Experimental investigation of mechanical properties of composite/plastic metals produced by 3d printing

Term Paper

Report

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Bachelor of Technology in

DEPARTMENT OF MECHANICAL ENGINEERING

<u>Submitted by</u>

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DEPARTMENT OF MECHANICAL ENGINEERING

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The Term Paper Report entitled "**Experimental investigation of mechanical properties of composite/plastic metals produced by 3d printing**" is a record of bonafide work of **KONA RAJESH, B RAVI PRABHAT, S Y KALYAN REDDY**, **T.M.V.P.S.TEJANAIDU** bearing Regd.**No190070042, 190070140,190079002,190079010** submitted in partial fulfillment for the award of B. Tech in **MECHANICAL ENGINEERING** in K L University. The results embodied in this report have not been copied from any other departments/University/ Institute.

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CERTIFICATE

This is to certify that the Term Paper Report entitled "**Experimental investigation of mechanical properties of composite/plastic metals produced by 3d printing"** is being submitted by K.Rajesh(190070042),Ravi Prabhat (190070140), S.Y.Kalyan Reddy(190079002),T.M.V.P.S.TejaNaidu (190079010), submitted in partial fulfillment for the award of B.Tech in Mechanical Engineering to the K L University is a record of bonafide work carried out under our guidance and supervision. The results embodied in this report have not been copied from any other departments/ University/Institute.

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ABSTRACT

This project investigates the effect of compression test on the wear rate of specimens developed by 3D printing .The materials of the specimen developed by 3D printing are Acrylonitrile butadiene styrene(ABS), Polylactic Acid(PLA) and Polyethylene terephthalate glycol(PETG). The 3D printer used is AION-500 which is India's first industrial grade professional 3D printer with patented Advanced Fusion Plastic Modelling (AFPM) technology

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INTRODUCTION

AION-500

India's first industrial grade professional 3D printer with patented Advanced Fusion Plastic Modelling (AFPM) technology.

The revolutionary AION 500 is a high performance, massive size 3D printer that offers a professional-level build volume at an affordable price point. Armed with our patented AFPM (Advanced Fusion Plastic Modelling) technology, the printer renders a stronger and durable output. With multiple connectivity options and sensors, it is one of the most advanced 3D printers available in India. Offering a large build size, ultra-fast print speeds, and unmatched precision, the AION 500 is designed for versatility.

AION 500 is a fully enclosed industrial grade 3D printer and assures a consistently high print quality and repeatability. It features, the Quick Load functionality for changing and loading filaments easily, anti-clogging filament sensors and a super-slicer that makes sure there's no time lost when the print is initiated - making it highly efficient and productive. The machine is easy to use allowing the user to alternate between quick-&- easy to professional-grade printing smoothly.

From prototyping to low-volume manufacturing, the AION 500 excels at any design application with impeccable accuracy and cost-effectiveness. AION 500 is designed to add maximum value to professional work setups.

Features of Aion 500

1. Massive build volume
2. Ultra-stable bed with moving gantry
3. Hassle-free auto-bed levelling
4. High endurance and rigid enclosed body design
5. Value for money
6. Multi-material compatibility
7. Dual direct drive extruder
8. Zero clogging filament tracker
9. Multiple connectivity options
10. Ease of use

Acrylonitrile butadiene styrene (ABS)

Acrylonitrile butadiene styrene (ABS) $(C_8H_8)_x \cdot (C_4H_6)_y \cdot (C_3H_3N)_z$) is a common thermoplastic polymer. Its glass transition temperature is approximately 200 °C (392 °F).ABS is amorphous and therefore has no true melting point.

ABS provides favorable mechanical properties such as impact resistance, toughness, and rigidity when compared with other common polymers.

ABS has a strong resistance to corrosive chemicals and/or physical impacts. It is very easy to machine and has a low melting temperature making it particularly simple to use in injection molding manufacturing processes or 3D printing on an FDM (Fused Deposition Modeling) machine. ABS is also relatively inexpensive. ABS plastic is not typically used in high heat situations due to its low melting point. These characteristics lead to ABS being used in a large number of applications across a wide range of industries.

There are countless applications for ABS. ABS's light weight and ability to be injection molded and extruded make it useful in manufacturing products such as drain-waste-vent (DWV) pipe systems, automotive trim components, automotive bumper bars. Musical instruments such as recorders, plastic oboes and clarinets, piano movements, and keyboard keycaps are commonly made out of ABS.

ABS plastic and 3D FDM/FFF printers are a very popular combination for many applications. The physical properties of this type of plastic, like its impact resistance, tensile strength and stiffness, and its heat deflection temperature, are real advantages. It can also be used for mechanical purposes, or for its electrical properties.

In addition to its chemical resistance and mechanical properties, ABS material has a good surface quality and is flame retardant. The raw material color is white, but the oxidation of the polymers can lead to a yellowing color. Moreover, it is easy to glue and paint plastic products printed with ABS material, offering possibilities of customization.

The low melting point makes ABS easy to machine with desktop 3D printers, or during an injection molding process.

ABS Material Properties - Food-Grade Plastic - Food Safe				
Property	**Metric**	**units**	**English**	**units**
General				
Density	1.01e3 - 1.21e3	kg/m^3	63.1 - 75.5	lb/ft^3
Mechanical				
Yield Strength	1.85e7 - 5.1e7	Pa	2.68 - 7.4	ksi
Tensile Strength	2.76e7 - 5.52e7	Pa	4 - 8.01	ksi
Elongation	0.015 - 1	% strain	1.5 - 100	% strain
Hardness (Vickers)	5.49e7 - 1.5e8	Pa	5.6 - 15.3	HV
Fracture Toughness	1.19e6 - 4.29e6	Pa/m^0.5	1.08 - 3.9	ksi/in^0.5
Young's Modulus	1.19e9 - 2.9e9	Pa	0.16 - 0.421	10^6 psi
Thermal				
Max Service Temperature	61.9 - 76.9	°C	143 - 170	°F
Insulator or Conductor	Insulator		Insulator	
Specific Heat Capability	1.39e3 - 1.92e3	J/kg °C	0.331 - 0.458	BTU/lb. °F
Thermal Expansion Coefficient	8.46e-5 - 2.34e-4	strain/°C	47 - 130	µstrain/°F
Eco				
CO2 Footprint	9.1e7 - 1.02e8	kg/kg	3.27 - 3.62	lb/lb
Recyclable	Yes		Yes	

Polylactic Acid (PLA)

Polylactic acid, also known as PLA, is a thermoplastic monomer derived from renewable, organic sources such as corn starch or sugar cane. PLA is the second most produced bioplastic and it is biodegradable.

The physical and mechanical properties differ according to the exact type of polymer, ranging from an amorphous glassy polymer to a semi or highly crystalline polymer with a glass transition of 60–65 °C, a melting temperature 130-180 °C, and a tensile modulus of 2.7–16 GPa. Several technologies such as annealing, adding nucleating agents, forming composites with fibers or nano-particles, chain extending and introducing crosslink structures have been used to enhance the mechanical properties of PLA polymers. The high surface energy of PLA makes it ideal for 3D printing.

PLA has a number of common uses, including for medical and food purposes. It is also widely used as a 3D printing feedstock for desktop fused filament fabrication 3D printers. PLA is popular for 3D printing as it can easily be sanded, painted or post processed. A user friendly material, this plastic works with low extrusion temperatures and there is no need for a heated bed, printer chamber or reinforced nozzle. Another benefit is that PLA behaves better than many tougher plastics and also doesn't release fumes or bad odours. Storage is easy and it can be produced in a variety of colors. PLA, created with injection moulding, casting or by being spun, is also used as a decomposable packaging material, film or for cups and bags. It is used for compost bags, food packaging, disposable tableware, and loose fill packaging.

Property	Value
Technical Name	Polylactic Acid (PLA)
Chemical Formula	(C3H4O2)n
Melt Temperature	PLLA: 157 - 170 °C (315 - 338 °F)
Typical Injection Molding Temperature	PLLA: 178 - 240 °C (353 - 464 °F)
Heat Deflection Temperature (HDT)	49 - 52 °C (121 - 126 °F) at 0.46 MPa (66 PSI)
Tensile Strength	PLLA: 61 - 66 MPa (8840 - 9500 PSI)
Flexural Strength	PLLA: 48 - 110 MPa (6,950 - 16,000 PSI)
Specific Gravity	PLLA: 1.24
Shrink Rate	PLLA: 0.37 - 0.41% (0.0037 - 0.0041 in/in)

Polyethylene terephthalate glycol(PETG)

Polyethylene terephthalate glycol, known as PETG or PET-G, is a thermoplastic polyester that delivers significant chemical resistance, durability, and formability for manufacturing.

As a copolymer, PETG combines the properties of PET and glycol. This combination means that the overheating issues associated with PET are reduced.

The main properties of polyethylene terephthalate glycol include hardness, chemical and impact resistance, transparency and ductility. An easily extruded material with good thermal stability, PETG is particularly compatible with food uses. polyethylene terephthalate glycol is particularly good for 3D printing, having an extrusion temperature of between 220° and 260°C, with a print speed of 40-60mm/s. PETG is both thermoformable and vacuum-formable, and can tolerate a tremendous amount of pressure without cracking.

PETG is commonly used in single use and reusable drinking bottles, cooking oil containers, and FDA-compliant food storage containers. However, PETG is also found across the medical field; its rigid structure allows it to survive harsh sterilization processes, making it a perfect material to be used in medical implants, as well as pharmaceutical and medical device packaging.

PETG is an excellent material to use in modern 3D printers, and is quickly becoming a favorite among the community as it becomes more accessible. With the correct print settings, PETG filament prints easily, has excellent layer adhesion, and is odorless while it prints. It also has very low shrinkage properties. At the same time, it's extremely strong and has great chemical resistance. This allows it to print objects that can sustain high temperature, food-safe applications, and exceptional impact.

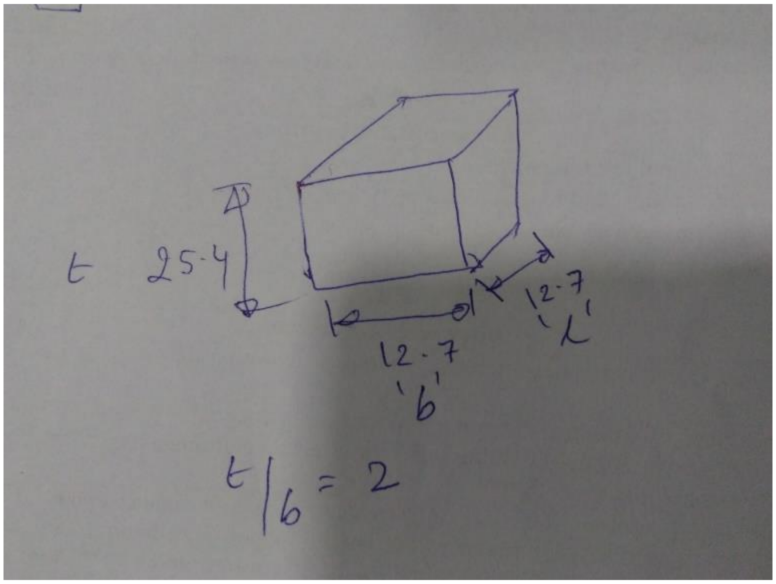
Material Properties of Thermoplastic PETG - Exceptionally Durable						
Property		**Metric**	**units**		**English**	**units**
General						
Density		1.26e3 - 1.28e3	kg/m^3		0.0455 - 0.0462	lb/in^3
Mechanical						
Yield Strength		4.79e7 - 5.29e7	Pa		6.95 - 7.67	ksi
Tensile Strength		6e7 - 6.6e7	Pa		8.7 - 9.57	ksi
Elongation		1.02 - 1.18	% strain		102 - 118	% strain
Hardness (Vickers)		1.41e8 - 1.56e8	Pa		14.4 - 15.9	HV
Impact Strength (un-notched)		1.9e5 - 2e5	J/m^2		90.4 - 95.2	ft.lbf/in^2
Fracture Toughness		2.11e6 - 2.54e6	Pa/m^0.5		1.92 - 2.31	ksi/in^0.5
Young's Modulus		2.01e9 - 2.11e9	Pa		0.292 - 0.306	10^6 psi
Thermal						
Max Service Temperature		51 - 64	°C		124 - 147	°F
Melting Temperature		81 - 91	°C		178 - 196	°F
Insulator or Conductor		Insulator			Insulator	
Specific Heat Capability		1.47e3 - 1.53e3	J/kg °C		0.352 - 0.366	BTU/lb. °F
Thermal Expansion Coefficient		1.2e-4 - 1.23e-4	strain/°C		66.8 - 68.1	µstrain/°F
Eco						
CO_2 Footprint		3.22 - 3.56	kg/kg		3.22 - 3.56	lb/lb
Recyclable		Yes			Yes	

2. Compression Testing:

Compression testing is a very common testing method that is used to establish the compressive force or crush resistance of a material and the ability of the material to recover after a specified compressive force is applied and even held over a defined period of time. Compression tests are used to determine the material behavior under a load. The maximum stress a material can sustain over a period under a load (constant or progressive) is determined.

Compression testing is often done to a break (rupture) or to a limit. When the test is performed to a break, break detection can be defined depending on the type of material being tested. When the test is performed to a limit, either a load limit or deflection limit is used.

2.1 Sample Size and Shape



$t/b \leq 2.0$ → Flat Specimen

$l/d \leq 2.0$ → Circular Specimen

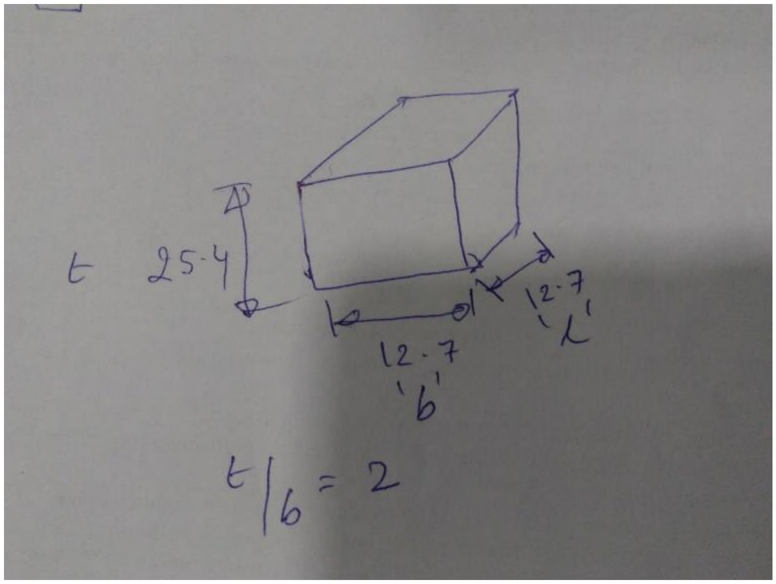
2.2 compression Test Procedure:

A compression test is a method for determining the behaviour of materials under a compressive load. Compression tests are conducted by loading the test specimen between two plates, and then applying a force to the specimen by moving the crossheads together. During the test, the specimen is compressed, and deformation versus the applied load is recorded. The compression test is used to determine elastic limit, proportional limit, yield point, yield strength, and (for some materials) compressive strength.

3. Experimentation:

3.1 compression test Data:

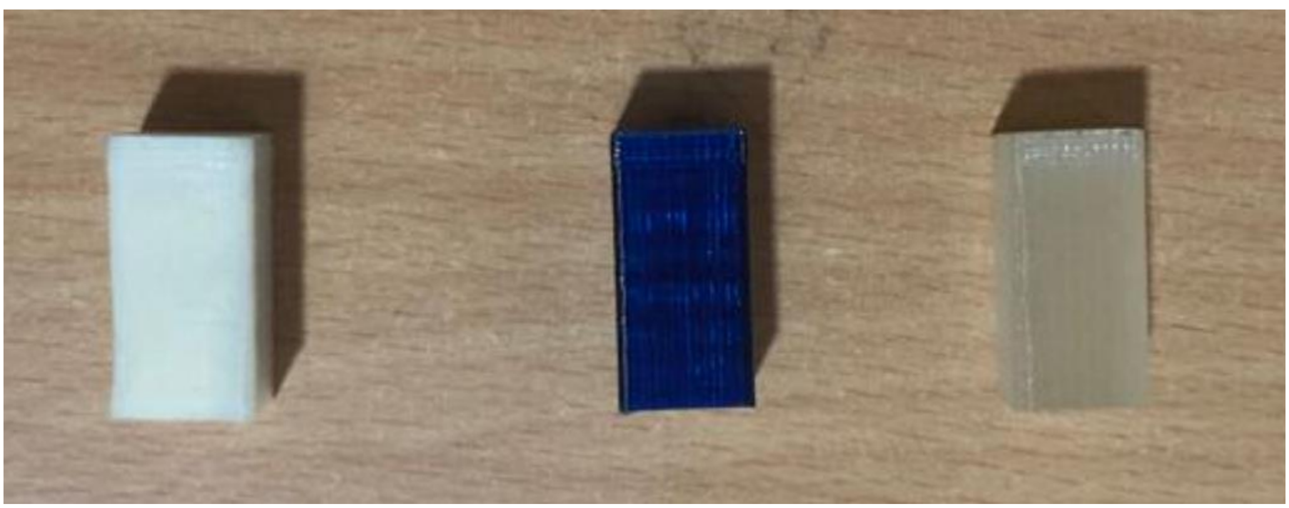
<u>Specimen dimensions:</u>



t/b ≤ 2.0 → Flat Specimen

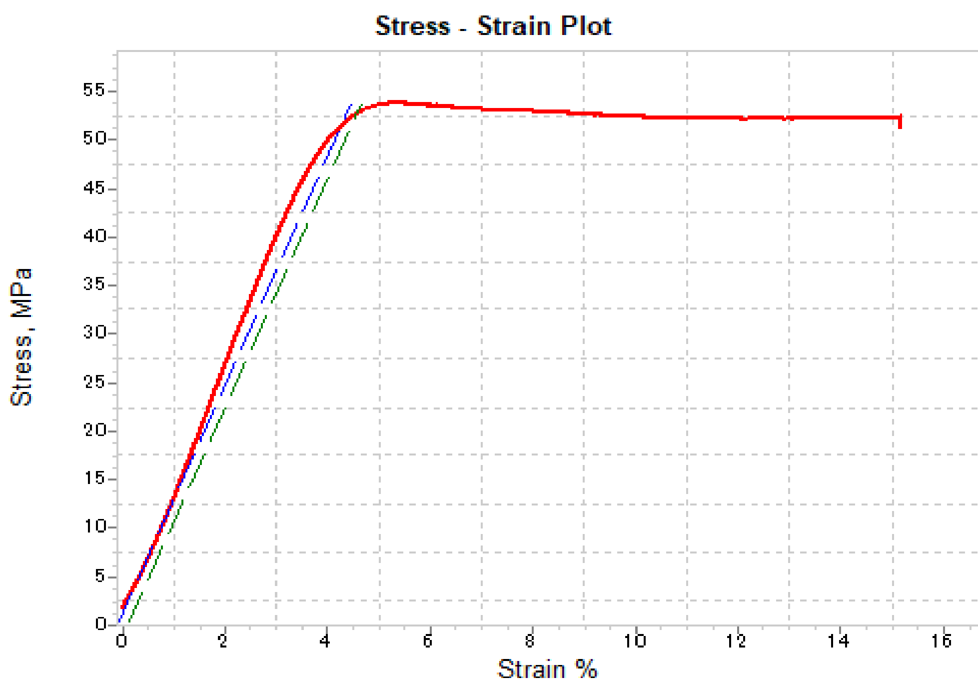
l/d ≤ 2.0 → Circular Specimen

3.2 <u>Specimens developed by 3-D Printing:</u>



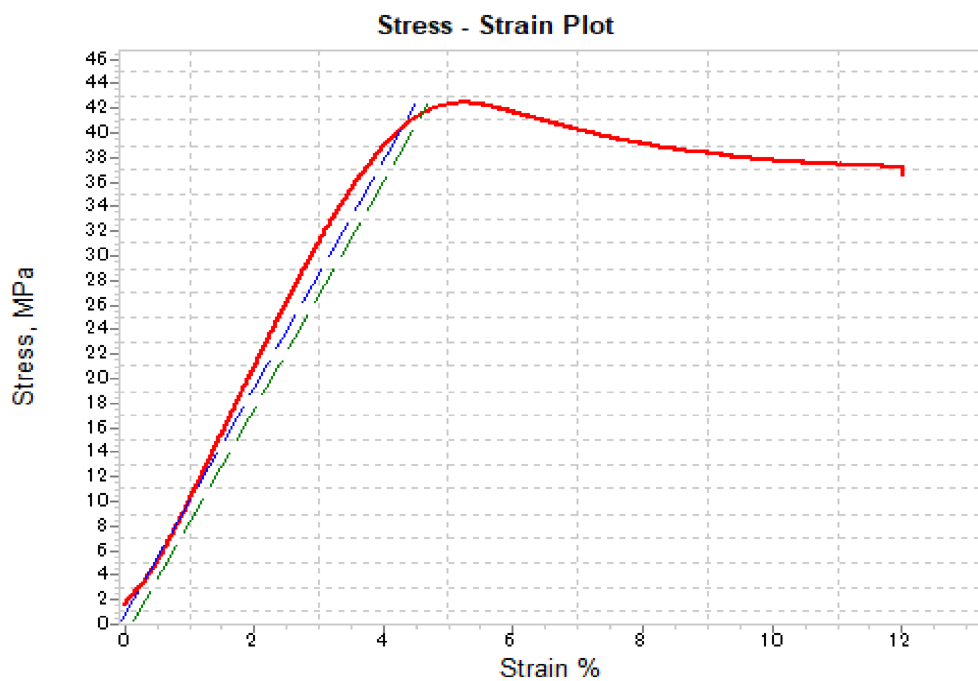
3.3 compression test Analysis of ABS material:

Area:	156.25	sq-mm
Gauge Length:	25	mm
Width:	12.5	mm
Thickness:	12.5	mm
Peak Stress	53.806	MPa
Peak Load	8.407	kN
0.2% Offset Yield Stress	52.745	MPa
Yield Strain	4.563	%
Yield Load	8.241	kN
Modulus	1.182	GPa
Total Energy	27.152	KN-mm
(Input:0.000,0.000)	0.289	KN
Energy under selected region		
(Input:0.000,0.000)	0	kN-mm
Extension at load(input:0.000KN)	0	mm
Load at Extension Point		
(Input:0.000mm)	0.289	KN
Strain Hardening Exponent	0.007	
Strain Hardening Coefficient	55.395	Mpa



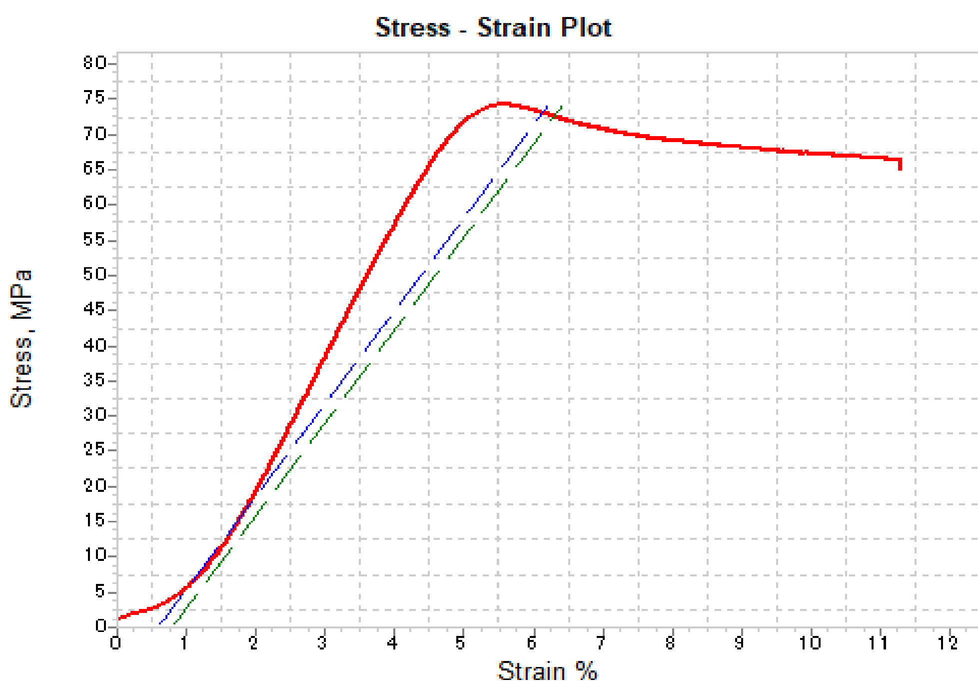
3.4 Compression test Analysis of PETG material:

Area:	156.25	sq-mm
Gauge Length:	25	mm
Width:	12.5	mm
Thickness:	12.5	mm
Peak Stress	42.461	MPa
Peak Load	6.634	kN
0.2% Offset Yield Stress	41.65	MPa
Yield Strain	4.618	%
Yield Load	6.508	kN
Modulus	0.926	GPa
Total Energy	15.592	KN-mm
Average load over extension range		
(Input:0.000,0.000)	0.25	KN
Energy under selected region		
(Input:0.000,0.000)	0	kN-mm
Extension at load(input:0.000KN)	0	mm
Load at Extension Point		
(Input:0.000mm)	0.251	KN
Strain Hardening Exponent	0.009	
Strain Hardening Coefficient	44.214	Mpa



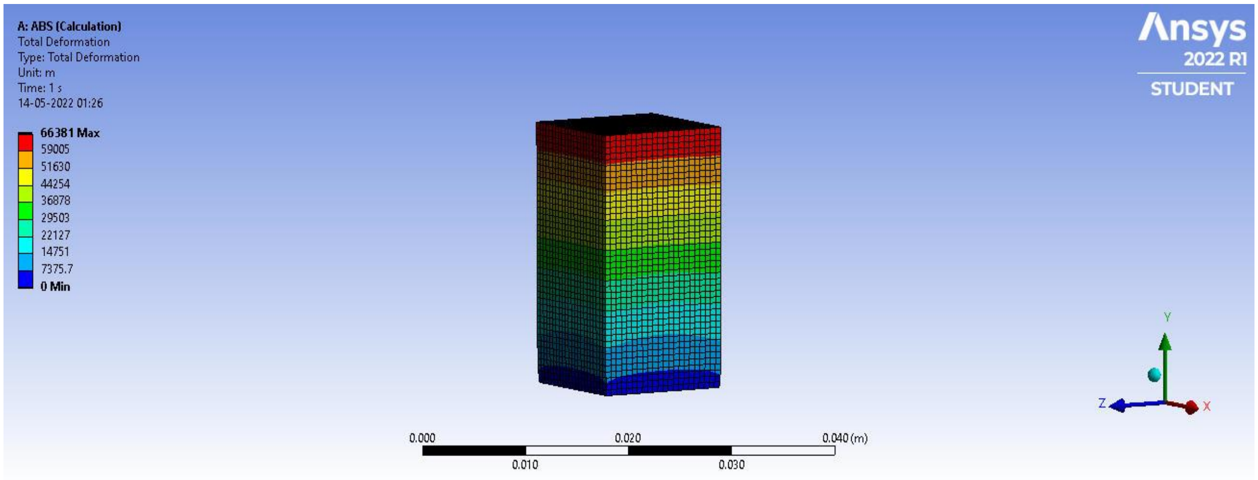
3.5 compression test Analysis of PLA material:

Area:	156.25	sq-mm
Gauge Length:	25	mm
Width:	12.5	mm
Thickness:	12.5	mm
Peak Stress	74.247	MPa
Peak Load	11.601	kN
0.2% Offset Yield Stress	72.6	MPa
Yield Strain	6.287	%
Yield Load	11.344	kN
Modulus	1.319	GPa
Total Energy	23.267	KN-mm
Average Load over extension Range		
(Input:0.000,0.000)	0.176	KN
Energy under selected region		
(Input:0.000,0.000)	0	kN-mm
Extension at load(input:0.000KN)	0	mm
Load at Extension Point		
(Input:0.000mm)	0.176	KN
Strain Hardening Exponent	0	
Strain Hardening Coefficient	0	Mpa

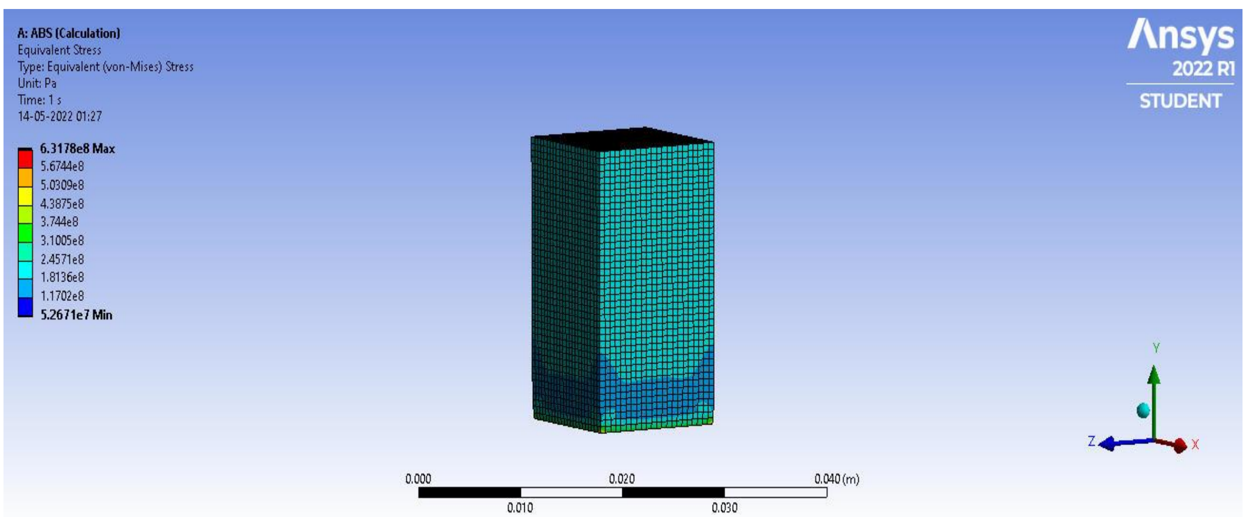


4.Analysis:

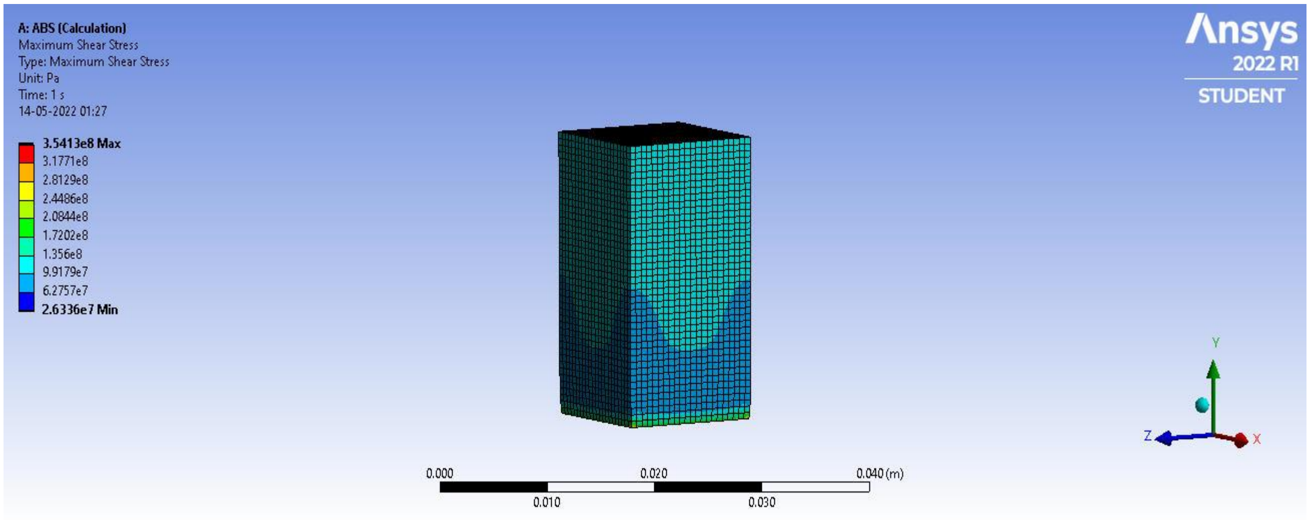
4.1 Analysis of ABS material:



Total Deformation			
peak load	min	max	Avg
8.407 KN	0	1.10E-0.3	5.40E-04

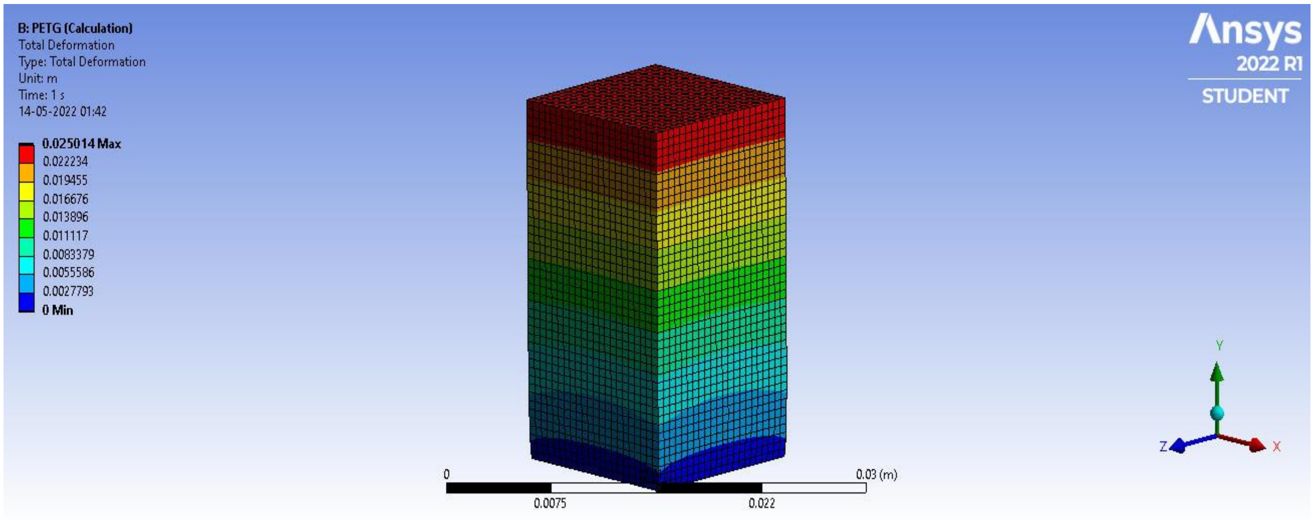


	Von misses stress			
Youngs modulus	peak load	min	max	Avg
1.182	8.4047 KN	1.36E+07	1.63E+08	5.07E+07

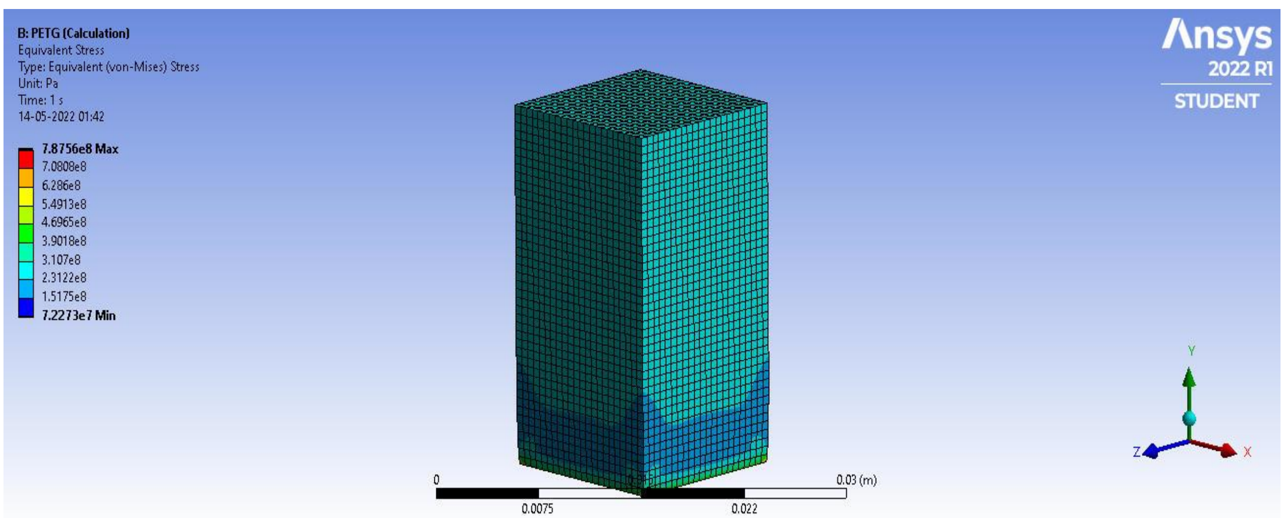


	Max shear stress		
peak load	**min**	**max**	**Avg**
8.4047 KN	6.81E+06	9.16E+07	2.56E+07

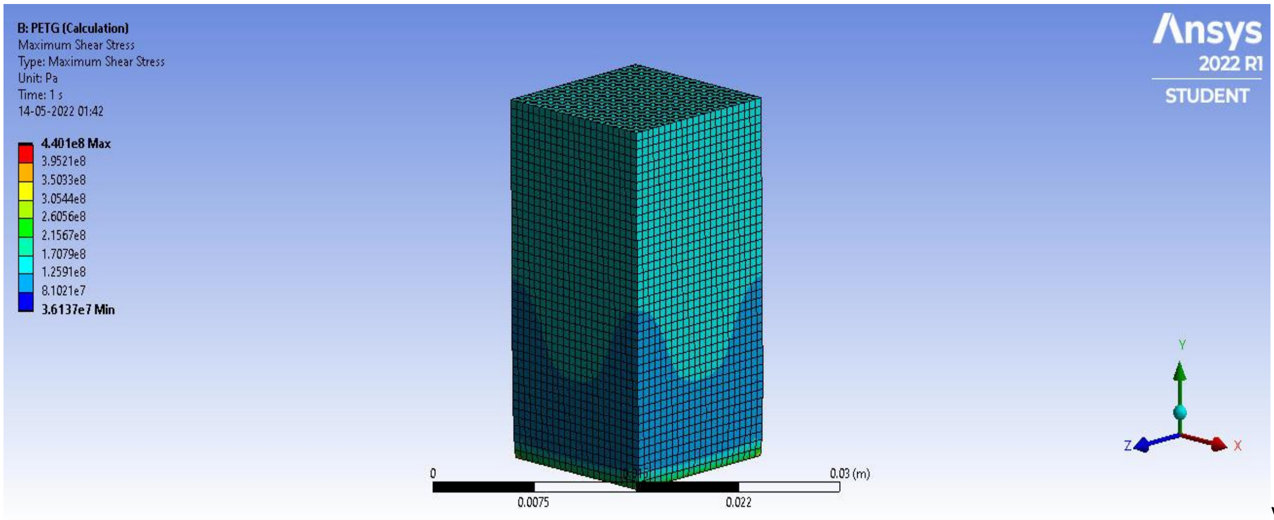
4.2 Analysis of PETG material:



Total Deformation			
peak load	min	max	Avg
6.634 KN	0	1.11E-0.3	5.45E-04



	Von misses stress			
Youngs modulus	peak load	min	max	Avg
0.926	**6.634 KN**	1.16E+07	1.27E+08	4.00E+07



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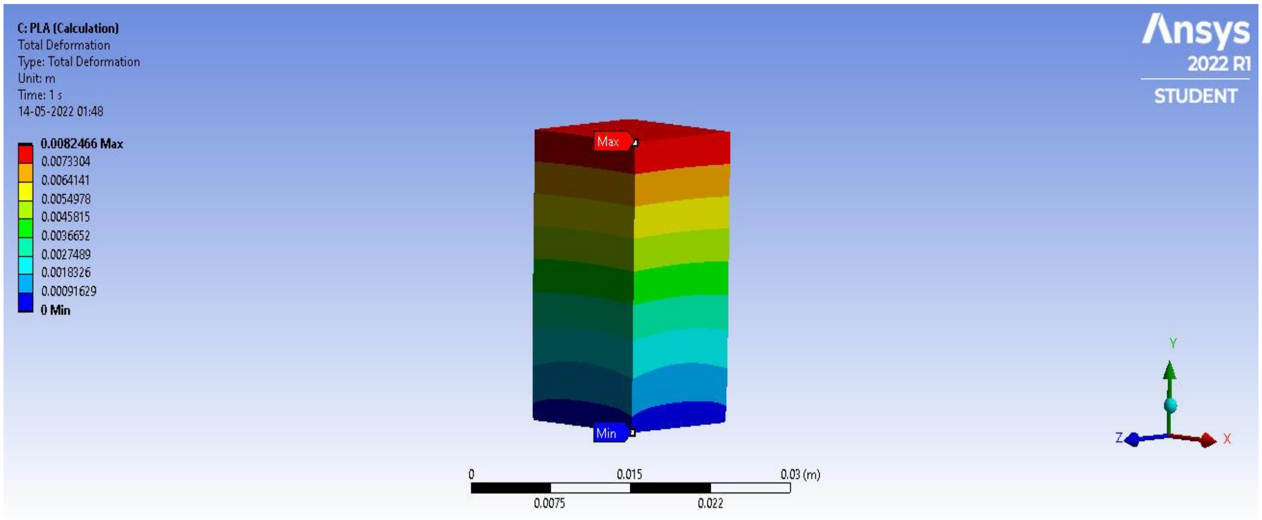
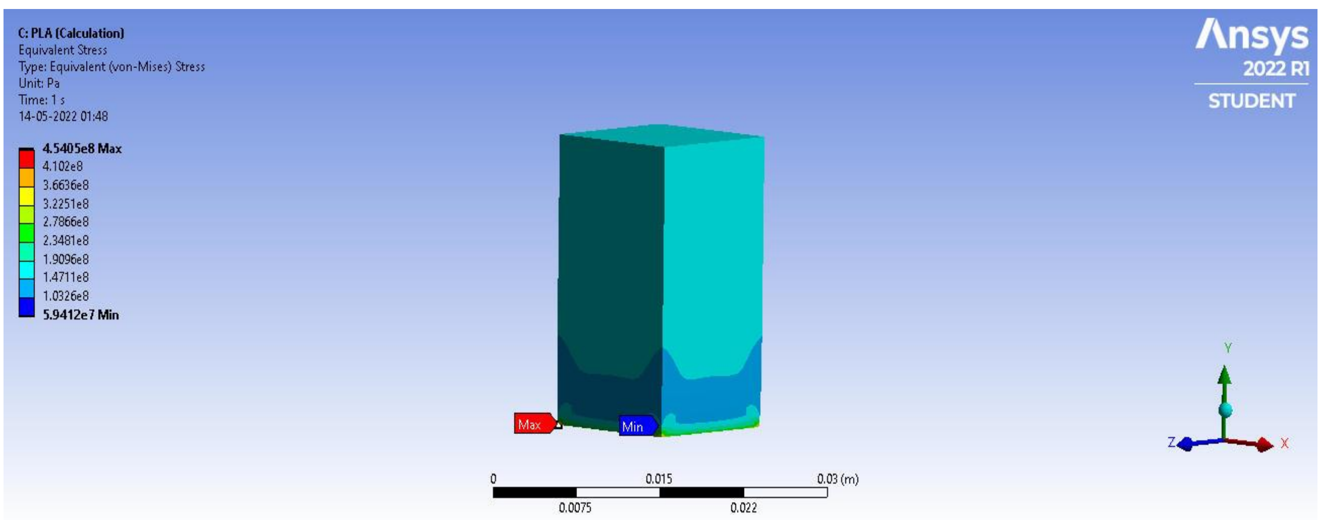
	Max shear stress		
peak load	min	max	Avg
6.634 KN	5.82E+06	7.09E+07	2.02E+07

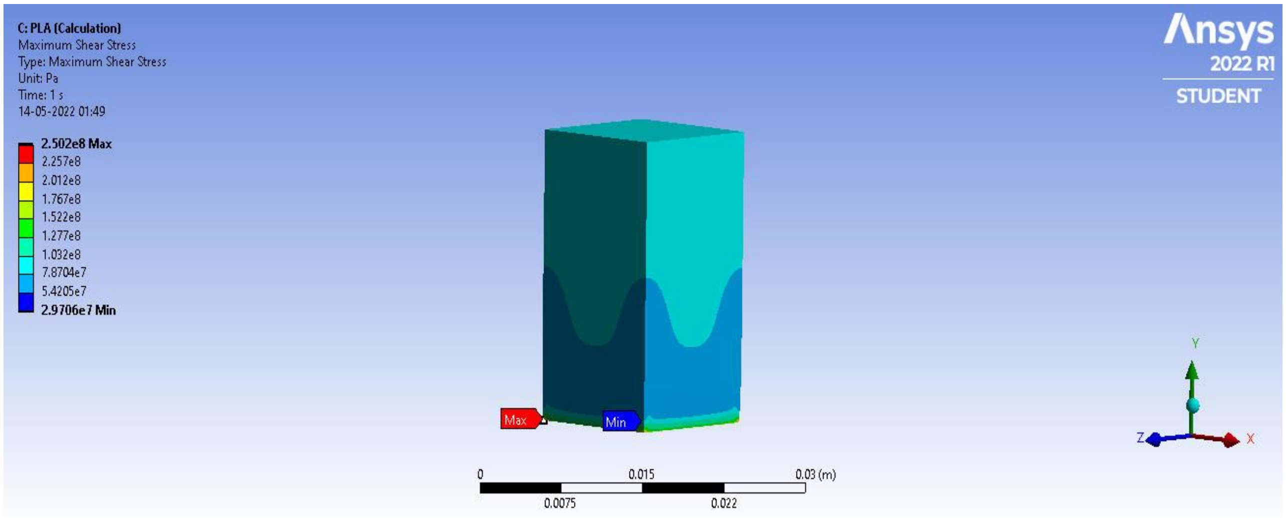
4.3 Analysis of PLA material:



Total Deformation			
peak load	min	max	Avg
11.601	0	1.37E-0.3	6.744



	Von misses stress			
Youngs modulus	peak load	min	max	Avg
1.319	11.601 KN	2.69EE+07	2.06E+08	7.01E+07



	Max shear stress		
peak load	min	max	Avg
11.601 KN	1.34E+07	1.13E+08	3.53E+07

5.CONCLUSION

From the Compression testing done on the 3D printing materials like PLA, ABS and PETG the results show that these materials have appropriate strength when compared to regular plastic molding materials

- At 8.407 KN load, maximum von-mises stress obtained for ABS Material and since specimen was printed layer by layer, fluctuation of failure or fracture takes place.
- At 6.634 KN load, maximum von-mises stress obtained for PETG Material and since specimen was printed layer by layer, fluctuation of failure or fracture takes place.
- At 11.601 KN load, maximum von-mises stress obtained for PLA Material and since specimen was printed layer by layer, fluctuation of failure or fracture takes place.

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