Experimental Investigation on Mechanical Properties of Annealed Specimens With Different Orientations

P. Devaraj[1], S.Parimala Murugaveni[2]
[1, 2] Dept of mechanical engineering
[1, 2] government college of technology, Coimbatore

Abstract- *Fusion deposition modelling is one of the rapid prototype processes of making three dimensional solid objects directly from a digital file. In this process, an object is created by adding successive layer of material in the filament form.In this project Polylactic acid (PLA), a bio based and bio degradable polymer commonly used for biomedical applications, in which the tensile strength of the material is to be high. In order to achieve the improvement in the required mechanical property, it is decided to change direction of layers during the fabrication of specimen and to do annealing of specimen after the fabrication. The 3D printed specimen was modelled according to ASTM standard D638.The specimen was fabricated with varying infill density of 60,70 and 80% in two axes.Annealing of plastic is the heating of polymeric part to below its glass transition temperature. The annealing process effects on crystallinity, residual stress relief and better inter layer bonding of 3D printed specimens. the specimen with two differentiation orientation in combination of with and without annealing was fabricated and tested. It found that heat treatment had influence on the tensile and elastic limit. The annealed specimen with have with perpendicular orientation with respect line of action have higher strength in comparison with non-annealed specimens of same orientation condition.*

Keywords- FDM, PLA, Annealing, D638

I. INTRODUCTION

Fused deposition modelling (FDM) is an additive manufacturing (AM) process in which a physical object is created directly from a computer-aided design (CAD) model using layer by layer deposition of a feedstock plastic filament material extruded through a nozzle. This is one of the earliest types of AM processes, originally developed and marketed by Stratasys Company in United States during the early 1990s. Because of its safe and efficient operation, durability, low cost, and its ability to process production-grade engineering thermoplastics, it has become one of the most widely used AM processes in the industry for functional prototypes and low volume production. By utilizing the FDM system, engineers can convert their conceptual models or part design of any complexity into accurate physical models readily within a normal office environment.

The FDM process was invented and patented by Scott Crump in 1988. He founded Stratasys Company in 1989 in Minnesota. Stratasys sold its first FDM machine, the 3D Modeler, in 1992. Over the years, Stratasys has attained the position of the unit market leader of AM systems in the world several times. Since the recent expiry of the original Stratasys FDM patents, several low-cost hand-portable versions of the FDM-like 3D printers have appeared in the market adding to its popularity and wider use in the hobbyist and consumer market. Since fused deposition modelling and FDM are trade names used by Stratasys, the manufacturers of other similar systems use different names such as melted extrusion modelling, fused filament fabrication, etc.

Apart from the design and functional prototype application, the FDM process has received considerable attention in the research and development sector in several areas including, part quality improvement, process improvement, new materials developments, and applications in biomedical engineering, tissue engineering (TE), and tooling.

This chapter gives an overview of the Stratasys FDM process, capabilities, and materials, and also presents a detailed review of research and development work undertaken over the years using FDM technology.

FDM is a filament extrusion-based process that integrates CAD system, materials science, computer numerical control, and the extrusion process to fabricate 3D parts directly from a CAD model. In the basic FDM process, a plastic filament is drawn into liquefier head, where the filament is heated to a semiliquid state and then extruded through a nozzle to deposit roads or beads to fill each layer of the part on to a platform in a temperature-controlled chamber. The computer-controlled head moves in X–Y plane while the platform moves in the z-direction as required by the selected layer thickness.

In general, there are four stages in part fabrication by FDM technology:

1. CAD modelling;
2. Pre-processing on FDM software;
3. Part building on FDM machine;
4. Support removal of fabricated parts.

First, a CAD solid model has to be created on any CAD system, and converted into a stereo lithography (STL) format, which is a faceted approximation of the model. The STL file of the model is then pre-processed using FDM software. This preprocessing consists of several important steps including determination of part orientation on the build volume, slicing into thin horizontal layers, selection of various FDM parameters, and generation of supports. A suitable part the orientation of the

STL model is important to minimize or eliminate supports and improve surface finish. Depending upon the type of FDM machine used, FDM process parameters may include raster width, build style, raster angle, air gap, nozzle tip size, model temperature, etc. For each sliced layer, the pre-processing software generates ‘tool paths’ or build instructions for the liquefier head to create each layer. The preprocessed file of the model and supports, called Stratasys machine language (SML) file or CMB file in some FDM machines, is then sent to the FDM machine for part building.

In the FDM machine, the feedstock filament of thermoplastic material is drawn from a spool into the FDM liquefier head by drive wheels, in which it is heated into a semiliquid state and then extruded out as ultrathin beads through the orifice of a nozzle tip fitted at the bottom of the head.

A feedstock filament of support material is drawn from another spool into the liquefier head to deposit the support material through another nozzle tip when needed. The head moves under the control of the computer and deposits the material in thin layers on a fixtureless base. The part is created layer by layer and the material is solidified immediately after being deposited from the nozzle tip and is bonded to the previous layer. The build chamber can be set to a temperature lower than the melting point of the extruding plastic to aid the building process. The completed part is then ready to be removed from the FDM machine. Support structures are later removed by breaking them away from the part or dipping the whole model in a solution. The accuracy and precision of the part depends upon the process parameters and some high-end FDM machines offer extremely high precision and accuracy. According to Stratasys, the FDM process accuracy and precision is also the result of the coordination of material feed rates and liquefier head motion.

The FDM machine uses powerful cura software to prepare and process the STL file of part model for building on the FDM machine. Using this software, the user will open an STL file, configure the machine, orient the model, slice the model, generate supports, generate tool paths for model and supports, create a tool path file (called CMB/SML file). The CMB or SML file is a compressed file that contains all the data that the FDM machine needs to build the part. It contains data about the layers, boundary paths, and tool paths.

Generating the CMB file requires the detailed steps of slicing the model, building supports, and computing tool path as shown figure1.2 in preview.

II. EXPERIMENTAL SET-UP AND FABRICATION

The specimen modelled in CAD design software. This specimen dimensions are according to ASTM D638 for plastic materials in AM. After completion of modelling it should be saved in the format of .STL because most of slicer software support this type of format only. The dimension of ASTM D638 as show in figure 4.1.

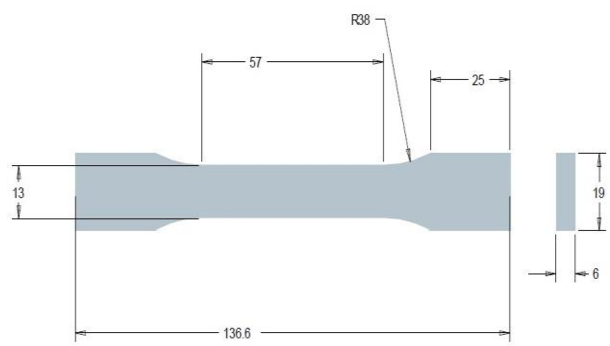

Figure 4.1 Dimension of specimen in mm

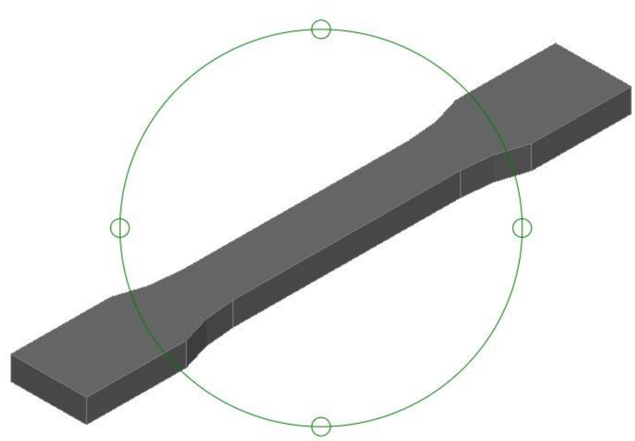

Figure 4.2 CAD model view

4.2 SLICING IN CURA SOFTWARE

In INSTABOT S2 type of FDM printers are mostly preferring UltimakerCura 4.1 for slicing pre-process of AM. The slicing parameter for my work are changing the orientation (object position in slicer software), infill pattern(cube) as constant and infill density (70,60 & 80%) because its affect major in mechanical properties of parts.

Import the CAD model into slicer software then change orientation of specimen and infill density in printing setting option. After importing the CAD model work these works should be sliced into the option visualize each layer generation of printing.
Finally saved into file of G-CODE for 3D printer.

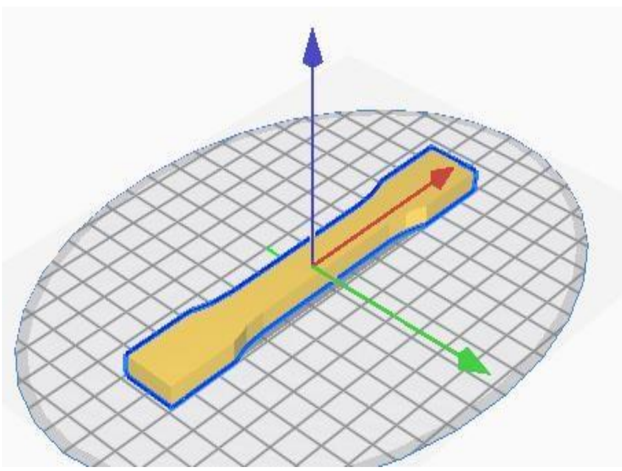

Figure 4.3 Specimen orientation Face up

The vertical position of specimen in cura software as shown in figure 4.4. The orientation along the length has changed with the help of rotation option. The object is rotated 90^{o} normal to bed surface.

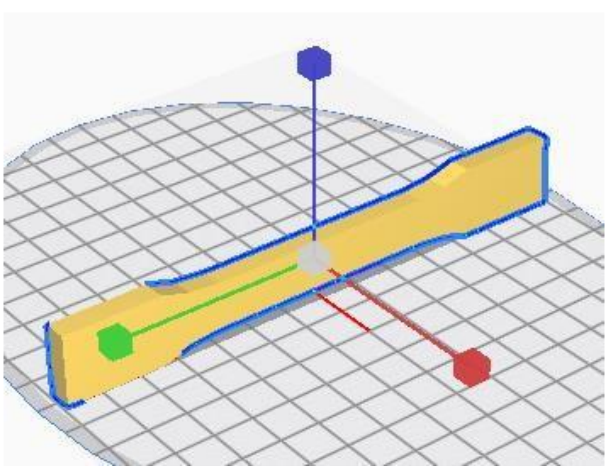

Figure 4.4 Specimen orientation Edge up

4.3 FABRICATION OF SPECIMEN

The sliced specimen G-CODE is saved in the portable device. In this INSTABOT S2 printer has a SD card insert option. Before starting of the fabrication necessary to check the enough filament is available for part fabrication. The image of during part .

Table 4.1 Part fabrication machine parameters

Bed temperature	40°C
Printing temperature	200°C
Printing speed	90mm/sec
Cooling fan speed	100%
Build plate adhesion type	Skirt

Figure 4.6 Fabricated specimens

4.4 ANNEALING OF SPECIMEN

The annealing of specimens in electrical oven have some problems such as it cannot easily measure temperature of medium and specimen placing surface have too much temperature comparing to medium(gas). So, the water method is mostly preferred to heat treatment, which is easily measure the temperature of water by using thermometer. It also has much temperature compared to medium of heat carry, due to this reason it transfers to another oven and wait until attain thermal equilibrium (thermal equilibrium temperature is glass transition of PLA). The water has melting temperature of 100ºC, it is higher than glass transition of PLA so it enough for heat treatment medium for PLA materials. The water should be heated up to 85°C, then it was changed into another pan because the heat of vessel surface higher than the heated water.

The temperature of heated water is to kept reduced to 75°C. After that the specimen is immersed in the heated water until the temperature reaches to room temperature. The temperature of water was measured by using thermometer as shown in figure 4.6.

Figure 4.6 Heat Treatment of Specimen

The temperature of water is decreasing very slowly after reaching at 45ºC, it takes time to reach more than one hour. After attaining room temperature, the part takes off and dried.

4.5 TENSILE TESTING IN UTM

This test is a destructive test method, in which a specimen of standard shape and dimensions is subjected to an axial load as shown in figure 4.7 , during a typical tensile experiment, a dog bone shaped specimen is gripped at its two ends and is pulled to elongate at a determined rate to its breakpoint; a highly ductile polymer may not reach its breakpoint.

The specimen is prepared according to ASTM D638 standard test for tensile properties of plastics. The setup of the experiment could be changed to accommodate to the ASTM standard (e.g compression test, etc). the following procedure followed to complete the test.

III. RESULTS AND DISCUSSION

The data from testing showed variations between different specimen sets for both the annealed with different time of holding and no annealed. The specimen all of them fabricated in constant cube pattern. An examination of the sample specimen for the changing the orientation and direction by 60%, 70% and 80% of the infill density for the materials.

The face up 60% infill density shows the result (average) for annealing Treatment is 12.758 N/mm^2, before the annealing treatment 10.597N/mm^2. The increasing of 2.161 N/mm^2 from the non-annealing strength due to the annealing effect.

The up edge 60% infill density shows the result (average) for annealing Treatment is 13.953 N/mm^2, before the annealing treatment 11.923N/mm^2. The increasing of 2.03 N/mm^2 from the non-annealing strength due to the annealing effect. The stress strain curve show in figure 5.1 for up edge 60% annealed.

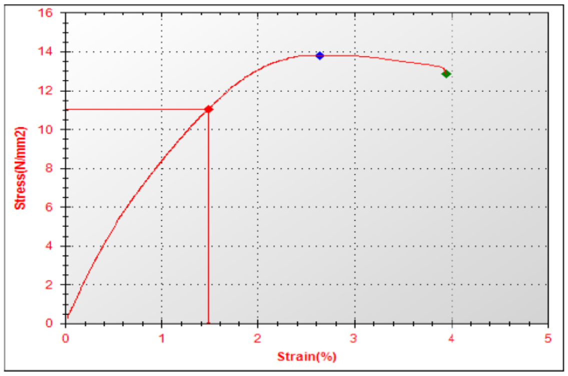

Figure 5.1 stress strain curve for 60% up edge annealed

The face up 70% infill density shows the result (average) for annealing Treatment is 17.477 N/mm^2, before the annealing treatment 14.457N/mm^2. The increasing of 3.020 N/mm^2 from the non-annealing strength due to the annealing effect.

The up-edge orientation of 70% shown the result (average) for annealing treatment 18.381N/mm^2, before annealing treatment 15.944N/mm^2. The variation of annealing before and after annealing shows the increasing of 2.437N/mm^2. The load CHT curve show in figure 5.2 for up edge 70% annealed

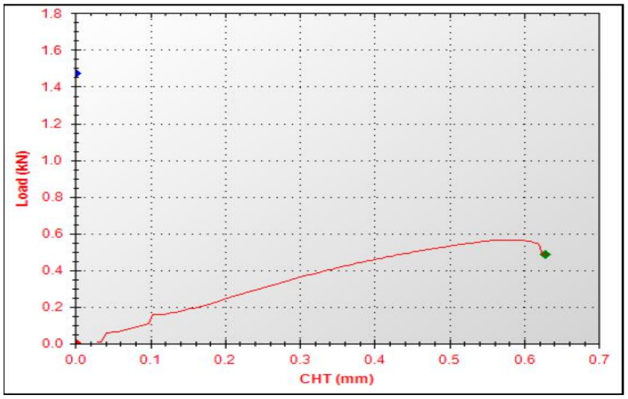

Figure 5.2 load vs CHT for up edge 70% annealed

The face up 80% infill density shows the result (average) for annealing Treatment is 22.315 N/mm^2, before the annealing treatment 20.198N/mm^2. The increasing of 2.117 N/mm^2 from the nonannealing strength due to the annealing effect.

Final specimen at up edge 80% infill density shows the result (average) for annealing Treatment is 24.840N/mm^2, before the annealing treatment 22.783N/mm^2.The increasing of 2.057N/mm^2 from the non-annealing strength due to the annealing effect. The load CHT curve show in figure 5.2 for up edge 80% annealed.

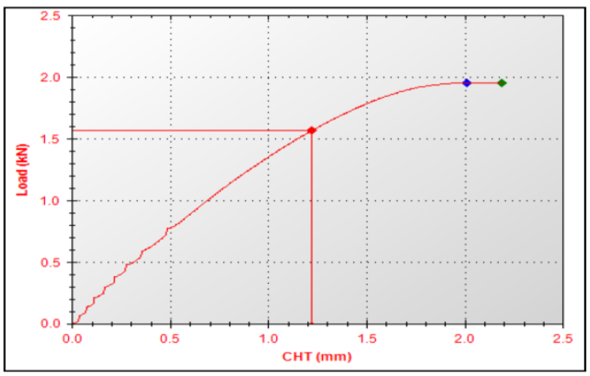

Figure 5.3 load vs CHT for up edge 80% annealed

Table 5.1 mechanical properties of specimens

Sample specification		Without annealed (N/MM^2)		Annealed (N/MM^2) (DIFFERENT TIME)					
				25 MINUTES		35 MINUTES		45 MINUTES	
		1	2	1	2	1	2	1	2
80%	X	20.198	20.095	21.996	22.005	22.843	22.793	22.300	22.315
	Y	22.783	22.698	24.386	24.407	25.164	25.075	24.925	24.840
70%	X	14.457	14.388	16.935	16.945	17.833	17.902	17.548	17.700
	Y	15.944	16.009	18.050	18.560	18.974	19.040	18.500	18.381
60%	X	10.597	10.896	12.172	12.302	12.945	12.765	12.386	12.758
	Y	11.923	11.346	12.343	12.856	13.495	13.120	13.203	13.953

Table 5.2 average value of mechanical properties

Specification		Without annealed	Annealed (N/MM^2) DIFFERENT TIME			
			25 MINUTES	35 MINUTES	45 MINUTES	Overall
80%	x	20.146	22.000	22.818	22.307	22.375
	y	22.740	24.396	25.119	24.882	24.799
70%	x	14.422	16.940	19.007	17.624	17.477
	y	15.976	18.305	19.007	18.440	18.584
60%	x	10.746	12.237	12.855	12.572	12.554
	y	11.634	12.599	13.307	13.578	13.161

From the table 5.2, up edge 80% have higher strength and up edge 60% have low strength after annealed these show that strength depend on strength. The 80% shows poor results in annealing when comparing others. The 60% up edge shows good result on annealing but it has low strength value.

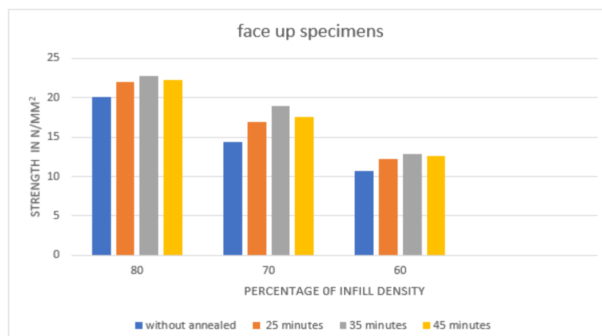

Figure 6.1 Pie chart for face up specimens

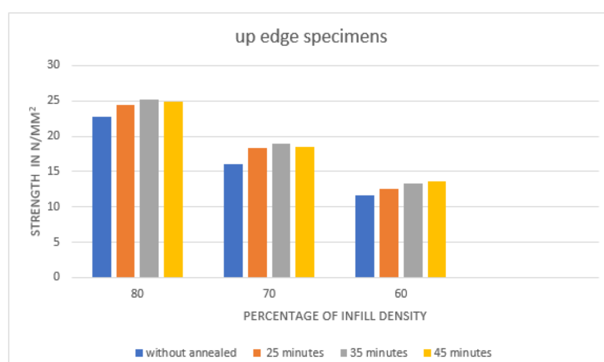

Figure 6.2 Pie chart for up edge specimens

The strength comparison of annealed and non-annealed for different infill density materials shown in figure 6.3. The percentage of increase for different infill density specimens shown figure 6.4.

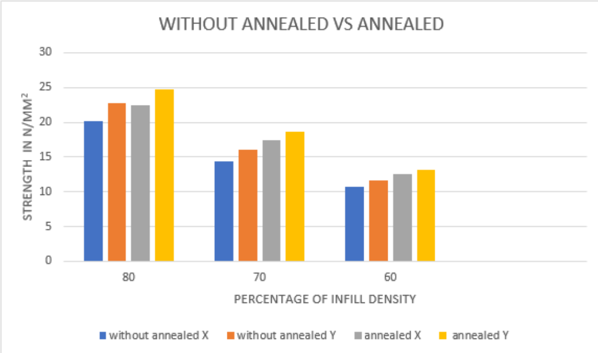

Figure 6.3 Pie chart for annealed vs non annealed specimens

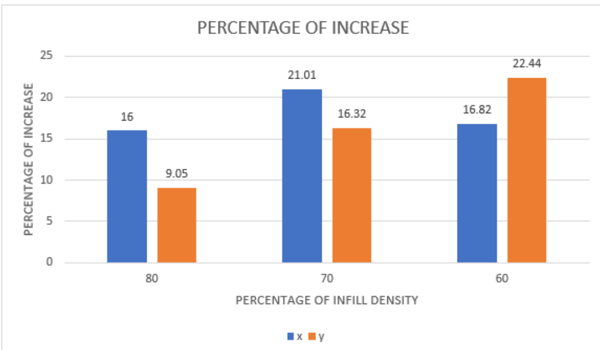

Figure 6.4 Pie chart for percentage of increase in annealed specimens

IV. CONCLUSION

The infill density has major impact on mechanical strength of 3D printed object. The printing orientation also has second variation but it depends up on applied load and printing direction. Naturally occurring normal to the printing direction, the test values show good results. The 80% and 70% in fill density shows higher strength but, has shown low heat treatment affect. On another side, the 60% show low strength but it has shown high heat treatment affect in their increment values.

The volume fraction of 60% infill density is low so it can easily attain glass transition temperature. The 70% and 80% are having higher volume fraction, due to that volume fraction that specimen take time to attain glass transition temperature. Thus, in 60% heat treatment affect time is high, when compare to 70% & 80%. The 80% up edge shows good result in the way of increment due to annealing. The strength comparison of different infill density of unidirectional made materials shown in figure 6.1&6.2 for face up & up edge specimens.

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