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HARDNESS TEST OF 3D PRINTED SPECIMEN FROM ABS PLASTIC

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Abstract: This paper presents the hardness testing of a specimen made by 3D printing using the material extrusion process with a filament of Acrylonitrile Butadiene Styrene (ABS) utilizing the Shore D scale method. ABS is the most commonly used material in 3D printing. One of the disadvantages of 3D printing is that the parts have much weaker mechanical characteristics and require testing to determine the functionality of the working part. According to ISO 17296–3: Additive technologies – General principles – Part 3: Main characteristics and corresponding test methods, hardness testing is provided for all groups of plastic parts. Hardness testing of plastic materials is defined by the standard EN ISO 868: 2015 – Plastics and ebonite – Determination of hardness by indentation using a durometer (Shore hardness) and was performed with an digital durometer – hardness tester.
Keywords: hardness testing, additive production, fused filament fabrication, Acrylonitrile Butadiene Styrene (ABS)

INTRODUCTION

Due to the lower quality of the processed surface and weaker mechanical characteristics of Acrylonitrile butadiene styrene (ABS) 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.

This standard also defines the 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 specimen made of Acrylonitrile Butadiene Styrene (ABS) plastic depending on the applied layer height in the shell and infill.

The hypotheses of the research are that the highest hardness of the specimen made of Acrylonitrile butadiene styrene (ABS) plastic is achieved at the 0.2 mm layer height both in the shell and in the infill, and that the best configuration setting layer height for ABS is from 0.1mm to 0.2 mm.

ADDITIVE MANUFACTURING

Additive manufacturing can be divided according to ISO 17296–2:2017: Additive technologies – General principles – Part 2: Overview of process categories and filling, into the following: Vat photopolymerization – laser stereolithography (SLA) and full–layer illumination–based stereolithography (DLP–SLA, LCD–SLA); Material extrusion (FFF – Fused filament fabrication); Binder jetting; Material jetting; Powder bed fusion – procedures using laser (SLS, SLM, DMLS) and procedures using electron beam (EBM); Directed energy deposition (DED – Deposition of materials using directed energy) and Sheet lamination (LOM – Laminated object manufacturing, PSL).

MATERIAL EXTRUSION

The process of material extrusion (FFF – Fused Filament Fabrication or FDM – Fused Deposition Modeling, the trade name of the company Stratasys [10], uses solid thermoplastic material – filament, which is pushed through a heated nozzle, whose temperature depends on the type of polymer, and in a doughy–melted state it is applied to a heated or unheated build plate Afterward, the material hardensand forms the desired piece, layer by layer.

The most important parameters that can be adjusted on 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.

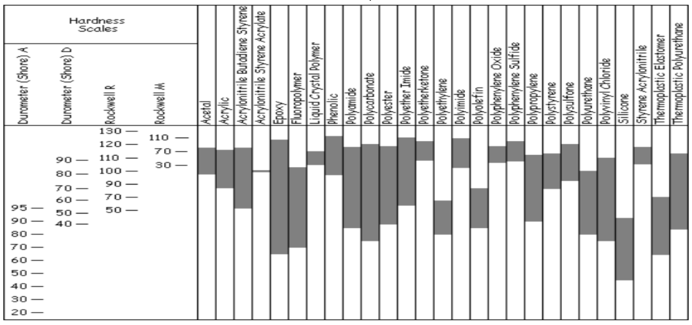
The main limitations of FFF are related to the anisotropic nature of parts. The layer–by–layer nature of FFF printing results in the parts that are fundamentally weaker in one direction.

The orientation during the printing process affects the strength in each direction. The infill percentage also has an effect on the strength of a part. Most printers produce parts and prototype with 20% infill which represents significant cost and time savings. However, a bracket subjected to loading requires a higher infill percentage (up to 100% or full infill). Higher levels of infill will result in a stronger part, but will increase build time and cost [1].

ACRYLONITRILE BUTADIENE STYRENE (ABS)

There are a large number of polymers with different mechanical, physical, chemical and technological characteristics, which have a wide range of applications.. Hardness is a complex material mechanical property influenced by a variety of factors. Hardness comparison chart is shown in Table 1. Any conversions using this chart will be a rough estimate and should not be considered an exact conversion.

Table 1. Hardness comparison chart [8]



The mechanical characteristics of Acrylonitrile Butadiene Styrene – ABS are shown in Table 2. [9].

Table 2. The mechanical characteristics of Acrylonitrile butadiene styrene (ABS)

The parameters	Values
Elongation at Break	10 – 50 %
Elongation at Yield	1,7 – 6 %
Hardness Shore D	100
Strength at Break (Tensile)	29,8 – 43 MPa
Strength at Yield (Tensile)	29,6 – 48 MPa
Toughness (Notched Izod Impact at Room Temp.)	200 – 215 J/m

3D PRINTING

ABS is one of the most versatile materials available for 3D printing today. ABS comes in the form of a long filament wound around a spool. The 3D Printing process that uses ABS is the FDM (Fusion Deposition Modelling) process. The objects printed using ABS have slightly higher strength, flexibility, and durability. Finally, ABS can be recycled, just like many other thermoplastic polymers. Acrylonitrile Butadiene Styrene (ABS) is an impact–resistant engineering thermoplastic. ABS is composed of three monomers: acrylonitrile, butadiene, and styrene. These properties include high rigidity, resistance to impact, abrasion, and strain.

It is used in electronic housings, auto parts, consumer products, pipe fittings, Lego toys, etc.

ABS is produced by emulsion or continuous mass polymerization technique. The chemical formula of Acrylonitrile Butadiene Styrene is $(C_8H_8 \cdot C_4H_6 \cdot C_3H_3N)_n$.

The molecular structure of Acrylonitrile Butadiene Styrene is shown on Figure1 [9].

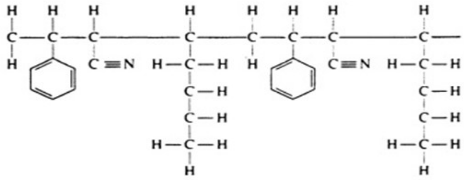


Figure 1. The molecular structure of Acrylonitrile Butadiene Styrene [9]

EXPERIMENTAL PART

A series of experiments was conducted on cylindrical test specimens, with dimensions □40 x 4 mm.

The 3D model (Figure 2) was created in the SOLIDWORKS 2016 software package, and then converted into the appropriate STL file with the maximum resolution allowed by the software.

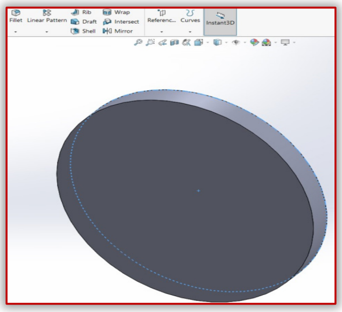


Figure 2. The 3D CAD model of specimen

The STL file was imported via Ultimaker open–source Cura software, as shown in Figure 3.

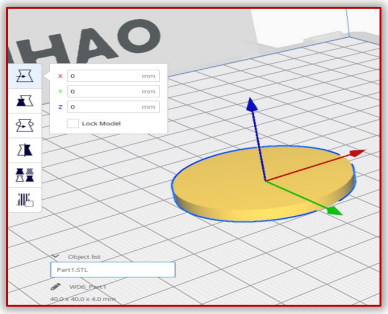


Figure 3. The imported STL file of specimen

Table 3. The features of Wanhao ABS filament

The parameters	Values
Filament type	ABS
Diameter (mm)	1.75
Melting point (°C)	220
Bed temperature (°C)	100 – 110
Exstruder temeperature (°C)	230–270

Subsequently, the relevant parameters were varied according to the experimental plan and a series of the specimen with the same external appearance but different characteristics was produced. The characteristics of Wanhao ABS filament are shown in Table 3.

The technical characteristics of the Wanhao Duplicator 6 3D printer on which the specimens for the experiment were printed, are given in Table 4 [7].

Table 4. Wanhao Duplicator 6 3D Printer Technical Features

The parameters	Values
Materials	PVA, PLA, ABS, PEVA, HIPS
Max. part dimensions (mm)	200 x 200 x 180
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

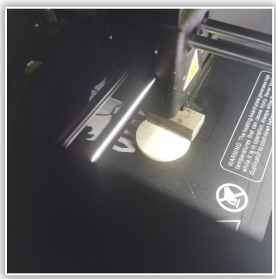


Figure 4. The 3D printer Wanhao Duplicator 6

Procedure of hardness testing

The test specimen was placed on a hard, horizontal, plane surface. The durometer was held in a vertical position with the point of the indenter at least 9 mm from any edge of the test specimen. The recommended mass was 5 kg for the type D durometer. The scale of the indicating device was read after 15 s ± 1s. Five measurements of hardness were taken at different positions on the test specimen, with a minimum separation of 6 mm, and the mean value was determined. A measure of the indentation resistance of elastomeric or soft plastic materials is based on the depth of penetration of a conical indentor (Figure 5). The hardness values range from 0 (for full penetration) to 100 (for no penetration) [2].

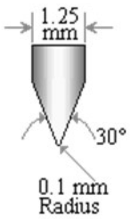


Figure 5. The Indenter Shore D [2]

Figure 6. The device for measuring the hardness of ABS parts

As a measuring instrument, a durometer hardness meter YHD–SHORE D was used, following the Shore D scale, featuring a conical–shaped needle with a 330° angle, requiring a minimum specimen thickness of 4 mm and possessing an accuracy of 0.5 HS (D), as shown in Figure 6.

RESULTS AND DISCUSSION

The surface quality of the specimen made of ABS plastic depends on the layer height applied in the shell and infill.

The lower the layer height applied, the higher the quality of the object and the greater the ability to perform details, but the production time increases nonlinearly.

Microscopic images of ABS objects with layer heights of 100, 200 and 400 microns, captured at 5x magnification, are shown in Figure7.

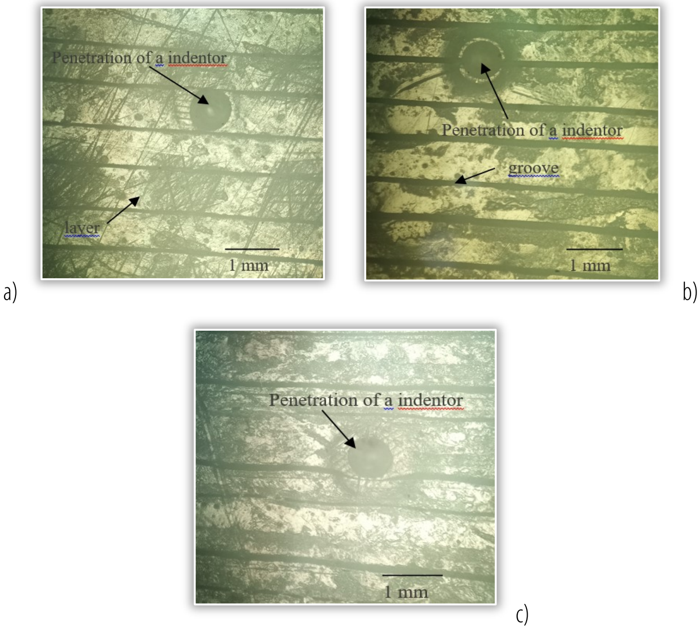


Figure 7. A microscopic image of an ABS object with a layer heights of 100, 200 and 400 microns, taken at 5x magnification

In Figure 7, the darker lines represent the grooves between the layers, which are areas of stress concentration. The wider these lines are, the rougher the surface.Microscopic inspection revealed that the width of the grooveses greatest at the highest layer height applied. It can also be observed that the width of the groove (unfilled) is largest at the highest layer height applied. The measurement inaccuracy, even significant, occurs when the indenter hits in between the two layers, actualy, when it hits the groove, as illustrated in Figure 7 b.

A cross section of specimen and the number of layers for an application height of 0,1 mm are shown in Figure 8.

The hardness values, depending on the height of the applied layer with 100% infill, linear infill patern, printing temperature of 250 °C, build plate temerature of 100 °C and printing speed of 30 mm/s, are shown in Table 5.

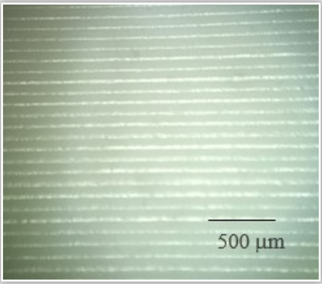


Figure 8. A cross–section of a layer with a layer height of 100 microns

Table 5. The hardness values for different heights of the applied layer

Pattern	Layer height (mm)	Hardness HS (D) No 1	No 2	No 3	No 4	No 5	Hardness HS (D) Main value
Lines	0.1	73	74	73,5	72	73	73,1
	0.2	81	78	80	79	80	79,6
	0.4	77	75	76	78	77	76,6

The hardness (HS–D) of the ABS plastic part depending on the height of the applied layer (h), as shown in Figure 9.

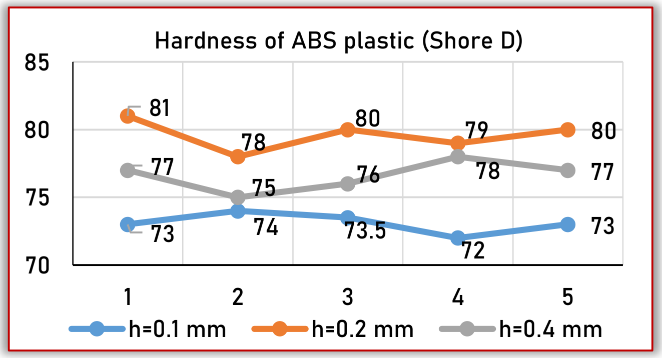


Figure 9. The hardness varies depending on the height of the applied layer

One of the main competitors of 3D Printing ABS is PLA. Unlike ABS, PLA is a renewably derived plastic. Similar to ABS, the hardness of PLA samples, produced using 3D printing with FFF technology, depends on the height of the applied layer. It is maximum for the smallest layer height and decreases almost linearly with increasing layer height during linear infill. The highest hardness of the specimen made of PLA plastic is achieved at the lowest layer height of 0.1 mm, with complete filling in the shell and infill, and decreases almost linearly according to the lowest hardness for the highest height at linear filling. The type of infill 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.

The heating of the build plate at the same infill and layer height has a slight effect, resulting in a 1% reduction in hardness. The hardness remains the same for the same layer height, regardless of the infill method used (linear, zigzag and concentric) [11].

The characteristics of Acrylonitrile Butadiene Styrene (ABS) as shown in Table 1, indicate that the hardness of ABS is from 55 HS (D) to 100 HS (D) [8].

The most accurate hardness test for 3D prints is the Shore test scale D, and the hardness value for 3D prints of ABS is 76.1 HS (D), with a difference between the maximum and minimum hardness of 8.08% [12].

CONCLUSION

3D printing using the extrusion process with FFF technology, results in a low quality of the processed surface. From a hardness perspective, the hypotheses is confirmed that the highest hardness of the Acrylonitrile Butadiene Styrene (ABS) plastic specimen, measuring 79.6 HS (D), is achieved at the layer height of 0.2 mm in both, the shell and infill configuration. The optimal configuration for ABS is a layer height of 0.2 mm.

The darker lines represent the grooves between the layers and microscopic inspection has revealed that the width of the applied layer is greatest at the highest layer height.

It can also be observed that the width of the groove is largest at the highest layer height applied.

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