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Evaluation of the Fatigue Properties of 3D Printed Acrylonitrile Butadiene Styrene (ABS)

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Abstract: The use of 3D printing technology has become more significant recently, especially in the area of developing new products. The process of creating a three-dimensional object or prototype using 3D printing technology is called layer-by-layer building. The present investigation has looked into the fatigue characteristics of 3D printed specimens. Acrylonitrile butadiene styrene (ABS) has been chosen as a study material due to its numerous applications. For the printing, three different raster angles 0°, 45°, and 90°, layer thickness of 0.255, infill density of 100%, and printing speed of 30 mm/s were used. The fused deposition modeling (FDM) method was employed to create the specimens. The dog bone-shaped object was made in accordance with ASTM D638 standard, and its mechanical properties were determined by a fatigue test. The fatigue test was carried out at tensile strengths of thirty, fifty, and seventy percent. The 3D-printed ABS samples at 45° and 90° raster angles show reduced fatigue cycles than the 0° raster angles for all loading percentages. The results indicated that the use of ABS material 3D printed at 45° and 90° raster angles might not be suitable for industrial environments.

Keywords: *3D Printing, ABS Plastic, Raster Angles, Layer Thickness, Infill Density*

INTRODUCTION

It is necessary to analyze the fatigue behavior of polymeric materials due to their increased use in applications such as passenger aircraft and automobiles where ensuring human life safety is critical. The development of polymeric materials enables their application in various structural and load-bearing applications. Cycle stress can cause fatigue in structural components, which can result in catastrophic failure at a stress lower than in the case of typical static mechanical loading (Bagheri *et al.*, 2018; Samiee & Azadi, 2018; Genova *et al.*, 2020).

Because polymeric materials are being used more often in situations where human life safety is paramount, like passenger aircraft and vehicles, it is imperative to examine their fatigue behavior. 3D printing is the process of turning a computer 3D model into a physical thing (Khan *et al.,* 2017; Donate *et al.,* 2020). If it is a copy of an existing object, the digital model is first created using CAD software or a 3D scanner. Once completed, the 3D model is split into hundreds or perhaps thousands of horizontal layers using specialized software. These layers are then fed to a 3D printer (which may interpret them differently depending on the model being used), which then uses a range of materials to print the object layer by layer, including plastics (ABS, PLA, PETG, etc.), resins, metals, and even ceramics (Hart, & Wetzel, 2017; Samiee & Azadi, 2018; Bardiya *et al.,* 2021). Generally speaking, 3D printing and additive technology have become paradigm-shifting innovations. One important factor to take into account when evaluating the feasibility of this technology for different applications is the strength of 3D printed items. Investigating the resilience of these components and the factors that contribute to it is crucial. The results of this inquiry can be utilized to optimize the materials and printing conditions for 3D printing, extending the lifespan of the produced items. Understanding the durability of 3D-printed components is ultimately necessary to achieve the full potential of this technology. Moreover, this technology is warranted due to its potential to transform traditional industrial processes while offering numerous distinct advantages (Morris *et al.,* 2017; Huang *et al.,* 2019). Owing to these advantages, it has been swiftly embraced and incorporated into numerous industries. Unlike traditional manufacturing methods that entail extracting or shaping material from a bigger block, 3D printing builds products layer by layer, piecing together components as needed. This shift in methodology enables the creation of intricate geometries and unparalleled design freedom, hence opening up a plethora of applications such as personalized products, large-scale manufacturing, and rapid prototyping.

According to Morris et al., (2017), AM comprises seven basic processing methods that are based on printing technology. These include binder jetting, direct energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, and vat photopolymerization. Fused Deposition Modeling (FDM) is the most widely used method for producing polymer-based models and structures; it is based on extrusion (Murphy and Atala, 2014; Rayegani *et al.,* 2014). Using FDM printing technology, the model to be printed is converted into a design model, which is then imported into the slicing software (Rengier *et al.,* 2010). The inability of different printing conceptual prototypes to have better mechanical qualities has led academics to look for ways to make FDM products stronger. Fiber composites based on polymers have recently been made using FDM (Schultz, 1977; Ziemian *et al.,* 2016; Yadollahi *et al.,* 2017). The addition of fiber to the thermoplastic matrix produced better modulus, tensile strength, and bending strength when compared to the plain thermoplastic material (Weibull, 2013). This increases the likelihood that FDM-produced materials will be used in load-bearing applications. However, uncertainties in the FDM manufacturing process, such as the production of voids, defects, and poor layer bonding, enhance the chance of failure in polymers and their composites (Ang et al., 2006). How FDM-printed polymers break under both static and dynamic loading circumstances is still unknown (Ang et al., 2006). Moreover, complicated geometries that are sometimes impossible or very challenging to create using traditional manufacturing methods may now be created thanks to 3D printing. This creates new avenues for design, enabling engineers and designers to produce previously unfeasible elaborate structures, organic shapes, and bespoke components. When material is removed from a larger block in the traditional subtractive manufacturing process, a significant amount of material waste is created. 3D printing, on the other hand, adds material layer by layer only where it's needed. This reduces material waste, which contributes to a more sustainable production process. 3D printing has made prototyping speedy and reasonably priced (Ashrafi *et al.,* 2019; Jatti *et al.,* 2019; Sodeifian *et al.,* 2019).

This speeds up product development processes and reduces time to market. 3D printing makes it possible to create extremely customized and personalized products. This is particularly helpful in the consumer goods and healthcare sectors, where customers can have customized products created to their specifications or where patient-specific medical implants and devices can be developed (Naveed, 2020). In conventional manufacturing, components and finished goods frequently need to be purchased from several vendors, assembled, and shipped internationally. 3D printing can simplify supply chains by reducing the need for significant quantities of warehousing and transportation by producing items locally or as needed. Traditional manufacturing procedures need the creation of molds, dies, and other equipment, which can be expensive and time-consuming. 3D printing eliminates or reduces the need for these specialized tools, allowing for the more economical production of highly customized or low-volume products (Farashi & Vafaee, 2022; Mushtaq *et al.,* 2023). Thanks to 3D printing, production could shift from centralized operations to localized sites. This can be especially helpful for businesses that need to handle production bottlenecks, minimize shipping costs, and require distributed manufacturing. Many materials, such as sophisticated polymers, metals, ceramics, and composites, can be used with 3D printing. This makes it possible to create new materials with special qualities that are suited for certain uses. Often in traditional manufacturing, multiple pieces are assembled to create a single component. 3D printing reduces the need for assembly and gets rid of potential weak points by printing several elements together into a single object (Zhang *et al.,* 2022). On-demand production is made easier by 3D printing, which enables producers to react swiftly to shifts in consumer demand, industry trends, or design adjustments. In industries that are changing quickly, this manufacturing agility can help businesses remain competitive. The goal of 3D printing is to revolutionize production processes by providing faster prototyping, lower waste, more design freedom, supply chain optimization, and personalization (Zhao *et al.,* 2020a; Zhao *et al.,* 2020b). Because of these advantages, 3D printing is a useful tool for many industries attempting to innovate, boost output, and adjust to shifting consumer needs (De Pasquale *et al.,* 2019). Acrylonitrile butadiene styrene is a commonly utilized polymer compound (ABS). Owing to its exceptional mechanical qualities, such as its resilience to heat, impact, chemicals, and abrasion, ABS is perfect for a variety of uses, such as high-wear toys, tool handles, phone covers, automotive trim parts, and electrical enclosures. But because ABS is prone to warping, it needs to be printed using bed adhesive on a heated print bed. Furthermore, a polyethylene terephthalate version called polyethylene terephthalate glycol (PETG) is increasingly being used as a material for 3D printing (PET). PETG can be used for many different things, including protective components, printer parts, and mechanical parts, because it is strong, flexible, and simple to print. Better compression strength was obtained with lower layer thickness and higher infill density; bigger layers required more energy to get the same outcome. High-impact polystyrene (HIPS) is a copolymer that combines the tensile strength of rubber with the hardness of polystyrene. It is widely applied to containers and protective packaging. When combined with ABS, it can also be utilized as a support material in 3D printing. HIPS is a good 3D printer filament and appropriate support material; however, it is only compatible with ABS and needs to be post-processed to remove supports. Moreover, water-soluble polyvinyl alcohol (PVA) is often used as a supply material in intricate 3D printing with projections. Accordingly, PVA filament is an excellent material for nourishment, even though it can be challenging to deal with and is moisture-sensitive. The development of polyvinyl alcohol in 3D printing has been facilitated, among other things, by its affordability, biodegradability, and suitable flowability.

MATERIALS AND METHODS

The samples were created in the form of a dog-bone flat using Solid Work 2020. Then, 2.75 mm of ABS plastic that had been wrapped from its coils and removed through a nozzle was melted to create it. The ABS plastic was extruded directly onto the build plate to create layers of material. To ensure that every layer had the exact form it required, the nozzle was shifted horizontally. After deposition, the ABS filaments bonded to the previous layer of material as well as to one another to form a single mass by cooling and hardening. The printing of the ABS was carried out under the following conditions; nozzle temperature equal to 220°C -230°C, build-plate temperature to 60°C, print speed to 30 mm/s, infill density to 100%, layer thickness of to 0.255 and 0.45 mm, and raster angles of 0°, 45°, and 90°. Fig.1 shows the CAD design of ABS sample: (a) vertical and (b) horizontal print direction, (c) The geometry of the fatigue sample.

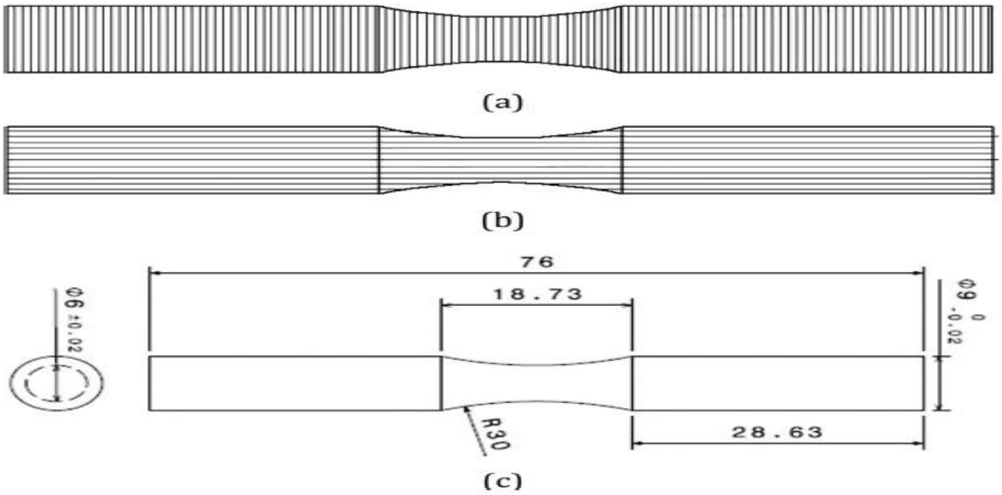

Fig. 1 CAD design of ABS sample: (a) vertical and (b) horizontal print direction, (c) geometry of the fatigue sample

The fatigue testing samples are designed in accordance with the fatigue rotating bend fatigue test machine. Fig. 2 shows the schematic diagram of the rotating bend fatigue test machine.

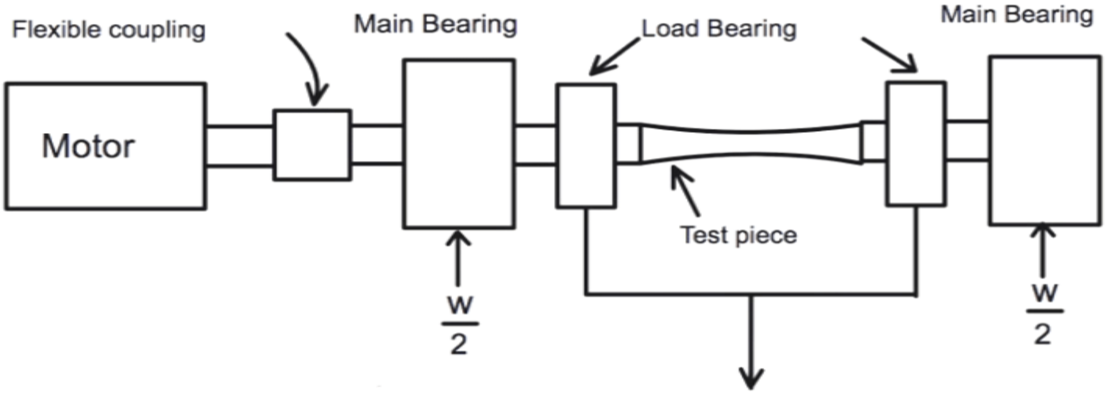

Fig. 2 Schematic diagram of the rotating bend fatigue test machine

Using a cantilever load, it rotates around the longitudinal axis of the ABS samples that were 3D printed to give reversing stress. Consequently, the stress varies sinusoidally throughout the entire surface of the cantilever. Three thousand revolutions per minute (RPM) is the speed at which the motor rotates the samples, and a single-phase, 200 V power source is provided. The loading is applied to the test object using a hanging weight. A spring balance determines the loading value. The hanging weight does not move when the sample is turned. The samples are symmetrically bent cyclically. When the sample fatigues, the machine abruptly stops due to a shift in load, and the cycle number is recorded. Each ABS sample was analyzed according to different raster angles and layer thickness. The specimens were exposed to a particular stress level up to a predetermined number of failure-free cycles or until failure happened. The number of cycles, the maximum and minimum stress levels, and the stress amplitude (minimum, maximum, and average) were noted.

RESULTS AND DISCUSSION

The results obtained indicated a Young Modulus of 12.01 GPa, 11.95 GPa, and 11.45 GPa respectively for a printed angle of 0°, 45°, and 90° as shown in Fig. 3. Thus, 3D printing at an orientation angle of 0° proof to be the best.

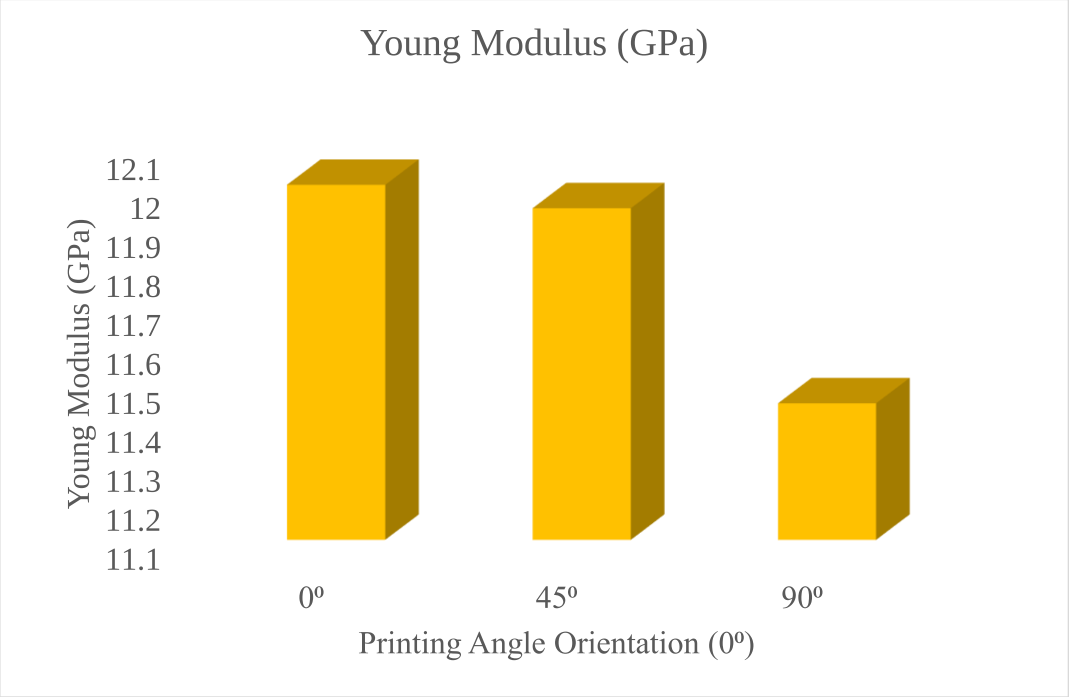

Fig. 3 Result of Young Modulus of Printed 3D ABS

Also, a good ultimate strength value was obtained for each of printing angles, the value be 18.1 MPa for 0°, 17.89 MPa for 45°, and 17.65 MPa for 90° respectively as shown in Fig. 4.

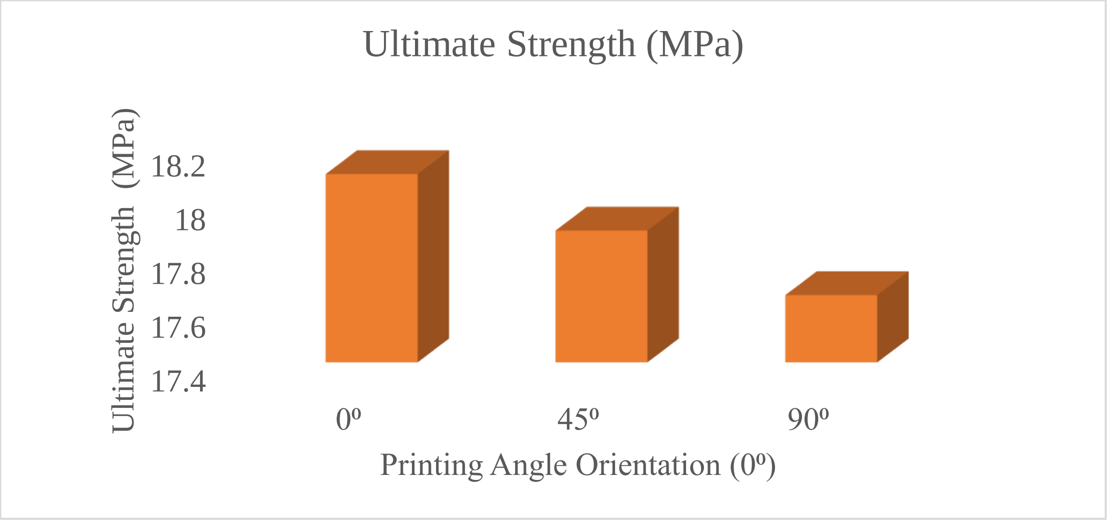

Fig. 4 Result of Ultimate Strength of Printed 3D ABS

However, there could be a number of factors that affect the various values of ultimate strength that are obtained. For example, the ABS plastic materials' regions with thickness layer fluctuations that do not appear to be completely dense have a lower mass/volume quantitative relation, which lowers the absolute strength and stiffness values (Huang, *et al.,* 2019). Moreover, Fischer (2016) found that the printing process technique had an impact on the large variations in ultimate strength. However, as molding involves compacting the material by force into a mold, molded plastic materials may have a higher ultimate strength. Therefore, although the strength of molding may be greater than that of 3D printed ABS, 3D printed ABS plastic is preferred due to its precision and speed of creation at a cheaper cost (Fischer, 2016). Furthermore, the breaking point results indicate that printing at 0° has the highest value of 0.61 kN in contrast to the values obtained for printing at 45° and 90°, which have respective values of 0.59 kN and 0.58 kN (Fig. 5).

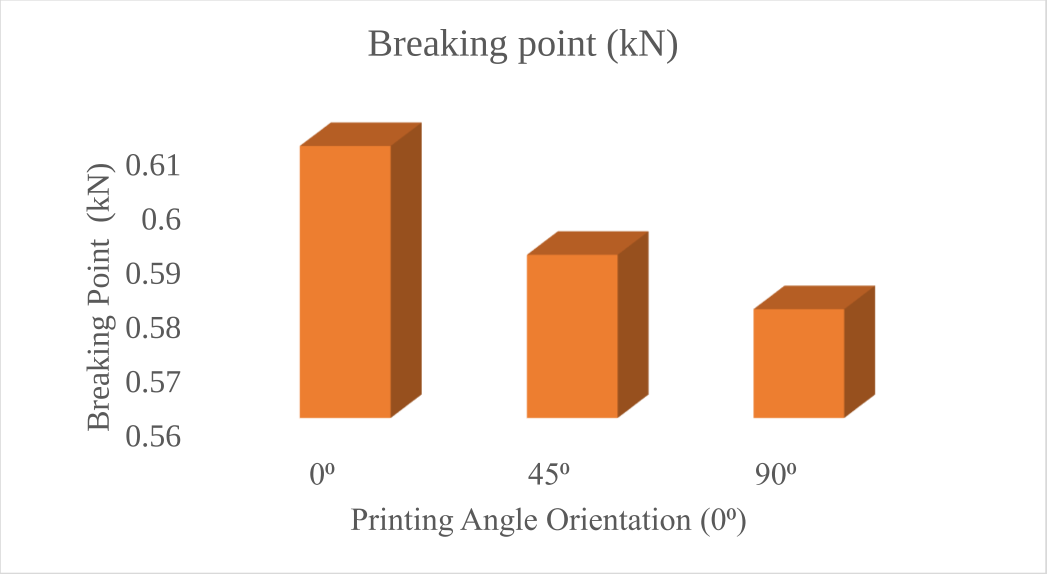

Fig. 5 Result of Printing Angle of Printed 3D ABS Plastic

The result of fatigue test under different loading values for 3D printed ABS plastic is shown in Table-1, and Fig. 6.

Table-1 Result of Fatigue Test under different Percentage loading Variation for 3D Printed ABS

Printing Orientations	0⁰	45⁰	90⁰
Ultimate Strength (MPa)	18.1	17.89	17.65
10% δu Test kN	1.81	1.789	1.765
20% δu Test kN	3.62	3.576	3.530
30% δu Test kN	5.43	5.367	5.295
40% δu Test kN	7.24	7.156	7.060
50% δu Test kN	9.05	8.945	8.825
60% δu Test kN	10.86	10.734	10.590
70% δu Test kN	12.67	12.523	12.355
80% δu Test kN	14.48	14.312	14.12
90% δu Test kN	16.29	16.101	15.885

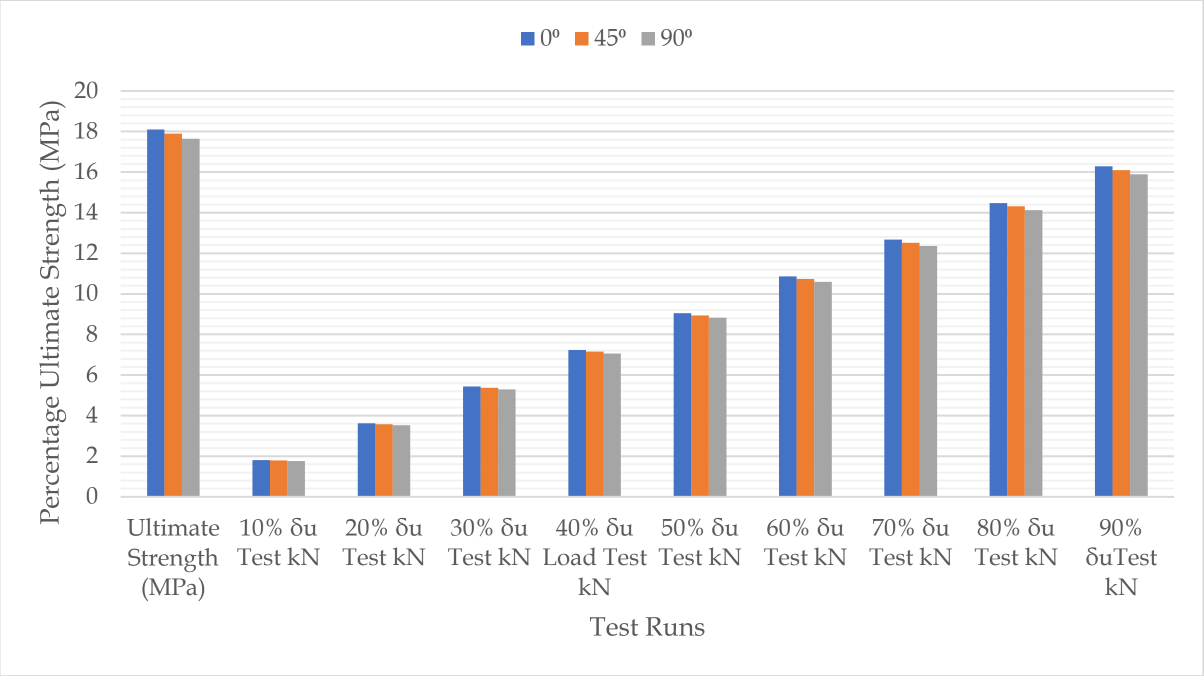

Fig. 6 Result of fatigue test under different loading values for 3D printed ABS plastic

The fatigue cycle of 0⁰ specimen shows the highest cycle for each load compared to 45⁰ and 90⁰ specimen. It was also observed that for each percentage loading variation of the ultimate strength,3D printing of raster angle 0⁰ produced the best results as compared to 45⁰ and 90⁰ respectively. This may due to the fill of material (Dawoud, 2016). Although, a higher value of fatigue is expected to be obtained for injection molding production than the 3D printing for ABS, because injection molding involves applying of high pressures that compact the material upon injection into the die cavity. Additionally, holding pressure that is supplied throughout the injection molding process compensates for material shrinkage, resulting in more compact samples than FDM components when each raster is simply deposited next to each other (Dawoud, 2016).

This aligns with the fatigue theory, which postulates that a material's ability to withstand a given number of cycles before failing decreases with increasing stress levels (Gulshan, 2009). The fatigue strength is the stress at which the failure spot occurs in a specific variety of cycles. Fatigue life is the number of cycles required for a material to break down under a specific stress (Önem, 2003).

CONCLUSION

From this project work, the ultimate strength value of 3Dprinted ABS plastic at 0º raster angle sample was higher compared to 3D printing ABS plastic sample of 45º, and 90º. Also, the fatigue life for 30% σu, 50% σu and 70% σu showed that the values for 0º raster angle sample were higher. Therefore, 3D printed ABS plaster should be carried out at raster angle of 0º.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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