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Effect of diverse raster angle in FDM processing on mechanical performance of PETG

[1]Sivanesh A R, [2]Selvaganesh A, [3]Selventhiran S, [4]Arulpandi S, [5]Abimanyu M

[1]Assistant Professor, [2,3,4,5]UGStudent

Department of Mechanical Engineering,

Sri Ranganathar Institute of Engineering and Technology, Coimbatore, Tamilnadu, India

Abstract : This study looks at how different raster angles (0°, ±45°, and 90°) in fused deposition modelling (FDM) affect the mechanical characteristics of PETG, a robust thermoplastic filament. The variation of raster angle affects the properties of 3D printed objects. An awareness of these implications is necessary for part design and production optimization for engineering, prototyping, and product development. The study helps engineers and designers select the optimal raster angles for a particular set of criteria by illuminating the trade-offs between flexural strength, impact resistance, and tensile strength.

***IndexTerms* – FDM, PETG, Raster angle**

I. Introduction

In additive manufacturing, the lifetime and general performance of printed goods are largely determined by the mechanical properties of PETG material. PETG, or polyethylene terephthalate glycol-modified, is a thermoplastic polymer with an amazing balance of impact resistance and mechanical strength. To ascertain the mechanical properties concerning raster angle, extensive testing is required. The orientation of the successive layers during the printing process, or raster angle, can have a significant influence on a variety of mechanical qualities, including impact resistance, tensile strength, and flexural strength. This is accurate as the raster angle, which also regulates the layer-by-layer bonding, determines the anisotropic behavior of the printed item. Anisotropic mechanical properties occur when a material's strength varies in several directions, usually parallel to the raster angle. To accurately determine these mechanical characteristics, a variety of standard tests, including tensile, flexural, and impact tests, should be performed on specimens printed with varying raster angles. The results of these studies will provide insight into how the material responds to different mechanical forces in relation to the raster angle. Engineers and manufacturers can then modify the raster angle to enhance certain mechanical aspects based on the intended application, ensuring that the final printed components meet the necessary performance requirements. Iterative testing and improvement is required to properly utilize PETG in additive manufacturing and tailor its mechanical properties to specific application demands. The impact of raster angles on the dynamic characteristics of ABS that is 3D printed is investigated. A certain winding angle defies brittleness assumptions and provides fresh insights into the mechanics of 3D-printed structures by improving impact strength despite decreasing tensile performance [1]. The research deviates from current polymer limitations and examines the incorporation of high-end synthetic polymers into FDM. Comparing the materials now in use with potential substitutes to assess sustainability and potential developments in filament-based additive manufacturing [2]. Research is being done on how the parameters of the FDM process affect the tensile characteristics of plastic composites reinforced with carbon fibers. To preserve the caliber of additive manufacturing, tensile testing and SEM analysis identify the mechanisms and causes of material failure [3]. The effects of moisture and raster angle on the mechanical properties of 3D printed PLA are investigated. A 90% raster angle and 10% moisture content produce the optimal strength and strain, according to tensile tests conducted on 27 specimens [4]. The mechanical characteristics of composites made of PLA and Al using FDM were examined. The impact of layer composition and raster angle on tensile and flexural characteristics is investigated. SEM shows ductile action and failure caused by cavities [5]. The advantages of PLA for the environment and the affordability of 3D printing are emphasized. According to research, the raster angle and infill density have an impact on the tensile characteristics of PLA, with a 0° angle yielding the highest strength [6]. Friction causes wear by changing the surface's size due to mechanical, thermal, and chemical forces. Evaluation of wear is essential for a long-lasting system. Casting, additive, and subtractive methods are commonly used in component manufacture [7]. Material extrusion 3DP uses thermoplastic polymers with certain qualities, just as FDM. Different infill patterns and orientations modify the mechanical properties of ABS specimens. It is essential to accurately evaluate how void geometry affects macro-scale behaviors [8]. The study looks at how printing factors that affect PLA items' tensile properties include layers height, print speed, and orientation angle (OA). It was discovered that 20–30 mm/s was the appropriate print speed and layer height. To get the appropriate tensile properties, OA modification is essential [9]. The fact that FDM produces components that appear to have been inserted is what makes it so popular. The 0° angle is recommended, according to a research comparing the impact of longitudinal and unidirectional raster angles on tensile strength. Fractured surface analysis can be used to identify failure patterns [10]. In order to better understand the parameters influencing FDM 3D printing outcomes, this study maps important variables and their relationships. It explores filament types, printing parameters, and production processes to identify areas in FDM technology that still need improvement and investigation [11]. Sections of FDM with varying raster orientations and angles are analyzed in this study. Results indicate that orientation affects mechanical properties and surface roughness more so than raster angle. Findings allow for cost reduction in the manufacturing solution modification process [12]. This report presents the study on optimizing FDM process parameters for improved component quality. Many experimental design approaches and procedures are investigated in search of improved mechanical properties. The likely future avenues of FDM research are examined [13]. Along with the strength properties of 3D printed parts, the influence of technological factors including printer orientations, infill rates, and patterns is assessed. Raster angles and infill patterns were adjusted to examine the mechanical properties [14]. Mechanical properties including hardness, impact resistance, and tensile strength were examined for CF-PETG material, which was created using the FDM technique and had layer thickness and raster angle constraints. The best result for all mechanical characteristics is shown by the produced specimen with the least layer thickness [15].

II. SELECTION OF MATERIALS

Polyethylene Terephthalate Glycol (PETG), a thermoplastic polymer, is renowned for its durability, clarity, and ease of manufacture. It is a well-liked option for 3D printing due to its little warping and low shrinking. By combining the best features of both PETG and glycol-modified PETG, PETG provides increased chemical and impact resistance. It may be utilized in a variety of contexts, including consumer goods, medical equipment, and packaging, due to its versatility.

III. FDM MACHINE

Fused Deposition Modelling, or FDM, is a widely used additive manufacturing technology for 3D printing. Thermoplastic filament is heated and extruded layer by layer in an FDM machine to create a three-dimensional object. Layers of material are printed on top of a digital 3D model that has been divided into layers by the printer. FDM is widely utilised due to its versatility, affordability, and ability to produce intricate designs, functional components, and prototypes for a variety of industries.

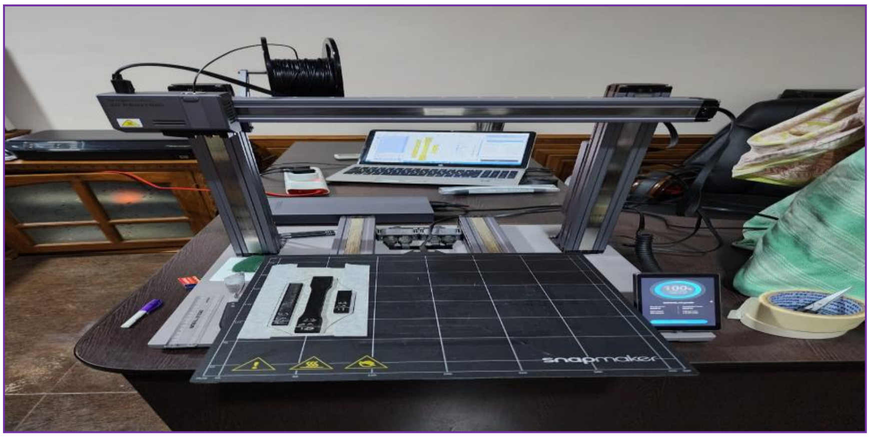

figure 1. FDM machine

IV. PRINTING OF TEST SPECIMEN

To 3D print PETG test specimens with varied orientations (0 degrees, ±45 degrees, and 90 degrees), printer parameters must be changed, and the model must be properly prepared. The 3D model is first rotated and transferred into slicing software to achieve the necessary orientations. Support structures are erected as needed, particularly for overhangs. The printer's parameters are then selected, including layer height, print speed, infill percentage, and PETG as the filament type. The printing and bed temperatures are typically set between 70 and 80°C. The slicing software generates the G-code, which is then transmitted to the 3D printer to begin the printing process.

figure 2 PETG Printed Testing material

V. RESULT AND DISCUSSION

5.1 TENSILE TEST

From figure 4 shows the tensile test samples were fabricated with 0 degree, ±45 degree, 90 degree respectively. This samples were tested with Instron 8801 machine with 100KN maximum load capacity and 1.5mm/min displacement rate.

Table 4.1 Tensile Properties of PETG material

Sl.NO	Tensile Strength[MPa]	Modulus (Automatic Youngs)[MPa]	Maximum Force [KN]	Tensile Strain (Displacement) at Tensile Strength[%]	Tensile Stress Yield (offset 0.2%)[MPa]	Tensile Strain (Displacement) at Yield (offset 0.2 %)[%]
1	11.55	595.60	1.05	3.72	8.21	1.57
2	7.62	428.78	0.69	2.82	5.19	1.40
3	7.66	468.70	0.70	2.58	5.28	1.32

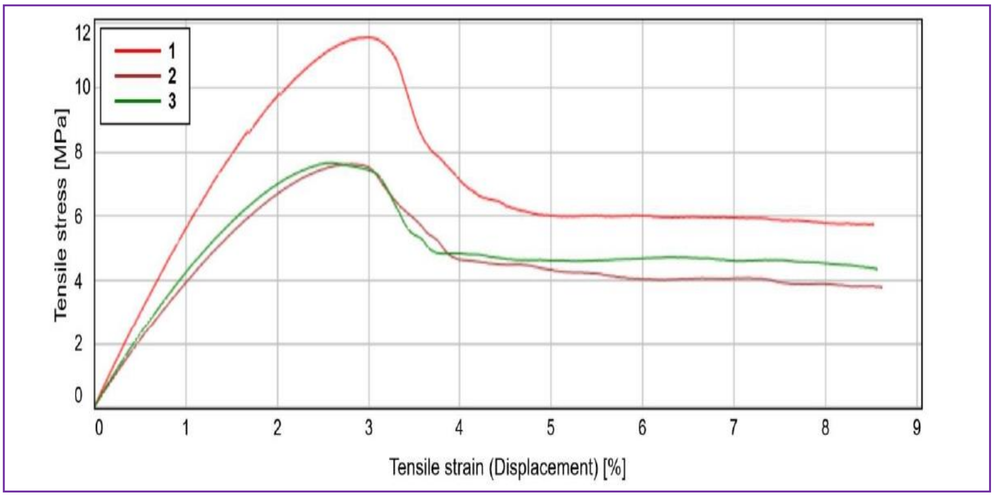

figure 3. Tensile strain vs Tensile Stress Graph of PETG material

The figure 3 shows the experimental graph of test results for tensile test of three different samples of different raster angle. The sample 1 indicates 0 degree, sample 2 indicates ±45 degree and sample 3 indicates 90 degree respectively. The graph is plotted between the tensile stress with tensile strain. Table 1 denotes the experimental tensile test values. From the table 1 it is clear that sample 1 has higher tensile strength as compare to the sample 2 and 3. Sample 1 indicates that the PETG material is fabricated with 0 degree raster angle which as 595.60 MPa tensile strength. Sample 2 and 3 indicates the PETG material is fabricated with ±45 degree and 90 degree with tensile strength of 428.78MPa and 468.70Mpa respectively.


figure 4. Before Tensile Test of the PETG Specimen

figure 5. After Tensile Test of the PETG Specimen

The filament lines align directly with the load when they are perpendicular to the tensile tension axis, resulting in efficient load transmission along the filament's strands. This alignment increases tensile strength by promoting an equal distribution of forces and lowering stress concentrations.

When printing, a 0 degree raster angle permits a high degree of surface contact between adjacent layers. Because of this, there is strong interlayer bonding as each layer effortlessly fuses with the layer behind it. The part's overall structural integrity and tensile strength are both enhanced by better bonding.

The 0 degree raster angle strengthens the material's tensile strength and resistance to deformation by encouraging filament alignment in the direction of applied stress.

5.2 FLEXURAL TEST

Figure 6 illustrates how the flexural test specimens were manufactured with 0 degrees, ±45 degrees, and 90 degrees, in that order. An Instron 8801 machine with a maximum load capacity of 100KN and a displacement rate of 1.5 mm per minute was used to test these samples.

figure 6. Before Flexural Testing of thePETG Specimen

figure 7. After Flexural Testing of the PETG Specimen

The experimental graph of the flexural test results for three distinct samples with varying raster angles is displayed in figure 8. Sample 1 shows 0 degrees, Sample 2 shows ±45 degrees, and Sample 3 shows 90 degrees, in that order. Flexural strain and stress are displayed against one other on the graph. The experimental flexural test values are shown in Table 1. Table 1 makes it evident that sample 2 has a greater flexural strength than samples 1 and 3. According to Sample 2, the PETG material has a flexural strength of 595.60 MPa and is manufactured with a ±45 degree raster angle. The PETG material used in Samples 1 and 3 has flexural strengths of 24.19 MPa and 27.15MPa, respectively, with fabrication tolerances of ±45 and 90 degrees.

Table 4.2 Flexural Properties of PETG material

SI.NO	Flexural Strength [MPa]	Maximum Force [KN]	Modulus(Automatic Youngs)[MPa]	Flexural Stress at Yield(offset 0.2%)[MPa]	Flexural strain(Displacement) at Yield (offset 0.2%0[%]
1	24.19	0.04	554.72	15.41	3.00
2	30.99	25.83	1031.44	25.83	2.99
3	27.15	0.04	917.82	25.99	3.27

During the bending test, a balance between tension and compression is guaranteed with an orientation of ±45 degrees. For materials that show varying strengths in compression and tension, this is crucial. we can evaluate the material's performance simultaneously under both forms of stress by testing at ±45 degrees.

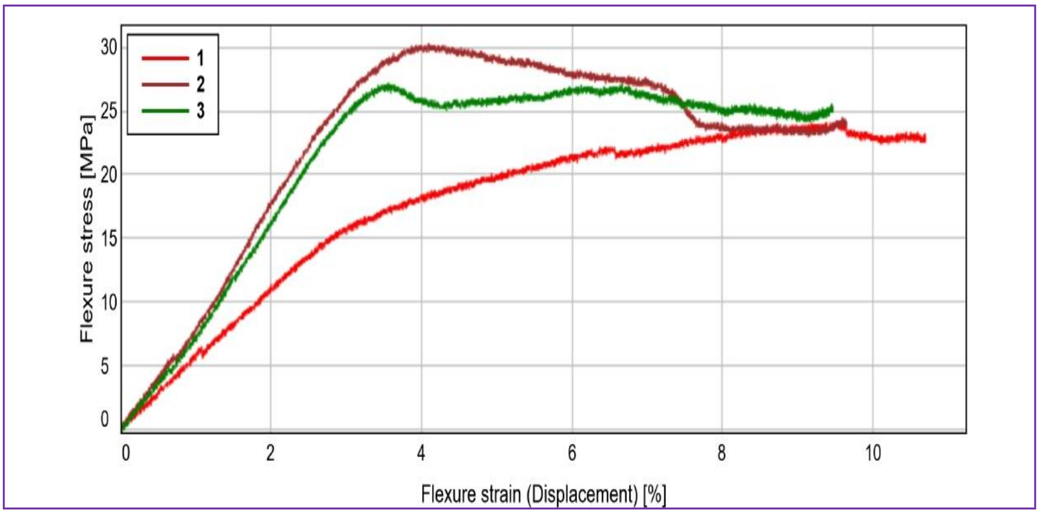

Figure 8. Flexural stress vs Flexural Strain Graph of PETG material

Shear loading is also related to ±45 degrees. Testing at this angle makes it possible to assess shear strength, which is important in situations where shear forces play a big role, like when designing beams and other structural components.

5.3 IMPACT TEST

The cross-ply structure that the ±45 degree orientation provides helps inhibit cracks from spreading between layers, which helps resist delamination. Generally, the ±45 degree orientation produces a good balance between strength and toughness, with transverse fibers contributing to toughness and longitudinal fibers contributing to strength.±45 degree has higher impact energy value of 39 J/m^2.

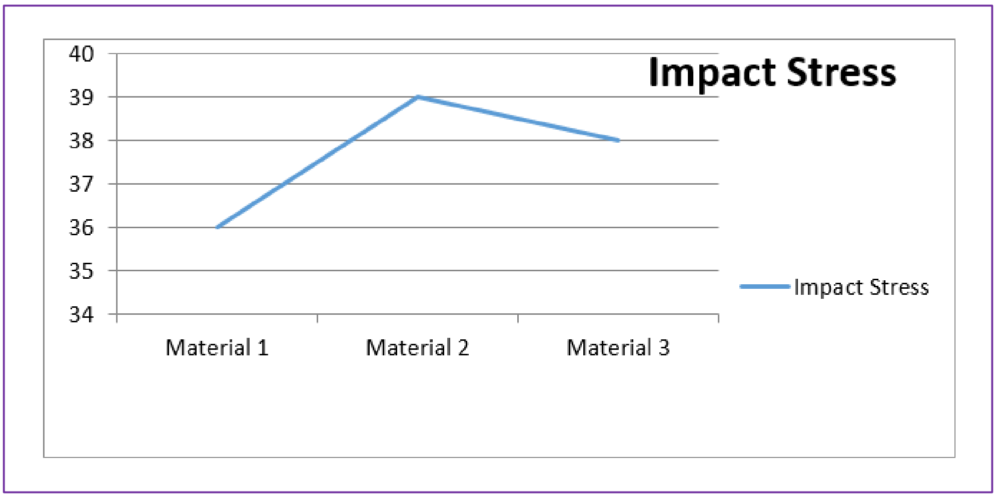

Figure 9. Impact Stress Graph of PETG material

Table 4.3 Impact Properties of PETG

S.no	Material 1 (0 Degree) (J)	Material 2 (±45 degree) (J)	Material 3 (90 Degree) (J)
1	36	39	38

VI. CONCLUSION

According to these technical considerations, 0 degrees is constant, providing useful design information and ensuring that the anticipated loading conditions are satisfied. The material's preferred direction, such as the metal grain structure, is met when the loading axis is aligned at 0 degrees. This alignment often yields the best tensile strength and clearly reveals the intrinsic qualities of the material. Materials designed to withstand multidirectional loads should pay particular attention to the ±45-degree orientation while undertaking flexural testing. However, the specific qualities of the material and the intended usage may alter the optimal orientation, thus these factors must be considered. Ultimately, a complete understanding of the material's behavior under flexural stress at ±45 degrees helps with the design of various technical applications as well as the selection of suitable materials. The ±45 degree orientation is an efficient way to absorb impact energy because of the combined effects of matrix cracking and fiber deformation, which are important factors in applications.

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