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Mechanical Modeling and Testing of 3D Printed Material

[1]Hemanth B R, [2]Mahendra Babu K J, [3]Swarnakiran S
[1][3] Assistant Professor, [2] Associate Professor
[1][3]ATME College of Engineering, Mysuru, [2] PES college of Engineering, Mandya

***Abstract:*-- Fused Deposition Modeling (FDM) is one of the best 3-D printing techniques, where specimen is built as layer by layer deposition from the extruded filaments of melted thermoplastic. Layer orientation plays an important role in surface finish, dimensionality and mechanical behavior. Present work is an attempt to determine the tensile strength, Young's modulus and fracture strain of the 3-D printed model built by using raster fill method according to ASTM D638 standards. The tensile strength and modulus were shown to vary based on the build orientation of identical test specimen. Fractured surface of the surface shows the 3D printed material behaves more like composite structures. Strain gauges were used to measure the uniform strain during the tensile testing. Numerical Modeling of the tensile set up was done in ABAQUS to replicate experimental results.**

Key Words- FDM, ASTM D638, Build Orientation, Strain Gauge.

I. INTRODUCTION

FDM (fused deposition modeling) Model works on the principle of Rapid Prototyping (RP methodology). Rapid Prototyping is a group technology which is used to quickly fabricate a scale model of part or assembly using computational drawing techniques like CAD/CAM. These 3-D Printing technologies enables user to quickly create prototypes of design compared to earlier technology which only created 2 D pictures.

Fused Deposition Modeling (FDM) is one of the best additive manufacturing process in which model is built as layer by layer deposition from the extruded filaments of melted thermoplastic [1]. Each layer is created by the molten filament of Ultem which is deposited in the extrusion head of a FDM machine. The extrusion head follows a particular toolpath and the bonding between layers is due to the thermal fusion and once the temperature cools down two layers will be permanently bonded [2]. The figure 1 shows the FDM process of building layer by layer.

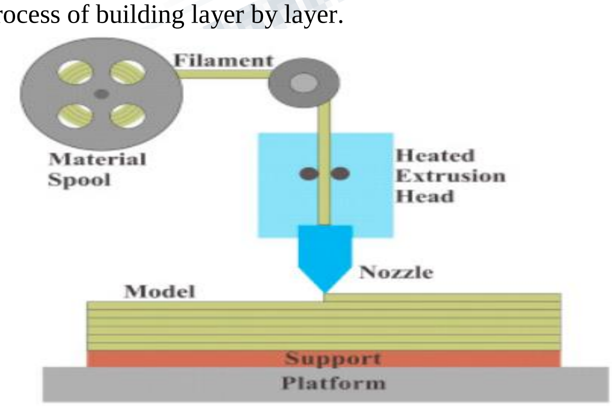

Figure 1.FDM process

To fill one layer by FDM technique the extrusion head should follow particular toolpath. Raster fill is the most commonly used toolpath in which first the perimeter is formed. Later interior is filled with back and forth pattern of an extrusion head and an angle of -45 degree and alternating layers are filled with raster angle of +45 degree to one another. The figure 2 shows the raster angle used to 3-D print the Dog bone samples for testing.

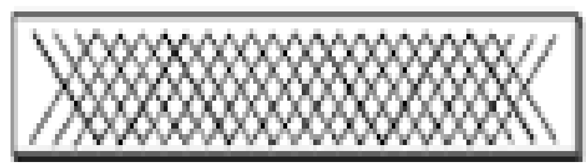

Figure 2. (+45o/-45o) Raster fill

Polyetherimide (PEI, trade name Utem*9085) is amorphous and transparent material with high mechanical properties, low toxicity and desirably low density compared with other materials [3]. These excellent properties make the 3D printed Ultem (FDM technology) most desirable material for aircraft cabins. In this paper we study the effect of three build orientations on the resultant ultimate tensile strength, elastic modulus and fracture strain of the dog-bone sample. The specimens are 3-D printed in X, Y and Z directions.

II. EXPERIMENTAL WORK

The dog bone shape specimens were 3D printed layer by layer with the dimensions are as per ASTM D638 standards. Figure 3 gives the information about specimen dimensions.

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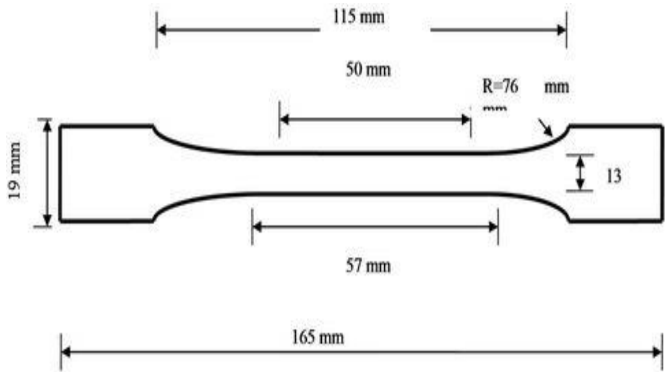

Figure 3. Dimensions of the test specimen

The specimens are 3D printed as per American standards ASTM D638 in a FDM machine layer by layer in X, Y and Z directions as shown in the figure 4. These specimens are further mounted with strain gauges to get strain values while tensile testing.

X-Direction	*Y-Direction*	*Z-Direction*

Figure 4. Specimens built in X, Y and Z direction.

Details of the strain gauges used in the test are provided in Table 1.

Table 1. Strain Gauge Specifications

Strain Gauge	
Type	FCA-2-11
Gauge length	2mm
Gauge factor	2.14 +- 1%
Gauge resistance	120+-0.5 ohms
Transverse sensitivity	0.3%

Two strain gauges were mounted on the middle section of specimen, one along the loading direction (longitudinal) and other perpendicular (lateral) to the loading direction. They are named as 1-L and 1-T. One redundant strain gauge is mounted on the side face along the loading direction, designed as 2-L. Test set up with strain gauges are shown in figure 5.

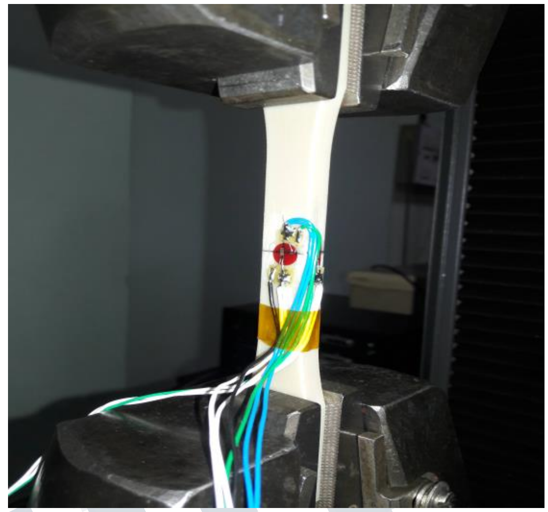

Figure 5. Specimen with Strain gauges.

III. TENSILE TEST

The Tensile test is carried on Instron machine and the loads, extension and corresponding strains for loads are noted down. The figure 6 shows the Instron machine with specimen loaded for tensile testing. We can also see that strain gauge data is collected during testing in a separate data acquisition system.

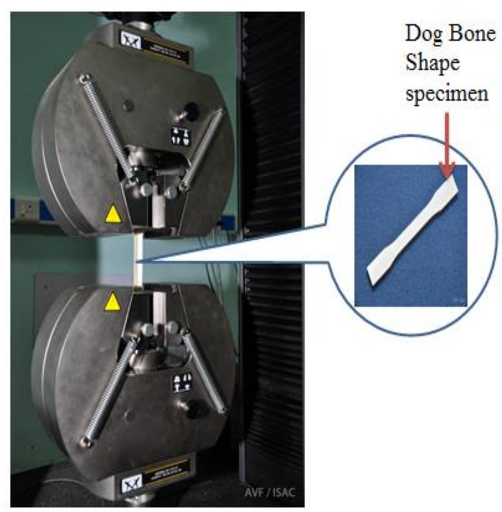

Figure 6. Test specimen loaded in Instron Machine

The testing is carried on until the specimen fractures into two pieces. The testing is carried on for specimens built in X, Y and Z direction and all the data is collected and tabulated.

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IV. TEST RESULTS

The tensile tests were conducted using the Instron universal tensile test machine according to American standards ASTM D638 at room temperature and velocity 5mm/min; test is carried out until the specimen broke into two pieces. The values are tabulated and graphs are plotted for longitudinal load v/s longitudinal extension, nominal stress (s11) v/s engineering strain (longitudinal and lateral) for each built direction. Figure 7 shows the load v/s extension comparison of X, Y and Z specimens. The figure 8 shows the stress v/s strain plot of the specimen build in X, Y and Z direction.

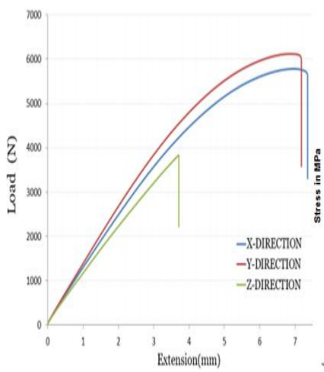


Figure 7. Tensile test results

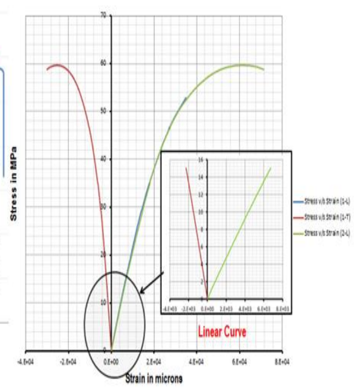


Figure 8.(a). X-component

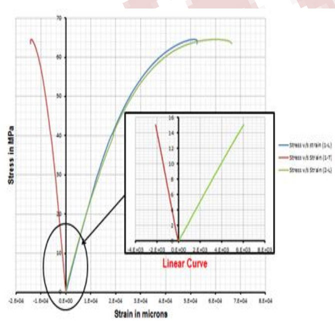


Figure 8.(b). Y-component

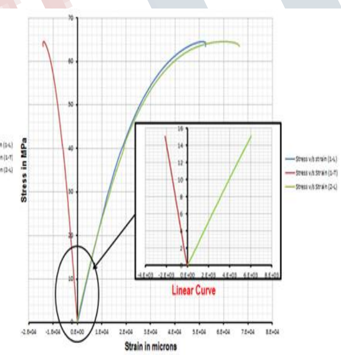


Figure 8.(c). Z-component

Figure 8. Stress v/s Strain graph for X, Y and Z built specimen.

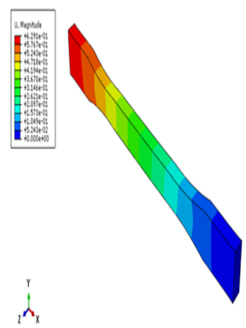
V. FEM MODELING

Characterization of ULTEM9085 has been performed [4] so that it can be simulate in FEM. All characterization reveals that FDM printed parts shows mechanical response based on the built directionality of the specimen. ULTEM 9085 material properties [4] used in simulation to compare with the present experimental results.

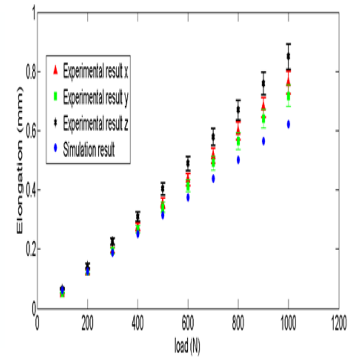
Table 2. Stiffness properties of ULTEM9085

E11 (MPa)	E22 (MPa)	E33 (MPa)	μ_{12}	μ_{12}	μ_{23}	G12 (MPa)	G13 (MPa)	G23 (MPa)	Ref.
2539.4	2327.9	2159.6	0.46	0.39	0.40	635.5	635.5	582.82	[4]

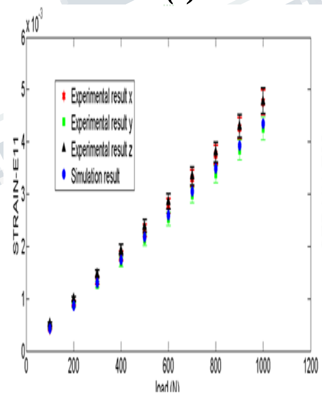
Simulation was performed in ABAQUS software to understand the deformation of part in different building direction. Figure 9 (a) shows the model of the part used for simulation. Figure 9 (b), (c) and (d) shows the comparison of simulation results with the tested results. Tested result may vary by 5% from nominal value and hence deviation from nominal value is reported in all the plots.



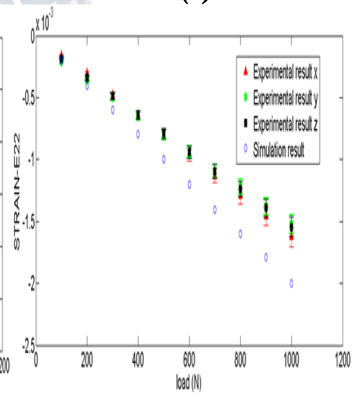
9.(a)



9.(b)



9.(a)

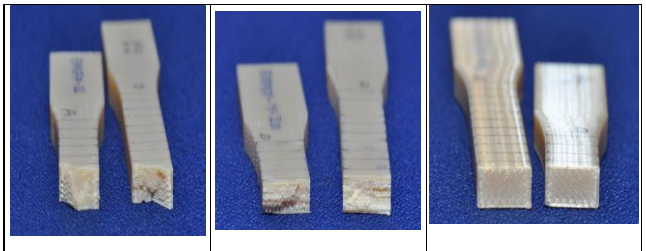


9.(b)

Figure 9. (a) FEM model in ABAQUS software. (b) Comparison of simulated and experimental elongation with load. (c) Comparison of simulated and experimental Strain (E11) with load. (d) Comparison of simulated and experimental strain (E22) with load.

VI. FRACTURED SPECIMEN

At the failure load the specimen broke into two pieces. Specimen built with X & Y direction are loaded perpendicular to the built direction while specimen built in Z direction was loaded in direction of built plane during tensile testing. Rough surface was seen in X & Y oriented sample while smooth shiny fractured surface appeared on Z built sample. Specimen with X & Y built showed breakage of the deposited material while specimen built in Z direction showed smooth sheared surface with no appreciable breakage of filament material. Figure 10 shows the fractured specimens built in X, Y and Z directions.



X-Component	*Y-Component*	*Z-Component*

Figure 10. Fractured specimens in X, Y and Z directions.

Specimens built in the X and Y direction shows brittle fracture as the layers of specimen takes the load crosswise and the raster fill starts to break in the perpendicular direction to loading direction. Due to this crosswise failure of layers the fractured surface will be rough in X and Y direction components. Specimen built in Z direction also shows brittle fracture. However In this as the loading increases the layer itself starts to fail instead of raster fill in the layer. Due to this layer failure the fracture has a smooth surface in the Z direction components.

CONCLUSION

Test specimen built in Y-direction obtain the maximum load of 6.15 KN and the elongation at the failure is 7.201 mm. Test specimen built in X-direction have comparatively lower maximum load 5.83 KN and higher elongation at failure of 7.252 mm. but the specimen in z- direction have lower values in both load and elongation with 3.92 KN and 3.715 mmm respectively.

Present paper presents an effective approach for characterization of properties of 3D printed material mainly focused on ULTEM 9085 material. Experimentation are used to understand the effects of built direction on different mechanical properties. From experimental results it has been found that material has higher young's modulus and ductility if the built is perpendicular to loading direction.

REFERENCES

[1] L. Villalpando, H. Eiliat, R. J. Urbanic, 2014, An optimization approach for components built by fused deposition modeling with parametric internal structures, CIRP Industrial product- service, 800-805.

[2] Wohlers Associates/ Last access 28.06.2010: http://www.wohlersassociates.com/JanFeb10TC.htm

[3] A. Bagsik, V. Schoppner, E. Klemp, 2010, FDM Part Quality Manufactured with Ultem 9085, Polymeric Materials, Halle (saale).

[4] A.S. El-Gizawy, S. Corl, B. Graybill, Process-induced properties of FDM products, in: Proceedings of the ICMET, International Conference on Mechanical Engineering's and Technology Congress & Exposition, 2011

