International Barraculate: Extended Essay

Investigation of the breaking points of ABS and PAHT CF15 filaments that are printed from a 3D printer and comparing the results with aluminum alloys (7075, 6061, 6063) which is highly requested in industry.

Research Question:

Can ABS and/or PAHT CF15 filaments which are printed from a 3D printer be a side option to aluminum alloys 7075,6061,6063, compared by their breaking points via Young's modulus?

Physics

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ESSAY OVERWEIV

Stress is an area of physics with lots of different branches. It has lots of complex subtopics and is a bigger subject than imagined. In most of the engineering branches, this subject is being thought differentiating in amount. Because of how important this subject is to engineering, I wanted to do further research on it and learn about it. In our IB syllabus this topic does not exist so I found it even more interesting to learn and experiment on.

In this essay I will be attempting to answer the question, "Can ABS and/or PAHT CF15 filaments which are printed from a 3D printer be a side option to aluminum alloys 7075,6061,6063, compared by their breaking points?"

Aluminum is an is an important mine for lots of areas in our lives. As much as its important, it is limited. This made me think if other material could be used instead of aluminum. The materials I chose to test if they can replace aluminum are ABS and PAHT CF15.

I will be attempting to compare these materials with the help of the concepts; stress, tensile stress, breaking point, tensile strength and strain.

To further investigate this topic, I will first give background information about the three different aluminum alloys and the usage of aluminum. I will talk about the materials ABS and PAHT CF15 and why I chose them. After informing about these, I will unpack the main terms. Second step is to experiment, model, observe and gather data. I will be talking about Youngs Modulus and the relationship with my topic with the help of the data gathered, I will graph my experiment and conclude.

BACKGROUND KNOWLEDGE

In the electronics industry, pure aluminum is mostly utilized for capacitor foil, hard disk drives, and conductor tracks on silicon chips. Even though the areas of usage in pure aluminum is limited, when alloyed it has a decent range as it becomes stronger (It can be designed to be even more durable than steel). (1)

Aluminum and its alloys are widely used in transportation (trains, planes, ships, and automobiles) because of their low density, which helps to reduce fuel consumption and carbon emissions. Packaging is another area where alloys of aluminium is highly used, mostly in canning drinks and foil protection to food. Pancake pans and other cooking equipment are common household items, and the alloys are widely utilized in construction for windows, doors, and cladding.

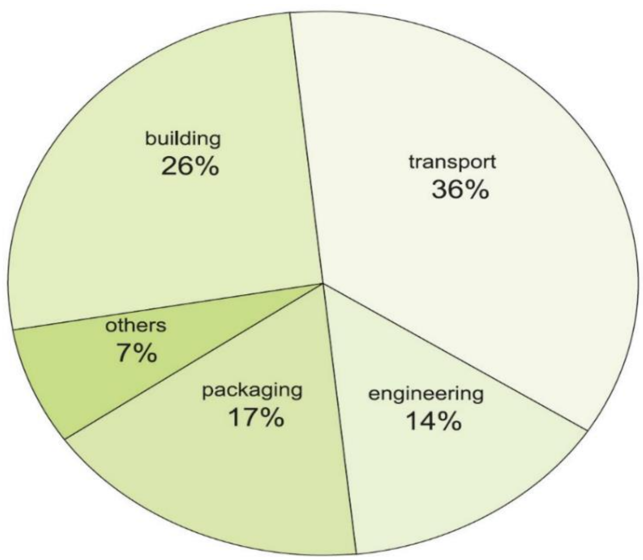


Figure 1.0 The pie chart illustration of the distribution of aluminium usage

Aluminum has lots of different alloys but I will be talking about its three specific alloys. Alloys differ in usage and with the compounds it has.

7075 Aluminum

It is very strong since zinc is the predominant alloying ingredient. It is one of the strongest alloys known and is similar to several varieties of steel. It is a member of the 7000 series. However despite its high strenght, its corrosion resistance is lower than other types of aliminium alloys. Because of the lack on corrosion it does not offer as good machinability or weldability. Its usage include areas where its is under a lots of stress. i.e aircraft wing spar and ground support equipment rrosion resistance it does not allow the same. (2)

6063 Aluminum

This alloy is called architectural aluminum as it is mostly used in architectural applications. The reason for this is because of its natural consideration. This alloy is also the most popular one for extrusion. It is a mid-strong alloy. Some usage areas include; railing, roofs, door frames, sign frames, irrigation tubing, construction products, electrical, marine, pipelines, recreation equipment, storage tanks, truck frames etc. (3)

6061Aluminum

This alloy is known as 'Alloy 61s'. It is one of the most widely used heat-treatable aluminum alloy in commercial applications. It has medium to high strength and lightweight. With different lots of different components, like magnesium, titanium, silicone, zinc etc. , it also includes a small amount of chromium which makes this alloy highly resistant to corrosion. The structural strength and toughness of 6061 aluminum, as well as its good surface finish, good corrosion resistance to atmospheric and sea water, machinability, and ability to be quickly welded and bonded, are all properties which help us in the industry. (4)

WHAT IS ABS FILAMENT?

ABS filament is an example of the most widely used 3D printing materials today. ABS is the short of Acrylonitrile Butadiene Styrene. It is a thermoplastic which is easily shaped when heated it can be molded and when cooled off it hardens evenly. Because of it form changing ability it is highly requested on the market. Even though it changes shape easily it maintains its qualities. This extremely durable thermoplastic also has a strong electrical conductivity. (5) This filament is soluble in esters, ketones and acetone. It can be used in lots of different areas in engineering and industry. Other than these areas we can also see this filament in household goods, LEGO bricks, bike helmets and office materials. The usage changes accordingly to the diameter of the filament so we can say it has a wide spread of use in different areas. (6)

WHAT IS PAHT CF15 FILAMENT?

It is an industrial-grade filament with a unique recipe that includes a polyamide base and a 15% micro-carbon fiber additive. These additives lets the filament copy the durability of nylon in addition to the rigidity of carbon fiber. With all these properties it still maintains its quite processable shape. This high performance filament offers high; dimensional stability, stiffness, chemical resistance. It is a highly requested material in engineering robotic, aerospace, automotive etc. (7)

Stress

Stress in physics is a physical quantity which is a sub topic of continuum mechanics. It is the internal forces molecules apply to one an other. We can basically say it is the force applied per unit area. It is represented by a lowercase Greek sigma (σ) and its SI unit is Pascal. (8)

$$\sigma = \frac{F}{A}$$

Where F is the force applied and A is the area which the force is acting.

A material can undergo 2 types of stress; tensile and compressive. The type of stress is determined by the way the force is applied on the material. If there is a pulling/stressing force, then we call it tensile. If the force is squeezing/suppressing, we call it compressive. Tensile stress makes the material stretch out while compressive stress end up with the shortening of the material. A material can be strong on tensile stress while weak on compressive or visa versa. (9)

Tensile Stress

Tensile stress can also be known as normal stress or tension. It measures the stress a body can endure until it tears apart. So we can say it measures the strength of the material. It is also shown with a lowercase Greek sigma (σ). (10) It is calculated via;

$$\sigma = \frac{F}{A}$$

F here is the force, in Newton, while A s the cross-sectional area, in mm^2.

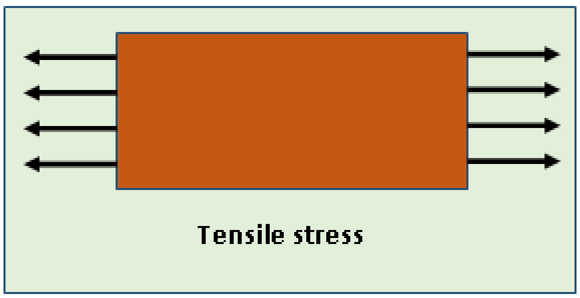


Figure 2.0 visual representation of the tensile stress with the applied force

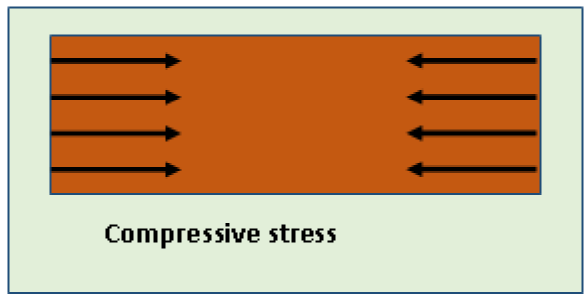


Figure 3.0 visual representation of the compressive stress with the applied force

Tensile Strength

It is the maximum tensile stress the matter can withstand before failure. The failure can change accordingly to the properties of the material and it depends on the accelerated corrosion rate. The value of the accelerated corrosion rate can change the failure either to be a ductile failure or a much more dangerous brittle failure. Tensile strength does not have a unit and it shows directions while tensile stress shows magnitudes. (11) There are 3 different types of tensile strength;

1. Yield strength: (12) Yield strength can be defined in different ways as there is no certain meaning of it. Different criteria is needed for each of these different types of explanations of yield. However yield strength or elastic limit is the stress a body can endure without having permanent deformation.
2. Ultimate strength: (13) It is the maximum stress a material can withstand while being under the influence of a force.

3. Breaking Strength: (13) It is the stress coordinate of the stress-strain graph at the time of the rupture.

Tensile strength can lead to tensile failures like aforementioned. We can observe these failures in two manners;

Deformation

When a fore is applied on a body, the inter-molecular forces act on the opposite way to keep the body in steady positioning. But if the force is too high to a point where the intermolecular forces can not resist than deformation happens. Material sciences defines deformation as the change in shape or size of an object caused by the applied forces or the temperature change . These forces can be exampled as; tensile, shear, compressive etc. Deformation mostly occurs as strain. (14) (15)

Ductile And Brittle Deformation

While ductile deformation occurs at low strain values, brittle occurs at high. The ductile deformation mechanism is quite flexible. Furthermore, ductile deformation refers to a material's shape changing due to bending or flowing, during which chemical bonds can be disrupted and then reform into new bonds. Brittle deformation is a type of deformation that happens when a material fractures or faults. This phrase refers to the breaking of chemical bonds that do not go back to their original state. As a result, the brittle deformation produces results similar to those seen in fractured plates, such as fractures. (16)

Normal Strain

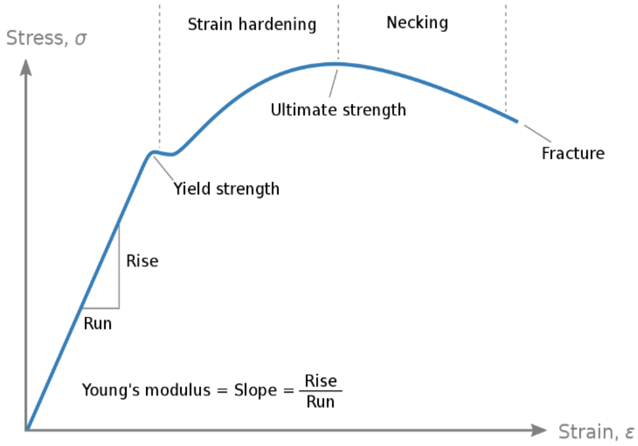
It is the measure of a material's deformation.

$$\epsilon = \frac{\Delta L}{L}$$

where ΔL is the change in length and L is the original length.

Normal strain can be classified as tensile and compressive. If the force acting on the object makes the object stretch out and elongate then the strain is tensile. If the force makes the object shorten or compress than we say that the strain is compressive. (17)

YOUNG'S MODULUS



$E = \frac{\sigma}{\epsilon}$ where σ is stress and ϵ is strain.

Youngs Modulus (E) is a mechanical property which decides the tensile or compressive stifles of a solid metal. It is calculated using the formula to identify the relationship between tensile/compressive stress and axial strain in the linear elastic zone of a material; (18)

EXPERIMENT SETUP AND PROCEDURE

The experiment is designed to observe the effect of the force on the ABS and PAHT CF15 filaments. Two bars are printed from a 3D printer in a shape of a square prism. The long side is 100mm while the short sides are 3.2mm. It is put on a support ground which is 10mm on the short and 50 mm on the long sides. The same amount of force is applied on the filament bars from the both ends of the stick. We can describe the force as a pulling force

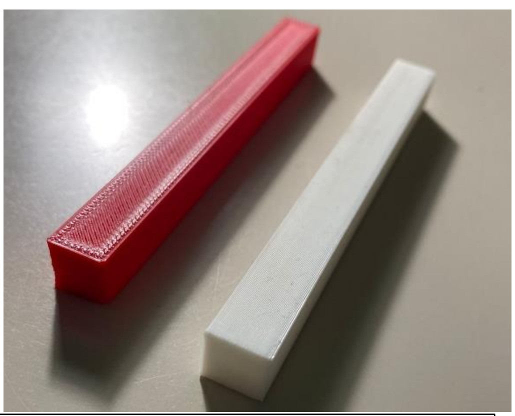


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Figure 4.0 ABS and PAHT CF15 sticks

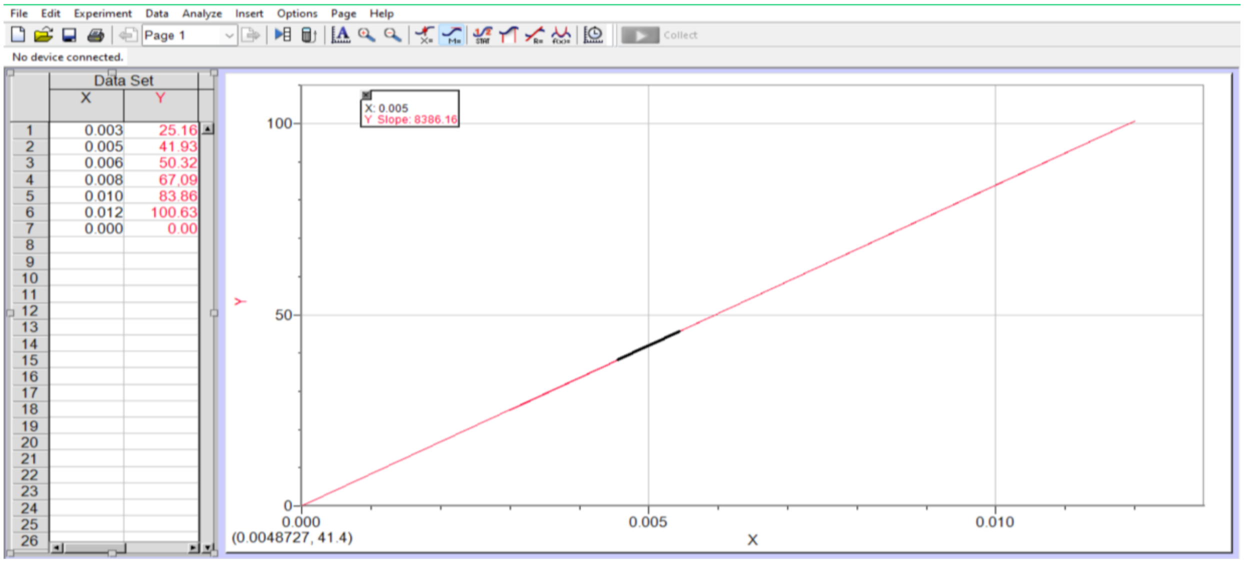
Because it is a pulling force we use tensile stress in our calculations. If it was a pushing force then we the type of stress we would use would change. The force is applied until the moment where we see a change in the length of the rod . The amount of change is measured with a vernier caliper.

After the results are observed and data are gathered Young's Modulus of ABS and PAHT CF15 is graphed. Finally the data for tensile strength is compared with the alloys of aluminum.

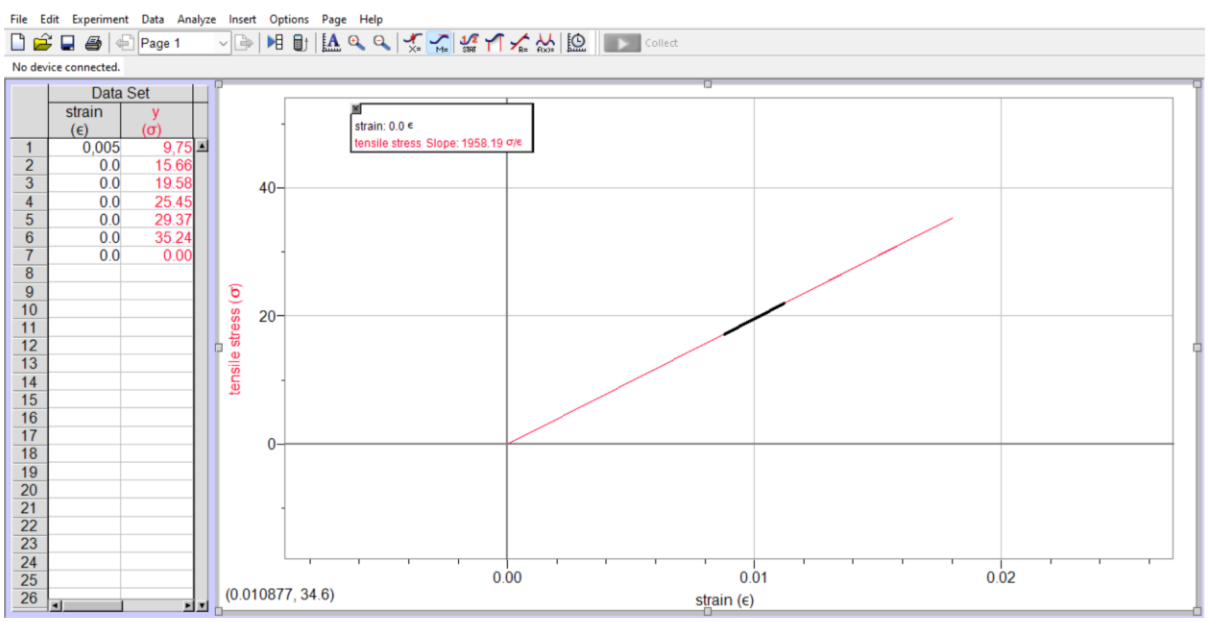
Table 1: Sample of Raw Data Collected

Independent	trials	Strain ($\mp 0.001mm$)	Tensile stress (∓ 0.03)	Force ($\mp$ $0.01N$)
ABS Filament	1	0.005	9.79	100.25
	2	0.008	15.66	160.36
	3	0.010	19.58	200.50
	4	0.013	25.45	260.61
	5	0.015	29.37	300.75
	6	0.018	35.24	360.86
PAHT CF15 Filament	1	0.003	25.16	257.64
	2	0.005	41.93	429.36
	3	0.006	50.32	515.28
	4	0.008	67.09	687.00
	5	0.010	83.86	858.73
	6	0.012	100.63	1030.45

Young’s Modulus For ABS Filament (Tensile stress and strain graph)



Young’s Modulus For PAHT CF15 Filament (Tensile stress and strain graph)



CALCULATIONS

To start the experimentation I had to determine a force to apply. To determine the force I used the theoretical values tensile strength for filaments ABS and PAHT CF15. With these values I was able to calculate the maximum force to reach the yield strength. To exemplify the process I will show my calculations on the ABS filament; (19)

Theoretical value of tensile strength in ABS filament = 36.3

The area (A)= $(3.2)^2$= 10.24

Note that the length of the ABS Filament does not effect the tensile strength. It effects the strain. So we just look at the area of the platform that is vertical to the force.

$$\frac{F}{A} = \sigma$$

$$\frac{F}{10.24} = 36.3$$

$$F = 371.712$$

As the force (F) Is in Newton's we convert it to kg to apply the force in the experiment. Thus $371.712N = 37.90\ kg\ x\ g$ which is the maximum force that needs to be applied to reach the yield strength. From here on I used forces lower than the said maximum force in 6 different trials. This process was applied to both filaments as shown on the Table 1.

After different force values are divided to the area (10.24) tensile strength values are gathered. The change in length after the force is applied measured. The initial length of the stick filament, which is 100mm, and the final value when the force is applied are observed, measured.

$\Delta L = final\ lenght - \ initial\ lenght$ is calculated and It is devided with the initial lenght. The value we obtain gives us the strain. When we divide the tensile stress to strain we will be reaching elastic modulus. As I obtain different elastic modulus for each trial, I will be getting their average value and using that in the final comparison.

This gives us the strain values. After we find the strain values, we use them to divide the tensile stress values. This calculations will finally lead us to the Young's Modulus. We measure the strain using a vernier caliper.

Table 2: Average and theoretical value of elastic modulus

Filaments	Average	Theoretical
ABS	1958.15	1958
PAHT CF15	8385.94	8386

Table 3: Theoretical Young's Modulus Values for Aluminum alloys

Aluminum alloy	Young's Modulus
7075	7500
6061	6900
6063	6730

CONCLUSION

To conclude we will be looking at the elastic modulus or so called Youngs Modulus (E). The stronger the material is the higher the elastic modulus will be. This is due to the fact that , to reach the elastic modulus we need to divide the tensile strength to strain where tensile stress is equal to F\A thus we say that as the F that the material can withstand increases the tensile stress which is directly proportional to the F increases. The same thing applies to the correlation between tensile stress and young's modulus. We can say that as tensile stress increases the Young's modulus increases. A higher value in young's modulus means it has higher limit in maximum force , so can be said that it can repel much higher force. When we look at the Youngs Modulus for ABS, PAHT CF15, Aluminum alloys 7075,6063 and 6061 we can see that ABS has the lowest E while PAHT CF15 has the highest.

From what gathered from the experiment, the elastic modulus values respectively;

ABS Filament <Alloy 6063< Alloy 6061< Alloy 7075< PAHT CF15 Filament

With reference to the results of my experiment, we can say that as the elastic modulus is the highest for Filament PAHT CF15, we can say that it has the highest breaking point, meaning it can withstand bigger forces than other before it is fractured. The other filament I use with the aim of replacing Aluminum alloys was ABS. ABS turned out to have the lowest elastic modulus. Meaning the breaking point is low. While it is even lower than the alloys, we can say that it is not possible to replace alloy with ABS. The theoretical elastic modulus for the alloy 7075 is the one that is close to the elastic modulus of PAHT CF15 so we can say that it may be possible to replace the Alloy7075 with that filament.

Even though my research question included comparison of the breaking points, as my equipment is limited, it made observing and analyzing the breaking point nearly impossible. So I decided to look at the yield strength of the materials because the breaking point is parallel with the yield strength. And the yield strength is the max value on my tensile stress and strain graph . To sum up, we can say that the yield strength when divided into the strain of the set value gives us the Young’s modulus. The Young’s modulus, gives us an idea on how much the material we are testing can withstand force (without any deformation). We can say that a material with higher Young’s modulus will deform less under the same tensile stress .So the one with higher Young’s modulus also has the higher value on the breaking point.

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