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Influence of printing direction on 3D printed ABS specimens

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Abstract
In the recent years, additive manufacturing became an interesting topic in many fields due to the ease of manufacturing complex objects. However, it is impossible to determine the mechanical properties of any additive manufacturing parts without testing them. In this work, the mechanical properties with focus on ultimate tensile strength and modulus of elasticity of 3D printed acrylonitrile butadiene styrene (ABS) specimens were investigated. The tensile tests were carried using Zwick Z005 loading machine with a capacity of 5KN according to the American Society for Testing and Materials (ASTM) D638 standard test methods for tensile properties of plastics. The aim of this study is to investigate the influence of printing direction on the mechanical properties of the printed specimens. Thus, for each printing direction ($0^\circ$and 90°), five specimens were printed. Tensile testing of the 3D printed ABS specimens showed that the 0° printing direction made the strongest specimen at an ultimate tensile strength of 22 MPa while at 90° printing direction it showed 12 MPa. No influence on the modulus of elasticity was noticed. The experimental results are presented in the manuscript.

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1. Introduction

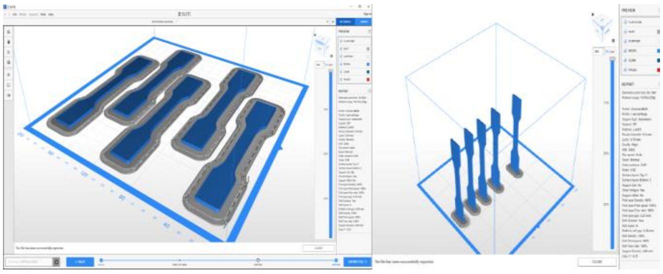
Additive manufacturing (AM) which is well known as 3D printing is a technology used to build three dimensional solid objects from 3D computer-aided design (CAD) model data usually layer by layer as opposed to traditional subtractive manufacturing methodologies. This technology has the capability to replace many conventional manufacturing processes as well as to allow new business models, new products, and new supply chains to flourish (Jiang et al., 2017). Various 3D printing techniques such as Stereolithography (SLA), Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Selective Laser Melting (SLM), 3D ink jet printing (Binder Jetting) and laminated object manufacturing (LOM) are available for manufacturing parts within a short period of time despite the diversity of materials (Sandeep and Chhabra, 2017). Additive manufacturing is not just limited for making models and prototypes but also different assembly parts as it has witnessed great interest in numerous applications such as automotive, aerospace, electronics, medical (Ilyés et al., 2019) and food industry (Sandeep and Chhabra, 2017). Nowadays, high quality 3D printers are being sold with affordable prices under 3,000$ which drives consumers to own one without hesitation, and by the way, a Delphi study was carried out with the help of experts predicted that in 2030 the majority of private consumers in industrial countries will have additive manufacturing printers at home (Jiang et al., 2017; Letcher and Waytashek, 2014)

Recently, fused deposition modelling (FDM) is widely used additive manufacturing technology along with thermoplastic materials such as polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) whereas 51% of parts produced by AM systems in the industry are from polymers (Urbanic and Saqib, 2019; Dizon et al., 2018). FDM is a material extrusion process introduced by Scott Crump the co-founder of Stratasys in 1989. In this process, a filament of thermoplastic materials are heated slightly above the melting point and extruded through a heated nozzle, then placed on a platform layer by layer until the part is manufactured (Keleş et al., 2017). However, despite of technical progress of this AM technology, the manufactured parts still generate a number of issues related to reliability and variability (Mbow et al., 2020). All AM techniques generally result in anisotropy in microstructure and mechanical properties of printed parts. This is primarily due to thermal history that the part experiences as well as the amount of diffused polymer chains, which, in turn depend on the selected printing parameters such as layer thickness, extrusion temperature, extrusion speed, printing orientation and build plate temperature…(Mukherjee, 2019; Luzanin et al., 2019).

Recent studies are focused on identifying the mechanical properties of printed polymeric materials. Tensile, flexural and fatigue tests of PLA material using a consumer level 3D printer presented in the reference (Letcher and Waytashek, 2014, November et al., 2020). Keleş, Ö., Blevins, C.W., & Bowman, K.J. (2017) investigated the effect of build orientation on the fracture stochastics of ABS tensile specimens with and without a hole in the center, they used the Weibull analysis to predict mechanical reliability. Shkundalova, O., Rimkus, A., & Gribniak, V. (2018) carried out tensile tests for investigating tensile strength and modulus of elasticity of four different polymeric materials polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), high impact polystyrene (HIPS), and polyethylene terephthalate (PETG). However, Sagias, V. D., Giannakopoulos, K. I., & Stergiou, C. (2018) presented the Taguchi methodology to improve the mechanical properties of 3D printed parts based on an experimental procedure through which the optimum combination of manufacturing parameters and their values can be determined. Luzanin, O., Movrin, D., Stathopoulos, V., Pandis, P., Radusin, T., & Guduric, V. (2019) investigated the influence of printing parameters (layer thickness, extrusion temperature, extrusion speed and build plate temperature) on tensile strength, crystallinity achieved during fabrication and mesostructure of PLA specimens (Tábi et al.,2016). García-Domínguez, A., Claver, J., Camacho, A. M., & Sebastián, M. A. (2020) carried out a series of tensile tests using solid specimens manufactured by FDM according to the specifications of UNE 116005:2012 (based in ISO 527–2) and ASTM D638–14 to determine which standard provides better results for the mechanical characterization of ABS material.. The aim of this study is to investigate the influence of printing orientation on mechanical properties of 3D printed ABS specimens by performing a tensile test.

2. Experimental

This section illustrates the method for the tensile testing of specimens printed using the ABS polymeric material. All specimens were printed using the Zortax M200 3D printer available at the faculty of transportation and vehicle engineering, department of vehicle elements and vehicle structures analysis at the Budapest University Technology and Economics. For each printing orientation, five identical specimens with the help of Z-suite software were printed together in order to obtain more accurate results. The standard printing parameters of Zortax M200 were used, so the ABS material was extruded at 250°C at a speed of 50 mm/sec with heated bed surface at 60°C. Figure 1 shows the five printed identical specimens in different directions. Figure 2 shows the printed samples.



(a) (b)

Fig. 1. Z-suite software: (a) specimens at 0° printing direction; (b) Specimens at 90° printing direction

(a) (b)

Fig. 2. Printed samples: (a) ABS 3D printed specimens at 0° printing direction; (b) ABS 3D printed specimens at 90° printing direction

The tensile tests were carried out using Zwick Z005 loading machine with a capacity of 5KN according to ASTM D638 standard test methods for tensile properties of plastics. The 3D printed ABS specimens were tested under displacement control of 5 mm/min loading rate. The thickness and width of each specimen were measured at several locations throughout the test section. The crosshead displacement was used to measure the strain of the 3D printed ABS specimens. All tensile tests were performed at room temperature (approximately 24°C). Figure 3 illustrates the testing setup.

(a) (b)

Fig. 3. Test setup: (a) the Zwick Z005 testing machine; (b) tensile testing procedure

3. Results and discussion

The tensile tests were carried out on five specimens at each printing direction until failure. Figure 4 shows the failure of the specimen. The results of the tensile tests are illustrated in table 1, 2 and table 3.

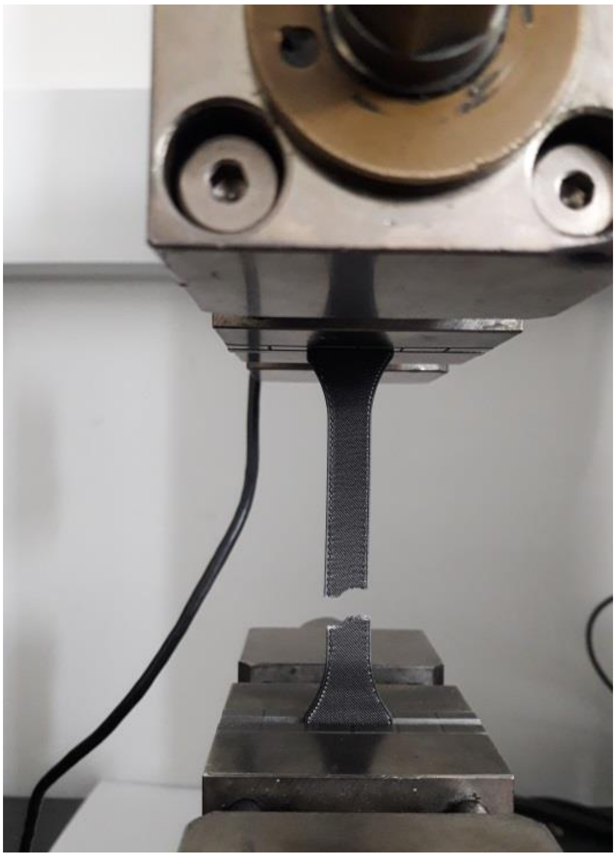


Fig. 4. Specimen failure

Table 1. Actual width and thickness for each specimen

Specimen Number	Printing Orientation [Degrees]	Actual Width [mm]	Actual Thickness [mm]
1	0	10.25	2.50
2	0	10.25	2.50
3	0	10.09	2.42
4	0	10.21	2.06
5	0	10.25	2.08
6	90	10.23	2.25
7	90	10.30	2.30
8	90	10.33	2.17
9	90	10.23	2.27
10	90	10.24	2.26

Table 2. Summary of the tensile tests results

Specimen Number	Printing Orientation [Degrees]	Ultimate Tensile Strength [MPa]	Modulus of Elasticity [GPa]
1	0	19.69	0.70
2	0	19.91	0.65
3	0	21.57	0.69
4	0	24.56	0.82
5	0	23.93	0.80
6	90	12.44	0.74
7	90	11.29	0.69
8	90	11.95	0.74
9	90	13.52	0.72
10	90	11.43	0.71

Table 3. The average of tensile tests results

Printing Orientation [Degrees]	Average Ultimate Tensile Strength [MPa]	Average Modulus of Elasticity [GPa]
0	21.93 ± 2.24	0.73 ± 0.074
90	12.13 ± 0.9	0.73 ± 0.074

The stress-strain diagrams for each printing direction are presented in figure 5 and 6, respectively.

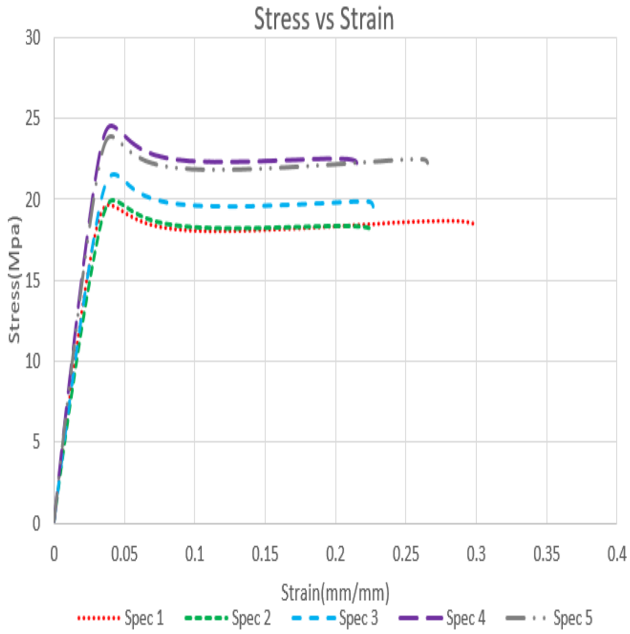


Fig. 5. Stress-Strain diagrams of the five specimens printed at 0°

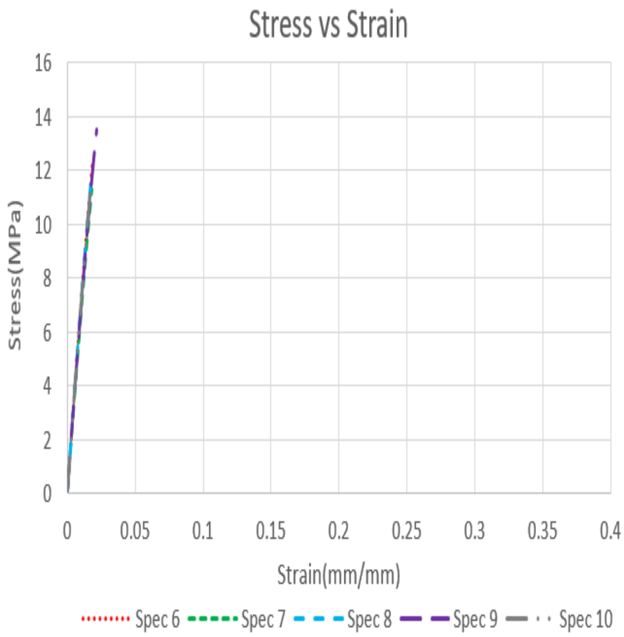


Fig. 6. Stress-Strain diagrams of the five specimens printed at 90°

Based on our investigation, all specimens were plastically deformed before the fracture due to the higher applied load then the ultimate tensile strength. It was observed that the material properties of the 3D printed ABS specimens in 0° and 90° had similar modulus of elasticity, while a huge difference in ultimate tensile strength. The average ultimate tensile strength of the 0° printed specimens had been reached 21.93 MPa which is higher by 44.7% than the 90° printed specimens that reached 12.13 MPa. However, the modulus of elasticity reached in both cases almost the same value of 0.73 GPa and 0.72 GPa, respectively. This evidence indicates that printing direction had no effect on the modulus of elasticity in our study. Based on the finding, it is clearly shown that the printed direction is one of the factors resulting in anisotropy behavior of the printed specimens. Hence, mechanical properties of 3D printed objects can be enhanced by optimizing the printing parameters.

4. Summary and conclusion

Ten ABS printed specimens had been printed using Zortax M200 3D printer (1-5 at 0° and 6-10 at 90°). The mechanical properties of these ABS specimens were tested, where the effect of printing direction was emphasized. Based on the tensile tests results, it was determined that the 0° printing direction specimens were the strongest by 44.7%. Moreover, the printing direction has no influence on the modulus of elasticity. The obtained results demonstrated that they are compatible with all researches in this field , thus all studies have shown that the mechanical properties of 3D printed polymer specimens at 0° are stronger than 90°. The methodology used was limited to some extent, since a consumer-level 3D printer was used as well as the standard printing parameters. However, further investigation with a high-level 3D printer can be utilized to demonstrate the quality of the printed specimens, hence the impact on the mechanical properties.

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打印方向对3D打印ABS标本的影响

關鍵詞
添加剂制造
ABS
拉伸试验
FDM
印刷方向

摘要
近年来，由于易于制造复杂物体，增材制造已成为许多领域的有趣话题。但是，如果不进行测试就无法确定任何增材制造零件的机械性能。在这项工作中，研究了以3D打印丙烯腈丁二烯苯乙烯（ABS）标本的极限拉伸强度和弹性模量为重点的机械性能。拉伸试验是使用Zwick Z005装载机进行的，其载荷能力为5KN，这是根据美国材料试验学会（ASTM）D638标准测试塑料拉伸性能的方法。这项研究的目的是研究印刷方向对印刷样品机械性能的影响。因此，对于每个打印方向（和），打印了五个样本。对3D打印的ABS样品的拉伸测试表明，在22的极限拉伸强度下，打印方向使强度最高，而在打印方向上显示12 MPa。没有发现对弹性模量的影响。实验结果列在手稿中。