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CHARACTERIZATION OF FUSED DEPOSITION MODELING OF PLA+ AND CARBON FIBER -PLA COMPONENTS

D. Dev Singh[1], Avala. Raji Reddy[2], Suresh Arjula[3]

Abstract- There are some difficulties in the manufacturing of complex engineering components by using subtractive machining processes and which leads to more wastage of materials. So to overcome these difficulties additive manufacturing (AM) processes are used. AM is a real scalable manufacturing process for producing any desire fully functional components using hi-tech materials. AM is the part of Rapid Prototyping. There are several additive manufacturing processes available. In this research work, fused deposition modeling process is selected. Mechanical Part Maker FDM 3D printer is used for manufacturing of sample mechanical components made of PLA plus and Carbon Fiber-PLA (abbreviated as CF-PLA) with the orientations of 0^0, 15^0, 30^0, 45^0, 60^0, 75^0 and having 11.1%, 22.2%, 33.3%, 44.4%,55.5%,66.6% densities for each orientation respectively for tensile tests.
ASTM D638-type1 standard specimen for tensile test are modeled by using CATIA V5-R20 software and saved into STL files. These STL files loaded into the CURA15.04.6 software, so it can mathematically slice and generate the G-codes files. The G-code files are sent to FDM machine through PRONTERFACE software and then the Mechanical Part Maker FDM 3D printer can print the required specimen. Tensile tests were performed using UTN-40 tensile test machine. The results shows that the Maximum yield stress and maximum tensile strength for PLA+ specimens.
Key words- Additive manufacturing (AM), Fused Deposition Modeling (FDM), CATIA V5-R20, and CURA15.04.6.

1. INTRODUCTION

1.1. Additive Manufacturing

It is a process of developing 3D CAD model. Additive manufacturing involves layer by layer material deposition process. Additive manufacturing is opposite to subtractive manufacturing process. Additive manufacture now enables both a design industrial revolution, in a various industrial sector such as aerospace, energy, automotive, medical and consumer goods.
According to ASTM standard F2792-10, additive manufacturing is the process of joining material to physical objects from 3D models, usually layer upon layer process as opposed to subtractive manufacturing methodology, such as traditional manufacturing process.
In 1980's first solid-modeling technology came into market. The stereo lithography format (STL) file used in most rapid prototyping machines is a simplified solid model consisting of only triangular faces (facets).

1.2 History of Rapid Prototyping

The development of Rapid prototyping started in the year 1980 by Japanese Dr Kodama Rapid Prototyping got first patent. Charles Hull developed Stereolithograph in 1986. Whereas the FDM was developed by Stratasys in 1992.For metal printing, SLS and SLM were introduced. The chronological developments of Rapid prototyping are provided in Table 1.

Table.1. History of Rapid prototyping

Year	Rapid prototyping Machine developments
1980	First patent by Japanese Dr Kodama Rapid prototyping
1986	Stereolithography taken up by Charles Hull
1988	First SLS machine by DTM.
1992	FDM patent to Stratasys
1995	Z Corporation obtained an exclusive license from the MIT
1999	Engineered organs bring new advances to medicine
2000	A 3D printed working kidney is created, MCP Technologies introduced the SLM technology
2005	Z Corporation Launched Spectrum Z510, color 3D Printer in the market

[1] Research scholar, Department of Mechanical Engineering, JNTUH, Hyderabad, Telangana, India, Associate Professor, Department of Mechanical Engineering, CMR Institute of Technology, Hyderabad, India
[2] Professor, Department of Mechanical Engineering, CMR Technical Campus, Hyderabad, India
[3] Assistant Professor, Department of Mechanical Engineering, JNTUH College of Engineering, Jagitial, India

2006	An open source project is initiated (Rep Rap)
2008	The first 3D printed prosthetic leg
2010	Urbee is the first 3D printed prototype car presented
2011	Cornell University began to build 3D food printer
2012	The first prosthetic jaw is printed and implanted
2015	Carbon 3D issues, their revolutionary ultra-fast CLIP 3D printing machine

1.3 . Rapid Prototyping Working Principle

The basic methods for all current rapid prototyping/ Additive Manufacturing techniques can be summarized as follows:

i. A CAD model is created using any CAD package and then converted to STL format. There are two types of STL files formats: 1.ASCII and 2.Binary. ASCII can read by human, but not binary
ii. The RP software processes the STL file by creating sliced layers of the CAD model and generates the G-code file/program.
iii. The G-code file is send to RP machine. The first layer of the physical object is created by the Rapid Prototyping machine. The object is then lowered or extrusion nozzle can move up by the height of the next layer, and the process is repeated until completion of the object.
iv. The object can be taken out from the manufacturing bed or platform.
v. The supports are removed from printed components. Then the surface of the component is finished and cleaned.

1.4. Fused Deposition Modeling (FDM)

Fused deposition modeling is the second widely used prototyping technology. The process involves first creation of three dimensional solid CAD model. The CAD model is saved as an STL file format. Then the slicing of the CAD model will be taken place into number of layer. Then the plastic filament is unwounded from a coil supplies to an extrusion nozzle. The nozzle is heated to melt the filament and has a mechanism which allows the flow of melted filament to be turned on and off. The nozzle is mounted on a mechanical stage, which can be moved either horizontally or vertically. As the nozzle moved over the table it requires geometry and deposits a thin bead of extruder filament form each layer. The plastic filament hardens immediately and bonds to the layer below. The entire system is contained within a chamber, which is held at a temperature just below the melting point of plastic.

1.5. PLA plus Filament

In the realm of home 3D printing, Polylacticacid (PLA) is king. Although, it is often compared to ABS, first and foremost, it’s easy to print with PLA has a lower printing temperature than ABS and it doesn’t warp as easily, meaning it doesn’t require a heating bed. Another benefit to use PLA plus is that it doesn’t give off an evil smell during printing. It’s generally considered an odorless filament, but many have reported smelling sweet, candy like fumes. Finally, as a biodegradable thermoplastic, PLA plus is more environmentally friendly than most 3D printer filaments, being made from annually renewable resources such as cone starch or sugar cane. It is available in the form of wires having diameter 1.75mm, 2.85mm, and 3.0 mm. Like ABS, PLA is the base material used in many exotic or recreational filaments, such as those with conductive or glow-in-the-dark properties or those infused with wood or metal. Applications are Common prints include models, Low wear toys, Prototype parts and Containers.

1.6. CARBON FIBER- PLA Filament

3D printing filaments like PLA, PETG are reinforced with carbon fiber result in an extremely stiff and rigid material with relatively little weight. Such compounds shine in structural applications that must withstand a wide variety of end use environments. Applications includes, it is a fantastic material for mechanical and body parts and Replacement of parts in model cars and aeroplanes. It is also available in the form of wires having diameter 1.75mm, 2.85mm, and 3.0 mm. The comparison of process parameters and properties obtained with different filaments is provided in Table 2.

Table.2. Comparison of PLA, PLA+ and Carbon fiber PLA

Filaments/ Properties	PLA	PLA+	CF-PLA
Printing easiness	Very easier	Easy to print	Easy to print
Hazardous	No	No	No
Shrinkage rate	Low	Minimum	Low
Wraping	No	Less	Less
Odor	No	No	No
Working temperature	Withstand as solid up to 55^{o}c	Withstand as solid up to 60^{0}C	
Extrude temperature	190-220^{o}c	190-220^{o}c	210^{0}C

Bed temperature	Not required, but for Big parts 40-60^{o}c	40-60^{o}c	60-80^{0}C
Surface finish	Not good than ABS	Low than ABS	Medium
Ductility	Less	Low	Low
Brittleness	More	More	High
Rigidity& flexibility	High rigidity with minimum flexibility	Low	High rigidity and low flexibility
Wraping resistance	More	Minimum	Low
Print quality	High	High	High
Thermal strength	Less than ABS, HIPS,PA,TPE, TPU,PETG	Less than ABS	High but compared to PETG and ABS is less
Toughness	Less than ABS, HIPS,PC, PA,TPE, TPU,PETG	High, compared to ABS low	High
Tensile strength	Equal to HIPS,PETG, more than ABS,TPE,TPU, less than PC,PA	High	High tensile strength
Soluble	No	No	
Specific gravity	1.25gr/cm^3		
Durable	Medium	High	Medium
Applications	Production of food container , biodegradable implants		Phone cases

2. EXPERIMENTAL WORK

2.1. Mechanical Part Makers (MPM) FDM Machine

Mechanical part maker is similar to Rip Rap and ultimaker FDM machine shown in Figure 1. The overall size of the FDM machine is 340mm*295mm*161mm. But this FDM machine produces 165mm length of ASTM D638 type-1 specimen in diagonally using PLA, PLA+, Carbon fiber- PLA, ABS, ABS+, PETG, Carbon Fiber-PETG and other commonly available 3D printing filaments. Table moves in Y-direction and nozzle moves in X and Z-directions. This FDM machine running with a CURA 15.04 6 software and orientations is specified as 0^0, 15^0, 30^0, 45^0, 60^0, 75^0, 90^0 in the software itself. Manually orientations cannot be changed in this software. For manual orientations, flash print software can used, but this machine cannot support it. The specification of the Mechanical Part Maker is given in the Table 3.

Table.3. Specification of Mechanical Part Makers

Build platform size	210mm *210mm*3mm
Part build size	150mm*150mm*125mm
Filament diameter	1.75mm
Nozzle Type	Metal-Hot end made of brass
Software supported	Open Source printing softwares and is compatible with Windows, MAC OS and Linux
Heater Capacity	upto240^{o}c
Timing belt:	3*1524mm GT2
Timing belt pulley	3*GT2 with 40 teeth
Power input	220V
Other features	LCD support and SD card connectivity can be made

Figure 1. Mechanical part makers FDM 3D printer

Designing of ASTM D638 tensile testing component by CATIA V5 R20 is shown is Figure 2. CATIA was developed in the year 1977 by French aircraft manufacturer Avions Marcel Dassault, abbreviation of CATIA is computer aided three dimensional interactive applications. CATIA is innovated rapidly in the year 2010 CATIA V5 R20 software was introduced it is supported by Windows XP, Windows NT and UNIX.CATIA enables the creation of 3D parts, from 2D sketches. It allows organizations to changes in the product or develops new products utilizing a unified performance based systems engineering approach. Slicing of the ASTM D638 Model by CURA 15.04.6 is shown in Figure 3 and saved as G-code file. In PRONTERFACE the saved G-code file is loaded, it consists of machine movements in X, Y and Z axes. Here in this software, it is required to specify the temperature of extruder as well as bed temperature based on the different filaments (see Figure.4).

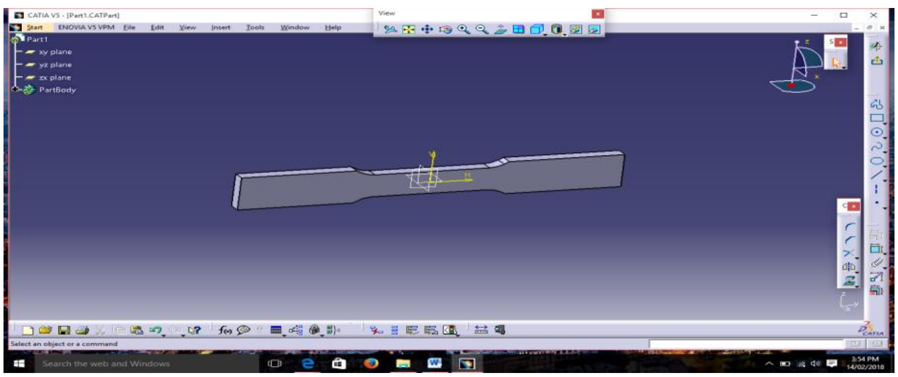

Figure.2. D ASTM D638 CATIA model

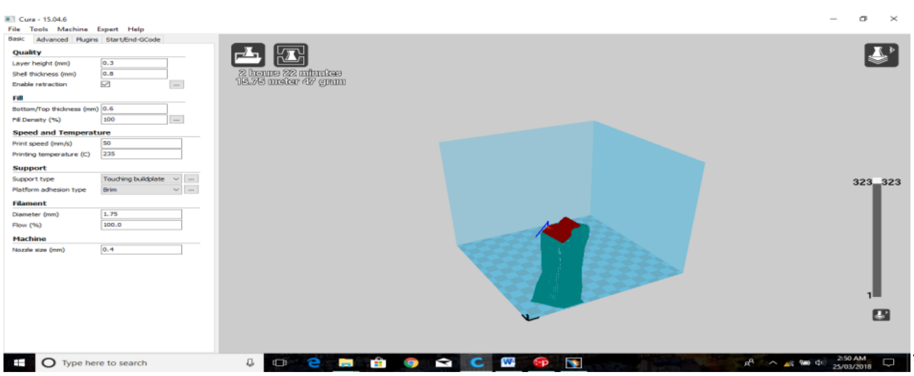

Figure 3. ASTM sliced model

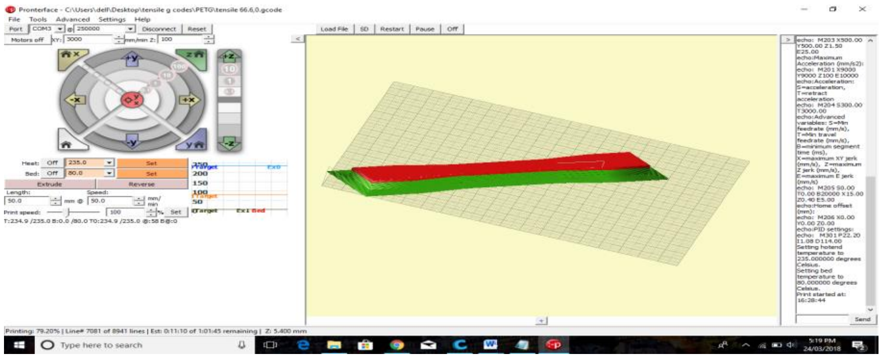

Figure 4. ASTM D638 in Pronterface software

2.2. Tensile Testing

In this experiment two different filaments are used to print six specimens with different densities and orientation. The following notations have been used. A series stands for PLA components, B series stand for Carbon Fiber PLA components. Table 4 shows the input and functional parameters taking for printing tensile testing component with filaments PLA and CF-PLA. Tensile tests were performed on these specimens (ASTM D638 Type I) using UTN-40 having400KN capacity. There are four main parameters: force capacity, speed, precision and accuracy. The machine must be able to apply the force, (quickly or slowly) on specimens based on parameters shown in Table 4, enough to properly mimic the actual application. The failure of the specimens is shown in Figure 6 and Figure 8.

Table 4. Input and functional parameters taken for printing PLA, CF-PLA

PLA specimens notation	1A	2A	3A	4A	5A	6A
CF-PLA specimens notation	1B	2B	3B	4B	5B	6B
Density %	11.1	22.2	33.3	44.4	55.5	66.6
Orientation (degrees)	0	15	30	45	60	75
Feed (m/min)	100	100	100	100	100	100
Speed (mm/s)	50	50	50	50	50	50

Figure 5. Specimens before testing

Figure 6. Specimens’ failure after testing

Figure 7. Specimens before testing.

Figure 8. Specimens' failure after testing.

3. RESULTS AND DESCUSSIONS

The results of 3D printed tensile test specimens of PLA+ and Carbon Fiber PLA build at different orientations and densities are tested by using Universal Testing Machine of model UTN-40 having 400KN capacity are shown in Table 5 and Table 6.

Table 5. Output Properties of PLA + Components after testing

	Specimen	1A	2A	3A	4A	5A	6A
	Load at yield (KN)	0.92	0.8	0.92	1.5	1.2	1.72
	Elongation at yield (mm)	6.850	6.00	7.04	9.44	6.80	8.56
	Yield stress (N/mm^2)	10.146	8.76	10.04	16.26	13.13	18.71
	Load at peek (KN)	1.120	1.00	1.16	1.80	1.48	2.04
	Elongation at peek (mm)	8.060	6.87	8.13	10.40	7.81	9.46
PLA +	Tensile strength (N/mm^2)	12.351	10.956	12.664	19.520	16.201	22.193
	Load at break (KN)	0.080	0.080	0.060	0.040	0.040	0.020
	Elongation at break (mm)	9.740	7.220	8.760	11.010	9.120	10.220
	% reduction area	2.19	1.97	2.01	2.33	2.27	2.38
	% Elongation	1.94	1.98	2.04	1.94	1.94	2.02

Table.6. Output Properties of CF-PLA Components after testing

	Specimen	1B	2B	3B	4B	5B	6B
	Load at yield (kN)	0.94	0.66	1.08	1.34	1.08	1.1
	Elongation at yield (mm)	5.800	7.250	9.880	8.490	7.980	7.340
	Yield stress (N/mm^2)	10.129	7.2	11.731	14.619	11.731	11.998
	Load at peek (kN)	1.120	0.840	1.360	1.640	1.380	1.380
CF-PLA	Elongation at peek (mm)	7.170	8.360	11.030	9.950	9.430	8.500
	Tensile strength (N/mm^2)	12.068	9.164	14.773	17.892	14.990	15.052
	Load at break (kN)	0.140	0.020	0.060	0.040	0.720	0.060
	Elongation at break (mm)	8.420	10.220	13.030	11.410	10.170	9.420
	% reduction area	1.61	3.61	3.48	3.53	4.26	3.86
	% Elongation	2.24	1.98	1.96	2.08	2.12	2.14

This research is focused on yield stress, tensile strength and percentage of elongation. The yield stress of specimens 1A (PLA) and 1B (CF-PLA) with 11.1% density and at 0^0 orientation are 10.146 N/mm^2 and 10.129.193 N/mm^2 respectively and have almost nearer values. So for a particular application PLA or CF-PLA having with same density will be selected. It is observed that there is a more variation of yield stress for specimens 6A and 6B.

The tensile strength of 3B (CF-PLA) specimen is more than 3A (PLA) specimen printed with same density and same orientation. Hence it is recommended to use CF-PLA wherever applicable. The maximum tensile strength is obtained for 6A PLA+ specimen. The percentage of elongation is same for specimens 2A (PLA) and 2b (CF-PLAPLA) with 22.2% density and15^0 orientation at 0.8KN and 0.66 KN respectively.

4. CONCLUSIONS

In this research, ASTM D638 specimen for tensile testing are printed using “mechanical part makers FDM 3D printer” and the following conclusions are drawn.

1. The maximum tensile strength is 22.193 N/mm^2 for 6A PLA+ specimen.
2. Maximum yield stress is 18.712 N/mm^2 for 6A PLA+ specimen, at specified orientations and
3. Maximum % Elongation is 2.14% for 1B CF-PLA, at specified orientations.

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