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FRICTION AND HARDNESS CHARACTERISTICS OF FDM-PRINTED PLASTIC MATERIALS

Sahar Zhiani Hervan
Zeynep Parlar
Vedat Temiz
Atakan Altınkaynak
I.T.U Mechanical Engineering Faculty
Inonu Cad. No 65, 34437, Istanbul
Turkey

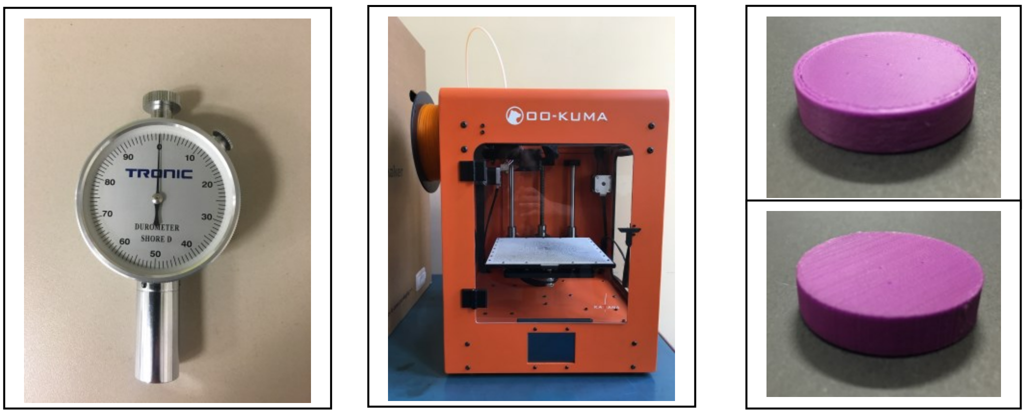
ABSTRACT
The aim of this study is the identification of the mechanical properties of samples printed by Fused Deposition Modeling (FDM) method. Since the mechanical properties of printed parts are different from primary materials, it is important to determine these differences in order to enhance their practical applications. In this study, Acrylonitrile Butadiene Styrene (ABS) is chosen as testing material. Samples were printed by Katana Printer with 0.1 mm, 0.15 mm and 0.2 mm layer thickness in two different orientations. In the first step, hardness of samples was tested by D-type shore hardness durometer and the results were compared with primary materials' properties. In the second step, friction coefficient of the samples was measured by Pin-on-disc setup. Five samples for each case were tested and the coefficient of friction was calculated. All the laboratory atmosphere and test specimen conditions were issued under ASTM standards. The results of this study will provide useful information about manufacturing products and will improve their application in various industries.

1. INTRODUCTION
Additive Manufacturing (AM) or 3D printing, as the name implies, is a sequential layer based manufacturing method [1]. 3D printing is a type of additive manufacturing technology in which a three-dimensional object is created by depositing successive layers of materials [2]. There are different 3D printing methods. Fused Deposition Modeling (FDM) is one of the widely used rapid prototyping methods based on materials that have a low melting point, even though harder materials can be used [3]. Creating complete models in a single process using 3D printing has great advantages. This innovative technology saves time, staff and cost for several applications. 3D printers allow engineers and designers to cost-effectively test ideas for dimensional products before performing the expensive manufacturing step. Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA) are the most commonly used materials in the form of filament in FDM method.

2. MATERIALS AND METHOD
Due to have a perfect toughness, easy processing ability and good dimensional stability, ABS has become the one of the most preferred 3D printing material [4].

2.1. Hardness Test: Test method and specimens
Hardness tests were completed under international standard ASTM 2240-15, Standard Test Method for Rubber Property Durometer Hardness [5]. According to this standard, for materials such as ABS, 'D' type durometer is appropriate. All the specimens were tested by TRONIC Shore D Durometer which is shown in Fig. 1(a). The conditions of these tests were conducted in the standard laboratory atmosphere as reported in ASTM D618. Room temperature range was from 20 to 26˚C. In this condition, the relative humidity should be 50% with standard tolerance of ±10% [6].

According to the ASTM D2240-15 standard, the thickness of test specimen must be at least 6.0 mm. The lateral dimensions of the specimen should be such that they allow measurements at least 12.0 mm from each edge. The surfaces of the sample should be flat and parallel to the test bed surface, so that the presser foot can come in contact with the sample in an area of at least 6.0 mm radius from the point of penetration. By considering these conditions, the sample dimensions were determined as 30 mm diameter and 7 mm thickness. Specimens were printed in three different layer thicknesses and two different orientations (horizontal and vertical) by KATANA printer. Figs. 1(b) and (c) show the KATANA printer used for printing specimens and an example of printed specimens, respectively. Following the ASTM D2240-15 standard, the median of five determinations separated by at least 6.0 mm at different points on each specimen was calculated.



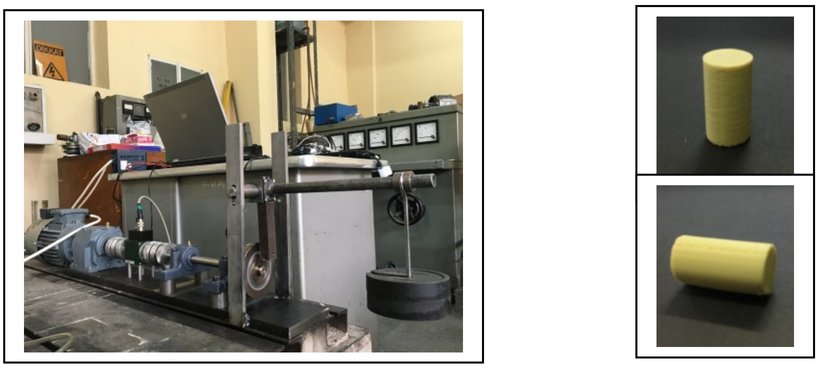
(a) (b) (c)

Figure 1. (a) TRONIC Shore D Durometer, (b) KATANA 3D Printer used for printing specimens, (c) Hardness test specimen with horizontal (top) and vertical (bottom) orientation.

2.2. Friction Test: Test method and specimens

ASTM G115-10, Standard Guide for Measuring and Reporting Friction Coefficients, covers information to help select the method for measuring the frictional properties of materials. This standard applies to most friction measuring techniques, test apparatuses and most solid materials [7]. Pin-on-disc method is an appropriate method for materials such as ABS. In pin-on-disc test, a pin (specimen) with a flat or radius tip is forced onto a flat circular disk. The pin's tip is travelling on the disk surface in the form of circle path. Loads are applied by a lever or arm and attached weights to the pin against the disk [8]. Pin-on-disc setup used for the experiments is shown in Fig. 2(a).

In the experiments, 3D printed ABS specimens are forced onto the rotating disc made of case hardening Steel (16MnCr5). For all specimens, 100 N of load were applied at a sliding speed of 1.2 m/s for a sliding distance of 1000 m. Laboratory temperature and relative humidity were in the range of 23±2˚C and 50±10%, respectively. Referring to ASTM G99 Standard, five to seven samples must be tested for each case. The dimensions of the pin samples were 10 mm diameter and 18 mm height. Five specimens were printed in three distinct layer thickness and two different orientations by KATANA Printer. An example of printed specimens is shown in Fig. 2(b).



(a) (b)

Figure 2. (a) Pin-on-disc apparatus, (b) Friction test specimen with horizontal (top) and vertical (bottom) orientation.

3. RESULTS AND DISCUSSION

The shore hardness results of ABS samples with different layer thickness is given in Table 1. The measurements were completed as discussed in Section 2.1.2 and the calculated mean and standard deviation (SD) of shore hardness values for each sample is reported in Table 1 for horizontal and vertical orientations. The results are also shown in Fig. 3. The coefficient of friction (COF) results with standard deviation for horizontal and vertical orientations are given in Figs. 4(a-c) and Figs. 5(a-c), respectively, for different layer thicknesses.

Shore D Hardness results presented in Table 1 indicated that the hardness values for horizontal and vertical orientations for all specimens were in the range of 72.6-76.6 and 60.2-75.0, respectively. As shown in Fig. 3, the hardness of ABS specimens is essentially the same with increasing layer thickness for horizontal orientation. Similar hardness results were also observed for vertical orientation samples with 0.2 mm layer thickness. However, for smaller layer thicknesses, the hardness values were approximately %14 lower. The reason for this behavior was due to the lack of good bonding between layers during manufacturing using vertical orientation. In horizontal orientation, the cross-section of each consecutive layer is the same whereas in vertical orientation it is changing which results in bonding problems especially for smaller layer thicknesses. Shore D hardness of injection molded ABS samples were reported as 71.84 [9], which is less than hardness of all horizontal and 0.2 mm vertical oriented specimens. The difference on the hardness may be related to the manufacturing method. In FDM method, the layers are ordered on the same direction and the printed part has a brick-like structure. However, the samples manufactured by injection molding do not have ordered layers which may result in lower resistance towards the presser foot.

Measured coefficient of friction data shown in Figs. 4 and 5 indicated that the mean value of COF was around 0.4 for all layer thicknesses and orientations. The exceptions were 0.1 and 0.15 mm layer thickness specimens with vertical orientation where COF increased and reached to 0.45 with increasing sliding distance. This change on COF was more apparent as layer thickness decreased. The reason for this behavior may be related to the direction of rotation vs. orientation. In vertical oriented specimens, the orientation of the specimen layers was perpendicular to the direction of disc rotation whereas in horizontal oriented specimens they were parallel. If the bonding between the layers are not good in vertical oriented specimens, the rotating disc may experience resistance from each layer due to the deformation of layers which resulted in an increase in COF. Thus, the layer thickness does not have a significant effect on COF for specimens with horizontal orientation. However, care should be taken if vertical orientation with smaller thickness is selected. The reported dynamic and static COF data in the literature for ABS-Mild Steel material pair is 0.30 and 0.35, respectively [10]. These values are substantially lower compared to that obtained from the experiments. It is clear that layered structures had a higher COF which may be related to further resistance between layers which does not exist in injection molded parts.

Table 1. Hardness results for horizontal (H) and vertical (V) orientation. Data reported are means of five samples. Means ± SD.

Sample No	Layer thickness (mm)		
	0.1	0.15	0.2
1-H	74.2 ± 1.48	74.0 ± 1.23	74.6 ± 2.88
2-H	73.2 ± 1.30	75.2 ± 1.10	75.4 ± 0.55
3-H	73.8 ± 1.10	76.6 ± 0.55	75.4 ± 1.67
4-H	73.4 ± 1.82	76.0 ± 2.00	75.4 ± 0.55
5-H	73.8 ± 2.39	72.6 ± 0.89	74.8 ± 0.84
1-V	64.0 ± 2.65	62.4 ± 3.29	72.8 ± 1.30
2-V	64.2 ± 3.11	60.2 ± 3.56	75.0 ± 1.22
3-V	62.8 ± 1.30	63.4 ± 5.86	75.0 ± 1.58
4-V	61.8 ± 2.95	61.8 ± 3.83	74.8 ± 1.48
5-V	63.2 ± 1.92	63.4 ± 4.72	74.4 ± 2.41

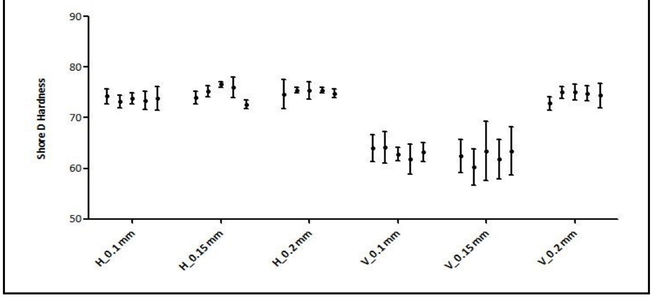
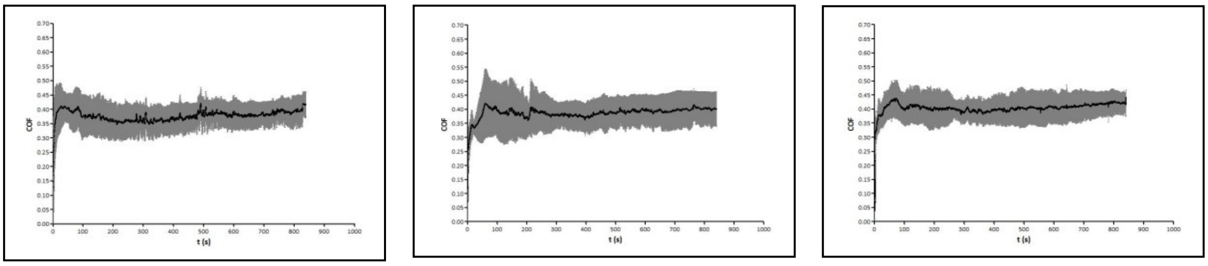
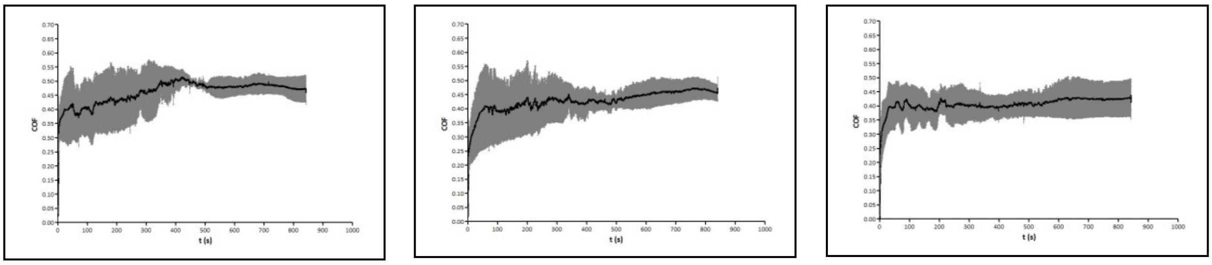


Figure 3. Qualitative analysis of hardness results.



(a) (b) (c)

Figure 4. Friction coefficient of a) 0.1 mm layer thickness, b) 0.15 mm layer thickness, c) 0.2 mm layer thickness along with standard deviation for horizontal orientation.



(a) (b) (c)

Figure 5. Friction coefficient of a) 0.1 mm layer thickness, b) 0.15 mm layer thickness, c) 0.2 mm layer thickness along with standard deviation for vertical orientation.

4. CONCLUSION

Acrylonitrile Butadiene Styrene (ABS) material is printed in three different layer thicknesses and two distinct orientations by KATANA printer and the specimens were tested for hardness and coefficient of friction properties. The hardness of specimens was tested by Shore D durometer. It was observed from the results that in horizontal oriented specimens the layer thickness does not have a significant effect on hardness whereas in vertical oriented samples a shift on the hardness values were observed. Friction coefficient of specimens was measured by pin-on-disc apparatus. It was found that the mean value of COF for all layer thicknesses and orientations is around 0.2 except small layer specimens with vertical orientation and COF of 3D printed specimens were less than the injection molded ABS samples.

5. REFERENCES

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