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HARDNESS TEST OF 3D PRINTED WORK PIECE FROM PLA PLASTIC

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Abstract: The paper presents a hardness test of a 3D printed workpiece with a filament of polymeric material – polylactide (PLA) by Shore A scale method. One of the disadvantages of 3D printing is that the parts have much weaker mechanical characteristics and need to be tested to determine the functionality of the working part. Hardness testing of plastic materials is defined by the standard SRPS EN ISO 868: 2015 – Plastics and ebonite – Determination of hardness by indentation using a durometer (Shore hardness) and was performed with an analog durometer – hardness tester.
Keywords: Hardness testing, Additive production, 3D printing, Polylactic acid (PLA)

INTRODUCTION

Due to the lower quality of the processed surface and weaker mechanical characteristics of polylactide (PLA) parts obtained by 3D printing, it is necessary to determine the mechanical characteristics: hardness, tensile strength, impact strength, compressive strength, bending strength, fatigue strength, creep, aging, friction coefficient, resistance to shear and crack propagation according to SRPS ISO 17296–3: Additive technologies – General principles – Part 3: Main characteristics and corresponding test methods. In addition, it also defines test categories for metal parts, plastic parts and ceramic parts and classifies them into three groups: group H (tests of functional parts that are highly safety–critical), group M (tests of functional parts that are not safety–critical) and group L: testing parts during construction or prototype parts. Hardness testing is provided for all these groups of plastic parts.

The goal of this work is to determine the hardness of the workpiece made of PLA plastic depending on the height of the applied layer in the shell and infill. In addition, it is necessary to determine the hardness for different filling methods (linear, zigzag and concentric) at the same layer height.

The hypotheses of the research are that the highest hardness of the workpiece made of PLA plastic is achieved at the lowest layer height both in the casing and in the filling, and that the hardness is the same for the same layer height, and different ways of filling.

ADDITIVE MANUFACTURING

Additive manufacturing can be divided according to SRPS ISO 17296–2:2017: Additive technologies – General principles – Part 2: Overview of process categories and filling, into: Bath photopolymerization – laser stereolithography (SLA) and full–layer illumination–based stereolithography (DLP – SLA, LCD –SLA), Powder substrate fusion – procedures using laser (SLS, SLM, DMLS) and procedures using electron beam (EBM), Material extrusion (FFF – Fused filament fabrication), direct printing (PolyJet, PolyJet Matrix) , Bonding printing (3D Print, 3D Print with suspension application), Lamination of foils (LOM – Laminated object manufacturing, PSL) and Deposition of materials using directed energy (DED – Directed energy deposition).

An overview of the types of additive manufacturing standards is shown in Figure 1 [10].

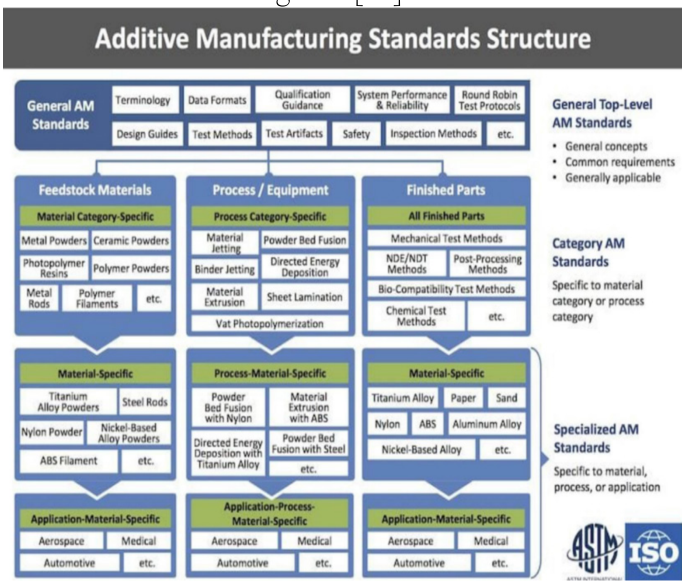


Figure 1. Overview of types of additive manufacturing standards according to ISO/TC 261 and ASTM F42

THE PROCESS OF EXTRUDING MATERIALS

The process of material extrusion (FFF – Fused filament fabrication or FDM – Fused Deposition Modeling, the trade name of the company Stratasys [11], uses solid thermoplastic material – filament, which is pushed through a heated nozzle, the temperature of which depends on the type of polymer, and in a doughy–melted state it is applied to a heated or unheated build plate, after which it hardens and forms the desired piece layer by layer.

The most important parameters that can be adjusted with a 3D printer for the process of extruding materials – FFF are: manufacturing speed, extrusion speed, the height of the applied layer in the shell and infill and the temperature of the nozzle and build plate.

POLYMERS – POLYLACTIC ACID (PLA)

There are a large number of polymers with different mechanical, physical, chemical, electrical, thermal and other characteristics, which have a wide range of applications.

PLA is a thermoplastic biodegradable plastic obtained from organic sources (corn starch, sugar cane or beet) – by fermentation of plant starch and has similar characteristics as polypropylene (PP), polyethylene (PE) or polystyrene (PS). It is used to produce food containers, foils and medical implants and has a high surface energy that makes it ideal for 3D printing. The disadvantages of PLA are low heat resistance and relatively low strength. The characteristics of PLA are given in Table 1 [8].

Table 1. Characteristics of polylactide acid – PLA

The parameters	Values
Heat Deflection Temparature– EN ISO 75	52 ℃
Density	1,24 g/cm^3
Tensile Strength EN ISO 527–1	50 MPa
Flexural Strength EN ISO 178	80 MPa
Impact Strength (IZOD) – EN ISO 180	96,1 (J/m)
Shrinkage rates	0,37–0,41%

The chemical formula of polylactide acid is H–[OCH(CH3)CO]n–OH, and the PLA polymer for this type of 3D printing is in filament form.

EXPERIMENTAL PART

In a series of experiments, a blind flange was used as a working object. These elements are used, during the construction of pipelines, to close the ends of pipelines or forks, as well as when testing pipe closures. They are connected with screws and nuts to pipeline flanges, forks or pipe closures with a mandatory seal between the elements. The blind flange, whose structural shape and dimensions were used in this work, was made according to the EN 1092–1 Type 11 / DIN 2632 PN6 standard. The outer dimensions of the flange are Φ 80 x 12 and it has four M10 holes spaced on a Φ 55 diameter.

The 3D model of the flange (Figure 2) was realized in the software package SOLIDWORKS 2016, and then it was formed into a suitable STL file with the maximum resolution allowed by the software.

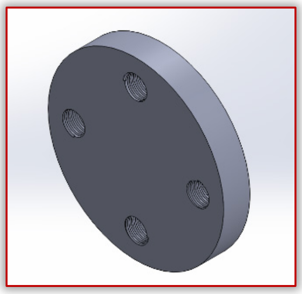


Figure 2. 3D CAD model of blind flange

The STL file of the flange was imported via Ultimaker open source Cura software and is shown in Figure 3.

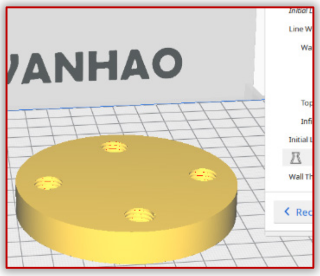


Figure 3. Imported STL file of blind flange

After that, the corresponding parameters were varied according to the experimental plan and a series of flanges with the same external appearance (Figure 4) but different characteristics was produced.

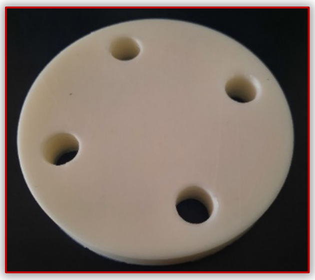


Figure 4. Appearance of the 3D printed object

As measuring instrumentation, a durometer – hardness meter (hardness meter) BAREISS, Germany, according to Shore, scale A with a conical shape of the needle at an angle of 350, shown in Figure 5, with a minimum sample thickness of 4 mm and an accuracy of 0.5 HS A [6].

Figure 5. Device for measuring the hardness of PLA parts

The characteristics of Wanhao PLA filament are shown in Table 2.

Table 2. Features of Wanhao PLA filament

The parameters	Values
Filament type	PLA
Diameter (mm)	1.75
Melting point (°C)	190 – 210
Build plate temperature (°C)	0 – 60

In Figure 6 is shown the 3D printer Wanhao Duplicator 6 on which the elements for the experiment were printed, and its technical characteristics are given in Table 3 [7].

Table 3. Wanhao Duplicator 6 3D Printer Technical Features

The parameters	Values
Additive technology	Material extrusion (FFF)
Materials	PVA, PLA, ABS, PEVA, HIPS
Max. part dimensions (mm)	200 x 200 x 180
Layer thickness (μm)	20 – 200
Filament diameter (mm)	1.75
Nozzle outlet diameter (mm)	0.4
3D printing speed (mm/s)	30 – 150
Working temperature (°C)	180 – 260
Build plate temperature (°C)	50 – 100

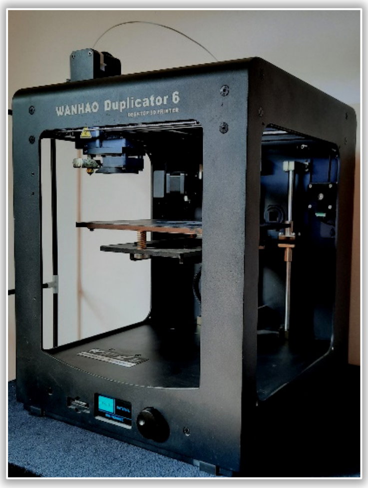


Figure 6. 3D printer Wanhao Duplicator 6

RESULTS AND DISCUSSION

The surface quality of the workpiece made of PLA plastic depends on the height of the applied layer in the shell and infill. The lower the height of the applied layer, the higher the quality of the object and the greater the ability to perform details, but the production time is nonlinearly longer.

The hardness values depending on the height of the applied layer and the type of filling, as well as the temperature of the build plate, are shown in Table 4, and the hardness values for different types of filling (pattern), with an unheated work plate, are shown in Table 5.

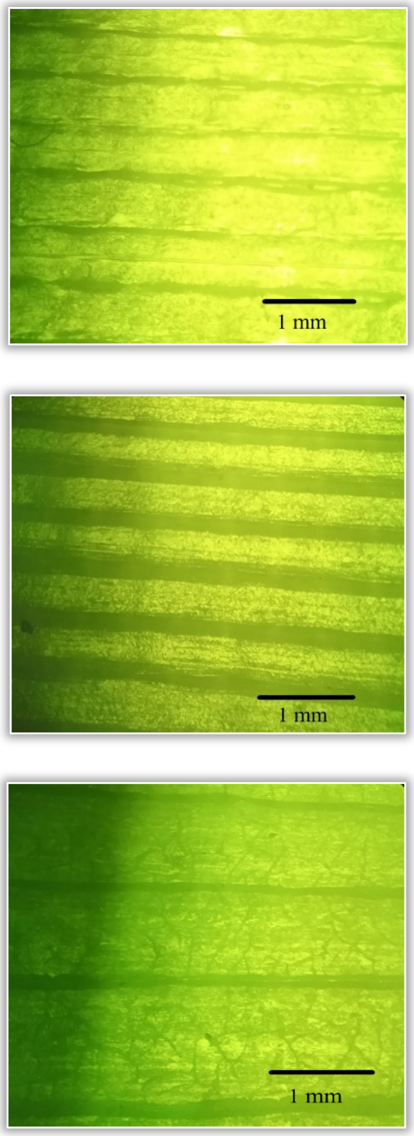
Table 4. Hardness values for different heights of the applied layer and heating of the build plate at the same linear filling

Pattern	Build plate temperature (°C)	Layer height (mm)	Hardness HS (A)
Lines	55	0.1	98
	20	0.1	99
	20	0.2	98
	20	0.4	96

Table 5. Hardness values for different types of fillings (patterns)

Pattern	The length of the filament used (m)	Layer height (mm)	Build time (min)	Hardness HS (A)
Lines	0.52	0.1	13	99
Zig Zag	0.52	0.1	13	99
Concentric	0.52	0.1	12	99

Macroscopic images of PLA objects with a layer height of 100, 200 and 400 microns at x5 magnification are shown in Figure7.



a)
b)
c)

Figure 7. Macroscopic image of a PLA object with a layer of 100, 200 and 400 microns high at x5 magnification and a cross–section of a layer with a layer height of 100 microns

In Figure 7a, the darker lines represent the furrows between the layers, which are places of stress concentration, and the wider they are, the rougher the surface. Macroscopic inspection revealed that the width of the applied layer (layer) is the largest at the highest height of the applied layer (Figure 7c) and that it is twice as large in relation to the height of the applied layer of 0.2 mm (Figure 7b). It can also be seen that the width of the groove (unfilled), almost twice as large at the height of the applied layer of 0.2 mm (Figure 7b) compared to the height of the applied layer of 0.1 mm (Figure 7a).

A cross section of flange and the number of layers for an application height of 0.1 mm is shown in Figure8.

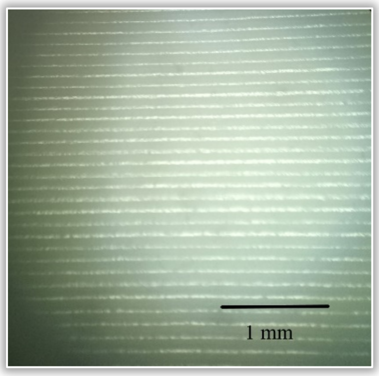


Figure 8. A cross–section of a layer with a layer height of 100 microns

The hardness (HS–A) of the PLA plastic part depending on the height of the applied layer (h) is shown in Figure 8.

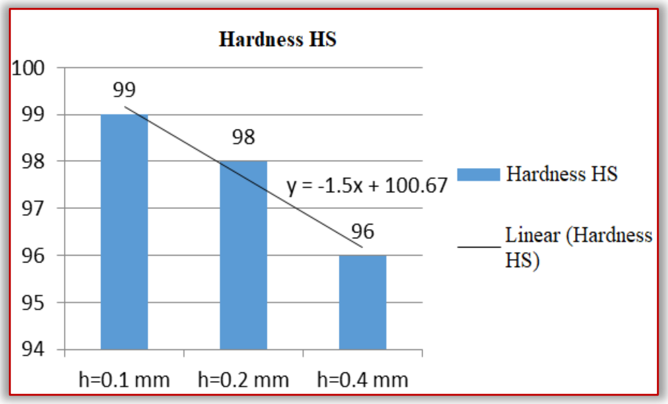


Figure 9. Hardness depending on the height of the applied layer

The hardness of PLA samples made by 3D printing with FFF technology depends on the height of the applied layer, so that it is maximum for the smallest height and decreases almost linearly according to the smallest hardness to the largest height during linear filling.

The heating of the board at the same filling and height of the applied layer has a slight effect, so that the hardness is lower by 1%.

The hardness is the same for the same layer height, with different filling methods (linear, zigzag and concentric).

CONCLUSION

3D printing with the process of extruding material with FFF technology has a low quality of the processed surface, and from the point of view of hardness, the hypotheses is confirmed that the highest hardness of the workpiece made of PLA plastic is achieved at the lowest layer height of 0.1 mm, with complete filling in the shell and filling (infill) and decreases almost linearly according to the lowest hardness for the highest height at linear filling.

The filling (pattern) does not significantly affect the hardness values because for all three types of filling (linear, zigzag and concentric) the hardness value is the same.

At the same filling and height of the applied layer, the heating of the plate only slightly affects the hardness of the workpiece, reducing it by 1%.

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