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STUDY OF ELASTIC BEHAVIOUR OF ABS PLASTIC: EXPERIMENTAL AND ANALYTICAL APPROACH

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ABSTRACT:
3D printing, a revolutionary manufacturing process, has transformed the landscape of rapid prototyping and small-scale production. Among various 3D printing technologies, Fused Deposition Modeling (FDM) stands out as a widely adopted method. FDM utilizes thermoplastic filaments, such as Acrylonitrile Butadiene Styrene (ABS), to construct objects layer by layer based on digital models. ABS, known for its exceptional strength, impact resistance, and heat tolerance, is a favored material in FDM. This abstract explores the synergy between 3D printing, FDM and ABS, elucidating the versatility and applications of this trio. ABS's mechanical properties make it a robust choice for creating functional prototypes, consumer goods, and automotive components. The FDM process, harnessing the accessibility and simplicity of 3D printing, empowers users to translate digital designs into tangible, high-quality objects. As technology advances, the seamless integration of 3D printing, FDM, and ABS promises continued innovation across industries, ushering in a new era of agile and customizable manufacturing. ASTM D638 standards were followed for carrying out tensile tests. Results of tensile test revealed that the hyper resolution sample can sustain maximum tensile stress and load as compared to other resolutions. Yet, these outcomes empower designers to grasp the correlation between resolutions. Armed with the data presented in this study, designers can effectively model and fabricate suitable 3D prototypes.

Keywords:
3D Printing; Rapid Prototyping; Acrylonitrile Butadiene Styrene; ABS; Fused Deposition Modelling; FDM; ANSYS

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1. INTRODUCTION

Traditional manufacturing methods involve shaping solid parts by removing or reshaping material from a block of workpiece according to a CAD file created in software like SolidWorks, CATIA, Pro-E, Uni-Graphics, and AutoCAD. However, these conventional machining processes face limitations when it comes to producing complex designs. Molding processes, while effective, often incur high costs for molds and may experience decreased accuracy over multiple production batches [1], [2].

To overcome these challenges, manufacturing has evolved with the integration of CAD and CAM, automating machining processes to reduce costs and time, particularly for intricate geometries [3]. Figure 1 shows the key stages involved within the Rapid Prototyping process. Rapid Prototyping (RP) has emerged as a popular alternative, enabling the rapid fabrication of complex parts or entire assemblies directly from CAD data without manual intervention.

RP, also known as Additive Manufacturing (AM), Solid Freeform Fabrication (SFF), Layered Manufacturing (LM), or Automated Fabrication (AF), builds objects layer by layer in the x-y plane, adding and bonding materials incrementally in the z-direction [4], [5]. This additive approach offers significant advantages in terms of speed and flexibility compared to traditional subtractive methods [6]. While the fundamental fabrication process remains consistent across all RP methods, the mechanism for creating and bonding individual layers varies depending on the specific system employed.

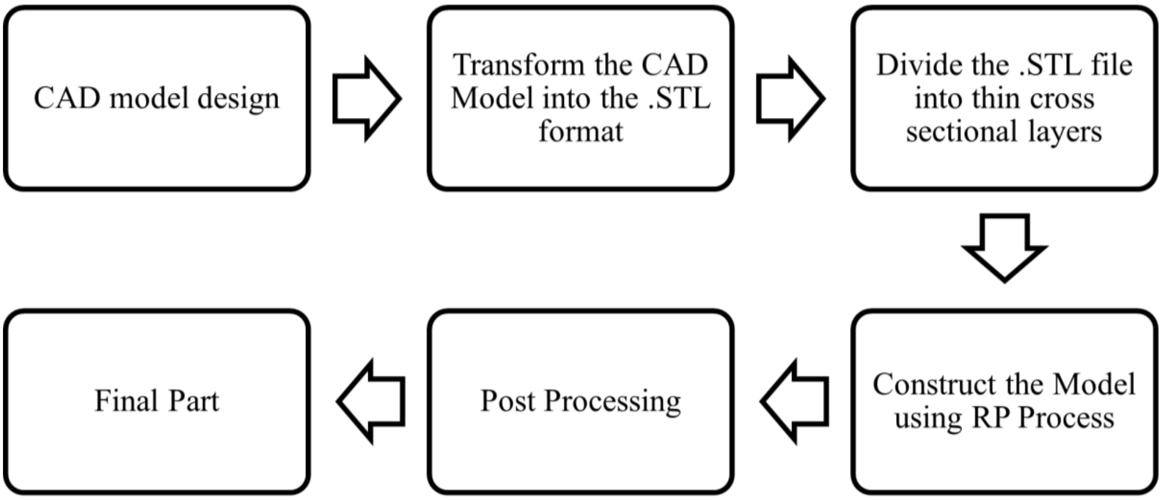

Figure 1: Key stages in the typical RP process

In the initial phase of the RP process, the foundation lies in creating a model using solid modeling software. This entails selecting a solid geometry that serves as the basis for generating the necessary data to precisely guide the fabrication process. This step ensures efficient control and execution of the manufacturing process [7], [8].

1.1 Acrylonitirile Butadiene Styrene (ABS)

ABS (Acrylonitrile Butadiene Styrene) is a copolymer comprising acrylonitrile, butadiene, and styrene. This thermoplastic resin offers a balance of strength, performance, and cost effectiveness [9]. The monomers of ABS plastic are illustrated in Figure 2. Positioned between standard resins like PVC, polyethylene, and polystyrene, and engineering resins such as acrylic, nylon, and acetyl, ABS delivers properties that often meet requirements at a reasonable price point [10].

Widely regarded as the premier member of the styrene family, ABS exhibits toughness, hardness, and rigidity. Its attributes include good chemical resistance and dimensional stability, making it a versatile choice for various applications [11]. The properties of ABS plastic are tabulated in Table 1 [12].

Chemical Formula of ABS: **$(C_8H_8)x.(C_4Hz_6)y.(C_3H_3N)z$**

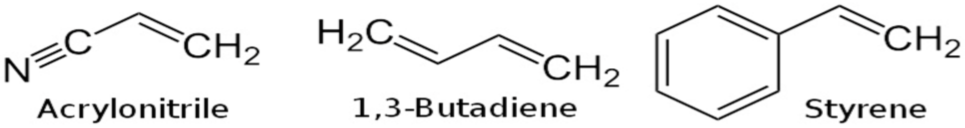

Figure 2: Monomers of ABS

Table 1: Properties of ABS

S.No.	Mechanical Properties	Values
1	Density	1.02-1.21 g/cm^3
2	Tensile Strength	43.8 MPa
3	Elastic Limit	38.45 MPa
4	Young's Modulus	2.0-2.6 GPa
5	Poisson Ratio	0.3
6	Elongation at break in (%)	7.2
7	Stress at break	29.58 MPa

2. EXPERIMENTAL ANALYSIS

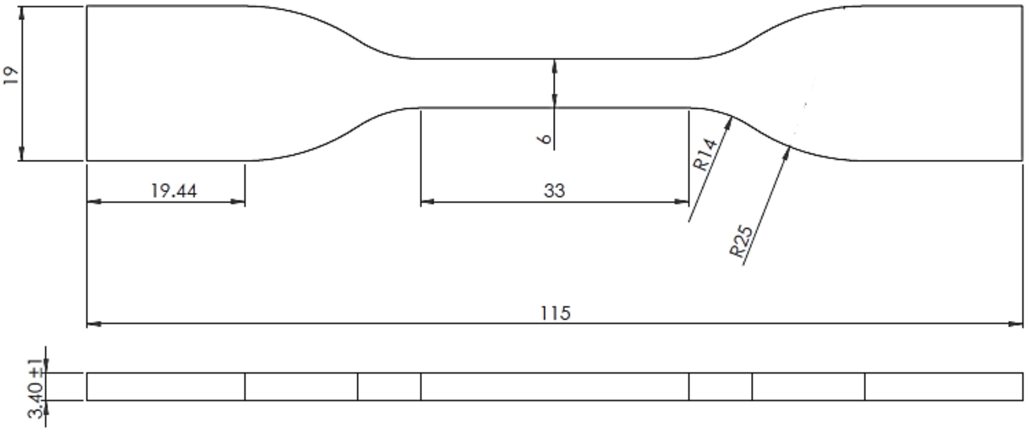

Figure 3: ASTM D683 Type-IV

ASTM D638 is a standard test method developed by ASTM International for determining the tensile properties of plastic materials [13]. ASTM D638 outlines the procedure for testing the ultimate tensile strength, elongation at break, and other mechanical properties of plastic materials in the form of standard test specimens. Figure 3 shows the standard dimensions for the ASTM D638 specimen [14]. The standard includes several types and categories of test specimens, each designed for specific applications or material forms [15].

The Flashforge Finder 3D printer shown in Figure *4*, is utilized for printing ABS plastic specimens under various printing conditions. Its user-friendly interface and precise control allow for the adjustment of parameters such as temperature, layer height, and printing speed to achieve optimal results [16]. Parameters for printing ABS plastic specimen were tabulated under Table *2* [17]. Its filament compatibility and compatibility with third-party slicing software offer flexibility in customizing print settings and experimenting with different configurations [18]. STL (Standard Tessellation Language) serves as a widely adopted 3D model file format, characterized by surfaces composed of triangles [19]. In a well-designed STL, all normal face outward, ensuring a continuous surface without any gaps.

Table 2: Parameters of 3D printer

Specimen	Resolution	Layer Height	First Layer Height	Print Speed	Travel Speed
I	Low	0.30 mm	0.30 mm	80 mm/s	100 mm/s
II	Standard	0.18 mm	0.27 mm	60 mm/s	80 mm/s
III	High	0.14 mm	0.21 mm	50 mm/s	70 mm/s
IV	Hyper	0.08 mm	0.20 mm	50 mm/s	70 mm/s

The specimen is mounted in the UTM and then the strain gauge is calibrated into it as shown in Figure 5. The initial dimensions of each specimen are measured using Digital Vernier Calliper [20]. After the specimen is calibrated, a pre-load of 200N is applied and gradual increase in load is set to 100N. The speed of UTM is set to 2mm/min. Total test time is set to be under 0.5-5.0 minute and load is applied till breaking of the specimen.

Before and after tensile testing of 3D printed ABS specimens provides valuable insights into the material's mechanical behaviour and structural integrity. Prior to testing, the specimen undergoes preparation and alignment within the testing apparatus. During the test, the specimen is subjected to increasing tensile load until failure occurs [21]. Measurements of load, elongation, and stress are recorded throughout the test. After testing, analysis of the fractured specimen offers crucial information.

Figure 6 shows before and after tensile testing of the specimens at UTM. Examination of the fracture surface can reveal fracture modes, such as brittle or ductile failure, indicating the material's response to tensile stress.

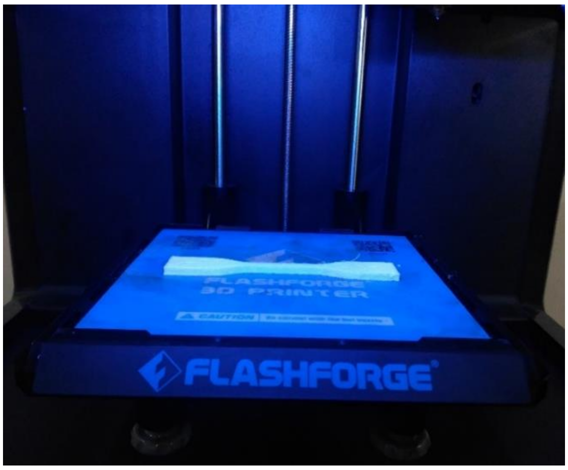

Figure 4: Flashforge Finder 3D printer

Figure 5: INSTRON 5982 Dual Column Floor Model UTM

Figure 6: 3D printed ABS specimens before and after Tensile Test

3. ANALYTICAL ANALYSIS

To create and analyze a part using SolidWorks and ANSYS, follow these steps. First, design the part in SolidWorks and extrude it. Save the extruded part in IGES format for ANSYS compatibility. To set up material properties for ABS Plastic in ANSYS Workbench's Static Structural analysis, begin by accessing the Static Structural module from the engineering data tabulated in Table 3 [22]. Then, proceed to specify key attributes such as Density, Young's Modulus, and Poisson's Ratio tailored to ABS Plastic. This step ensures accurate representation of the material's behavior within your simulation environment. Import the IGES file into ANSYS and adjust mesh settings for accuracy, then generate the mesh. Set analysis parameters, including fixing the end side of the grip face as a fixed support. Define solution settings to include Total Deformation, Max. Principal Stress, Max. Principal Shear Stress, and Max. Principal Elastic Strain. Solve the analysis to obtain results and charts based on the specified data. This process ensures a comprehensive analysis of the designed part's performance under specified conditions.

Table 3: Engineering Data for ABS Material

Sr. No.	Properties	Values
1	Density	1.3 gm/cm^3
2	Young's Modulus	2.6 GPa
3	Poisson's Ratio	0.39
4	Tensile Yield Strength	37.5 MPa
5	Compressive Yield Strength	37.5 MPa
6	Tensile Ultimate Strength	50 MPa
7	Compressive Ultimate Strength	50 MPa

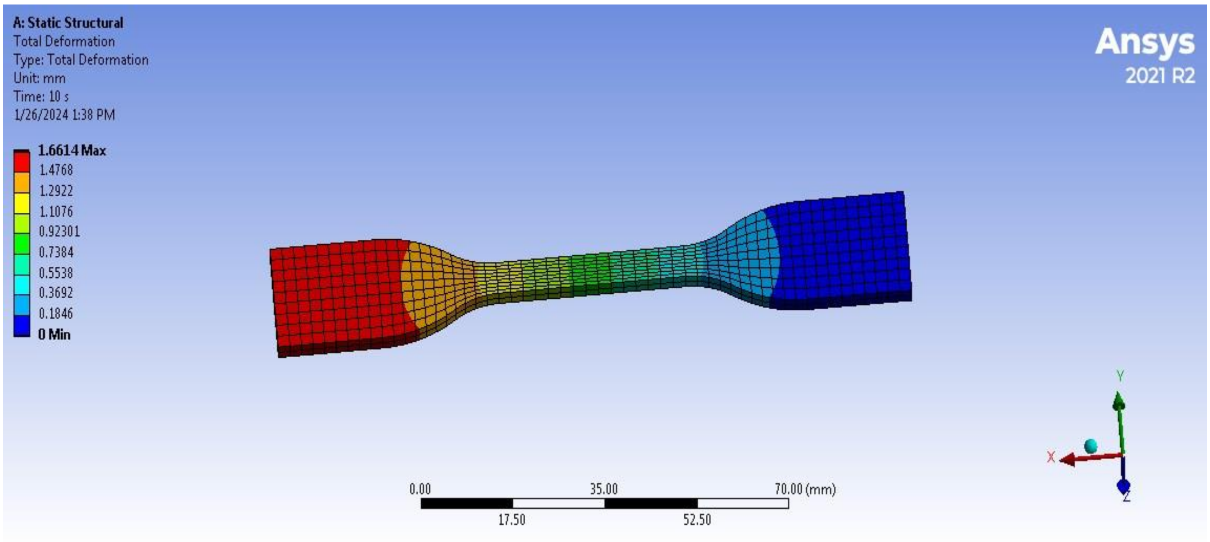

Figure 7: Total Deformation

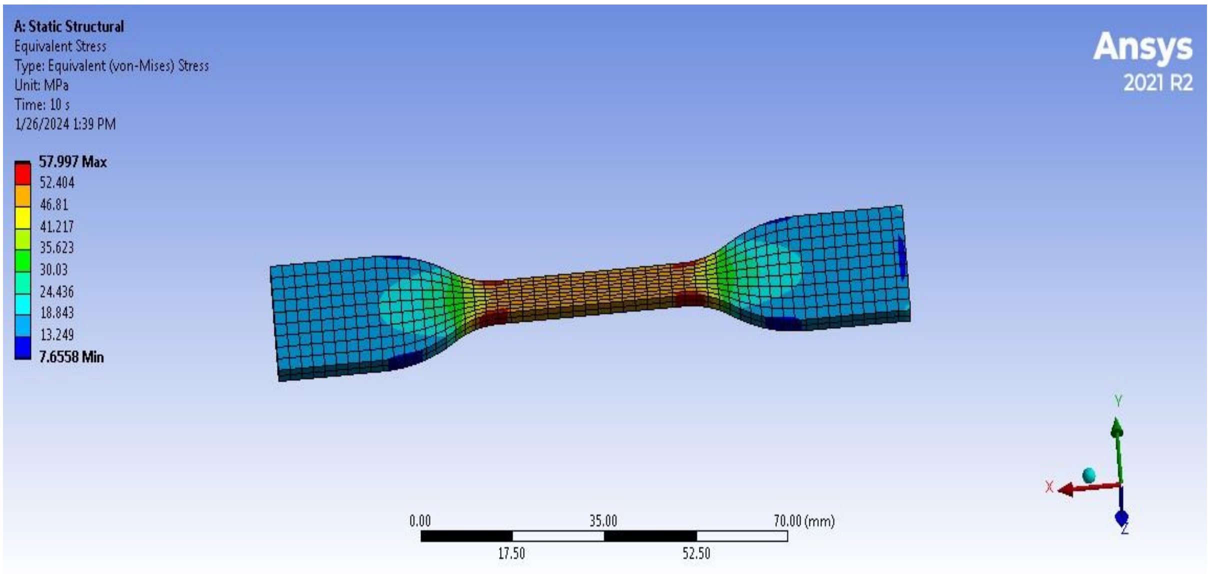

Figure 8: Equivalent (Von-Mises) Stress

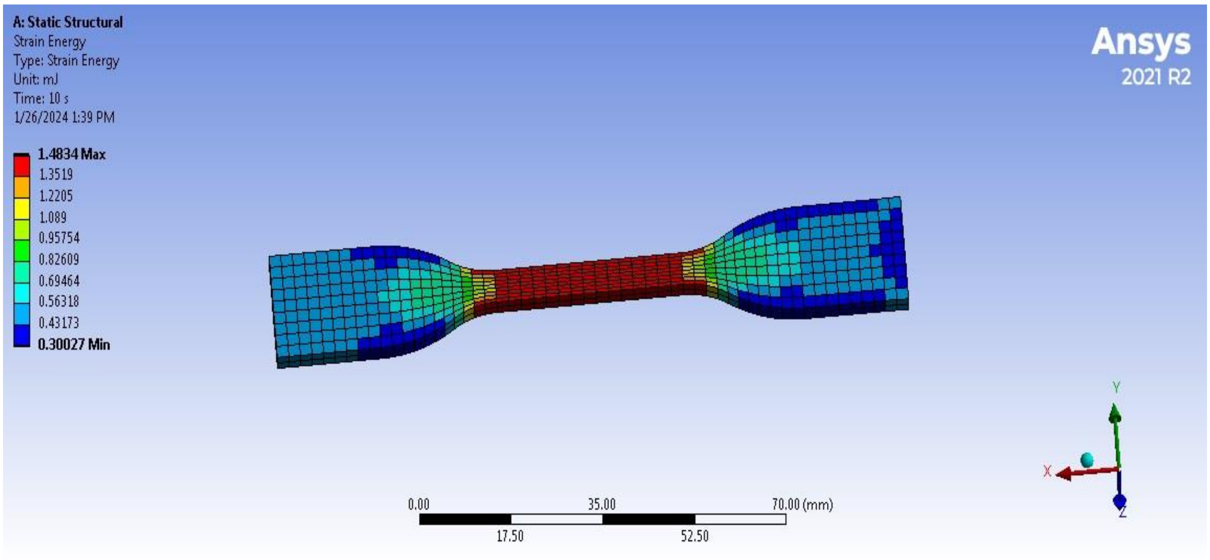

Figure 9: Strain Energy

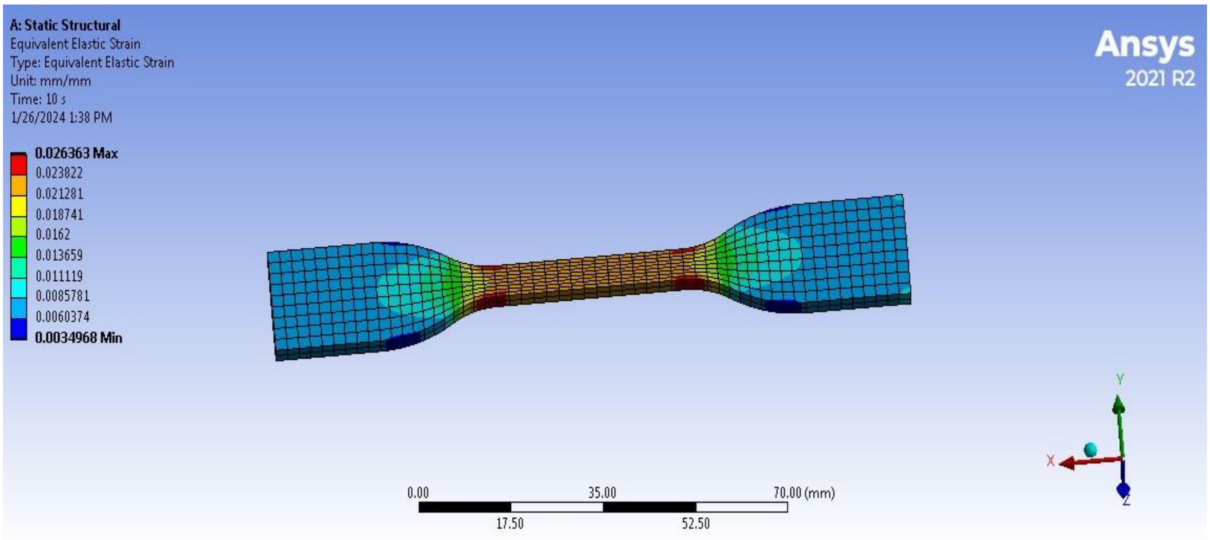

Figure 10: Equivalent Elastic Strain

In Figure 7, the Total Deformation of the specimen is depicted, while Figure 8 illustrates the Equivalent Von-Mises Distribution across the specimen. Figure 9 and Figure 10 present the Strain Energy and Equivalent Elastic Strain Distribution along the specimen, respectively.

4. RESULT AND DISCUSSION

4.1 UTM Tensile Test Result

The UTM Tensile Test Results shows how gradually increasing load effects the deformation of the specimens. Figure 11 shows Load v/s Extension graph for specimens I, II, III and IV respectively. Figure 12 shows Stress v/s Strain graph for specimens I, II, III and IV respectively. Some of the data retrieved from the UTM graph plots can be evaluated for the result and conclusion and is shown in Table 4. The mean values provided in the table are derived from the data obtained from specimens I, III, and IV. This value serves as a representative measure of the average strength exhibited by ABS plastic specimens. Specimen II is excluded from mean values calculation because of its premature failure while testing [19].

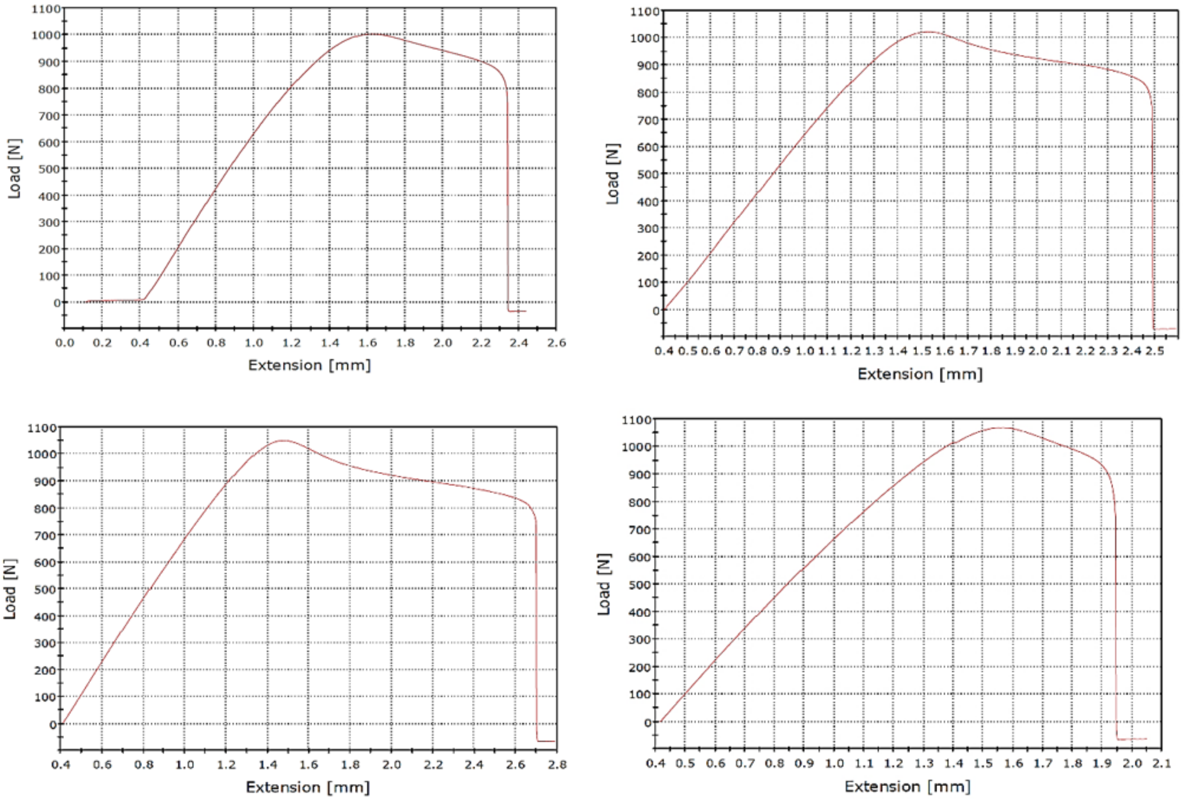

Figure 11: Load-Extension Graph for specimen I, II, III, IV

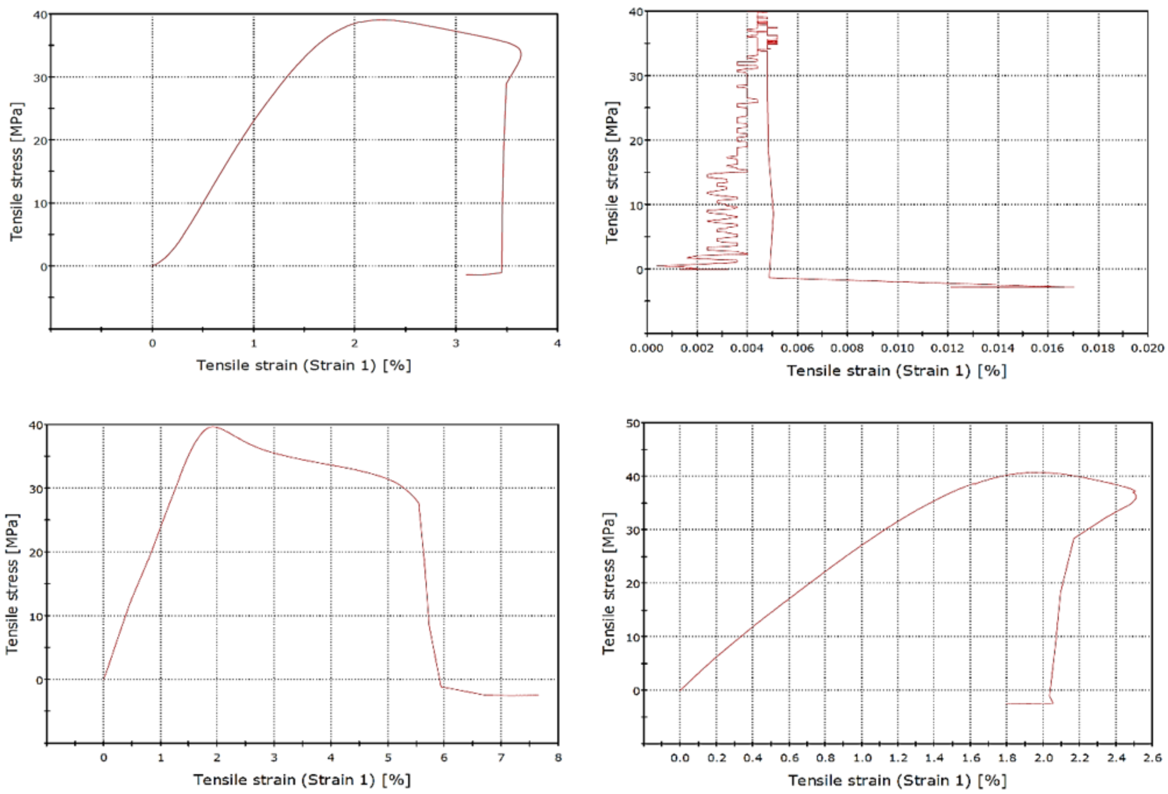

Figure 12: Stress-Strain Graph for specimen I, II, III, IV

Table 4: Result of Tensile Test in UTM

Specimen	Layer Height (mm)	Maximum Load (N)	Maximum Displacement (mm)	Tensile Strain (ε_T break in %)	Tensile Strain (ε_T max load in %)	Tensile Stress (σ_T max load in MPa)	Modulus (GPa)
I	0.30	1002.737	1.62298	3.1	2.252	39.061	2.440
II	0.18	1021.394	1.5258	0.0	0.0044	39.927	2.413
III	0.14	1049.787	1.49149	7.6	1.936	39.657	2.270
IV	0.08	1068.306	1.56362	1.8	1.986	40.701	2.503
Mean		1035.556	1.55097		2.058	39.8365	2.406

4.2 ANSYS Simulation Result

In ANSYS simulation of a tensile test, the material undergoes a series of computational processes to replicate its behaviour under tension. Initially, the 3D model of the specimen is created, accurately representing its geometry and material properties. Boundary conditions are then applied to simulate the loading conditions, typically involving fixing one end of the specimen while applying a gradually increasing load to the other end. Throughout the simulation, ANSYS provides detailed results such as stress-strain curves shown in Figure 13 and load versus deformation graph as shown in Figure 13, von Mises stress distribution, displacement fields and equivalent strain results were also tabulated in Table 5.These results offer insights into how the material responds to tension, including areas of high stress concentration, plastic deformation, and potential failure modes. By analysing these results, engineers can optimize designs, predict material behaviour, and ensure the structural integrity and performance of components under tensile loading conditions.

Table 5: Result of ANSYS Simulation Test

Steps	Time (s)	Load (N)	Maximum Displacement (mm)	Equivalent (Von-Mises) Stress (MPa)	Equivalent Strain (mm/mm)
1	1	100	0.16614	5.7997	2.6363 x10^{-3}
2	2	200	0.33228	11.599	5.2726 x10^{-3}
3	3	300	0.49842	17.399	7.9088 x10^{-3}
4	4	400	0.66456	23.199	1.0545 x10^{-3}
5	5	500	0.83071	28.998	1.3181 x10^{-3}
6	6	600	0.99685	34.798	1.5818 x10^{-2}
7	7	700	1.1630	40.598	1.8454 x10^{-2}
8	8	800	1.3291	46.398	2.1090 x10^{-2}
9	9	900	1.4953	52.197	2.3727 x10^{-2}
10	10	1000	1.6614	57.997	2.6363 x10^{-2}

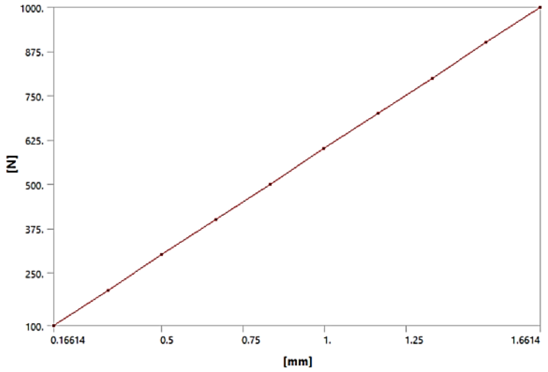

Figure 13: Stress v/s Strain Graph

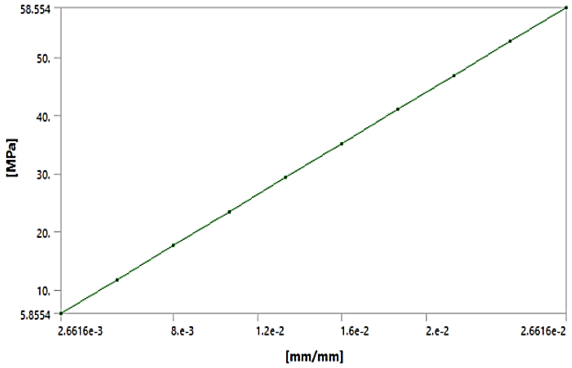

Figure 14: Load v/s Deformation Graph

5. CONCLUSIONS

The result observed are as follows:

- Specimen 4 exhibited a maximum stress of 40 MPa when subjected to a load of 1068 N during UTM testing. In comparison, specimen 1 reached its maximum deformation of 1.622 mm under a load of 1002 N during the same testing procedure. These measurements provide insights into the mechanical behavior and performance characteristics of the respective specimens under applied loads.
- The obtained deformation of 1.66 mm is observed under simulation (at 1000 N) while under UTM 1.622 mm is observed (at 1002 N), error being under 2.3%.
- Specimen 2 exhibited a distinct behavior compared to the other specimens. Its failure occurred prematurely due to the material's fragility, causing it to fail before reaching its yield point. Specifically, it failed at a load of 1021 N, indicating a lower tolerance to stress and a lack of ductility compared to the other specimens.

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