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Characterization of Additive Manufactured PETG and Carbon Fiber –PETG

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Abstract- Production of complex engineering shapes by using subtractive manufacturing processes is difficult and there is a lot of wastage of raw materials. In order to avoid this, additive manufacturing (AM) processes can be adopted. AM is a Rapid Prototyping method[7] for producing desire fully functional components with available thermoplastic filaments. Here in this research, the selected additive manufacturing process is fused deposition modeling. RipRap FDM 3D printer is used for the production of ASTM D638 Type-I specimens made of PETG and Carbon Fiber- PETG (abbreviated as CF- PETG) with the zero degree orientations only for the varying densities of 11.1%, 22.2%, 33.3%,44.4%,55.5%,66.6% and 77.7%.

ASTM D638 standard specimens for tensile test were generated using CATIA V5-R20 software and saved into STL files. These STL files are loaded into the CURA15.04.6 software; the CURA15.04.6 software can slice and create the g-codes files. These g-code files are transfer to RipRap FDM machine through PRONTERFACE software and then the FDM 3D printer can print the desired specimens. UTN-40 tensile test machine was used for performing tensile tests. It is observed from the results that the tensile strength (27.37 N/mm^2), yield stress (25.2N/mm^2), percentage elongation (2.24mm), percentage reduction in area(4.19mm) are more for Carbon Fiber PETG than PETG components.

Keywords- Additive manufacturing (AM), RipRap FDM, CATIA V5-R20, CURA15.04.6 and PRONTERFACE.

I. Introduction

A. Stereo lithography format[2]

Solid model (data conversion) → STL file [3] (slicing) → cross sectional boundaries (laser drawing) →Layer

The machine controller can slice the model efficiently. Each slice consists of one or several closed-boundary piece-work linear curves. Hatching algorithms are used to generate the desired laser drawing paths.

Since the 1990’s many other rapid prototyping processes [5] have been invented. Almost all of these processes are based on the same general concept, layer by layer deposition process. Another variation of the process combines the concept of using powder and molten powder onto a layer. A heat source, such as a high powered laser, melts the powder before it touches the surface of the object. Another process is based on the process of welding layers of metal sheets together. The layers can be cut by machine or by Electro discharge machining. The success of this process is based on the cost, accuracy, speed and material properties. Rapid prototyping were used primarily for visualization of the general geometry. However, as material properties and build accuracy improved, parts made of rapid prototyping have been used in some functional application. Early rapid-prototyping system could produce objects for form application only. Dimensional accuracy and surface finish requirements are much higher than those for form. Currently, a dimensional accuracy of +/- 0.005 is achievable. Function means that the prototype will be used for function checking; where a load is applied to the

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prototype as it would be applied to the real parts. To ensure success, the material property must be similar to that used in the final product. Recently many new rapid prototyping techniques are evolved in production process.

B. Working Process of FDM [3], [5]

i. First, a CAD model is created by CATIA V5 R20 software and converted to STL file, ii. The STL file needs to be imported to CURA 15.04.6, iii. This software slices the STL file into horizontal layers mathematically and generating the required support, iv. CURA creates the tool paths required for the extrusion head, v. PRONTERFACE is used to connect the computer to the RP Machine, vi. The system draws the cross sectional layers one at a time in the X, Y and Z coordinates by using a heated material extrusion process.

C. Process involved in Part building [3],[5]

i. Import the STL file of part model into CURA, which slices the model in to horizontal layers, ii. The supports are created if required and tool paths for the extrusion head are planned, iii. Filament is loaded into temperature controlled FDM extrusion head, where it is heated to a semi liquid state, iv. The head extrudes and deposited the material in layers on the base platform one layer at a time in X and Y co-ordinate first, v. When the layer is finished, the nozzle moves in Z direction for the next layer, vi. Each layer is extruded with precision, and layers are bonded and solidified, vii. The design object becomes a physical solid 3D part.

D. Types of FDM Filaments

The filament materials presently used in FDM are PLA, PLA +, PLA Carbon Fiber, H –PLA, Conductive PLA, Silk PLA, PLA Glow in the dark, ABS, ABS Natural, ABS +, PC-ABS, Conductive ABS,ABS-M30,ABS -Glow in the dark, ABS-P430, ABS-P400, ABS P30,Flame retardant ABS, PETG, Carbon fiber PETG, HIPS, Wood infill, PA, PC,TPE, TPU, Twinkling, PVA, POM, ASA, Wax, Ceramic infill, Marble infill, Multicolor Filament, Metal infill, Copper infill, Poly Phenyl Sulfone (PPSF), Poly Ether Ketone, ULTEM9085 and PEEK.

E. PETG Filaments

Polyethylene Terephthalate Glycol-modified (PETG) is a very strong and versatile material with high thermal resistance. It is the great material for printing mechanical parts. PETG is for printing large object, because it has almost no warping. The filament having specific gravity 1.27 g/cm^3 requires 220-240^{o}c Extrude temperature and 50-90^{o}c bed temperature. Figuratively speaking, it combines the ease of use of PLA filament with the strength and durability of ABS filament. First, its strength is much higher than PLA and it is FDA (Food and Drug Administration) approved for food containers and tools used for food consumption. Unlike ABS filament, it rarely warps and produces no odors or fumes when printed. PETG filament is not biodegradable, but it is 100% reclaimable. It's known for its clarity and is also very good at bridging. PETG filaments are available in a wide range of color options and they come in 1.75mm, 2.85mm and 3.0mm diameter.

Features of the filaments are i. Higher melting temperature for better mechanical strength, ii. Free from harmful or hazardous materials, iii. Lower shrinkage rate, iv. High rigidity combines with good flexibility, v. Produces objects with higher toughness, vi. Proper for objects with good toughness, higher working and with minimum warping during printing, vii. It shall be printed on heat bed, viii. Parts can withstand to temperature of 80^{o}C without losing strength, ix. Parts can be vapor smoothed for greater strength and better surface finish, x. Easy to glue with acetone.

F. Carbon Fiber – PETG Filaments

When 3D printer filaments like PLA, PETG are reinforced with carbon fiber, the result is an extremely stiff and rigid material with relatively little weight. Very good ductile, impact resistance, higher strength than PLA-carbon fiber, such compounds shines in structural applications that must withstand a wide variety of end-use environments. Carbon Fiber-PETG filaments are available in 1.75mm, 2.85mm and 3.0mm in diameter with wide range of color options. Printing and bed temperature are in the range of 230-250^{o}c and 80-100^{o}c respectively. Applications are it is a fantastic candidate for mechanical body components and replace a part in your model car or plane. Table1 shows the comparison of PETG and Carbon Fiber – PETG.

G. Comparisons of Filament Properties

Table 1 Comparison of PETG and CF- PETG

Filaments/ Properties	**PETG**	**CF PETG**
Printing easiness	Not Easier than PLA	Easy to print
Hazardous	No	No
Shrinkage rate	Low	Low
Wraping	No	No
Odor	No	Very low
Working temperature	Withstand as solid 80^{o}c	Withstand as solid 100^{o}c
Extrude temperature	220-240^{o}c	230-250^{o}c
Bed temperature	50-90^{o}c	80-110^{o}C
Surface finish	Good	Good
Ductility	High	High
Rigidity& flexibility	High with good flexible than TPO,TPE	Medium
Wraping resistance	Less than same ABS,HIPS	Less
Print quality	High	High

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Thermal strength	More than PLA same as ABS ,HIPS,PA less than PC,TPE,TPU	More than PLA+, ABS, CF-PLA.
Toughness	More than PLA same as ABS ,HIPS less than PC,TPE,TPU	More than PLA+, ABS.
Tensile strength	More than ABS,TPE,TPU same as PLA,HIPS and less than PC	More than ABS,PLA+, CF-PLA etc.
Soluble	Acetone	Acetone
Application s	Printing of Mechanical parts	Phone cases, High wear toys, Tool handles and electrical enclosure.

II. EXPERIMENTAL WORK

A. Rip Rap FDM machine

Rip Rap machine [1], [4], [5] is similar to ultimaker FDM machine as shown in figure1. The total size of the machine is 340mm*295mm*160mm with part build size of 150mm*150mm*125mm.This FDM machine [6] produces 165mm length diagonally of ASTM D638 specimen when table moves in Y-direction and nozzle moves in X and Z-directions. This FDM machine operating with a CURA 15.04 6 software at zero degree orientations. It can print 1.75 mm PLA, PLA+, Carbon fiber, ABS, ABS+, PETG, Carbon Fiber-PETG and other commonly available 3D printing filaments with Metal-Hot end nozzle (upto240^{o}c) made of brass. It can also manufacture color parts similar to combination of plastic powder and binder.

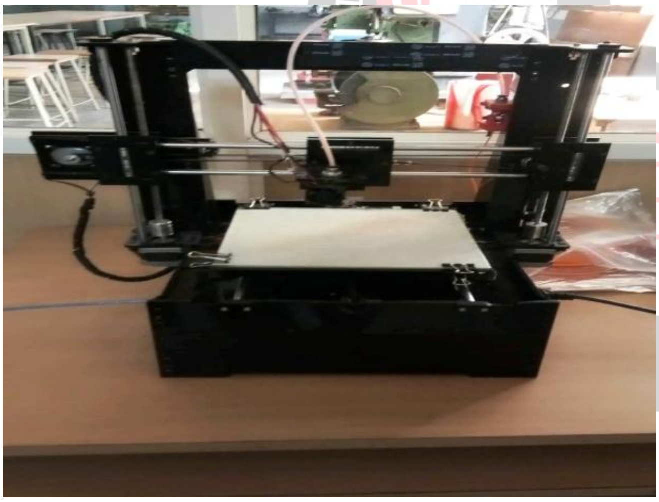

Figure1. Rip Rap FDM machine

Some of the Precautions to follow for running the machine are i. Should not touch heated bed; because sometimes it gives electrical shocks, ii. Should not change position of nuts on the vertical threaded rods, iii. Check home position of extruded nozzle and build plate, iv. Extrude the material by using "extrude" icon provided in CURA software, before giving printing, v. Check working condition of limit switches (end stops). vi. Supply 220V power input to FDM machine, vii. Remove the printed specimen after 20 minutes cooling from the build platform, viii. If the specimen having support structure, remove them after 20 minutes from the build plate and allow for cooling another 30 minutes away from the machine. Then remove the specimen from the support structure.

Modeling of ASTM D638 tensile specimen by using CATIA V5 R20 is shown in figure2 and the complete printed model with accurate dimensions in PRONTERFACE window as shown in figure 3 after being loaded as g-code file in it. Which consists of machine movements in X, Y and Z axes.

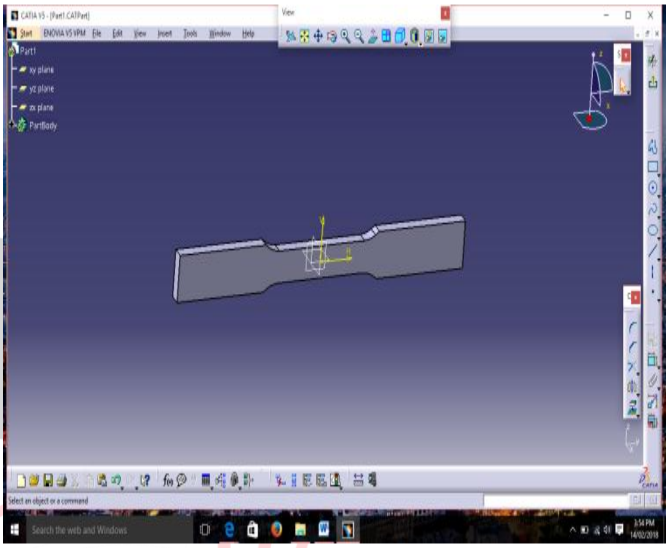

Figure.2. 3D ASTM D638 model

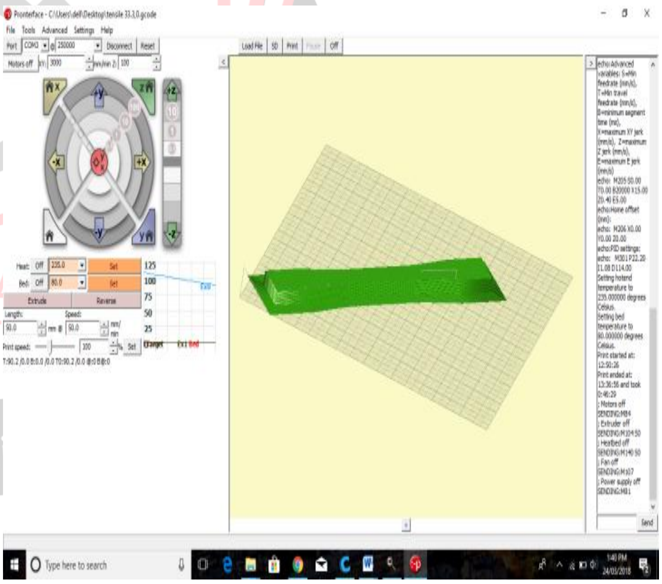

Figure.3. Printed ASTM model in Pronterface

B. Tensile testing

These notations are used to identify the specimens. E series for PETG components, F series for Carbon Fiber PETG components as shown in table2 and table3 at constant speed of 50mm/s. Figure4 and Figure5 shows the failure of PETG and CF-PETG specimens by using UTN-40 having 400KN capacity.

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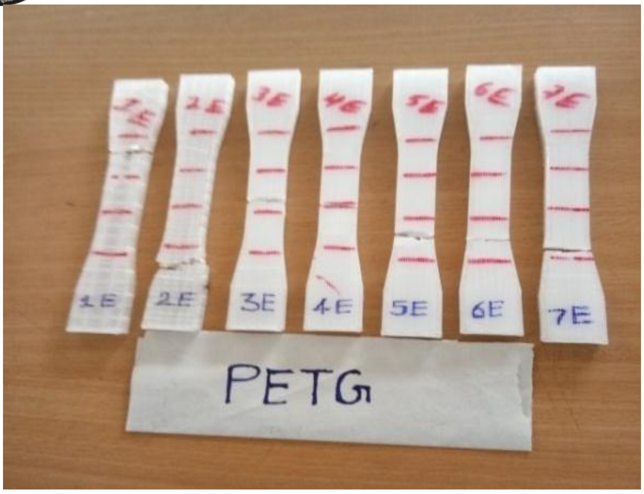

Figure.4. PETG failure specimens

Figure.5. CF-PETG failure specimens

III. RESULTS AND DESCUSSIONS

The tensile test is performed on the Universal Testing Machine of model UTN-40. The tensile strength, Yield stress, Elongation at yield, elongation at break, % reduction area and % Elongation for the specimens obtained is as follows. Later specimens are identified by the notations such as PETG is named by series E and CF-PETG identified by the series F.

Table 2. Results of PETG Components

Specimen	1E	2E	3E	4E	5E	6E	7E
Orientation (Degrees)	0	0	0	0	0	0	0
Density (%)	11.10	22.2	33.3	44.4	55.5	66.6	77.7
Load at yield (KN)	0.74	0.9	1.12	0.76	1.36	1.58	2.08
Elongation at yield (mm)	8.35	8.97	11.40	6.64	9.83	10.27	11.17
Yield stress (N/mm^2)	8.04	9.75	12.1	8.23	14.72	17.19	22.62
Load at peek (KN)	0.94	1.16	1.34	0.96	1.64	1.94	2.42
Elongation at peek (mm)	10.08	10.99	14.17	8.23	11.53	11.82	12.81
Tensile strength (N/mm^2)	10.21	12.57	14.53	10.40	17.75	21.11	26.32
Load at break (KN)	0.080	0.240	0.10	0.04	0.02	0.04	0.14
Elongation at break (mm)	13.23	12.97	15.22	10.69	13.40	12.78	13.58
% reduction area	1.41	3.57	2.19	3.47	2.29	4.19	3.46
% Elongation	2.06	1.94	2.06	1.98	2.08	2.12	2.08

Table 3. Results of CF-PETG Components

Specimen	1F	2F	3F	4F	5F	6F	7F
Orientatin (Degrees)	0	0	0	0	0	0	0
Density (%)	11.1	22.2	33.3	44.4	55.5	66.6	77.7
Load at yield (KN)	0.68	0.7	0.94	0.88	1.48	1.7	2.32
Elongation at yield (mm)	7.38	7.15	9.18	5.92	9.73	9.56	10.88
Yield stress (N/mm^2)	7.39	7.57	10.24	9.59	16.05	18.58	25.2
Load at peek (KN)	0.82	0.86	1.16	1.10	1.68	1.88	2.52
Elongation at peek (mm)	8.64	9.08	11.08	7.15	11.44	11.20	12.63
Tensile strength (N/mm^2)	8.91	9.30	12.63	11.99	18.22	20.55	27.37
Load at break (KN)	0.06	0.28	0.14	0.02	0.10	0.08	0.24
Elongation at break (mm)	9.09	10.66	11.99	8.71	11.81	12.94	13.48
% reduction area	2.25	3.03	2.44	1.61	2.86	2.75	3.74
% Elongation	1.82	1.92	2.04	2.02	2.06	1.96	2.24

It is observed from the above results tables that the tensile strength (27.37 N/mm^2), yield stress (25.2N/mm^2), percentage elongation (2.24mm), percentage reduction in area(4.19mm) are more for Carbon Fiber PETG than PETG components. Load at yield, Load at break, Load at peek, elongation at yield, yield stress, tensile strength are increases for specimens 1E,2E,3E, 1F,2F,3F, and decrease

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for specimens 4E,4F, then again increases for specimens 5E,6E,7E, 5F,6F,7F. Elongation at peek loads is minimum and Load at break continuously increasing for CF-PETG specimens. Elongation at break for CF-PETG is less due increase of carbon content. Because carbon content can decrease the ductility.

Here all the specimens of PETG, CF-PETG are printed at zero degree orientation to get the good bond between the layers by maintaining constant bed temperature. The percentage of reduction in area is more for CF-PETG specimens of 1F, 2F, 3F, 5F, 7F and for specimens 4E, 6E made of PETG. The percentage of elongation is more for PETG specimens compared to for CF-PETG specimens, but it is less for 4E PETG component. PETG, CF- PETG components are printed based on ASTM D638 standard with the variation of densities; hence CF-PETG components almost have better properties.

IV. CONCLUSIONS

In this research work ASTM D638 specimens at zero degree orientation produced by FDM 3D printer are tensile tested and following conclusion are made.

The maximum tensile strength 27.37 N/mm^2 and maximum yield stress 25.2N/mm^2 for 7F Carbon Fiber PETG specimens are observed. The maximum percentage of Elongation is also observed for the same specimen is 2.24mm. It is recommended that the CAD 3D model can be printed with different orientations and densities by others researchers and manufacturers. Finally speaking, the overall performance of Carbon Fiber PETG components is better than PETG components.

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