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9th INTERNATIONAL SCIENTIFIC CONFERENCE ON DEFENSIVE TECHNOLOGIES

Belgrade, 15-16, October 2020

PROCEEDINGS

TOPICS

AERODYNAMICS AND FLIGHT DYNAMICS
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MATERIALS AND TECHNOLOGIES
QUALITY, STANDARDIZATION, METROLOGY, MAINTENANCE AND EXPLOITATION

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Col **Bojan Pavković,** PhD (Eng)

Editors
Miodrag Lisov
Ljubica Radović

Technical Editing
Dragan Knežević

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PREFACE

Military Technical Institute, the first and the largest military scientific-research institution in the Republic of Serbia with over 70 years long tradition, has been traditionally organizing the OTEH scientific conference, devoted to defense technologies. The Conference is supported by the Ministry of Defense and it takes place every second year.

Its aim is to gather scientists and engineers, researchers and designers, manufactures and university professors in order to exchange ideas and to develop new relationships.

The ninth International Scientific Conference OTEH 2020 is scheduled as follows: lecture on the occasion of “Mihailo Petrovic Alas”, given by Prof. Žarko Mijajlović, PhD, and plenary lecture on “Electromagnetic Pulsed Weapon Treat Hmp and Hemp“, given by Prof. Momčilo Milinović, PhD Eng, and working sessions according to the Conference topics.

The papers which will be presented at the Conference have been classified into the following topics:

- Aerodynamics and Flight Dynamics
- Aircraft
- Weapon Systems and Combat Vehicles
- Ammunition and Energetic Materials
- Integrated Sensor Systems and Robotic Systems
- Telecommunication and Information Systems
- Materials and Technologies
- Quality, Standardization, Metrology, Maintenance and Exploitation.

The Proceedings contain 97 reviewed papers which have been submitted by the authors from 13 different countries. I would also like to emphasize that 23 papers are from abroad. The quality of papers accepted for publication achieved very high standard. I expect stimulated discussion on many topics that will be presented online, during two days of the Conference.

On behalf of the organizer I would like to thank all the authors and participants from abroad, as well as from Serbia, for their contribution and efforts which made this Conference possible and successful.

I would also like to thank the Ministry of Education, Science and Technological Development of the Republic of Serbia for its financial support.

Finally, dear guests and participants of the Conference, I would like to wish you a pleasant and successful work during the Conference. I am looking forward to see you again at the tenth Conference in Belgrade. All the best and stay healthy.

Belgrade, October, 2020

Col. Miodrag Lisov PhD Eng
President of the Scientific Committee
OTEH 2020

C O N T E N T S

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1. SECTION : AERODYNAMICS AND FLIGHT DYNAMICS - AFD

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DIMENSIONAL ACCURACY AND EXPERIMENTAL INVESTIGATION ON TENSILE BEHAVIOR OF VARIOUS 3D PRINTED MATERIALS

MOHAMMAD SAKIB HASAN
University of Belgrade, Faculty of Mechanical Engineering, Belgrade, sakibhasan89@yahoo.com

TONI IVANOV
University of Belgrade, Faculty of Mechanical Engineering, Belgrade, tivanov@mas.bg.ac.rs

DRAGOLJUB TANOVIĆ
University of Belgrade, Faculty of Mechanical Engineering, Belgrade, dtanovic@mas.bg.ac.rs

ALEKSANDAR SIMONOVIĆ
University of Belgrade, Faculty of Mechanical Engineering, Belgrade, asimonovicc@mas.bg.ac.rs

MILOŠ VORKAPIĆ
University of Belgrade, Institute of Chemistry, Technology and Metallurgy- Centre for Microelectronic Technology, Belgrade, worcky@nanosys.ihtm.bg.ac.rs

Abstract: *Additive manufacturing (AM) or 3D printing is becoming very popular in the aerospace and defense industry because of its ability to manufacture complex parts at a low price. Fused deposition modeling (FDM) is one of the most popular 3D printing techniques currently on the market. Acrylonitrile butadiene styrene (ABS) or poly (lactic acid) (PLA) are the two most commonly used 3D printed materials. Dimensional accuracy of FDM processed 3D printed materials (PLA, ABS, PETG, and HIPS) and experimental investigation of the tensile properties of those materials is the main scope of this paper. Tensile testing machine SHIMADZU AGS-X 100 kN was used to carry out the experimental study.*

Keywords: *3D printer, FDM, Tensile properties, Tensile test.*

1. INTRODUCTION

3D printing is an additive manufacturing (AM) or rapid prototyping (RP) process where an object is made by joining materials from 3D model data, usually layer by layer. Charles Hull described the technology in 1986 in a process known as Stereolithography (SLA). The developing interest of 3D printing technology in the defense industry is global. For the last 10 years, the aerospace industry has been one of the top sectors leading the AM market. Wohler's report shows that 18.2% of the total revenue in the AM industry is received from the aerospace industry [1].

Additive manufacturing technology creates objects by adding successive layers of materials by heating thermoplastic filament on top of each other through a small nozzle while reaching satisfactory geometric accuracy. It begins with a meshed 3D computer model that can be created by computer-aided design (CAD) software like SolidWorks, Catia, etc. A STL (Surface Tessellation Language) file is commonly created from CAD software. The mesh data will be further sliced into a build file of 2D layers from where a G-Code is formed and then sent to the 3D printing machine [2].

Various printing processes have been invented since the late 1970s. Among them, some techniques are well known, such as fused deposition modeling (FDM), powder bed and inkjet head 3D printing (3DP), stereolithography (SLA), selective laser sintering (SLS), digital light processing (DLP) technology, etc. In this research fused deposition modeling technology is used. It is perhaps the most versatile and low-cost additive manufacturing technique. Freedom of design to create complex parts without the need to invest in dies and molds and the capability to fabricate internal features, which is impossible using traditional manufacturing processes are two of the main advantages of FDM. Contrarily, fragile mechanical properties, layer-by-layer appearance, poor surface quality, and a limited number of thermoplastic materials are the main drawbacks of FDM. Fig 1. shows the schematic view of the FDM process [3].

FDM printers are easy and safe to use, printed parts do not necessarily require complicated post-processing techniques, and the range of materials and upgrades continues to grow with popularity. Some of the commercially available materials nowadays are PLA (polylactic acid), ABS (Acrylonitrile Butadiene Styrene), PETG (Polyethylene Terephthalate), high impact polystyrene (HIPS), nylon, PC (Polycarbonate), PEI (Polyetherimide, Ultem 9085) and more others.

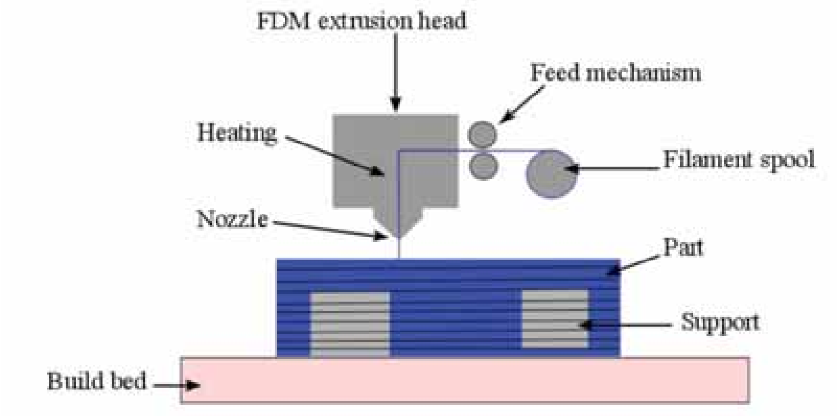


Figure 1. Schematic view of fused deposition modeling [3].

There are many research papers that focused only on processing parameters such as building orientation [4], while [5] concentrates on different parameters concomitantly and studied their combined effects. The influence of the extrusion temperature on the mechanical properties was discussed in [3]. Effect of infill parameters on tensile behavior presented in [6]. Mechanical properties of different materials are investigated in recent years. The tensile properties of four different polymeric materials with the same filling density (~ 20%) were investigated in [7]. [8] investigated the fatigue response of PLA parts manufactured through FDM techniques. Tensile and flexural tests of PETG material were investigated in [9].

This work is dedicated on the tensile strength and modulus of elasticity of 4 different materials: PLA, ABS, HIPS, and PETG with the same infilling density of 100%.

2. METHODOLOGY

The tensile properties of four different printing materials were examined. Project workflow started with the selection of materials. Sample preparation was in the second stage of the investigation and finally, mechanical characteristics of materials were determined in the experiment step. Fig. 2 illustrates the methodology of the research.

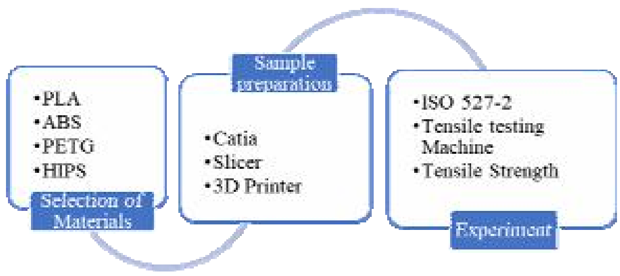


Figure 2. Workflow of the project

2.1. Selection of Material

Four types of filaments were used in the experimental part for the test specimens, which were PLA (Polylactic Acid), ABS (Acrylonitrile Butadiene Styrene), PETG (Polyethylene Terephthalate with a glycol modification) and HIPS (High Impact Polystyrene). 20 specimens were printed with 5 samples of each material for the research. Table 1 shows the types of material that were used and the name of their manufacturer companies.

Table 1. 3D printing materials and their manufacturers.

Material type	Manufacturer
PLA	Wanhao
ABS	Wanhao
PETG	Devil Design
HIPS	Devil Design

2.1.1 PLA (Polylactic Acid).

PLA is one of the most commonly used filaments currently on the market. It is commercially available in a wide range of colors and texture. PLA filament melts at around 200 [°C].

2.1.2 ABS (Acrylonitrile Butadiene Styrene)

ABS is a very popular filament thanks to its low cost and good mechanical properties. ABS is known for its toughness and impact resistance which allow printing durable parts that will hold up to extra usage and wear. The melting temperature of ABS is around 240 [°C]. Acrylonitrile Butadiene Styrene tends to shrink a bit as it cools so it is recommended to use a 3D printer that has enclosed chamber.

2.1.3 PETG

PETG is a Glycol Modified version of Polyethylene Terephthalate (PET), which is commonly used to manufacture water bottles. It is known for its good impact resistance. Glistering and smooth surface finish are the main pros of this kind of material.

2.1.4 HIPS

HIPS, or High Impact Polystyrene, is a lightweight water-resistant dissolvable support material that is frequently used with ABS. The authors decided to print specimens with HIPS to investigate their mechanical characteristics.
The specifications of all 4 materials (with a diameter of 1.75 [mm]) are shown in Table 2 and are specified by the manufacturer.

Table 2. Recommended printing parameters for PLA, ABS, PETG and HIPS according to their respective manufacturers

Material type	Nozzle temperature [°C]	Bed temp. [°C]
PLA	190-225	50-60
ABS	220-235	80-110
PETG	220-250	70-80
HIPS	230-240	90-100

2.2. Sample preparation

The specimens used in this were designed based on the International Organization for Standardization ISO 527-2 standards for determining the tensile properties of molding and extrusion plastics. Figure 3 shows the dimensions of such a specimen.

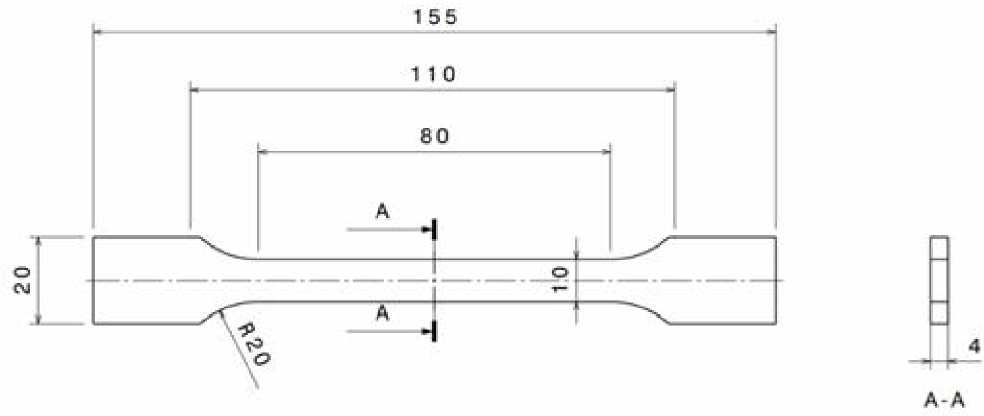


Figure 3. Dimensions of specimen (units are given in [mm])

Thus, a set of bone-shaped specimens, with a thickness of 4 [mm], with 110 [mm] of initial distance between grips was created.

Preparation for printing and selection of priting parameters was done in Ultimaker Cura version 3.1.0. Ultimaker Cura is the world's most popular 3D printing software which gives over 400 settings for granular control [10]. Figure 4 presents the interface of the slicing software with a three-dimensional view of the model.

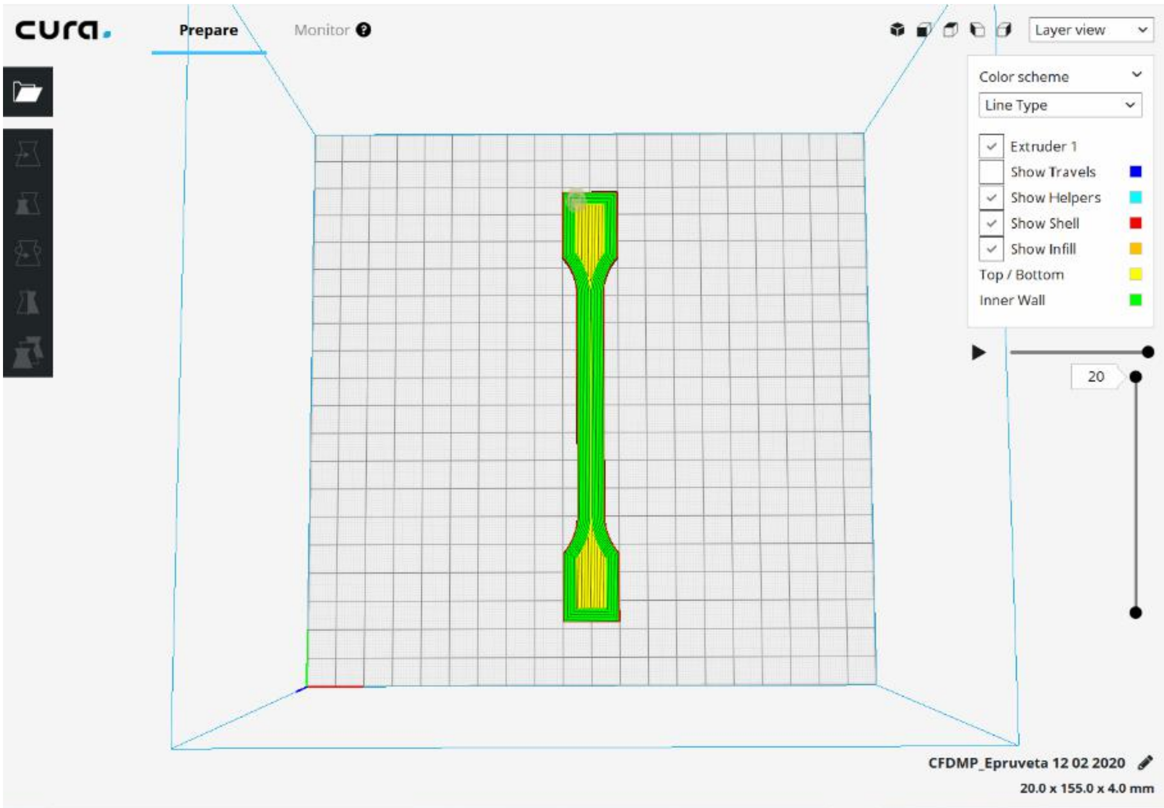


Figure 4. Graphical user interface of Ultimaker Cura

The layer height (0.2 [mm]), wall thickness (5 [mm]), printing speed (60 [mm/s]) and infill density (100 [%]) were set identical for all specimens. Only the extrusion and bed temperatures were different depending on the material used. Table 3 shows the printing parameters that were used for creating the G-code in Ultimaker Cura.

Table 3. Printing parameters

Specimen number	Material	Nozzle temperat-ure [°C]	Bed Temperat-ure [C°]	Layer Height [mm]	Density [g/cm^3]
1- 5	PLA	215	60	0.2	1.31
5 -10	ABS	255	80	0.2	1.01
10 -15	PETG	255	80	0.2	1.23
15 -20	HIPS	230	100	0.2	1.05

The specimens were printed on the Wanhao Duplicator 6 printer. Fig 5 illustrates the printing process and the printed samples.

(a)

(b)

Figure 5. 3D printing: (a) printing process; (b) specimens from different materials

2.3. Experiment

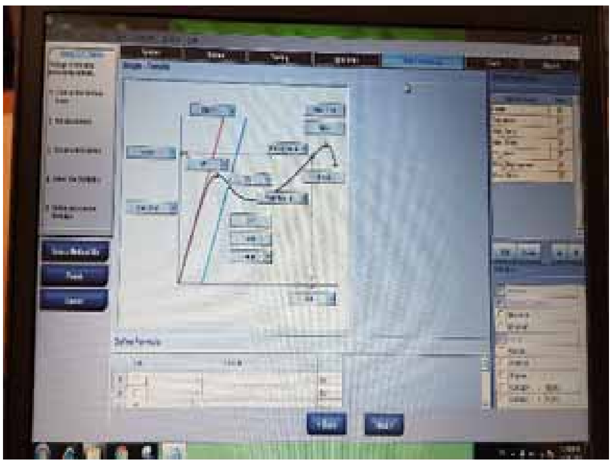
The tensile test was performed on a universal testing machine- Shimadzu AGS-X with a capacity of up to 100 kN. The entire setup was calibrated and testing was performed according to the ISO 527-2 standard with a testing speed of 1 mm/min. Mechanical properties like Young's Modulus of elasticity and maximum tensile strength were calculated using the recorded data. Figure 6 represents the tensile testing machine and specimens after the tensile test.

(a)

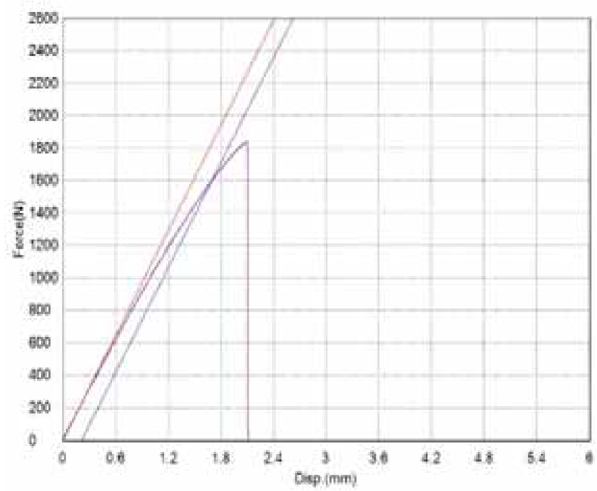
(b)

Figure 6. 3D printed sample after tensile testing

Trapezium-X software was used for monitoring tensile properties results and drafting stress-strain diagrams. Figure 7 shows the Trapezium software and the stress-strain diagram obtained from the trapezium.



(a)



(b)

Figure 7. Trapezium-X software and stress-strain diagram obtained from the software

3. RESULTS AND DISCUSSION

3.1. Dimensional accuracy

To investigate the dimensional accuracy, all printed specimens were measured and compared to the designed CAD model (fig. 4). Three points were chosen to measure width and thickness value using a Vernier caliper as shown in figure 8.

Figure 8. Measured location of the FDM specimen

All three values then averaged to a single value. The overall measurement results are summarized in Table 4.

Table 4. Average values of the samples

Specimens	Material type	Thickness [mm]	Width [mm]
CAD model		**4**	**10**
1		3.69	10.02
2		3.83	10.04
3	PLA	3.82	10.02
4		3.81	10.04
5		3.87	10.09
6		3.81	10.05
7		3.82	10.26
8	ABS	3.84	10.40
9		3.74	10.04
10		3.80	10.16
11	PETG	3.90	10.14
12		3.87	10.20
13		3.84	10.28
14		3.86	10.30
15		3.87	10.27
16		3.77	10.19
17		3.78	10.17
18	HIPS	3.85	10.21
19		3.82	10.10
20		4.05	10.12

Figure 9 illustrates the percentage of error on thickness and width from the designed CAD model. It can be seen that all four materials have better width accuracy than thickness accuracy.

Overall, every material had better accuracy while printing on the x and y-axis and less accuracy while printing on the z-axis.

PETG shows better accuracy while printing on the z-axis having only 3% of error in thickness but at the same time had the largest deviation on the x and y-axis (2.4 %). On the other hand, PLA shows the exact opposite behavior. The average percentage of error in thickness was 5 % while only 0.4 % in width. ABS has the same percentage of error in thickness as PLA but has more inaccuracy in width (1.8%). It should be noted that ABS has the highest material shrinkage during cooling, which is not greatly influenced by the small size and robust internal structure (100% infill density) of the specimen. The average percentage of error in thickness and width for HIPS was 4% and 1.6% respectively.

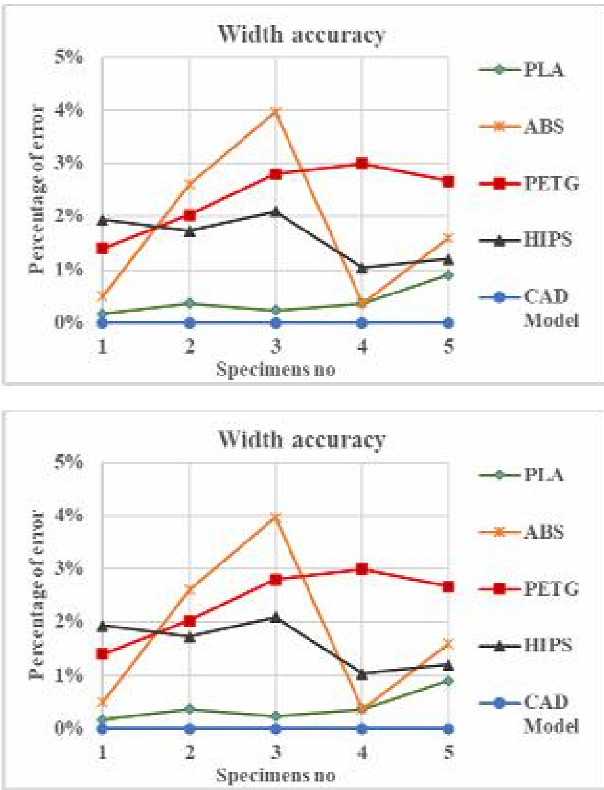


Figure 9. Thickness and width accuracy of four different materials

3.2. Tensile properties

The tensile tests were carried on until the specimens were fractured. Table 4 shows the average values of the tensile test obtained from the Trapezium-X software.

Table 5. Average values of the tensile properties

Specimens	Max Force [N]	Max Stress [MPa]	Max Strain [%]
PLA	1854.75	46.37	2.03
ABS	1329.68	33.24	2.34
PETG	1830.06	45.75	3.30
HIPS	525.98	13.15	1.15

Fig.10 depicts the maximum stress of four different materials obtained from the tensile test. It is clear from the diagram that the tensile strength of PLA and PETG are much higher than ABS and HIPS. The maximum tensile stress of PLA is 46.37 [MPa] which is 1% higher than PETG (45.75 [MPa]). When compared to PLA, the decrease in the strength of ABS and HIPS are 22% and 71% respectively. The obtained values for PLA and ABS also agree with the values from the reference [11]. Although the maximum stress of HIPS is much less than other materials, because of its outstanding dimensional stability it is frequently used in machining pre-production prototypes.

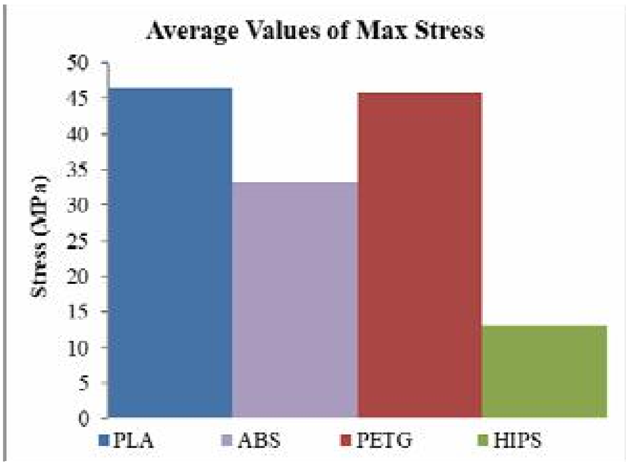


Figure 10. Average values of the maximum tensile stress for four different materials

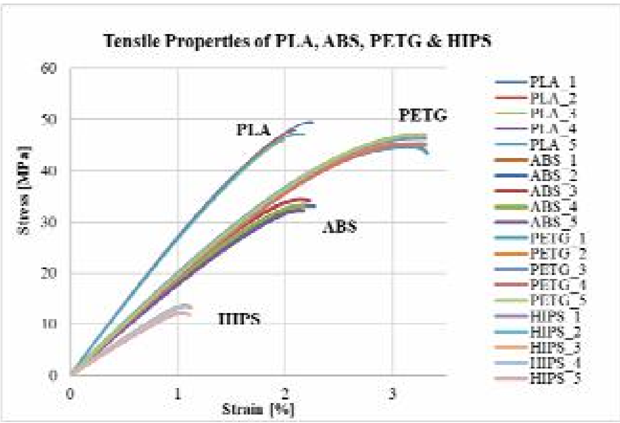


Figure 11. Averaged stress-strain curves

Fig.11 shows the stress-strain curves plotted for different materials obtained from the Trapezium-X software. It can be seen from figure 11 that all curves are almost linear until the maximum load when the failure of the specimens happens. It can be noticed that PETG has the highest elongation at break whereas HIPS has the smallest elongation at break.

4. CONCLUSION

The following considerations are made from the current work,

- Every material has better width accuracy than thickness accuracy.
- PETG shows better accuracy on thickness than width while PLA shows exactly opposite characteristics.
- All four materials have a percentage of error of less than 6%.
- The tensile strength of the PLA is greater than all other materials used for the experiment.
- PETG has the highest elongation at break and HIPS has the lowest elongation at break.

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