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Effect of Raster Angle on Tensile Properties of PLA Part Fabricated Using Fused Deposition Modeling Process

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Abstract

The present study investigates the tensile properties of polylactic acid (PLA) parts fabricated using fused deposition modeling process. Experimental investigation is carried out in order to understand the effect of raster angle on tensile properties of PLA parts. Raster angle is varied from 0° to 90° to study the effect on tensile strength. Further, part with crisscross raster angle is also fabricated and compared with the part fabricated with unidirectional raster angle. Experiments has been performed as per ASTM D638 – type I standard. The result shows that tensile strength is significantly affected by raster angle. Higher tensile strength is observed at 0° raster angle and lower tensile strength is observed at 90° raster angle. Further, to understand the material failure mechanism, microscopic examination of fractured surface is also carried out.

Keywords: Additive Manufacturing, Fused Deposition Modeling (FDM), Polylactic Acid (PLA), Raster Angle, Tensile Strength.

1. INTRODUCTION

Additive manufacturing (AM) has gained rapid popularity in last decade due to its ability to create part with complex geometry shapes without any specific tools or manual involvement or monitoring. AM techniques help to reduce product development cycle time as it produces part directly from CAD model [1,2].

Fused Deposition Modeling (FDM) is one of the most widely used AM techniques with a capability to fabricate plastic parts as compared to conventional manufacturing techniques. In FDM, thermoplastic feedstock filament is fed through the heated nozzle. The heated nozzle has a movement in X-Y plane. The filament is extruded through heated nozzle where in thermoplastic material is heated above glass transition temperature. The solid part of the filament pushes the molten filament through the nozzle and material is deposited on the build table or previously deposited layer as defined by CAD geometry. FDM part is not only applicable to prototype, model and mould but also increasingly used as end use product in various sectors such as automobile, medical, aviation, consumer product etc. however, compared to conventional plastic processing techniques such as injection molding, FDM produced part has less mechanical properties which reduces the application of FDM parts [1,2]. As now, with the growing popularity of FDM parts for end use application, the mechanical properties evolution of FDM produced component is of research interest.

In order to understand the effect of process parameters on the responses including dimensional accuracy, surface finish, tensile strength, flexural strength, compressive strength and impact strength some work has been carried out by various researchers. Garg and Bhattacharya [3] carried out finite element analysis for FDM tensile specimen and they found that 0° raster angle have higher tensile strength over 90° raster angle. Lanzotti et al. [4] studied the effect of layer height, raster angle and number of shell perimeter on the tensile strength of open source 3D printer printed PLA part. They observed that tensile strength decreases with an increment in raster angle towards 90°, while they observed higher tensile strength at lower value of layer height. Song et al. [5] investigated the mechanical properties of unidirectional printed PLA. Tanikella et al. [6] investigated the tensile strength of FDM printed part using different commercial available polymer material such as ABS, Nylon, PC, HIPS, and T-Glass. They found the higher tensile strength with PC filament. Liu et al. [7] applied the gray taguchi method to study the mechanical properties of FDM part. They studied the effect of deposition orientation, layer thickness, deposition style, raster width and raster gap on the tensile, flexural and impact strength of the part. Perez et al. [8] used a reinforcement in polymer matrix to improve the mechanical properties of the part. TiO_2 as a reinforcement in ABS gives higher tensile strength and introduces the brittle failure. Rankouhi et al. [9] investigated the effect of layer thickness and orientation on mechanical properties of the FDM printed ABS part. They found that at lower layer thickness part exhibits higher elastic modulus and tensile strength. Tymark et al. [10] compared the mechanical properties of the FDM printed part using open source 3D printer over the commercial printer. Sood et al. [11] investigated the effect of layer thickness, orientation, raster angle, raster width and air gap on the tensile, flexural and impact strength of the ABS part. They observed that more number of layers improves the strength due to the increase in diffusion between rasters. Smaller raster angle and negative air gap improves the mechanical properties of FDM part. Riddick et al. [12] studied the anisotropy in tensile properties of FDM produced ABS part. They found that vertically build part has lower tensile properties. Durgun et al. [13] investigated the effect of raster angle and orientation to improve the mechanical properties and surface finish of FDM part. They found that smaller raster angle has optimal condition for mechanical properties and surface finish at a lower production cost.

However, majority of the previous FDM research studies is focused around the mechanical evaluation of the ABS part. Few attempts have been made to study the mechanical behavior of the PLA part, which is more environmental friendly and very popular among the 3D printer community. FDM produced PLA

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parts have also been widely used in the medical field, due to the biocompatibility of PLA for use in applications such as tissue engineering and implants custom-made per patient needs [14,15,16].

In this context, it required to investigate the tensile properties of PLA part. In the present investigation, the effect of raster angle of tensile properties of FDM produced PLA part has been reported. Raster angle has been varied for both unidirectional structure and crisscross structure to investigate its effect on tensile properties on PLA part.

2. EXPERIMENTAL DETAILS

All specimens have been printed using OMEGA Dual Extruder, a high precision open source FDM printer. The machine has a capacity to build a part with a volume of 500 mm X 500 mm X 500 mm with a positional accuracy of ± 10 µm and a nozzle diameter of 0.4 mm. Printer is capable of printing with various filament i.e. PLA, ABS, Nylon, PVA etc. of 1.75 mm diameter.

The primary objective of the present work is to evaluate the tensile properties of the FDM produced PLA part. The test specimen has been designed and fabricated as per ASTM D638 type I standard as shown in Fig. 1, which represent the geometry and dimensions of tensile specimen.

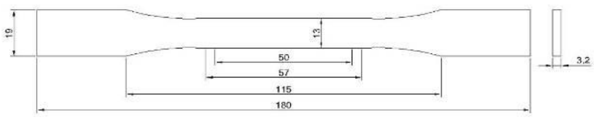


Fig. 1. Tensile specimen according to ASTM D638

Raster angle can be defined as the inclination of raster deposition with respect to the X-axis of machine. Raster angle has been varied for the both unidirectional and crisscross type raster structures. In unidirectional structure, all rasters are laid at constant angle in all layers throughout specimen. In crisscross structure, raster angle rotates each layers in 90° increment relative to previously deposited layers. For unidirectional structure raster angle has been varied at five levels viz., 0°, 30°, 45°, 60° and 90°. While in the case of crisscross type structure raster angle has been varied at 0°/90°, 30°/60° and 45°/45°.

All the specimens were created using a constant set of process parameters as shown in table 1. The specimens were fabricated with the same brand of PLA filament spool to keep the same properties of filament material.

Table 1

Constant process parameters

Parameters	Value
Layer height	0.1 mm
Liquefier temperature	210 °C
Bed temperature	70 °C
Scan speed	50 mm/sec
No. of perimeters	1
% Infill	100 %
Material	Poly lactic acid (PLA)

Table 2

Properties of PLA Filament

Property	Values
Density	1.20-1.25 kg/m^3
Melt point	190-220 °C
Melt flow index	7.8 g/10 min
Tensile strength	62.63 Mpa
Elongation at break	4.43 %
Flexural strength	65.02 MPa
Impact strength	4.25 KJ/m^2

Tensile test was conducted on universal testing machine (Tinius Olsen H50KL) with a 50KN load capacity. The constant strain rate of 5 mm/min was maintained for tensile test.

3 RESULT AND DISCUSSION

Number of specimens have been fabricated and tested in order to evaluate the tensile properties of the FDM printed PLA part. Raster angle has been varied from 0° to 90° for unidirectional structure and the tensile test has been performed. Fig. 2 shows the effect of the raster angle on the tensile strength of the PLA part for unidirectional deposition. It can be seen from fig. 2, tensile strength is found to be decreased with increment in raster angle. Higher tensile strength is obtained at 0° raster angle, which may be due to at 0° raster angle all the rasters are deposited parallel to the tensile loading direction where in each raster bares the load and effect of raster to raster bonding is minimized. The failure takes place due to pulling and necking of each individual raster. For the specimen having raster angle 30°, 45° and 60°, failure takes place due to the shear of the raster bonding at deposition angle. For 90° raster angle, failure takes place due to delamination or separation of raster bonding which is weaker than raster.

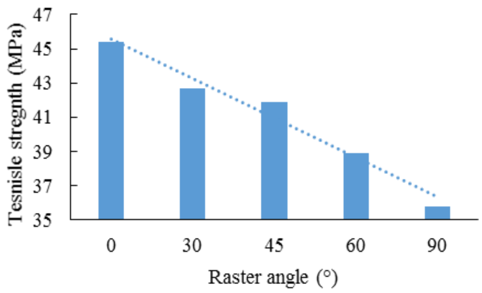


Fig. 2. Effect of raster angle on tensile strength for unidirectional structure

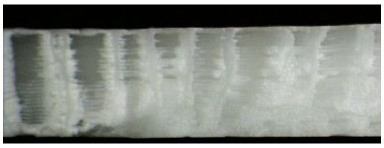
Fig. 3 shows the fractured surface of the tensile specimen at unidirectional raster angle. It can be seen that angle of fracture is similar to the angle of raster deposition except for 0° raster angle where angle of fracture is perpendicular to angle of raster deposition. Further, it can be also observed for smaller raster angle ductile failure occurred with significant amount of ductility and as the raster angle increases mode of failure shifted towards brittle failure.

Fig. 4. shows the effect raster angle on the tensile strenght of PLA part for crisscross structure. It can be seen that higher tensile sterngth has been obtained at 45°/45° followed by 30°/60° and 0°/90°. It may be due to at 45°/45° rasters are deposited at ± 45° angle to the tensile loading direction and mode of failure is due to shearing of the raster bonding, rasters

have more bonding area which may increae the load bearing capacity of the part. While in 0°/90° half of the rasters laid parallel to loading direction and half of the rasters laid perpendicular to the loading direction. So that effect of raster bonding may reduce the strength of the part.

(a)

(b)



(c)

(d)

(e)

Fig. 3. Fractured surface at (a) 0°, (b) 30°, (c) 45°, (d) 60° and (e) 90° unidirectional raster angle

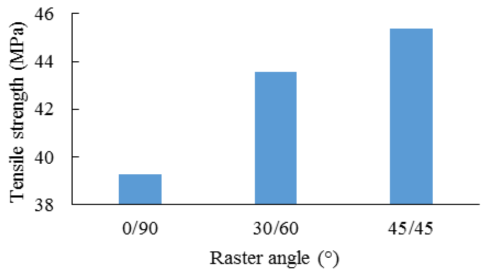


Fig. 4. Effect of raster angle on tensile strength for crisscross structure

Further, comparasion has been made between unidirectional and crisscross raster angle structures. Fig. 5 shows the tensile strength at 0°, 90° and 0°/90° raster angle. It can seen that higher tensile strenth has been observed at 0° raster angle followed by 0°/90° and 90° raster angle because at 0° raster angle all the raster deposited in line with the loading direction.

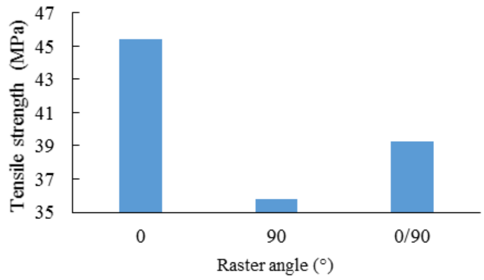


Fig. 5. Tensile strength at 0°, 90° unidirectional and 0°/90° crisscross raster angle

Fig. 6 show the tensile strength at 30°, 60° and 30°/60° raster angle. Higher tensile strength can be observed at 30°/60° followed by 30° and 60° raster angle. At crisscross structure due to the rotation of each raster slice, better contact between adjacent slice can be obtained which improves the strength of the part.

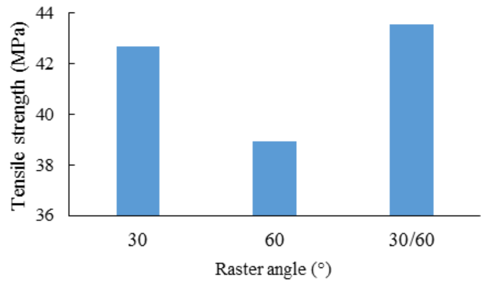


Fig. 6. Tensile strength at 30°, 60° unidirectional and 30°/60° crisscross raster angle

Fig. 7 show the tensile strength at 45° and 45°/45° raster angle. As discussed previsoulsy similar trend has been observed. At 45°/45° raster angle higher tensile strenth has been obtained due to the crisscross strcuture over the unidirectional 45° raster angle.

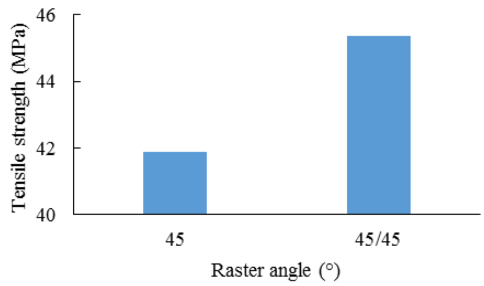
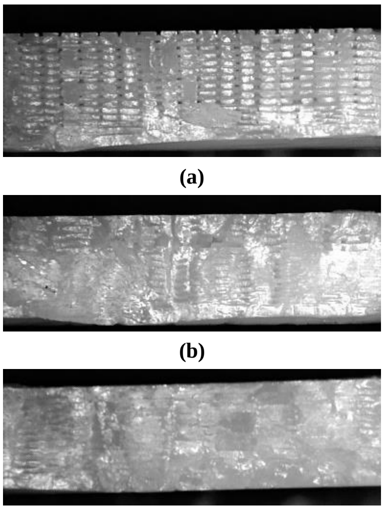


Fig. 7. Tensile strength at 45° unidirectional and 45°/45° crisscross raster angle

Fig. 8 shows the fractured surfaces for crisscross structure having different raster deposition angle. It can be seen that comparitively less voids has been observed with crisscross type structure which improves the bonding between adjacent raster. Improved adhseion between rasters enhance the tensile properties over the unidirectional raster deposition. However, the highest tenisle strenth has been observed at unidirectional 0° raster angle.



(a) **(b)** **(c)**

Fig. 8. Fractured surface at (a) 0°/90°, (b) 30°/60° and (c) 45°/45° crisscross raster angle

4 CONCLUSIONS

In the present study, effect of raster angle on tensile properties of FDM printed PLA part has been reported. Based on experimental investigations, few conclusions can be drawn out as below.

- Higher tensile strength is found at the smaller value of raster angle and it is found to be decreased, as the raster angle is increases for unidirectional raster angle.
- Tensile strength is increased, as the raster angle increases for crisscross type raster deposition.
- Highest tensile strength has been observed at the 0° unidirectional raster angle while lower tensile strength has been obtained at 90° unidirectional raster angle.
- Crisscross type structure have higher tensile strength than those with unidirectional raster angle. However, highest tensile strength has been obtained at 0° unidirectional raster angle.
- Specimen is found to be fractured in line with angle of deposition except for the 0° raster angle. While for crisscross structure, zigzag type failure has been observed irrespective of raster angle.

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