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Investigation of Strength properties of Additively Manufactured Fiber-Reinforced Polymeric Composites

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ABSTRACT

Additive Manufacturing, often known as 3D printing, is a disruptive manufacturing technology that has received a lot of attention recently. This abstract investigates the use of additive manufacturing, taking into account different crucial elements that influence the process and the end result. This abstract then helps us to find out the importance of essential parameters and the many types of additive manufacturing materials used in 3D printing. The effects of layer height, print speed, infill density, raster angle and wall thickness on print quality, strength, and production time are investigated. The first section looks at the additive manufacturing process, such as Fused Deposition Modelling (FDM) with the Stereolithographic (SLA) technique, With some other SLS (Selective Laser Sintering) and Extrusion processes etc. Each process has advantages and disadvantages that influence parameters such as resolution, material compatibility, and production speed. Including tensile and flexural strength parameters of PLA, PLA+C, PETG and ABS manufacturing composites (i.e Tensile and Bar specimens) were investigated.

Finally, the abstract recognizes continuous advances in additive manufacturing technology, with the ANSYS workbench analysis as researchers continue to explore new materials, and enhance printing parameters to broaden the variety of applications.

Keywords: Additive Manufacturing(AM), Carbon fibre reinforced composites(CFRP), Polylactic acid(PLA), Acrylonitrile butadiene styrene(ABS), Fused Deposition Modelling(FDM), Stereolithographic (SLA).

1. INTRODUCTION

1.1 Additive manufacturing:

Additive Manufacturing, also known as 3D printing, is a breakthrough manufacturing technology that has revolving a wide range of sectors by allowing the manufacture of sophisticated and complicated products directly from digital design files.

1.2 AM Materials:

Polymers and plastics: Because of their versatility and low melting points, these materials are commonly employed in additive manufacturing. Thermoplastics such as ABS, PLA, PLA + CARBON, ABS+CARBON, nylon, and TPU are used to make a variety of products.

Stereolithography (SLA) Resins: When subjected to UV light, these liquid photopolymers harden. They are frequently used to create detailed, high-resolution models or prototypes.

Filaments for Fused Deposition Modelling (FDM): To form objects, thermoplastic filaments are heated and extruded layer by layer. PLA, ABS, PETG, and other common filaments are available.

Selective Laser Sintering (SLS) Powders: A laser is used to sinter fine plastic powders together. SLS frequently employs nylon and other powdered polymers which include PLA + Carbon, ABS+ Carbon fibres.

1.3 Types of 3D printing processes:

FDM (Fused Deposition Modelling): Fused Deposition Modelling (FDM) is a common additive manufacturing process that deposits material layer by layer to produce three-dimensional objects. It is one of the most well-known and widely used 3D printing technologies. Scott Crump invented and patented FDM in the late 1980s, and it has since become a crucial method in the realm of 3D printing.

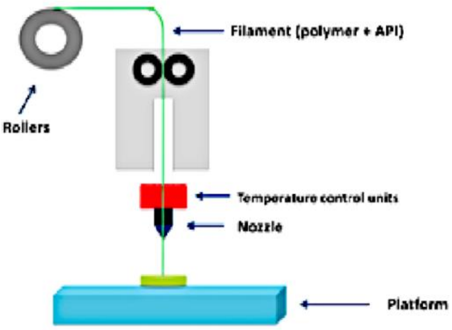


Fig: Schematic diagram of FDM process

Stereolithography (SLA): SLA solidifies liquid photopolymer resins layer by layer using a UV laser. The build platform is lowered into the resin tank, and the laser cures each layer. It is known for manufacturing high-detail, smooth-surface items, and it is frequently used in jewellery, dentistry, and elaborate prototypes.

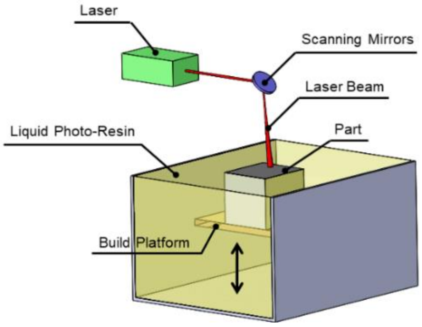


Fig: Schematic diagram of stereolithography process

2. LITERARURE SURVEY

Montalvo Navarrete, et al [1] The materials such as Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) are used for the manufacturing of the filaments. This paper presents a thermogravimetric study of samples of wood flour and bio-composites, in order to study the thermal stability of these materials, and to identify mainly the safe zone of heating and processing of bio-composites for applications in additive manufacturing FDM.

Tuazon, B et al [2] Prototyping and Design: It enables the production of complex geometries that might challenging or costly to achieve using traditional manufacturing methods.

Customization: Automotive manufacturers can create customized parts and components to meet specific customer needs. This is particularly useful for interior features, such as dashboard panels, steering wheels, and seats.

Functional Parts: 3D printing has advanced to the point where it can produce functional parts that are used in the final product. These can include brackets, connectors, and housings.

Ning, F et al [3] In this paper, the authors are going to experimentally investigate if adding carbon fibre into ABS plastic can improve the mechanical properties of FDM-fabricated parts. Tensile test and flexural test were conducted according to ASTM (American Society for Testing and Materials) standards for CFRP composite parts to obtain the mechanical properties. In this ABS wired specimens and Carbon +ABS wired specimens were manufactured, each have different properties. Specimen with 5wt% carbon fibre content had the largest mean value of tensile strength and specimen with 7.5wt% carbon fibre content had the largest mean value of Young' modulus.

Muhammad Shafique et al [4] Additive manufacturing of recycled carbon fibre (RCF) has significant potential for addressing waste from carbon fibre-reinforced polymer composites (CFRPC) and creating high-performance engineering parts. The surface treatment of RCF can enhance its properties to be comparable to virgin carbon fibre (VCF) Using RCF in additive manufacturing is cost-effective and environmentally sustainable. There are challenges that need to be addressed for future developments in manufacturing CFRPC.

F. Ning, W. Cong, Y. et al [5] In this paper author tells us about composite fiber additive manufacturing (CFAM) process. By improving design freedom and reducing production time and cost, additive manufacturing (AM) of carbon fiber reinforced thermoplastic composites can be advantageous over traditional carbon fiber manufacture. A relationship between the amount of compaction pressure and the volume percentage of fibers or porosity within component.

Wang, Y., et al [6] This review investigated current AM technologies, including liquid, solid, powder and hybrid of liquid-powder based AM printings, and corresponding AM composites, including particle, nano-fillers and fiber reinforced AM composites. Upon the understanding of all AM technologies, eg Printing mechanisms, strength and weakness, and AM composite materials formulations, applicability and performance, the limitations and massive potentials.

Abeykoon, C et al [7] was carried out a comprehensive study to investigate the effects of infill density, infill pattern, infill speed, set nozzle temperature and material/reinforcement type (i.e., key process parameters) on mechanical and physical properties of 3D printed structures to widen the understanding. As was expected, the parts printed with 100% infill density provided the highest Young's modulus. Also the strength of the printed parts decreases as infill density decreases. Among the printing speeds tested (70-100 mm/s) speed gave the optimum tensile/flexural modulus performance of 3D printed specimens.

Muhammad Ateeq et al [8] was identified that systematic overview of the RCF obtained after the waste of the CFRPs from the different sectors. The research reviewed the additive manufacturing of the RCF with the different polymers using the 3D printer, the CF potential, and the RCF applications in various sectors. Layer-by layer manufacturing with FDM allows the rapid fabricating of complex geometries; however, component performance depends on the precise configuration of printing settings and the RCF materials used.

Omar, N. et al [9] studied that fibre reinforced composites are widely used in various sectors such as aerospace, wind energy and automotive. Carbon fibre reinforced composites in additive manufacturing are reviewed from the perspective of mechanical properties. The reinforcements generally improve mechanical properties, in particular for tensile modulus and tensile strength. It is clear that the addition of carbon fibre in additive manufacturing of thermoplastics could improve mechanical properties of the product.

Tekinalp, H. L., et al [10] investigated that Additive manufacturing is distinguished from traditional manufacturing techniques such as casting and machining by its ability to handle complex shapes with great design flexibility and without the typical waste. Tensile tests in a servo-hydraulic testing machine at a strain rate of 0.0254 mm/s. A 12.5 mm gage-length extensometer was used for strain measurements. The tensile strength and modulus of 3D-printed samples increased 115% and 700%, respectively.

3. METHODOLOGY

3.1 Over view of the Project:

Here in this report, main objective going to study Tensile specimens (200*20*10) which are used to perform tensile tests, involve pulling a sample in opposite directions to measure its response to stress. These tests help determine the material's strength, elasticity, and elongation before it fails. When 3D printing tensile specimens, it's essential to ensure accurate dimensions and minimal defects to obtain reliable mechanical property data. As the same way BAR specimens (180*20*10) are used to perform bend tests, Flexural tests which assess a material's ductility and resistance to fracture when subjected to bending forces. The specimen is bent around a specific radius to evaluate its ability to deform without fracturing. Like tensile specimens, Bar specimens need to be accurately 3D printed to obtain reliable data. Here 60%, 80% infill densities, 60%, 80% speeds, cross, triangular, Rectilinear, grid patterns with different types of polymeric materials are taken into account. Finally, ANSYS analysis will be made according to the material properties which are used in this project work.

3.2 Process Chart

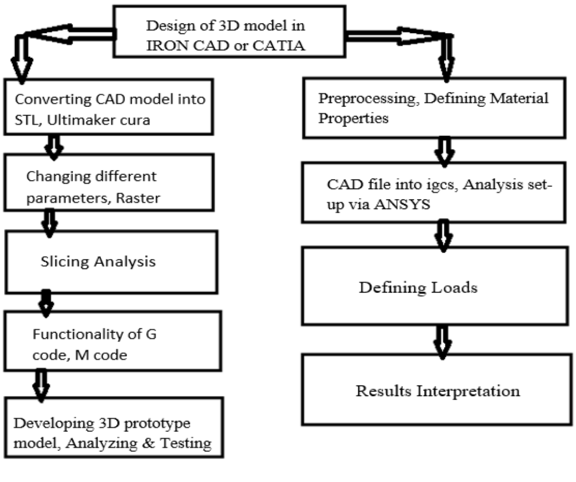


Fig: Process Methodology

4. MARERIALS AND EXPERIMENTATION

4.1 MATERIALS

Fig: X MAX 3D printer

Fig: 3D printed wire, nozzle and heated bed

Fig: Universal Testing Machine(Tensile SET-UP)

Fig: Universal Testing Machine(Flexural SET-UP)

4.2 EXPERIMENTATION

Experimentation involving both physical testing and ANSYS Workbench analysis can provide a comprehensive understanding of a 3D model's behavior. Here's a procedure that combines both approaches:

1. **CAD Modelling:** Create a detailed 3D CAD model of the component using software like SolidWorks or Iron CAD. Ensure the model is accurate, well-defined, and represents the real-world geometry.
2. **Adjustment of Raster Angles and parameters:** Depending upon the material used the Raster angle and infill densities, speed, temperature, pattern type can be varied. The best Raster angle is 45 degree-50 degrees.
3. **Physical Prototype Preparation:** Fabricate a physical prototype of the 3D model using appropriate manufacturing techniques (e.g., 3D printing, machining, etc. Choose materials that closely match the intended real-world application.
4. **Physical Testing:** Apply the defined loads, constraints, or conditions to the physical prototype. Collect data on stress, strain, deformation, temperature, etc., during the testing process.
5. **ANSYS Workbench Analysis:** Import the 3D CAD model into ANSYS Workbench. Set up the analysis environment (boundary conditions, loads, materials, etc.) based on the physical testing conditions.
6. **Preprocessing:** Mesh the geometry appropriately for the analysis type (structural, thermal,). Define material properties, boundary conditions, and loads.
7. **Analysis Setup and Solver Run:** Configure analysis settings in ANSYS Workbench. Run the analysis using the defined setup and solver options.
8. **Postprocessing and Comparison:** Analyse the simulation results, including stress distribution, deformation, temperature gradients, etc. Compare the ANSYS simulation results with the physical testing data. Identify similarities and differences, and understand potential reasons for discrepancies(dissimilarities).

9. **Iteration and Validation:** If there are discrepancies between the physical test results and ANSYS simulation, iterate by refining the analysis setup, mesh, or assumptions. Validate the ANSYS model by ensuring it accurately predicts the behaviour observed in physical testing.

Fig: Tensile and Bending specimens of PLA composites

Fig: Tensile and bar specimens of PLA + C composites

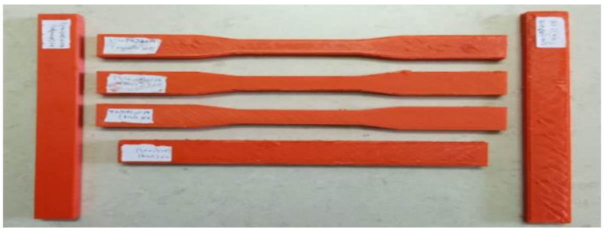


Fig: Tensile and Bending specimens of PETG composites

Fig: Tensile and Bending specimens of ABS composites

5. RESULTS AND DISCUSSIONS

Fig: Tensile specimens after fracture

Fig: Flexural specimens after fracture

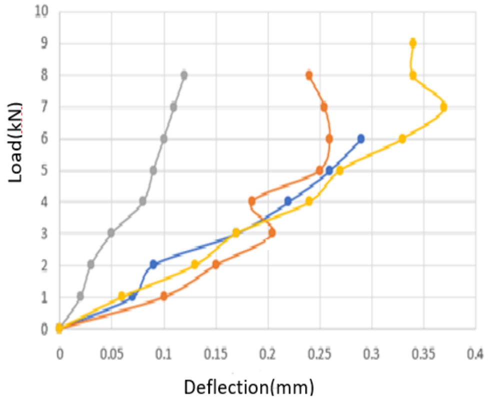


Fig: Load vs Deflection(mm)

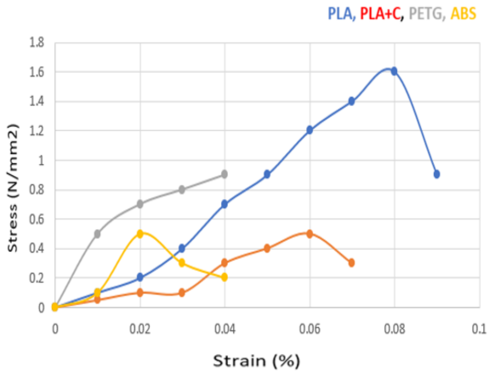


Fig: Stress(N/mm2) vs Strain (%)

- From the above graph 1- PLA having more Deflection = 0.35 mm
- PETG having more Load capacity is 7kN.
- From the above results PLA having more Ultimate Tensile Strength is 1.6 $\frac{N}{mm}2$
- PLA having more Fracture Point is 0.9$\frac{N}{mm}2$

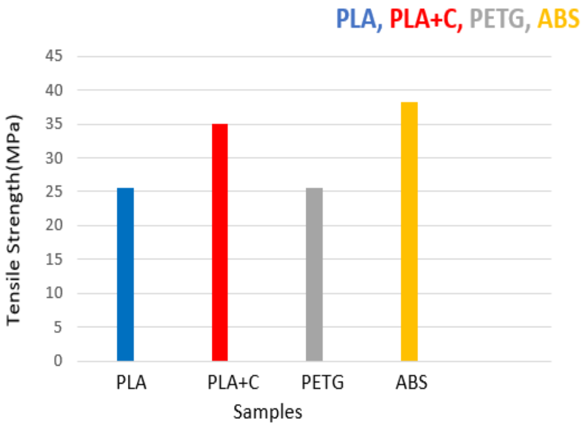
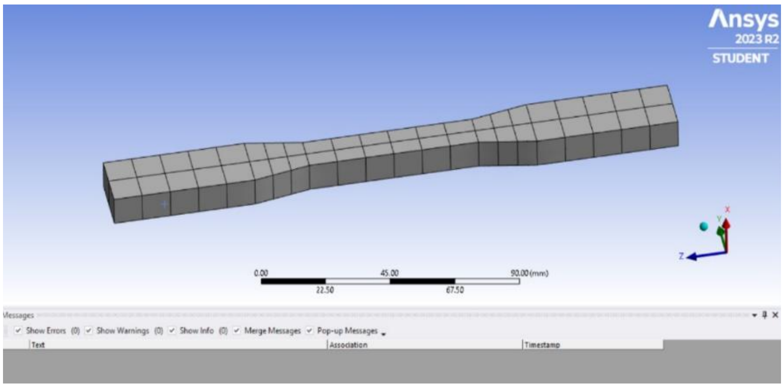
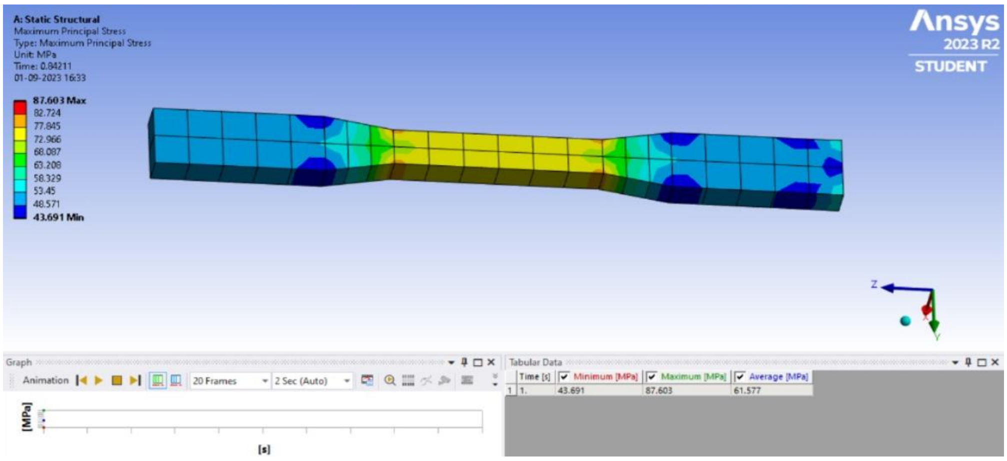


Fig: Tensile Strength (MPa) vs Samples of Specimen

- From the above results ABS having more Tensile Strength is 38.21MPa.

Imported Tensile Geometric Model (PLA)





A: Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 0.84211
01-09-2023 16:33

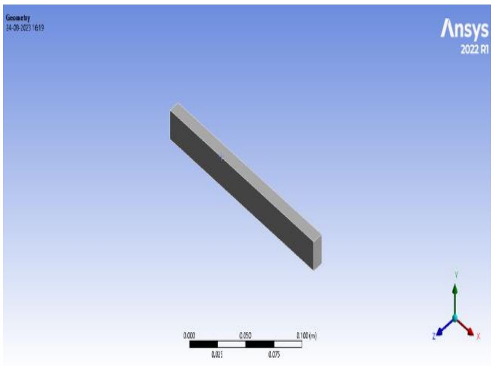
Time [s]	☑ Minimum [MPa]	☑ Maximum [MPa]	☑ Average [MPa]
1.	43.691	87.603	61.577

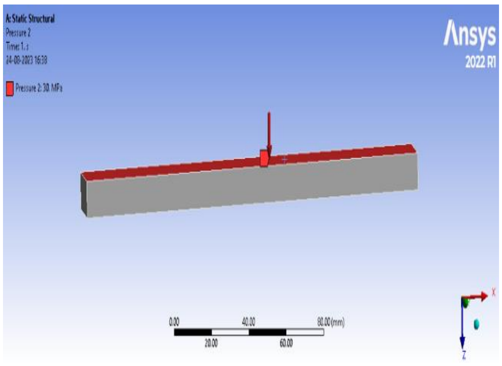
Fig: Maximum principal stress

Material Properties of PLA, PLA + C, PETG, ABS

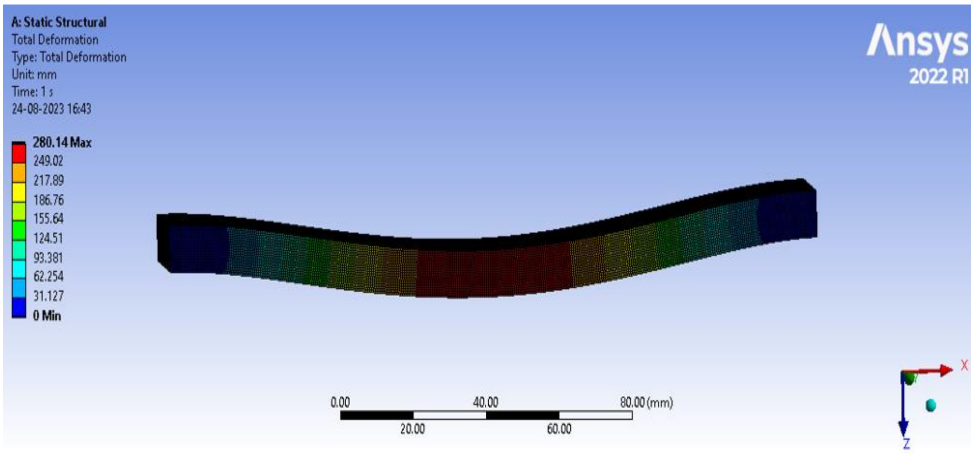
PROPERTY	PLA	PLA + C	PETG	ABS
Tensile Strength	60	47.5	53	50.5
Flexural Strength	100	114	70	56
Young’s modulus (MPa)	3100	3500	2020	1900
Poisson’s ratio	0.35	0.37	0.33	0.38
Density(kg/m3)	1240	1290	1290	1050
Temperature(C*)	200	210	190	240

Imported Bar Geometric Model (PLA)





A: Static Structural
Pressure 2
Time: 1. s
24-08-2023 16:38



A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1 s
24-08-2023 16:43

Fig: Total Deformation

From all the ANSYS analysis the following results will be developed are:

Compared to the PLA + C fibre composites and ABS composites these Polymer composite specimens have usually good durable strength and deformation as observed experimentally.

- PLA Tensile having the maximum principal stress is 87.60 N/mm2 at 7kN Load applied at both the ends.
- PLA Bar specimen having the total deformation of 280 mm at 7kN load applied at the middle area of the specimen.
- The Directional deformation is 23.16 mm through downwards.
- PETG Tensile having the maximum principal stress is 80.50 N/mm2 at 7kN Load applied at both the ends.
- PETG Bar specimen having the total deformation of 88 mm at 7kN load applied at the middle area of the specimen.
- The Directional deformation is 10.29 mm through downwards.

6. CONCLUSIONS

- ▪ From the studies, observed that: Additively manufactured (AM) Carbon fibre reinforced polymer composites (CFRPs) offer a number of advantages over traditional manufacturing methods, including:
- ❑ **Design flexibility:** AM allows for the fabrication of complex CFRP geometries that would be difficult or impossible to produce using conventional methods.
- ❑ **Reduced lead times:** AM can produce CFRPs parts in a matter of hours or days.
- ❑ **Cost:** Additively manufactured CFRP composites can be more expensive to produce than traditional CFRP composites, due to the cost of AM printers and materials.
- Comparing to ANSYS analysis, Physical testing results are more-better and accurate manner. Beyond the limitations the fibre reinforced polymer composites (CFRPs) have good durable strength and mechanical properties.
- Finally, this paper concludes that Strength properties will be depends upon the selection of the materials, properties of the materials, infill densities and infill patterns etc.

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