39. Savetovanje proizvodnog mašinstva Srbije – SPMS 2023

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ZBORNIK RADOVA
PROCEEDINGS

University of Novi Sad
Faculty of Technical Sciences

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MECHANICAL PROPERTIES VARIATION DUE TO BUILDING ORIENTATION OF ABS RESIN MATERIAL

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Abstract: *Considering that additive manufacturing technology, has evolved significantly over the past few decades, understanding of materials mechanical properties became important part of researches with the goal of further improvement of production Among the seven different AM technologies, in this research is used digital light processing (DLP) 3D printing process with LCD projector. The thermoplastic polymer material acrylonitrile butadiene styrene (ABS) is a widely used material for 3D plastics printing, and in this study, it is chosen in the resin form. So far, this type of material has not been sufficiently studied, and the aim of this study was to determine the mechanical properties for two different specimens' building orientations (45° and 90°). Specimen's geometry is chosen according to the respective standards for mechanical testing's. Because of the difficulties and warping which occur when printing the flat, thin and long specimens, orientation 'on edge', i.e., 90° is chosen, as well as the 45° orientation, for comparison. Tensile, three point bending and compression mechanical tests were performed and Matlab is used to create stress-strain curves. Additionally, microscopy is performed for more comprehensive insight of the behaviour of the ABS resin printed via DLP-LCD technology. Comparison of mechanical properties for two orientations leads to the overview of printing parameters which result in better mechanical properties regard to specific application. Better behaviour and compression mechanical properties are noticed in 90° orientation printed ABS resin specimens, compared to 45° ones, while flexure behaviour of ABS is the same regardless to building orientation.*

Keywords: *additive manufacturing, DLP-LCD, ABS resin, mechanical properties, microscopy.*

1. INTRODUCTION

Additive manufacturing (AM), also known as 3D printing, has been developing since the 1980s and has quickly become an important technology with various applications in different industries e.g. in the automotive, aerospace, equipment, or medical industry [1,2,3]. Polymer based AM technology enables cost-effective manufacture in small batches of user-specific products regarding their shape, size and aesthetics [4].

According to the ISO/ASTM 52900:2021 standard, there are seven types of AM technologies. Among them vat polymerisation technology was chosen, particularly Digital Light Processing (DLP) technology due to versatility and low energy demand [4,5].

The latest developed 3D printing vat technology is DLP-LCD. Photosensitive liquid polymer is exposed to projections of UV light emitted by a digital projector that uses LCD device in which each pixel acts as a small window that blocks or let's light through. Projected image of the entire layer solidifies through photo-polymerization at once. For highly-detailed parts made by DLP-LCD the various photopolymers are available: ABS-like, rigid PC-like, semi-flexible PE-like, durable PP-like [4,6].

Overall, the preferred AM material is Acrylonitrile Butadiene Styrene – ABS and variations of it [4]. Therefore, for research is chosen ABS-like photopolymer suitable for DLP-LCD. ABS-like resin consists of three parts, acrylonitrile-styrene copolymer, SAN in the matrix and grafted polybutadiene rubber in a dispersed phase.

For the ABS specimens were reported that raster orientation largely affects the mechanical properties [5]. Various raster angle orientations (0°, 90°, 45°, −45°) were investigated and the majority of results are by utilizing the FDM technology. Rankouhi et al. suggested that 0° raster angle ensures the highest tensile strength [7]. Ziemian et al. suggested 0° raster orientation for the largest flexural yield strength, and for the highest compression strength suggests axial build orientation [8]. Exploitation of viscous materials for 3D printing suggests that 90° raster angle gives better mechanical properties [9]. Naik and Kiran were testing the various building on-edge orientations (0°, 15°, 30°, 45°, 60°, 75°, 90°) of specimens printed by photo-polymerisation technology, and confirmed better tensile properties in case of on-edge than in case of flat building orientation [11]. Brighenti et al. examined fracture toughness were it was concluded that maximum mode I fracture toughness was for 0° specimen orientation. Decrease of the fracture toughness happens for the orientation of 90°, which is logic because of the arrangement of the printed layers parallel to the crack plane [12].

The objective of this research was to examine the mechanical properties obtained by tensile, three point bending and compression testing of ABS similar resin samples build using DLP-LCD printing technology. Additionally, specimens were 3D printed in two different building orientations in order to compare mechanical properties for two cases. Microscopy was performed to get a better overview of the material properties.

2. METHODOLOGY

Specimens were modelled in SOLIDWORKS software in compliance with the specified standards ISO 527-2, ISO 178:2019 and ISO 604:2002 for tensile, flexure and compression respectively (see Fig1). ABS like resin material (Creality, Shenzen, China) was used for common desktop DLP-LCD 3D printer (Creality LD-002R, Shenzen, China). Five specimens were printed with 100% infill density, per two print orientations (90° and 45°) that are presented as ChituBox screenshots in Figure 1.

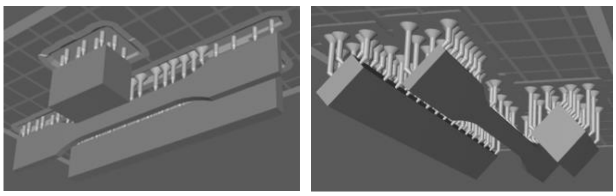


Figure 1. Specimens' STL models according to ISO 527-2, ISO 178:2019 and ISO 604:2002 standards in two building orientations: left –90°, right -45°.

Since the flattened dog-bone shape parts' orientation is problematic because it's the flat, thin and long part, the building orientation of 90° is chosen as the quickest one, considering building time. Building orientation of 45° is chosen as the comparing orientation. The main printing parameters were the same: exposure time – 8s, bottom exposure time – 80s, layer height – 0.05mm, lift distance – 5mm, lift and retract speed – 100mm/min. After printing, all the specimens were stored and tested at room temperature of 23℃ and humidity of 55% RH.

Universal testing machine Shimadzu AGS-X (Shimadzu Corp., Kyoto, Japan) with load cell of 100 kN and the testing speed of 1 mm/min was used for the three type of mechanical testing.

After tensile, flexure and compression testing, the microscopy was performed using a digital optical microscope (Mustool, Shenzen, China). Obtained images of the fractured surfaces provide qualitative assessment of the material's structure.

3. RESULTS AND DISCUSSION

Visual inspection before and after mechanical testing were performed. DLP-LCD built specimens of ABS resin material are more rubbery and have a silicon-like touch effect. This is effect is quite unexpected, since ABS material in filament form is more like firm plastic. A representative specimen of each mechanical tests showed the brittle fracture: (a) in a normal direction to the tensile stress localized in adequate position at narrowing part of geometry (Figure 2a); (b) in a middle of specimens with either clear and strait fracture line for on-edge printing specimen, or step-like fracture line for slanted printed specimen (Figure 2b); (3) after the initial barrelling, splinters separate from conical core (Figure 2c).

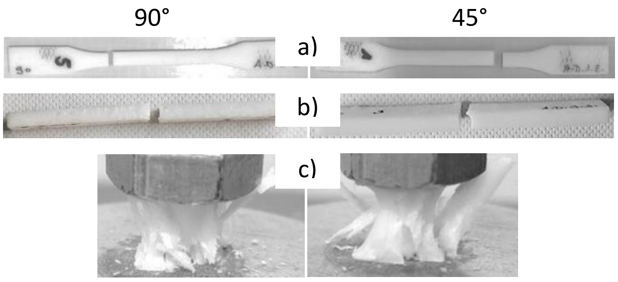


Figure 2. Fractured specimens printed by DLP-LCD after: a) tensile, b) flexure and c) compression testing.

2.1 Microscopy

Digital optical microscopy is used in order to additionally observe topography and morphology of examined specimens at magnification 50x. Similarity in fractured surfaces' appearance for the both orientations is expected and obvious, as it can be seen in Figure 3. DLP-LCD prints isotropic material regardless to building orientation.

Fractured surface of the tensile specimen built on-edge exhibits irregularities in shape of bubbles, which are in a middle of image in Figure 3a-left. The bubbles have been found quite often in ABS resin parts and caused fracture in that specific region. Tensile tested specimen built in 45°orientation has slanted striation at fractured surface that evolves along layers (Figure 3a-right side).

Two zones can be differentiated on the fractured surfaces of 3 point bended specimens: (1) ductile zone with striation and (2) the brittle zone as dark, flat and shiny (Figure 3b). Distinction between orientations is mainly in stair-like fractured surface in case of slanted building orientation (Figure 2b-right and Figure 3b-right).

The sharp splinters in Figure 3c) confirm brittle mode that compressed specimens undertake. Splinters could be monolith spear-like (Figure 3c-left) altogether with layers or tiny spikes separated from core, which has stress lines along shiny zone (see Figure 3c-right).

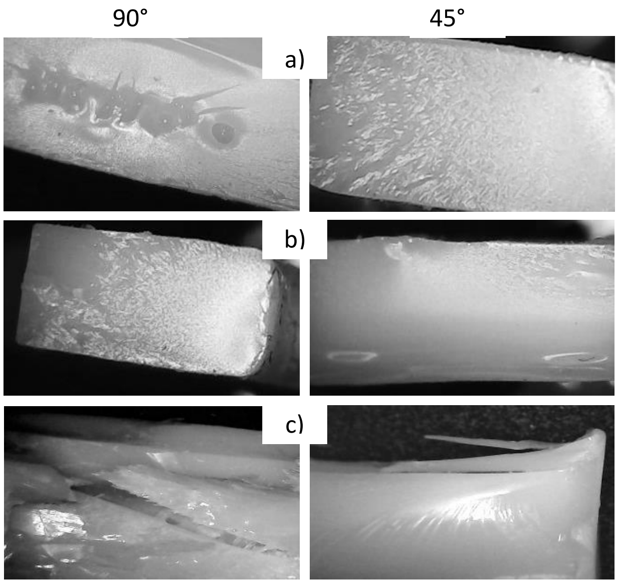
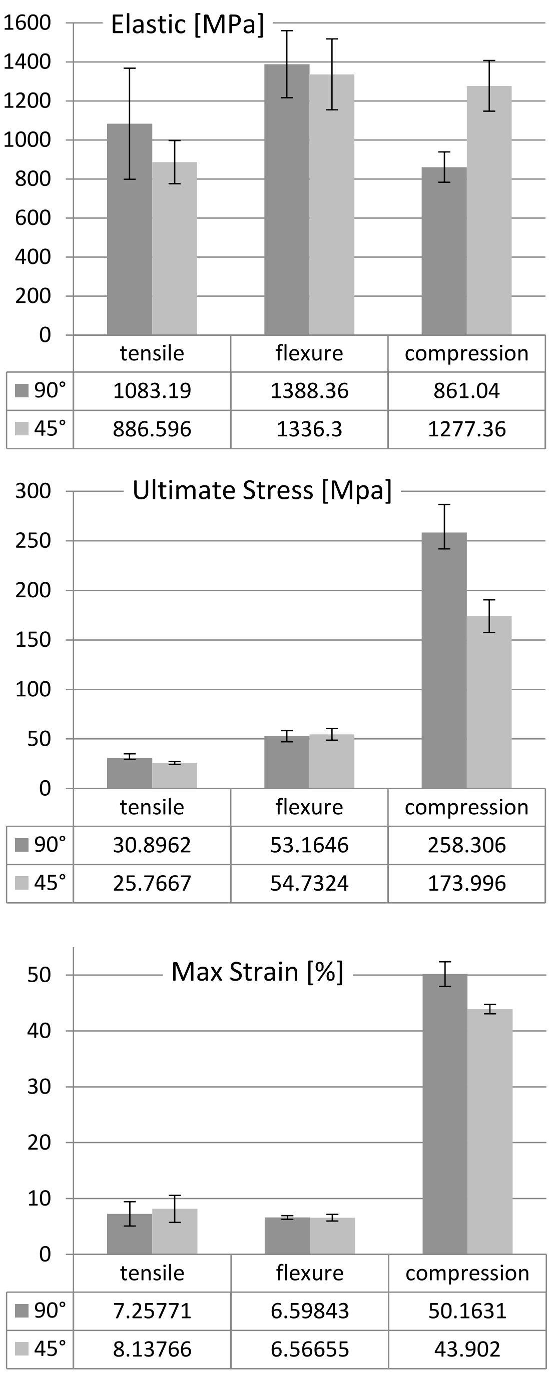


Figure 3. Fractured surfaces of DLP-LCD printed specimens after: a) tensile, b) flexure and c) compression testing.

2.2 Mechanical testing

The charts, which are presented in Figure 4, show average values along with standard error of main mechanical properties for each type of testing. Mechanical properties for flexural testing have similar values regardless to building orientation. Flexure modulus is the highest compared to the tensile and compressive. Tensile modulus for on-edge specimen is higher compared to slanted printed specimen. Oppose to it, compressive modulus is lower for on-edge specimen compared to slanted printed one. Ultimate stress and max strain values are the highest in case of compression compared to other tests regardless to building orientation. Tensile and compressive ultimate stress for building orientation of 90° are higher than for 45°orientation. Strain value for building orientation of 90° is lower for tensile and higher for compressive test.



	tensile	flexure	compression
90°	1083.19	1388.36	861.04
45°	886.596	1336.3	1277.36

	tensile	flexure	compression
90°	30.8962	53.1646	258.306
45°	25.7667	54.7324	173.996

	tensile	flexure	compression
90°	7.25771	6.59843	50.1631
45°	8.13766	6.56655	43.902

Figure 4. The main mechanical properties of ABS specimens DLP-LCD printed in two building orientations.

Matlab software was used to compute the average stress–strain curves for five ABS specimens that undertake each of three mechanical tests. The curves dedicated to DLP-LCD built specimens in particular orientation have same line type at diagrams (Figure 5).

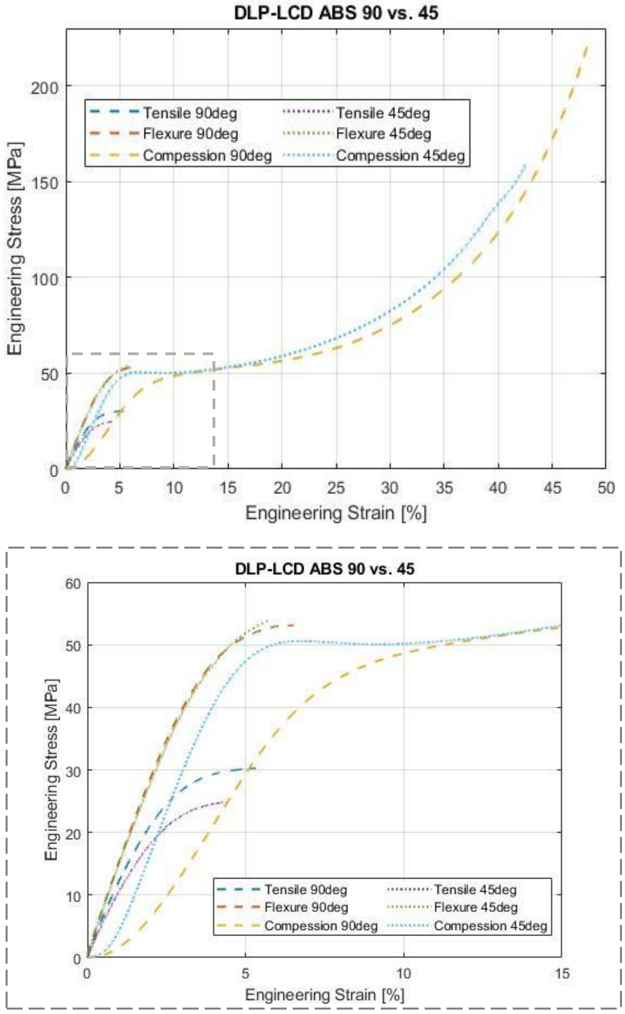


Figure 5. Stress-strain curves of DLP-LCD printed specimens made of ABS resin in two building orientations.

Specimens reveal slightly different stress-strain curves under tension, where on-edge building orientation shows better behaviour. Comparison of curves' slope in zoomed Figure 5, shows concurrence in flexure, divergence in tensile, and initial disparity in compression case. Regardless to printing orientation, specimens demonstrate same behaviour for flexure and very similar values of mechanical parameters. Generally, mechanical testing perceives dominant behaviour under compression, especially for 90° building orientation since the max strain value is 50% and ultimate stress is higher 5 to 8 times compare to flexure and tensile respectively.

4. CONCLUSION

It should be noted that

The mechanical properties compared in charts reveal:

- similar values regardless to building orientation for flexural case,
- dominant behaviour under compression, especially for 90° building orientation,
- flexure modulus is the highest in comparison with tensile and compressive,

Generally, DLP-LCD printed ABS parts are more appropriate for compression applications. In case of flexure applications printed parts are suitable, regardless to building orientation. Whenever possible, 3D printed part should align the load/stresses in a part with the strongest orientation. This research provide additional notion regarding building orientation.

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