

Fatigue Characteristics of 3D Printed Acrylonitrile Butadiene Styrene (ABS)

M. M. Padzi^{1*}, M. M. Bazin¹, W. M. W. Muhamad¹

¹Department of Mechanical Engineering, Malaysia France Institute, University Kuala Lumpur, 43650, Bangi, Selangor, Malaysia

mahfodzah@unikl.edu.my

Abstract. Recently, the use of 3D printer technology has become significant to industries, especially when involving the new product development. 3D printing is a technology, which produces the 3D product or prototype using a layer-by-layer technique. However, there becomes less research on the mechanical performance of the 3D printed component. In the present work, fatigue characteristics of 3D printed specimen have been studied. Acrylonitrile butadiene styrene (ABS) has been chosen as a material research due to its wide applications. Two types of specimen used, which is the 3D printing and moulding specimens. Fused deposition modelling (FDM) technique was used to produce the specimens. The dog bone shape part was produced based on ASTM D638 standard and the tensile test has been carried out to get the mechanical properties. Fatigue test was carried out at 40%, 60% and 80% of the tensile strength. The moulded part shows higher fatigue cycles compared to 3D printed part for all loading percentages. Fatigue lives for 40%, 60% and 80%, were 911, 2645 and 26948 cycles, respectively. The results indicated that 3D printed part has a lower fatigue life, which may not suitable for industrial applications. However, the 3D printed part could be improved by using various parameters and may be introduced in low strength application.

1. Introduction

Rapid prototyping is the prior additive manufacturing (AM) process that develops in the 1980's in creating prototypes and model [1]. In addition, according to Karina M.C et. al [2], a 3D printer is an associate innovative technology and was initiated accustomed earlier produce prototypes. 3D printing is one of the additive layer fabrication processes [3]. The primary 3D printer was created by means of Charles Hull in 1984. That enables the tangible 3D object to be made of digital information [4]. During the 90's, the primary SLA (Stereolithographic) machine was made by 3D System. It proved that complex and advanced components could be manufactured. Moreover, this technology has been engaged within the medical space. After getting into the 21st Century, 3D printing technology has been utilized in the various fields, such as medical, manufacturing, automotive, aviation, jewelry, and others. Within the last decades, the world's 1st 3D written robotic craft was inbuilt seven days in 2011. Also, the world's first 3D written automobile was in-built an equivalent year [5].

3D printing enhanced the productivity. 3D printing technology is a saving time process than conventional techniques of making objects which include prosthetics and implants, which require milling, forging, and a protracted transport time [6]. Besides, 3D printer is able to manufacture an object at low cost [7]. The cost to produce a 3D object is least, with the first object being as cheap as the final. That is mainly high quality for organizations, which have lower manufacturing volumes or that, produce



components or merchandise, which can be complicated or require frequent adjustments. 3D printing could reduce costs because it can efficiently use raw materials and produce less waste [8]. For example, a pharmaceutical tablet weighing 10mg may want to doubtlessly be custom-fabricated on demand as a 1-mg pill. Some capsules will also be revealed in dosage bureaucracy, which can be less complicated and greater price-effective to deliver to patients. By 3D printing enables to design with novel geometry that might be troublesome or impossible to produce by using the conventional method. So, this can improve engineering component performance in term of creating an innovation and creativity in design for 3D printing.

There are many types of filler that can be used in a 3D printing machine. One of them is Acrylonitrile Butadiene Styrene (ABS). ABS is a group of thermoplastic of “terpolymers” [9]. Typically, ABS contains 15% to 35 % acrylonitrile, 5% to 30 % butadiene and 40% to 60% styrene. However, this proportion could be a change in a quite wide variety. Monomer is an atom or small molecule, which will be secured to alternative identical molecules to create a polymer [10]. This combination of materials makes it become an outstanding impact strength and high mechanical strength [11]. Furthermore, it gives a stiff thermoplastic polymer property which compatible with rough customer products. ABS yields plastically instead of tearing and shows ductile failure. ABS includes a sensible long-term load carrying capability with stresses higher than their tensile strength. However, ABS has a greater modulus of elasticity and hardness. It has comparatively low creep nature and high heat resistance which makes it become a decent dimensionally stability and has good electrical insulation properties. ABS is utilized in the wide selection of an application in trade these days. Its uses among several others producing ways, such as injection molding, blow molding, extrusion and as a filament for 3D printing merchandise [9].

Fatigue is chargeable for up to 90 % of the in-service part failure that occur in industry area [12]. In the 19th century, fatigue was a mysterious phenomenon due to its no warning fracture and did not give any plastic deformation visible. This lead to an erroneous believes that fatigue was merely an engineering matter. In the 20th century, fatigue seems not to be as engineering issues, but also as material and design development [12]. Fatigue on 3D printed component is branches of a part in studying of materials and manufacturing area. There are two cases that have found where the cases of fatigue on 3D printing component. According to [13], 3D printed component has produced dog-bone specimen by using rapid prototyping that fulfills the UNI EN ISO 527-1 (1997) standard, which designates a 10 mm by 4 mm cross-section with a gauge length of 8mm. The maximum number of cycles for running test respectively is set to 10,000 to prevent overflow data in the equipment. The materials that have been used are ABS and ABSplus. For rapidly prototyped component, usually, the printing orientation and pattern will influence the material properties [14]. Besides, there was a case of 3D printed fatigue for elastomer material, which is Tango Black Plus material. The comparison specimen is between interface specimen and specimen with no interface. The ratio of elongation that is conducted on each specimen is about 20 %, 30 %, 40 %, 50 % and 60 %. The maximum 60 % was chosen because it indicates the maximum elongation before it breaks.

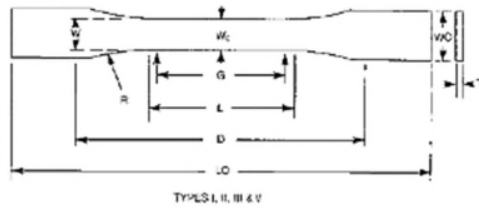
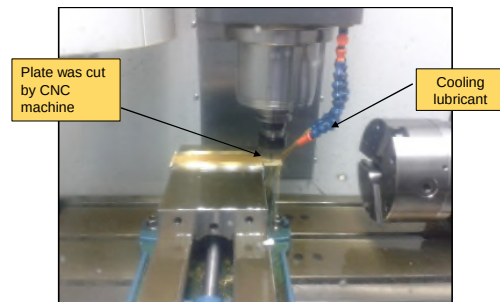
2. Experimental

2.1. Sample preparation

The material used was ABS due to its availability and its wide application in most research field. The dimension of the specimen is based on the standard ASTM D638 as shown in figure 1. Sample thickness is 3 mm (figure 2) and was produced by using a 3D printer shown in figure 3. For moulding specimen, the specimen was prepared from ABS plate, cutting in the same shape by using CNC machines, as shown in figure 4. Figure 5 shows the specimen cutting from CNC machine.

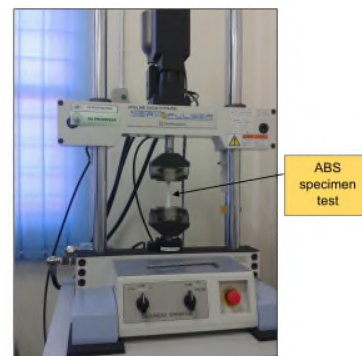
2.2. Tensile testing

The tensile testing was conducted using Universal Testing Machine (UTM) 250 kN as shown in figure 6. This test was done to determine the mechanical properties of ABS materials such as yield strength, ultimate tensile strength (UTS) and modulus of elasticity.

**Figure 1.** Dimension of specimen.**Figure 2.** 3D printed Specimen.**Figure 3.** 3D printed machine.**Figure 4.** CNC machine used to cut specimen.**Figure 5.** Specimens obtained from cutting process.

2.3. Fatigue testing

Fatigue testing was performed using machine SERVOPULSER model EHF- LV020K1-020 shown in figure 7. The test was done at frequency 1 Hz with tension-tension cyclic loading, $R=0$. Two different applied loads were used, which are 40%, 60% and 80% from UTS value. Fatigue test was run until the specimen breaks.

**Figure 6.** Tensile testing machine.**Figure 7.** Fatigue testing machine.

3. Results and discussion

3.1. Mechanical properties

Table 1 shows the mechanical properties for both 3D printed and moulding specimens. Ultimate tensile stress and young's modulus of moulding contribute the higher value compared to 3D printed specimen. Young modulus values obtained from both specimens do not have much difference. The percentage difference is shown in table 2 and figure 8. However, the difference was higher for UTS, which was influenced by several factors. The regions in the material, which do not seem to be absolutely dense, have a lower mass/volume quantitative relation resulting in lower absolute strength and stiffness values [15]. Furthermore, the fabrication process technique also influenced the high differences of UTS [16]. This is because moulding is a process where the material was compacted by force into a mould. So, it makes the strength of moulding is higher than 3D printer.

Table 1. Mechanical properties of 3D printing and moulding specimen.

Properties	3D Printed Specimen	Moulding Specimen
UTS (MPa)	17.8	48.5
Modulus Young (GPa)	12.5	17
Breaking point (kN)	0.63	1.27

Table 2. Percentage differences of UTS and Young's Modulus.

Types of specimen	UTS	Young's Modulus	Percentage difference	
			UTS	Young's Modulus
3D printer	17.8	12.5	30.7 %	4.5 %
Moulding	48.5	17		

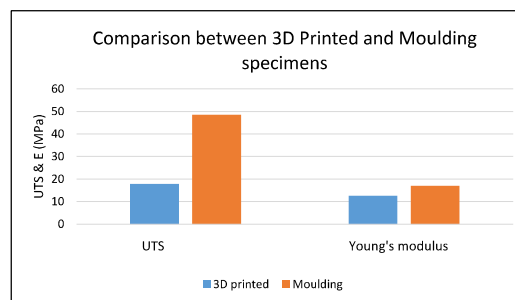


Figure 8. Comparison of percentage differences for printed and moulding specimen.

3.2. Fatigue Properties

Table 3 shows the load applied for fatigue testing. The result of fatigue test under different loading values for 3D printed and moulding specimen is presented in table 4. The fatigue cycle of moulding specimen shows the highest cycle for each load compared to 3D printing specimen. This may due to the fill of material [17]. This result's conceivable in sight of the actual fact that injection moulding involves the applying of high pressures that compact the material upon injection into the die cavity. Moreover, applied holding pressure throughout the injection moulding in addition compensates material shrinkage, leading to additional compact samples compared to FDM components, wherever the individual raster's area unit simply deposited next to every alternative [17].

From table 4, 40 % of load test shows the highest number of cycles for both 3D printed and moulding specimens. This coincides with the fatigue theory which is the higher the magnitude of the stress, the smaller the number of cycles the material is capable to sustain before failure [18]. The stress at where the location of failure happens in a given variety of cycles is that the fatigue strength. The number of cycles needed for a material to fail at an explicit stress is fatigue life [19]. The percentages of differences in fatigue life between 3D printed specimen and moulding specimen for 40 %, 60 % and 80 % are 30 %, 39 %

and 55 % respectively. This fatigue behaviour for 3D printed specimen seems to be accepted to compete with moulding for certain application in industries.

Figure 9 present a comparison of fatigue life between 3D printed and moulding specimens. At 40% and 60%, the number of cycles for moulding specimen was higher than 3D printed. Hence, less differences between both specimens. This is because, at 40 % and 60 %, the amount of load applied is moderate, make the specimen able to withstand longer for fatigue life. While, at 80 %, the percentage differences for 3D printed was half of mouldings specimens. Thus, it shows bigger differences among the specimens. This is because, at 80 %, the amount of load applied was high, thus, make specimen to fail short and low fatigue life.

Table 3. Load applied for fatigue testing.

Types of specimen	σ_u (MPa)	Load test(kN)		
		40 % σ_u	60 % σ_u	80 % σ_u
3D printed specimen	17.8	0.3	0.4	0.5
Moulding specimen	48.5	0.7	1.1	1.5

Table 4. Fatigue life of 3D printed and moulding specimen.

Types of specimen	σ_u (MPa)	No. of cycle		
		40 %	60 %	80 %
3D printed	17.8	1.9×10^4	1.62×10^3	4.09×10^2
Moulding	48.5	2.6×10^4	2.65×10^3	9.11×10^2
Percentages difference (%)	63	30	39	55

The stress - cycle (S-N) curves are shown in figure 10 for 3D printed specimen and moulding specimen, comparing with previous research. S-N curves show that 3D printed experiments exhibit similar fatigue life to the 3D printed specimen from previous research. The fatigue life between 3D printer and previous research shows the fatigue life from previous research is a little bit higher compared to 3D printing for loading 80 % and 60 %. The trend was changed for 40 % fatigue loading which 3D printed contributes a higher fatigue life compared to previous research. Thus, this result can be accepted.

Besides, for fatigue life of moulding specimen demonstrated the higher cycle compared to others' cycles. Shown in figure 9, fatigue life for these three different load values is below 10^5 of the number of cycles. Thus, it means that ABS material is considered as low cycle fatigue materials. The trend of curves between 3D printed and previous research shows that the results obtained were validated. Besides, the trend of curves for moulding specimen was steeper compared to others and was considered in the same range (10^2 to 10^3 for 40 % loading test) with 3D printed and previous research results. The moulding specimen has the highest trend is due to its ability to withstand high stress applied.

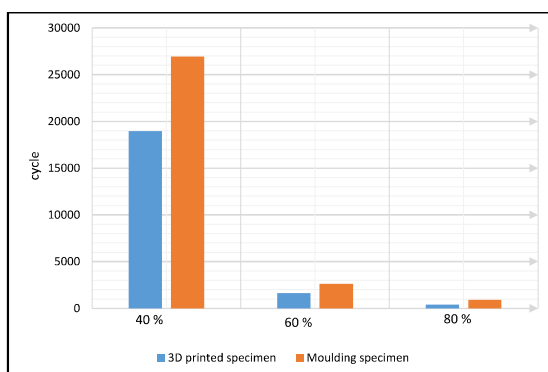


Figure 9. Comparison of fatigue life between 3D printed and moulding specimen.

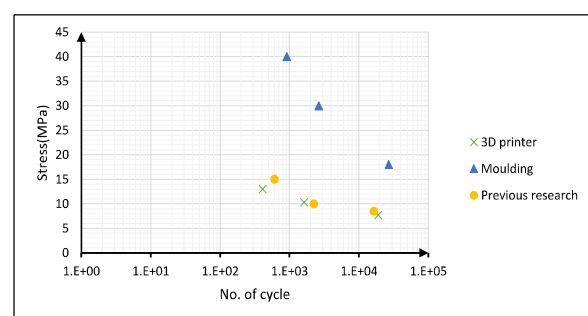


Figure 10. S-N curve for 3D printed and moulding specimen, comparing with previous research data.

4. Conclusion

From this work, it can be concluded that fatigue life was determined by the tensile strength value. Ultimate tensile strength (UTS) value of the moulding specimen (48.5 MPa) was higher compared to 3D printing specimen (17.8 MPa) where it causes the fatigue life of moulding specimen was higher than 3D printed specimen. Fatigue life for 40% σ_u , 60% σ_u and 80% σ_u is 2.6×10^4 , 2.65×10^3 and 9.11×10^2 for moulding specimen, respectively, while for a printed specimen is 1.9×10^4 , 1.62×10^3 and 4.09×10^2 , respectively. This gives the percentage differences in fatigue life between 3D printed specimens and moulding specimens is 30 %, 39 % and 55 %. This is due to moulding process and the fabrication technique that produce more ductile properties [16]. Therefore, 3D printed component might not suitable for high strength industrial application. However, within the context of production, 3D printed components may be grown in low volume, customized design components and for low strength application. Moreover, the technology of 3D printing could produce a complex design of a product that could not be brought about by the moulding method.

5. References

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