INFLUENCE OF RASTER ORIENTATION AND LAYER THICKNESS ON MECHANICAL PROPERTIES OF ABS MATERIAL USING FDM PROCESS

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ABSTRACT

Rapid prototyping (RP) technologies apply a layered manufacturing (LM) process to fabricate 3D physical models with high efficiency. Fused deposition modeling (FDM) using Acrylonitrile butadiene styrene, (ABS) has emerged as a powerful method in rapid prototyping. In this paper, mechanical properties of the ABS material were evaluated. The influence of raster orientation of 0°, 45°, 60°, and 90°, and layer thicknesses of 0.254 mm and 0.331 mm were studied in detail. All the ABS materials with different conditions were subjected to tensile tests. The results clearly demonstrated that raster orientation has no serious influence on the tensile strength of ABS materials. However, a marginal improvement in tensile strength were observed while the layer thicknesses was increased from 0.254 to 0.331 mm and the 0° raster orientation given better strength than 45, 60 & 90. The anisotropic properties were attributed due to weak interlayer bonding and interlayer porosity.

Keywords: Rapid Prototyping; ABS; FDM; Tensile strength.

1. INTRODUCTION

Rapid prototyping (RP) is used to fabricate a scale model of a physical part or assembly using three-dimensional computer aided design (CAD) data at a faster rate. Fused Deposit Modeling (FDM) is a technique in RP that is based on surface chemistry, thermal energy, and layer manufacturing technology. In this process, filaments of heated thermoplastics are extruded from a tip that moves in the x-y plane. The controlled extrusion head deposits very thin beads of material onto the build platform to form the first layer. The platform is maintained at a lower temperature, so that the thermoplastic quickly hardens. After the platform lowers by the specified distance (i.e., layer thickness), the extrusion head deposits a second layer upon the first. The process is continued to form the desired prototype of specified dimensions. Supports are built along the way, fastened to the part either with a second, weaker material or with a perforated junction [1].

The goal of this paper is to find the tensile strength of the ABS samples with different orientation and different layer thicknesses. The samples were prepared in four different orientation and two layer thicknesses. The deposition was created 0° orientation the layers were deposited along with the direction of the tensile load acting on the axis. Similarly other orientations 45°and 60° were also made in the different angle of 45°and 60°. Similarly, 90° orientation where the layers are at an angle of 90° i.e. perpendicular to the axis of the tensile load [2] was also tested.

There have been several attempts [3-8] to determine suitable part deposition orientation for different objectives like accuracy, build time, support structure etc. Surface accuracy was maximized by minimizing average weighted cusp height. Cost models were presented for stereolithography (SL) and fused deposition modeling (FDM) in such a way that the cost of the component can be estimated for different orientations. A suitable orientation for one of the objectives is determined from the list of pre-selected candidate base planes [10] developed an interactive system to decide suitable part deposition orientation.

II Preparation of specimen

ABS test specimen were prepared asper ASTM standards with different raster orientation of 0°, 45°, 60°, and 90°, and layer thicknesses of 0.254 mm and 0.331 mm. The tensile testing specimen is prepared according to ASTM D638. The schematic representation of the tensile test sample is shown in figure 1.

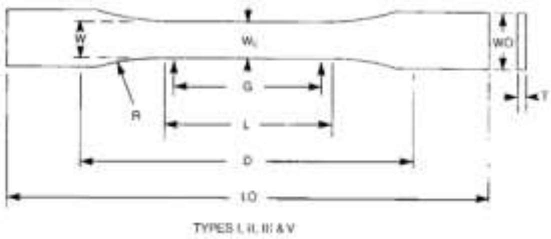

Figure 1: Tensile specimen according to ASTM D638 .

In the present work variations in mechanical properties of test specimens when the raster orientation and layer thickness is varied during fabrication was evaluated. The initial goal was to get the models fabricated by varying the raster orientation angle through 0^0, 30^0, 45^0, 60^0, and 90^0. A schematic representation of the tensile sample with different orientation is shown in figure 2. FDM is a time intensive process; as a result of which the fabrication cost is calculated per-hour basis. The 30^0 orientation was simulated to take up at least 2.5 h of fabrication time per specimen, while the others were estimated a fabrication time of 30 mins per specimen. As a result 30^0 orientations was omitted for further investigation because of excess of time consumption.

The tensile test is one of the main material tests and belongs to the quasi-static and destructive tests. It is used to describe mechanical and deformation properties of a specimen at a parallel tension with a given velocity. ASTM D638 is one of the most common plastic strength specifications and covers the tensile properties of unreinforced and reinforced plastics. A universal testing machine (tensile testing machine) was used to perform these tests.

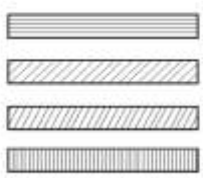

Figure 2: A schematic shows the variation of raster angle orientation during fabrication.

Each tensile specimen was made as dog bone structure with T12 nozzle, two layer thicknesses (0.254 mm, 0.331 mm) and four different raster orientation [0°,45°,60°,90°] is of particular interest as the Quickslice software defaults to this raster. The FDM specimen consists of 12 layers and 9 layers respectively.

III RESULTS AND DISCUSSIONS

The test results of the FDM made parts are tabulated in Table 1 & 2. In Ultimate tensile strength of 0° orientation, are 20.86 and 21.71 MPa respectively. The 45°, 60° and 90° will not have much influence in the strength oriented test specimens were tabulated in table 1 and 2. The weaker orientation was 90° for 0.25 layer thickness 19.15 MPa for and 45° for 0.33 layer thickness 19.45 MPa. The low strength of the test specimen due to be the volumetric shrinkage, weak interlayer bonding [11], or inter layer porosity [12]. The test data clearly shows that layer orientation and layer thickness of the layer manufactured samples were not affected the tensile strength. The properties of the layered manufactured samples are anisotropic [13]. These results confirms the hypothesis that the strength of anisotropy is affected by the directional processing of the 2D layers, i.e., direction of the layered extrusion orientation within the layer [14] or the preferred orientation of weak interface of bonding of the layer and inter laminar porosity [12]. In 0° oriented samples, molecules tend to align with the direction of the stress axis, and produces the strongest direction. The weaker point of the layer orientation is the perpendicular and inclined to the tensile axis of the sample.

The tensile sample of the ABS material made through FDM process were elongated by <2%, (Figure 3 & 4) and failed as semi-brittle manner. The elongation of the ABS was so low.

The fracture surfaces were examined and the fracture path that was controlled by weak interlayer bonding or interlayer porosity [11, 12]. Weak inter layer bonding also caused by the low modular diffusion and low cross-link between the polymers layers deposition during the melt. On the other hand the interlayer porosity reduced the load bearing area across the layers hence there is easy way to create the fracture path. Between the 2D layers the pores were located. So that the weakest links of the interlayer could be easily separated by the shear load

Table 1: Tabulated results of tensile specimen with 0.254mm layer thickness.

Raster Orientation (degrees)	Maximum Tensile stress (MPa)	Maximum Tensile strain (%)	Load at Maximum Tensile Stress (N)	Extension at Maximum Tensile Stress (mm)
0	20.86	1.02	521	2.08
45	19.52	0.98	487	2.19
60	19.6	1.24	490.	2.54
90	19.15	1.58	477	1.84

Raster Orientation (degrees)	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (%)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)	Modulus (Automatic) (GPa)
0	15.8	4.86	395.02	6.44	2.77
45	13.74	2.62	343.62	5.08	3.24
60	13.05	1.65	326.28	3.65	2.57
90	17.73	3.56	443.31	3.28	1.72

Table 2: Tabulated results of tensile specimen with 0.33mm layer thickness.

Raster Orientation (degrees)	Maximum Tensile stress (MPa)	Maximum Tensile strain (%)	Load at Maximum Tensile Stress (N)	Extension at Maximum Tensile Stress (mm)
0	21.71	1.42	542.75	1.94
45	19.45	0.80	486.17	1.96
60	20.98	0.91	524.45	2.12
90	21.11	1.06	527.71	1.89

Raster Orientation (degrees)	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (%)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)	Modulus (Automatic) (GPa)
0	17.94	1.62	448.39	2.41	2.11
45	16.55	0.8	413.83	2.1	3.03
60	18.78	0.87	469.38	2.33	2.86
90	18.35	1.1	458.69	2.01	2.66

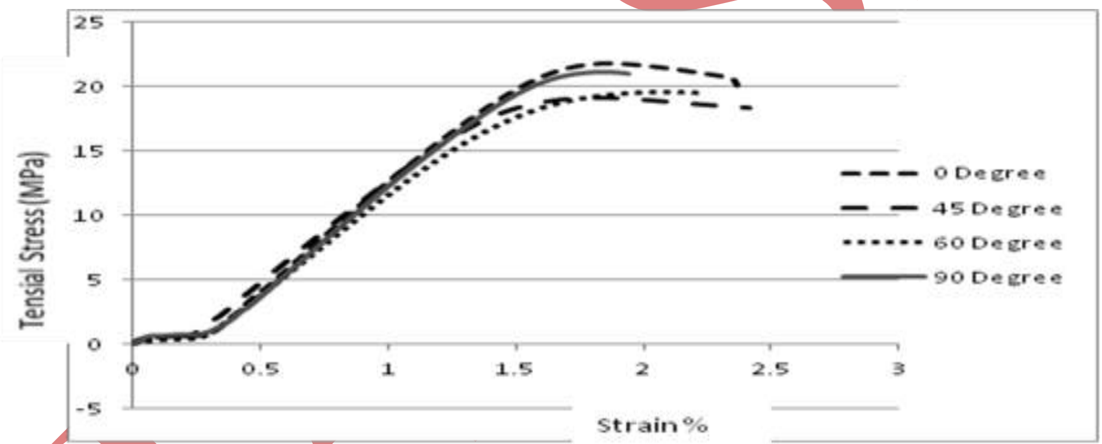

Figure 3: Different Raster Orientation of 0.254 Layer Thicknesses

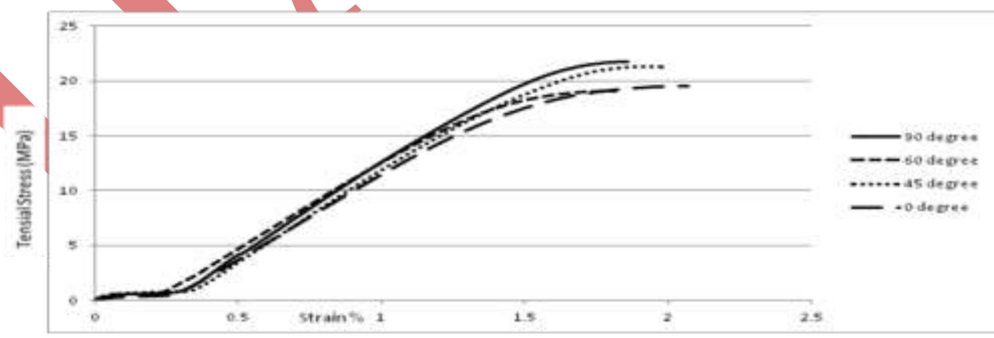

Figure 4: Different Raster Orientation Of 0.33 Layer Thickness

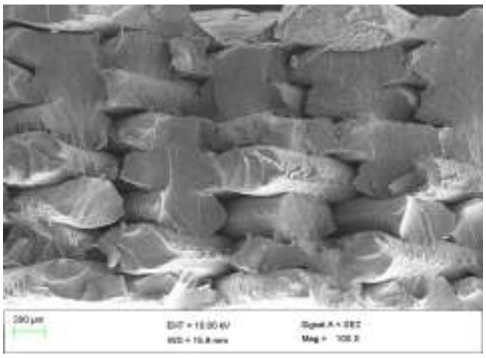	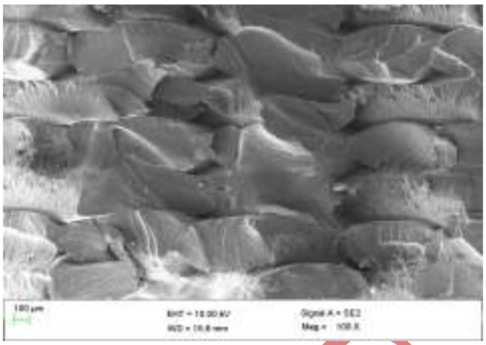
(a) 0.254 layer thickness	(b) 0.331 layer thickness

Figure 5: Fracture Surface of the both layer thickness

SEM image figure 5 shows the fracture surface of both layer thickness of 0° orientation . The weaker interlayer bonding or some amount of interlayer porosity was evident in the failure of the specimens with raster orientations other than 0° [6]. The tensile strength of these specimens depends much more heavily upon the fiber-to fiber fusion and any air gap resulting between the fibers, as opposed to the strength of the fibers themselves. Under the microscopic examination, the 0° orientation of 0.254 and 0.331 layer thickness specimens were displayed multiple failures of individual raster fibers in both shear and tension (Figure 5 a & b) .The SEM result clearly demonstrate that failure occurred by the pulling and eventual rupturing of individual fibers.

IV CONCLUSION

ABS material was successfully fabricated using FDM process, with various raster orientations and layer thicknesses. The following conclusions were drawn: Tensile strength and axial load carrying capacity increases with raster orientation for ABS material with 0.254 mm layer thickness. Also, the ductility decreases up to 60^0 and then increases up to 90^0. For ABS material fabricated with 0.331 mm layer thickness, tensile strength and axial load carrying capacity decreases up to 45^0 and then increases up to 90^0 raster orientation. Axial rigidity and brittleness have increased with raster orientation. The 0°raster orientation given better strength than 45, 60 & 90

The fracture paths of the tensile samples were depending on the layer orientation, where fractures occurred due to de-lamination. This was because by the weaker inter lamination bonding and/or interlayer porosity.

REFERENCE

[1]. Anitha, S. Arunachalam, P.Radhakrishnan. "Critical parameters influencing the quality of prototype in fused deposition modeling", *Journal of Materials Processing Technology*, *Volume 118, Issues 1–3, 3 , (2001). pp. 385-388,*

[2]. Ahn SH, Montero M, Odell D, Roundy S, Wright PK. ,"Anisotropic material properties of fused deposition modeling ABS." *Rapid Prototype Journal;8(4) (2002). pp248–257.*

[3]. Khan ZA, Lee BH, Abdullah J. "Optimization of rapid prototyping parameters for production of flexible ABS object." *Journal of Material Process Technology, 169: (2005). pp.54–61.*

[4]. Rodrıguez, J.F., Thomas, J.P. and Renaud, J.E. “Mechanical behavior of acrylonitrile butadiene styrene (ABS) fused deposition materials. Experimental investigation”, Rapid Prototyping Journal, Vol. 7 No. 3, (2001). pp. 148-158.

[5]. O. S. Es-Said, J. Foyos, R. Noorani, M. Mendelson, R. Marloth& B. A. Pregger. *(2000).* “Effect of Layer Orientation on Mechanical Properties of Rapid Prototyped Samples*”. Materials and Manufacturing Processes, Vol15, No1, pp 107-122.*

[6]. Constance Ziemian, Mala Sharma and Sophia Ziemian. “Anisotropic Mechanical Properties of ABS Parts Fabricated by Fused Deposition Modeling” *Mechanical Engineering, (April 2012). pp 159- 180.*

[7]. S.H. Masood, W. Rattanawong, P. Iovenitti. “ A generic algorithm for a best part orientation system for complex parts in rapid prototyping” *Journal of Materials Processing Technology*, *Volume 139, Issues 1–3, 20,* (*2003*). *pp.110-116.*

[8]. Hong-SeokByun, Kwan H. Lee. “Determination of the optimal build direction for different rapid prototyping processes using multi-criterion decision making”, *Robotics and Computer-Integrated Manufacturing*, *Volume 22, Issue 1, (2006). pp. 69-80.*

[9]. J.E. McClurkin, D.W. Rosen, “Computer-aided build style decision support for Stereolithography”, Rapid Prototyping Journal 4 (1) (1998). pp.4–13.

[10]. P.M. Pandey, N.V. Reddy, S.G. Dhande, (2003). “Surface roughness simulation for FDM processed parts”, Proceedings of 18th International Conference on Computer Aided Production Engineering, pp. 413–421.

[11]. Mattox.R.and J.Knesek, “A Glimpse at Rapid prototyping Technologies”, Aerospace America, (1993). pp.28-32.

[12]. Brown, A.s. “Rapid prototyping without tools” ”, Aerospace America, (1991). pp.18-23.

[13]. Salpekar, S.A., I.S.Raju, and T.K.O’Brien, “Strain-Energy Relese Rate Analysis of Delimitation in a Tapered Laminate subjected to Tensile load”, Journal of Composite Materials, Vol.25, (1991). pp.118-141.

[14]. Gentle, D.F. “Function and Properties Factors in processes Selection”, Engineering Plastics, Engineered Material Handbook, ASM International, Vol.2, (1988). pp.279-287.