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EVALUATION OF MECHANICAL PROPERTIES OF POLYMER COMPOSITES PROCESSED BY 3D PRINTING

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Abstract

A well-known method that is gaining popularity is 3D printing for the production of functional parts like prototypes, membranes, shields, and sports wearables. An innovative method for simulating. Failure in a 3D-printed cellular structure was constructed to highlight the significance of the effects of several process variables. There are not many suitable printing materials compared to standard materials, according to evidence. The consequences of it can be explained by the 3D printing techniques' limitations in terms of using a wide range of materials. For over a decade, 3D printing technologies have been widely used in several industries, such as the military field, as a quick prototype and a manufacturing method for products. However, the range of commercially existing printing polymers and their mechanical properties, such as strength and stiffness, were inherently lower than those of other conventional manufacturing materials. Multi-material additive manufacturing (AM) technology is considered an excellent alternative strategy for manufacturing complex structures with a wide range of mechanical characteristics compared with the traditional assembly procedure. 3D printers have the opportunity for innovations and possibilities, motivating additional study into the fast manufacturing of complex items with enhanced material qualities. An attempt is being made to fabricate a polymer composite with 3d printing technique with various reinforcement materials of Carbon fibres and multi walled carbon nano tubes (MCNTs) for the matrix material like ABS and PETG.

Keywords: *ABS, PETG, Carbon Fibres, MCNTs, 3D Printing.*

Heading 1 Introduction

Today's technology calls for materials with superior qualities to everyday living materials, one such material is referred to as composite. In comparison to monolithic materials, the properties of stiffness, deformation resistance, and indentation resistance capacity are better for composite materials. Therefore, researchers are concentrating on creating newer, better, and more affordable composite materials. Composite materials have been introduced as a new class of materials in the field of materials engineering. The development of materials science and technology has opened up numerous opportunities for composite materials to be used more extensively in the automotive, aerospace, and other industries where strength is a key component [1,2].

The sort of composite materials used most frequently in the automobile sector are polymer composites. Natural fibre reinforced polymer composites are particularly employed in the manufacture of door panels, instrument panels, armrests, headrests, seat shells, window frames, molded panel components, bumpers, and underfloor protection for passenger cars. Additionally, nameplates, rear view mirror panels, two-wheeler visors, billion seat coverings, indication covers, and cover L-sides have all been made using sisal, carbon and roselle fibres [3,4].

The method of combining materials to create three-dimensional (3D) objects is known as additive manufacturing (AM), according to the technical committee of the American Society for Testing and Materials. Fused filament fabrication (FFF) is a 3D printing technique based on thermoplastic polymers that makes use of a continuous filament in this context.

One of the most popular materials in 3D printing is poly(ethylene terephthalate)-glycol (PETG), which has a number of advantages including chemical alkali resistance, transparency, gloss, low haze, and good printability. Furthermore, great layer adhesion and very low shrinkage qualities can be attained with the right print parameters. At the same time, it is very sturdy, making it possible to print things with superior impact performance that can operate at high temperatures or in food-safe applications. Due to all these benefits, this material can be used in the food and medical industries [5]. For instance, in the last scenario, its stiff structure enables it to withstand abrasive sterilizing procedures, making it the ideal material for use in medical implants.

However, the properties of the polymers can be enhanced by the addition of carbon fibres, which increases the material's resistance and resilience making it a great option for use in industrial applications and the automobile industry. The addition of carbon fibres expands its range of use to the automotive and aviation industries. Because the material becomes more resilient and resistant, in addition to further lowering the risk of warping, it can be used in this industry and others (such as prosthetics or adjustable wheelchair components) [6,7]. On the other hand, the applications can be expanded to the aerospace and aviation sectors when reinforced with aramid fibres, and MCNT where strong resistance to friction and impact is anticipated [8].

Investigation conducted researchers on PETG and PETG reinforced with carbon fibres and discovered that for both materials, raster orientations of 0 yielded the optimum mechanical performance. In addition, it was found that when raster orientation increased, Young's modulus and ultimate tensile strength decreased. Therefore, it was able to draw the conclusion that the raster orientation and shell presence had a substantial impact on the mechanical properties of PETG with layers printed unidirectionally [9, 10].

The mechanical characteristics of materials are significantly enhanced by the inclusion of carbon fibres. At this time, long carbon fibres, short carbon fibres, and powder are the three basic types of carbon fibres available on the market [11]. The architecture of carbon fibres allows them to endure high-strength mechanical characteristics, but for large-scale composite products, it is challenging to mix the fibres and matrix equally because of the electrostatic attraction of the surface of the fibres[12,13].

Although powdered carbon fibres mechanical characteristics are inferior to those of long and short carbon fibres, preparing them is simpler. The influence of carbon fibres powder content on the mechanical characteristics of composites is examined through the measurement of the mechanical properties of carbon fibres powder reinforced ABS composites, which serves as a guide for the usage of carbon fibres in manufacturing practice [14,15,16].

Heading 1 Experimental Work

The details of the experimental work including the base materials selected, reinforcements, its weight percentage, processing techniques adopted and testing parameters are discussed in brief in this section.

Heading 2 Base Material

Heading 3 PETG: Polyethylene terephthalate glycol, known as PETG or PET-G, is a thermoplastic polyester that delivers significant chemical resistance, durability, and formability for manufacturing. Table1 shows the physical properties of PETG.

Table 1 Physical Properties of PETG [17]

Parameters	Value
Density	1.23g/cm^3
Shore Hardness	78
Yong's Modulus	2950MPa
Melting Temperature	260^{0}C

Heading 3 ABS: ABS or Acrylonitrile butadiene styrene is a common thermoplastic polymer typically used for injection molding applications. This engineering plastic is popular due to its low production cost and the ease with which the material is machined by plastic manufacturers. Table 2 shows the physical properties of ABS.

Figure 1 (a)show the raw material in form of spool which appears to be white color with a diameter of 1.75mm, Figure 1 (b) shows the raw material in form of spool which appears to be crystal clear with a diameter of 1.75mm.

Table 2 Physical Properties of ABS [18]

Parameters	Value
Density	1.04g/cm^3
Shore Hardness	100
Yong's Modulus	3200Mpa
Melting Temperature	200^{0}C

(a) (b)

Figure 1 (a) PETG Spool (b) ABS Spool

Heading 2 Reinforcement Materials

Heading 3 Carbon Fibre: Carbon Fiber is a polymer and is sometimes known as graphite fiber. It is a very strong material that is also very lightweight. Carbon fiber is five-times stronger than steel and twice as stiff. Table 3 shows the physical properties of Carbon Fibre. Figure 2 shows the carbon fibre in powder form.

Table 3 Physical Properties of Carbon Fibre [19]

Parameters	**Value**
Density	1.75g/cm^3
Hardness	50.5 HRC
Yong's Modulus	183Gpa
Melting Temperature	1500^{0}C

Figure 2 Carbon Fibre (Powder Form)

Figure 3 MCNT Fibre (Powder Form)

Heading 3 Multi Walled Carbon Nano Tubes: WNTs can be thought of as consisting of a series of single wall tubes nested within one another. There may be as few as 6 or as many as 25 such concentric walls. MWNTs diameters may, therefore, be as great as 30nm as opposed to 0.7 – 2.0 nm for typical SWNTs. Table 4 shows the physical properties of MCNT. Figure 3 shows the MCNT fibre in the powder form.

Table 4 Physical Properties of MCNT [20]

Parameters	Value
Density	1.72g/cm^3
Shore Hardness	70 HRC
Yong's Modulus	270Gpa
Melting Temperature	3550^{0}C

Heading 1 Processing Technique

3D printing technique is utilized for processing the polymer material, Figure 4 shows the 3D printing apparatus used in the present work. Figure 5 shows the build orientation of X, Y and Z. Table 5 shows the percentage of matrix and reinforcement used while processing the polymer composites.

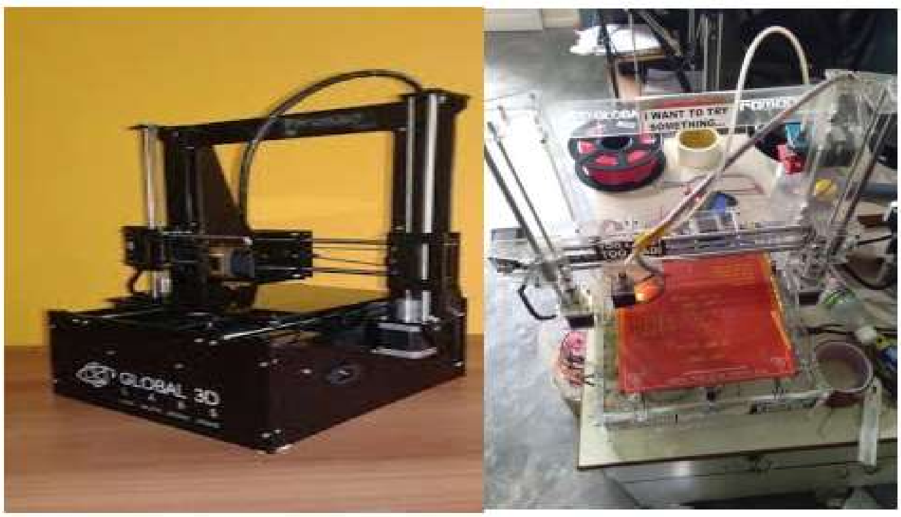

Figure 4 FDM Apparatus Used

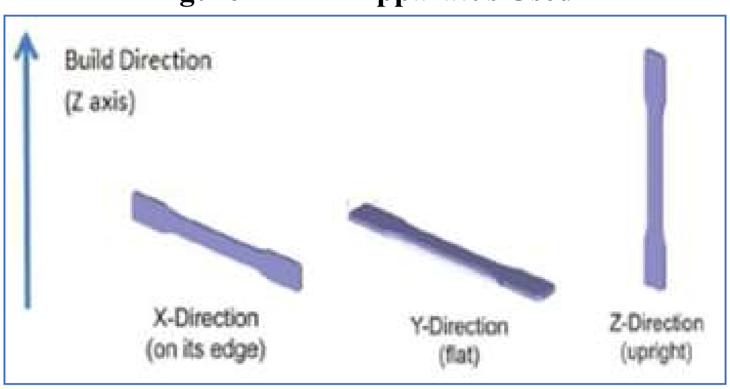

Figure 5 Build Orientation [21]

PETG and ABS composites are processed directly as, it will be in the form of fibres. For processing the composite materials, especially the carbon fibre and MCNT fibres the reinforcements will in the form of the powder which will be blended together and materials will extrude to obtain it in the form of fibres. These fibres will be built on the required direction with changes in the weight percentages.

Table 5 Matrix and Reinforcement Details

Sl.No	Matrix Material	Weight Percentage	Reinforcement Material	Weight Percentage
1	PETG	100	-	-
2	ABS	100	-	-
3	PETG	98	Carbon Fibre	2
4	ABS	98	Carbon Fibre	2
5	PETG	96	Carbon Fibre	2
			MCNT	2
6	ABS	96	Carbon Fibre	2
			MCNT	2

Heading 1 Results & Discussions

Heading 2 Evaluation of Mechanical Properties

Heading 3 Shore Hardness Test

The most popular test for determining a polymeric material's mechanical qualities is its hardness. Materials are classified as rigid, hard, and tough based on their resistance to penetration by another harder substance. In order to assess hardness using the penetration method, a penetrating body (indenter) of any shape is indented into the surface of the material being tested with a specific amount of force.

The Durometer is a device used to measure shore hardness. A calibrated spring loads an indenter in a durometer. The indenter's depth of penetration while being loaded determines the measured hardness. The penetration and modulus of elasticity of the material, as well as its viscoelastic characteristics, all influence the indentation hardness, which is inversely related to both. The results of the test are influenced by the indenter's shape, the force used, how long it was used for, and some other aspects. Table 6 shows the hardness of various materials with % of increase in the strength. Figures6 to 8 shows the hardness of various materials at different build orientations.

Table 6 Hardness of Various Materials with % of Increase

Sample	PETG	ABS	% of Increase in Hardness
A1 (X 80)	85	89	4
A2 (Y90)	87	91	4
A3 (Z100)	89	90	1

Sample	PETG+CF2	ABS+CF2	
A4 (X 100)	84	89	6
A5 (Y80)	85	90	6
A6 (Z90)	79	91	13
Sample	**PETG+CF2+MCNT2**	**ABS+CF2+MCNT2**	
A7 (X 90)	59	87	32
A8 (Y100)	56	74	24
A9 (Z80)	69	88	22

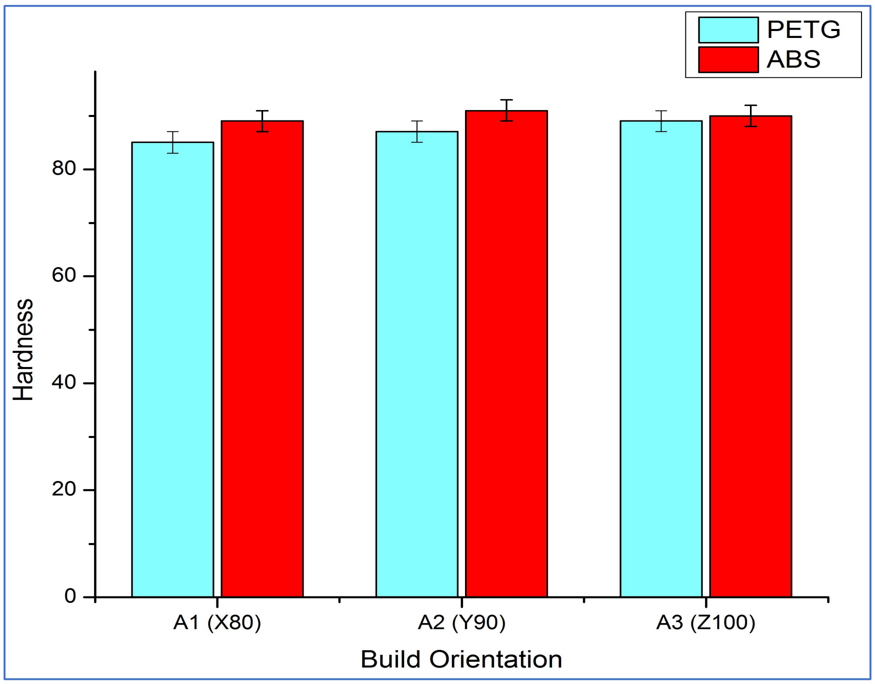

Figure 6 Hardness v/s Various Materials (Build Orientation)

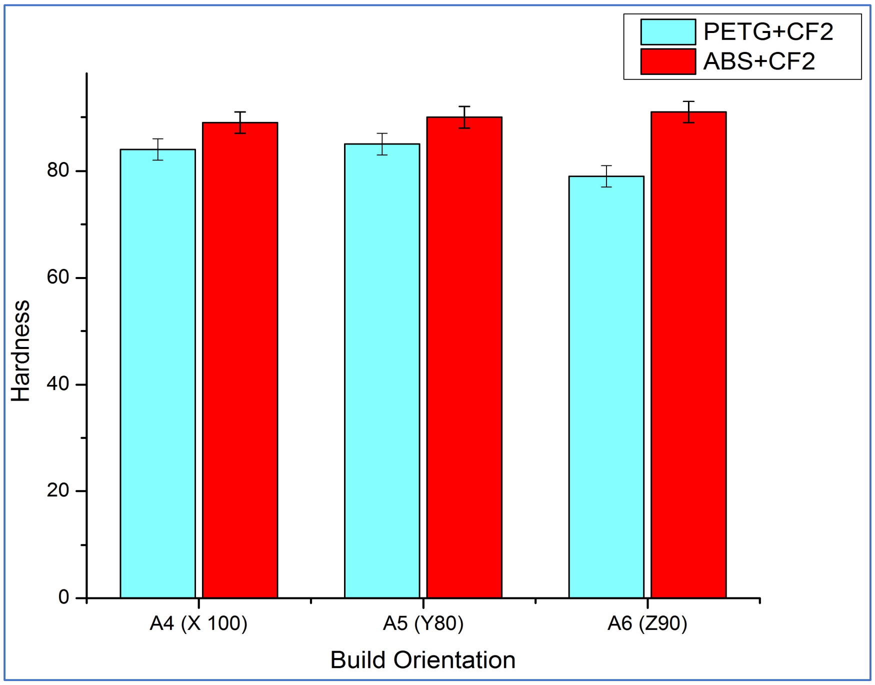

Figure 7 Hardness v/s Various Materials (Build Orientation)

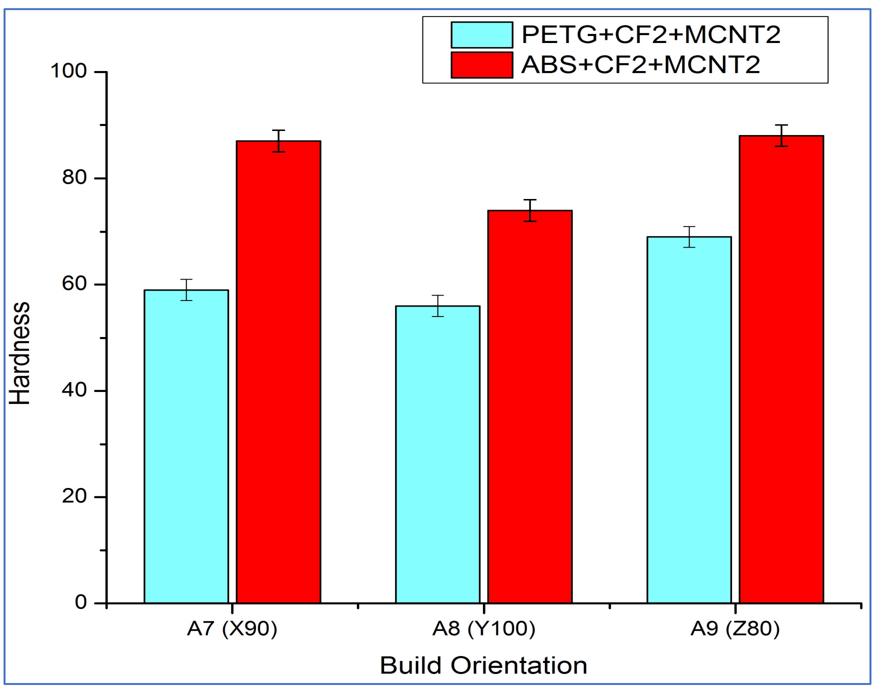

Figure 8 Hardness v/s Various Materials (Build Orientation)

Figure 8 shows the hardness findings for the various build orientation specimens, it can be noted that the ABS+CF2 reinforced composite has the highest hardness rating compared to PETG+CF2. As the ABS materials came into contact with the penetration indentor (test needle), the hardness rises as a result of the material rigidity when compared to the PETG. The lower hardness noted with PETG reinforcement due to the penetration of the indentor from the shell of the PETG surface. The presence of the Carbon fibre resists the deformation but when the load is increased the indentor will shear the surface of the fibre and pass through it. Since PETG hardness is eventually lesser compared to carbon fibre, so the material shears of easily. Irrespective of the build direction the trend remains the same. The presence of the MCNT further showed an improvement in the strength due to its hardness compared to other elements.

Heading 3 Impact Test

The main goal of an impact test is to provide a general assessment of a material's toughness or "fracture resistance" by calculating the energy needed to totally break a material. The metrics obtained in the IZOD, a bending-type impact test, include the energy required to completely break a sample as a function of thickness (i.e., impact resistance) and as a function of the shattered cross-sectional area (i.e., impact energy). In essence, the measured energy is the total energy needed to start a crack in the sample and let it develop until it is the same length as the sample (for fracture resistance) or to start a crack and let it grow until it is the same surface area as the cross-sectional area of the sample (for fracture resistance).Impact test is being carried out to study properties of various materials including huge and deep scars on the component, stretching, and layer pullout.

Table 7 shows the impact test details of various materials with % of increase in the strength. Figures9 to 11 shows the impact energy of various materials at different build orientations.

Table 7 Impact Test of Various Materials with % of Increase

Sample	PETG	ABS	% of Increase in Impact Strength
A1 (X 80)	12	14	14
A2 (Y90)	10	12	17
A3 (Z100)	13	16	19
Sample	**PETG+CF2**	**ABS+CF2**	
A4 (X 100)	16	20	20
A5 (Y80)	19	21	10
A6 (Z90)	14	23	39
Sample	**PETG+CF2+MCNT2**	**ABS+CF2+MCNT2**	
A7 (X 90)	18	22	18
A8 (Y100)	19	23	17
A9 (Z80)	21	24	13

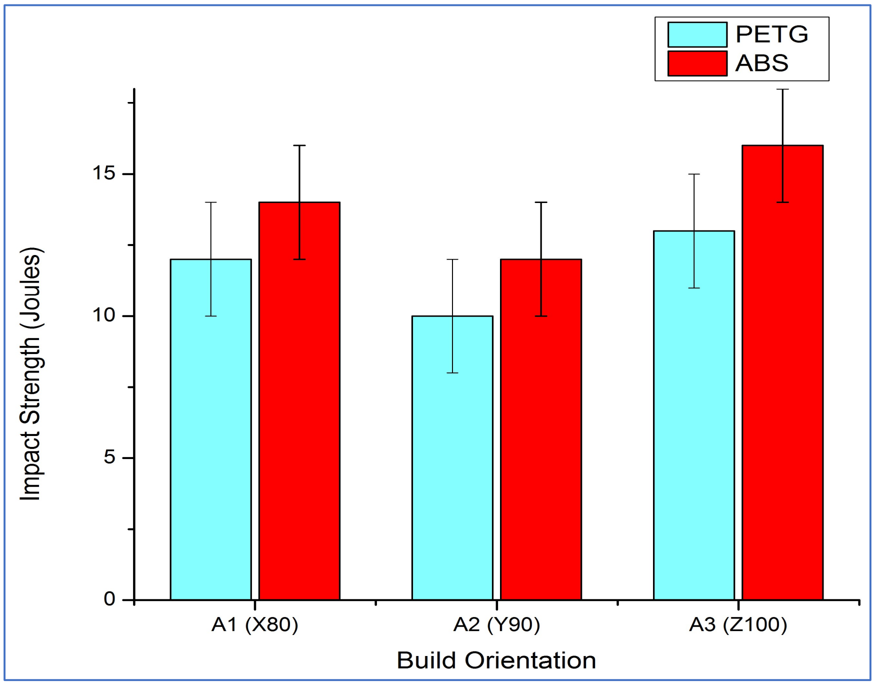

Figure 9 Impact Strength v/s Various Materials (Build Orientation)

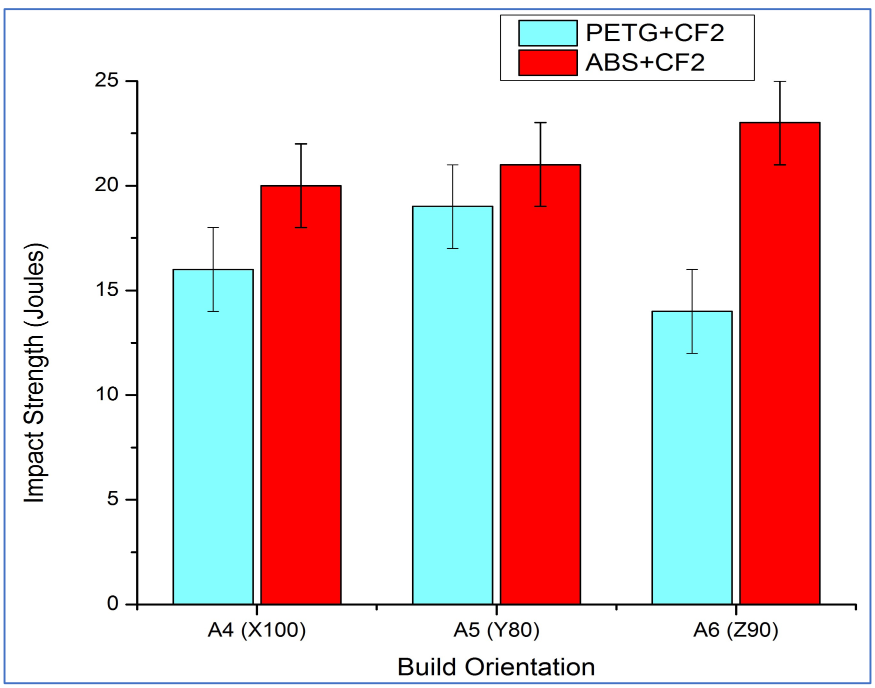

Figure 10 Impact Strength v/s Various Materials (Build Orientation)

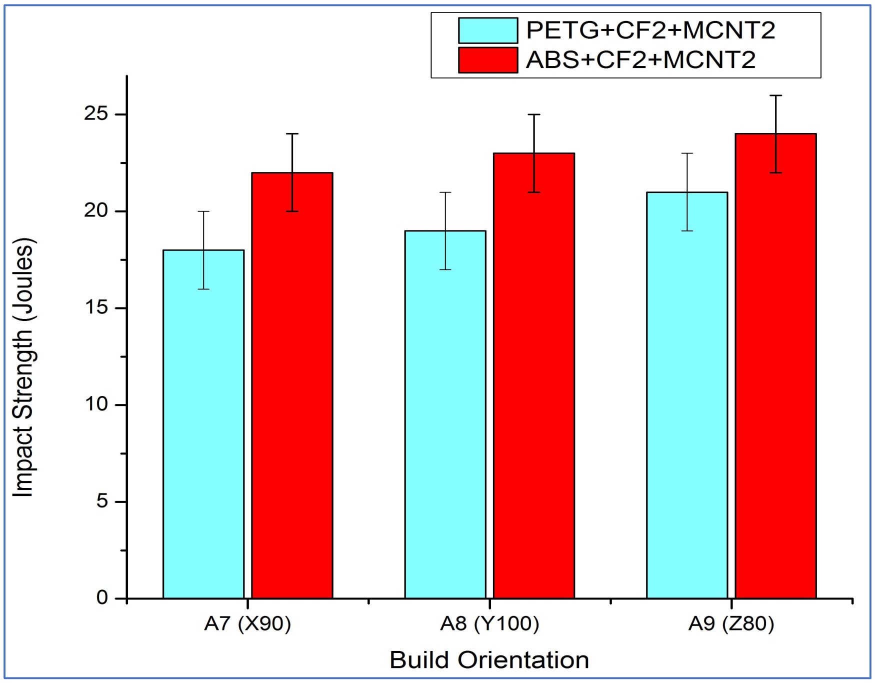

Figure 11 Impact Strength v/s Various Materials (Build Orientation)

Impact testing determines the material's toughness value by measuring the test sample's energy absorption during instantaneous cracking. Figures 9 to 11 displays the test sample impact energy results. These findings demonstrate that PETG and Carbon fibre addition decreased the impact resistance compared to ABS and carbon fibre. This reduction is the strength is due to the formation of stress-failure zones at the ABS-Carbon fibre contact area. This is due to the fact that the Carbon fibre in ABS composites is the phase that carries the majority of the load placed on it during the impact test. The impact strength of the composites may be greatly improved by the fibre, particularly if it has a high tensile strain to failure feature. Strictly from the material point of view, the addition of Carbon fibre has resulted in a substantial increase in impact strength of the ABS compared to PETG. The addition of MCNT reinforcements has also showed the similar trend of the improvement.

Heading 3 Tensile Test

Table 8 shows the tensile characteristics for each investigated parameter. The main focus of this test is to analyze the relationship between stress and strain for tensile specimens of each print condition. But in order to provide a thorough understanding of the general material behavior, average values for each sample set's ultimate tensile strength (UTS) are calculated.

When a stress is applied to a material, a linear zone is seen where the material deforms elastically before expanding back to its original length. When the yield point is achieved and the material begins to exhibit plastic behavior, this region comes to an end. When the load is removed under these circumstances, it no longer returns to its former length. However, the linear area exhibits variable extensions depending on the substance, indicating that some materials have longer elastic regimes than others.

From the results of the tensile test (Figures12-14), it can be seen that the PETG and Caron fibre combination has lesser strength compared to ABS and Carbon fibre combination. The reduction has been noted because the carbon fibre bears the majority of the stress and there could be a poor adhesion between the PETG and the fibres and little load transfer at these locations. The air gaps between the neighbouring printed layers, as well as the high shear forces acting on the layer interface and fiber-matrix contact, all contribute to this decrease in the strength of the PETG and carbon fibre combination.

If there are voids and local imperfections in composites, especially at the matrix/fiber interface or between layers, the material will break down brittlely. However, neither the microstructure nor the fracture surface showed any defects in the composite with ABS and Carbon fibre combination. This suggests that a large number of carbon fibres caused stiffness as well as strength increases in the composites, leading to brittle failure of the material. Similar purpose is being served by the addition of MCNT reinforcements.

Table 8 Impact Test of Various Materials With % of Increase

Sample	**PETG**	**ABS**	**% of Increase in Tensile Strength**
A1 (X 80)	5.24	7.68	32
A2 (Y90)	16.33	18.27	11
A3 (Z100)	18.66	19.1	2
Sample	**PETG+CF2**	**ABS+CF2**	
A4 (X 100)	22.16	29.33	24
A5 (Y80)	29.4	34.805	16
A6 (Z90)	27.58	30.31	9
Sample	**PETG+CF2+MCNT2**	**ABS+CF2+MCNT2**	
A7 (X 90)	28	34.5	19
A8 (Y100)	39	40	3
A9 (Z80)	40.76	45.13	10

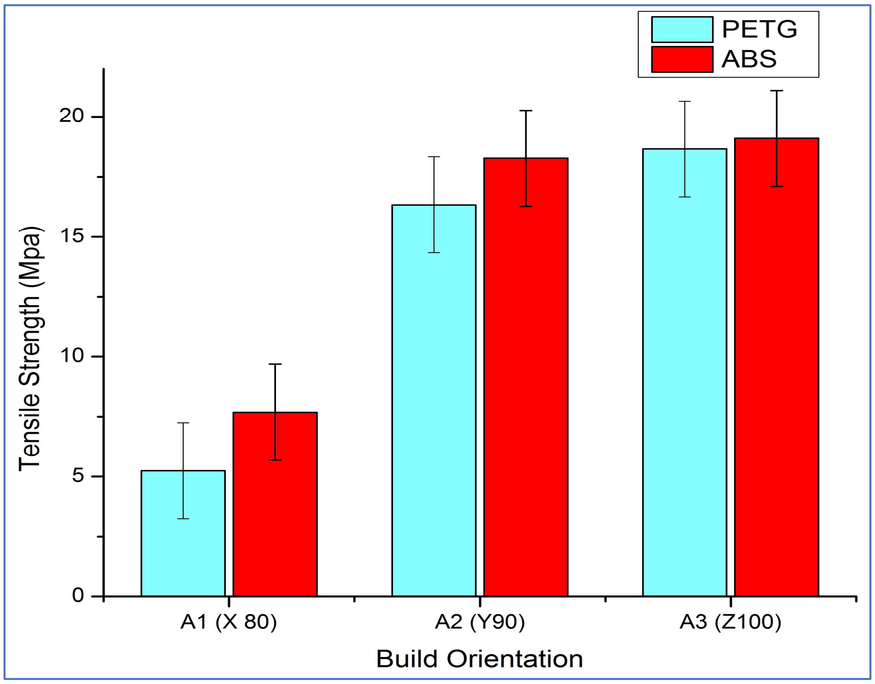

Figure 12 Tensile Strength v/s Various Materials (Build Orientation)

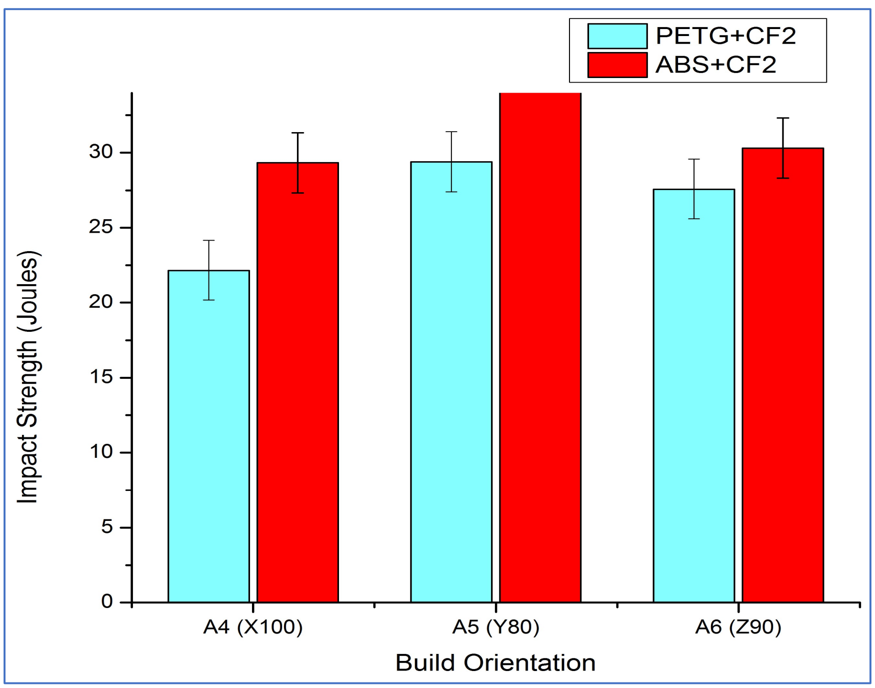

Figure 13 Tensile Strength v/s Various Materials (Build Orientation)

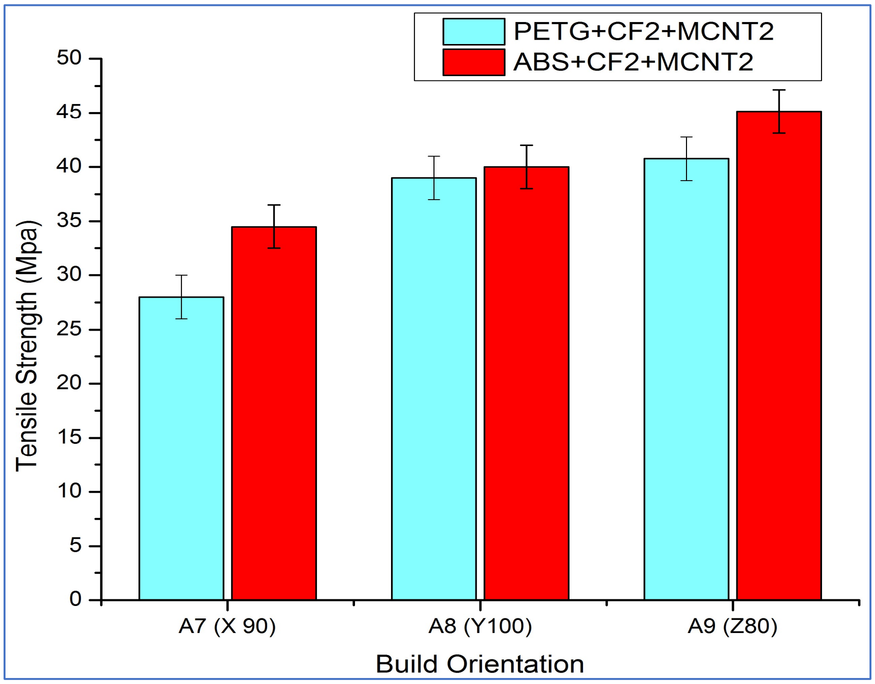

Figure 14 Tensile Strength v/s Various Materials (Build Orientation)

Heading 1 Conclusions

The following are the conclusions that are drawn from the present investigations:

1. Carbon fibre reinforced with PET and ABS composites were developed through the fused deposition modeling process and examined for various mechanical properties.
2. A comparison of properties of PETG with Carbon fibre and ABS with Carbon fibreis conducted, with the addition of carbon fibres to the matrix materials; flexural strength and impact strength were increased.
3. It was possible to improve the hardness by 4% with ABS addition, 13% for ABS with Carbon fibre and 32% improvement for the ABS with Carbon Fibre and Carbon nano tubes (MCNT).
4. It was possible to improve the impact strength by 19% with ABS addition, 39% for ABS with Carbon fibre and 18% improvement for the ABS with Carbon Fibre and Carbon nano tubes (MCNT).
5. It was possible to improve the tensile strength by 32% with ABS addition, 24% for ABS with Carbon fibre and 19% improvement for the ABS with Carbon Fibre and Carbon nano tubes (MCNT).
6. The incorporation of carbon element has significantly improved the flexural and impact properties of the matrix and paved the way for the investigation of various reinforcement levels.

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