.

Experimental Investigation on Mechanical Behaviour and Parameters of FDM Printed Carbon Fibre Reinforced PET-G and PET-G

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Abstract

In present study tests like Tensile, Compression and Flexural on the 3D Printed standard specimens of PETG and CARBON FIBER REINFORCED is carried on PETG by changing the printing parameters to find their mechanical properties by using FDM.The experimental results indicated that the tensile strength of carbon fiber reinforced pet-G is 1.28% higher than pure PET-G sample. Its optimum value is observed from Taguchi L9 to be 30.804 from SN curve and same as 34.629 in MEAN curve. The variation in the two values is noticed to be 12.12 % for SN curve and 0 % in case of MEANS Carbon fiber PET-G specimen with 300μ layer thickness, 80% infill density, 60 mm/sec print speed had the largest mean value of tensile strength. The ultimate tensile strength of fabricated specimen with 300μ layer thickness, 80% infill density, 60 mm/sec print speed could increase 1.28% when compared with pure PET-G specimen.

Keywords:*3D printing;BiodegrdablePolymers; FDM;PET-G,Fabrication,Testing.*

1. Introduction

In recent years,biodegradable companies are drawing attentions in aerospace applications because of serious environmental problem which are cause due to thermosetting composite. Osgouei *et al* reviewed the application of enviromental polymers and came to conclusion bioploymers can offer enviromental benefits such as biodegrabilibty and renewability[1].Polyethylene terephthalate (PET-G) is a biodegradable and eco-friendly material having good-mechanical properties.3D printing method is widely investigated in processing the thermoplastic resin of PETG due to the good characteristics of strong operation, low cost and no need of tooling or mold. Lithography Apparatus (SLA) and Fused Deposition Modelling (FDM) are two printing techniques[2].For industrial production fused deposition modelling is a better choice with low cost of printing device and thermoplastic materials.Various types of devices are printed using FDM. Hopkinson, N& Dickens have introduced materials that are appropriate for final manufacture, which has in turn introduced the possibility of directly manufacturing finished components[3]. Hutmacher *et al.* (2001) and Ahn *et al.* (2002) investigated the mechanical strenght and anisotropic properties of devices or parts produced using FDM technique[4][5].Matsuzaki *et al.* (2016) investigated that continuos fibre reinforced composites can be fabricated and manufactured using 3D printing and this technique has the potential to become the methodology for next generation[6].Mori *et al.* (2014) printed a sandwich structure with carbon fibers placed between lower and upper plastic plates and heated after 3D printing to bond the carbon fibers with the plastics[7].These printing methods mention above can manufacture continuous carbon fiber reinforced thermoplastic composites.However the the major disadvateges is the weak infiltration and between fibre and resin which can reduce the performance of printed composites.

To develop the continuos carbon-fibre re-inforced PET-G composites with curved structures and with higer mechanical strength a proto-typing approach has been propsed in this paper which can be used for rapid and continues printing.Rapid proto-typing refers to a class of technologies in which physical models can be automatically constructed using CAD data. The key idea of rapid prototyping technology is based on decomposition of 3-D computer models into thin cross-sectional layers, followed by physically forming the layers and stacking them up “layer by layer.”[8] Mansour, and Saleh N investigation into the advent of Rapid Manufacturing in influencing an individual designer's approach to product design and materials selection is detailed.[9] Bitzez developed adaptive design technologies by investigating current design methods and knowledge of deployable technologies in the area of engineering design and manufacturing[10] John K Borchardt used unmanned aerial vehicles spur composite, keeping flight time of the UAV’s in mind, the UAV’s are made of light but durable materials.and new composites that are being developed make use of high molecular weight polyethylene, S glass, E glass, aramid, quartz, bismaleimide and graphite fibres reinforcing epoxy, polyester, vinyl ester, phenolic and polyimide resins.[11].

1.1 Methodhology of Rapid prototyping.

The basic methology of for all current rapid prototyping techniques is almost same with some variation .A cad model is designed and constructed and the cad model is converted into .stl format [12].The Rapid prototyping machine can process the .stl model by creating sliced layers of the model.The model is then lowered by the thickness of the next layer,and the process is repeated untill the completion of the layer.The surface of the model is cleaned at the last.

1.2 Designing of 3d printing:

The first step in genrating any FDM part is to create a three dimensional solid model.The stl format is used because it simplifies the geometry by the reducing it to most basic components.Once the stl part is created it is exported to slicer where it is horizontally sliced into many thin sections.

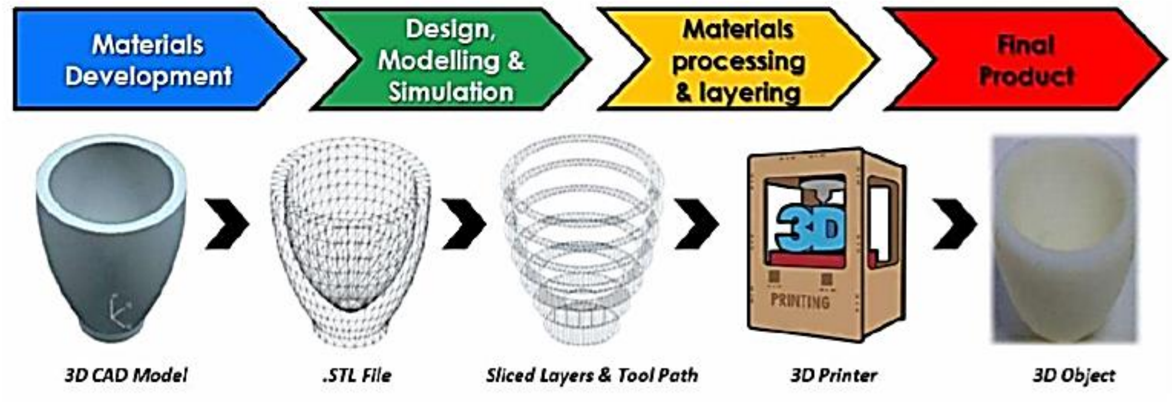

Fig. 1: Process of 3D printing.

2. Fabrication and Experimental.

Three different types of specimen are modelled in stl format and fabricated using FDM machine. FDM works on an "additive" principle by laying down material in layers; a plastic filament or metal wire is unwound from a coil and supplies material to produce a part. FDM begins with a software process which processes an STL file (stereolithography file format). During the pre-processing stage, the wall thickness of the CAD model was offset so as to account for the metal foil thickness that would be realised during the deposition phase. Figure 2 and 3 shows the ASTM standard dimensions for the samples fabricated.Figure 4 shows schematic diagram of 3D printing machine and 3D printer used for printing the specimen.Figure 5 shows the specimens which are printed by the 3D printer.These specimens will be used for the testing the mechanical properties .

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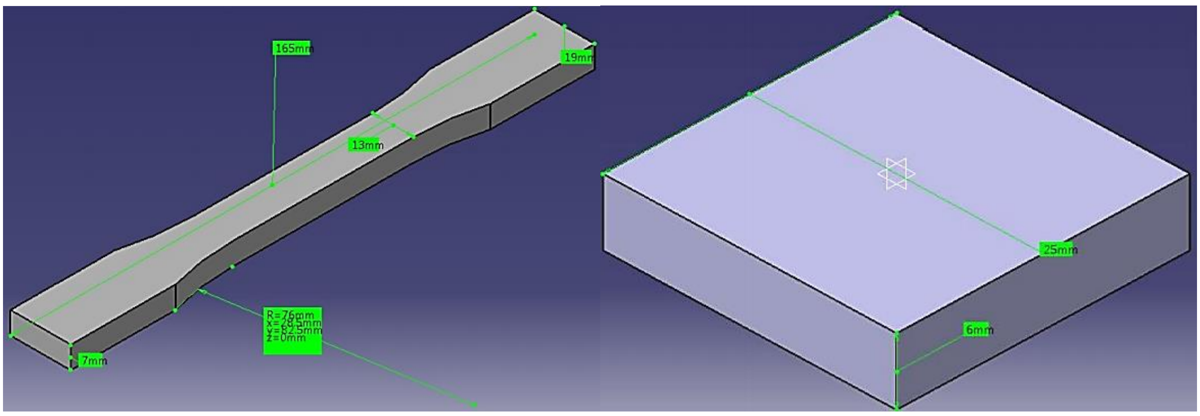

Fig. 2: Process of 3D printing

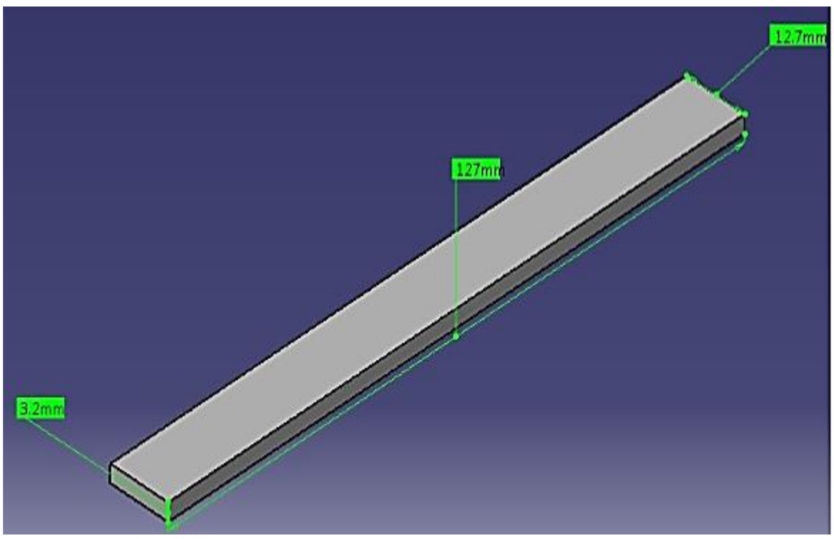

Figure: 3 Design of Specimen

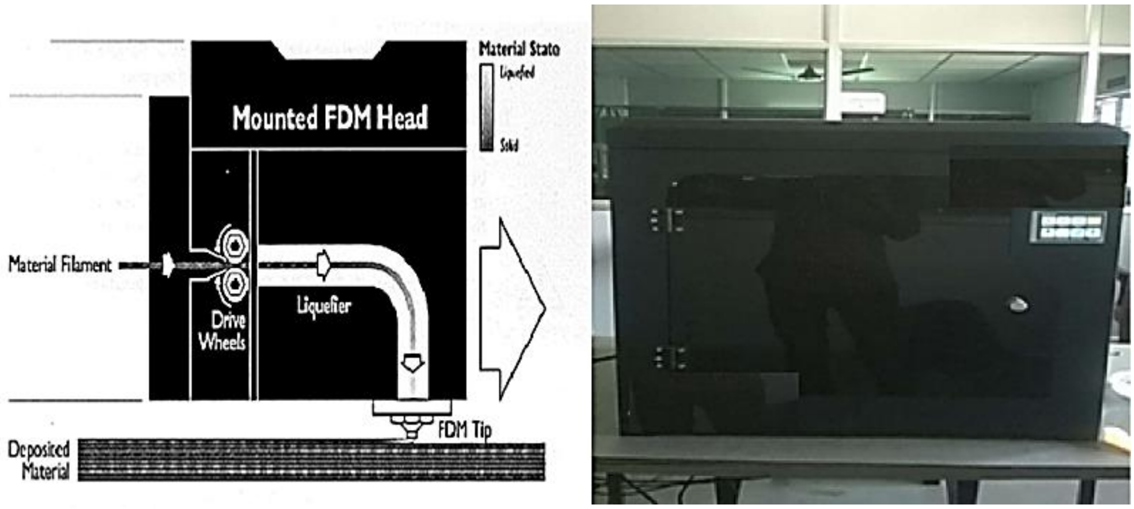

Figure: 4 Schematic Diagram of 3D printer(left) and 3D printer (right)

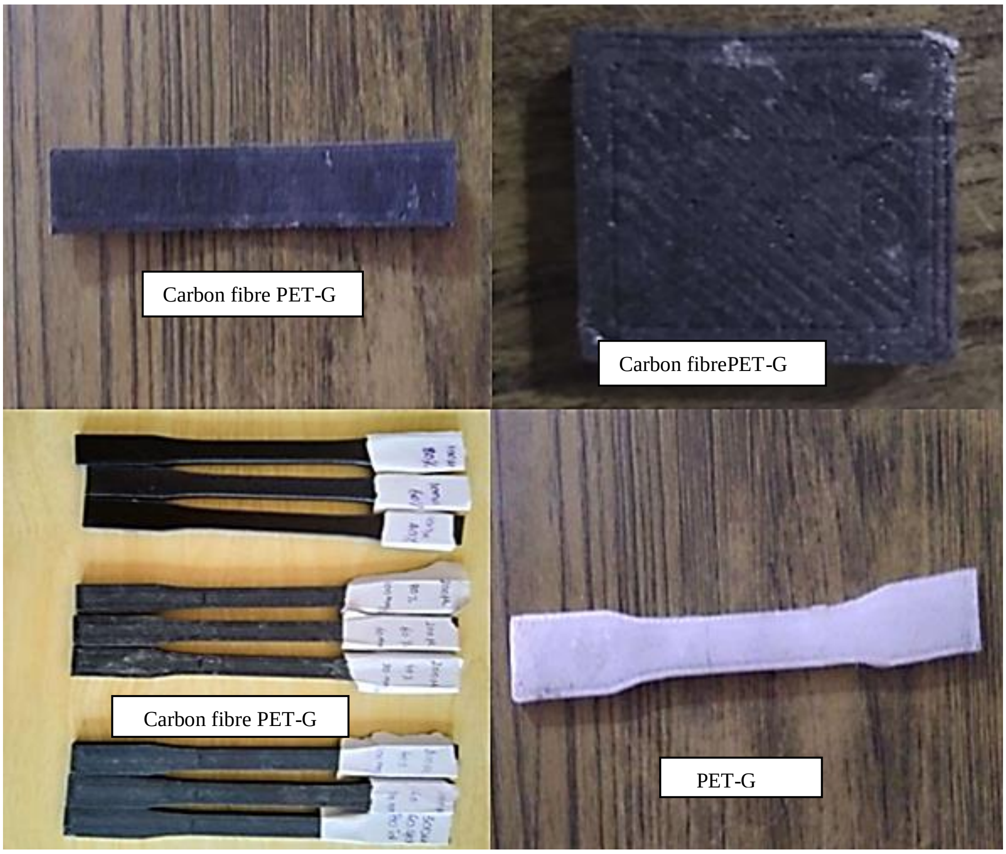

Figure: 5 3D Printed Specimen before testing

2.1 Testing of fabricated design :

Since the work is on testign Carbon fibre reinforced Pet-G for MAV applications 3d printing nine samples specimens ASTM D638 of different paraments according ti Tguchi L9 mecthod and comparing thr largest outcome with Pet-G and also testing the carbonfibre reinforced Pet-G with the same parameter by conducting flexural ASTM D790 and shore hardness test ASTM D785..Three types of tests will be performed in accordance with ASTM standard on an Universal Testing Machine of 60 T capacity as shown in figure 7.The test specimen was first conditioned at 23± 2 and at 50 ±5 relative humidity for not less than 40 h prior to the test.The widht and thickenss of each specimen to the nearest 0.025 mm[0.001] was measured.The width and thickenss measurements at the centre of each speciemen were also made within each end of the gage length.

2.1.1 Uttimate Tensile Testing

Specimens were placed in the grips of the Universal testing machine,taking care to align the long axis of the specimen and the grips with an imaginary line joining the points of attachement of the grips to the machine.The testing between the ends of the surface was noted and set according to the standard.The grips were tightened evenly and firmly then, a Calibrated extensometer was attached to the specimen and gage length. The crosshead speed was set to 50mm/min and the machine was started, during testing the inbuilt software records and plots the load-extension curve of the specimen using which the properties such as tensile strength, Young modulus and elongation at break were then calculated and recorded

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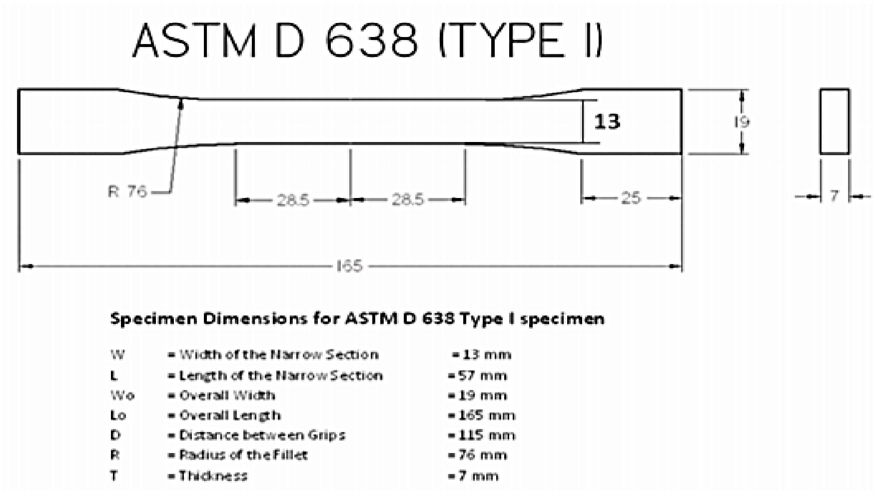

Figure: 6 Dimensions of Specimen according to ASTM

Figure: 7: Mechanical tests conducted on 60T UTM (Tensile Test)

2.1.2 Flexure Testing

The stree-strain behaviour of polymers in flexure is of interest to a designer as well as a polymer manufacturer.Flexural strength is the ability of the material to withstand bending forces applied perperndicular to this longitudinal axis.The flexural modulus is a measure of the stifness during the first or initial part of the bending process.The value of flexural modulus is ,in many cases equal to the tensile modulus.The flexural test was carried out using an UTM machile according to ASTM D790.Since the modulus was determined between small initial deflections,a low force load cell(100N) was used to ensure good accuracy.Flexural test were carried out using a simple supported beam.The distance between the spans is 100mm and a crosshead speed of 3mm/min was used.The test was carried out at room temperature.In this research,five samples were tested for each composition and average values were recorded.Flexural toughness was calculated from the area under stress-strain curve.The calculation of flexural modulus and strength is as follow.

$Flexural\ modulus = Flexural\ Strength = \frac{L^3 \Delta W}{4bd^3 \Delta S}$ Where W is the ultimate failure load (N), L is the span length between the supports (m), b is the mean width of the specimens (m), d is the mean thickness of the specimens of the sample (m), w is the increment load (N) and S is the increment in deflection.Figure 9 shows flexural testing machine used for testing the flexural strength of 3D printed samples.

Figure 8: Flexural Testing Machine (60T UTM) Hardness Test

2.1.3 Hardness Testing

Hardeness is a characteristic of a material,not a fundamental physical property.It is defined as the resistance to indentation,and it is determine by measuring the permanent depth of the indentation.Figure 10 shows hardness testing machine used for testing hardness of the specimens.

Figure 9 : Flexural Testing Machine (60 T UTM)

3.Results and Discussions:

3.1 Tensile Test Results

The tensile load is gradually applied till the specimen is broken at the average max. Values of 1.68 - 2.98 KN. The load then falls to zero. The maximum tensile strength obtained for Carbon Fiber Pet-G from the experimental value is 34.629 MPa. Its optimum value is observed from Taguchi L9[13] to be 30.804 from SN curve[14] and same as 34.629 in MEAN curve. The variation in the two values is noticed to be 12.12 % for SN curve and 0 % in case of MEANS. Tensile test resultsThe maximum tensile strength obtained for Carbon Fiber Pet-G and for PET-G from the experimental value is 34.629 MPa and 34.192 MPa respectively, where the variation is noticed to be 1.28% increase in Carbon fiber PET-G.Figure 10 shows the carbon-reinforced PET-G samples after the tensile test been performed on them.Figure 11 shows PET-G sample after the tensile test been performed on them.Figure 12 shows the ultimate strength of 9 different samples for testing and comparison of ultimate strength of carbon-reinforced PET-G sample and PET-G sample.

Fig. 10: Tensile Specimens After Testing (Carbon fiber PET-G)

Fig. 11 : Tensile Specimen After Testing (PET-G)

Note: At 300 microns, 80 %, 60 mm/sec we got more ultimate load as well as ultimate tensile strength. So, we performed tensile test on PET-G and flexural, shore hardness tests on carbon fiber Pet-g with same parameters

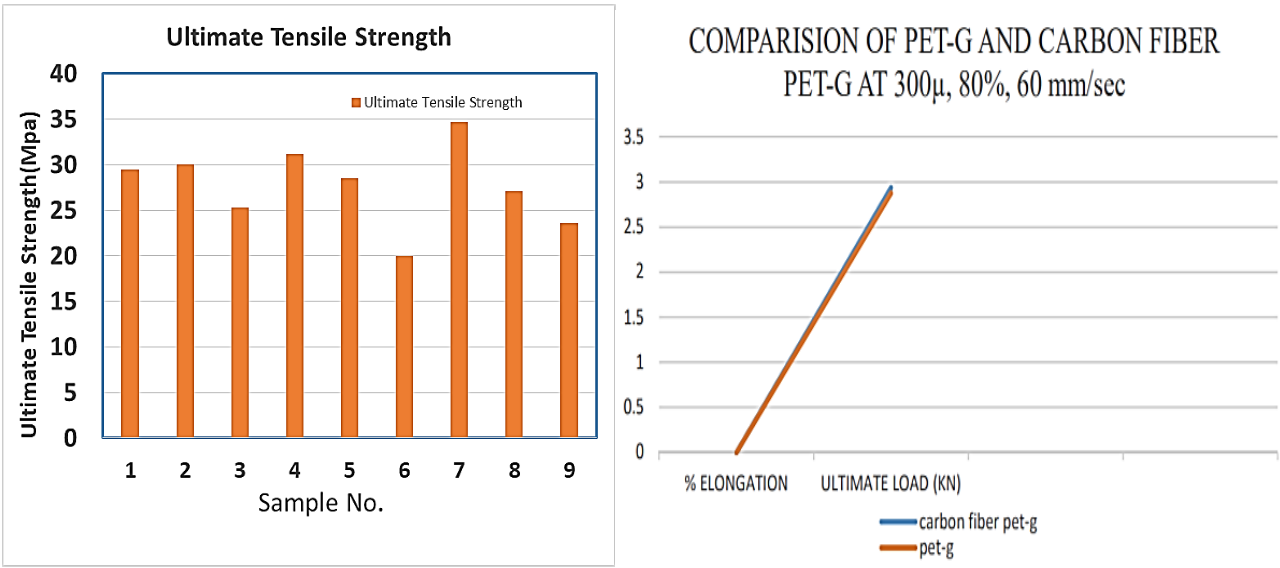

Fig. 12 : Ultimate strength of tensile specimens and comparison of ultimate load in KN

Table 1 Mechanical properties of Carbon Fiber Pet-G Tensile Specimen

Sample No.	Ultimate Load (KN)	Ultimate Tensile Strength
1	2.7	29.466
2	2.7	30.030
3	2.28	25.244
4	2.58	31.174
5	2.34	28.481
6	1.68	20.005
7	2.94	34.629
8	2.28	27.049
9	1.98	23.571

3.2 Flexural Test results:

The flexural strength obtained by experimental analysis is 255.08N/mm2 . This flexural test is performed under maximum parameter which is obtained in tensile test i.e, at 300µ, 80%, 60 mm/sec.Figure 13 shows flexural tested specimen before and after the been performed.

Table 2 : Flexural test results

S.NO.	Specimen	Load P(N)	L(mm)	3PL	b(mm)	D(mm)	d*d	$2bd^2$	Flexural Strength (N/mm^2)
1	300µ, 80%, 60mm	480	50	72000	13.28	3.26	10.6276	282.27	255.08

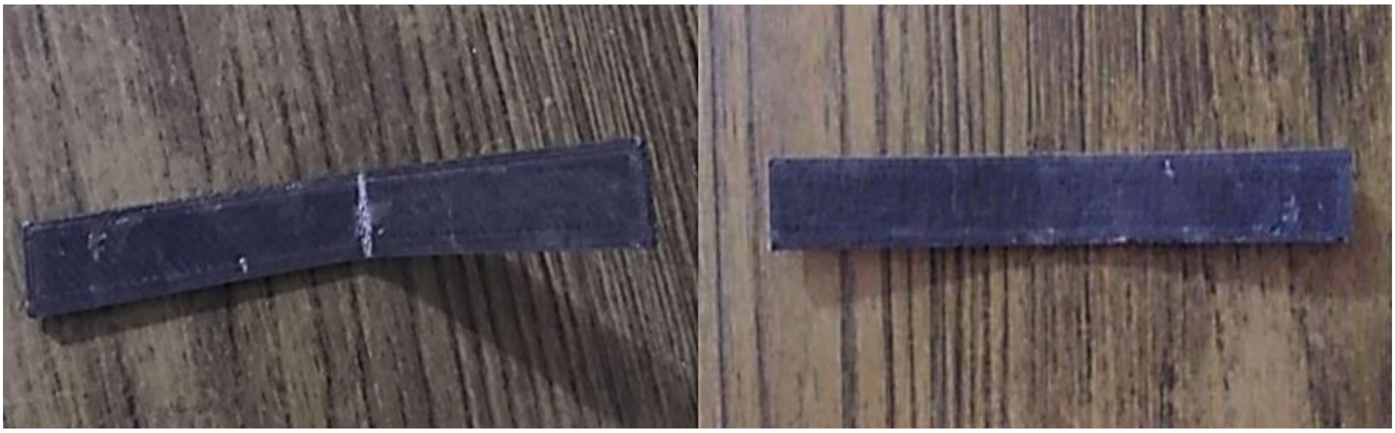

Fig. 13 : Flextural tested specimen.

3.3 Hardnes test results:

Total test forces range from 15kgf to 150 kgf (superficial and regular) to 500 to 3000 kgf (macro hardness). This test procedure is carried out on a standard block of ASTM D 2240:2003 The hardness number is observed in case of Carbon Fiber Pet-G is 52, 52, 53 respectively.Figure 14 shows specimen before and after hardness tests been performed.

Table 3: Shore hardness values

S/NO.	SPECIMEN	SHORE HARDNESS(D)
1	300µ,80%,6mm/sec	52,52,53

Fig. 14 :Specimen before and after hardness test

Conclusions :

In this study, CFRP composite filaments were directly available in the form of carbon- fiber reinforced Pet-G in which it can also be prepared from extrusion processes. FIBER REINFORCED is carried on PETG by changing the printing parameters to find their mechanical properties by using FDM.The experimental results indicated that the tensile strength of carbon fiber reinforced pet-G is 1.28% higher than pure PET-G sample. Its optimum value is observed from Taguchi L9 to be 30.804 from SN curve and same as 34.629 in MEAN curve. The variation in the two values is noticed to be 12.12 % for SN curve and 0 % in case of MEANS Carbon fiber PET-G specimen with 300µ layer thickness, 80% infill density, 60 mm/sec print speed had the largest mean value of tensile strength. The ultimate tensile strength of fabricated specimen with 300µ layer thickness, 80% infill density, 60 mm/sec print speed could increase 1.28% when compared with pure PET-G specimen. Materials with high strength to weight ratio like Carbon Fiber composite materials can be used to manufacture light weight parts which can be used to produce MAV's and also to replace some parts in other beneficiary industries.

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