[1.]Mihai–Paul TODOR, [2.]Ciprian BULEI, [3.]Imre KISS

AN OVERVIEW ON KEY TRENDS IN COMPOSITE MATERIALS CONTINUOUS INNOVATION AND IMPROVEMENTS WITH FOCUS ON COMPOSITES BASED ON CELLULOSE FIBERS

[1–2.]University Politehnica Timisoara, Faculty of Engineering Hunedoara, Doctoral School, Timisoara / Hunedoara, ROMANIA
[3.]University Politehnica Timisoara, Faculty of Engineering Hunedoara, Dept. Engineering & Management, Hunedoara, ROMANIA

Abstract: The composite materials have shown improved properties compared to those of metal and polymeric materials, which made the composites being used as structural parts. On the other hand, fiber reinforced polymers are predominantly made of synthetic fibers, such as glass or carbon, and a petro–chemically sourced thermosetting resin or thermoplastic matrix. In this context, an emerging field of high–performance natural fibers, especially bast fibers (which include flax, hemp and jute), is gaining interest and are immediately attractive. Therefore, the industry includes many significant innovations at every stage of the manufacturing of composites, which is extends from the fibers and their precursors or preforms through to the manufacturing processes and their associated industries. Lots of innovations are taking place in the market across the value chain, most innovations being focusing on performance improvement and cost benefits in composites industry. This paper is an overview on key trends in composite materials continuous innovation and improvements with focus on composites based on cellulose fibers.
Keywords: composite materials, cellulose fibers, naturally–derived fibres, innovation and improvements, trends

INTRODUCTORY NOTES

Many composites used today are at the leading edge of materials technology, with performance and costs appropriate to ultra–demanding applications and conquered different sectors such aerospace industry, aeronautics, automotive industry, manufacturing industries, construction and the marine sector. Moreover, increasing usage of composite applications are emerging.[1–18] This highly competitive market continues to evolve, with the major emphasis in the past being to produce materials with adequate strength, and high wear resistance. [1,7,8]

For a long time, composites enabled us to make remarkable products with exceptional capacities, but often they are being made in a unique or small series production. Today, the end–use sectors, particularly the aeronautics and automobile industries, require a large–scale production. Therefore, the composites industry must meet the specifications of a large series production which is need for the innovative industries. This is an unprecedented opportunity for the composites industry which has grown rapidly thanks mainly to innovation that has created new applications for users and improved on existing applications. In the future, the industry's growth will depend on other capabilities.[1–18]

Composites becoming the material of choice for various industries due to its cost–performance benefits. Moreover, significant innovations in the area of composites in the next years are expected, having in view that the composites industry must meet the specifications of large series production to increase large penetration in several advanced industries. The weight reduction and improved mechanical property are one of the prime factors to develop new materials for automotive and other means of transportations. Composite materials have thus become the most attractive candidate due to their excellent property and light weight. In particular, fiber reinforced polymer (FRP) composite materials have been used as an alternative to metals.[1–18] The composite materials have shown improved properties compared to those of metal and polymeric materials, which made the composites being used as structural parts. [1–18] On the other hand, fiber reinforced polymers are predominantly made of synthetic fibers, such as glass or carbon, and a petro–chemically sourced thermosetting resin or thermoplastic matrix.

In this context, an emerging field of high–performance natural fibers, especially bast fibers, is gaining interest. [1–18] These bast fibers include flax, hemp and jute and are immediately attractive as they provide comparable or improved tensile strength and stiffness to that of glass fiber, as well as contain favorable vibration dampening and non–abrasive properties.[7–18] However, natural fibers and resins are on the rise because of their beneficial properties, competitive cost, legislative drivers, and consumer preferences. There are some key innovations for these types of fiber composites.[1]

The industry sectors, users of natural fibers, are now engaged in an eco–design approach. The main goal is to upgrade the knowledge of fibers and preforms (materials for matrix and for reinforcements – matt, long or short fibres, woven and non–woven fabrics –, manufacturing technologies, prepreg composites, compounds, hybrid association of materials etc.) and attract new industries. [4, 5]

KEY TRENDS IN COMPOSITE MATERIALS

The industry includes many significant innovations at every stage of the manufacturing of composites, which is extends from the fibers and their precursors or preforms through to the manufacturing processes and their associated industries. These innovations are not only providing opportunities for a wide–range of companies at each step of the part production, but are also developing both improved and new materials which are taking this market into expanding and emerging applications.[1–8]

Lots of innovations are taking place in the market across the value chain, most innovations being focusing on performance improvement and cost benefits in composites industry. Innovation creates "business value", where value can be derived from a combination of: [1–8]

- meeting functional needs in target markets, and/or
- meeting existing needs better or more economically

All these needs highlight the importance of an open–innovation approach in order to meet the need of the industry for the medium and long term.

Nowadays, key trends in composite materials continuous innovation and improvements are as follows:

- continued light weighting of automotive, aerospace and industrial parts
- enhanced higher performance of reinforcement (fiber, fabric or particulate) and matrix (resin) systems to meet higher mechanical and chemical requirements;
- cost reduction in various composite parts;
- faster and more predictable technologies, applicable of large series production;
- reduction in number of part counts in many applications, developing one–piece or modular products technologies;
- environmentally friendly reinforcement (fiber, fabric or particulate) and matrix (resin) systems, with focus on development of high strength green materials

The usages of the composite materials range from simple household to light–to–heavy industrial purposes. Therefore, composite materials are playing an increasing role in various industry segments like aerospace, automotive, defense and space, marine, consumer products due to desirable characteristics of lightweight, corrosion resistance, high strength, and design flexibility among many others.[1–18] Albeit it continues to replacing traditional materials in several industries, composites are underrepresented in many markets and potential applications.

The above mentioned innovations trend will enable composite materials to increase penetration across different industries. Therefore, aerospace, automotive, transportation, wind sectors and construction segments are expected to grow at a higher rate in the next years. Continuous innovation is expected in development of higher performance glass fibers to meet higher mechanical and chemical requirements. Also, improvement in stiffness and strength along with development of low–cost carbon fiber or particulate composite parts for different applications in automotive, wind, and industrial applications are the major innovation trends. Relative to the core materials in the layered composites, the emerging innovations are conducted for improvement in strength and stiffness for automotive and other applications and obtaining the lower density to meet end use industries demand. Therefore, light weighting and cost reduction are the major trends in various application segments, such as automotive, aerospace, or wind energy.

FOCUS ON GREEN MATERIALS

The evolution of composite materials has given an opportunity to use new and better materials resulting in cost reduction, increase in efficiency and better utilization of available resources.[1–8] Moreover, the focus on green materials would give momentum to development of high strength natural fibers to increase penetration in automotive, construction and other industries. Durability, compatibility, affordability and sustainability, including resource availability, land use, biodiversity, environmental impact, are the challenges for converting renewable resources into industrial materials.[1–8] In this sense, the emerging innovations in composite materials relative to the natural fibers, are:

- improvement in strength and stiffness to compete with glass fiber;
- finding new application areas to expand the footprints in different industries;
- improvement in strength and stiffness for automotive applications;
- improvement in impact resistance and aesthetic properties;
- expect the advanced and innovative industries to use new reinforced composites to replace parts currently made with other materials or other types of composites.

Environmental concern has resulted in a renewed interest in bio–based materials. Among them, plant fibers are perceived as an environmentally friendly substitute to glass fibers for the reinforcement of composites, particularly in automotive engineering. Due to their wide availability, low cost, low density, high–specific mechanical properties, and eco–friendly image, they are increasingly being employed as reinforcements in polymer matrix composites. [2,7,8]

Increasing environmental concerns and depletion of petroleum resources calls for new green eco–friendly materials. Among various natural materials, cellulosic natural fibers or fabrics are envisioned as the most suitable ways to solve these problems especially environment related issues. The potential of cellulosic fibers as reinforcement in composite materials have been well recognized, but the renewed interest in the natural fibers resulted in a large number of modifications in order to bring it equivalent and even superior to synthetic fibers.

After tremendous changes in the quality of natural fibers, they emerged as a substitute for the traditional materials, being an environment friendly material for the future. Considering the high performance standard of composite materials in terms of durability, maintenance and cost effectiveness, applications of natural fiber reinforced composites as a substitute for the synthetic fiber reinforced composites is an emerging trend.

Due to the disadvantage of the synthetic and fiber glass as reinforcement, the use of natural fiber reinforced composite gained a great attention. With the advancement of science and technology the new means of characterization and evaluation of physico–chemico–thermo–mechanical properties of the composite have been used that have explored the new horizon of utilizing them for various applications.

Natural fiber reinforced polymer matrix got considerable attention in numerous applications because of the good properties and superior advantages of natural fiber over synthetic fibers in term of its relatively low weight, low cost, less damage to processing equipment, good relative mechanical properties such as tensile modulus and flexural modulus, improved surface finish of molded parts composite, renewable resources, being abundant, flexibility during processing, biodegradability, and minimal health hazards.

Global awareness of environmental issues has resulted in the emergence of economically and environmentally friendly bio–based materials free from the traditional side effects of synthetics. With scopes for the utilization of natural resources–based materials as potential replacements for traditional petroleum products, more researchers are exploring new composite materials based on biorenewable resources. Also, the development of polymers from renewable resources has received considerable attention in recent years, in particular due to volatility of crude oil prices and the desire to avoid landfill disposal.[1–18]

Natural fiber composites from renewable resources offer significant sustainability. Industrial ecology, eco–efficiency, and green chemistry are guiding the development of the next generation of materials, products, and processes. Considerable growth has been seen in the use of natural fiber composites in many industrial applications over the past decade and many types of natural fibers have been investigated with polymer matrices to produce composite materials that are competitive with the synthetic fiber composites.[3] Therefore, the increased focus on green technology will result in high strength fibers to increase penetration in manufacturing. Resins, together with natural fibers, have sustainability.[1–18] They can create lightweight components for interior/exterior structural components. Moreover, in the future, bioinspired materials may replace traditional composites and come to dominate the industry.

FOCUS ON COMPOSITES BASED ON CELLULOSE FIBERS

Natural fiber reinforced polymers have been identified as a potential low impact alternative to glass– and carbon–fiber reinforced polymers. Although the replacement of glass– and carbon–fiber with natural fibers for reinforcement in polymer composites appears to be a modern phenomenon, the natural fiber reinforced polymers are not strictly modern by invention. However, the large environmental concern has resulted in a renewed interest in this bio–based materials.

In this sense, composites based on cellulose fibers from wood and plants constitute a relatively new and promising class of composite materials. They are environmentally friendly, and they offer good technical performance. The use of cellulose fibers as reinforcement in composite materials has increased in recent years as a response to the increasing demand for developing biodegradable, sustainable, and recyclable materials. For several load–carrying applications, where glass or carbon fiber composites are conventionally used, cellulose fiber composites can be a worthwhile alternative. This is particularly the case for applications where the green advantages (renewability, biodegradability) play an important role, and top–end mechanical properties are not the primary motivation.

Composite materials derived from natural, renewable sources have received significant interest in recent years, in particular due to the increased awareness of and drive towards more environmentally sustainable technologies. This innovation in the composite industry, dictated by new environmental directives, depends on both the ecological performances of the raw materials and their technical performances. With their strong double bonus – ecological and technological – flax, jute and hemp fiber uses in thermoplastic and thermoset composites have imposed themselves in the industry. In many cases bio–based materials offer weight reduction, added functionality (e.g. damping / impact absorption) and occupational health benefits. A significant market driver for high volume applications is the potential to disassociate material costs from the fluctuating price of oil and energy.

The most interesting fibers for composite reinforcements are from plants, in particular bast, leaf and wood fibers. Bast fibers, such as flax, hemp, jute and kenaf, are taken from the stem of the plant and are most commonly used as reinforcements because they have the longest length and highest strength and stiffness. Natural fibers, such as hemp, flax, jute and kenaf, have good strength and stiffness, whilst being significantly lighter than conventional reinforcements such as glass fibers, and they are relatively low cost and biodegradable.

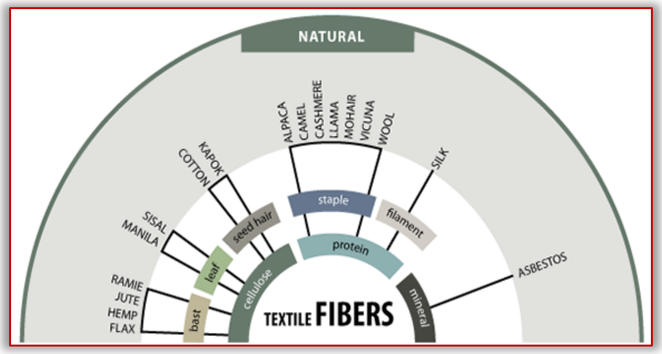

Figure 1. Classes of textile fibres

Natural fibers are currently used in significant quantities, in particular in automotive interior components, to reinforce synthetic polymers. More recently, combinations of these natural fibers and bio–based polymers have been shown to have appealing composite properties, offering the enticing prospect that fully bio–based composites are an increasing commercial reality.

Bast fibers (flax, jute and hemp) solutions meet not only the technical requirements of composite manufacturers in terms of innovative and high–performance reinforcements, but also societal expectations in terms of fiber traceability. Furthermore, the use of these fibers helps to reduce the environmental impacts of composites and provides a view on sustainability through life cycle analyses. Many research in this field, focuses on the flax, jute and hemp reinforcements available on the market, confirms that these fibers provide efficient solutions for the composite industry, due to the remarkable properties besides the fibers' excellent mechanical performance, as added value for composite products.

Figure 2. Bast fibers (flax, jute and hemp)

The ecological properties of the bast fibers put these natural fibers to be increasingly used in various, innovative sectors of the industry which are today obliged to take into account sustainable development in their production methods. Flax, jute and hemp fibers, with their specific mechanical properties also bring performance and competitively to the new materials used. All specialists from industries, technical institutes and universities now see natural vegetation fibers as an alternative solution to synthetic fibers as they develop composite materials. Today, the entire flax, jute and hemp industry is focusing its research on a new generation of materials which guarantee protection of the environment all the way to their end–of–life cycle. A necessary advance dictated by environmental questions and the oil crisis.

Thanks to the weak density of these natural fibers in relation to glass fibers (–40%), composite materials using flax, jute and hemp prove interesting for those applications where light weight is a defining element. Flax, jute and hemp fibers' mechanical properties offer characteristics comparable to glass fibers because of their characteristics. Natural fibers offer several advantages over glass fibers:

- plant fibers are renewable and their availability is unlimited.
- when natural fiber reinforced plastics are subjected to combustion or landfill at the end of their life cycle, the released amount of carbon dioxide is less with respect to that assimilated during its life cycle.
- natural fibers are less abrasive and can be easily processed as compared to glass fiber.
- natural fiber reinforced in biodegradable polymer matrix are environment friendly and can be composted easily.

After the fibers have been extracted from the plants – by a retting process, followed by a series of mechanical processes –, the fibers can be converted into non–woven mats or into a continuous plant fiber yarn, which can be used directly to produce composites using a yarn preform or can be used as woven fabrics preform. In fact, the natural fibers can be used in their loose form (as non–woven mats) or can be spun into yarns and woven into textiles. The types of plant fiber preforms available for composites are shown in Figure 3. The long fibers tend to be used for higher quality applications (e.g. cloth for apparel and furnishings) and therefore command high prices, whilst the short fibers are less valuable and are used in ropes, carpets and insulation. Both types can be used for composite reinforcements, although it is usually only economically viable to use the cheaper short fibers. Whilst many natural fiber yarns and textiles are commercially available, in particular for carpet backing, bags, upholstery, clothing etc., these are generally unsuitable for composite reinforcement. A number of woven and unidirectional / biaxial flax and jute fabrics are now commercially available.

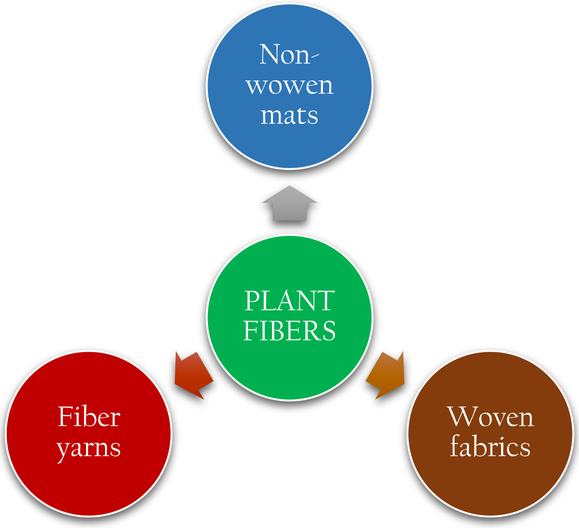

Figure 3. Types of plant fiber preforms available for composites

Figure 4. Bast fibers (flax, jute and hemp) solutions for non–wowen mats

Figure 5. Bast fibers (flax, jute and hemp) solutions for yarns

Figure 6. Bast fibers (flax, jute and hemp) solutions for woven fabrics

Woven fabrics are fabricated with a range of weaving patterns, such as plain, twill and satin weave, in which the yarns are differently interlaced in the two main, orthogonal, planar directions. The yarns in the two directions can have different linear densities, and they can be placed with different distances to each other. The woven fabrics offer the possibility of having a planar yarn configuration in two dimensions designed to meet the loading profile of a given composite application. Woven fabrics of flax, jute and cotton fibers are widely available, but they are most often tailored for textile applications, and not for composite applications.

CONCLUSIONS

Composite materials can offer significant environmental benefits because of their characteristically low weight, good mechanical properties, excellent resistance to corrosion and the possibility of being sustainably sourced. However, although the in–service environmental benefits of composites are known, there is far less understanding of the environmental and social implications associated with the manufacture of composite materials and products, and the options at end–of–life. Natural materials and technologies have been developed, in part, to help address these problems, but to date there has still been confusion within the industry as to the detailed benefits of these alternatives. Generally, naturally–derived fibres and polymers are perceived as being 'greener' than their synthetic alternatives, but in some instances this has been proven to not be the case.

Also, the recovery of the housing market is likely to drive the construction market in coming years. To meet market expectations of low cost composite a natural–based fiber or particulate made from recycled materials has the ability to replace glass fibers in high–performance composites used in cars and airplanes. Also, it is more sustainable and environmentally friendly unlike the traditional composites. From a waste point of view new polymer matrices will need to be developed that can either be recycled or degraded at the end of life for those composites in order to recover the expensive fillers and reduce overall costs.

Trends in sustainability, recycling and the circular economy require greater focus on minimizing waste and environmental impacts.

Composites have attractive mechanical and physical properties that are now being utilized on a grand scale world–wide. New fibers, polymers, and processing techniques for all classes of composites are constantly being developed. Research is also ongoing to improve repair techniques, recyclability, and the bonding between fibres and matrix materials.

The increase in environmental consciousness and community interest, the new environmental regulations, led to thinking of the use of environmentally friendly materials. In this sense, the natural fibers are getting attention to use in polymer composites due to their ecofriendly nature and sustainability. Natural fiber is considered one of the environmentally friendly materials which have good properties compared to synthetic fiber. Therefore, the use of natural fiber from resources such as flax, sisal, hemp and jute to produce composite materials, gained considerable attention in the last decades.

There is no doubt that, if processing costs can be substantially reduced, composite materials will be increasingly employed in applications that require light weight in addition to toughness and wear– and abrasion–resistant properties. The new applications that are being found on an almost daily basis, and the continuous reporting of company investments into the manufacture of composite parts, tend to indicate that important progress has been made towards the reduction of processing and manufacturing costs.

However, it is important to realize that the use of composites requires an integrated approach between user and designer/manufacturer to ensure functionality. This entails a knowledge of the structural efficiency of the material, its isotropic or anisotropic behaviour, environmental effects, and its manufacturing requirements, assembly, and repair.

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