scientists, and environmentalists, in order to avert soil degradation and optimize agricultural production.
Keywords: soil degradation, soil organic matter, rainfall runoff, erosion control, soil conservation

INTRODUCTION

Land degradation through soil erosion is considered a natural and geologic phenomenon, and it is identified as one of the key challenges that impact on diverse sectors of human existence ranging from the depletion of top natural rich soils, lowering of agricultural productivity and volume storage depletion of reservoirs through sedimentation (Coulombo et al., 2010; Wang et al., 2013). It is therefore pertinent that the soil be protected from the natural and accelerated erosion phenomenon. It is important to state here that the most practical approach to runoff/ erosion control is preventive rather than curative. Preventing erosion by keeping the soil in place through good management techniques is termed, "Best Management Practices" (Syed et al., 2012).

The best management practices (BMP) are required to be implemented in order to control the erosion phenomenon and secure food production via agricultural productivity, enhance the water resources and promote biodiversity and carbon sequestration, as well as influence the agricultural and forestry ecosystems positively. The choice of the technique used in reducing or subsiding erosion problems must fulfil the criteria including cost effectiveness, feasibility, availability, durability, compatibility and labour and management (Jabatan, 1996).

The less the soil is covered with vegetation, mulches, crop residues, etc, the more the soil is exposed to the impact of raindrops. When a raindrop hits bares soil, the energy of the velocity detached individual soil particles from soil clods. These particles can clog surface pores and form many thin, rotten impermeable layers of sediment at the surface, referred to as surface crusts. They can range from a few millimetres to 1cm or more; and they are usually made up of sandy or silty particles. These surface crusts hinder the passage of rainwater into the profile; with the consequence that runoff increases. The breaking down of soil aggregates by raindrops into smaller particles depends on the stability of the aggregates, which largely depends on the organic matter content.

Increased soil cover can result in reduced soil erosion rates close to the regeneration rate of the soil or even lower as reported by Debarba and Amado(1997) for an oats and vetch/ maize cropping system.When the soil is protected with mulch, more water infiltrates into the soil rather than running off the surface. This causes streams to be fed more by subsurface flow rather than by surface runoff. The consequence is that the surface water is cleaner and resembles groundwater more closely compared with areas where erosion and runoff predominate. Greater infiltration should reduce flooding by increased water storage in soil and slow release to streams. Increased infiltration also improves groundwater recharge, thus increasing well supplies (Debarba and Amado, 1997).

Soil erosion fills surface water reservoirs with sediment, reducing their water storage capacity. Sedimentation also reduces the buffering and filtering capacity of wetlands and the flood-control capacity of floodplains. Sediment in surface water increases wear and tear in hydroelectric installations and pumps, resulting in greater maintenance costs and more frequent replacement of turbines. Sediments can also reach the sea, harming fish, shellfish and coral. Eroded soil contains fertilizers, pesticides and herbicides; all sources of potentially harmful offsite impacts. One of the most significant factors affecting organic matter content is erosion (Oregon, 1984). Studies in the United State have shown that OMC was the variable most closely associated with runoff from moderately sloping soils encompassing a broad range of textures.

CLIMATIC CONDITION OF THE STUDY AREA

In humid tropical area like Uyo, rainfall characteristic is one major factor that influences erosion. In Uyo, south-south Nigeria, the rains are of high intensity and of bimodal pattern with two peaks in July and September, and period of 2 – 3 week of little or no rain called August break in between. The dry season gives rise to the pose-season characteristics of a maximum rainfall regime in which the months with the heaviest rainfall are June and July for the first rainfall maximum and September for the second maximum. The annual rainfall ranges from 2000mm on the northern fringe to over 3000mm along the coast (Essien, 2012).

Research reveals that at least 40% of vegetation cover is appropriate to gain considerable protection from rainfall (Jabatan, 1996), but in most regions of Uyo, the native vegetation has been completely replaced by secondary forest of predominantly oil palms and woody shrubs such as grasses. The forest is noticeable around hamlets, watercourses, tree crop plantations and forest reserves. The state lies north of the equator and within the humid tropical and has a mean annual temperature between 26 – 27° and two distinct seasons: the wet season (April to October) and the dry season (November - March). In the south and central parts of the state, the rainy season lasts for about 7 or 8 months but, towards the far north of the state, it reduces to about 6 months (SLUK-AK, 1989).

The geological formation in Uyo is coastal plain sand, which occupies more than 75%of Akwa Ibom State soils (SLUK-AK, 1989). The soils are derived from the parent material and are highly weathered and dominated by low activity clays; the dominant soils in Uyo are of inter-fluvial slope with a pattern of increase in clay content down the profile and are generally of low organic matter cover (OMC), low water storage capacity, and low CEC and highly susceptible to erosion. The dominant forest types in Uyo include the saline water swamp, fresh water swamp forest and the rainforest (Essien, 2012).

It is an established fact that organic matter content increases the stability of soils, thereby reducing its susceptibility to erosion (Gupta et al., 2010; Udoumoh eta l., 2020). The organic content of Uyo soils are low (Udoumoh et al., 2020). Many researchers including (Brady and Weil, 2012; Toy et al., 2002), observed that soils with relatively low organic matter are very vulnerable to water erosion since organic matter increases the stability of the soil. Organic matter binds the soil particles together and creates forces between particles and thus creating stability (Brady and Weil, 2012).

ENHANCING ORGANIC MATTER ACCUMULATION IN THE SOIL

Soil organic matter is the fraction of the soil that consists of plant or animal tissue in various stages of breakdown (decomposition). Most of our productive agricultural soils have between 3 and 6 % organic matter. Organic matter is made up of different components that can be grouped into three major types, namely: plant residues and living microbial biomass, active soil organic matter also referred to as detritus, and stable soil organic matter, often referred to as humus (Cornell, 2006).

The living microbial biomass includes the micro-organisms responsible for decomposition (breakdown) of both plant residues and active soil organic matter or detritus. Humus is stable fraction of the organic matter that is formed from decomposed plant and animal tissue. It is the final product of decomposition. Over time, the application and incorporation of organic materials can result in an increase in stable soil organic matter levels. Sources of organic materials include; crop residues, animal manure, compost (see figure 1), cover crops (green manure), perennial grasses and legumes (Cornell, 2006).

Figure 1: Compost application aimed at increasing soil organic matter levels and promoting aggregate stability Source: FAO (2005).

Soil organic matter (SOM) level depends on both uncontrollable factors ie weather conditions, and controllable factors, that is, soil management. Managing SOM is a balancing act of additions; crop residues, manure, and compost and losses; decomposition plus erosion. Addition of organic materials including animal manure, compost, cover crops (green manure), and some off-farm materials such as municipal leaves and food

residues will increase SOM (Umass, 2020). SOM improves many physical, chemical, and biological characteristics of the soil, including water holding capacity, cation exchange capacity (see figure 2), pH buffering capacity, and chelating of micronutrients.

Furthermore, well decomposed SOM improves soil structure by increasing aggregation, enhances biological activities in the soil, slowly releases nutrients, and suppresses some diseases. A loss of SOM can lead to soil erosion, loss of fertility, compaction and general land degradation (Umass, 2020; Doran and Parkin, 1994; Karlen et al., 2001; Dexter, 2004a). The accumulation of SOM within soil is a balance between the return or addition of plant and animal residues and their subsequent loss due to the decay of these residues by microorganisms and mismanagement of soil (U)to plant loss due to the decay of these residues by microorganisms and mismanagement of soil (Umass, 2020).

For the study area, the relative proportion of the organic matter fraction is small compared to the clay fraction on a dry weight basis (Udoumoh et al., 2020). Humic materials (humus) along with clay particles would provide cation exchange sites in soils that hold the positively charged plant nutrients improving the soil's ability to reduce nutrient losses by leaching.

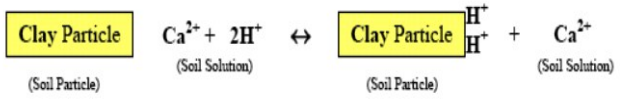

Figure 2: Cation exchange mechanism. Source: Oregan (1998)

Some plant nutrients and metals exist as positively charged ions, or "cations", in the soil environment. Among the more common cations found in soils are hydrogen (H^{+}), aluminium (Al^{3+}), calcium (Ca^{2}+), magnesium (Mg^{2+}), and potassium (K^{+}). Most heavy metals also exist as cations in the soil environment. Clay and organic matter particles are predominantly negatively charged (anions), and have the ability to hold cations from being "leached" or washed away. The adsorbed cations are subject to replacement by other cations in a rapid, reversible process called "cation exchange".

Cations leaving the exchange sites enter the soil solution, where they can be taken up by plants, react with other soil constituents, or be carried away with drainage water. The "cation exchange capacity", or "CEC", of a soil is a measurement of the magnitude of the negative charge per unit weight of soil, or the amount of cations a particular sample of soil can hold in an exchangeable form. The greater the clay and organic matter content, the greater the CEC should be, although different types of clay minerals and organic matter can vary in CEC.Cation exchange is an important mechanism in soils for retaining and supplying plant nutrients, and for adsorbing contaminants. It plays an important role in wastewater treatment in soils. Sandy soils with a low CEC are generally unsuited for septic systems since they have little adsorptive ability and there is potential for groundwater (NRCS, 2014).

The CEC of soils varies according to the clay %, the type of clay, soil pH and amount of organic matter. Pure sand has a very low CEC (Moore et al., 1998). Microorganism supported by the rich food substrate of soil organic matter would stabilise soil particles through encouragement of aggregation, which would result in better water holing capacity in the sandy soils and consequently improve soil drainage in clay soils by promoting large sized pores.

Improved soil structure would improve drainage and also decrease the erosion potential of the previous top soil by reducing the runoff. Many studies have revealed that repeated use of organic amendments will improve the organic matter level (Bauer and Black, 1992; Esu, 2005). Other factors which influence the activity of SOM include organic soil pH and temperature.

EFFECTS OF RUNOFF AND INCIDENCE OF SOIL EROSION

There is pronounced relationship between rate of runoff and incidence of erosion. Runoff water has the energy to detach soil particles by scour and to transport entrained soil materials either in suspension or by pushing or rolling larger particles. In this way overland flow causes erosion. Erosion by scouring accounts for less than 10% of the erosion process, the rest being causes by raindrop impact. Secondary forms of erosion resulting from the transporting effects of runoff are more damaging and are usually classifies as rill, gully and stream channel erosion according to increasing concentration of runoff and the degree of damage caused to land. Runoff erosive capacity is a function of its volume and velocity; as the volume and velocity increase, so do the energy to scour away soil particles and the load-carrying capacity or transport ability. Doubling the velocity of runoff increases its scouring capacity and transportability to the fifth and sixth powers, respectively (Gupta et al., 2010).

Gully erosion is a characteristic feature on the landscape of Uyo agro-ecological/climatic zone, and is attributed to land use and management, especially continuous cropping with the associated shortened or lack of natural fallow and loss of the protective vegetal cover (Ukpong, 1997; Udoumoh et al., 2020). Gully erosion is an advanced stage of rill erosion. Rills are localised washes or channels created when water concentrates into small rivulets in the field. The little streams or rills carry more soil as they pick up speed or grow in size. The abrasive particles they carry scour the sides and bottom of the channels. Rills are relatively small and can be obliterated by conventional tillage equipment. However, total soil loss, even in a single storm can be great because rill and sheet erosion occur simultaneously. Rills when neglected develop in size and become gullies. Rills can be upto 0.3m deep. If they

become any deeper than 0.3m they are referred to as gully erosion. Thus, rill erosion is often described as the intermediate stage between sheet and gully erosion. Sheet erosion is the planar removal of surface soil by the action of either raindrop splash, shallow flows of surface of water, or even by wind. Another name for rill erosion is inter-rill erosion (Suresh, 2006; Aina, 2020).

Gully could also be caused by runoff concentrating at a point on agricultural land. In this case, water concentrates in depression caused by localized weakening of the vegetation cover by grazing or bush burning and enlarges until several depressions coalesce and an incipient channel is formed. Erosion is concentrated at the heads of the depressions where near-vertical scarps develop over which supercritical flow occurs. Some soil properties are detached from the scarp which results in deepening of the channel and undermining of the headwall, leading to collapse and retreat of the scarp up slope (Suresh, 2006).

RAINFALL RUNOFF MANAGEMENT TECHNIQUES FOR EROSION CONTROL

It will not be an overstatement to assert that runoff is perhaps the greatest water management problem on rain-fed crop lands, probably because not only is it the loss of potential water resources but it also causes damaging soil erosion. Runoff occurs when rainfall intensity exceeds the infiltration capacity of the soil which is a measure of the ability of the soil to absorb and transmit rain water. Runoff is limited on soils with a high infiltration capacity. This in turn depends on the water transmission characteristics and structural stability of the soil and its ability to maintain continuous pores. The transmission pores may exist in the soil as a result of coarse texture, good aggregation, or from the burrowing activities of the soil fauna, particularly certain species of earthworms. The rate and amount of runoff are also influences by the intensity and amount of rainfall received, the previous soil moisture content, the degree of relief, slope steepness and aspect. These factors manifest themselves in a wide range of runoff management problems and conservation needs (Aina, 2020).

Runoff is best minimized by ensuring high infiltration of rainwater into the soil through biological conservation measures. Where this cannot be done to full effect, particularly in areas of high-intensity storms or where there are periods of poor crop cover, earth works (physical control measures) can provide surface protection by holding water to give it time to soak through the surface. Such physical conservation measure involves land shaping, the construction of contour bunds, terraces and ridges. These require considerable technical design, supervision, proper construction and maintenance. In contrast, the biological methods include some soil management and agronomic cultural practices that are normally the companion of profitable agriculture such as appropriate land use and preparation, fertility maintenance, crop residue management, the use of cover crops and appropriate crop husbandry (Aina, 2020).

Below are some of the best management practices on erosion control due to runoff:

Mulching

Mulch farming is an efficient method of conserving water and soil by maintaining a protective cover of vegetative residues. One way to improve the condition of the soil is to mulch the area requiring amelioration (FAO, 1995). The beneficial effects of mulching include protection of the soil surface against raindrop impact, decrease in flow velocity by imparting roughness, and improve infiltration capacity. It also enhances burrowing activities of some species of earthworms (e.g. *Hyperiodrilus* spp. and *Eudrilumspp*) which improves transmission of water through the soil profile and reduces surface crushing and runoff and improves soil moisture storage in the root zone (Lal, 1976a). Crop residue mulching is a system of maintaining a protective cover of vegetation residues such as straw, maize stalks, palm fronds and stubble on the soil surface. The system is particularly valuable where a satisfactory plant cover cannot be established rapidly when erosion risk is greatest (FAO, 1993).

Mulching adds organic matter to the soil, reduces weed growth, and virtually eliminates erosion during the period when the ground is covered with mulch. The two principal mulching systems are: in situ mulching system (i.e. a system where plant residue remains where they fall on the grown), and cut-and-carry mulching system (a system where plant residues are brought from elsewhere and used as mulch) (FAO, 2005). Lal (1976a) reports an annual saving of 32% of rainfall in water runoff from mulching in humid western Nigeria. The quantity of mulch required for maintenance of favourable filtration capacity and structural stability depends on the rate of residue decomposition, climate, soil properties, relief and rainfall characteristics.

Vegetation Cover (Cover crops)

Growing cover crops is one of the best management practices for improving organic matter levels of soils and, hence, soil quality. Cover crops help to reduce evaporation, runoff and erosion. The vegetation cover provides shelter to the soil surface by intercepting rain drops which hamper erosion process (Zuazo, 2011). A range of crops which can be used as vegetation cover include grains, oil crops, legumes such as *Mucuna pruriens utilis, Centrosema pubescens, Glycine spp, Setaria spp, Stylosenthes spp*. These are the cover crops which can provide in situ mulch to the soil.

Depending on the land topography, climatic region and other related features it is preferred to use native grass species to alleviate rain drop impacts which therefore reduces runoff an increases rate of infiltration.

Figure 3: A gully in Uyo (near old dumpsite along Uyo village road), gradually becoming stabilized by vegetation cover. Source: Researcher.

For the rainfall intensity of 45mm/h, runoff rate from the grass cover was found to be 4.2 mm/h whereas for shrubs cover it was found to be 9.3 mm/h whereas soil loss remained relatively constant for both the grass and shrub covered plots under the same intensity which reveals the efficiency of grass cover (Xiao et al., 2011). Increasing the grass cover decreases surface runoff (Li, 2011). Moreover, in most areas, grasses have produces desired and intended results for erosion control as they grow rapidly and provide complete protection layer for the ground surface (De, 2006). The most effective way to restore degraded soil is by improving natural vegetation (Garcia-Esringana, 2010). Furthermore, studies by Lal (1988) shows that fallowing for one or two years with the above-named cover crops has been reported to improve soil structure and infiltration capacity.

- Conservation Tillage Practices (e.g. zero tillage or no tillage)

Several studies have revealed that conventional plowing and disking breaks down natural (composite) soil aggregates thus creating an avenue for wind and water erosion. In most conservation tillage practices, the number of field operations and soil disturbances are minimised, mulch is used and herbicides are used for weed control. Different types of conservation tillage include: mulch tillage, sub-surface tillage, zero tillage (Onwualu et al., 2006). Repetitive tillage degrades the soil structure and its potential to hold moisture, reduces the amount of organic matter in the soil, breaks up aggregates and reduces the population of soil fauna such as earthworms that contribute to nutrient recycling and soil structure. Avoiding mechanical soil disturbance implies growing crops without mechanical seedbed preparation or soil disturbance since the harvest of the previous crop. The term zero tillage is used for this practice synonymously with terms such as no-till farming, no tillage, direct drilling, and direct seeding (FAO, 2005).

Whereas conventional tillage practices accelerates soil carbon losses and speed up organic matter decomposition; conservation (or reduced) tillage minimize soil carbon losses and thus slow down organic matter decomposition processes. In other words, conventional tillage exposes the organic matter to air and sunlight, and the resultant effect is the lowering of the stable organic matter. As much as a 5-fold reduction in runoff has been reported under no-tillage compared to conventional tillage (Lal, 1976a). The effectiveness of no-tillage farming in soil and water conservation is improved when used in association with planted cover crops. The pulverising effect of conventional tillage can be minimized by reducing the number of operations on the land. This can be achieved by cultivating only the small strips of land required for seedbeds thus leaving wide untilled zones (strip zone tillage); by carrying out tillage with a mulch retained on the ground (mulch tillage) or completing as many activities as possible in one pass (minimum tillage) as with plough-plant operations (Aina, 2020).

- Repeated application of organic amendment (manure)

Saying that organic matter is the key to health and contributes to soil productivity is saying the obvious. Many studies have revealed that a single manure application will not increase the percentage organic matter significantly. In other words, it takes ample time to improve the soil organic matter level. It is unlikely that a single incorporation of manure or cover crops will noticeably increase the percentage of organic matter. Repeated application of an organic amendment in continuation with reduced tillage will improve the organic matter level (Umass, 2020), thereby producing more biomass.

The use of organic inputs such as crop residues and manure have great potential for improving soil productivity and crop yield through improvement of the soil physical, chemical, microbiological and nutrient supply (Abassi et al., 2009). Ofori and Santana (1990) noted that cow dung improves the productivity of soil more than inorganic fertilizer owing to its slow release of nutrient. Poultry manure (PM), swine waste (SW), cow dung (CD), and sewage sludge (SS) were added to a hydromorphic utisol and it influenced the physical properties of soil (Okenmuo et al., 2018). Physical properties of soil influenced by animal wastes were bulk density, total porosity, hydraulic conductivity, gravimetric moisture constants, aggregate stability, and rheological characteristics. Organic manures can also increase water infiltration, water holding capacity, water content and aeration (McCauley, 2017). Erosion will be reduced and root penetration and tillage operation will be enhanced when the soil is well aggregated (USDA, 2003). Addition of soil organic matter is also an important soil conservation measure that accomplishes soil carbon sequestration and mitigation of climate change (McCauley, 2017; NDSU, 2020).

- Crop Rotation

Another technique of improving the soil organic matter content as a result of the decomposition of the root

mass, as well as the reduction of erosion is he rotation of annual row crops with perennial grass or legume sods. The perennial grasses will sure add biomass above the ground as well as below-the-ground, thus maintaining adequate stability of the aggregate (Syed et al., 2012; Okafor et al., 2017).

CONCLUSION AND RECOMMENDATIONS

Soil, as the most important component of an ecosystem, can secure the food production, enhance the water resources and promote the biodiversity and carbon sequestration if it is well managed. Soil erosion can be managed and controlled through cultivation of vegetation cover, application of proper soil and water conservation practices, proper crop management techniques, reduced human interference on the environment, government assistance and public awareness activities/ campaigns through agricultural extension workers.

References

[1] Abbasi M. k, Mushtaq A., Tahir M. M. (2009). Cumulative effects of white clover residues on the changes in soil properties, nutrient uptake, growth and yield of maize crop in the sub-humid hilly region of Azad Jamnu and Kashmir Pakistan. African Journal of Biotechnology 8(22):61-91.

[2] Aina, P.O. (2020). Rainfall runoff management techniques for erosion control and soil moisture conservation.

[3] Bauer A., Black A. L. (1992). Organic carbon effects on available water capacity of three soil textural groups. Soil Sci. Soc. Am. J. 56 (1): 248-254.

[4] Brady C. N., Weil R. R. (2002). The Nature and properties of soils. 13th Edition, Prentice Hall: New Jersey.

[5] Cornell Soil Health Assement Training Manual.Cornel University, College of Agricultural and Life Sciences. Agronomy Fact sheet 41 – soil organic matter.

[6] Coulombo, C., Palumbo, G., Aucelli, P., De Angelis, A and Rosskopf, C. M. (2010). Relationship between soil properties, erodibility and hillslope features on central Apennines, Southern Italy. 19th World Congress of Soil Science, Soil solutions for a changing world. 1-6 August 2010, Brisbane, Australia.

[7] De Baets, S. (2006). Effects of grass roots on the erodibility of topsoils during concentrated flow. Geomorphology, 76 (1-2): p. 54-67.

[8] Debarba, I., and Amado, T.J.C 1997. Desenrohrimento de sisternas de producaodemilho no suc do brasilcomcaracteristics de sustentabilidade. Rer-Bras. Cien. Solo, 21:473-480.

[9] Dexter, A. R. (2004a). Soil physical quality, part 1. Theory, effects of soil texture, density, and organic matter, and effects on root growth. Geoderma, 120, 201-214.

[10] Doran, J. W and Parkin, T. B. (1994). Defining and assessing soil quality. In: Doran, J. W., Coleman, D. C., Bezdicek, D. F., Stewart, B. A.(Eds.). Defining soil quality for a sustainable environment. Special publication No. 35. SSSA. Madison, W. I. pp. 3-21.

[11] Essien, O. E. & Essien, I. A. (2012). Rainfall characteristics, runoff rate and the traffic flow on gully morphometric parameter growth and soil losses in sand- mined peri-urban, Uyo. Journal of Geology and Mining Research, Vol. 7(3), 1307-1318.

[12] Esu I. E. (2005). Soil characterization and mapping for food security. A Keynote Address at the 29th annual conference of Soil Science Society of Nigeria held at University of Nigeria, Abeokuta, from 6th to 10th December 2004.

[13] FAO (1993). Soil tillage in Africa: needs and challenges. FAO soils Bulletin No. 69 Rome.

[14] FAO (1995). Tillage systems in the tropics.Management options and sustainability implications. FAO soils Bulletin. No. 71 Rome.

[15] FAO (2005). The importance of soil organic matter: Key to drought resistant soil and sustained food production. FAO soils Bulletin. No. 80, Rome, Italy.

[16] Garcia-Esringana, P. (2010). Use of Mediterranean legume shrubs to control soil erosion and runoff in central Spain: A large-plot assessment under rainfall conducted during the stages of shrub establishment and subsequent colonization. CATENA.

[17] Gupta, R. D., Arora, S., Gupta, G. D., and Sumberia, N. M. (2010). Soil Physical variability in relation to soil erodibility under different land uses in foothills of siwaliks in N-W India, (2), 183-197.

[18] Jabatan Alam, S. (1996). Guidelines for prevention and control of soil erosion and siltation in Malaysia. Kuala Lumpur: Dept of Environment, Ministry of Science and Technology and Environment.

[19] Karlen, D. L., Andrews, S.S., Doran, J. W. (2001). Soil quality: current concepts and applications. Advanced Agronomy, 74, 1-40.

[20] Lal, R.(1976a). Soil erosion on alfisols in Western Nigeria: effects of slope, crop rotation and residue management. Geoderma, 16, 363-373.

[21] Lal, R., (1988). Erodibility and erosivity. Soil Ero Res. Methods, 141-160.

[22] Li, X. H. (2011). Effects of Bahia grass Cover and Mulch on Runoff and Sediment Yield of Sloping Red Soil in Southern China. Pedosphere, 21 (2): p. 238-243.

[23] McCauley A. Jones C., Olson-Rutz (2017). Soil pH and organic matter. Nutrient management Module No. 8, 4449-8. Montana State University/ Extension.

[24] Moore G, Dolling P, Porter B. and Leonard L. (1998). Soil acidity. In Soilguide: A handbook for understanding and managing agricultural soils. (Ed. G. Moore) Agriculture Western Australia Bulletin No. 4343.

[25] NRCS (USDA National Resources Conservation Service, Technical Resources, 2014.

[26] Ofori C. S., Santana R. (1990). Fertilizer, their potential and use in Africa agriculture in organic matter management and tillage in sub-human Africa-IIBSRAM PROC 10:213219.

[27] Okenmuo, F. C., Odili, O. U.; Okolo, C.C. (2018). Short-term amelioration of soil properties and maize yield using animal wastes in degraded hydromorphic soils of Southeastern Nigeria. Journal of Soil Science and Environmental Management.

[28] Okorafor, Okore Okay; Akinbile, C. O., and Adeyemo, A. J. (2017). Soil Erosion in South Eastern Nigeria: A review. Scientific Research Journal (SCIRJ), Volume v, issue ix, pp. 2201-2796.

[29] Onwualu, A. P., Akubuo, C. O and Ahaneku, I. E. (2006). Fundamentals of Engineering for Agriculture. Immaculate Publications Limited, Enugu, Nigeria.

[30] Oregon Porland (1984) The Importance of Soil organic matter and its influence on soil properties and crop product.US Department of Agriculture, Soil Conservation Service, technical Note Bo. 19.

[31] SLUK-AK (1989). Physical background, soils and land use and ecological problems. Technical Report of Task Force on soil and Land Use Survey, Akwa Ibom State Government prints.

[32] Suresh, R. (2006). Soil and Water Conservation Engineering. Standard publishers Distributors. Delhi 110-006.

[33] Syed Muzzamil Hussain Shah, Ahmad Mustapha Hashin, Khamaruzaman Wan Yusuf, Zahiraniza Mustaffa (2012). Best Management Practices on slope Erosion Controls due to runoff.

[34] Toy, T. J., Foster, G. and Renard, K. G. (2002). Soil erosion: processes, prediction, measurement and control: John Wiley and sons. New York.

[35] Udoumoh, U. I. , Antia O. O., Ahuchaogu, I. I., Ehiomogue, P. O., Sam, E. M. (2020). Analysis of some soil characteristics of gully erosion sites across different land areas of Uyo, Nigeria. Journal of research and innovations in

Engineering, Faculty of engineering, university of Uyo, volume 5, number 2, pp.333-340.
[36] Ukpong, I. E. 1997. Nutrients built-up in bush fallow soils and its implication to subsistence agriculture in Akwa Ibom State. Ibom Journal Soc. Issues 3: 82-88.
[37] Umass extension crops Dairy, Livestock, Esuire, www. Umass.edu/cell.Retrieved 12th June, 2020.
[38] United State Development Agency (USDA, 2003). Organic matter management and soil conservation into agricultural service information bulletin No. 229.
[39] Wang, B., Zhang, F., Romkens, M. J., Darboux, F. (2013). Soil erodibility for water erosion: A perspective and Chineese experiences. Geomorphology, 187:1-10.
[40] www.ag.ndsu.edu. Retrieved 12th June, 2020. NDSU Extension Service, North Dakota State University London. Soil organic matter & US benefits.
[41] Xiao, P.,W. Yao, and M. J. M. Romkens (2011). Effects of grass and shrub cover on the critical unit stream power in overland flow. International Journal of Sediment Research, 26(3): p. 387-394.
[42] Zuazo, V. H. D. (2011). Environmental impact of introducing plant covers in the taluses of terraces: implications for mitigating agricultural soil erosion and runoff. CATENA, 84(1-2):P. 79-88.

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IoT BASED AUTOMATION IN SEWAGE TREATMENT PLANT

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Abstract: Generally, the manual Sewage Treatment Plant ought to be monitored by an individual all the time in our college. To eliminate human dependency, we have come with an idea that completely automates the sewage treatment process in our college. This project detects the level, pH, quality, toxic level and quality of gasses of the STP by using IOT technology with different sensors, Wi-Fi modules and Arduino to make the traditional STP more robust and efficient. All these parameters are tracked by the authorized people through the website which indicates the tank's activity periodically and alerts the user. The STP automation aims to achieve this by making use of IoT technology, to reduce power consumption, human dependency and give a better water quality which can be used for further use.

Keywords: Automation of Sewage Treatment Plant; IoT; Arduino; Ultrasonic Sensor; STP

INTRODUCTION

The Traditional Sewage Treatment Plant works in a manual mode where the motor should be operated manually. It needs the involvement of an experienced operator to make sure if the process is completed in each reactor. The main purpose of the treatment of sewage water is to remove contaminants from sewage to produce an effluent that is suitable for discharge to the surrounding environment. This provides the residential and commercial areas clean and pure water by reusing the wastewater. A sewage treatment plant in our college consists of three tanks namely the BBR reactor, FAICR reactor, and AICR reactor. The BBR stands for Baffled Bio-Reactor i.e., primary reactor, FAICR stands for Fluidised Advanced Immobilised Cell Reactor i.e., secondary reactor and AICR stands for Advanced Immobilised cell reactor i.e., tertiary reactor.

The plants are under the supervision of the operator and they will be deciding the processing time to time. Once the reactor is full or based on time, they have to turn on the motor to fill the next tank. The operator in general has no tool or device which can help him know if the plant is running smoothly or there is a problem in the plant. As seen above the whole process is not very reliable and also time-consuming this is because it is dependent on the operator.

So, we have come up with an idea to automate our college STP using IoT by using various sensors, Arduino UNO and Wi-Fi module. The proposed system is installed with an Ultrasonic sensor to track the level of the reactor and turns on the motor automatically and closes the valve when the reactor reaches a certain level. We use a pH sensor to detect the pH of the reactor.

Generally domestic sewage contains high concentration of pathogens, carbonaceous matter, harmful microorganisms and toxic compounds. Due to decomposition of organic waste products the wastewater has a high level of toxic contents. So, we use special sensors to detect the toxic level in the reactor by using the MQ-4 sensor that detects the methane level. We use an MQ-135 sensor to detect the air quality of the reactor. MQ-135 senses hazardous gas levels of NH3, NOx, Alcohol, Benzene, smoke. Both the sensor measures the values in terms of ppm. This parameter helps to ensure reduced health hazards for the staff working in STP. These are the parameters we consider to automate the Sewage Treatment Plant to make it work more robust and efficient.

The authorized users can view the reactor's activity from anywhere and anytime by viewing the webpage.

LITERATURE SURVEY

- [1] Control Console of Sewage Treatment Plant with Sensors as Application of IoT. Automation is achieved by deploying sensors in the STP to detect the number of different gasses present in the plant. This paper handles the security of the details that are being exchanged between the server and the database by having different logins for different users. The limitations of the project are that it is not completely automated.
- [2] IoT Based Water Supply Monitoring and Controlling System. An IoT-based water supply monitoring and control system is discussed in this paper. The Arduino UNO is mostly used for controller units, while the Raspberry Pi 3 serves as a mini-computer and data uploader to the Adafruit cloud server. Sensors, relays, pumps, and other devices can all be regulated with

Arduino. The data in this device can be accessed from any location with internet access.

- [3] A Minimalist Model of IoT based Sensor System for Sewage Treatment Plant Monitoring. The method was found to be successful for monitoring ETP/STP plants in this paper. Outside the STP plant's tank, Arduinos with sensors have been mounted. The Arduinos' raw data was sent to a Raspberry Pi-based local data concentrator via the built-in Wi-Fi Modules. Using various data mining techniques, the collected data can also provide a wealth of useful knowledge.
- [4] IoT based Sewage Monitoring System. To prevent exposure to certain occupational risks, an IoT-based surveillance system is being implemented. Many factors were taken into account, including humidity, temperature, and the generation of live videos. There will be live video streaming from the camera connected to the Raspberry-pi when assisting sewage employees to search for blockages.

EXISTING SYSTEM

In our existing system, we have a Baffled BioReactor (BBR), Fluidised Advanced Immobilised Cell Reactor (FAICR) and Advanced Immobilised cell reactor (AICR) which is handled by an operator. The problem with traditional Sewage Treatment Plant is that they have a manual system of running the plant. It involves an operator being at the plant all the time to check if everything is running smoothly. The operator in general has no tool or device which can help him know if the plant is running smoothly or there is a problem in the plant.

For example, if the motor that transfers sewage from one tank to the other is dry running then the operator will know about it only after a certain duration i.e., when there is no change in the destination tank. By the time he realizes this issue, the motor would have either broken-down or significant damage would have been done to the motor. As seen above the whole process is not very reliable and also time-consuming this is because it is dependent on the operator. Thus, there is a need for automation.

PROPOSED SYSTEM

The main aim of the project is to control and automate the appliances in STP by using different sensors. The proposed system consists of Arduino Uno, Level sensor (Ultrasonic sensor), Turbidity sensor, pH sensor, MQ-4, MQ-135 sensors, and each sensor is explained below.

— Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The Mega 2560 board is compatible with most shields designed for the Uno.

It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

Arduino is an open-source prototype framework with simple hardware and software. It consists of a programmable circuit board and ready-to-use software called Arduino IDE (Integrated Development Environment) for writing and uploading computer code to the physical board.

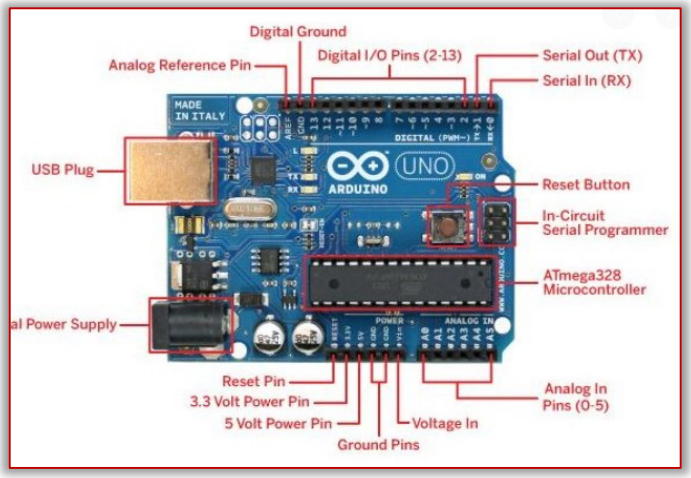

Figure 1. Arduino Uno

— Level Sensor (HC-SR04)

HC-SR04 Ultrasonic (US) sensor is a 4-pin module, whose pin names are Vcc, Trigger, Echo, and Ground respectively. A level sensor is a device for determining the level of fluids, liquids, or other substances that flow in an open or closed system. This sensor measures the distance or senses the objects.

This sensor has two modules i.e., Ultrasonic transmitter and Receiver. The Ultrasonic transmitter transmits an ultrasonic wave. When it senses an object by any material it gets reflected toward the sensor. Once the liquid level is detected, the sensor converts the data into an electric signal.

Ultrasonic sensor is used to track the water level of the reactor and turns on the motor automatically and closes the solenoid valve when water level reaches 90% of the reactor.

— MQ-4 SENSOR

To track the amount of Methane there is a MQ-4 sensor. This sensor measures the values in terms of ppm. Ensure that Methane value is less.

— MQ-135 SENSOR

To track the air-quality of the reactor there is a MQ-135 sensor. This sensor measures the values in terms of ppm. Ensure that CO2 value is high. MQ135 also senses hazardous gas levels of NH3, NOx, Alcohol, Benzene, smoke.

— pH SENSOR

pH scale is used to measure the acidity and basicity of a liquid. It can have readings ranging from 1-14 where 1 shows the most acidic liquid and 14 shows the most basic liquid. pH meter plays a vital role in STP as it determines the acidic component in the water. If the water is more acidic it can't be used for domestic purposes.

— Wi-Fi Module

ESP8266 Wi-Fi Modules are embedded with Arduino UNO and using this network the three Arduino UNOs have been connected to Raspberry Pi. The arrays of sensors which are connected with Arduinos send the data to the Raspberry Pi with the help of Wi-Fi Modules. Raspberry Pi is connected with the central database using the Internet.

— 16X2 LCD

An electronic device that is used to display data and the message is known as LCD 16×2. As the name suggests, it includes 16 Columns & 2 Rows so it can display 32 characters (16×2=32) in total & every character will be made with 5×8 (40) Pixel Dots. So, the total pixels within this LCD can be calculated as 32 x 40 otherwise 1280 pixels.

SYSTEM DESIGN

In this proposed system, the inlet water is the wastewater or the polluted water i.e., discharged water from the college. Tank 1 or BBR tank collects the water from inlet and removal of coarse solids and other large materials are proceed. Tank 2 or FAICR tank does the sedimentation process and removes dissolved and suspended biological matter. FAICR tank fetches the treatment water to the AICR tank. This tank is the final tank which disinfect chemically and produces clean water. This water is used for gardening and other purposes.

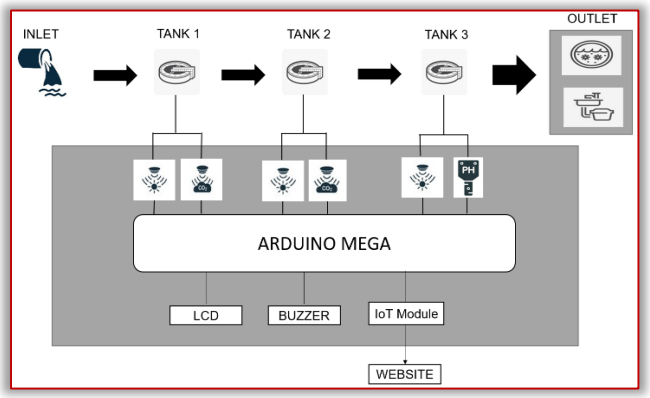

Figure 2. Prototype model

To automate this entire process, we are using an Arduino MEGA microcontroller which is used to interface with the sensors and to communicate with the devices. The MQ 135 – air quality sensor is used to monitor the quality of air like CO2 and other gasses. The MQ 4 – Methane sensor senses the methane value of the tank. The pH sensor evaluates the pH value which helps to pump the water to the outlets. Also, in each tank we have level sensor which calculates the water level in the tank and indicates the Arduino.

If all these sensor values come under the required condition, the final tank i.e., AICR tank allows the water to the outlet pipe.

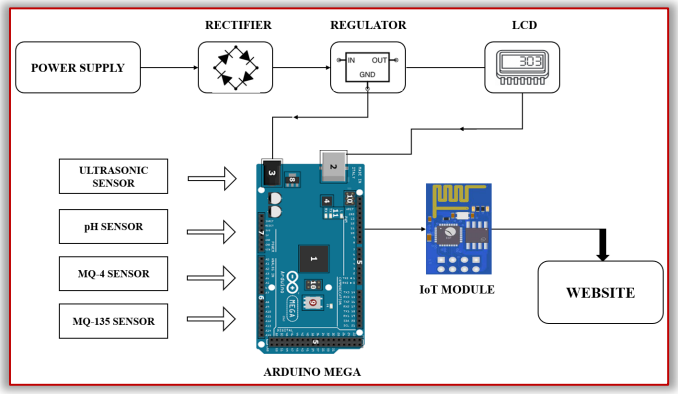

Figure 3. Prototype circuit

The end result can be monitored in the webpage. The LCD is used to display the updated value from the sensors and if any abnormality occurs it is indicated by the buzzer. The IOT module ESP8266 is used to update the information of sensors to the cloud.

IMPLEMENTATION

A sewage treatment plant consists mainly of three tanks namely the BBR reactor, FAICR reactor, AICR reactor. When the BBR reactor gets filled up to 90%, the motor should be switched on automatically with the help of a level sensor and along with a level sensor it also has a methane sensor. MQ4 methane gas sensor is a metal oxide semiconductor type sensor, used to detect the methane gas concentration within the air at industries and generates output like analog voltage by reading it. This gas sensor mainly includes a detecting element like ceramic based on aluminum-oxide (Al_2O_3), coated with Tin dioxide (SnO_2) and arranged within a stainless-steel mesh.

Here, the range of concentration for sensing ranges from 300 pm – 10,000 ppm which is appropriate for the detection of a leak. When the methane level is higher than the required amount, the motor does not pump the water to the next tank. Also, the buzzer gives us an alert ring. If all the conditions are satisfied the pump motor fetches the water to the next tank.

In the FAICR tank, we have two sensors namely ultrasonic sensor and MQ-135 sensor i.e., level sensor and air quality sensor respectively. The MQ135 gas sensor has high sensitivity to ammonia gas, sulfide, benzene series steam, and can monitor smoke and other toxic gasses. It is widely used in domestic gas alarms, industrial gas alarms and portable gas detectors. The level sensor detects the level or length of the tank and MQ-135 detects the air quality. If both conditions are satisfied, the pump motor located between FAICR and AICR gets switched on automatically

and fetches the water into the AICR tank. Both the sensor, MQ- 135 and MQ- 4 measure the values in terms of ppm.

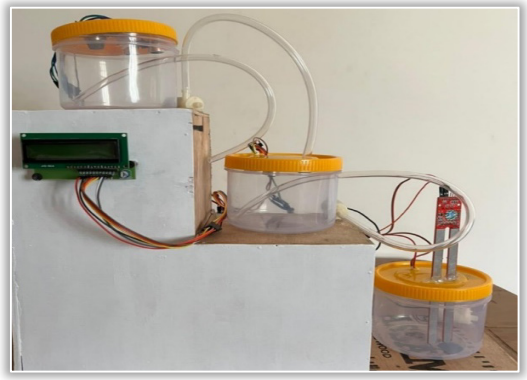

Figure 4.a. Prototype model

The final AICR tank consists of a level and pH sensor. The pH sensor is able to measure the amount of alkalinity and acidity in water and other solutions. Once used correctly, pH sensors are able to make sure the safety and quality of a product within a wastewater or manufacturing plant. Also, pH sensor will allow you to keep pH levels at a level that is most ideal for the process. When the condition of the pH sensor is satisfied then the motor pumps the water into the outlet pipe where it leads to many purposes like watering plants and used as flush water in toilets. If condition fails AICR tank motor pumps the water into the previous tank i.e., FAICR tank.

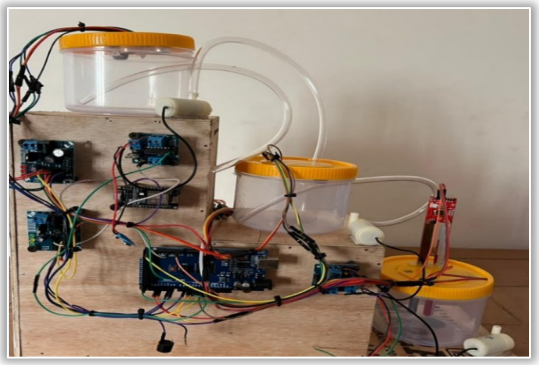

Figure 4.b. Prototype model

The LCD is used to display the updated value from the sensors so that we can watch the absorbed records of the sensor and the tank's activity and if any abnormality occurs it is indicated by the buzzer. The IOT module ESP8266 is used to update the information of sensors to the cloud. The end result can be monitored in the webpage. So that the user can view the tank's activity from anywhere and anytime. The final pump motor is activated based on the pH level.

CONCLUSION

Automation, cost savings, and security are the key goals of the project. To eliminate any human dependence and to avoid the expense of hiring someone to manage the STP at the plant all of the time we came up with this idea with Arduino and IoT module. We handle the security of the information that is shared between the server and the database when doing all of this by providing separate logins for different users.

Finally, the main goal of developing this model was to provide clean, treated water to all at a low cost. This is advantageous to both the people who use the water and the environment because water is conserved rather than wasted. This way, we will keep the environment in balance and contribute to keeping the planet clean and green.

References

[1] Koripella Rishitha and S Ullas, "IoT based Automation in Domestic Sewage Treatment Plant to Optimize Water Quality and Power Consumption" in Proceedings of the Third International Conference on Computing Methodologies and Communication (ICCMC 2019)

[2] Hafiz Abdur Rahman, "A Minimalist Model of IoT based Sensor System for Sewage Treatment Plant Monitoring"

[3] Anushka Pendharkar, Jyothi Chillapalli, Kanksha Dhakate, Subhalaxmi Gogoi and Yogesh Jadhav "IoT based Sewage Monitoring System".

[4] Hideyuki Tadokoro and P.E. Jp Nobuyuki Nakamura, "Monitoring and Control Systems for the IoT in the Water Supply and Sewerage Utilities".

[5] Wanhao Zhu and Zhidong Wang, "Renovation of Automation System Based on Industrial Internet of Things: A Case Study of a Sewage Treatment Plant" 10 April 2020; Published: 12 April 2020.

[6] Sonali S.Lagu, "Raspberry Pi for Automation of Water Treatment Plant" in Proceedings International Conference on Computing Communication Control and Automation 2015.

[7] S Ullas, "Control Console of Sewage Treatment Plant with Sensors as Application of IoT" in 11th ICCCNT 2020 July 1-3, 2020 - IIT – Kharagpur.

[8] Chunbo Xiu and Liying Dong, "Design of Sewage Treatment Monitoring System Based on Internet of Things" The 31th Chinese Control and Decision Conference (2019 CCDC).

[9] M Ramprasath, AK Vijay Varman, J Sanjay and M Sheik Abdul Kather, "IoT based Water Quality Monitoring and Flow Control of Tank Water" International Research Journal of Engineering and Technology (IRJET).

[10] Mg Myo Thwin, "IoT (Internet of Things) Based Water Supply Monitoring and Controlling System" International Journal of Scientific & Engineering Research Volume 9, Issue 12, December-2018.

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PILOT RESEARCH & DEVELOPMENT OF A MULTIFUNCTIONAL AND MULTI–PURPOSE SPORTS EQUIPMENT – AUTOMOTIVE TECHNOLOGIES FOR THE OLYMPICS

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Abstract: Teqball, a new football–based sport developed in Hungary, is played on a specially curved table (Teq table). This recently invented sport is a great way for both professional and amateur athletes to improve their technical skills, concentration and endurance. The development of the first versions of the special curved Teq table suitable for mass production and the technologies to produce them started in 2017. At the outset of the development process, there was a clear commitment to create a high–quality product. The manufacturing technologies have therefore been based on the requirements, standards and technologies used in the automotive industry, given the high–quality expectations of the industry. The research & development of the first versions of the Teq tables posed a number of technical challenges: how to apply automotive solutions to sports equipment manufacturing.
Keywords: curved table, automotive, innovation, composite, welding, CDP painting, flexible bonding, logistics, robotisation, automation

INTRODUCTION

The Teq table is a multifunctional sports equipment similar to a ping–pong table, except that the tabletops are curved instead of flat (Figure 1). Despite the seemingly insignificant difference between the two sports equipment, there are significant differences in the background, both in terms of the design and the manufacturing technology. There are also significant differences in the type of sports played on the sports equipment.

1Figure 1: Teq table

Among the sports that can be played on the Teq tables, Teqball is the basic sport for which the sports equipment must be suitable. For Teqball, a size 5 soccer ball weighing 350–450 grams [1] is used, giving the ball a static load more than 100 times that of a ping–pong ball and an even higher dynamic load.

In Teqball, the main guiding principle in designing the bouncing characteristics of the ball was that it should always bounce towards the player standing behind and/or next to the table for ease of play and continuity of play. This principle provided the basis for developing a curved tabletop shape for the game in the early stages.

The development of the design and manufacturing technology of the Teq table as a sports equipment required a new approach due to the increased load of the game and the curved shape of the tabletop. As the Teq tables are mainly used outdoors due to the larger space requirements, the sports equipment must be able to withstand extreme weather conditions.

In 2017, Teqball Kft., a Hungarian company has set the goal of developing designs suitable for mass production that meet the complex and high requirements, where the appropriate production technology is taken into account during the research and development phase, in addition to the choice of materials.

CONCEPTS, RAW MATERIALS, PRODUCTION TECHNOLOGIES

As a first step in the development project, we analyzed the initial concepts. As a result of the analysis, we have clearly concluded that the concept of Teq tables needs to be completely changed, with new technical solutions in terms of the structural design, material composition and manufacturing technology. During the research, we collected the known requirements that formed the basis for the conceptual design of the project. In developing these concepts, we have set ourselves two main objectives:

- defining and standardizing the dimensions of the Teq tables, and
- creating the design plans.

The conceptual design started with a fixed–design table and selected the three best development directions:

- Version with lattice bracing

For the first version, a lattice–framed structure was created, with lattice–framed stiffening ribs under the tabletops to achieve the required rigidity. In this case, it is not necessary to design and manufacture tabletops with high rigidity, the load bearing is provided by the lattice supports under the tabletops.

- Integrated strut version

For this concept, the bracing ribs are integrated into the structure of the tabletop providing the playing surface. This would allow faster assembly with more compact components.

- Separate tabletop frame and playing surface

The key part of the Teq table is the curved tabletop. Since the tabletops need to be sufficiently rigid but also provide the gaming experience, we developed a concept where the actual playing surface is separated from the structure that provides the rigidity.

Once the concepts were developed, we looked at the possible materials that could meet the requirements.

1Table 1. Main structural units

Material type	Main structural units		
	Foot structure	"Net"	Tabletop
Wood	with appropriate surface treatment	–	with appropriate surface treatment
Structural steel (S235)	with appropriate surface treatment	with appropriate surface treatment	with appropriate surface treatment
Stainless steel	X	X	X
Aluminum alloy	X	X	X
Polymers (PE, PA, PVC, PMMA, PC, etc.)	–	X	–
Composites (laminated)	X	X	X
Composites (pressed)	X	X	X

Following the research, a list of possible materials was compiled. The main criteria for selection were adequate rigidity, corrosion resistance and good formability. Wood materials may be suitable for the leg structure and the tabletop, but surface treatment is required to make them suitable for outdoor use. Wooden materials should not be used for the "net" structural element, as there is a high risk of rapid deterioration due to the cyclical, heavy load ball impact, tiring the structure. Structural steel (S235) is a very good alternative for all structural elements. It has the advantage of being rigid and formable, but due to the outdoor use, corrosion protection is an important aspect. The polymers are well suited to Teq tables in smaller sizes (e.g. the "net" element), but in larger sizes (leg structure and tabletop) rigidity problems can occur. Composite materials would be well suited for all structural elements, as several material compositions can be implemented to provide the required rigidity. [2] They are also very good in terms of geometrical adaptability and fully meet the requirements for outdoor use.

For the different materials different types of manufacturing technologies would be used. At this stage of our research, we only considered the feasibility of the manufacturing technologies, and the cost implications of production were considered later.

CONSTRUCT DESIGN, VALIDATION

The 3 concepts described above were developed in the second phase of the design process. The most suitable material for each design was selected from the possible materials: at this stage we also took into account the manufacturing technology and the likely cost implications of the material.

The following designs have been developed and prototyped:

- Version with truss beams

In this version, we tried to combine different types of materials. The tabletop is made of plywood and the surface is coated with a resin layer for outdoor use. The tabletops are assembled on a structural steel leg structure and a truss beams structure, also made of structural steel, is used. The metal parts are phosphated and then powder coated to ensure proper surface protection.

- Integrated rib version

This construction is made almost entirely (except for the "net") of aluminum alloy. There is no separate stiffening structure under the tabletops in this version, but the tabletop construction itself contains the ribs as a stiffening structure. Welding aluminum alloy during production is more complicated than for structural steel, but the material has the advantage of corrosion resistance: it does not require any special surface treatment to withstand the stress of outdoor use over the long term.

- Separate tabletop support frame and playing surface

For the third construct, different materials were combined: the legs of the table are made of structural steel, but the legs are not assembled in two parts, but four separate legs are made. A further important difference for the leg structure is that we also use a separate bracing, but for this we developed a curved rib rolled from a hollow section. We have also reworked the structural design of the tabletops: a truss support structure welded together from hollow sections provides rigidity, while the playing surface is made of a special composite material (HPL = High Pressure Laminated). [3] The composite plate was attached to the metal grid support frame by an "invisible bond", i.e. by gluing. This solution provides a completely clean playing surface, with no protruding fixings on the tabletop surface. For the

"net" element, we also used the same material (HPL) as for the playing surface: we glued several layers together with contact adhesive.

Once the prototypes were ready, we carried out a series of tests. The load test and the high speed camera test, as well as the climate tests, were only carried out on the 3rd construct, which we considered to be the best design option. In addition to the above tests, combustion tests were also carried out on the materials used for the construct. During the load test, the surface of the assembled table was loaded at several points on the tabletop with a 3,000 N load, and the deflection values were monitored using strain gauges. A rapid camera test was used to investigate the bounce of a ball dropped on a table: the ball was dropped from specific points and heights on the table, and the trajectory of the ball bounces was recorded using a special evaluation software. We also performed a fatigue test on the samples to simulate how continuous, cyclical ball bouncing affects the quality of the playing surface. The final part of the test phase involved climate studies, simulating the expected environmental climate loads for different paint coatings, materials and binders used. The main objective of these tests was to test corrosion resistance and UV resistance. [4] [5]

From the designs and prototypes, we selected the best one, which was the "separate tabletop frame and playing surface" design. This design is the fixed–type table version, which we have given the product name Teq One. Based on this design, in the next phase of the project we started to work on a foldable, mobile version as well, which we call Teq Smart. For the Teq Smart tables, there are also several different designs, but all of them are based on the same materials and technologies as the selected fixed–type table, thus unifying the technologies used in our different products.

For the Teq Smart tables, the most challenging part was the solution we use for the mechanism to provide the rigidity required for a Teq table while still providing foldability and mobility. In addition to the rigidity of the construct, we also consider the design to be very important, so we had to pay attention to this in the design of the construct. In order to achieve the necessary rigidity, the combined weight of the Teq Smart table's raised and lowered parts (tabletop, leg) is quite high, so we had to ensure ergonomic and safe raising and lowering, which we achieved with the help of a gas spring.

In the test phase, the full scope finite element simulations of the developed designs were carried out. The aim of these simulations was to investigate the load capacity, rigidity and stability of the tables as a whole structure. [6]

Once the constructs got approved, we were able to start obtaining the certificates, which we managed to obtain for the parent company of Teqball Kft. due to the intellectual property rights. Separate certification is required for the European market and for the North American market. The main challenge for the certification bodies was to find a way to test the equipment, but long negotiations resulted in success: we obtained a UL (USA and Canada) certification and a GPSD (General Product Safety Directive) certification for the European markets.

We have also prepared the necessary quality management and quality assurance standards for the finished constructs, against which the Teq tables are certified. The quality management and quality assurance are very complex systems themselves, as we have set high quality standards for our products. [7] We have prepared a lot of internal standards, work instructions for the quality management staff, the mass production quality control processes, the sample FMEA analysis protocols, etc.

MASS PRODUCTION PLANNING

Getting finished designs into mass production is one of the most complex parts of the whole product development process. Setting up the production equipment and production lines is essential for mass production, but logistics is equally important at this stage.

One of the crucial technological parts in terms of the manufacturing techniques is welding. In order to produce welded assemblies with the correct tolerances in terms of dimensions, precise devices are needed to position the parts to be welded. As a first step in the mass production, we have created provisional welding machines, which will be followed by mass production welding machines. The provisional machines have a simpler design, which makes them faster and cheaper to produce, however they are capable to produce up to 2,000 products only. These provisional welding devices are made for both the Teq One and Teq Smart tables. To complete the project, we will build the mass production welding machines based on the experiences we gained.

Another very important technological element of the constructs is the gluing of the tabletops. A flat HPL sheet is glued to the curved metal frame, thereby cold deforming it and fixing it to the metal frame by gluing. To ensure proper positioning, we have developed a gluing device that positions the parts to be glued and holds the playing surface itself under pressure until the glue sets. In developing the gluing devices, we have placed great emphasis on ensuring that during the adhesive curing period, these devices – and with them the tabletops under clamping – can be stored easily, with little space requirement and are easy to move. Gluing is a very complex process, and the technological description of the gluing process, which we developed together with the supplier. [8] To apply the gluing technology in large series, we have started to develop and adapt a technology to reduce the curing time of the adhesive from 48 hours to 8

hours. To do this, we need a special extrusion device called a Booster pump. The introduction of this into the production process is still in progress.

In terms of logistics, the biggest challenge was to transport the parts of different sizes and shapes at the same time. [9] We needed to develop solutions that would allow us to transport the painted products without damage, while maximizing the capacity of the available means of transport. In mass production, individual containers are always developed for the transport of parts, allowing both internal and external logistical processes to be optimized.

We have developed a "stocks" system, also used in the automotive industry, first for the fixed–type table and then for the folding version. With the Teq One table – because it is simpler and has fewer components – we have managed to use individual containers for each component. For the Teq Smart table, we have designed complex containers with several types of components due to the complexity and large number of parts. An individual container consists of two main parts: the metal support frame, which is the stocks, and the separators, which are placed inside it to keep the parts at a distance from each other, avoiding contact and damage.

The metal stocks are welded steel structures made of hollow sections, which must be able to support several tons of weight for certain components. Through continuous development, we have optimized the structure of the stocks, strengthening them where necessary and making them lighter where lower inertia sections were sufficient. We needed to make the stocks easy to dismantle so that they would take up less space when empty during return shipments and would be easily accessible during the packaging process.

The tabletops (both before and after gluing) are stored in a unique bag made of strong fabric, which is very easy and simple to handle. For the other components, a modular system of high–density technical foams, the so–called logistics trays, has been assembled. These logistics trays separate the parts from each other, and the high–density technical foam ensures that they can withstand loads of up to several hundred kg when stacked on top of each other in rows. For each part, the separator elements had to be designed individually to match the shape of the part.

The stocks and the separators together form a complex logistics system. During the development, we had to carry out a lot of tests: test unpacking and packing, test unloading, test deliveries, and we also had to test how the stocks or sets could be rotated between the different stations (e.g. between a supplier and the logistics center).

One of the most important elements of modern manufacturing is the supply chain, and within it, logistics. The current trend in manufacturing is for OEMs (Original Equipment Manufacturers) to focus on core or basic activities, while outsourcing all other functionality. Due to the fact that Teqball Kft. does not yet have its own manufacturing capacity, we had to outsource most of the manufacturing activities. This production organization in turn increases the importance of supply chain and logistics: many materials and parts need to be moved at the same time, and in a coordinated production process, they must always be in the right place at the right time. Reducing lead times is one of the most important goals in production optimization, which is best achieved by optimizing the internal logistics processes. As the concept of outsourced manufacturing means that there are many locations in the process, lead times are increased.

CONCLUSIONS

In this article, we presented the design process of an innovative product, the Teq table technology, in which we successfully solved the following tasks:

- selection of the raw materials
- selection of the technologies
- prototype production
- testing
- development of the quality management procedures and documentation
- design and development of the production technology
- supply chain and logistics system development
- development of the transport and storage equipment
- outsourcing

Within the R&D project, we could implement more manufacturing technologies that are used in the automotive industry. On the other hand, we developed the first serial producible Teq table and there is not compromise in the requirements. This generation of the Teq tables is really rigid, so the game experience on it is enjoyable, and can be used all around the world as an outdoor product.

We combined the different segments of the industries from the technology, used materials or requirements points of view. This kind of development does not happen so often, especially in the sports industry.

The development of the Teq tables is continued, we try to robotize the gluing process based on also the automotive industry and optimize the existing technologies, researching new materials or reducing the mass of each part of the Teq table.

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References

[1] [Online] https://digitalhub.fifa.com/m/2cd75dccd94ad3ea/original/FIFA–Quality–Programme–for–Football–Testing–Manual–October–2022.pdf.

[2] [Online] Sheet Moulding Compound, https://www.sciencedirect.com/topics/engineering/sheet–moulding–compound
[3] [Online] High Pressure Laminate (HPL) High pressure laminate or HPL is the direct descendent of the original plastic laminate, https://www.compositepanel.org/products/decorative–surfaces/high–pressure–laminates/#:~:text=HPL%20is%20produced%20by%20saturating,(more%20than%201%2C000%20PSI)
[4] EN ISO 9227:2017 Corrosion tests in artificial atmospheres. Salt spray tests
[5] EN ISO 4892–2:2013 Plastics. Methods of exposure to laboratory light sources. Part 2: Xenon–arc lamps
[6] Végeselem–Módszer, Szerkesztette: Kovács Ádám Írta: Moharos István, Oldal István és Szekrényes András, 2011 (https://www.edu.u–sze–ged.hu/nt/hu/?q=hu/kepzesi_programok/bolognai/diak_munka_elvarasok/hivatkozasi_szabalyzat)
[7] EN 14468–1:2015 Table tennis. Part 1: Table tennis tables, functional and safety requirements, test methods
[8] [Online] Sika manufacturer product information and datasheet (https://industry.sika.com/en/home/appliance–and–equipment/hvac/sikaflex–252.html)
[9] [Online] 3D rakománytervezés a hatékony logisztikáért, 2020.05.16., https://newtechnology.hu/3d–rakomanytervezes–a–hatekony–logisztikaert/

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EFFECT OF BOREHOLES CLOSENESS TO SEPTIC TANKS / PIT LATRINES ON DRINKING WATER QUALITY (MICROBIOLOGICAL LOADS) IN UYO METROPOLIS, AKWA IBOM STATE

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Abstract: Poor water quality due to faecal contamination with potential pathogenic microorganisms is life threatening. In this study, the effect of boreholes closeness to septic tanks / pit latrines on drinking water quality in Uyo metropolis, Uyo was investigated. The water samples were collected from thirty different locations and grouped into: (i) water from boreholes close to septic tanks/ pit latrines ($\mathbf{W_{close}}$) and (ii) water from boreholes far away from septic tanks/ pit latrines ($\mathbf{W_{far}}$). Some microbiological parameters analyzed were total coliform (TC), Escherichia coli (E. coli) and Heterotrophic bacteria (HB) using standard method. Pairwise comparison among quality parameters of $\mathbf{W_{close}}$ and $\mathbf{W_{far}}$, and World Health Organization permissible limit ($\mathbf{W_{Lim}}$) and $\mathbf{W_{close}}$ revealed significant mean differences (MD) while $\mathbf{W_{far}}$ and $\mathbf{W_{Lim}}$ did not show any statistical significant MD at 5% level of probability. The ANOVA result showed that the mean value of the combined parameters in $\mathbf{W_{close}}$ was significantly higher than of $\mathbf{W_{far}}$. Based on the results, the presence of intolerable amount of TC, E. coli and HB is an indication of faecal contamination and probably due to inadequate water treatment which may likely pose public health threat. Hence, it is suggested that boreholes should be drilled at a reasonable distance away from septic tanks/ pit latrines, and that proper routine treatment should be adopted to ensure safe drinking water to the populace.

Keywords: Boreholes, Septic tanks/ pit latrines, Drinking water, Quality, Microbiological loads

INTRODUCTION

The quality of drinking water has been of great importance because it determines the welfare of humans. Poor water quality due to faecal contamination with potential pathogenic microorganisms represents an obvious health risk (Cunningham and Saigo, 1997). Occasional epidemics of bacterial and viral diseases are carried in drinking water (Meybeck and Helmer, 1992). Borehole water can be a transmitting medium for variety of disease causing organisms. A major outbreak of cholera and water borne toxic chemicals is now posing the greatest threat to the safety of water supplies in industrialized nations and this is particularly true of groundwater. In view of this, the World Health Organization has spelt out permissible limits of water quality parameters for various applications (WHO, 2008). However, Uyo Metropolis is characterized by indiscriminate siting of pit latrines and septic tanks. Pit latrines and septic tanks are often located quite close to potable water sources such as shallow boreholes and hand dug wells. This practice is bound to affect the quality of potable water. According to Etang (2000), the people of Uyo mostly depend on water from boreholes for drinking, general household and domestic sanitation. Drilling of boreholes / wells has been a thing for almost every compound. The migration of underground contaminants is dependent on the permeability and porosity of the subsurface rocks strata, which control the capillary and hydraulic system of the soil (Pettijohn, 1965). Increase in population and socio–economic activities in Uyo has led to increase in pollution stress on the groundwater and it can be inferred that borehole water quality in the vicinity of public supply sources are threatened by waste dumps. Domestic waste causes water pollution when mineral and organic substances such as refuse, faeces, urine and decomposed organic matters are channeled into water bodies (Salami et al., 2001). However, recent study by Akpan et al. (2020), on impact of locating boreholes near septic tanks/ pit latrines on drinking water quality in Uyo Metropolis based on physicochemical parameters revealed that all parameters were within World Health Organization permissible limit except temperature and pH. Consequently, water treatment was still suggested. So, there was need to also examine the quality of these water samples based on the microbiological parameters (total coliform [TC], Escherichia coli [E. coli] and Heterotrophic bacteria [HB]) to ascertain its status. Therefore, the main objective of this research was to examine the effect of boreholes closeness to septic tanks/ pit latrines on drinking water quality (microbiological loads) in Uyo Metropolis. The specific objectives were to: (i) sample domestic structures where boreholes were close to, and far away from septic tanks / pit latrines; (ii) determine water quality from both sources based on some microbiological parameters; (iii) carry out multiple pairwise comparisons of their mean

values with World Health Organization permissible limits (W_{Lim}) using Ordinary Least Significant Difference (LSD) Test and (iv) determine the influence of borehole proximity to septic tanks / pit latrines on combined microbiological parameter using Analysis of Variance (ANOVA). The study would create awareness on the status of water quality from sampled sources in Uyo Metropolis and sensitize the populace on the danger of rampant and indiscriminate drilling of boreholes for drinking water. However, the theory behind this study is based on the fact that the infiltration or permeation of sewage disposal from septic tanks/ pit latrines into nearby groundwater, aquifer formation or boreholes may be possible. Consequently, the quality of this water when subjected to analysis may be objectionable.

MATERIALS AND METHODS

— Study Area

Global Positioning System was used to generate the position and geographical co–ordinates of thirty (30) sampling points in Uyo Metropolis, Uyo, Akwa Ibom State as shown in Figure 1. The co–ordinates of ten (10) locations of boreholes far from septic tanks / pit latrines (BFS) were between the altitude of 73 – 84 m, 5.00431 – 5.02532 0 N and 7.51484 – 7.563820 E while that of twenty (20) locations of boreholes close to septic tanks/ pit latrines (BCS) were within the altitude of 52 – 84 m, 5.00341– 5.00339 0N and 7.3543 – 7.564630 E.

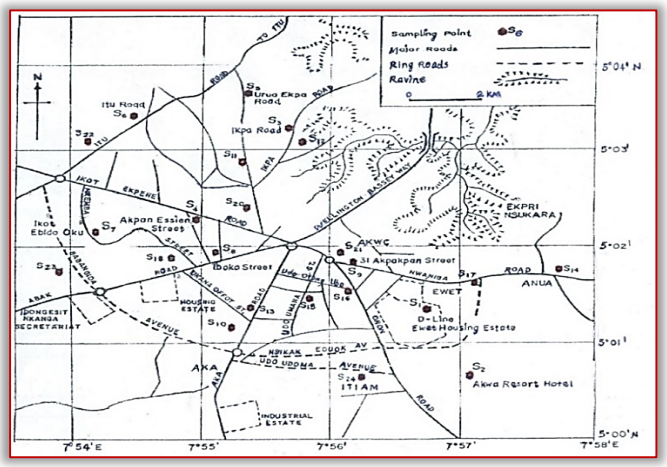

Figure 1: Map of Uyo Metropolis showing sampling points.
Source: GIS–University of Calabar (2010).

— Data Collection

Data were initially collected through reconnaissance survey from boreholes owned by private individuals and those dug by Akwa Ibom Rural Water and Sanitation Agency (AKRUWATSAN) for public use, boreholes located close to, and far away from septic tanks/pit latrines. Some of these facilities are presented in Figure 2 to 5. Meanwhile, distances of 10 BFS ranged from 12.5 – 22.5 m while that of 20 BCS ranged from 3.0 – 7.0 m, where B/H = borehole, GP tank = general purpose tank and S = septic tank/pit latrine.

Figure 2: Borehole located 4.2 metres away from septic tank at a premises located along Akpan Essien Street

Figure 3: Borehole located 4 metres away from septic tank with GP tank on top along Ikpa Road

Figure 4: Borehole located 4 metres away from septic tank along Akpakpan Street

Figure 5: Akwa Ibom Water Corporation (AKWC) reservoir tank and pipe borne water treatment facility about 18 metres away from septic tank

≡ Procedure

Ten (10) and twenty (20) water samples were obtained from BCS and BFS, respectively. They were stored in clean, sterilized and well–labelled one–litre containers. These containers were kept in a cooler and later transferred to a refrigerator at 4 °C prior to analysis to prevent further reaction. Microbiological parameters of water samples were analyzed in Quality Control Laboratory, AKWC, Uyo.

≡ Determination of Microbiological Parameters

Media preparation and culturing were used to determine the microbiological content (total coliform [TC] Escherichia coli [E. coli] and Heterotrophic bacteria [HB]) of borehole water samples from different locations in order to ascertain the presence of TC and E. coli per 100 ml of the sample. Nutrient agar and sodium lauryl sulphate broth were commercially formulated and prepared according to the manufacturer's specification. The major techniques employed were pour plate technique and membrane filtration technique with varying incubation temperatures of 37 °C and 44 ± 0.5°C and incubation periods of 24 hours and 29 hours as required. Other laboratory analyses were carried out for nutrients based on standard methods. These include: argentometric method (titration) analysis for chloride, cadmium reduction method (reduction column) for nitrate, ascorbic acid method for phosphate and turbidimetric method for sulphate (Rodier, 1975). The experiment was conducted in duplicates.

≡ Statistical Analysis

The range, values of mean and standard deviation of the microbiological parameters of water samples from both sources were calculated using Statistical Package for Social Scientists Version 20.0 (SPSS). Multiple pairwise comparisons of their mean values as well as WHO permissible limits (WHO, 2008) were carried out using Ordinary Least Significant Difference (LSD) Test, and ANOVA used to determine the influence of borehole proximity of septic tanks / pit latrines at 5% level of probability (Stephen, 1998; SPSS, 2011).

RESULTS AND DISCUSSION

The summary of values of some microbiological parameters of water samples from boreholes close to ($\mathbf{W_{close}}$), and far from septic tanks / pit latrines ($\mathbf{W_{far}}$) and WHO permissible limit (WHO, 2008) is presented in Table 1, while that of multiple pairwise comparisons of their mean values is shown in Table 2.

Table 1: Summary of values of microbiological parameters of water samples from boreholes close to ($\mathbf{W_{close}}$) and far away from septic tanks /pit latrines ($\mathbf{W_{far}}$), and WHO permissible limits ($\mathbf{W_{lim}}$) (WHO, 2008)

BHP		Microbiological Parameters		
		Total coliform (per 100 ml)	E. coli (per 100 ml)	H.B (per 100 ml)
$\mathbf{W_{close}}$	Range	30 – 80	11 – 73	72 – 124
	N	20.00	20.00	20.00
	Mean	51.45	40.30	94.05
	S.D.	14.90	20.30	15.50
$\mathbf{W_{far}}$	Range	0 – 7	0 – 5	0 – 14
	N	10.00	10.00	10.00
	Mean	2.60	1.30	4.80
	S.D.	2.40	1.80	4.70
$\mathbf{W_{LIM}}$		0.0	0.0	–

Note: BHP = boreholes proximity, N = number of observations and italicized values are standard deviations.

Table 2: Summary of multiple pairwise comparisons among mean values of microbiological parameters of water quality from boreholes close to and far away from septic tanks /pit latrines and who permissible limit

Parameters	Pairs	MD	$\mathbf{P_{cal}}$
Total coliform (T.C) (per 100 ml)	$\mathbf{W_{Lim}/W_{far}}$	−2.600	0.784
	$\mathbf{W_{Lim}/W_{close}}$	−51.45*	0.000
	$\mathbf{W_{far}/W_{close}}$	−48.85*	0.000
Escherichia coli (E.coli) (per 100 ml)	$\mathbf{W_{Lim}/W_{far}}$	1.300	0.920
	$\mathbf{W_{Lim}/W_{close}}$	40.30*	0.003
	$\mathbf{W_{far}/W_{close}}$	39.00*	0.000
Heterotrophic bacteria (HB) (per 100 ml)	$\mathbf{W_{Lim}/W_{far}}$	–	–
	$\mathbf{W_{Lim}/W_{close}}$	–	–
	$\mathbf{W_{far}/W_{near}}$	−89.25*	0.000

NB: MD = mean difference; MD values with asterisk (*) are significant at $\mathbf{P_{cal}} < 0.05$

From Tables 1 and 2, the concentration of TC in $\mathbf{W_{close}}$ ranged from 30–80 counts per 100 ml with a mean value of 51.45 counts per 100 ml, while that of $\mathbf{W_{far}}$ was within 0–7 counts per 100 ml, and with mean value of 2.6 counts per 100 ml. Their mean values were statistical different from each other. Pairwise comparison between the amount of TC in $\mathbf{W_{close}}$ and WHO permissible limit ($\mathbf{W_{Lim}}$) also revealed significant mean difference (MD) at 5% level of probability while that of $\mathbf{W_{Lim}}$ and $\mathbf{W_{far}}$ did not have any statistical significant MD. This might have been attributed to the fact that greater number of water samples from 10 locations recorded TC within 0 to 4 counts per 100 ml. The amount of E. coli in $\mathbf{W_{close}}$ and $\mathbf{W_{far}}$ ranged from 11–73 counts per 100 ml and 0– 5 counts per 100 ml ; with mean values of 40.3 and 1.3 counts per 100 ml, respectively. Statistically, there were significant mean differences. Comparison between the concentration of E. coli in $\mathbf{W_{close}}$an $\mathbf{W_{Lim}}$ (0 count per 100 ml) recorded significant MD while that of $\mathbf{W_{Lim}}$ and $\mathbf{W_{far}}$ did not show any statistical significant MD. This might be as a result of 7 out of 10 locations recorded between 0–1 count per 100 ml of E. coli. The amount of HB in $\mathbf{W_{close}}$ and $\mathbf{W_{far}}$ were within 72–24 counts per 100 ml and 0–14 counts per 100 ml ; with mean values of 94.05 and 4.8 counts per 100 ml, respectively. On comparison between content of HB in $\mathbf{W_{close}}$ and $\mathbf{W_{far}}$, there was statistical significant MD. This implies that both water sources varied in HB content. However, as at the time of this report, there was no information on the $\mathbf{W_{Lim}}$ which could have been used in comparison. Besides, HB was observed to record the highest content in both water sources. Meanwhile, Heterotrophic bacteria majorly help in breaking down organic matters or recycling of minerals in aquatic ecosystem.

Generally, the observed values of microbiological parameters in $\mathbf{W_{close}}$and $\mathbf{W_{far}}$ are not tolerable and are an indication of faecal contamination and probably due to inadequate water treatment which may likely result in gastrointestinal illness, urinary tract infections, bacteraemia, meningitis, diarrhea, acute renal failure and haemolytic anaemia (UW Extension, 2009; NIS, 2015;

CENGAGE, 2020). Meanwhile, the summary of ANOVA result of the effect of boreholes closeness on drinking water quality based on combined microbiological parameters is shown in Table 3 while a bar chart showing the mean concentration of combined microbiological parameters of W_{close} and W_{far} is presented in Figure 6.

Table 3: Summary of ANOVA result of the effect of boreholes closeness on drinking water quality based on combined microbiological parameters

Source Variance	SS	df	MS	R^2	F	P_{cal}
BHP	23720.82	1	23720.82	0.834	140.52*	0.000
Error	4726.65	28	168.81			
Total	28447.47	29				

NB: F–values = variance ratio; F– value with asterisk (*) is significant at P_{cal} (calculated value of probability distribution) < 0.05.

From Table 3, since $P_{cal} <$ 0.05, then F–value was significant coupled with high coefficient of determination (R^2) of 0.834, which implies that W_{close} had significant different concentrations of combined microbiological parameters from that of W_{far}.

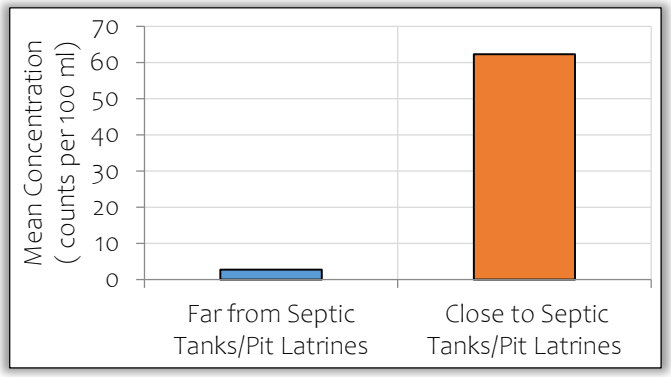

Figure 6: Bar chart showing the mean concentration of combined microbiological parameters of water quality from boreholes close to and far from septic tanks/pit latrines

From Figure 6, the mean concentration of combined microbiological parameters of W_{close} and W_{far} were 62.35 and 2.7 counts per 100 ml, respectively. The mean concentration of these parameters in W_{close} was higher than that of W_{far} by 95.7%. Hence, water from boreholes close to septic tanks/pit latrines is bacteriological unsafe for drinking.

CONCLUSIONS

In summary, the coliform groups of bacteria were virtually found in all W_{close}, but were greatly reduced in W_{far}. Some samples of W_{far} did not record any trace of coliform groups of bacteria. However, the concentrations of microbiological parameters in W_{close}were all above W_{Lim} for drinking water. The ANOVA result showed that the mean value of the combined microbiological parameters in W_{close} was significantly higher than of W_{far}. Based on the results of water quality analysis (microbiological load), the presence of traces of TC, E. coli and HB is an indication of faecal contamination and probably due to inadequate water treatment which may likely pose public health challenge. Hence, it is recommended that boreholes should be drilled at some rational distance far away from septic tanks/ pit latrines with adequate routine treatment to ensure bacteriological safe drinking water.

References

[1] Cunningham, W. P. and Saigo B.W. : Environmental Science. A Global Perspective" (4th Edition), Boston, M. Graw Hill, 1997.
[2] Meybeck, M. and Helmer, R: An Introduction to Water Quality. *In*: Deborah C. (Ed), Water quality assessment. A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring." London, Chapman and Hall, 1992.
[3] WHO (World Health Organization): Guidelines for Drinking Water Quality (3rd edition), Vol. 1, WHO, Geneva, 515p, 2008.
[4] Etang, B. B.: Applicability and reliability of WHO Sanitary Survey (SS) method in borehole water quality analysis in Uyo. Global Journal of Pure and Applied Science, Bachudo Science 7, 2000.
[5] Pettjohn, F. J.: Sedimentary Rocks," Third Edition, New York, Haper and Row, 1965.
[6] Salami, T., Iroegbu, C. and Egila, J. N.: Impact of refuse dump sites on groundwater quality in Jos, Bukum and Environs, Nigeria," Global Journal of Pure and Applied Sciences, 7(3): 437–441, 2001.
[7] Akpan, S. A., Eze, E. B. and Assian, U. E.: Impact of locating boreholes near septic tanks/ pit latrines on drinking water quality in Uyo Metropolis, Akwa Ibom State. International Journal of Trend in Scientific Research and Development (IJTSRD), 4 (6): 700–705, 2020.
[8] GIS–University of Calabar: Geographical Information System Unit, University of Calabar, Calabar, Cross River State, 2010.
[9] Rodier, J.: Analysis of Water, New York–Toronto, John Wiley and Son Inc., 1975.
[10] Stephens, L. J.: Schaum's Outline of Theory & Problems of Beginning Statistics, New York, McGraw– Hill Companies, 380p, 1998.
[11] SPSS "Statistical Package for Social Scientists," User's Guide Version 20.0 for Windows. SPSS Inc., Illinois, Chicago, 170p, 2011.
[12] UW Extension: Interpreting drinking water quality results, Center for Watershed Science and Education: 1–6, 2009. Available Online at www.uwsp.edu/cnr/watersheds.
[13] NIS (Nigerian Industrial Standard) : Nigerian Standard for Drinking Water Quality, Standards Organization of Nigeria Handbook: 1–28, 2015.
[14] CENGAGE: Heterotrophic Bacteria, World of Microbiology and Immunology, 2020. Available Online at https://www.encyclopedia.com/science/

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RECOVERY OF WASTE FROM THE WINE INDUSTRY – GRAPE SEED OIL

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Abstract: Recently, the main objectives in the food industry have been to create easy–to–consume food products, to eliminate waste as much as possible by valorizing it in the context of the circular economy, and the efficient use of by–products as ingredients for the manufacture of new functional foods. As for the wine industry, it generates large amounts of grape pomace, a biological waste that is composed of seeds, skins, stems and remaining pulp. The main by–products that can be recovered from grape pomace are grape seed oil and grape seed meal.

Keywords: waste, industry, grapes, oil, circular economy

INTRODUCTION

In the food industry, the current trends are based on the development of sustainable strategies and the efficient recovery of waste and by–products. Even though waste from the agri–food industry is harmful to the environment, it has a high potential as a raw material for obtaining new products with high added value (*Milanović J. et al., 2021*).

In the world, one of the most used plant species in the agricultural industry is the vine, due to the products and by–products it offers and due to the socio–economic impact, it has (*Sargolzaei M. et al., 2021*).

By–products from the wine industry account for approximately 20%–25% of the processed grapes, and their value leads to an increase in economic efficiency by obtaining valuable products used in different industrial sectors (*Oprea, O.B. et al., 2022*).

The main wastes and by–products of the wine industry are grape stalks, marc/ marc and wine yeast, pulp, tartaric acid and tartrates, ethylic acid, oil and tannin. (*Wounds J. et al., 2020*).

Marc is a by–product that results from the pressing of grapes and sweet musts. Also, here we find bunches, skins, seeds and scraps of mash. Due to certain components (carbohydrates, seed oil, ethyl alcohol) the marc is used to obtain protein feed, tartaric acid, food oil, tannin, dyes (red wine) etc. (*Chicken B. 2018*).

One of the most affordable by–products in the wine industry is grape seeds that can reach about 2.4 million t/year. Due to its high content of proteins, fiber, minerals, polyphenols, antioxidants, phenolic compounds, nonphenolic antioxidants (tocopherols and beta–carotene), and tannins, grape seeds are used as a functional ingredient (*Oprea, O.B. et al., 2022; Spinei, M. et Oroian, M. 2021*). Also, the presence of this grape seed oil, among other benefits, has antioxidant, anti–inflammatory and antitumor activities, thus contributing to human health (*Rosa da Mata I. et al., 2022*).

MATERIALS AND METHODS

— Grape seed oil

The oil is described as a fatty, viscous liquid, having animal, vegetal or mineral origin, with multiple uses such as: in the food industry, technical industry, pharmaceutical, in obtaining and improving cosmetics, in painting, etc.

The recovery of the residues is mainly used in large wine–growing basins, which can provide a significant quantity of grape seeds (*Rusnac L.M.1995*).

Figure 1 – Grape seed oil

— Obtaining grape seed oil

The grapes arrived in the winemaking centres are subjected to a crushing operation, so the berries are broken and crushed, favoring the release of the juice.

The duration of the crushing operation must be reduced to avoid the diffusion of the component substances coming from the skin, pips, bunches into the mustache mass.

After the must drain, the marc remains exhausted, which favors the separation of the grape seeds. The grape seeds are cleaned, washed and conditioned reaching a humidity

value below the critical value for temporary storage, following the operation of obtaining itself (Jordan, M., 2002).

Obtaining oil from grape seeds can be achieved by pressing (cold or hot), by extraction with solvent or even with ultrasound.

— Cold–pressing extraction

The cold pressing method is a method that retains several components beneficial to health because it does not involve heat or chemical treatment (Parry, J., et al. 2006). Unlike conventional solvent extraction, the yield is usually lower. As a result of the cold pressing process, there is no solvent residue from the oil, resulting in a safer and more desired product by consumers (Shinagawa, F.B. et al., 2015).

The extraction method by cold pressing is carried out by means of a hydraulic press. Native (unwrapped) dry seeds (humidity from 8 to 10%) are processed under pressure of 600 bar at the cylinder temperature set at 50°C. The temperature of the extracted oil is 30 °C.

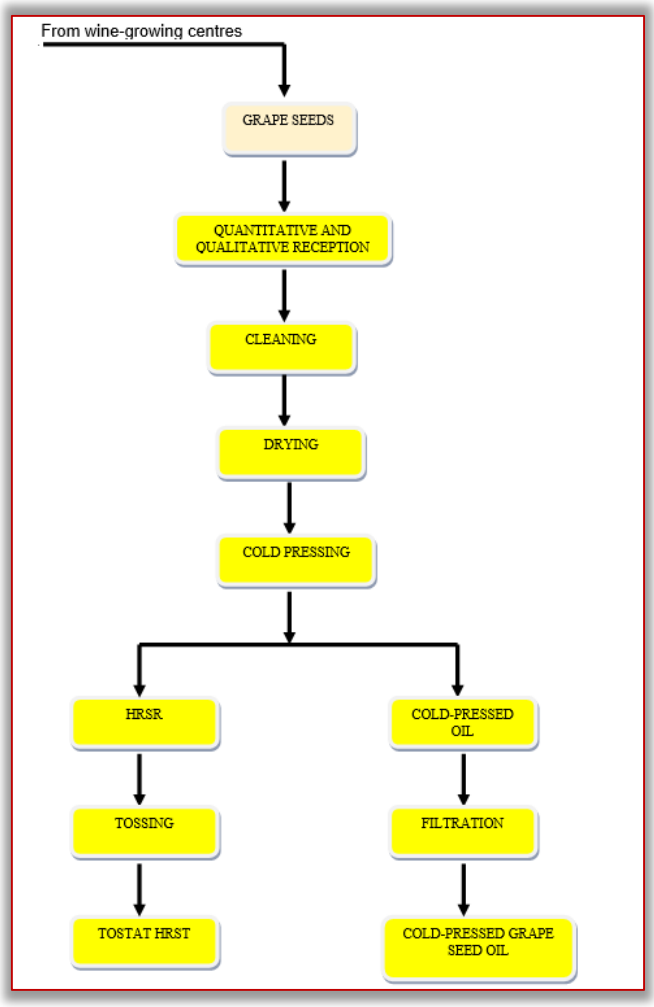

Figure 2 – Technological scheme of obtaining oil from cold–pressed grape pits, (*Adapted from Jordan M. 2002*)

— Ultrasonically Assisted Extraction

For this method the grape seeds are ground, a quantity of 50g is placed in an Erlenmeyer beaker over which 100 ml of n–hexane is added, covered with aluminum foil and are exposed for 90 minutes to ultrasound in an ultrasonic bath maintaining a temperature of 30 °C with the help of a pump water from the thermostatic bath is circulated. The solid is separated by decanting, it washes with n–hexane solution, and using a rotary evaporator the solvent is evaporated at a temperature of 37°C, and a pressure of 0,8 bar using 150 revolutions per minute (*Malićanin M. et al., 2014*).

The use of ultrasonics in oil extraction has multiple advantages such as: reducing extraction time, solvent consumption, and avoiding thermal damage to the extract or loss of bioactive components because the extraction is carried out at lower temperatures (*Mushtaq A. et al., 2020*).

— Composition of grape seed oil

Grape seed oil is a healthy rainy fat, especially due to the high levels of hydrophilic constituents such as phenolic compounds and lipophilic constituents such as vitamin E, unsaturated fatty acids and phytosterols (*Karaman S. et al., 2015,*). Grape seed oil has a nutritional profile similar to that obtained from sunflower seeds, which has led to its use as a culinary oil in countries such as Germany, France and Italy since 1930.

The composition of grape seed oil is influenced by certain environmental factors, the variety of vines or the degree of maturity of the seed because it retains both the quality and aroma of the grape variety (*Shinagawa F.B. et al., 2015*).

A proximal composition of grape seed oil is described in Table 1 (*Akkurt, M. 2001*)

Table 1. Fatty acids composition of grape seed oil:

Acid	Bloke	Proportion
Linoleic acid	ω 6 – unsaturated	46 ÷ 55,5 %
Oleic acid	ω 9 – unsaturated	35,5 ÷ 37 %
Palmitic acid	saturated	5,5 ÷ 8 %
Stearic acid	saturated	2,5 ÷ 3,5 %
Linolenic acid	ω– unsaturated	0,1÷2 %

RESULTS

The benefits of grape seed oil have long been studied and confirmed in the literature.

— Antioxidative activity

The main capacity of grape seed oil is antioxidative, this ability plays the role of eliminating ROS (oxygen–reactive species) and inhibiting lipid oxidation (*Freedman J.E. et al., 2001*), removes free radicals that influence the functioning of the immune system (*Soobrattee M.A., 2005*) and decreases the level of low–density lipoproteins (LDL) (*Valls–Belles V. et al., 2006*) thus reduces the process of occurrence of diseases.

Grape seed oil has also been used in cosmetics, it has been shown that its addition to sunscreens has increases the effectiveness of sunscreen creams in the order of protecting the skin against UV rays (*Souza Sanches P. et al., 2022*). Grape seed oil has benefited the sunscreen

formula due to its synergistic effect with antioxidants, anti–aging properties, anti–inflammatory effects (*Chee Chin Chu et Kar Lin Nyam, 2021*).

Introduced in the diet of birds, grape seed oil has improved their health and weight gain (*Dumitra Panaite T. et all., 2020*). The use of grape seed extracts also benefited chicken eggs, the yolks showed less oxidized lipids even though the weight of the eggs was reduced (*Romero C. et al., 2022*).

Another study showed that grape seed oil increases productivity in rabbits and can be successfully used as a dietary supplement in their diet (*Ahmed M. et al., 2022*).

— Anti–inflammatory effect of grape seed oil

Generally, chronic diseases are associated with inflammatory processes, and the consumption of nutrients with an anti–inflammatory role have a beneficial role in treating of chronic diseases. Grape seed oil dried platelet adhesion in vitro (*Olas B. et al., 2012*) and plays a reducing role in oxidized LDL, thus showing the cardioprotective potential of grape seed oil (*Sano A. et al., 2007*).

— Cell cycle control

The phenolic compounds present in grape seed oil have anticancer activities and act in cell cycle modulation (*Engelbrecht A.M. et al., 2007; Huang S. et al., 2012*), are cytotoxic to tumor and cancer cells without attacking healthy cells (*Husein A.I. et al., 2014*).

— Antimicrobial activity of grape seed oil

The oil extracted from the grape seeds has been shown to have an inhibitory effect on the growth of *Staphylococcus aureus* and *Escherichia coli* (*Rotava R. et al., 2009*). Phenolic compounds such as resveratrol, responsible for antimicrobial activity involve inducing oxidative damage to the bacterial membrane, especially *E. coli*, without harming host cells. In conclusion it is suggested that the use of resveratrol can replace traditional therapies in which antibiotics are ineffective (*Subramanian M. et al., 2014*).

In other words, the phenolic compounds present in the grape seed oil have not only antioxidant activity, but also antimicrobial, anticancer, cardioprotective and anti–aging effects, whether it is introduced directly into the food of humans or animals or in different extracts.

CONCLUSIONS

The magic word that characterizes the peculiarity of waste in the food industry is "recovery". The waste of the food industry should be regarded as raw materials for the production of high–value–added products, rather than as waste within the meaning of the dictionary definition.

There is practically no 'waste' of the food industry that cannot be used as a raw material for the production of products with market value. Even after exhausting all the possibilities of recovery as raw materials, there is the alternative of using this waste as fuels, to ensure at least part of the energy needed to support the production. The food industry is under increased pressure to improve its environmental performance, both from consumers and a from legislative for that are also responding to consumer pressure.

A series of 'clean and friendly' technologies for the processing of food products have been precisely developed with the aim of enabling producers to better understand the effects that their activities have on the environment and to be able to adopt practical measures to achieve sustainable production.

The complex use of waste, residues and by–products from the wine complex (marcs seeds, berry skin, green shoots and unripe grapes, yeast sediments, etc.) allows us to capitalize on their high economic potential on the basis of modern and efficient biotechnologies.

Biotechnologies for the processing of waste and wine–sector by–products have as a major objective the protection of the environment (soil, water and air) from dangerous pollution, caused by their uncontrolled decomposition.

The complex capitalization of the wine by–products is determined by the high share of them and of the substances, active principles they contain, useful to different industries.

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References

[1] Ahmed M. et all. 2022, A comparative study among dietary supplementations of antibiotic, grape seed and chamomile oils on growth performance and carcass properties of growing rabbits, Saudi Journal of Biological Sciences Volume 29, Issue 4, 2483–2488;

[2] Akkurt, M., 2001, Oil Content and Oil Quality Properties of Some Grape Seeds. Ankara University Faculty of Agriculture Department of Horticulture –Ankara – TURKEY. Turk J Agric For 25, 163–168;

[3] Chee Chin Chu, Kar Lin Nyam, 2021, Application of seed oils and its bioactive compounds in sunscreen formulations, Journal of the American Oil Chemists' Society (JAOCS), Volume98, 713–726;

[4] Dumitra T. Panaite, et all. 2020, Effect of The Inclusion of Grape Seed Oil in Broiler Diet on The Intestinal Microflora Balance, Journal of Hygienic Engineering and Design, Vol.33 .225–232

[5] Engelbrecht, A.M., Mattheyse, M., Ellis, B., 2007; Proanthocyanidin from grape seeds inactivates the PI3–kinase/PKB pathway and induces apoptosis in a colon cancer cell line. Cancer Lett. 258(1): 144–153;

[6] Freedman, J.E., Parker, C., Li, L., 2001, Select flavonoids and whole juice from purple grapes inhibit platelet function and enhance nitric oxide release. Circulation.; 103(23): 2792–2798;

[7] Hen B., 2018, By–Products of Wine Origin and Their Use (Informative Study);

[8] Huang, S., Yang, N., Liu, Y., 2012; Grape seed proanthocyanidins inhibit colon cancer–induced angiogenesis through suppressing the expression of VEGF and Ang1. Int J Mol Med. 30(6): 1410–1416;
[9] Husein, A.I., Ali–Shtayeh, M.S., Jondi, W.J., Zatar, N.A., Abu–Reidah, I.M., Jamous, R.M., 2014, In vitro antioxidant and antitumor activities of six selected plants used in the Traditional Arabic Palestinian herbal medicine. Pharm Biol.; 52(10): 1249–1255;
[10] Iordan, M., 2002, Mineral food industries, Macarie Publishing House, Târgoviște;
[11] Karaman, S., Karasu, S., Tornuk, F. 2015, Recovery potential of cold press byproducts obtained from the edible oil industry: physicochemical, bioactive, and antimicrobial properties. J Agric Food Chem.; 63(8): 2305–2313;
[12] Malićanin, M.; Cancer, V.; Antić, V.; Ancient, M.; Palade, L.M.; Kefalas, P.; Rakic, V., 2014, Content of Antioxidants, Antioxidant Capacity and Oxidative Stability of Grape Seed Oil Obtained by Ultra Sound Assisted Extraction. J. Am. Oil Chem. Elderberry., 91, 989–999;
[13] Milanović, J.; Malićanin, M.; Rakić, V.; Jevremović, N.; Karabegović, I.; Danilović, B., 2021, Valorization of Winery Waste: Prokupac Grape Seed as a Source of Nutritionally Valuable Oil. Agronomy, 11, 1864;
[14] Mushtaq, A.; Roobab, U.; Denoya, G.I.; Inam–your–Raheem, M.; Gullón, B.; Loorenco, J.M.; Francisco, B.J.; Zeng, X.A.; Wali, A.; Aadil, R.M. 2020Advances in green processing of seed oils using ultrasound–assisted extraction: A review. J. Food Process Preserv., 44, e14740;
[15] Olas, B., Wachowicz, B., Stochmal, A., Oleszek, W. 2012, The polyphenol–rich extract from grape seeds inhibits platelet signal signaling pathways triggered by both proteolytic and non–proteolytic agonists. Platelets. 23(4): 282–289;
[16] Oprea, O.B.; King, M.E.; Apostle, L.; Gaceu, L. 2022, Research on the Potential Use of Grape Seed Flour in the Bakery Industry. Foods, 11, 1589
[17] Parry, J., Hao, Z., Luther, M. 2006, Characterization of cold–pressed onion, parsley, cardamom, mullein, roasted pumpkin, and milk thistle seed oils. J Am Oil Chem Soc.; 83: 847–854;
[18] Rani, J., Indrajeet, Rautela, A., & Kumar, S. (2020). Bio valorization of winery industry waste to produce value–added products. Bio valorization of Wastes to Renewable Chemicals and Biofuels, 63–85;
[19] Romero, C.; Arija, I.; Viveros, A.; Chamorro, S. Productive Performance, Egg Quality and Yolk Lipid Oxidation in Laying Hens Fed Diets including Grape Pomace or Grape Extract. Animals 2022, 12, 1076;
[20] Rosa da Mata I., Morelo Dal Bosco, S., Garavaglia, J., 2022, Chapter 17 – Different biological activities (antimicrobial, antitumor, and antioxidant activities) of grape seed oil, Multiple Biological Activities of Unconventional Seed Oils, Academic Press, 215–227;
[21] Rotava R., Zanella, I., da Silva, L.P., 2009; Antibacterial, antioxidant and tanning activity of grape by product. Cienc Rural. 39(3): 941–944;
[22] Rusnac, L.M., 1995, Technology of vegetal and volatile oils, "Politehnica" University of Timisoara, Timisoara,
[23] Sano, A., Uchida, R., Saito, M., 2007, Beneficial effects of grape seed extract on malondialdehyde–modified LDL. J Nur Sci Vitamin (Tokyo). 53(2): 174–182;
[24] Sargolzaei, M.; Rustioni, L.; Cola, G.; Ricciardi, V.; Bianco, P.A.; Maghradze, D.; Failla, O.; Quaglino, F.; Toffolatti, S.L.; By Lorenzis, G. 2021, Georgian grapevine cultivars: ancient biodiversity for future viticulture. Front. Plant Sci., 12, 630122;
[25] Shinagawa, F.B., Santana, F.C., Torres, L.R.O., 2015, Grape seed oil: a potential functional food? Food Sci Technol (Campinas). 35(3): 399–406;
[26] Soobrattee, M.A., Neergheen, V.S., Luximon–Ramma, A., Aruoma, O.I., 2005; Bahorun, T. Phenolics as potential antioxidant therapeutic agents: mechanism and actions. Moved Res. 579 (1–2): 200–213;
[27] Souza Sanches, P., et all. 2022. Influence of grape seed oil on sun protection factor in sunscreen formulations: a study using Central Composite Design approach. Drug Analytical Research, 6(1), 40–45;
[28] Spinei, M.; Oroian, M. 2021 The Potential of Grape Pomace Varieties as a Dietary Source of Pectic Substances. Foods, 10, 867;
[29] Subramanian, M., Goswami, M., Chakraborty, S., Jawali, N. 2014; Resveratrol induced inhibition of Escherichia coli proceeds via membrane oxidation and independent of diffusible reactive oxygen species generation. Redox Biol. 2: 865–872.
[30] Valls–Belles, V., Torres, M.C., Muñiz, P., Beltran, S., Martinez–Alvarez, J.R., Codoñer–Franch, P., 2006; Defatted milled grape seed protects adriamycin–treated hepatocytes against oxidative damage. Eur J Nutr. 45(5): 251–258;
[31] https://encrypted–tbn0.gstatic.com/images?q=tbn:ANd9GcRKhDX5D9LrGtkeshhCui–CePYB8PbZHR0VQg&usqp=CAU

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ANALYSIS OF THE CYLINDRICAL GEAR WHEELS IN THE GEAR OF THE CENTRAL DRUM OF THE CABLEWAY

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Abstract: The present paper presents aspects related to the analysis of the cylindrical gears of the central drum gear of the sled-type forestry cableway. This analysis helps to choose and correctly size the gear in the cableway winch drum. Based on the analysis performed on the gears teeth shapes, the analysis of the gear lubrication, and the analysis of the backlash of the teeth the final shape of the gear drive system will be presented. At the end of the work, the analysis with finite elements of the cylindrical gear is presented in order to obtain the optimal structure.

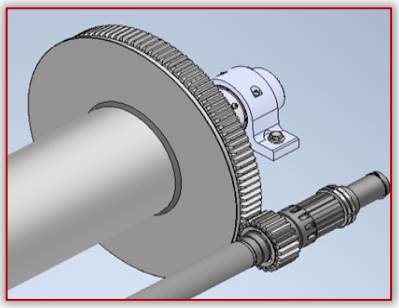
Keywords: cableway, gear drive, FEM analysis, backlash, gear lubrication

INTRODUCTION

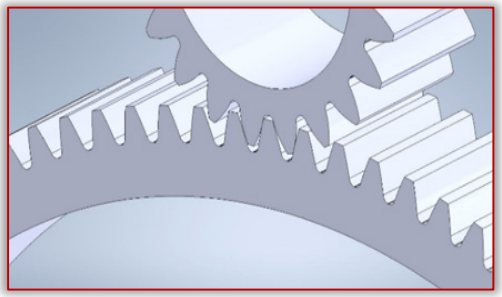
In the logging industry, the construction of access roads has a negative impact on the entire forest ecosystem, especially in the case of high-slope hills or mountains. The national and international legislation recommends the use of alternative log transportation systems when the slope exceeds a certain value. One of the most used solutions are forest cableways, used for clear cut or selective cutting in hilly or mountain terrains. These installations are usually composed of cable drums driven by mechanical power units placed on mealy sleds that allows the system to be self-propelled to the place of operation, usually at the top of the slope *(Lates et. al, 2022)*. To ensure that the mechanical transmission of the forest cableway can cope with the high torque levels specific to such application, a thorough analysis of the components is required. In this article the structural analysis of the gears is performed using Finite Element Analysis (FEA), aiming to evaluate the geometry. By using FEA the potential weak spots in the analysed structure can be identified in the design stage, before the actual build of the component. The are several steps that are required for such an analysis: defining the 3D geometry, assigning the materials, setting the constraints, applying forces and pretensions, meshing, processing and post-processing, followed by refining the model for the next iteration, if required *(Zah, M., Lates, D., Besoiu, S, 2012)*.

GEAR DRIVE DESCRIPTION

The studied gear drive, shown in Figure 1 a), consists of two cylindrical gears, with a 1:5 ratio. The first gear has 22 teeth, while the second one has 110 teeth. Figure 1 b) presents a detail of the system, showing the profile of the two gears' teeth.



(a)



(b)

Figure 1 – Cylindrical gear drive, a) 22/110 Gears; b) detailed view

GEAR DRIVE ANALYSIS

The studied drive system is part of the mechanical transmission of a forest cableway used for transporting the logs downhill from the cutting location to the base of the slope, where the logs are handled for storage and transportation. The same system must be able to develop high torque levels required for transporting the logs from their initial location to somewhere beneath the carrier cable, for distances up to 50 meters. Also, in for the initial set–up stage, the entire cableway must be self–propelled uphill to the top of the slope.

Based on geometrical dimensions of the gears obtained in the design stage, a 3D model of the system was created in

Kissoft, a FEM–based simulation software. Since the system is exposed to wear when not properly lubricated, the mechanical endurance of the gears is studied, focusing on the analysis of teeth shape, lubrication process and the backlash.

TEETH SHAPE ANALYSIS

For a smother translation between the two gears the teeth shape is very important. The specific nominal values of the two gears are included in Tables 1 and 2.

Table 1

Calculation of Gear 1 (A_s= –0.090 mm)		
Tooth from, Gear 1		
Pressure angle	[alfn]	20.0000 °
Normal module	[mn]	5.0000 mm
Data of the corresponding topping cutter:		
Addendum	[ha0]	6.2500 mm (ha0*=1.250)
Radius	[roa0]	1.9000 mm (roa0*=0.380)
Dedendum	[hf0]	5.1076 mm (hf0*=1.022)

Table 2

Calculation of Gear 2 (A_s= –0.160 mm)		
Tooth from, Gear 2,		
Pressure angle	[alfn]	20.0000 °
Normal module	[mn]	5.0000 mm
Data of the corresponding topping cutter:		
Addendum	[ha0]	6.2500 mm (ha0*=1.250)
Radius	[roa0]	1.9000 mm (roa0*=0.380)
Dedendum	[hf0]	5.1963 mm (hf0*=1.039)

DRIVE LUBRICATION ANALYSIS

The importance of the lubrication process analysis comes from the need to reduce gear friction wear and to ensure an efficient and smooth gear roll. During the gear drive operation, it is recommended that a grease is always present between the two teeth that are in contact. Table 3 shows the values that were considered for the simulation, based on standard AGMA925–A03.

Table 3

Effect of Lubrication on Gear Surface Distress (AGMA925–A03) Risk of scuffing / Risk of wear		
General and Geometry input data		
Profile modification		
Material input data		
Average surface roughness at L_x, pinion	[R_{a1x}]	0.6300 µm
Average surface roughness at L_x, gear	[R_{a2x}]	0.6300 µm
Filter cutoff of wavelength x	[L_x]	0.8000 mm
Mean coefficient of friction	[µm]	0.135600
Method for approximate mean coeff. friction	:	Constant, with formula (85)
Welding factor	[X_w]	1.000

The local movement between the two gears is not purelly rotational, a small slip also occures. Depending on the rotation angle and the relative position of the the two teeth that are in contact, the sliding and also the rotational contact are identified in the diagram in Figure 2, showing the specific angle positions A,B,C,D and E.

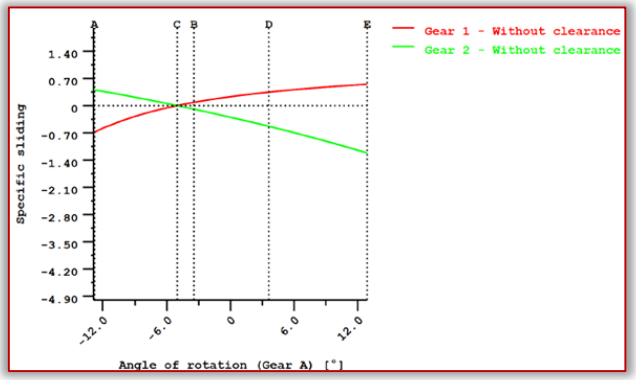


Figure 2 – The specific sliding between two teeth depending on the angle of rotation

— Teeth backlash analysis

In order to avoid the tightening of the gear drive the design process considers a minimum backlash value. Table 4 shows the values that were obtained in the simulations.

Table 4. Meshing gear 1 – gear 2

Accuracy of calculation	Medium	
Partial load for calculation [w_t']	120.0000 (%)	
Working flank	Right tooth flank	
Centre distance	[a]	330.7437 (mm)
Single pitch deviation	[f_{pt}]	7.0000 (µm)
Coefficient. of friction	[µ]	0.0853
Proportional axis deviation error	[$f_{\Sigma b-p}$]	0.0000 (µm)
Proportional axis inclination error	[$f_{\Sigma d-p}$]	0.0000 (µm)
Torque	[T_1]	1970.1104 (Nm)
Speed	[n_1]	385.0000 (1/min)

Figure 4 shows the reference rack and the gear profile, using the following values, for the refference diameters and gaps: d_{a1}= 125.2235 mm; d_{f1}= 102.5082 mm; A_{s1}= –0.09 mm; d_{a1}= 556.1975 mm; d_{f2}= 533.3049 mm; A_{s2}= –0.16 mm.

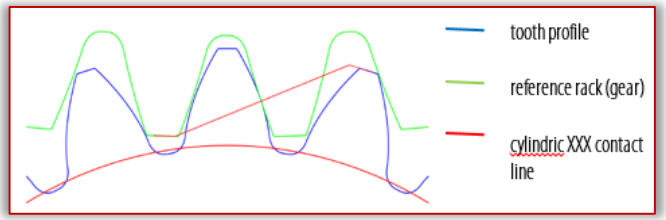


Figure 3 – Gear profile

The stiffness depending on the rellative position of the two teeth is presented in Figure 4.

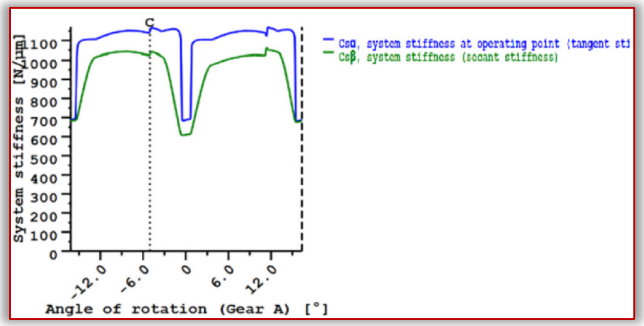


Figure 4 – System stiffness

— Finite element analysis of the gear drive

The optimal teeth shape is obtained using Finite Element Analysis for the cylindrical gear drive *(Moaveni, S., 2003)*.

The mesh is obtained using the automatic generation tool, allowing the definition of the node coordinates, the optimal numbering of the nodes and the connection between the elements, as shown in Figure 5.

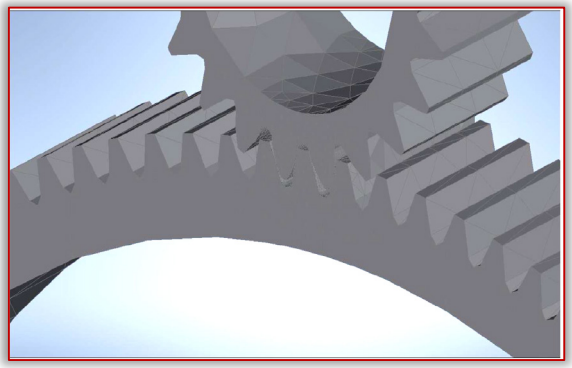
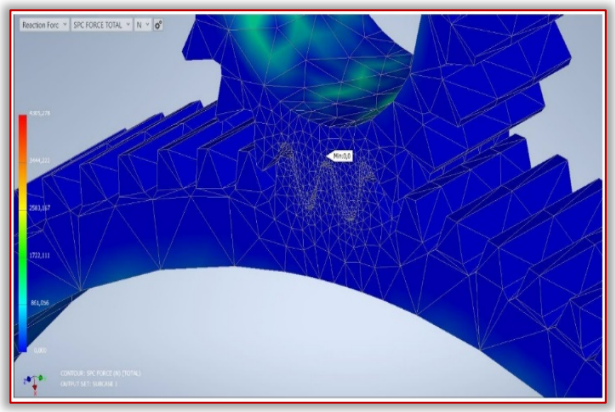
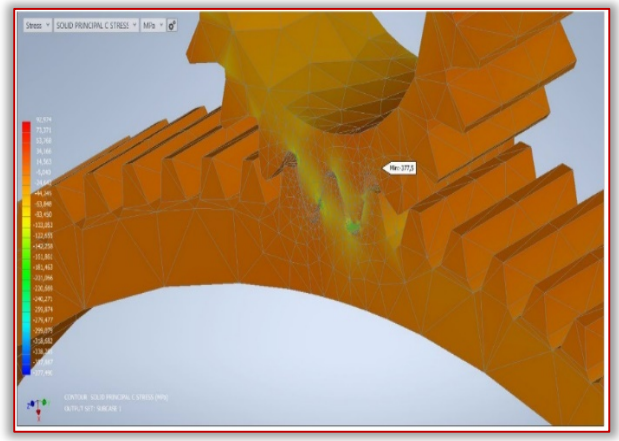


Figure 5 – The mesh

During the processing, the FEM software, starting from the input data, determines the nodal variables, such as the relative displacement of the nodes. Based on these the tension is determined, along with valued derived from the primary variables. Figure 6 a) shows the force repartition in the structure, while Figure 6 b) shows the total pressure forces *(Rares, M. 1992, Noveanu, S. et al, 2020, TTuğrul, Ö., Erol, Z., 2005)*.



(a)



(b)

Figure 6 – FEA analysis. (a) Reaction force distribution; (b) Pressure forces in the system

The finite element method (FEM) used for deformation analysis is the most widely used method for solving engineering problems and mathematical models *(Daryl, L., 2011, Chaskalovic, J., 2008, Zienkiewicz, O. C.,Taylor, R. L. et al, 2005, Baie, K. J., 1976)*. This is achieved by a certain discretization space in the dimensions of the space, which is implemented by constructing a mesh of the object: the numerical domain for the solution, which has a finite number of points. The method approximates the unknown function over the gear domain in which it has been successfully applied.

CONCLUSIONS

The analysis of the drive system, considering the teeth geometrical shape, the lubrification process and the backlash between the teeth that are in direct contact, allows a more precise design of the gear drive. This a vital requirement for the considered application, where high forces are applied when the logs are handled by the forest cableway.

The paper presents the results obtained following the numerical analysis of the mechanical structure with the help of a FEM based commercial software, with an emphasis on sensitive areas (stress concentrators, deformations) in order to develop an optimal structure such as resistance and robustness.

Based on the results obtained in this analysis the gear drive will be manufactured and integrated in the mechanical transmission of the cableway.

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References

[1] Lates, D., Inte, R., A., Chirca, M., Dranca, M., Oprea, C. Initial evaluation of the performances of a sled–type forest cableway, International Conference INTER–ENG 2022, Interdisciplinarity in Engineering, Targu Mures, 2022.

[2] ZAH, M., LATES, D., BESOIU, S. Epicycloidal Gear Shaping Machine, Acta Universitatis Sapientiae Electrical and Mechanical Engineering, 4 (2012) 96–102.

[3] Moaveni, S. Finite Element Analysis. Theory and Application with ANSYS, Pearson Education Inc, New Jersey, 2003

[4] Rares, M. Analiza cu elemente finite, curs Finite Element Analysis, Universitatea Politehnica Bucureşti, 1992.

[5] Noveanu, S., Lates, D., Fusaru, L., Rusu C. A New Compliant Microgripper and Study for Flexure Hinges Shapes, Procedia Manufacturing, Volume 46, 2020, Pages 517–524.

[6] Tuğrul, Ö., Erol, Z. Finite element method simulation of machining of AISI 1045 steel with a round edge cutting tool. Proceedings of the 8th CIRP International Workshop on Modeling of Machining Operations. 2005.

[7] Daryl L. Logan (2011). Un prim curs în metoda elementelor finite. Cengage Learning

[8] Chaskalovic, J.: Elemente finite Metode pentru ştiinţe inginereşti, Springer Verlag, (2008).

[9] Zienkiewicz, O. C.,Taylor, R. L., Zhu, J. Z. Metoda elementelor finite: baza și elementele sale fundamentale, Butterworth–Heinemann (2005).
[10]Baie, K. J. Metode numerice în analiza elementelor finite, Prentice–Hall (1976).

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FEASIBILITY ANALYSIS OF FLUTED ROLLER DISPENSER APPLICATION FOR PRECISION FERTILIZATION

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Abstract: With depleting resources, it is essential to increase the application of Agriculture 4.0 principles and technologies. Blueberry cultivation includes various operations, one of them is fertilization. To precisely discharge the correct amount of fertilizer, a volumetric dispenser utilizing a straight fluted roller could be considered as an option. The aim of this research is to verify whether such a dispenser could be used for precision fertilization with solid granulated fertilizers. The output of the dispenser was measured on different conditions with three NPK fertilizers. Based on statistical analysis, the required 10% discharge uniformity cannot be achieved and it is necessary to modify the dispenser or use another one.

Keywords: Agriculture 4.0, smart farming, volumetric dispenser, blueberry cultivation, granulated fertilizer

INTRODUCTION

Cultivation of low–bush blueberries (Vaccinium angustifolium Ait.) on depleted peat fields is seen as an economically profitable way to reduce greenhouse gas emissions (*Vahejõe et al., 2010*). However, the peat fields are commonly located in remote areas where workforce is scarce. Therefore, the mechanization and automation of technological operations is essential. Traditional agricultural machinery is intended to be used on mineral soils, which restricts its use on peat fields, as the traditional machinery may be too heavy (*Olt et al., 2013*). This creates a need for autonomous robots which are manufactured for use on peatlands. Notably the automation of the technological operations is also more efficient than mechanization (*Virro et al., 2020*).

Cultivation of blueberries requires several technological operations (*Olt et al., 2013*): soil preparation, planting, plantation maintenance, fertilization, plant protection, harvesting, post–harvesting processing, and cutting back the plants or carrying out rejuvenation pruning. From the list of technological operations above, fertilization is particularly important, as it may increase the yield from 3 to 8 times (*Vahejõe et al., 2010*). In order to achieve high yield, one must consider the issues of economic loss and potential environmental pollution due to excessive fertilization and plant's nutritional disorders due to excessive or insufficient fertilization (*Chang et al., 2016*). Thus, precision agriculture plays an enormous role in the sustainable development of the cultivation system (*Chen et al., 2014*) and furthermore, precision fertilization is a key to economic and environmental success.

For effective and sustainable fertilization, suitability of machinery is essential. Evolution of machinery used for fertilization has been significant and in constant improvement. This has narrowed down the acceptable tolerances for fertilizer spread and discharge uniformity. Initially commonly used centrifugal spreaders provided approximately 30% uniformity (*Boson et al., 2016*). After improvement and further development of such spreaders, 15% uniformity has been achieved (*Bulgakov et al., 2021*). Major improvements have been done based on mathematically modelling the trajectory of fertilizer particles (*Olt & Heinloo 2009*). With computer–aided engineering softwares, which are based on discrete element method, more complex and precise simulations are being introduced (*Liedekerke et al., 2009*). This results in centrifugal disc spreaders providing less than 10% deviation from the target discharge rate (*Bulgakov et al., 2021*). This is acceptable for eg. grain cultivation, but for some cases, such as blueberry cultivation, regardless of improved uniformity and enhanced control over discharge, broadcast fertilization with centrifugal–type disc spreader is not feasible and is unacceptable in terms of sustainable cultivation. Blueberry bushes are cultivated in rows (*Arak et al. 2020*), which means that applying fertilizer only for a row would have significant advantages compared to broadband spreading. More suitable is a spreader based on roller with outer grooves, often often referred as a fluted roller dispenser, which has gained significant popularity and is considered very efficient when cultivating in rows (*Lv et al., 2012*). Such dispensers are simple, easy to manufacture, lightweight and compact (*Kuş et al., 2021*) capable of providing discharge uniformity usually between 10% to 20%, where better than 20% is considered acceptable and better than 10% is considered good (*Huang et al. 2018*). Due to the plantation pattern on

the blueberry field, there are bare spots (*Soots et al. 2021*) between plants. Applying fertilizer to such spots would not only encourage weed growth on the field but also contaminate and simply waste fertilizer (*Olt et al., 2013*). Instead of simply applying fertilizer for the whole row, spot application has a significant effect to save up fertilizer costs, increase yield and decrease weed growth (*Chang et al., 2016*).

On the global scale the recommended fertilization rate for low–bush blueberries varies to a large extent. The recommended rate of nitrogen (N) in Canada (*Lafond, 2000*) is significantly higher than rates that have shown highest yield in Estonia (*Albert et al., 2011*). These locations differ by their latitude which implies differences in the length of vegetation period and climate condition. Moreover, meteorological conditions have shown to have the greatest impact on low–bush blueberry yield (*Parent et al., 2020*) and fertilization should take the length of vegetation period into account, as excessive amount of nitrogen during autumn fertilization may impede the lignification of shoots, which then are susceptible to frost damages (*Paal et al., 2004*). Therefore, the dispenser must allow fertilization rate adjustment while maintaining precision. However, the variety of granulated fertilizers with significant differences in granule shape and size (*Lillerand et al., 2021*) add further complexity to the technical requirements of dispensing automation.

The aim of this paper is to clarify suitability of a common straight fluted roller dispenser for precision fertilization application by evaluating its precision in terms of agrotechnical and economic requirements, fulfilling 10 % discharge deviation criteria from determined target fertilization rate, while using three widely available granulated low–bush blueberry fertilizers.

MATERIALS AND METHODS

A commercially available volumetric dispenser was selected (figure 1), based on fluted roller design. Such a dispenser was considered due to its fairly simple construction, low price, versatility and longevity (*Huang et al., 2018, Bangura et al., 2020, Kuş et al.,2021*). In addition, such dispensers have proven themselves to be accurate enough in the grain seed sowing applications (*Kuş et al.,2021*). The roller is divided into grooves, with volume dependent on the radius of the flute and length of the roller. Rotating the roller by corresponding number of degrees results in output of a single groove while a revolution results in output of single grooves multiplied by number of grooves.

In the study, a straight fluted roller (figure 2) was selected with 10 grooves, each of them with volume of 2.048 cm^3. With altering roller parameters such as flute diameter, shape, length and angle, the discharge rate is affected (*Liping et al., 2018, Kuş et al.,2021*). Using an optimal roller that ensures uniform discharge can result in saving up to 40% from fertilizer costs (*Bangura et al., 2020*). The number of flutes and their diameter is selected according to required discharge rate in time and considering size of the particles (*Gujar et al., 2018*).

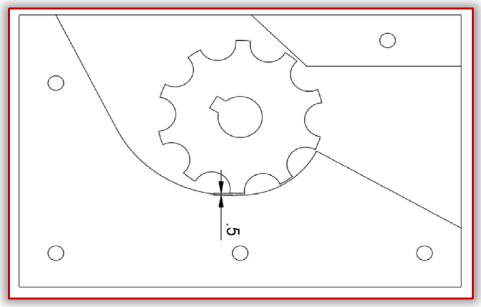
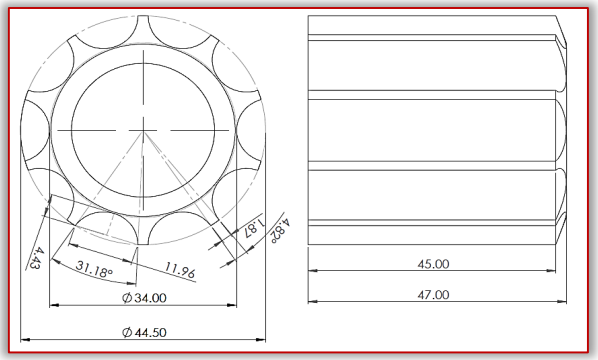
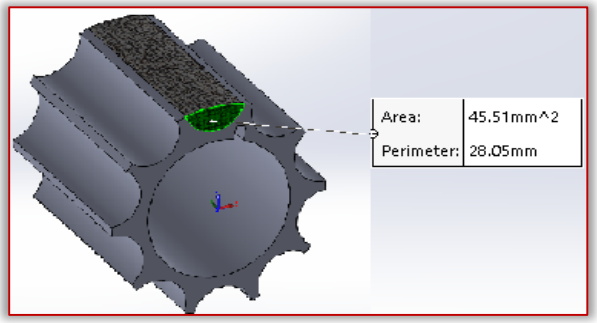


Figure 1 – Simplified cross–section of the volumetric dispenser



(a)



(b)

Figure 2 – The selected fluted roller (Lillerand et al., 2021)
(a) measurements of the roller; (b) cross–section area of its groove

As seen on figure 3 and figure 4 the groove is never fully filled due to irregular placement and granulometric variations of fertilizer particles. In this case, the empty volume should be defined as porosity, where the porous part consists of the empty gaps between the fertilizer granules. Porosity is variable not only between different fertilizers but also within a single fertilizer and therefore, average porosity must be taken into account. It must be assumed that the fertilizer particles are spherical (Valius & Simutis, 2009). To express porosity:

$$\Phi = \frac{V_p}{V_s} = \frac{V_s - V_f}{V_s} = 1 - \frac{V_f}{V_s}, \quad (1)$$

where:

V_p – volume of pores;

V_s – volume of a groove;

V_f – volume of granules in groove, with m_f.

Equation 1 reveals that by knowing discharged volume V_o, eg volume of groove and measured weight of discharged fertilizer m_f from it, the porosity can be easily found. To presume that granulated fertilizer particles are with similar diameter spheres, then porosity is expressed:

$$\Phi = 1 - \frac{V_t}{V_s} = 1 - \frac{\pi}{6} n \left(\frac{d}{a}\right)^3, \quad (2)$$

where:
n – number of granules in cube with side length of a;
d – diameter of granules.
It can be presumed that number of granules in volume $V_s = a^3$ depends on their positioning. Theoretically it can be expressed if their placement is regular:

$$n = \frac{a}{x} \cdot \frac{a}{y} \cdot \frac{a}{z} = \frac{a^3}{xyz}, \quad (3)$$

where: x, y, z on is distance between granules in direction according their X, Y and Z axis.
By combining equation 3 with 2:

$$\Phi = 1 - \frac{\pi \cdot d^3}{6xyz}, \quad (4)$$

When observing two situations, with dense and and sparse positioning, then porosity can be expressed:

$$\Phi_s = 1 - \frac{\pi}{6} \approx 0.48 = 48\%, \quad (5)$$

$$\Phi_d = 1 - \frac{\pi\sqrt{2}}{6} \approx 0.26 = 26\%, \quad (6)$$

This indicates that theoretically the porosity doesn't depend on the size of particles, but only how they position. From measuring the length, width and thickness of fertilizer granules, it is clear that the dimension is not constant and varies greatly. Therefore, to define diameter of the particles, geometric mean d_m is used. To measure porosity directly in the dispenser, computed tomography device Yxlon FF35 CT was used. The porosity was measured from the corresponding groove, straight before discharging of the fertilizer in 10 repetitions of for each fertilizer, resulting in mean average porosity 48% for Substral, 59% for Agro NPK and 68% for Agro Organic.
The output of such dispensers is affected not only by the parameters of the roller or the granulometric parameters of a specific fertilizer, but also by the gap between the roller and dispensers' bottom flap (*Huang et al., 2018*). Every time the roller is being rotated, the moving particles can be divided in two separate layers: forced moving layer and influenced layer. Particles in the first layer rotate along with the roller while particles in the influenced layer are being dragged along by friction and interlocking between the particles (*Huang et al., 2018*). In addition, motion of the particles in the influenced layer is affected by friction between particles and the dispenser shell, including the adjustable bottom flap. Adjusting the gap to minimum, results in less drag but too small gap can result in seized dispenser, crushed particles or even damaged dispenser. Too large gap creates greater drag, which decreases discharge uniformity (*Huang et al., 2018*). Therefore, the optimal gap was chosen based on granulometric properties of 3 fertilizers in this research scope (*Lillerand et al. 2021*), considering the mean average of the geometric mean diameters of the particles in the sample sets. Using the Industrial Computed Tomography device Yxlon FF35 CT, the measured gap was 4.38 mm (figure 4) which was fixed and remained the same through all the experiments carried out.

Figure 3 – Straight fluted roller with a filled groove

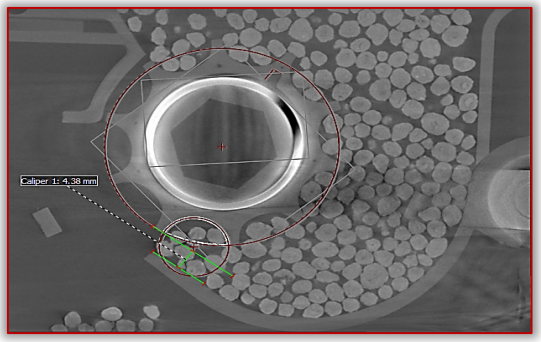


Figure 4 – Dispenser cross–sectional view 4.38 mm gap measured between the roller and adjustable bottom flap

The necessity of using different fertilizers during the vegetation period comes from that for spring and autumn fertilization, different fertilizers are required due to different concentration of minerals, where in spring growth is stimulated and in autumn, the plant receives minerals to enhance its resistance against the cold (*Paal et al., 2004*). As provided in table 1, concentration of nitrogen can vary up to 3 times. Taking examples from other similar research papers (*Bangura et al., 2020, Huang et al., 2018*), the size of a sample set was 100 granules per fertilizer. For all three fertilizers, length, width and thickness of 100 particles were measured with a digital caliper Mahr 16 EWRi. Mean geometric diameter of 100 particles varies by 15%, sphericity varies by 21% and bulk density varies by 25%. This creates an additional requirement for the dispenser to be simultaneously suitable for three significantly different fertilizers (figure 5).

Table 1. Properties of blueberry fertilizers in scope

Fertilizer	N [%]	P [%]	K [%]	E_f [€·g^{-1}]	$d_{m,100}$ [mm]	φ [–]	γ [kg·m^{-3}]
Agro NPK	12	6	24	0.0026	4.29	0.90	1030
Agro Organic	4	3	8	0.0016	3.64	0.74	775
Substral	5	15	30	0.0062	3.68	0.93	950

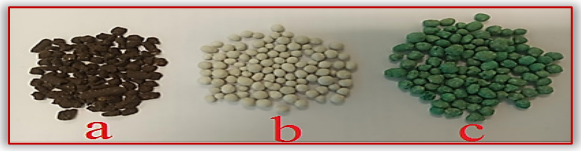


Figure 5 – Examples of used fertilizers
(a) Agro Organic; (b) Substral and (c) Agro NPK

Opposed to other similar research where the fertilizer discharge on field is measured in time (*Gujar et al., 2018, Huang et al., 2018, Bangura et al., 2020, Kuş et al., 2021*) in this study a different approach has been selected due to spot application. The number of discharged grooves is controlled by the feedback from the encoder attached to the fluted roller. Therefore, it is essential to clarify and establish the best possible discharge uniformity from a single groove. The output of the selected 10 groove fluted roller dispenser with bottom flap gap adjusted to 4.38 mm was measured respectively: output of single groove in 10 repetitions, output of full revolution in 10 repetitions, for each fertilizer. Each time the output was weighted with analytical scale Kern ABJ 220–4NM (figure 6), creating a dataset that was used for predicting the output based on the required number of grooves to be emptied.

Figure 6 – Kern ABJ 220–4NM analytical scale (*Lillerand et al., 2021*)

Average groove discharges ($\underline{m_g}$) of a single groove and the full revolution of the grooved roller were compared in order to understand if the mass of multiple consecutive groove discharges differs from the mass of a single groove discharge. As the grooved roller had 10 grooves, the discharged mass of a full revolution was multiplied by the factor of 0.1 in order to make the values comparable with the discharge mass of a single groove. Normality of data was evaluated with Shapiro–Wilk test. As the distributions did not significantly differ from normal distribution ($p > 0.171$ in all cases), two–sample t–test was used to compare the $\underline{m_g}$ of the single groove and full revolution conditions.

Discharging precision was evaluated by setting target fertilization rate Q_t [g·plant $^{-1}$], calculating the number of groove discharges η_c, and then calculated fertilization rates Q_c were found using η_c and measured m_g values.

Nitrogen rates resulting high yield in an Estonian low–bush blueberry fertilization experiment (*Albert et al., 2011*) were used to set Q_t value. The average of the two N rates with highest yield, Q_{tN} = 1.6 g plant $^{-1}$, was then divided by the fertilizer's N concentration (table 1) to calculate the Q_t for each fertilizer (table 2). The number of groove discharges η_c was calculated:

$$\eta_c = \frac{Q_t}{\underline{m_g}}, \tag{7}$$

The η_c values were rounded to the nearest integer and denoted as η_t. Then, the number of possible combinations C that can be obtained with η_t and the quantity of m_g data was found:

if $\eta_t < 10$, then

$$C = \frac{n!}{(\eta_t!\,(n-\eta_t)!)}, \tag{8}$$

if $\eta_t > 10$, then

$$C = \frac{n!}{(x!\,(n-x)!)} \cdot \frac{n!}{(y!\,(n-y)!)}, \tag{9}$$

where: $n = 10$, $10x + y = \eta_c$, $x = \{1, 2, \ldots, 9\}$ and $y = \{0, 1, \ldots, 9\}$.

For each fertilizer all C combinations of m_g data were obtained with a custom MATLAB script. Combinations of m_g data, denoted as m_c, were then used to calculate Q_c:

$$Q_{c_i} = m_{c_i} \cdot \eta_t, \qquad [\mathrm{g \cdot plant^{-1}}], \tag{10}$$

where: $i = \{1, 2, \ldots, C\}$.

Table 2. Parameters of discharging precision evaluation

Fertilizer	Q_t [g·plant $^{-1}$]	$\underline{m_g}$ [g]	η_t –	C –
Agro NPK	13.3	2.705	5	252
Agro Organic	40.0	1.730	23	5400
Substral	32.0	2.664	12	450

Targeted (E_t) and calculated (E_c) fertilizer expenses were calculated as follows:

$$E_t = Q_t \cdot E_f, \qquad [€], \tag{11}$$

$$E_c = \underline{Q_c} \cdot E_f, \qquad [€], \tag{12}$$

where: $\overline{Q_c}$ is the average calculated fertilization rate, and E_f is fertilizer's unit expense €·g^{-1} (table 1).

RESULTS

In the case of Agro NPK the differences of average groove discharges between the single groove ($\underline{m_g}$ = 2.705 g) and full revolution ($\underline{m_g}$ = 2.672 g) conditions were not statistically significant, $t(18) = 0.21$, $p = 0.836$. Similarly, in the case of Agro Organic the differences of average groove discharges between the single groove ($\underline{m_g}$ = 1.730 g) and full revolution ($\underline{m_g}$ = 1.955 g) conditions were not statistically significant, $t(18) = 1.64$, $p = 0.119$. In contrast, in the case of Substral the differences of average groove discharges between the single groove ($\underline{m_g}$ = 2.664 g) and full revolution ($\underline{m_g}$ = 2.377 g) conditions were statistically significant, $t(18) = 2.97$, $p = 0.008$.

In all cases the Q_c values fall in the range of the minimum and maximum fertilization rates (fig 7) providing the highest yield in the experiment of Albert et al. (*Albert et al., 2011*). However, in the case of Agro Organic and Substral the calculated rate is significantly different from

the target, where with Organic the fertilizer is potentially wasted and with Substral, the fertilization is significantly below target rate. With fertilizer Organic the actual cost per plant is also higher than the target is. The fertilization rates provided in the experiment of Albert et al. (*Albert et al., 2011*) do not consider modern agricultural machinery capabilities or the precision fertilization principles and simply provide the data for fertilization rates that the plant can handle without damaging and providing the greatest yield.

By adding the 10% discharge deviation requirement to the target fertilizer rate, then only with Agro NPK the dispenser meeting the requirements. For Agro Organic, the calculated discharge rate is rather near the upper 10% limit from the target rate and for Substral, the calculated discharge rate is near the bottom 10% limit. On some cases, the discharge rate is out of the 10% tolerance limits. This indicates that in terms of precision farming and precision fertilization, the dispenser is not meeting the requirements (*Huang et al. 2018*).

Discharging excessive fertilizer has effect on increased weed growth and environmental contamination, which both inhibit yield and profit from the blueberry cultivation (*Olt et al., 2013*). Provided in the research of Albert et al. (*Albert et al., 2011*) and Paal et al. (*Paal et al., 2004*)., it is rather preferred to fertilize below the target than above it, as over–fertilization has greater effect on the yield than under–fertilization.

In addition to plant health, yield and environmental aspects, there is also an economical aspect. Due to vast increase in the prices of available fertilizes, the significance of precision in fertilization process becomes progressively dominant. On a blueberry field of 25 ha area and 1 by 1 m^2 plotting, with technological paths and infrastructure, fertilization of over 200 000 plants can result in excessively spent 1400 € when using one of the three fertilizers (Organic) studied in the paper. Moreover, in the long run additional issues may rise from the inability to predict precise quantity of fertilizer for the whole vegetation period (table 3). This is especially important considering the instabilities in supply chains.

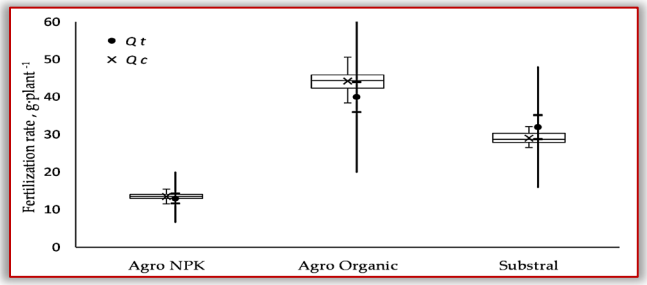


Figure 7 – Targeted (Q_t) and calculated (Q_c) fertilization rates boxplots represent distribution of Q_c, the lines next to boxplots cover the range of two highest yielding fertilization rates in (Albert et al., 2011) with target rate Q_t and 10% deviation tolerance for it

Table 3. Target of fertilizer cost per plant, calculated cost, difference between target and calculated

Fertilizer	E_t [€·plant $^{-1}$]	E_c [€·plant $^{-1}$]	$E_c - E_t$ [€·plant $^{-1}$]
Agro NPK	0.035	0.035	–0.001
Agro Organic	0.065	0.072	–0.007
Substral	0.197	0.179	0.018

The answer to the main question of the paper – is a common straight fluted roller dispenser suitable for precision fertilization application in terms of agrotechnical and economic requirements while using three widely available granulated low–bush blueberry fertilizers is to fold. Firstly, the agrotechnical requirements are met, as these are robust and perhaps outdated. The agrotechnical requirements reflect the capabilities of the previous generations of agricultural machinery and do not allow to apply the full potential of machinery in the Agriculture 4.0 framework, as the paradigm of precision has obtained stricter tolerances. Further research is needed to determine the agrotechnical requirements for precision fertilization in context of increased potential of the machinery. Secondly, the economic requirements are heavily influenced by fertilizer's parameters (unit cost, nutrient composition, granulometric and mechanical parameters) and agrotechnical requirements (need to adjust the fertilization rate during the vegetation period). The selected common fluted roller dispenser managed to achieve acceptable fertilization rate only in the case of one of the three fertilizers (fig 7). This is an insufficient result, as the dispenser is expected to achieve precision regardless of the fertilizer's parameters. Fertilizer must be chosen considering the needs of the plant not by the capabilities of the dispenser, therefore the dispenser design needs to be altered to support precise discharging of various fertilizers.

The total deviation of a fluted roller dispenser's output is incremental and depends on the number of required grooves to (Bangura et al., 2020). By reducing the necessary number of dispensed grooves, decreasing porosity in a groove and increasing discharge uniformity, better results can be expected. The design and optimization are advised to be done by using discrete element method–based simulation software, as trial and error approach is ineffective and time consuming and may require over 20 iterations considering a single fertilizer (Huang et al. 2018). Alternative design, verified by discrete elements method simulations is most likely to enhance the results and provide a design fulfilling the requirements for all three fertilizers.

CONCLUSIONS

Due to the fact that different fertilizers with different chemical, mechanical and granulometric properties are used during the vegetation period, key requirement to the dispenser is compatibility with all the fertilizers

simultaneously, providing accurate and consistent output. The aim of this paper was to clarify suitability of a commercially available common straight fluted roller dispenser for precision fertilization application. This was done by evaluating its precision in terms of agrotechnical and economical requirements while using three widely available granulated low–bush blueberry fertilizers. It was found that the selected dispenser when used with one of the three fertilizers is suitable and accurate enough to support both, the agrotechnical and economical requirements. While in the case of the remaining two fertilizers, the agrotechnical requirements are met, but the conceptual requirements and economic aspects involve risks due to inability to precisely meet the targeted fertilization rates. In conclusion, practical tests and data analysis revealed that in current state, the commercially available dispenser is not suitable for precision fertilization applications and further development is required by mainly designing a suitable roller for the fertilizers in scope.

References

[1] Albert, T., Karp, K., Starast, M., Moor, U., & Paal, T. (2011). Effect of fertilization on the lowbush blueberry productivity and fruit composition in peat soil. Journal of Plant Nutrition, 34(10), 1489–1496.
[2] Arak, M., & Olt, J. (2020). Technological Description for Automating the Cultivation of Blueberries In Blueberry Plantations Established on Depleted Peat Milling Fields. Rural Development 2019, 2019(1), 98–103
[3] Bangura, K., Gong, H., Deng, R., Tao, M., Liu, C., Cai, Y., Liao, K., Liu, J., & Qi, L. (2020). Simulation analysis of fertilizer discharge process using the Discrete Element Method (DEM). PLOS ONE, 15(7), e0235872
[4] Boson, E.S., Verniaev, O.V., Smirnov, I.I., Sultan–Shach, E.G. 2016. Theory, Construction and Calculation of Agricultural Machines: Vol 1., Scientific Publisher, 314 pp
[5] Bulgakov, V., Adamchuk, O., Pascuzzi, S., Santoro, F., & Olt, J. (2021). Experimental research into uniformity in spreading mineral fertilizers with fertilizer spreader disc with tilted axis. Agronomy Research, 19(1), 28–41
[6] Bulgakov, V., Adamchuk, O., Pascuzzi, S., Santoro, F., & Olt, J. (2021). Research into engineering and operation parameters of mineral fertiliser application machine with new fertiliser spreading tools. Agronomy Research, 19(Special Issue 1), 676–686
[7] Chang, Y. K., Zaman, Q. U., Farooque, A., Chattha, H., Read, S., & Schumann, A. (2017). Sensing and control system for spot–application of granular fertilizer in wild blueberry field. Precision Agriculture, 18(2), 210–223
[8] Chen, C., Pan, J., & Lam, S. K. (2014). A review of precision fertilization research. Environmental Earth Sciences, 71(9), 4073–4080
[9] Gurjar, B., Sahoo, P. K., & Kumar, A. (2017). Design and development of variable rate metering system for fertilizer application. Journal of agricultural engineering, 54(3), 12–21.
[10] Huang, Y., Wang, B., Yao, Y., Ding, S., Zhang, J., & Zhu, R. (2018). Parameter optimization of fluted–roller meter using discrete element method. International Journal of Agricultural and Biological Engineering, 11(6), 65–72
[11] Kuş, E. (2021). Seed Damage Test for Roller–Type Device Designed at Different Flute Helical Angles. Uluslararası Tarım ve Yaban Hayatı Bilimleri Dergisi, 7(3), 495–502
[12] Lafond, J. (2000). Fertilization in Wild Blueberry Production. Wild Blueberry Production Guide in a Context of Sustainable Development.
[13] Liedekerke, P., Tijskens, E., & Ramon, H. (2009). Discrete element simulations of the influence of fertiliser physical properties on the spread pattern from spinning disc spreaders. Biosystems Engineering, 102(4), 392–405
[14] Lillerand, T., Virro, I., Maksarov, V. V., & Olt, J. (2021). Granulometric Parameters of Solid Blueberry Fertilizers and Their Suitability for Precision Fertilization. Agronomy, 11(8), 1576
[15] Liping, Z., Lixin, Z., & Weiqiang, Z. (2018). Fertilizer feeding mechanism and experimental study of a spiral grooved–wheel fertilizer feeder. Journal of Engineering Science and Technology Review, 11(6), 107–115
[16] Lv, H., Yu, J., & Fu, H. (2013). Simulation of the operation of a fertilizer spreader based on an outer groove wheel using a discrete element method. Mathematical and Computer Modelling, 58(3–4), 842–851
[17] Olt, J., & Heinloo, M. (2009.). On the formula for computation of flying distance of fertilizer's particle under air resistance. Journal of Agricultural Science 20(2), 25–34.
[18] Olt, J., Arak, M., & Jasinskas, A. (2013). Development of mechanical technology for low–bush blueberry cultivating in the plantation established on milled peat fields. Agricultural Engineering, 45(2), 120–131.
[19] Paal, T., Starast, M., & Karp, K. (2004). Influence of different fertilisers and fertilising frequency on the developing of seedlings of Vaccinium angustifolium. Botanica Lithuanica, 10(2), 135–140.
[20] Parent, S. É., Lafond, J., Paré, M. C., Parent, L. E., & Ziadi, N. (2020). Conditioning machine learning models to adjust lowbush blueberry crop management to the local agroecosystem. Plants, 9(10), 1–21
[21] Soots, K., Lillerand, T., Jogi, E., Virro, I., & Olt, J. (2021). Feasibility analysis of cultivated berry field layout for automated cultivation. Engineering for Rural Development, 20, 1003–1008
[22] Thielke, Dipl.–Wirtsch.–I., Kemper, Dipl.–I., & Frerichs, S. (2015). Simulation of agricultural processes using the discrete element method. Scientific Proceedings III International Scientific and Technical Conference "Agricultural Machinery", 1, 21–24.
[23] Valiulis, G., & Simutis, R. (2009). Modeling of Continuous Fertilizer Granulation–drying Circuit for Computer Simulation and Control Purposes. In ICINCO–SPSMC 98–103.
[24] Virro, I., Arak, M., Maksarov, V., & Olt, J. (2020). Precision fertilisation technologies for berry plantation. Agronomy Research, 18(Special Issue 4), 2797–2810

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A COMPLEMENTARY APPROACH TO PREDICTING THE MAGNITUDE OF FLOOD ALONG FOMA RIVER USING CROSS–SECTIONAL VARIABLES

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Abstract: Flood hazards have been on the increase in recent years, especially along the river bank. The hazards tend to impact human lives and result in severe economic damage across the world. However, forecasting the magnitude of flood especially in Nigeria across the coastal areas have been hindered by several complications, including inaccurate data, poor assessment of drainage basin, pollution, and encroachment. This study made use of the Geographical Information System (GIS) tools to derive cross–sectional variables that were significant in complementing the prediction of the magnitude of flood along Foma–river areas. Global Position System (GPS) was used to obtain the coordinate points along the river areas and Google earth imagery and topographical data of the study areas were obtained. The basin areas, streamlines, lengths of the river, and tributaries were also generated. The buffering of the river in 15 and 30 meters exposes the vulnerability status of structures along the river. Out of the 530 structures captured, 49 structures were highly vulnerable, while 105 structures were fairly vulnerable to flood hazards. The predictive accuracy of the ordered logit model approximated 81%. While a 10% error in classification was resulting from the harmonization of the precision value (0.8026) and the recall value (0.6386). The cross–sectional variables that were found to be significant at $\alpha = 0.005\%$ are the river watersheds, the vulnerability status classification of structures across the river areas, the vulnerable structures identified, inadequate bridges and culverts along the river areas, inappropriate size of bridges and culverts, and extreme pollution along the river areas. This study is recommending the use of significant cross–sectional variables to complement the prediction of the magnitude of flood along the river banks.
Keywords: buffering, cross–sectional, georeferenced, magnitude, spatial

INTRODUCTION

Floods are among the most periodic and overwhelming natural hazards, which tend to impact on human lives and result in serious economic damage across the world. Its intensity tends to threaten the entire world due to the underlining effect of climate change (Hasselaar, 2020). However, evaluating the possibility and magnitude of flood has been hindered by several complications including, climate change, inaccurate data, poor assessment of drainage basins, pollution, and encroachment (Ayanshola, et al., 2018). Studies have reported some difficulties in the sampling technique of conventional rain and discharge measurement, which have hindered the accurate evaluation of the magnitude of the flood, especially along the river areas. The work of Nassery, et al., (2017), also established that many existing prediction equations are based on the experimental data having many experimental and constant parameters with an ambiguous estimate often required to be fixed. Such problems from previous predictions are the difficulty in the sampling of conventional rain and discharge measurement networks, which makes it difficult to predict accurately.

The existing assessment of rivers tends to indicate that the level of flood quite differs from one river to the other even despite being in the same geographical location. This can be attributed to both natural and human factors such as, watershed, drainage basin, drainage capacity, level of pollution, encroachment activities, and many others (Du, et al.. 2019). Studies mostly focus on the relationship between the amount of rainfall and the magnitude of floods. This practice cannot be so accurate because, in the actual sense, rainfall is often not evenly distributed along the same geographical location, which may likely have the presence of several streams or rivers with their peculiar factors and determinants (Du et al., 2019).

Studies have established that Geographic Information System (GIS) is a very powerful tool that allows the collection, and processing of geographically related data. The tool has been equally used as an instrument in problem–solving, and decision–making processes, and as a tool for visualizing data in a spatial location (Kraak, & Ormeling, 2020). The tool has several advantages, which include, analyzing geographical data to determine the location of structures and relationships to other landscapes, determination of watershed, and drainage density, what is likely to happen to an area of interest, and particularly, how and in what way an area has changed over time (Picuno, et al., 2019). The realization of data with the use of GIS techniques will give a complementary approach to determining cross–sectional variables, which are significant to predicting the magnitude of flood along

the river course. Cross–sectional variables can be observed at the local scale. The procedures involve numerical data about intrusion and runoff dynamics (Rogger, et al., 2017). The variables have some peculiar characteristic that dictates the direction of flow of flood in each river or stream rather than just a prediction through generalization, which may not be so accurate. Figure 1 presents the watersheds of the Foma river areas.

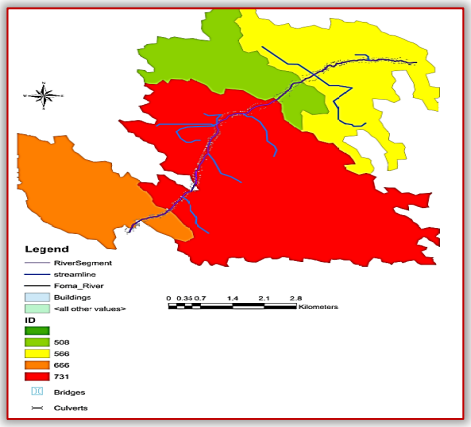

Figure 1. Foma River Watersheds

THE CHALLENGE OF FLOOD FORECASTING AND MITIGATION IN NIGERIA

Nigeria is likely to face the consequences of climate change due to its geographical location. The country is bounded by located along Atlantic Ocean to the south and the Sahara Desert to the north. This, by implication, may lead to an increase in the temperature that influences the rainfall pattern and results in the rise of extreme drought and flood (Ayanshola, et al., 2018). Due to its location, several cases of flooding in Nigeria have been reported in recent times, mostly in Sokoto, Lagos, Ibadan, Abeokuta, Gusau, and Makurdi (Chindo, et al., 2019). No less than 39 people were killed due to flooding in central Nigeria, Plateau State, towards the end of July 2012. The Flamingo dam had an overflow and swept across several localities in Jos, and about 200 houses were inundated or devastated after protracted rain. At least 35 people were reported missing, prompting the head of the Red Cross organization to announce that relief efforts were being initiated (Chindo, et al., 2019). The spatial distribution of areas extremely affected by the flooding in Nigeria is shown in Figure 2.

Similarly, Olorunfemi and Raheem (2013) reported that the major causes of flooding in the Ilorin are building on the floodplain, dumping of refuses in drainages and rivers, farming on the floodplain, all of which cause siltation, blocking off waterways and drainage channels, and inundation. The city of Ilorin is the Kwara State capital, located in the north–central part of Nigeria. The state is found between the latitude 8024'N and 8036'N and between longitude 4010'W and 4036'E, also experiencing flooding in some parts of its metropolis. During the 2017 rainy season, the city of Ilorin experienced a devastating flood hazard. Many residential buildings were reported to have submerged after a protracted rain that lasted for hours. The heavy rain, which was accompanied by flooding, washed away asphalt on some township roads. The ravaging flood also washed away bridges and destroyed valuable properties, as reported in the Nigeria Tribune newspaper (Azeez, 2017). The Alagbado bridge along the Foma river which was washed away during the 2017 heavy raining season is captioned in Figure 3.

Figure 2. Distribution of Areas Affected by Extreme Floods in Nigeria

Figure 3. Alagbado bridge along Foma–river washed away by the flood.

This study aims to develop a supervised model to complement the prediction of the magnitude of floods along the banks of the Foma river. Other sub–objectives are to examine the river buffering in 15 meters and 30 meters across the Foma river floodplain areas, identify the cross–sectional variables in complementing the prediction of the magnitude of flood along the buffering areas of Foma river, determine the significance of the cross–sectional variables in complementing the prediction of the magnitude of flood along Foma river banks using Ordered Logistic Regression (OLR) model, and evaluate the performance of OLR in complementing the prediction of the magnitude of flood along Foma river using performance measurement metrics.

FLOOD EVALUATION USING GIS AND CROSS–SECTIONAL METHODS

A cross–sectional study is an established method to estimate the outcome of interest at a particular time, for a specified location and it is usually applied for health planning, hazard, or risk exposure. In the work of Ezzatvar, et al., (2020), a cross–sectional study reflected a short period of exposition and has some characteristics associated with a specific period. A cross–section design was used to study the mental health status of adults affected by each of the flood–affected households of

Koonimedu village and Tami Nadu. The Study revealed the effects of the flood evidence concerning the standard of living and economy. Similarly, a multidisciplinary evaluation of the effects of green infrastructure and flood administration on physical health, mental health, economy, and flood resilience of individuals, households, and communities was carried out by Venkataramanan, et al., (2019). Among the reasons for carrying out the cross–sectional study is to describe the survey exercise, which usually does not have a hypothesis. The main aim is to describe some groups or sub–groups about the outcome of risk factors. Also, the goal is to elicit the prevalent outcome of interest for a descriptive population or group at a given time (Venkataramanan, et al., 2019).

The GIS application to flood hazard evaluation and management has not been an often–used method until the year 2000. The work of Mejía–Navarro, et al., (1994), initially used the GIS to estimate several risks in many areas of Colorado, to determine the suitability of land. The development of GIS modeling for excess rainfall was the approach adopted by Schumann, et al. (2000). In Nigeria, Isma'il, and Saanyol (2013) observed that the difficulty in the sampling technique of the conventional rain coupled with discharge measurement networks makes it challenging to observe and predict flood accurately. Similarly, Ngene, et al., (2015) elicited some technical deficiencies that have been preventing Nigeria from getting preferred, and accurate, rainfall data. The research enumerated the present capacity of Nigeria's rain gauge network and the need according to the World Meteorological Organization's (WMO) guidelines. Nigeria presently has 87 rain gauges, instead of 1057 (Ngene, et al., 2015). In essence, the country needs extra gauges of 970 to achieve a gauge density of 874 km2 per gauge for the appropriate measurement of rainfall. As a result of this deficiency and based on the current insufficiency of gauges, Nigeria is suffering from a 10% error in design. Because the standard condition to minimize and maximize the effectiveness for areas in the temperate Mediterranean and tropical is a range of 600–900 km2, the inaccurate records of rain data led Nigeria to be hugely affected by the devastating flood of September 2012. This event had negative effects on the economy, roads, ports, rail lines, and most especially the water infrastructures (Ngene, et al., 2015).

METHODOLOGY

This study focused on the assessment of a complementary approach to flood prediction using the GIS software. The software was initiated through Global Positioning System (GPS) to obtain the coordinates of the river channels, while the images of the earth are referenced in eastern (X) and northern (Y) coordinates. The processes elicited some cross–sectional variables from the river areas, which are significant in determining the magnitude of flood along the Foma river channel. Arc GIS 9.3® software was used to analyze high–resolution imagery from Google earth.

— Research Designs

The problem focused upon and addressed in this study is to develop a supervised model of cross–sectional variables to complement the prediction of the magnitude of flood along the Foma river.

This study investigated how GIS–generated variables and direct observation can be utilized to develop a supervised model for predicting the magnitude of the flood (dependent variable) along the Foma river. The GIS application elicited the river buffer to determine the vulnerable areas, generate watersheds, obtain the drainage densities, and determine the vulnerable structures along the buffered areas of the Foma river. Meanwhile, site observations resulted in the location of the bridges and culverts along the river, the size of the bridges and culverts measured, the observation of specific locations along the river, and the pollution rate. The flow chart for the study is shown in Figure 4.

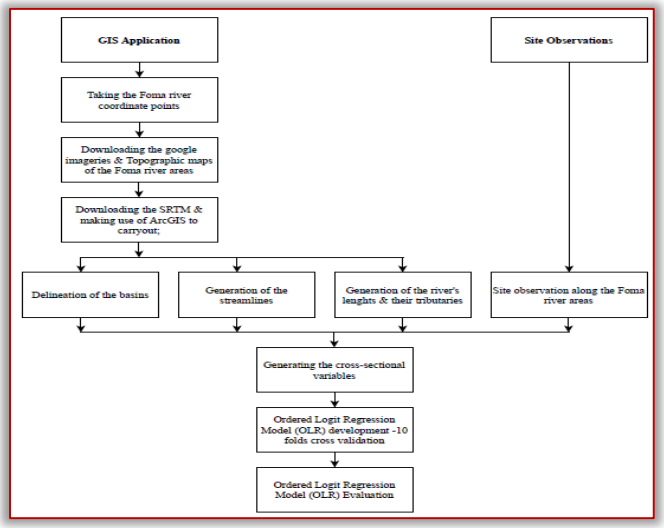

Figure 4. Flow Chart Showing the Research Design

Table 1: Cross–sectional Variables from Foma river Areas

Variable Name	Task	Values	Data Type
River Watershed	Input	Shed1, Shed2, Shed3, Shed4	Nominal
Drainage Density	Input	0.0001, 0.0002, 0.0005, 0.0007	Ordinal
Vulnerable Status of structures	Input	Not Vulnerable, Fairly Vulnerable, Highly Vulnerable	Ordinal
Types of Vulnerable Structures	Input	Hospital, Police post, Fishery ponds, Abattoir, Educational, Commercials, Slum, Agriculture, Residentials	Nominal
Bridges and Culverts	Input	CAIS, Apalara, Oke–foma, Foma–bridge, Ajetunmabi, Oloje–bridge, Abata Baba–oyo, Alagbado Bridge, Sobi–bridge	Nominal
Size of Bridges and Culvert (m)	Input	2.1, 4.5, 7.2, 11.2, 14.9, 15, 19.5, 60.8	Ordinal
River Point	Input	Source, Middle, Extreme, Terminal	Nominal
River Pollution	Input	Fair, High, Severe, Extreme	Ordinal
Magnitude of Flood	Target	Mild, Moderate, Severe, Extreme	Ordinal

Source : Field Work (2019)

The use of GIS tools and methods ensures the generation and observation of some cross–sectional variables that are suspected to be significant in predicting the magnitude of flood along the Foma river. Table 1 presents the cross–section variables that were derived through the application of GIS and site observations.

The study captured the vulnerability status of structures induced by flood activities along the course of the Foma river using remote sensing techniques. This was carried out in flood–prone areas and the buffering was examined using Arc–GIS. Structures located within 15 meters of the river bank were considered highly vulnerable to flood hazards, while those structures within 30 meters of the river were considered fairly vulnerable (The map of Ilorin west was acquired to create a database for the buffering). Also, the Foma river map was extracted, georeferenced, and digitalized into 1:50,000 from the topographical map of Kwara state. The digitalization of the map involves the process of electronic scanning to convert it to points and lines using on–screen digitization. Specifications were then made to identify the objects on the map so that the Arc–GIS was linked using the spatial data with attributes of identified structures.

The buffering of the river revealed the number of structures that were highly vulnerable, fairly vulnerable, and those that cannot be affected by flood hazards. Figure 5 exhibits the status of vulnerable structures along the river areas, while Table 2 reflects the delineation of the vulnerable status and number of structures within each drainage area along the Foma river.

Figure 5. Showing Vulnerable status of structures along Foma river areas

Table 2: Vulnerable Status Classification along the River

ID	Description	Frequency
0	Not Vulnerable	377
1	Fairy Vulnerable	105
2	Highly Vulnerable	49

To carry out the pre–classification exercises, the original sample was split into 90/10 % repeated seed training/ testing sets. A non–exhaustive cross–validation k–fold was used with k=10 so that the original sample be randomly divided into k equal–sized subsamples. Thus, taking out the subsample to be known as validation variables to test the model, where outstanding k–1 subsamples were considered as training data. The process is repeated until every k–fold serves as the test set, such that the average record scores (E) of the 10 folds become the performance metric of the model. Where E as defined in equation 1 is the addition of performance scores in the iteration. The cross–validation technique in the study is demonstrated in Figure 2, where,

$$E = \frac{1}{10}\sum_{i=1}^{10} E_i \quad (1)$$

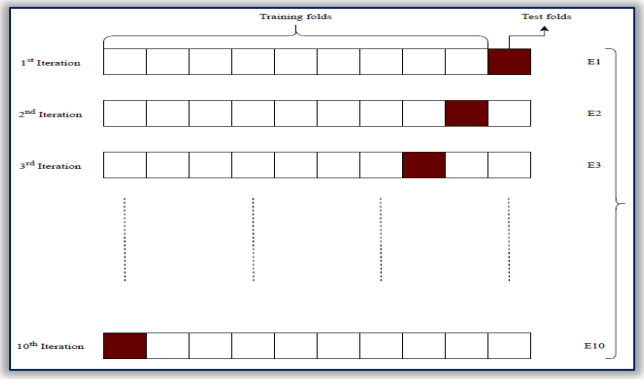

Figure 6. Cross–validation technique in the study

However, the dependent variable (magnitude of the flood) is taking more than two categories. Thus, we employed the use of ordered logit approach due to its capability to predict the presence or absence of a dependent variable. Also, its uniqueness in predicting the probability of each character in the model because the chance is a ratio. The interpretation of results in the odd ratio, parameter estimate, and probability is quite an added advantage in the area of the results' analyses. Since the dependent variable has more than two categories, and the interval between the categories was in the relative sequential order in a way that the value is indeed higher than the previous one, then the ordered logit approach would be deemed applicable.

Ordered response models are usually applied when the dependent variable is discrete and when there is ordered measurement. In general, consider an ordered response variable Y, which can take the value Y+1, 0, 1, 2……j. Such that the general linear function

$$\hat{Y} = X\beta + \varepsilon \quad (2)$$

The latent variable $\hat{Y}$ is not directly observed, thus, the threshold set by which the observed value change as the predicted, otherwise known as 'CUT POINT'. Cut points establish the relationship between $\hat{Y}$ and Y, let α_i be the threshold. Then:

$$Y = \begin{cases} Y_o & \text{iff} \quad \hat{Y} < \alpha_o \\ Y_1 & \text{iff} \quad \alpha_o \le \hat{Y} \le \alpha_1 \\ Y_2 & \text{iff} \quad \alpha_1 \le \hat{Y} \le \alpha_2 \\ Y_3 & \text{iff} \quad \hat{Y} \ge \alpha_2 \end{cases} \quad (3)$$

The response variable Y takes four value categories: 0= mild flood, 1= moderate flood, 2= severe flood, and 3= extreme flood. Therefore, the unknown parameters α_i are estimated jointly with β_s via maximum likelihood. The $\hat{\alpha_i}$ estimates are reported on Gretl as cut_1, cut_2 , and cut_3 in this case. In other to apply the models in Gretl, the dependent variable must either take only non–negative integer values or be explicitly marked.

— Measurement Metrics to Determine the Performance Level of OLR

In multi–class measurement, errors in classification have different implications. Errors in classifying Y as X may likely have different weighted implications than classifying C as D, and many more such errors. The accuracy measure does not take any of such problems into account. The pre–determined assumption was that the sample distribution among classes is balanced. Thus, in the case of imbalanced distribution, the most commonly used classification approach repeatedly produces a disappointing estimate. In this case, the conventional approaches need to be re–examined to address the problem of imbalanced data classification. However, the confusion matrix will create an error table to derive the measurement metrics.

In order to determine the level of accuracy of the significant classifications, the study developed 4 by4–by–4 4 confusion matrices for each of the 10 folds. The matrices enabled the derivation of the measurement metrics (accuracy, F1–Score, precision, and recall). Previous studies have established that accuracy works well in describing balanced data and misleading the performance in imbalanced data. Addition, F1 score–score has proven to be a useful metric when the data is imbalanced.

RESULTS AND DISCUSSION

The 10–folds cross–validation classification accuracy is demonstrated in Table 3.

Table 3: Ordered Logit Classification Performance estimate

Ordered Logit Accuracy For the Folds					
Fold1	Fold2	Fold3	Fold4	Fold5	Fold6
80.7	80.5	80.5	80.5	80.3	81.1
Fold7	Fold8	Fold9	Fold10	Average	
81.3	80.1	81.6	80.3	80.7%	

It was observed that the average number of cases correctly predicted is 80.7%. By this impression, the OLR model is said to be approximately 81% good to predict the magnitude of floods along the Foma river areas. With this classification accuracy, the variables are well fitted to complement the prediction of the magnitude of the Foma river flood. This correct percentage classification is quite high and explains how strongly significant the variables are. Similarly, this study presented eight (8) cross–sectional variables in predicting the magnitude of flood along the Foma river for classification. However, six (6) out of the eight (8) variables' average P–values were less than 0.05. The six variables were found significant and relevant to complement the prediction of the magnitude of flood along the Foma river flood channel. The 6 cross–sectional variables are the river watersheds, vulnerable status, vulnerable structures, bridges and culverts (B & C), size of bridges and culverts, and river pollution. Meanwhile, the 2 other cross–sectional variables were omitted due to exact collinearity, which indicated serial linearity between the two variables; they are the river drainage density and river points along the river channel.

There was an indication of a continuous increase in the probability of the magnitude of flood along the river which was demonstrated by the cut point estimates. The estimates of P–values were highly significant all through the folds, and their coefficients were equally positive. The significance of the P–value is an indication that there is a steady and continuous rise in the level of magnitude of flood across the Foma river areas. Meanwhile, due to the imbalanced data distribution, this study further evaluates the level of significance of the cross–sectional variables using the measurement metrics.

— The Measurement Metrics

The OLR model estimate was quite high which is at 81%, this suggested a high level of classification of the cross–sectional variables in complementing the prediction of the magnitude of flood along Foma river. This study further described the classification performance of OLR using the measurement metrics due to the high disparity in the sampling distribution. Figure 7 demonstrates the level of sampling disparity in the study.

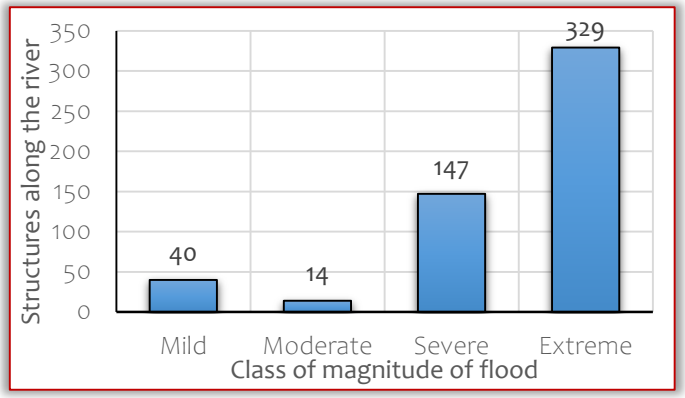

Figure 7. Level of magnitude of flood along Foma river areas

There was an indication of high disparity in the magnitude of flood along the Foma river areas. Thus, the prediction of the magnitude of flood tends to favour the higher categories compared to the lower categories. In order to describe the performance of the OLR model, the F1–score metric was used to measure the OLR performance and minimize the sampling disparities through the use of precision and recall.

Table 4: Values of the Measurement Metrics

Folds	Measurement metrics			
	Accuracy	Precision	Recall	F1–score
Fold – 1	0.8092	0.8778	0.6462	0.7444
Fold –2	0.8050	0.8764	0.6390	0.7390
Fold – 3	0.8050	0.8761	0.6397	0.7394
Fold – 4	0.8050	0.6262	0.6209	0.6236
Fold – 5	0.8029	0.8739	0.6381	0.7376
Fold – 6	0.8113	0.6321	0.6259	0.629
Fold – 7	0.8134	0.8822	0.6681	0.7601
Fold – 8	0.8008	0.6224	0.6221	0.6222
Fold – 9	0.8155	0.8833	0.6463	0.7466
Fold – 10	0.8029	0.8750	0.6396	0.7390
Average	0.8071	0.8026	0.6386	0.7081

The weighted average of precision and recall were used to measure how good the OLR classification is at predicting the magnitude of flood along Foma river. The four–

measurement metrics employed in this study are accuracy, precision, recall, and F1–score to determine the strength of the prediction. The results of the four–measurement metrics for the models are presented in Table 4.

The average values of each of the multi–class metrics derived in Table 4 were directed towards determining the performance of the OLR model in predicting the magnitude of flood along Foma river areas. Figure 8 illustrates the supervised model for complementing the prediction of the magnitude of a flood using cross–sectional variables.

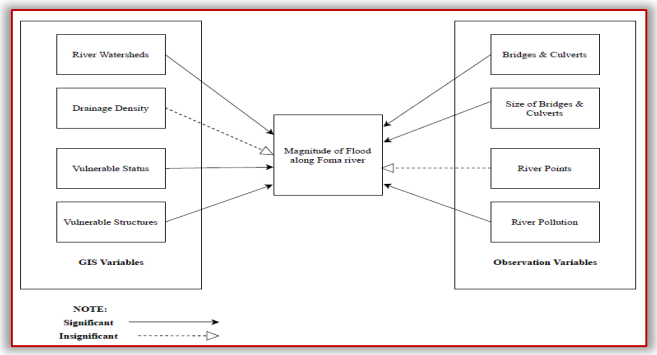

Figure 8. Supervised Model for Complementing the Prediction of Magnitude of Flood along Foma river using Cross–sectional Variables.

CONCLUSION AND RECOMMENDATIONS

This study examined the influences of precision, recall, and F1–score on the process of adjusting the inherent sampling distribution along the course of offering a significant cross–sectional variable in complementing the prediction of the magnitude of flood along Foma river areas. The ordered logit regression average prediction value of 80.71% is vulnerable to error due to the high disparity in the sampling distribution. Consequently, the model was subjected to further evaluation using the F1–score analysis. The F1––score made use of the weighted averages of precision value (0.8026) and recall value (0.6386) to reduce the sampling error by approximately 10%, such that, the model's average capacity to predict the magnitude of flood along Foma river areas is 70.81%. Similarly, the model classification provided six (6) out of the eight (8) cross–sectional variables evaluated to be significant in complementing the prediction of the magnitude of flood along Foma river areas. The average P–values of the six cross–sectional variables are less than 0.05. While the other two variables were considered insignificant due to absolute collinearity.

The river buffer areas within 15 meters and 30 meters established the vulnerability status of structures along the Foma river floodplain. This exercise identified a total number of 154 structures to be vulnerable to flood hazards along the riverbank areas. One hundred and five (105) of the structures were vulnerable, while forty–nine (49) similar structures were at a very high risk of flood hazards along the river areas. In conclusion, this study is recommending the use of significant cross–sectional variables to complement the prediction of the magnitude of flood along the riverbanks.

References

[1] Ayanshola, A., Olofintoye, O., &Obadofin, E. (2018). The Impact of Global Warming on Precipitation Patterns in Ilorin and the Hydrological Balance of the Awun Basin. Slovak Journal of Civil Engineering, 26(1), 40–46.
[2] Biola Azeez (2017). Flood Damages Property in Ilorin–Latest News–Tribune Online. From https//tribuneonline.com. May 28, 2017
[3] Chindo, A. A., Mohd Shaharanee, I. N., & Mohd Jamil, J. (2019). A conceptual framework for predicting the effects of encroachment on magnitude of flood in Foma–river area, Kwara State, Nigeria using data mining. TEST Engineering & Management, 81, 3913–3918.
[4] Du, J., Cheng, L., Zhang, Q., Yang, Y., & Xu, W. (2019). Different flooding behaviors due to varied urbanization levels within river Basin: A case study from the Xiang river Basin, China. International Journal of Disaster Risk Science, 10(1), 89–102.
[5] Ezzatvar, Y., Calatayud, J., Andersen, L. L., Aiguadé, R., Benítez, J., & Casaña, J. (2020). Professional experience, work setting, work posture and workload influence the risk for musculoskeletal pain among physical therapists: a cross–sectional study. International Archives of Occupational and Environmental Health, 93(2), 189–196.
[6] Hasselaar, J. J. (2020). Hope in the Context of Climate Change: Jonathan Sacks' Interpretation of the Exodus and Radical Uncertainty. International Journal of Public Theology, 14(2), 224–240.
[7] Isma'il, M., & Saanyol, I. O. (2013). Application of remote sensing (RS) and geographic information systems (GIS) in flood vulnerability mapping: case study of River Kaduna. International Journal of Geomatics and Geosciences, 3(3), 618.
[8] Kraak, M. J., & Ormeling, F. (2020). Cartography: visualization of geospatial data. CRC Press.
[9] Mejía–Navarro, M., Wohl, E. E., & Oaks, S. D. (1994). Geological hazards, vulnerability, and risk assessment using GIS: model for Glenwood Springs, Colorado. In Geomorphology and Natural Hazards (pp. 331–354). Elsevier.
[10] Nassery, H. R., Adinehvand, R., Salavitabar, A., &Barati, R. (2017). Water management using system dynamics modeling in semi–arid regions. Civil Engineering Journal, 3(9), 766–778.
[11] Ngene, B. U., Agunwamba, J. C., Nwachukwu, B. A., & Okoro, B. C. (2015). The Challenges to Nigerian Raingauge Network Improvement. Research Journal of Environmental and Earth Sciences, 7(4), 68–74.
[12] Olorunfemi, F. B., & Raheem, U. A. (2013). Floods and rainstorms impacts, responses and coping among households in Ilorin, Kwara Stat. Journal of Educational and Social Research, 3(4), 135.
[13] Picuno, P., Cillis, G., & Statuto, D. (2019). Investigating the time evolution of a rural landscape: How historical maps may provide environmental information when processed using a GIS. Ecological Engineering, 139, 105580.
[14] Rogger, M., Agnoletti, M., Alaoui, A., Bathurst, J. C., Bodner, G., Borga, M.,& Holden, J. (2017). Land–use change impacts on floods at the catchment scale: Challenges and opportunities for future research. Water resources research, 53(7), 5209–5219.
[15] Schumann, A. H., Funke, R., & Schultz, G. A. (2000). Application of a geographic information system for conceptual rainfall–runoff modelling. Journal of Hydrology, 240(1–2), 45–61.
[16] Venkataramanan, V., Packman, A. I., Peters, D. R., Lopez, D., McCuskey, D. J., McDonald, R. I., & Young, S. L. (2019). A systematic review of the human health and social well–being outcomes of green infrastructure for stormwater and flood management. Journal of environmental management, 246, 868–880.

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MATHEMATICAL MODELLING FOR WINDOW AIR–CONDITIONING USING R–290 DROP–IN REPLACEMENT OF R–22

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Abstract: New working fluids with favorable features of moderate environmental effects are presently being developed to avoid high global warming potential. These hydrocarbon refrigerants have excellent energy efficiency and a low global warming potential, which means they have a low overall environmental impact. Some of these choices are non–flammable, and the flammable ones have substantially lower flammability than the much more flammable hydrocarbons. This paper examines the performance of hydrocarbon refrigerants in commercial refrigeration applications as alternatives for R–22. The findings of MATLAB software analysis of R–22 and R–290, as well as comparisons of the results in various parameters, systems, and components, are presented, demonstrating the benefits of using these hydrocarbon refrigerants. R–290 shows better performance at various evaporator and condenser temperatures. R–290 has a 4% higher performance than R–22.

Keywords: Window Air–Conditioning, MATLAB and Hydrocarbon Refrigerants

INTRODUCTION

The industrial revolution in the twentieth century raised the demand for new equipment for human comfort. These products need more energy, which has become a necessity in today's world.[1] As a result, a main goal in the engineering industry is vital to reduce energy consumption through efficient utilization. This decrease in energy use has a direct impact on global warming reduction.

Energy consumption is directly linked to a country's economic progress; yet, due to rising costs of conventional fuels and worldwide environmental concerns, this subject is receiving a lot of attention right now. To reduce costs, experts are looking for alternative and sustainable energy sources. Due to rising energy consumption, environmental degradation, global warming, ozone layer depletion, and other factors, efficient energy usage for practical applications are critical.

Following the Kyoto and Montreal Protocols, researchers are focusing on alternative and environmentally kind refrigerants. However, in the current situation of competitive business, the a highly significant effort to identify alternate and environmentally kind refrigerants [2].

Because thermal comfort is so important in both the home and industrial sectors, air conditioning comes at a high price. The major challenge is to reduce power consumption and make them more efficient and environmentally friendly for Air–conditioning. The thermodynamic processes in any system are critical for optimal utilization and proper optimization.[3] A large number of practical and theoretical studies on performance evaluation and optimization are accessible in the literature.[4–8] The Montreal Protocol was established in 1987 as a framework for protecting the ozone layer by phasing out the refrigerants that cause ozone depletion. [9]

Table 1. Thermodynamics properties of R–22 and R–290

Properties		Refrigerants	
		R–22	R–290
Molecular weight	[g/mole]	86.5	44.10
Critical temperature	[°C]	96.2	96.8
Critical pressure	[bar]	50.5	42.5
Latent heat	at 25°C[kJ/kg]	180.3	423.3
Bubble pressure	at 25°C[bar]	10.4	11.06
Saturated liquid density	at 25°C[kJ/m^3]	1191	580.88
Saturated vapour density	at 25°C[kJ/m^3]	44.8	241.162
Saturated liquid specific heat	at 10°C[kJkg/k]	1.29	1.48
	at 50°C[kJkg/k]	1.46	1.62
ODP		0.055	0
GWP	(100 years)	1700	11
Freezing point	°C	–160	–97

As prospective refrigerant replacements, Dalkilic and Wongwises [10] examined the energy performance of various refrigerants and R–600a blends to different refrigerants. The results showed that the refrigerant mixes R–290/R600a (40/60 wt%) and R–290/R1270 (20/80 wt%) is the most viable R–12 and R–22 alternatives, respectively. To charge R–290 and R–1270 for performance trials, an original R–22 AC cooling capacity of 2.4 kW and energy efficiency ratio of 3.2. According to the

findings, adopting a larger displacement compressor would result in higher performance for R–290 [11]. As a result, hydrocarbon refrigerants may one day become a solution of component of refrigerant solutions.

The calculations were performed on a 2TR window air conditioning system that used R–22 as the refrigerant. Energy analysis was performed using R–290 to determine the losses for the vapour compression cycle under various operating circumstances. REFPROP software to determine the refrigerant properties, and the results are described in detail. To get the best system performance, more research is being done on the design and operating circumstances. Because hydrocarbons have a larger latent heat than R–22, their absence of chlorine atoms results in zero ozone layer depletion potential. The thermodynamic properties of R–290 and R–22 are shown in Table 1.

MATHEMATICAL MODELLING

The equation of states of refrigerant can be determine the thermodynamic parameters. The NIST procedures, which are currently an industry standard, were utilised to calculate these attributes in the MATLAB–SIMLINK calculations. The mathematical formulation of thermodynamic relations for systems and system components was done using mass, energy, and work conservation principles[12].

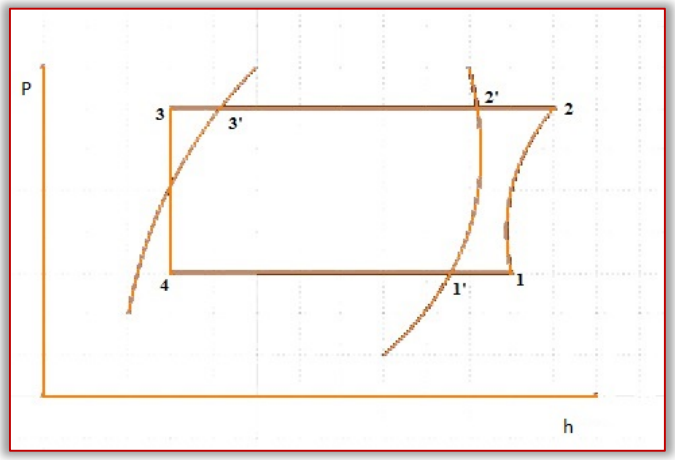

Figure 1. P–h diagram for refrigeration cycle

The figure–1 shows the four salient points (1,2,3 and 4) of an ideal cycle on the p–h diagram.

The cycle consists of:

- 1–2 – Compression (Isentropic process)
- 2–3 – Condensation (Isobaric process)
- 3–4 – Expansion (Isenthalpic process)
- 4–1 – Evaporation (Isobaric process)
- 1'–1 – Superheated
- 3–3' – Sub cooled

The energy performance are as follows[13]:

- Pressure ratio

$$P_r = P_c / P_e$$

- Mass Flow Rate (Kg/s)

$$m = \frac{\text{Displacement rate} * \eta v * N}{v1 * 60}$$

- Refrigeration effect (kJ/kg)

$$q_e = h_1 - h_4$$

- Coefficient of Performance

$$COP = \frac{h1 - h4}{h2 - h1}$$

- Isentropic compressor work (kJ/kg)

$$W_{isen} = h_2 - h_1$$

- Refrigeration Capacity (kW)

$$Q_e = m*(h_1 - h_4)$$

- Compressor Power (kW)

$$P = m*(h_2 - h_1)$$

- Overall performance index (kJ.°C/m^3)

$$OPI = \frac{(Tc - Te) * (h1 - h4) * Pe}{v1 * Pc}$$

OPI = Temperature Drop * Volumetric heat of vaporization/ P_r

Enthalpies h_1,h_2 and h_4, specific volumes V_1 and V_2 and P_c (condenser pressure), P_e (evaporator pressure) are taken from saturation and super–heated table of R–22 and R–290 from REF PROP 7.0 software.

RESULTS AND DISCUSSIONS

Because R–290 has good performance, it was chosen as an R–22 substitute based on thermodynamic cycle simulation study. The results were compared to R–22 and R–290 refrigerants. R–290 is thought to be the best performing refrigerant. R–290, on the other hand, is extremely combustible. As a result, it is recommended that R–290 refrigerant be used, particularly in practical applications.

— COP

Figure 2 shows the COP variation for R–22 and R–290 refrigerant at evaporator temperatures ranging from 1°C to 10°C which enhances the COP. The COP drops as condenser temperature varies between 40°C, 45and 50°C. It is identified that as the condenser temperature rises, the cop value falls, and as the evaporator temperature rises, the cop value rises. The highest cop attained R–290.

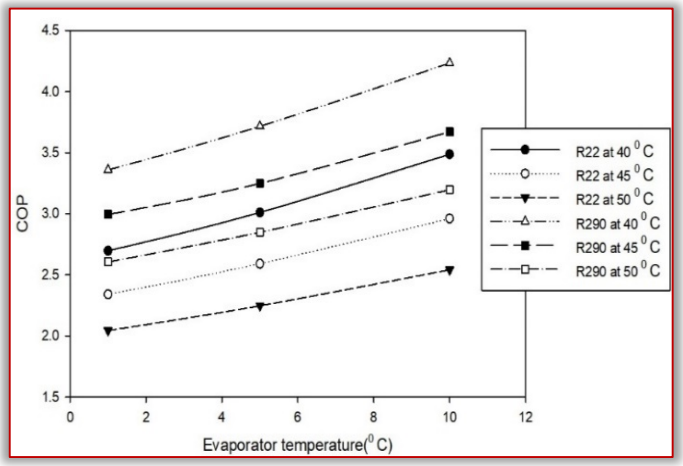

Figure 2. Evaporator temperature vs COP at various condenser temperature

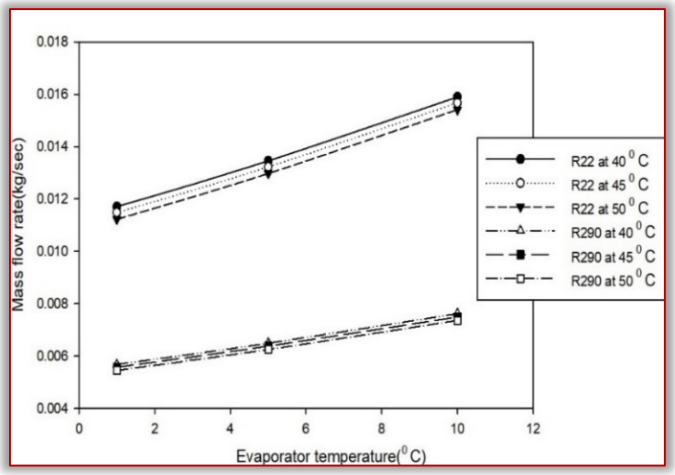

Figure 3. Evaporator temperature vs Mass flow rate at various condenser temperature

— Refrigeration mass flow rate

Figure 3 shows the mass flow rate fluctuation for refrigerants R–22 and R–290 when the evaporator temperature is varied from 1°C to 10°C which increases the mass flow rate. It drops in the range where the condenser temperature varies between 40°C and 50°C.

— Refrigeration capacity

The Refrigeration Capacity variation for R–22 and R–290 refrigerant is illustrated in figure 4. The refrigerant combination enhances the Refrigeration Capacity as evaporator temperature increases. It decreases in the range where the condenser temperature varies between 40°C and 50°C.

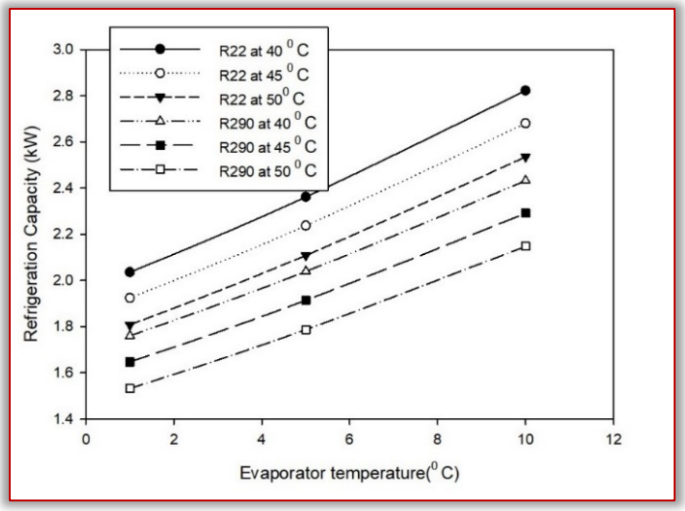

Figure 4. Evaporator temperature vs Refrigeration capacity at various condenser temperature

— Compressor power

The Compressor Power variation for refrigerant R–22 and R–290 while the evaporator temperature is adjusted from 1°C to 10°C which increases the Compressor Power shown in figure 5. When the condenser temperature varies between 40°C and 50°C, the compressor power rises.

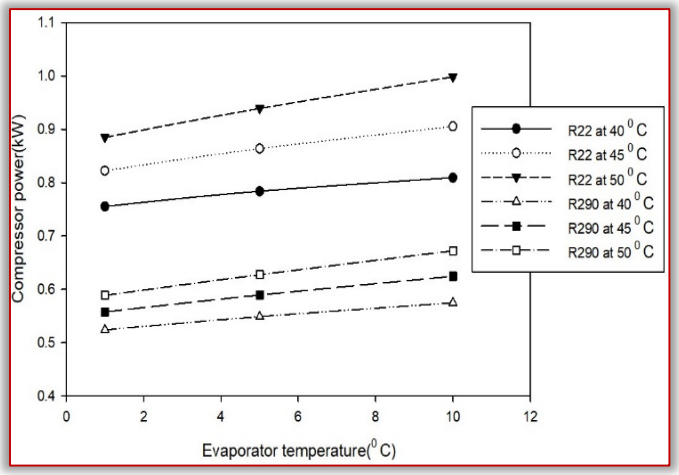

Figure 5. Evaporator temperature vs Compressor power at various condenser temperature

— Overall performance index

Figure 6 shows the overall performance index fluctuation for refrigerant R–22 and R–290 while the evaporator temperature is varied 1°C to 10°C. The refrigerant combination enhances the Overall performance index. When the condenser temperature adjusted 40°C to 50°C, the overall performance index drops.

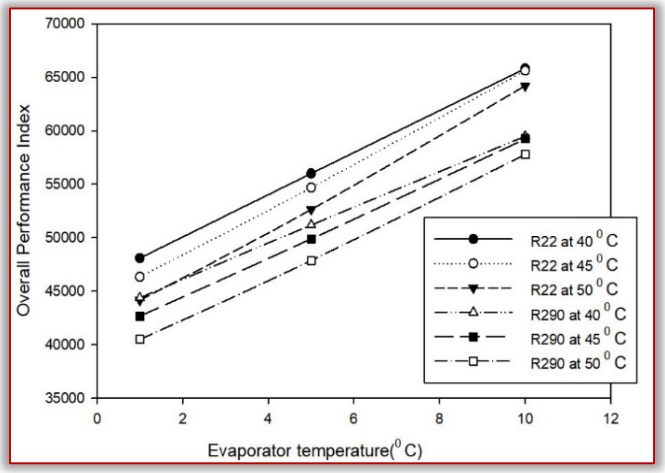

Figure 6. Evaporator temperature vs overall performance index at various condenser temperature

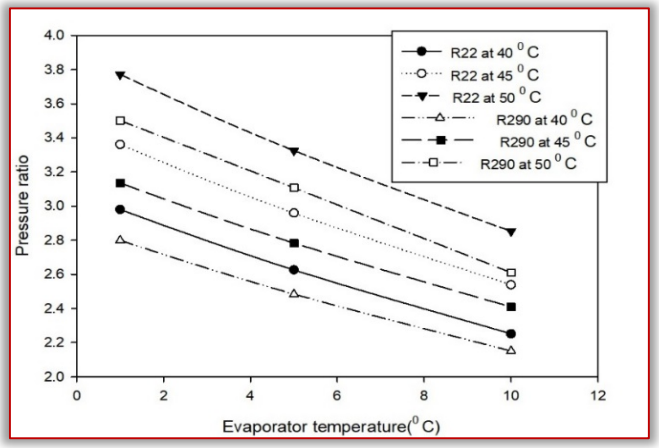

Figure 7. Evaporator temperature vs Pressure ratio at various condenser temperature

— Pressure ratio

Figure 7 shows the Pressure Ratio fluctuation for R–22 and R–290 refrigerant while the evaporator temperature is adjusted from 1°C to 10°C. The refrigerant mixture decreases the Pressure Ratio. When the condenser temperature is adjusted between 40°C and 50°C, the Pressure Ratio rises.

CONCLUSIONS

Hydrocarbon refrigerants have a higher coefficient of performance and mass flow rate when utilized in small window air conditioners. The compressor's power consumption is reduced. We used the MATLAB–SIMLINK programme to examine the refrigerant and discovered that R–290 refrigerants perform better. The refrigerant data is calculated by the REFPROP programme.

The following findings have been reached:

- In the case of R–290, the refrigerant capacity and COP rises, but compressor power and pressure ratio drops.
- In the case of R–290, performance features such as refrigeration capacity and COP increase when the evaporation temperature rises.
- R–290 has a lower compressor power than conventional one.
- The R–290 has a 4 % higher average COP than the R–22.
- Finally, when comparing R–290–charged systems to R–22–charged systems, the R–290–charged systems consistently outperformed the R–22–charged systems. However, the refrigerant R–22 is also being phased out in favour of R–290 because to its high ozone depletion, which has a negative impact on our ecosystem. R–290 has a high volumetric cooling capacity and no ozone depletion. The R–290 refrigerant runs at a higher pressure than the R–22 refrigerant.

References

[1] S. Brown, "Single–site and industrial–scale schemes," Appl. Energy, vol. 53, no. 1–2, pp. 149–155, 1996, doi: 10.1016/0306–2619(95)00059–3.

[2] S. Anand and S. K. Tyagi, "Exergy analysis and experimental study of a vapor compression refrigeration cycle: A technical note," J. Therm. Anal. Calorim., vol. 110, no. 2, pp. 961–971, 2012, doi: 10.1007/s10973–011–1904–z.

[3] S. Aprhornratana and I. W. Eames, "Thermodynamic analysis of absorption refrigeration cycles using the second law of thermodynamics method," Int. J. Refrig., vol. 18, no. 4, pp. 244–252, 1995.

[4] H. C. B. and A. E. Ozgur, "Energy and exergy analysis of vapor compression refrigeration system using pure hydrocarbon refrigerants," in INTERNATIONAL JOURNAL OF ENERGY RESEARCH, 2009, vol. 33, no. 4, pp. 1070–1075.

[5] S. Kalaiselvam and R. Saravanan, "Exergy analysis of scroll compressors working with R–22, R407c, and R417a as refrigerant for HVAC system," Therm. Sci., vol. 13, no. 1, pp. 175–184, 2009.

[6] B. O. Bolaji, "Exergetic performance of a domestic refrigerator using R12 and its alternative refrigerants," J. Eng. Sci. Technol., vol. 5, no. 4, pp. 435–446, 2010.

[7] R. Vijayan and P. Srinivasan, "Experimental evaluation of internal heat exchanger influence on R–22 window air conditioner retrofitted with R–407C," Therm. Sci., vol. 14, no. 1, pp. 39–47, 2010

[8] C. Aprea, A. Greco, and A. Maiorino, "An experimental investigation of the energetic performances of HFO1234yf and its binary mixtures with HFC134a in a Étude expérimentale des performances énergétiques du HFO1234yf et de ses mélanges binaires avec du HFC134a dans un réfrigérateur domestique," Int. J. Refrig., vol. 76, pp. 109–117, 2017

[9] P. Arora, G. Seshadri, and A. K. Tyagi, "Fourth–generation refrigerant : HFO 1234yf," pp. 1497–1503, 2018.

[10] A. S. Dalkilic and S. Wongwises, "A performance comparison of vapour–compression refrigeration system using various alternative refrigerants," Int. Commun. Heat Mass Transf., vol. 37, no. 9, pp. 1340–1349, 2010

[11] J. H. Wu, L. D. Yang, and J. Hou, "Experimental performance study of a small wall room air conditioner retrofitted with R–290 and R1270," Int. J. Refrig., vol. 35, no. 7, pp. 1860–1868, 2012

[12] X. Liu, K. Yu, X. Wan, and X. Li, "Performance evaluation of CO2 supermarket refrigeration system with multi–ejector and dedicated mechanical subcooling," Energy Reports, vol. 7, pp. 5214–5227, 2021

[13] C. H. de Paula, W. M. Duarte, T. T. M. Rocha, R. N. de Oliveira, and A. A. T. Maia, "Optimal design and environmental, energy and exergy analysis of a vapor compression refrigeration system using R–290, R1234yf, and R744 as alternatives to replace R134a," Int. J. Refrig., vol. 113, pp. 10–20, 2020

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APPROACH TO DEVELOPMENT OF THE LEAN CONCEPT PROJECT

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Abstract: We are on the threshold of joining the European Union (EU) and our business environment is experiencing a severe economic and financial crisis, which is a part of the global crisis. Based on the fact that mental and technological creativity grows just in times of crisis, the Lean concept is gaining recognition and becoming a challenge to future scientists, researchers and entrepreneurs in our country. Inspired by the Japanese automotive industry, it is synonymous with a good way to get out of the crisis. The time of crisis in giving us the best time to develop the strategies of work process improvement and the application of Lean concept. The crisis facilitates the use of new paradigms with completely new mental models in the business of organizational systems. This concept provides a focus on people, their training in work processes, teamwork and continuous improvement. They are crucial for the efficiency level in the use of key resources: people, techniques, property or capital invested in human labour performance.

Keywords: Lean concept, principles, methods, tools, effectiveness, efficiency, project of lean concept

INTRODUCTION

We live in a time of crisis and economic recession when all companies, of all sizes and shapes, from industrial giants, medium and small enterprises, to the micro-organization of companies, are faced with challenges to their own survival. In these difficult and complex times of recession and financial crisis, the usual actions of management in leading a company are to reduce costs and waste in all its forms. Therefore, company managers do not usually choose new business programs nor accelerate programs that are under development.

Major changes in the management have resulted from the crisis, affected by large and developed countries, modern scientific and technological progress in the field of computer science, new technologies, new materials, energy development, and communication development, directly influencing each company. Thus, we can no longer talk about running business under stable conditions for a long period of time, but the business in terms of constant changes.

Today's management structure and managers should first know how the company generates profit and then redesign those activities. Toyota's struggle for survival has resulted in the discovery of appropriate programs, principles, methods and tools for the implementation of the Lean concept. Recently, during the crisis, the Lean concept has become the philosophy of efficient business and has increased the interest of businessmen and scientists in the processes of its introduction and implementation. Through systematic and continuous Lean programs and establishment of business under the Lean environment conditions, we achieve: flexibility and willingness to start production to the demands of customers – the market; better utilization of space resources – layout; better utilization of human resources; continuous increase of knowledge and understanding; the change of the organizational culture and faster identification of workers with work processes and the company and so on [3,4,6,14].

In times of crisis, Lean implies abandoning the reactive management style in which time is spent dealing with emergencies and it totally accepts the proactive management style in which all available time is devoted to solving the root causes of the inefficiency of systems and processes. It takes a lot of effort for an enterprise to become Lean – long-term, flexible and vital in providing the customer with the full value of products or services. The customer wants the product or service with the highest efficiency, lowest cost of procurement and maintenance during exploitation. It is necessary to establish a continuous process of constant systemic identification and elimination of unnecessary work processes and business waste, everything that does not represent a value from the customer's perspective. The constant systemic elimination of activities that do not create new or additional value to a product or service is a challenge to the survival of any organizational system. Because of all this, it is becoming a challenge for human resource management studies, and the Lean concept holds all the answers.

LEAN CONCEPT

Over the last few decades of the 20th century, Lean production as a source of improvement of effectiveness in work processes was getting more and more importance day by day. Lean production has initiated the development of this kind of approach and has generally

been a breakthrough into more significant process analyses towards the improvement of production and factory layout in which products are being manufactured. It has changed the way the participants in the work process think and behave and created a state (environment) where the work management is done: the work process, waste elimination in the process of work, constant training of employees at all levels and functions in order to achieve shorter delivery times and cheaper products. In this way, the companies create an environment that represents the Lean concept or doctrine in the way of organizing and managing businesses.

In the late 1980's, the Massachusetts Technology Institute (MIT) studied the International Program on motor vehicles. In this research, it analysed automakers comparing the United States, Europe and Japan. The book "The Machine that Changed the World" [11] was based on this project. It practically presented the term 'Lean manufacturing' in America. The authors concluded that in Japan, streamline processes and ways of organizing production systems were credited for its success. They found that a mixed system based on keeping minimum stocks and maintaining high quality was the basis for the success of Japanese manufacturers, particularly Toyota. Babson [1] noted that there are similarities with TQM, although many analysts had already pointed to it. Even though they popularized the term "Lean" to describe the Toyota production system, authors of the MIT study initially presented many of these ideas to the West. In fact, many books written before Womack's represented different characteristics of the concept. For example, Ohno, Japanese architect of the Toyota production system, wrote "Toyota Production System: Beyond Large-Scale Production" [9]; Shingoe's Study of Toyota production system from the perspective of industrial engineering [8]; Goldrat and Cox published the first edition of "The Goal" (1984); Schonberger wrote "World Class Manufacturing" [7] and so on. However, the book "The Machine that Changed the World" was very popular with executives and highly sought after document for Lean production systems. Another book written by authors Womack and Jones, "Lean thinking" [12], offered an alternative way of applying Lean production. It deals with companies outside the automotive sector which have successfully implemented this principle.

Lean Manufacturing: Tools, Techniques, and How to Use Them [10] is based mainly on designing efficient and effective operation of manufacturing processes that are applicable, flexible, consistent and sustainable in time and space. The labour force was foreseeable and entrepreneurial. Lean production creates a system based on real customer's needs and continuous improvements in all work processes. In this way, the labour force is being developed and trained in the use of Lean tools and methods necessary for the achievement of the objective function of the production system and its rise to the world class level.

Womack argues that the Lean concept must be a meaningful concept adopted in the enterprise, in all functions, to see improvement and maintain a system of designed objective functions. A segment or organizational-functional understanding of the application of Lean concepts, principles and its actions lead only to a small improvement compared to the effects of comprehensive application.

THE PRINCIPLES AND TOOLS OF LEAN CONCEPT

In their book "Lean Thinking" [12], move further from the specific functional approach in the design of production systems and establish the five principles of Lean manufacturing:

- Value - focus on customers (the ability or possibility to meet customer's requirements at the right time and for a reasonable price)
- Value stream - effective and efficient work processes (the specific activities necessary for designing, commissioning and provision of certain products from concept to production, from order to delivery, from raw materials to the customer's hands. It is, in fact, the flow encumbrance profile, i.e. process from an idea to finished product to buyers in the market),
- Flow - continuous flow (the full realization of tasks during the "value stream" work process, so that the product passes the process from design to its launch on the market, from order to delivery, from raw materials to customer's hands, without stopping, without scrap, poor quality and without overloading the work process)
- Pull – starting the production to costumer's request (production and delivery of products to customer's request, in which case there will not be any production without their previous request,
- Perfection - perfection in work (complete elimination of waste where high values are achieved during the "value stream"). Today, many companies include these principles, but usually only in some of the functions, and less frequently in all functions. These five principles lead the companies to the understanding of the Lean approach because their common use of all production system functions can significantly increase production.

To enable the implementation of the whole Lean concept, there is a set of tools (Figure 1) which have to be used within the company. Besides the tools shown in the figure, it is possible to create and design other tools that for certain conditions provide better results (with tools and methods, for a more detailed description of lean tools

and methods see [2] and [13]). If we represent the tools used in the procedures of Lean concept design as a house – a firm creation of human work, and if we should explain the Lean concept as parts of the house, then the supporting pillars would be Just-In-Time and Jidoka (or making quality at source).

The foundations of such a house would be Lean philosophy, visual system control, stable and standardized processes, and balanced production. The house would be held by teams through teamwork with the aim of continuous business improvement.

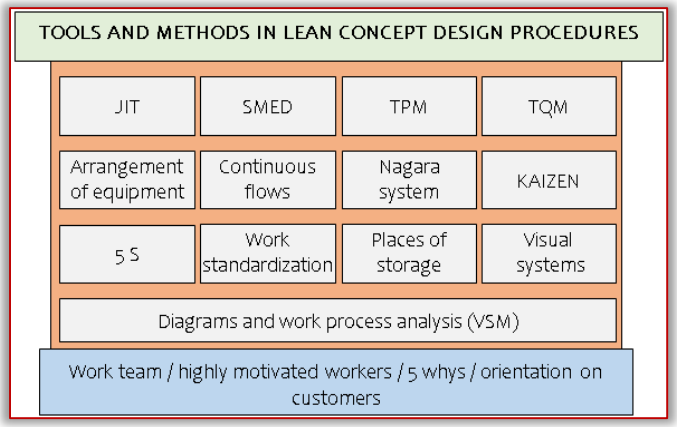

Figure 1. Tools in Lean concept design

FROM AN IDEA TO PROJECT LEAN CONCEPT

Design of a Lean concept starts after the management's decision that work processes within systems must be changed in order to achieve greater competitiveness in the market. Its design is a complex process of state analysis and synthesis of those elements into a whole that will bring the greatest benefit to the industrial system. The design procedure consists of the following stages:

— The first stage: preparation for designing. This is the stage where as a result of sets of activities we make certain proposals, conclusions and decisions:

- identification of key losses, errors, problems and guidelines for their solving,
- defining the terms of reference and their goals,
- time framework for the completion of all activities,
- the appointment of a team to implement the whole project,
- the decision of management to introduce the Lean concept.

In fact, it is the process of assessing the need to switch to the Lean concept and determining the current state of the industrial system. States and views on the necessity and importance of the changes must be critically represented. After the changes had been introduced, the next step is to publically present the expected results.

They motivate (drive) employees to pun in greater effort. Motivation, persistence and management of change-inducing processes play a key role in the successful development of the Lean concept. If individuals or most employees are not motivated to change, if there are no signs for the next steps after the changes and if, above all, there is no persistence to endure the great challenges in the way of building the Lean concept, it is better not to start at all.

— The second stage: diagnosis of the current state. This is the stage in which output documents of the previous stage are used as input, and concrete suggestions and conclusions compiled in a diagnostic study of the current state are considered outputs. This study should include:

- the diagnosis of the application degree of Lean principles, methods and tools,
- the possibility of the Lean concept implementation,
- the strategy of the Lean concept implementation: terms of reference with all proposals and activities and a detailed timetable.

The terms of reference need to define the objectives and results, while the timetable should identify the main stages of the project, the planned deadline for their execution, and many other details related to the realization of the defined framework. The team also need to skilfully use modern information technologies and application software that support the planning and scheduling of the individual stages of the project. Thus, individual project stages or segments can be entrusted to one part of the formed team.

The terms of reference and the timetable should also be accompanied by the following supporting documents (they are considered to be an essential part of good project practice):

- the framework chart of the required steps and work procedures with objective deadlines for implementing the Lean concept,
- project protocol (timetable for team meetings, place, duration),
- organization and project team members,
- established rules and responsibilities,
- ways to identify and address potential risks,
- teamwork rules,
- terms of reference (efficiency indicators, list of financial costs),
- table of results (catalogue of project results, actions, deadlines),
- the team register.

Terms of reference and the timetable created by the team are the first documents of the plan for the Lean concept introduction. These documents should be approved and signed by the top management to minimize the risk of failing to carry out the implementation process of such a project. Therefore, the announcement should be represented at all meetings of the industrial system functions.

— The third stage: design of the Lean concept model. This is the stage where the team from a set of activities creates a study that includes specific variants of the model and financial costs of its implementation. The study should include:

- general assessment of the future economic conditions,
- deficiencies in the existing activities and concepts of loss reduction,
- application of the principles, methods and tools across the Lean concept elements (procedures and instructions),
- economic analysis assessments of the application effects of principles, methods and tools, the financial plan for the implementation of the whole project.

This stage is the most complex part of the project. Here, the state assessment and observing are done in a more detailed way in order to shape certain models of the Lean concept.

— The first step: state assessment for Lean concept introduction (Figure 2). It is a process of state identification by individual work processes and one by one production program from the standpoint of the Lean concept. At this stage, the team should try to identify where the suitable areas and business focal points are. They start by writing a plan that includes methods and contents of work in all elements of the Lean concept that improve business.

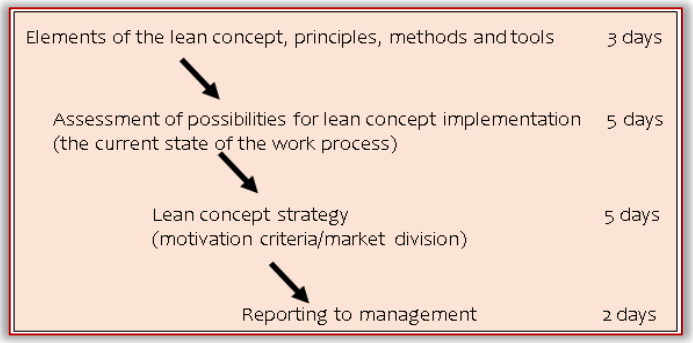

Figure 2. The first step: The assessment of possibilities for Lean concept introduction

The team must have the strength to use all five principles of the Lean concept in all five of its elements: flows, organization, control, measurements and logistics. In each element, Lean principles are analyzed: identifying the value that the customer considers to be important (value), identifying the section of flow loads (value stream), homogeneous flows of materials, information and energy (flow) and process perfection (perfection).

— The second step: system state recording (Figure 3). The recording provides a basic assessment of where the system is currently.

At this step, the team:

- conduct the analysis of the process value,
- analyze the process linking through flows of materials, information and energy,
- make charts of the work process,
- assess where there are opportunities to eliminate wasted time,
- shape the planning criteria to market requirements,
- create a sketch of the supply chain (supplier-input-process-output-customer - SIPOC), charts of all major work processes to understand the relationship customer/supplier and required inputs and outputs that activate these processes,
- analyze the levels of current losses and errors and perceive opportunities to eliminate what is unnecessary,
- develop a list of quick actions for short-term progress and demonstrate activities that will provide rationalization.

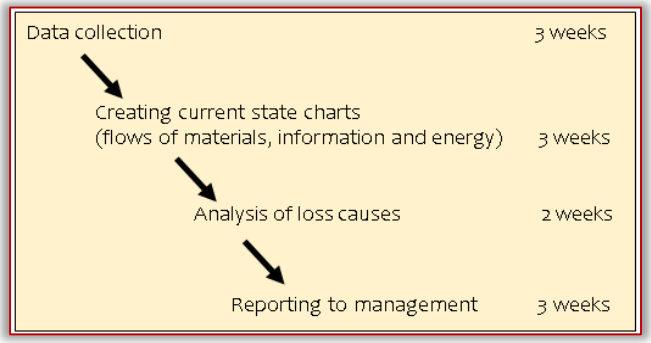

Figure 3. The second step: State recording

— The third step: shaping the future state. This project step begins after the acceptance of the management report on step 2. It is based on shaping the future state that gives greater effects (Figure 4). This process usually takes two to three weeks and includes:

- identifying the groups of products that are profitable and competitive on the market,
- harmonization of system conditions with the project,
- analyzing the range of product requirements and the flow of materials and information,
- team training of employees in the use of tools and methods of the Lean concept,
- process development of the new management requirements for the performance of other functions of industrial system in terms of logistics for the Lean production.

When the proposal of one part of the project relating to the future state is approved, the team focuses on the other part of this step for another three to four weeks, i.e. the formation of Lean concept details. The formation of details includes the following:

- staff plans in all functions across the industrial system,
- presentation of work units in the schedule,
- actions to be performed during the transitional period,
- the implementation plan of activities with short-term and long-term effects of the planned improvements,

- the role of layout reconfiguration and accountability for its consistent implementation,
- charts and tables of the effects on notice-boards,
- a plan for training employees to implement the work process,
- a plan of communications in the industrial system.

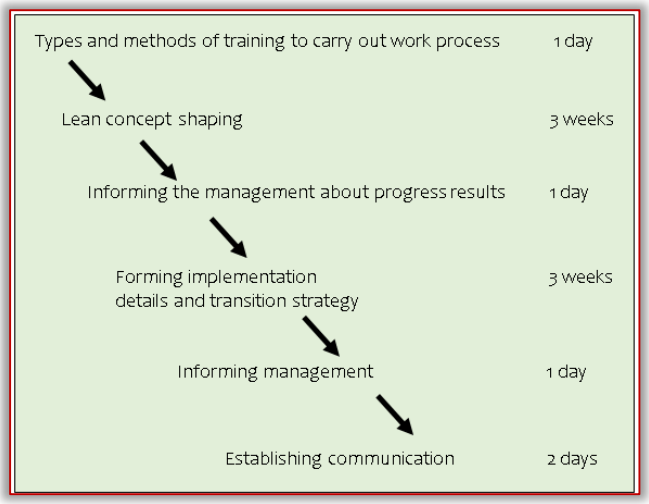

Figure 4. The third step: Shaping the future state

This plan of the future state is presented to the management for approval. The conversation in terms of plan implementation has to be done with all employees, explaining what was observed, who is involved, what was decided, what the aims of the organization are and what all employees involved in are. At this point the project team reach the fourth step.

— The fourth stage: application of the designed model. This is the stage related to the introduction of the Lean concept project into the system. It contains the following activities:

- financing the activities defined in the study,
- direct application and the establishment of work process standards to eliminate losses through the principles, methods and tools,
- establishing communication and training of employees,
- measurements and monitoring procedures for the selected characteristics,
- shaping the final work process standards.

CONCLUSIONS

The Lean concept represents a group of efficient and rational procedures in the systematic use of principles, methods and tools in industrial systems on finding and eliminating wasteful activities (losses and errors) in the working processes, thereby creating the necessary conditions for harmonious activities of functions in a company in the given time and in the existing conditions of the environment. Its implementation leads to efficient and effective procedures in working processes which have to be improved, standardized and accepted as models in performing working processes leading to the achievement of high competitiveness and business excellence in work. This contributes to the TQM system by establishing and integrating standard management systems, as well as applying adequate tools for increasing efficiency.

To implement the Lean concept in industrial systems, a number of evaluations provided by the management are required. Its implementation depends on people, i.e. the team selected by the management. To make any team successful in its task of developing and introducing the Lean concept, the management must answer the following questions:

- Is it possible to hire three to eight people for the period of six to nine months?
- Is it possible to handle failures and mistakes before achieving success and complete the implementation of improved production through the Lean concept?
- Is it possible to maintain work team members' participation even when they do not see significant results after two months?
- Is it possible to maintain the engagement of employees in work teams to the final implementation of the project?
- Is it possible to stabilize production in one, two or three weeks?

Additionally, the management should ensure: the time required for project implementation, funds for the project, personnel, full-time project team (team focused on the task), full performance control of certain stages and steps of the project and approving the following activities of the team.

By establishing the Lean concept, the very principles, methods and tools which contribute to efficiency and effectiveness of working processes are being affirmed. It creates a productive climate in industrial systems and a good foundation for further improvements of TQM. The final result is overall satisfaction of employees, users of products or services and society in general.

References

[1] Babson, S. Lean Work: Empowerment and Exploitation in the Global Auto Industry, Detroit, MI: Wayne State University Press, 1995.
[2] Bozickovic, R. Lean concept in effective production systems; Ph.D. thesis. FTN, Novi Sad, 2005.
[3] Bozickovic, R., Maric, B. Lean Concept – a Challenge to Managers for the Better Future of the Company, Chapter 27 in DAAAM International Scientific Book 2013, pp. 491-510, B. Katalinic & Z. Tekic (Eds.), Published by DAAAM International, ISBN 978-3-901509-94-0, ISSN 1726-9687, Vienna, Austria, 2013. DOI: 10.2507/daaam.scibook.2013.27
[4] Broughton, R. Business Excellence – The way how Business schould be done, Recuperado el 23 de March de 2012, de Lean Manufacturing: http://www.bexcellence.org/Lean-manufacturing.html#, 2012.
[5] Kirk D. Zylstra. Applying Lean manufacturing to logistics and supply chain, John Wiley and sons, Hoboken, 2006.
[6] Maric, B., Bozickovic, R. Maintenance of technical systems & Lean concept, Faculty of Mechanical Engineering, University of East Sarajevo, East Sarajevo, 2014.

[7] Schonberger, R. World class manufacturing: The lessons of simplicity applied. New York: Free Press, 1986.
[8] Shigeo Shingo. Study of "Toyota" production system from the industrial engineering Viewpoint. CRC Press, Boca Raton, 1989.
[9] Taiichi O. Toyota Production System: Beyond Large-Scale Production. Diamond Inc., Tokyo, 1978,
[10] William M Feld. Lean manufacturing: Tools, techniques and how to use them. The St. Lucie Press / AP; CS Series on Resource Management, International Standard Book Number, 1-57444-297-X, Florida, 2001.
[11] Womack, J., Jones D., and Ross, D. The Machine that Changed the World, Rawson Associates, New York, 1990.
[12] Womack, J., Jones D., Lean Thinking: Banish Waste and Create wealth in Your Corporation, Simon&Schuster, New York, 1996.
[13] Quality Assurance Solutions – Lean Manufacturing, https://www.quality-assurance-solutions.com/Lean-manufacturing.html#, accessed 10.6.2022.
[14] Page, J. Implementing Lean Manufacturing Techniques, Hanser Gardner, Cinncinati, 2004.
[15] James, J. & Frederick, M. The Lean Company Making the Right Choices. Society of Manufacturing Engineers. International Standard Book Number 0-87263-523-6, Dearborn, Michigan, 2001.

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CONNECTION AND COMMUNICATION IN THE CLUSTER OF BUILDINGS AND MECHANIZATIONS MAINTENANCE FOR THE REGIONAL COOPERATION

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Abstract: The paper discusses the possibility of information and communication links between activities related to maintenance in the construction sector in the Western Balkans. However, the precondition for this connection is the organization of clusters at the national level so that as many companies as possible are involved in regional cooperation. The development of information technologies enables local and regional connections. The common goal is to inform each other for the purpose of business development and competitiveness. In the regional sense, the areas of interest are parts of the Bosnia and Herzegovina, the Republic of Croatia and Republic of Serbia. In practical terms, an information and communication model of regional cooperation with clear objectives is proposed.

Keywords: information, cluster, maintenance, construction

INTRODUCTION

In the global economic world, there is a tendency for information to connect different actors for the purpose of sustainable development and competitiveness. In this sense, groups already established in most European countries are known as clusters. On this occasion, the starting point of research is maintenance activities that have their place in all economic systems. In essence, these are economic activities, mainly technical occupations that deal with ensuring the functioning of various technical systems. This primarily refers to the maintenance of machinery and equipment, electrical appliances, installations and complex systems, agricultural machinery and machinery, buildings and machinery, and information hardware and software and other technical systems. In the teaching text, special attention will be paid to the maintenance of buildings. The reason for this starts from similarity of business problem and technical characteristics provide the conditions in construction, and thus in maintenance.

With the development of technique and technology, there is a need to improve maintenance activities. Such tendencies favor certain legal solutions in all European economies that enable groups of similar goals and problems, ie clusters. For now, there is no evidence of the existence of clusters from the maintenance business, so this is becoming an increasingly interesting area of research. Special emphasis should be placed on the fact that these activities are not competitive in a regional, non–national sense with regard to the market in different systems. In this case, it refers to the markets of Slavonia and Baranja – within the Republic of Croatia, the market of Vojvodina within the RS and the northern part of Bosnia and Herzegovina. Namely, the companies that deal with maintenance are of a local character, so they are not in direct competitive relations, so there are no obstacles to cooperation in mutual information and development.

Research shows that the formation of clusters, especially in the Republic of Croatia and the RS, has reached a solid organizational and legal regulation, so there is a basic prerequisite for the formation of regional clusters in this case from technical maintenance. Of course, the goal should be in the organizational sense something absolutely of common interest, and that is certainly mutual information and development of activities. Therefore, this paper deals with maintenance activities and their specifics, information system and common information point where all economic entities are able to communicate and inform each other, and there are technical possibilities for this. Defining the organization and functioning of information and communication activities sets the technical and organizational solution for regional cooperation in the field of maintenance.

In the next part of this paper, special attention will be paid to the basic elements of maintenance of buildings and machinery, clusters as institutional aspects of regional cooperation and information system for joint relationships with clients and other business partners and all companies in maintenance. It is the common information system that can contribute to the intensification of research and application of new achievements in the development of techniques and technologies, as well as applications in the field of maintenance.

Different scientific methods have been used in the research and definition, and as a result, an information system is proposed that uses various development achievements in the field of information and communication sciences.

SPECIAL MAINTENANCE FEATURES OF BUILDINGS

The maintenance of buildings is regulated in all countries of the region by certain similar legal regulations, and in the Republic of Croatia, according to the Ordinance on maintenance, the maintenance of buildings includes:

- Regular inspections of the building or its parts, at intervals and in manner determined by project of building and a written statement of contractor on work performed and conditions of the building maintenance, this Ordinance and /or special regulations adopted in accordance with the Construction Act, devices and installations and other and with a service plan within the deadlines prescribed in the guarantees of the manufacturer of installed products,
- Extraordinary inspections of building or its parts after an extraordinary event or after an inspection,
- Performance of works by which the building or its part is retained or returned to the technical and / or functional condition determined by the project of the building or regulations and acts for construction in accordance with which the building was built,
- Keeping and keeping documentation on maintenance of the building: in the continuity of ordinal numbers listed and compiled on the day of creation records with attachments on regular and extraordinary inspections and work performed in order to preserve the designed basic requirements for construction, functionality and safety of the building in use [1].

Assuming that this matter is regulated by appropriate regulations in Serbia and Bosnia and Herzegovina, similar problems arise in the maintenance of buildings as well as types of work. In addition, the maintenance of buildings is usually organized either independently or with the help of a company that is at a shorter geographical distance. In addition, such companies in the region are not burdened with mutual competition, so this creates opportunities for communication and information in order to develop and increase quality. In this sense, it is necessary to set up an organization of information and communication system through which to communicate. This communication would have two basic common goals. This primarily refers to mutual communication for the presentation of new maintenance methods, the use of new technologies in terms of means of work, equipment and materials. Another extremely valuable activity is public relations in order to inform users in the region about all innovation achievements in the region. In the era of high level of informatization, a common way of informing and communicating should be devised, i.e. the organization of the information and communication system of the cluster should be set up.

CLUSTERS–RESEARCHED EXPERIENCES

A cluster is a form of strategic alliance or group of related companies or associations of producers from one branch, including producers of raw materials, as well as governmental and NGO and scientific and educational institutions that solve common problems and improve business above–average competitiveness and promotion at home and abroad [2]. Analysing the above definition, it can be concluded that the following reasons for the formation of the cluster are:

- affinity of the company in terms of type of activity.
- solving common problems.
- improving business through innovation.
- increasing competitiveness.
- promotion through information and communication relations, especially in relations with the rest of the public.

Analysing the stated reasons for formation of cluster, goals of participants in cluster can be identified, such as increasing competitiveness and better use of own resources. Support for companies by scientific and educational institutions and links with development finance funds should also be added. Given this cluster formation is a strategic move oriented to the global market. In order to consider a topic, it is necessary to explore certain experiences related to clusters in the region to which this applies. In this sense, there are already some regional experiences. According to information from a specialized conference held on the island of Brač clusters are tools through which small and medium–sized companies become more competitive in foreign markets [3]. At the conference, participants from the region (Croatia, Serbia and Bosnia and Herzegovina) presented a number of interesting analyses, criticisms and proposals, highlighting the following:

- Tomislav Radoš, Vice President of the Croatian Chamber of Commerce for Industry and Information Technology, believes that the main problem in Croatian clusters is poor communication and noted that the establishment of 13 clusters has just been launched in order to increase competitiveness.
- Danka Milojković, director of the Cluster House from Niš, pointed out that the sustainability of the cluster depends on; sustainability of members, managerial management and public sector support, but also on national economic strategy.
- Marko Šantić, President of the Chamber of Commerce of Bosnia and Herzegovina, says that there are no clear state strategic documents there in order to organize and support clusters.

- Jacques Viseur Communication Manager from the Laboreuropean Cluster Collaboration Platform stressed the importance of clusters in national economies but also the need for international communication and cooperation for development and competitiveness.

In other countries of the wider region there is some experience in organizing clusters, such as in Slovenia it is the approach of "dynamic concentric circles" or grouping smaller companies around large companies. Similar gatherings are taking place in Hungary around the world's multinational companies. Slovakia's goal is to explore the possibilities of local connections of related smaller companies. In Poland, a special goal and interest is to connect with world high–tech centres for the purpose of developing products and services [4].

From the previous information it is evident that there is a desire and need for cluster organization and their international connection, especially when there is a high degree of similarity in product type, organization and the need for mutual information for development and competitiveness. Therefore, on this occasion, the activity of maintenance of buildings was chosen, especially for group housing and other infrastructural activities. Such buildings in the region have similar maintenance problems and can exchange knowledge and experience through information and communication links in order to increase the quality of activities. The common interest of construction maintenance activities is certainly mutual information and communication. This means that an information and communication system should be set up, and a common approach to the relations between clusters and their partners should be built on that.

INFORMATION AND COMMUNICATION SYSTEM OF CLUSTERS FOR MAINTENANCE OF BUILDINGS

Maintenance of buildings in particular is an activity that has a tendency to long–term cooperation with customers or clients. This stems from the need for the maintainer of the facility to be well acquainted with all its characteristics, because only in this way can an efficient service be provided. In order for each maintainer to be able to communicate effectively and permanently with clients, he must establish a minimum information system or organize an information process with his business environment. In modern conditions, Figure 1 shows one possibility of a communication system that is suitable for the maintenance of buildings. A developed web or portal is the main starting point from which the user starts when connecting to the Internet, so opening a web portal is the minimum that every entrepreneur should do [5]. Once the market segment or group of clients with whom it will cooperate in the long term is determined, we move on to personalizing the website. This means that information important to each other will be delivered to each important client. Once the clients for long–term cooperation have been defined, a blog is opened that enables constant asynchronous information with relevant information. Modern dynamic blogs are interactive that allow visitors to leave their comments [6]

The information process can be extended through an application known as a forum. Forums perform a function similar to that in bulletin board systems, which were first created in the late 1970s. Early web forums date back to 1994; so many alternatives have been created. A sense of virtual community often develops around forums that have regular users with a large number of topics. [7] This enables the exchange of written information between each entrepreneur and his clients as well as the general public. This is followed by a video conference that connects individuals and groups through telecommunications networks and video technology so that people have the impression of attending meetings simultaneously in the form of a live video link on a computer monitor. [8] Defining video conferencing enables discussion with several participants, and with the help of social networks, the information and communication process is professionally developed in accordance with the needs of clients. As the highest level of communication and management with clients, a set of methods and business processes called CRM (Customer Relationship Management). [9] In technical terms, this is done through the organization of a single contact centre that has the following functions: [9]

- Providing marketing information and answering inquiries.
- Receiving requests for services.
- Receiving problem reports, complaints and customer complaints.
- Providing insight into the status of customer orders.

In order to better connect with their clients and the rest of the public, every entrepreneur–maintainer can open one of the social networks. In that sense, Facebook, as the most downloaded mobile application of the decade, from 2010 to 2019, enables better connection of immediate participants in maintenance. [10] In addition, opening Instagram can help promote commercial products and services. It can be distinguished from other social media platforms by its focus on visual communication. Instagram marketing is an effective way to advertise a product, given that an image is said to speak a thousand words. The platform can also help commercial entities save on branding costs, as it can be used for free even for commercial purposes. [11] There is also specialized software for this kind of professional communication – e.g. Trello (Figure 1).

Given that there are information and technical possibilities for connecting contact centres in the region, regional information and communication cooperation can be achieved. Figure 2 shows three contact centres that can

connect three companies or three or more national clusters. A higher level of integration is the harmonization of national regulations and the formation of an interregional cluster (Figure 2).

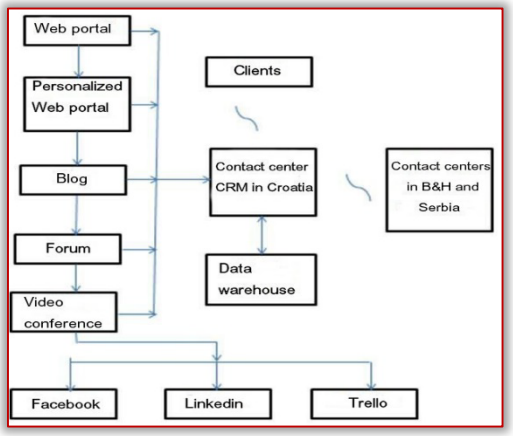

Figure 1. Cluster–public relations

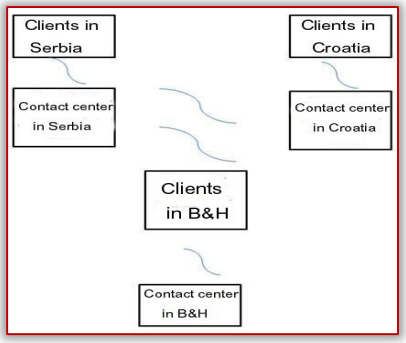

Figure 2. Contact centre

There are no obstacles to regional cooperation, given that companies in the field of maintenance of construction facilities are of a local character and are not in direct competition. The main reasons for such regional cooperation are the following:

- Mutual information on all innovations in terms of new tools, materials and working methods of common interest.
- Increasing labor productivity and quality levels.
- Harmonization of national regulations with international regulations in the field of maintenance.
- Analysis and harmonization of working conditions of related companies in the region.
- Mutual exchange of other relevant information related to the wishes and problems of clients in the region.

CONCLUSIONS

Previous considerations show that there is a need but also technical possibilities for connecting economic entities in the region. In order to increase the representation, it is proposed to first form a cluster for the maintenance of buildings, because these are companies that are local type and are not in conflict with strong competition. After such grouping, the next phase is to connect clusters in the region (Croatia, RS and BiH) and their common interest is to inform and develop activities. Given the possibilities of the mentioned CRM, there are no obstacles to regional cooperation. Thus, all companies retain legal personality as well as clusters in individual countries, but the possibility of cooperation opens up where topics of common interest are discussed. In this way, interregional cooperation is achieved, which can make a certain economic contribution and a small political and regional incentive for cooperation.

References

[1] Pravilnik o održavanju građevine, Narodne Novine 122/2014, Republika Hrvatska, Čl. 8
[2] https://www.hcpm.agr.hr, 2022
[3] Kroz klaster rivali postaju partneri, Privredni vjesnik, 3974, Hrvatska, 2017.
[4] https://www.hrčak.srce.hr, Dragičević,M., Obadić, A.,Regionalni klasteri i novo zapošljavanje u Hrvatskoj, Ekonomski fakultet u Zagrebu, Serija članaka–Članak 06–03.(date 16.4.2022)
[5] Ružić,D. Biloš, A., Turkalj; D., e–marketing, Ekonomski fakultet Osijek, 2009, 79.
[6] Mutum, Dilip; Wang, Qing (2010). Consumer generated advertising in blogs. Yp.: Neal M. Burns; Daugherty, Terry; Matthew S. Eastin. Handbook of Research on Digital Media and Advertising: User Generated Content Consumption. 1. IGI Global. 248–261
[7] Vremenska crta softvera Foruma 1994–2010. Pregledi softvera foruma (date 2022–04–04)
[8] Adeshina, Emmanuel. In–Person visits fade as jails set up video units for inmates and families, The New York Times website, August 7, 2012, pg. A15 of the New York Edition.
[9] Panian, Ž. Odnosi s klijentima, Sinergija, Zagreb, 2003, 115.
[10] Miller, Chance (2019–12–17).These were the most downloaded apps and games of the decade
[11] Silva, Thiago H.; Melo, Pedro O.S. Vaz de; Almeida, Jussara M.; Salles, Juliana; Loureiro, Antonio A.F. (2013.). Slika Instagrama vrijedi više od tisuću riječi: Karakterizacija radnog opterećenja i primjena. Međunarodna konferencija IEEE–a o distribuiranom računarstvu u senzorskim sustavima 2013. 123–132
[12] Lacković, Krešimir; Ivanović, Milan (2020): Smart and networked villages – information system for rural development, X International Conference Industrial Engineering and Environ–mental Protection, October 8–9, 2020, Zrenjanin, Serbia, Proceedings, 128 – 135

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RECYCLED PLASTIC CONSTRUCTION BLOCKS AND BRICKS

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Abstract: Plastic waste was initially landfilled along with every other type of waste. This has proved not to be an acceptable long-term solution considering the time it takes plastics to decompose, which ranges from 100 to 600 years. The ideas about reusing plastics emerged as early as the 1970s. Any kind of production is inevitably accompanied by waste, which is generated both in the production facilities and as a result of worldwide product use. This points to a logical conclusion that, owing to the plastic production growth, the amount of waste generated over time increases on a daily basis. This paper discusses the possibility of using recycled plastics to produce construction blocks and bricks.

Keywords: plastic, recycling, building blocks, bricks

INTRODUCTION

Plastics are organic polymers composed of groups of monomers containing carbon and hydrogen. Natural polymers have been used since the dawn of humanity, whereas synthetic polymers are considerably more recent. Over the previous several decades, plastics gained popularity because of their ability to retain their mechanical properties after modeling, crushing, fabrication of threads, and post-use recycling. Plastic masses are processed using rolling into foils, injection molding, extrusion under pressure, etc. Owing to their mechanical and chemical properties, plastic masses have outperformed numerous other materials. Among other things, the use of plastics has been increasing owing to the low cost of the raw materials, small mass, and processing versatility.

Large amounts of plastic waste are deposited at landfills and often outside landfills. Waste disposal at landfills is unsuitable, because of its large volume and its weathering non-degradability.

Recycle plastic is used to obtain synthetic materials that are then used to produce clothing, foils, packaging (e.g., bottles, bins, barrels), and other products. It is only in recent years that recycled plastic has been used to produce construction blocks and bricks.

European plastics industry has opted to maximize the use of plastic waste as a resource and to minimize plastic waste disposal at sanitary landfills. This involves the utilization of plastics through mechanical or chemical recycling or as an energy-generating raw material, which is a path toward integrated waste management. Such a policy is in keeping with the EU Directive on packaging and packaging waste, which set a goal to utilize a minimum of 45% of packaging waste, 15% of which has to be recycled [2].

Of all packaging materials, plastic has enjoyed the highest growth rate over the previous decade. The first European strategy for plastics was adopted in Strasbourg in January 2018. Three years prior, the EU enacted the Circular Economy Action Plan, and the European strategy for plastics is the extension of this policy, which is supposed to regulate plastic production, use, and disposal flows and to incentivize a transition to circular economy.

The goal is to ensure the reuse and recycling of all plastic packaging on the EU market by 2030. To ensure a higher demand for recycled plastics, the EU Commission also launched a campaign aimed at taking on the obligation of putting ten million tonnes of recycled plastics into new products across the EU by 2025.

The EU generates over 28 million tonnes of plastic waste annually. Less than 30% of that amount gets recycled, while the remainder is either incinerated or landfilled. Analyses have shown that such a high degree of landfill disposal and incineration incurs losses of 70 to 105 billion euros due to a short utilization cycle of the raw materials.

In everyday life, plastics are used for a wide variety of purposes, from clothing, footwear, and tableware to cosmetics and car parts. Plastic is a light material that is easy to produce and mold. It is highly resilient, which means that every piece of plastic ever produced still exists on earth in one form or another. These properties of plastic and irresponsible management of plastic flows have caused one of the crucial environmental issues affecting the planet – it is overrun by plastics.

In 2020, Serbia generated 356,021 tonnes of plastic waste, of which only 45,219 tonnes were recycled. [3,4].

In order to standardize and globalize recycling, special labels were globally adopted to inform customers about the material of which the product is made and to facilitate collection and subsequent sorting before recycling. The law mandates that every item has to contain a label

informing the user about the material used to produce it. Figure 1 shows the universal symbols for labeling plastic materials (each type of plastic has only one symbol). Recycled plastics are classified according to their basic chemical composition.

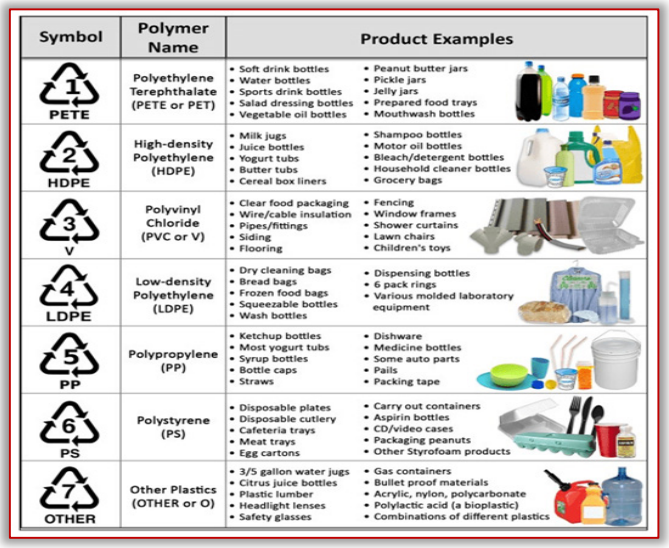

Figure 1. Plastic labeling symbols

Regarding the recycling process itself, it should be emphasized that there are four types of recycling: primary, secondary, tertiary, and quaternary. The classification was established based on product lifecycle, which then dictates its later use after recycling.

- Primary recycling: Re-extrusion, or return of the plastics with the same properties into the production process. If the molding of plastic products generates waste (e.g., a material left over after trimming the product edges, a material that goes through a machine first during processing and is then discarded, a product that does not meet the shape requirements, etc.) that remains within the production facility, it is considered uncontaminated and may be returned to the polymer processing procedure.
- Secondary recycling: Mechanical recycling, developed to recycle different plastics using physical procedures. When a material leaves the production facility and is collected after its shelf life, cleaned of all traces of other materials, washed, and dried, it can be reshaped through processing, pure or combined with a pure polymer and other materials. Mechanical recycling is the only one of the four recycling types that maximizes the utilization of plastic waste while minimizing the negative environmental impact. When using mechanical recycling, it is important to select a suitable method of sorting and different processing stages. Despite the rapid technological progress, manual sorting of plastics is still the most common method, as it is a simple process requiring little technological support. It is a labor-intensive, cost ineffective, and inefficient method for sorting any material, especially plastic. Consequently, a labeling system was introduced with codes for the six most used types of plastic.
- Tertiary recycling: Chemical recycling is used to produce raw materials for the chemical industry. It is a process decomposing plastic materials into polymers with lower molecular mass (usually liquids or gases), which are then used as raw materials for new petrochemical products or plastics [1]. The term *chemical* is used because the process changes the chemical structure of the polymers.
- Quaternary recycling: Its purpose is energy generation, or complete or partial oxidation of plastic waste to produce heat and/or gaseous fuels and oils and/or disposable materials (e.g., ash). Parts of the waste, most often specific types of polymers that cannot be processed using any of the previous three procedures, may be used for energy generation or as fuels, both on their own and combined with other wastes and fuel to generate heat due to the breaking of chemical bonds.

RECYCLED PLASTIC CONSTRUCTION BLOCKS

ByFusion Global Inc., a US company, plans to recycle 100 million tons of plastics and convert them into construction blocks by 2030. ByFusion Global created a new alternative construction material. ByFusion's Blocker system converts 100% of plastic waste into ByBlock® – an advanced and affordable construction material. ByBlock® is a multi-colored construction block made of recycled plastic. Its dimensions are 40x20x20cm and it weighs 10kg. It is the first construction material made entirely out of recycled (and often un-recyclable) plastic waste. The blocks are designed to be placed without any glue or adhesive, the same as regular concrete blocks. However, as opposed to concrete blocks, ByBlocks® do not crack or crumble.

Figure 2. Recycled plastic blocks – ByBlock

The manufacturer claims that the production of these blocks generates zero waste. One ton of plastic yields one ton of ByBlocks®. These multi-colored construction blocks are visually appealing and functional. They can be used for the construction of retaining walls, sound walls, sheds, terracing, and even furniture. They can replace cement

blocks in building foundations or indoor walls and are no different than concrete blocks.

The manufacturer also stresses that the production process has zero carbon emissions and does not require any additional chemicals. The plastic is not melted during recycling and standard construction materials such as plaster walls and tiles may be added later. Greenhouse gas emissions of ByBlock® production are 41% lower than emissions during concrete block production [5].

CONSTRUCTION BLOCKS MADE OF RECYCLED PLASTIC AND SILICATE WASTE

Indian company Rhino Machines invented a new design technology for plastic construction blocks. The blocks are called silica plastic blocks (SPBs) and are strong enough to be used for building a house. *Rhino Machines* conducted experiments to determine the sustainability of these blocks made from plastic waste and silicate foundry dust. The experiments were conducted by the company's R&D division to prove that SPBs can be used in construction instead of traditional blocks. The general goal was to attempt to find a permanent solution for the growing issue of plastic waste in India.

According to the Indian Central Pollution Control Board data from 2012, India produced over 23,500 tonnes of plastics daily, of which 10,000 tonnes were deposited with other waste without being sorted. This waste is non-biodegradable and reaches the natural environment, polluting rivers, agricultural land, and the entire environment.

Figure 3. Figure caption

Initially, the aim of creating SPBs was to achieve zero discharge from the foundry reclamation process. In the early stages of the experiments, tests were conducted using foundry dust mixed with cement to produce bricks. The experiment yielded the following results: 7-10% of recycled waste went into concrete bricks and 15% into clay bricks. The experiments indicated that other resources, such as cement, earth, and water, were also required, which was not justified by the recycled waste. Further research resulted in the mixing of foundry dust with plastic waste, which was used as a bonding agent, thus eliminating the need for water and cement during mixing. SPBs require a mixture of approximately 80% foundry dust and 20% plastic, which means that neither water nor cement are necessary. Such blocks are less dependent on natural resources, while also reducing inorganic waste. According to *Technology Times*, SPBs are 2.5 times stronger than standard red clay bricks and their production costs are lower owing to the use of waste [8].

Even though some countries banned the use of single-use plastic products, the problem with plastic waste gives serious cause for concern. Therefore, technologies such as SPBs could significantly help reduce the amount of plastic waste. In addition to contributing to the solution of the plastic waste problem, such technologies should also help alleviate another global problem, which is the growing demand for residential space in urban environments. According to UN data, 55% of the world population reside in urban environments, where the problem of plastic waste is logically more pressing. It is estimated that about 68% of the world population will live in urban areas by 2050.

RECYCLED PLASTIC BRICKS

The House in Colombia shown in Figure 6 was built from recycled plastic by Fernando Llanos. Together with the architect Óscar Méndez, he founded the company Conceptos Plásticos, which patented the innovative system of construction using recycled plastic bricks, which allowed the cheap and fast construction of houses at difficult-to-reach locations. The construction of a plastic house with the total surface area of approximately 40 m^2 cost 6,000 euros and took only five days. The plastic bricks were joined together similar to LEGO® blocks.

Plastic bricks have good insulation properties, they are not flammable, and they comply with the local seismic building codes. Since 2011, the company has employed 15 persons to build plastic brick houses in areas affected by natural disasters [7].

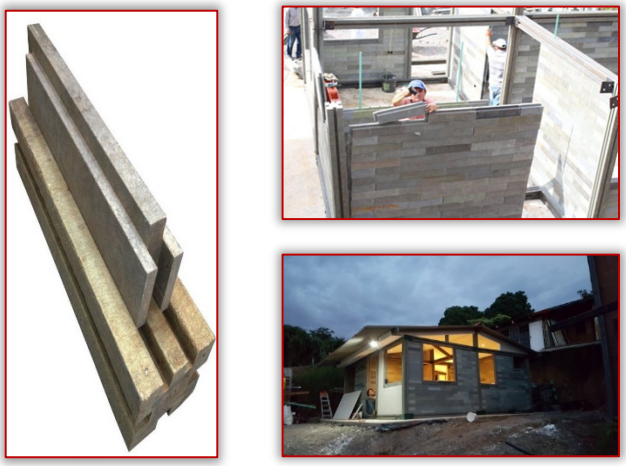

Figure 4. A house made of recycled plastic bricks

Located in Alta Gracia, province of Córdoba, Argentina, the non-profit organization Ecoinclusión works to reduce plastic waste, specifically PET bottle waste, by producing

recycled plastic bricks. These bricks are also intended for housing construction in vulnerable areas. The bricks received the technical certification by the *UN – Habitat Secretariat*, after being developed by *Ceve-Conicet*. The production of one plastic brick requires twenty recycled bottles. The brick's properties are similar to a standard clay brick's but with better thermal insulation characteristics [9].

Figure 5. A recycled plastic brick

The Kenyan startup Gjenge Makers, located in Nairobi, founded by 29-year-old Nzambi Matee, developed a cheap recycled plastic paving brick, which is harder than concrete bricks. Nzambi Matee was declared the Young Champion of the Earth 2020 for Africa by the UN Environment Programme (UNEP). The plastic waste paving bricks are now used to pave households, schools, and streets.

She conceived and developed a prototype of a machine that converts plastic materials into pavers for paths and sidewalks. The machine's output capacity is 1,500 plastic pavers a day. The production is cost-effective because waste is used and their superior hardness makes them ideal for the paving of areas that require harder materials.

Figure 6. Recycled plastic pavers in different colors

The company's innovations in the civil engineering sector offer both economic and environmental benefits, because they involve a transition from linear to circular economy, in which products remain in the system as long as possible. Thus far, more than 20 tonnes of plastic waste have been recycled to produce paving bricks and tiles in a variety of colors (red, blue, brown, and green). Testing showed that they are two times stronger than regular concrete bricks [10].

CONCLUSION

The entire world is facing the problem of plastic waste today. Modern life is almost unimaginable without polymers, as everyday items, clothing and footwear, vehicles, construction materials and products, and information and communication devices are made of different types of polymers. Waste generation accompanies any kind of production, whether in production facilities themselves or as a result of product use throughout the world. Consequently, the increased production of plastics generates increasing amounts of plastic waste on a daily basis. Initially, plastic waste was landfilled with other waste, but it soon became clear that this could not be a long-term solution, because of the long period of plastic degradation.

Many plastic materials can be reused to create new items that are used in every sphere of life. The obtained plastic regranulate is used directly in the production of plastic items. This paper discussed how the plastic regranulate may be used to produce recycled plastic construction blocks and bricks. These new construction materials are then used for the construction of residences and for outdoor paving.

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References

[1] Al-Salem, S.M., Lettieri, P., Baeyens, J., Recycling and recovery routes of plastic solid waste (PSW), Waste Management, Vol. 29, pp. 2625–2643, 2009.
[2] Brydson, J., Plastics Materials, 7th Edition, Elsevier, Amsterdam, 1999.
[3] Program upravljanja otpadom u Republici Srbiji za period 2022 – 2031. godine (Službeni glasnik RS, br.5/2022).
[4] Tchobanoglous, G., Kreith, F., Handbook of Solid Waste Menagement. McGraw-Hill, 2002.
[5] https://www.byfusion.com/
[6] https://www.youtube.com/watch?v=GKZ1INm3o1Q
[7] https://www.archdaily.com/869926/this-house-was-built-in-5-days-using-recycled-plastic-bricks
[8] https://www.designboom.com/architecture/conceptos-plasticos-blocks-waste-plastic-02-09-2021/
[9] https://www.youtube.com/watch?v=qUMiumBW1h4
[10] https://www.youtube.com/watch?v=QbZKP4UAtL8

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CHEMICAL TREATMENTS IMPACT ON THE MECHANICAL CHARACTERISTICS AND MORPHOLOGY OF BANANA FIBRE

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Abstract: Natural fibres are less expensive than other types of fibre, the greatest replacement for synthetic fibre composites today is a natural fibre reinforced biodegradable composite. For uses in domestic goods, natural fibres like sisal, kenaf, plam, banana, jute, and coir have been employed as reinforcement in polymer composites. At the moment, research into composite materials is focused on employing natural fibres rather than synthetic ones. When used as reinforcing fibres in matrices, natural fibres made from yearly renewable resources have a positive impact on the environment in terms of final disposal and raw material use. Because of their low density, superior mechanical performance, universal availability, and disposability, natural fibres provide an alternative to technical reinforcing fibres. Chemically altering the fibre surface can strengthen the bond between the fibre and matrix. The fibre surface can be cleaned, chemically modified, and given a rougher finish through chemical treatment. Scanning electron microscopy was used to investigate surface analyses on fibre for before and after treatment. The banana fibre's stress–strain curve is identified. As a function of fibre diameter, test length, and testing speed, properties like initial modulus (YM), ultimate tensile strength (UTS), and percentage elongation are assessed. The failure is caused by the pull–out of microfibrils along with the tearing of cell walls, according to scanning electron microscopy (SEM) investigations of the broken surfaces of these fibres; the likelihood for fibre pull–out appears to diminish with increasing testing speed.
Keywords: chemical process, surface examination; natural fibre; banana fibre; mechanical characteristics; alkaline

INTRODUCTION

Natural fibres like banana and coir have low densities and poor mechanical qualities, yet they are renewable resources. About 1.5 million acres of land in India are used for banana plantations, which produce 3 × 10Stons of fibre [1]. Natural Plant–derived fibres and a plastic binder are combined in natural fibre composites. Wood, sisal, hemp, coconut, cotton, kenaf, flax, jute, abaca, fibres from banana leaves, bamboo, wheat straw, and other fibrous materials are examples of natural fibre components. Lightweight, low–energy production, and environmental friendliness are a few benefits of natural fibre composites. Natural fibres reduce weight and production energy requirements by 80% and 10%, respectively, while the component costs 5% less than equivalent fibre–glass–reinforced components. Fibre composites combine a plastic binder with fibres produced from plants. Wood, sisal, hemp, coconut, cotton, kenaf, flax, jute, abaca, fibres from banana leaves, bamboo, wheat straw, and other fibrous materials are examples of natural fibre components. Lightweight, low–energy production, and environmental friendliness are a few benefits of natural fibre composites. Natural fibres provide weight reduction of 10% and an 80% reduction in production energy requirements, while also costing 5% less than equivalent fibre glass–reinforced components [2]. Banana fibre's mechanical characteristics were investigated by Kulkarni et al. [3]. They discovered that pulling out of microfibrils and ripping of cell walls cause the banana fibre intention to fail.

Natural fibre is one of the ecologically friendly materials that are being taken into consideration for the majority of applications due to their superior qualities when compared to synthetic fibre in terms of eco–relationship [4]. Utilizing materials that are waterproof, moderately strong, and corrosion–resistant, natural fibre is used in the majority of technical components for the production of cars, aircraft, home appliances, and packaging. Global industry researchers predicted that the global market for natural fibres would be worth $6.4 billion by 2022 and rise at a compound yearly growth rate of 10.2% from 2022 to 2026. The purpose of this work is to assess the effects of chemical modification on the fibre surface of Banana by employing some of the common treatments for natural fibres. These steps are intended to separate the technical fibres from the non–structural fibres in the fibre bundles. How these changes affect the banana fibre that is extracted and whether the resulting fibres will have increased stiffness and strength as potential reinforcement for polymer matrices [5].

Natural fibres are categorized into different categories. It provides a substitute for synthetic fibres because of their affordability, low density, and biodegradability. For the development of natural fibre–reinforced composites, a deeper comprehension of the fibre–matrix interface and

the capacity to transfer stress from the matrix to the fibre are required [6].

Chemical modifications are seen to be a viable option for altering the surface properties of fibres because they can both lessen natural fibres' water absorption and strengthen the interaction between fibre and matrix. Several researchers looked into chemical treatments for natural fibres [7]. The common chemical treatments are acetylated, H_2SO4, and alkaline treatments. When employed as reinforcement in thermoplastics and thermosets, alkaline treatment is one of the most popular treatments for natural fibres. The sodium hydroxide used in this investigation was selected due to its efficiency and low cost. To get the ideal concentration, three different NaoH percent concentrations were tested [8].

METHODS AND MATERIALS

In order to obtain straight, long fibres, banana fibre were separated through due retting and scraping. The fibre were then properly cleaned with lots of water and dried outside in the sun for hours. Banana pseudo stem were collected from a neighbouring farm in Ikere Ekiti, Ekiti State, south–western Nigeria, during the harvest season, and the fibre was removed utilizing dew retting techniques. The earliest and most popular method of retting used to separate fibres from the appropriate plants is dew retting. Since this procedure requires the proper levels of moisture and temperature, it cannot be applied anywhere. The plants are left in the field after harvesting (scattered out in uniform, thin, no overlapping swaths) so that microorganisms can separate the fibres from the cortex and xylem. To achieve uniform retting, the plants are frequently flipped over. To avoid cellulose destruction by microorganisms, the retting process needs to be watched carefully and interrupted when necessary; if this doesn't happen, it's known as over–retting. Under–retting makes subsequent fibre processing challenging while over–retting decreases the mechanical performance of the fibres. Dew retting typically takes 3–6 weeks and is dependent on the weather.

Figure 1. Banana plant

Alkaline Treatment of fibres

The outer layer of the fibre cell wall is covered by natural oils, waxy substances, and lignin in natural fibres. Sodium hydroxide (NaOH) is the chemical reagent employed in this procedure, which changes the structure of the natural fibres. By cleaning the surface and a procedure known as alkalization, the alkaline reagent is used to change the structure of the cellulose in plant fibres. The banana fibres were treated with NaOH at 50°C for about 4 hours, and the surplus NaOH was subsequently neutralized by washing the materials in distilled water. The treated and untreated fibres' thermal characteristics, surface morphology, and crystallinity index were investigated. According to research, chemically treated fibres demonstrated improved fibre–resin adhesion, which increased interfacial energy and improved the thermal and mechanical properties of composite materials.

Figure 2. Alkaline treatment of the fibres NaOH

Scanning electron microscopy (SEM)

SEM was used to conduct a study on the morphology of the fibre surface both before and after treatment. The goal was to identify the structural alterations brought about by treatment and differential by using different concentrations.

Mechanical Properties of Fibre

At room temperature, tensile tests were performed on both untreated and treated fibres in accordance with ASTM D 3822 utilizing general–purpose Instron testing equipment, model 3369, with a 25 N load cell full range. Fibres were assessed at a gauge length of 10 mm in their as–received state with displacement control and a crosshead speed of 1 mm/min. Density measurements of treated and untreated fibres were taken in accordance with ASTM D3800–99. Using a Zeiss Gemini Scanning Electron Microscope (SEM), plantain fibres, both untreated and treated, were examined to see how chemical treatment altered the surface properties of the fibres.

RESULTS AND DISCUSSIONS

The banana fibre's stress–strain curve is identified. As a function of fibre diameter, test length, and testing speed, properties like initial modulus (YM), ultimate tensile strength (UTS), and percentage elongation are assessed. It is discovered that for fibres with a diameter range from 0.1 to 0.6/m, YM, UTS, and% elongation show little variance in their values.

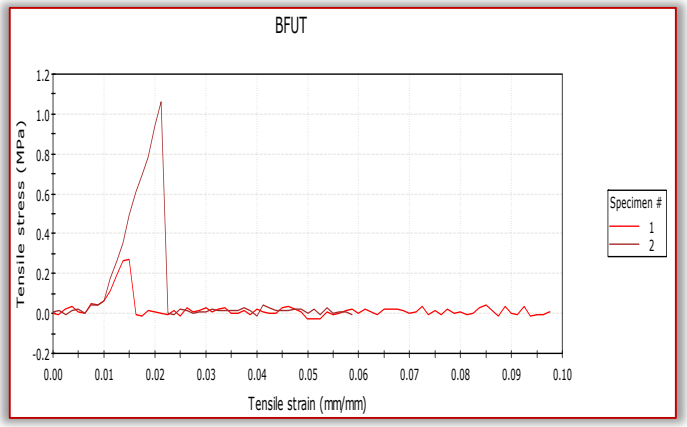

Figure 3. Tensile Strength Test result of physical properties of Untreated Banana Fibres

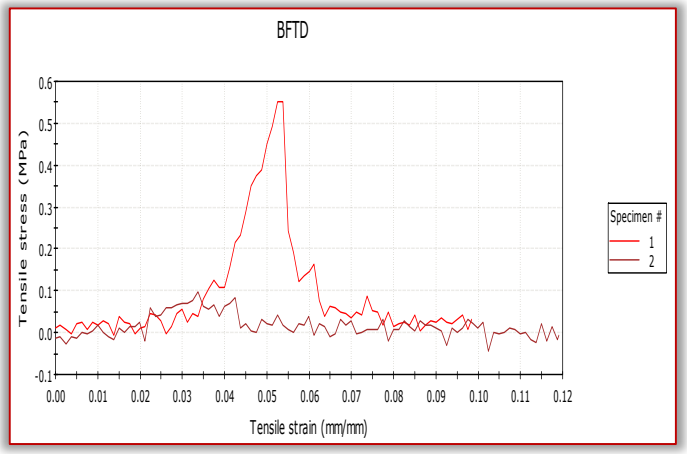

Figure 4. Tensile Strength Test result of physical properties of Treated Banana Fibres

The UTS and breaking strain are observed to decrease as test duration increases, while breaking strength and breaking strain are found to remain constant until test speed increases from 0.0 to 100 x 10–3 m, after which they both decline. These observed characteristics are explained in light of the fibre's internal structure, specifically the quantity of cells and spiral

Optical Microscopy

Figure 5, (b), illustrates how alkali treatment cleans the banana fibres of various artificial and natural contaminants (c). It has been discovered that alkali treatment causes a process known as fibrillation or fibre separation, which results in the disintegration of the fibre composites' bundles into individual fibres. The surfaces after the alkali treatment exhibit a noticeable difference. Following alkali treatment, it was shown that surface contaminants were removed and the final cells were separated as a result of the elimination of the cementing elements, such as lignin and hemicellulose. The inter fibrillar region was expanded and the surface's texture was made rougher by the dissolving of waxy components. The surface of the untreated fibre was smooth and covered in waxes and other impurities. The surface roughness of the fibre increased alkaline solution concentration. This may be due to the fibre's surface being roughened and the prominence of the fibrous region being raised by the limited removal of hemicellulose, lignin, and considerable removal of surface impurities.

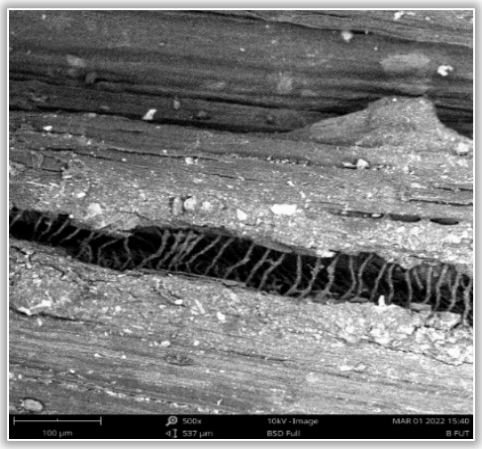

Figure 5 (a) – Untreated Banana fibre

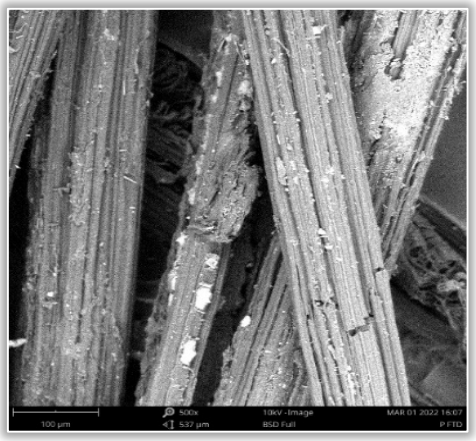

Figure 5 (b) 5% NaOH treated for 1 hour at room temperature

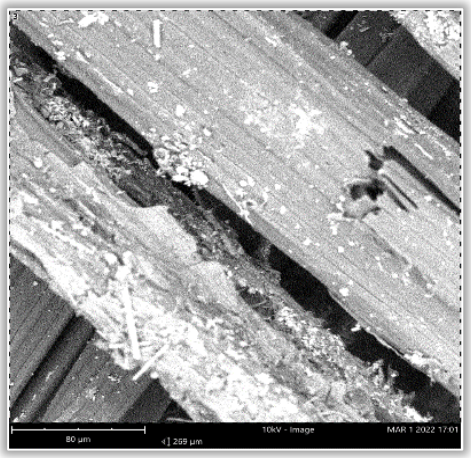

Figure 5. (c) 10% NaOH treated for 10min at room temperature

CONCLUSION

Effect of alkaline treatment has looked at the impact of chemical treatment on the mechanical properties of banana fibre. Although the surface treatment has a negative effect on costing, it may still be able to solve the incompatibility issue. The qualities of natural fibres, such as their surface, ability to eliminate impurities, strength, and improved interaction with the matrix, can be modified by chemical treatments.

References

[1] Geethamma VG, Thomas Mathew K, Lakshminarayanan R, Sabu Thomas. Composite of short coir fibers and natural rubber: Effect of chemical modification, loading and orientation of fiber. Polymer 1998; 6:1483–90

[2] Kulkarni AG, Satyanarayana KG, Rohatgi PK, Vijayan K. Mechanical properties of banana fiber. J Mater Sci 1983; 18:2292–6.

[3] I.O. Oladele, T. F. Omotosho, G. S. Ogunwande, F. A. Owa, A Review on the Philosophies for the Advancement of Polymer–based Composites: Past, Present and Future Perspective, Applied Science and Engineering Progress, 2021, pp. 1–27

[4] Mohd Edeerozey, A.M., Hazizan Md Akil, Azhar, A.B. & Zainal Ariffin, M.I. (2006). Chemical Modification of Kenaf Fibres. Materials Letters.

[5] Yan Li, Yiu–Wing Mai & Lin Ye. (2000). Sisal Fibre and Its Composites: A Review of Recent Developments. Composites Science and Technlogy, 60, p.2037–2055

[6] Murali Mohan Rao,K & Mohana Rao, K (2007) Extraction and Tensile Properties of Natural Fibres: Vakka, Date & Bamboo.Composites Structure.77,p. 288–295.

[7] Wielage, B., Th. Lampke, Utschick, H. & Soergel, F. (2003). Processing of Natural–Fibre Reinforced Polymers and the Resulting Dynamic–Mechanical Properties. Journal Of Materials Processing Technology, 139, p. 140–146.

[8] Geethamma, V.G., Thomas Mathew, K & Lakshminarayanan, R.(1997). Composite of Short Coir Fibres and Natural Rubber: Effect of Chemical Modification, Loading and Orientation of Fibre

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COCONUT SHELL AND FIBRE ASHES FOR LATERITIC STABILIZATION: INDEX AND BEARING CAPACITY PROPERTIES

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Abstract: This paper presented results of stabilizing lateritic soil with Coconut husk ash and Coconut shell ash calcined at 450°C of Coconut husk and Coconut shell respectively to index and bearing capacity in road construction. Lateritic soil was treated with 2, 4, 6, 8, 10, 12, and 14% of Coconut husk ash and Coconut shell ash separately. Both Coconut husk ash and Coconut shell ash were subjected to elemental analysis using Energy Dispersive Spectroscopy and Scanning Electron Microscope. Laboratory tests were conducted to determine the index properties and bearing capacity effects on the untreated and treated soil samples. Elemental analysis showed that both Coconut husk ash and Coconut shell ash are pozzolans. The Maximum Dry Density of the soil sample increases with an increase in Coconut husk ash and Coconut shell ash percentage replacement but a decrease in Optimum Moisture Content and plastic index. A decrease in the plastic index indicates a reduction in the swelling potential of the soil sample. The California Bearing Ratio value increases with an increase in percentage replacement with Coconut husk ash and decreases with Coconut shell ash. Coconut husk ash improved the engineering properties of lateritic soil and, Coconut shell ash alone may not be appropriate

Keywords: coconut husk ash, coconut shell ash, lateritic, road construction, pozzolanic materials

INTRODUCTION

The rate at which waste are been generated over the years worldwide is skyrocketing as a result of an increase in population and socio-economic activities. Mostly, these wastes come from agricultural and industrial establishments. The resultant effects of accumulating these wastes include unsightly surroundings and obstruction to traffic flow due to their improper disposal. However, to minimize these effects, researchers have made several efforts to examine their suitability in construction industries to stabilize construction materials that are deficient in morphological properties and incapable of meeting construction. They serve as substitute materials for traditional soil stabilizers like cement, lime, and bitumen which had been in use since ancient times [5,25]. The act address challenges that have been thrown up by continuous economic decline and over-dependence on these most common and widely used soil stabilizers. Besides, the excessive cost of production like cement and the adverse environmental consequences associated with its products coupled with its corrosive action when working with it in the field has made sourcing for alternatives important. This has however made researchers focus on the use of industrial and agricultural byproducts whose ashes could produce good pozzolans and are available in exploitable quantity [9,10,15,17,18,20,21,22,24].

Lateritic soils can be described as products of tropical weathering with red, reddish brown, or dark brown colour, with or without nodules or concretions, and generally, they are found below hardened ferruginous crusts or hard pan [28]. They are one of the most naturally predominant civil engineering materials in tropical regions used in construction industries. At times they are deficient in morphological properties thereby limiting their suitability as construction materials and such soils are termed problematic soils because they have low strength, high compressibility, susceptibility to excessive deflection, and differential settlement [29] characterized by alternate dry and wet seasons [8,14,33]. Hence, there is a need for improvement through stabilization either partially or wholly to improve its morphological properties. One of these agricultural residues is coconut.

Coconut produce is readily available in very large quantities throughout the tropical countries in the world. According to [7], coconut production was estimated at 61.52 million metric tons across the globe. Coconut has a wide range of applications, and its tree is commonly referred to as the "tree of life" due to its wide applications. The coir, a natural elastic fibre taken from coconut husks, can be used to make floor mats and brushes; coconut oil and coconut milk are among the products extracted from coconut meat. Coconut is considered a potent cure for illnesses such as nausea, rash, fever, and the like by Asian cultures.

However, the produce from coconut which was regarded as wastes like coconut shell and coconut husk among others have been used severally in construction industries

either as additives or to replace certain construction materials partially along with other materials that were necessary to serve as reinforcing elements. They are natural fibers from the plants. In accordance with [27], the husk of the coconut is composed of 70 percent pith and 30 percent fibre on a dry weight basis. Normally, they are 50–350 mm long, and consist mainly of lignin, tannin, cellulose, pectin, and other water-soluble substances. The water absorption is about 130–180% and, with diameters ranging between 0.1 and 0.6 mm with a service life of 4–10 years which poses a problem to stabilization. This fibre deteriorates slowly and affects the performance of the pavement [13,30].

In the modern history of soil stabilization, coconut husk ash has been categorized as pozzolana, with about 67-70% silica and, approximately 4.9 and 0.95% of aluminum and iron oxides, respectively [16]. Hence, this study looked into the effectiveness of the ashes of coconut husk and coconut shell as additives to improve the engineering properties of lateritic soil in road construction.

MATERIALS AND METHODS

Samples collection and preparation Coconut husk and shell (Plates 1-2) used for this research were collected from Badagry, Lagos State, and, the lateritic soil sample was from a borrow pit site at 0.3 m depth in Abeokuta. The lateritic soil samples were sealed in airtight plastic bags to prevent loss of moisture content and transported to the Department of Civil Engineering laboratory for testing.

Plate 1: Coconut Husk

Plate 2: Coconut Shells

Before putting coconut husk and shell into use, they were processed and reduced to fine particles as follows.

Coconut husk and shell were dried in sun, crushed into pieces and, oven dried at 105°C to remove moisture. These were later calcined at 450°C under a controlled temperature and, prepared samples of coconut husk ash (CHA) (Plate 3) and coconut shell ash (CSA) (Plate 4) were taken to the University of Ibadan, Ibadan, for elemental analysis using Electron Diffraction Spectrum (EDS) and Scanning Electron Microscope (SEM) while lateritic soil was subjected to moisture content, particle size distribution, soil classification, Atterberg Limit, Compaction and California Bearing Ratio (CBR) tests in accordance with [6].

Plate 3: Coconut Husk Ash

Plate 4: Coconut Shell Ash.

The percentage replacement of 2, 4, 6, 8, 10, 12, and 14% by coconut husk ash and coconut shell ash was added to lateritic soil separately.

RESULTS AND DISCUSSIONS

— Chemical Analysis Results

The oxides of Al, Si, and Fe were significantly present in CHA and CSA as revealed by EDS (Figures 1-2), and these chemical compounds are usually present in materials that are classified as pozzolans [5], indicating that CHA and CSA are pozzolanic materials.

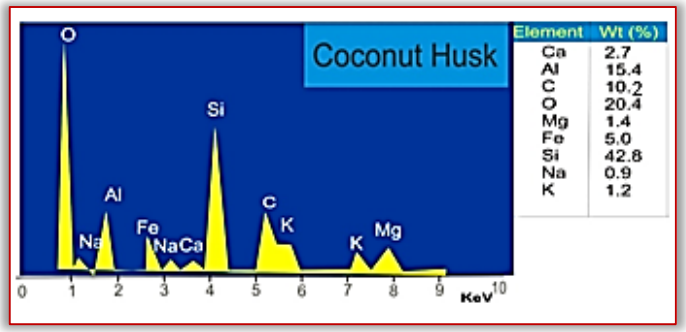

Figure 1: EDS for Coconut Husk Ash

These materials, pozzolans react with calcium hydroxide when water is present to form cementitious properties to stabilize materials. Also, the Calcium content in these materials indicates that they have self-cementing properties though calcium content is small in CHA (2.7%) compared with CSA (15.4%).

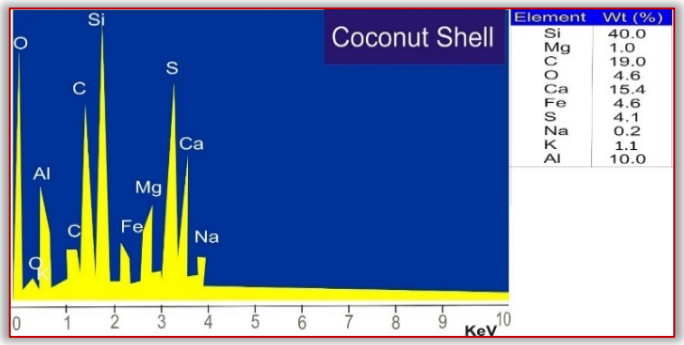

Figure 2: EDS for Coconut Shell Ash

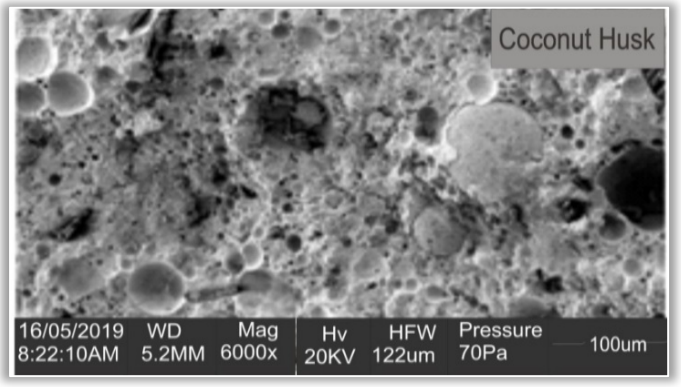

Figure 3: SEM for Coconut Husk Ash

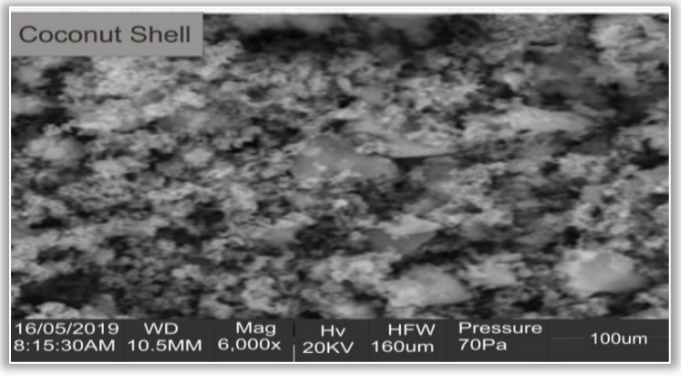

Figure 4: SEM for Coconut Shell Ash

The SEM analysis revealed that CHA has voids that are spherical (Figure 3) while voids in CSA are platy in shape (Figure 4). The arrangement of the particles showed that their voids can accommodate other compatible materials for proper mixing.

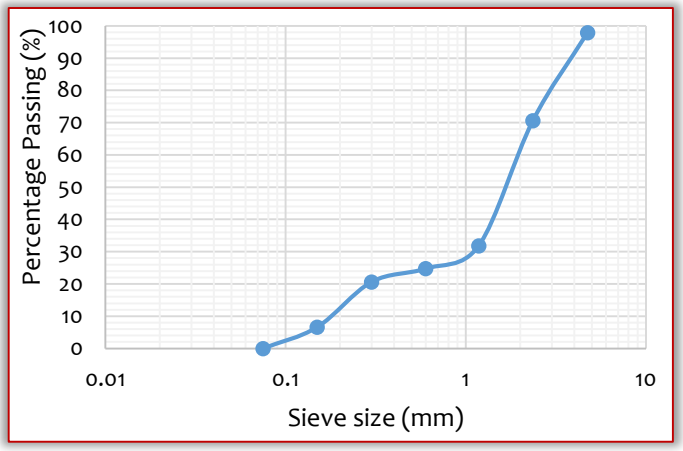

Figure 5: Particle size distribution (Soil Sample)

— Soil Sample

The average natural moisture content of the lateritic soil was 19.41%. Particle Size Distribution The particle size distribution analysis revealed that the laterite sample satisfied the Specification limits for Roads and Bridges [11] with not greater than 35% passing through sieve No 200 (Figure 5). The coefficient curvature, C_C (2.84) and coefficient of uniformity, C_U (11.01) not greater than 5, showed that the sample is well graded. The lateritic soil can be classified further as A-2-7 under the AASHTO classification based on the analysis.

— Consistency of the soil sample

The liquid limit (50.8%) and plasticity index (14.8%) results did not satisfy [11] liquid limits of 50% and plasticity index of 10% maximum for sub-base and base materials, therefore, rendering the soil unsuitable for use as sub-base and base materials.

— Compaction

The soil sample has a maximum dry density (MDD) of 1600 kg/m^3 and the optimum moisture content (OMC) of 23.81%

— California bearing ratio (CBR)

The CBR of 17.42% and 16.01% were obtained for the unsoaked and soaked soil samples accordingly. The lateritic soil is classified further as S5 in the subgrade class designation by [12] (Table 1).

Table 1: Subgrade Classification by [12]

	Subgrade Class Designation					
	S1	S2	S3	S4	S5	S6
Subgrade CBR ranges %	2	3-4	5-7	8-14	15-29	30+

— Effect of CHA and CSA on Compaction of soil with CHA, CSA

The result of MDD is presented in Figure 6, it was observed that MDD increases with different percentages of CSA and, CHA only increased to 8% which is the optimum value while the reverse case was observed for OMC (Figure 7).

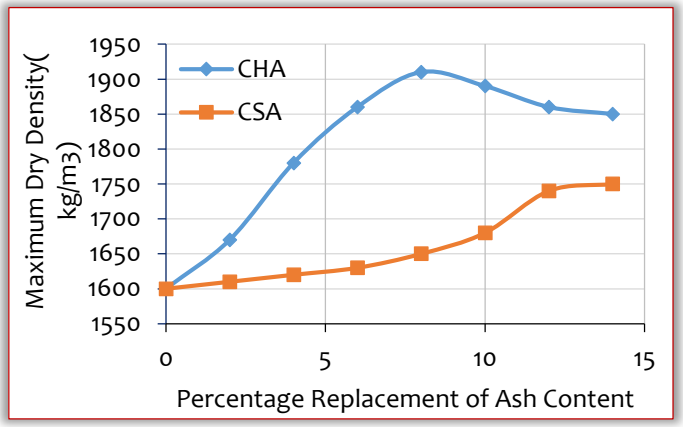

Figure 6: Relationship between MDD and Ash content of CHA and CSA

The increase in MDD could be attributed to the rearrangement of the soil molecular structure to form "transitional compounds" [21] by the finer particles of the ashes filling the voids in the soil particles when compaction takes place [32] and, the increase in MDD is a good indication of improvement in soil property. The decreased value in MDD for CHA immediately after 8% could be a result of the pores created within the soil sample by the continuous addition of CHA to the soil sample [23]. The decrease in OMC recorded was probably due to self–desiccation in which all the water was used when the reaction took place.

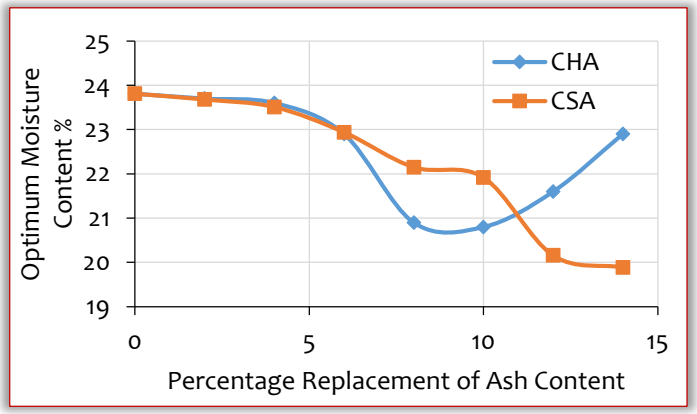

Figure 7: Relationship between OMC of CHA and CSA and its ash content

— Effect of CHA and CSA on Atterberg Limit of the soil sample

Figures 8 and 9 indicate the effect of CHA and CSA on the Atterberg's limit of the stabilized lateritic soil. Liquid limits of the stabilized lateritic soil increase as CHA increases and the treated soil sample was classified as s high plasticity (liquid limit between 50% and 70%) while it decreases as CSA was added to the soil sample reducing the LL from high plasticity to intermediate plasticity (liquid limit between 35% and 50%) [23].

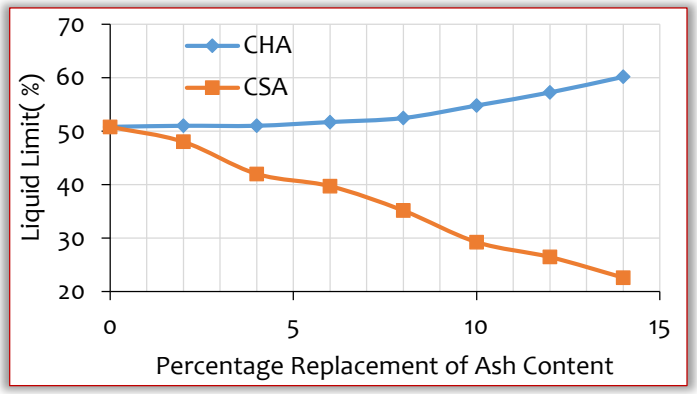

Figure 8: Relationship between Liquid Limit and Ash content of CHA and CSA.

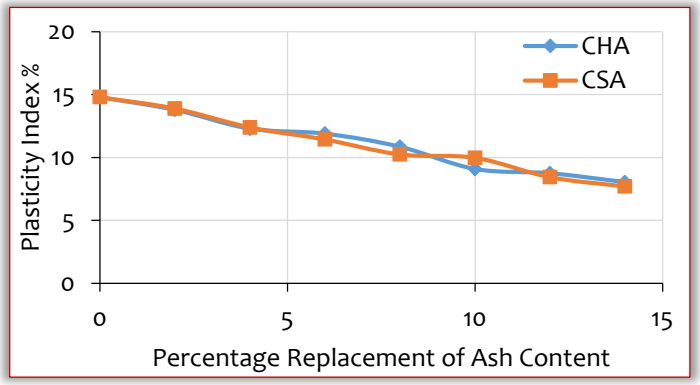

Figure 9: Relationship between Plasticity Index and Ash content of CHA and CSA

Stabilizing the lateritic soil with either CHA or CSA shows a decrease in plasticity index. This may be as a result of the decrease in the amount of soil-sized fraction owing to the flocculation and agglomeration or coagulation of clay particles that is, absorption of Ca2+ ions in soil particles and, resulting in the formation of cementitious compounds of greater effective grain size due to their pozzolanic action [31]. And it showed a reduction in the swelling potential of the soil sample which agreed with [3,4]. This shows a relative decrease in the repulsive forces present in the soil mixed with either CHA or CSA, hence, an increase in the strength of the soil to a specific value.

— Effect of CHA and CSA on California Bearing Ratio (CBR)

Figure 10 shows the unsoaked and soaked CBR of the stabilized lateritic soil with CHA and CSA. CBR increases gradually as CHA increases. The highest value was observed at 14% percentage replacement with CHA for both soaked and unsoaked CBR with an increase in CBR values of 103.25% and 97.70% respectively (Figure 10). An increase in CBR value may be attributed to higher cementitious material present in CHA which resulted in a pozzolanic reaction between the clay particles present in the soil and CHA which agreed with [25]. This enhances the strength of the stabilized soil. The class designation of the CBR values increased from S5 to S6 [11]. The CBR values of the soil sample decreased with an increase in

CSA percentage replacement for both soaked and unsoaked which agreed with [19] conditions and, the least value was observed at 14% percentage replacement with a reduction in values by 43.72% and 32.72% accordingly. A decrease in CBR value of the soil with CSA could be attributed to the elements identified by the EDX result, a low content of silica and alumina coupled with the shape resulted in low strength formation. The class designation of the CBR values decreased from S5 to S4 when CSA was added to the soil sample. It implied that CSA alone cannot be used effectively to stabilize laterite soil.

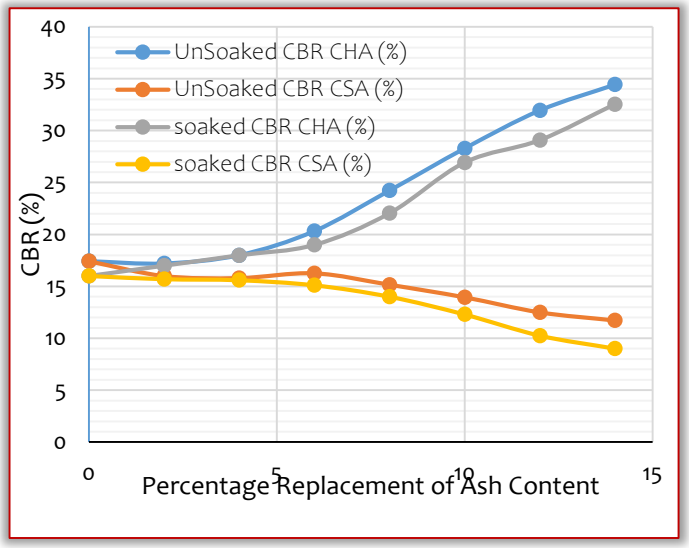

Figure 10: Relationship between Soaked and Unsoaked CBR and Ash content of CHA and CSA

CONCLUSIONS

The geotechnical analysis carried out on soil samples with CHA and CSA showed that both influenced the engineering properties of the lateritic soil sample. The MDD of the soil sample increased as percentage replacement with both CHA and CSA increased while a decrease in OMC occurred. Soil sample with CHA had the highest value at 8% replacement (1910 kg/m^3) with an increase in MDD by 19.38%, and a decrease in OMC by 12.22% while at 8% replacement, soil sample with CSA had MDD value (1650 kg/m^3) and increased by 3.13% and, a reduction in OMC value by 6.91%. But the highest value was at 14% replacement with an increase in MDD value (1750kg/m^3) by 9.38%, and a reduction in OMC value by 16.46%. Also, as percentage replacement with CHA increases, the liquid limit of the soil sample increases but decreases the liquid limit of the soil with CSA decreases its liquid limit. But the plastic index of the soil sample decreases with the addition of various percentages of both CHA and CSA to the soil sample. These revealed a reduction in the swelling potential of the soil sample, hence an increase in strength properties. Besides, there was an increase in CBR of the soil sample with CHA percentage replacement but a decrease in the value of CBR was observed when CSA was used. However, with these results, CHA can be added to improve the engineering properties of soils especially soil with low CBR values, but CSA alone may not be appropriate as a stabilizing agent for improving lateritic soils.

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References

[1] Amu O.O. & Owokade O.S. (2011). Potentials of Coconut Shell and Husk Ash on the Geotechnical Properties of Lateritic Soil for Road Works.
[2] ASTM C618-12a, (2014). Standard Specification for Fly Ash and Raw and Calcined Natural Pozzolan for Use in Concrete. ASTM International
[3] Ayyar R., Krishnaswamy R., Viswanadham S. (1989). Geosynthetics for foundations on swelling clay. Int work on geotextile. Bangalore, India
[4] Balarabe W. (2013). Effect of Coconut Shell Ash on Properties of Fired Clay Brick. Journal of Civil Engineering and Environmental Technology, Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 1, Number 6; August 2014 pp. 7- 11
[5] Barasa, P.K., Too, D., Kiptanui J., Mulei, S.M., (2015). Stabilization of Expansive Clay using Lime and Sugarcane Bagasse Ash. International Journal of Science and Research (IJSR), Volume 4(4), pp. 2112–2117
[6] British Standards (BS) 1377: 1990. Method of Testing Soils for Civil Engineering Purposes. British Standards Institution: London, UK
[7] Chhachhia, A., Mital, A., (2015). Review on Improvement of Clayey Soil Stabilized with Bagasse Ash. International Journal of Research Review in Engineering Science and Technology (IJRREST), Volume 4(1), pp. 238–241
[8] Chittaranjan, M., Vijay, M., Keerthi, D., (2011). Agricultural Wastes as Soil Stabilizers. International Journal of Earth Sciences and Engineering, Volume 04(06), pp. 50–51
[9] Ezziane K., Kadri E. and Siddique R., (2011). Investigation of slag cement quality through the analysis of its efficiency coefficient. European Journal of Environmental and Civil Engineering, 15, pp 1393-1411
[10] Faleschini F., De Marzi P., and Pellegrino C., (2014). Recycled concrete containing EAF slag: environmental assessment through LCA. European Journal of Environmental and Civil Engineering, 18, pp 1009-1024
[11] Federal Ministry of Works and Housing. (1997). General Specification for Roads and Bridges. Volume II. 145-284. Federal Highway Department: Lagos, Nigeria
[12] Federal Ministry of Works, Federal Republic of Nigeria, (2013), Highway Manual part 1, Design. Volume III Pavement and Material Design
[13] Food and Agriculture Organization of the United Nations-FAO (n.d.), Coconut – Tree of Life. http://www.fao.org/docrep/005/Y3612E/y3612e 03.htm Accessed 1/2/16
[14] Jegede G., (2000): Effect of Soil Properties on Pavement Failures along the F209 Highway at Ado Ekiti, South-Western Nigeria. Construction and Building Materials. Vol. 14, pp 311-315.
[15] Medjo, E. and Riskowiski, G. (2004). "A Procedure for processing mixtures of soil, cement and sugar cane bagasse." Agricultural Engineering International Journal of Scientific Research and Development. Manuscript BC 990, Vol. III, pp 1-6
[16] Olugbenga O.A., Opeyemi S.O., Olakanmi I.S., (2011), Potentials of Coconut Shell and Husk Ash on the Geotechnical Properties of Lateritic Soil for Road Works
[17] Oluremi, J.R., Adedokun S.I., Osuolale, M.O., (2012). Effects of Coconut Husk Ash on Stabilization of Poor Lateritic Soil. The Pacific Journal of Science and Technology, 13(2): 499-507.
[18] Oluremi, J. R., Siddique, R. and Adeboje, E. P. (2016) Stabilization Potential of Cement Kiln Dust Treated Lateritic Soil. International Journal of Engineering Research in Africa. 23, 52-63 Doi: 10.4028/www.scientific.net/JERA.23.52
[19] Oluremi J.R., Osuolale O. M., Adeoye T. T. and Akingbade A. A. (2016). Strength Development in Lateritic Soil Stabilized with Coconut Shell Ash for Highway Pavement Construction, Innovative Systems Design and Engineering

www.iiste.org ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online) Vol.7, No.11, pp 49 – 56.
[20] Osinubi, K. J. and Medubi, A. B. (1997) "Effect of lime and phosphatic waste admixture on tropical black clay." Proceedings, 4th Regional Conference on Geochemical Engineering, GEOTROPIKA '97, Johor Bahru, 11- 12 Nov., Malaysia, pp. 257–272
[21] Osinubi, K. J. (1998). "Influence of compactive efforts and compaction delays on lime treated soil." Journal of Transportation Engineering. Vol. 124, (2), pp 149-155.
[22] Osinubi, K. J. (1998b). "Laboratory investigation of engineering use of phosphatic waste." Journal of Engineering Research, University of Lagos, Vol. JER-6, No 2, pp 47-60
[23] Osinubi, K.J., and Stephen, T.A. (2006). "Effect of curing period on bagasse ash stabilized black cotton soil." Book of Proc. Bi-monthly Meetings/Workshop, Material Society of Nigeria., Zaria. pp.1-8
[24] Osinubi, K. J., Akinmade, O. B. And Eberemu, A. O. (2009). "Stabilization potential of locust bean waste ash on black cotton soil." Journal of Engineering Research, University of Lagos, Vol. 14, No. 2, pp. 1-13.
[25] Roy. A., (2014). Soil Stabilization using Rice Husk Ash and Cement. International Journal of Civil Engineering Research, Volume 5(1), pp. 49–54
[26] Sayyed M.H., Mohammad S., Sayyed M.A., Ali Z., (2011). A Simple Review of Soil Reinforcement by Using Natural and Synthetic Fibers
[27] Shahbandeh M. (2022). https://www.statista.com/statistics/577497/world-coconut-production/ Jan. 21, 2022
[28] Singh H. and Huat B. B. K. 2004. Origin, formation and occurrence of tropical residual soils," in Tropical Residual Soils Engineering, Journal of Engineering B. B. K. Huat, G. See-Sew, and F. H. Ali, Eds., Taylor & Francis, London, UK, 2004.
[29] Tsado, T.Y., Yewa, M., Yaman, S., Yewa, F., (2014). Comparative Analysis of Properties of Some Artificial Pozzolana in Concrete Production. International Journal of Engineering and Technology, Volume 4(5), pp. 251–255
[30] www.wikipedia.naturalgeofibres.com
[31] Whitlow, R. (1995) Basic soil mechanics, 3rd ed., Edinburgh Gate: Addison Wesley Longman Limited.
[32] Xin Kang; Louis Ge, Gi-Chun Kang and Christopher Mathews (2015). Laboratory Investigation of the Strength, Stiffness, and Thermal Conductivity of fly ash and lime kiln dust stabilized clay subgrade materials. Road Materials and Pavement Design, 16(4), 928-945
[33] Yohanna, P., Nwaiwu, C.M.C., Oluremi, J.R. (2015) Effect of Sample Re-use on the Compaction Characteristics of Concretionary Lateritic Soil as Subgrade Material. International Journal of Scientific and Engineering Research, 6 (5):513-523.

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- The all margins of page (top, bottom, left, and right) shall be 20 mm.
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- Single-spaced text, tables, and references, written with 11 or 12-point Georgia or Times New Roman typeface.
- No Line numbering on any pages and no page numbers.
- Manuscript length must not exceed 15 pages (including text and references).
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- Manuscripts that exceed these guidelines will be subject to reductions in length.

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The manuscript should be organized in the following order: Title of the paper, Authors' names and affiliation, Abstract, Key Words, Introduction, Body of the paper (in sequential headings), Discussion & Results, Conclusion or Concluding Remarks, Acknowledgements (where applicable), References, and Appendices (where applicable).

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The title is centered on the page and is CAPITALIZED AND SET IN BOLDFACE (font size 14 pt). It should adequately describe the content of the paper. An abbreviated title of less than 60 characters (including spaces) should also be suggested. Maximum length of title: 20 words.

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The author's name(s) follows the title and is also centered on the page (font size 11 pt). A blank line is required between the title and the author's name(s). Last names should be spelled out in full and succeeded by author's initials. The author's affiliation (in font size 11 pt) is provided below. Phone and fax numbers do not appear.

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Place equations on separate lines, centered, and numbered in parentheses at the right margin. Equation numbers should appear in parentheses and be numbered consecutively. All equation numbers must appear on the right-hand side of the equation and should be referred to within the text.

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In a very short period the ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering has acquired global presence and scholars from all over the world have taken it with great enthusiasm.
We are extremely grateful and heartily acknowledge the kind of support and encouragement from all contributors and all collaborators!

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