PEAK OF FLIGHT NEWSLETTER

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PEAK OF FLIGHT

Compression Tests of Tubing Used in Rocketry

By Trevor Toft

High power rocketry requires a thorough evaluation of engineering topics including aerodynamics, propellant characterization, electronics, and material design. Material testing and evaluation is crucial to ensuring a successful flight under extreme compressive loads. The purpose of this test was to determine the mechanical properties of multiple materials in hollow cylindrical form to augment and enhance the design of the body tube on our rocket. The three materials, standard cardboard, blue, and fiberglass tubing, were placed under compression until fracture and the mechanical properties were recorded. These properties were analyzed and important specifications were calculated to determine the optimum body tube material. The compressive strength of fiberglass, 175.1379 [MPa], outperformed the other materials by an excellent margin. This value was evaluated and determined to withstand an average thrust value of 90018.35 [N]. It was determined that fiberglass is the best material for high power rocketry.

Introduction

For nearly 100 years, rocketry has been a peak interest for many, and a thrilling engineering marvel. The complications of the subject are extensive although the reward from success can be exhilarating. There are many aspects to building and designing a rocket, consisting of nozzle design, aerodynamics, propellant, and even electronics. To enhance the performance in each of these categories, the designer must consider the materials necessary. In this portion, material design and testing will be evaluated and discussed. Our team, MACH Rocketry, conducted compression tests on multiple materials to determine the best possible material for our body tube. This can improve strength, aerodynamics and save weight, ultimately achieving a greater altitude. The purpose of this test was to determine the mechanical properties of multiple materials in hollow cylindrical form to augment and enhance the design of the body tube on our rocket.

Materials

This test will consist of three separate materials to be evaluated under compression. The materials will be: standard cardboard tubing, tubing commonly referred to as blue tube, and filament wound fiberglass.

Methods

The compression tests were conducted using the Instron Machine as well as the certified MTP concrete compression tester. The pre-processing of the materials consisted of cutting down an original 4 feet length tube of each of the materials into smaller sample sizes. The tubes were cut down into 6 inch lengths with each material consisting of 4 inch diameter sections. The ends of the cylinders were sanded down to ensure a flat contact surface for the testing devices. The exact lengths, inside diameter, and outside diameters were measured before conducting the compression test. The cross sectional area was then calculated using equation (1) to record and calculate the stress later on.

$$A_c = \pi * \left(\frac{O.D^2}{4} - \frac{I.D^2}{4} \right)$$

FIGURE 1: EQUATION 1

Where *O.D* is the outside diameter of the tubing and *I.D* is the inside diameter of the tubing. Once these values were calculated and recorded, the samples were ready to test. The Instron was used for the first two samples, the standard cardboard tube and the blue tubing. The Instron was calibrated and the sample was placed into the machine. The software was set to record the extension in millimeters and load in Newtons. The extension rate on the machine was set to 2 mm/min which was later determined too slow and was increased to 10 mm/min. The safety stop on the Instron was set to 25kN to ensure that if the sample exceeded the limits of the machine, the load cell would not malfunction and break. The heads of the Instron were lowered to right above the sample and then using the small increment adjustment, brought down to flush with the top of the sample. The loads were then balanced on the software

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Compression Tests

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and the protective door was closed. The compression test was then conducted until the sample failed and the data was recorded. This process was repeated multiple times for a total of 6 samples, three for each material. The fiberglass was then placed into the Instron and tested in compression. The material was too strong for the machine, exceeding the 25kN load cell, and was determined that it must be tested in a larger, more powerful machine. Our team decided to use the MTP concrete compression testing machine. The samples of fiberglass were placed in the machine and the steel heads were placed on the top and bottom of the sample. The machine was calibrated and began compressing the material. Once the material had failed, the samples were removed carefully, being aware of any fiberglass splinters, and evaluated further.

Results

Following the testing of the materials under compression, the data was analyzed and the mechanical properties were calculated. The results from the compression test of standard 4 inch diameter (*D = 101.6mm*) cardboard, blue, and fiberglass tubing are shown below in Tables 1, 2, and 3 respectively.

Sample	Length [mm]	Thickness [mm]	Area [mm²]	Compressive Strength [MPa]	Elastic Modulus [MPa]
1	151.84	2.06	323.38	10.5441	1540.5075
2	151.12	1.91	300.26	10.6399	1683.6040
3	152.76	2.06	323.05	11.0509	1354.4987
Mean	151.9067	2.0066	315.5633	10.7449	1526.2034
Std. Dev	0.82203	0.08798	13.25410	0.269241	165.01827

FIGURE 2: COMPARISON OF MECHANICAL PROPERTIES FOR STANDARD CARDBOARD TUBING WITH D = 101.6 MM

Sample	Length [mm]	Thickness [mm]	Area [mm²]	Compressive Strength [MPa]	Elastic Modulus [MPa]
1	152.40	4.57	715.98	24.7780	2460.9125
2	151.23	3.25	516.66	29.5440	2327.4321
3	150.93	3.71	577.63	25.9180	2505.1468
Mean	151.5190	3.8439	603.4233	26.7467	2431.1638
Std. Dev	0.77786	0.67074	102.13270	2.48872	92.51685

FIGURE 3: COMPARISON OF MECHANICAL PROPERTIES FOR BLUE TUBING WITH D = 101.6 MM

Sample	Length [mm]	Thickness [mm]	Area [mm²]	Compressive Strength [MPa]	Elastic Modulus [MPa]
1	152.8826	3.61	568.86	162.5692	500.1300
2	152.1206	3.25	513.81	175.1379	544.4593
3	152.7048	3.40	537.62	157.2036	484.7590
Mean	152.5693	3.4189	540.0961	164.9702	509.7828
Std. Dev	0.39865	0.17915	27.60658	9.20508	30.99860

FIGURE 4: COMPARISON OF MECHANICAL PROPERTIES FOR FIBERGLASS TUBING WITH D = 101.6 MM

Given these results and from the calculations of stress and strain from the compression tests of each material, plots were created to show the relationship between stress and strain for the given materials. These plots are shown in Figure 7 for the cardboard and blue tubing. The fiberglass was tested in the Instron initially but unfortunately, maxed out the 25 kN load cells capabilities. Due to this, our team tested the fiberglass samples in the concrete compression machine which only produced a total load applied value. A plot for the fiberglass samples is not available at this time. Future samples will be wound on the filament

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Compression Tests

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winder and tested appropriately and plots will be created for these results. The compression tests produced the load in Newtons and the deformation in millimeters and from this raw data, the stress and strain can be calculated. The stress is calculated using equation (2).

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

FIGURE 5: EQUATION 2

Where σ is the stress in MPa, *F* is the load applied to the part in Newtons, and *Ac* is the cross-sectional area of the sample in millimeters. The strain can then be calculated using equation (3) below.

$$\varepsilon = \frac{L - L_0}{L_0}$$

FIGURE 6: EQUATION 3

Where ε is the strain in [mm/mm], *L* is the length of the sample after deformation has occurred in millimeters, and *L0* is the original length of the sample in millimeters. These values were plotted and shown for the cardboard and blue tubing in Figures 7 and 8 respectively.

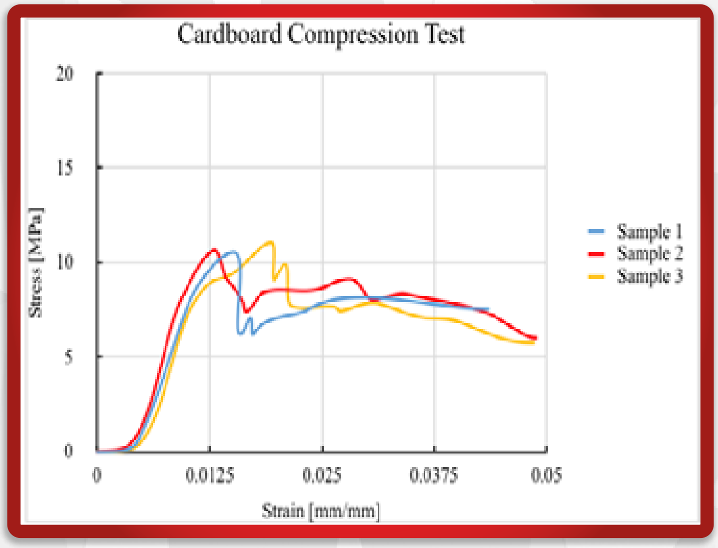

FIGURE 7: STRESS STRAIN CURVES FOR THREE CARDBOARD TUBES, D = 101.6 MM, TESTED IN COMPRESSION

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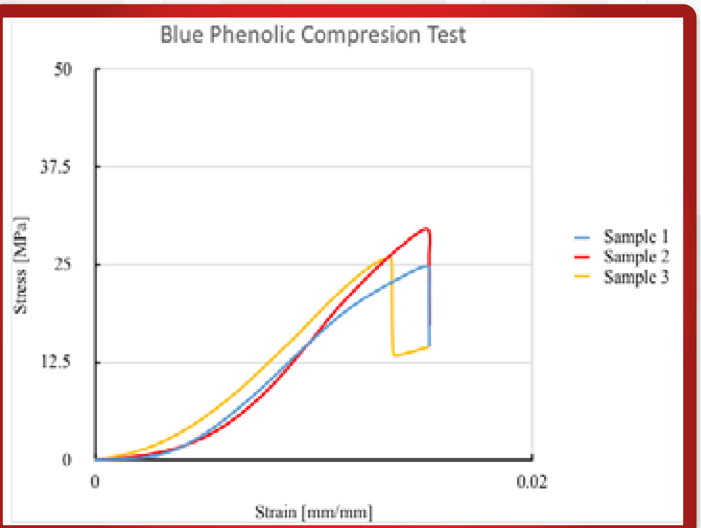

FIGURE 8: STRESS STRAIN CURVES FOR BLUE TUBES, D = 101.6 MM, TESTED IN COMPRESSION

A comparison of compressive strength and thrust was calculated to show the maximum allowable thrust that each material can withstand. The tabulated results are shown below in Table 4.

Material	σ_{max} [MPa]	A_c [mm²]	Max Thrust [N]
Cardboard	11.0509	300.26	3319.28
Blue Phenolic	29.5440	516.66	15269.43
Fiberglass	175.1379	513.81	90018.35

FIGURE 9: COMPARISON OF MAXIMUM ALLOWABLE THRUST IN NEWTONS FOR THREE DIFFERENT MATERIALS

Discussion

The purpose of this study was to determine the mechanical properties of multiple materials in hollow cylindrical form to augment and enhance the design of the body tube on our rocket. The strength of these components is critical in knowing how the material will perform under an applied load. The compressive strength is the critical value for a rocket body tube because it is the main force acting on the body during the boost phase. The results from the cardboard tube show a maximum compressive strength value of 11.0509 [MPa]. The results from the blue tubing produced a maximum compressive strength value of 29.5440 [MPa]. The results from the fiberglass compression test produced a maximum compressive strength value of 175.1379 [MPa]. When comparing these values, it is clear that the strongest material in compression is the fiberglass tubing by a large margin. When designing a rocket body it is extremely important to take into account not only the strength, but the weight. The densities of these materials were recorded to be 0.689, 1.75, and 1.45 [g/cu. cm] for the cardboard, blue and fiberglass tubes respectively. Cardboard has the lowest density and therefore is extremely light weight, which may be used for low force rocket applications, but when launching high thrust motors, the compressive strength of the material is too weak and can fail during boost phase. Comparing the blue to the fiberglass is essential, because

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Compression Tests

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the densities are similar. The fiberglass tube had a lower density of 1.45 [g/ cu. cm] and a much larger compressive strength value of 175.1379 [MPa]. Compare this to the blue tubing density of 1.75 [g/ cu. cm] and a compressive strength of 29.5440 [MPa]. The fiberglass is clearly the superior product for large rockets producing extreme amounts of thrust. This initial thrust off of the launch rail produces a very large compressive force and the fiberglass is proven to take the force without failure. The fiberglass is also lighter, which is a great advantage for the designing and building of rockets. With less weight, the rocket can travel to a higher altitude given the same amount of thrust. The maximum allowable thrust for a given material was shown in Table 4 and the results show that the fiberglass is the strongest material for large thrust motors. The maximum allowable thrust value for fiberglass was 90018.35 [N]. The cardboard and blue tubing produced maximum allowable thrusts of 3319.28 and 15269.43 [N]. The cardboard tube works great with small scale motors, typically Level 1 flights with an impulse range of 0 – 320 [N-s]. The blue tube would be recommended for Level 2 flights or for structural components like couplers or electronics bay tubing. The fiberglass is the strongest material and is recommended for impulse ranges of 320 [N-s] and above. This is the optimum material for rocket that our team is designing.

Conclusion

The compression test of three different composite tubes was successful in determining the mechanical properties and assuring the optimum material for high thrust rocket design. The materials tested were 4 inch diameter (D = 101.6 mm) standard cardboard, blue, and fiberglass tubing. The compressive strength is critical in rocket body tube design. The compressive strength for the fiberglass was substantially larger at a value of 175.1379 [MPa] and clearly the best material for our design of the body tube.

About the Author

My name is Trevor Toft and I am a Senior Mechanical Engineering student at University of Colorado Denver and a level 2 certified high powered flyer. I have been flying rockets since spring 2017 and have found a true passion for the hobby. My current role on our team is the design and construction of the nozzle and air frame materials. I look forward to a future in aerospace engineering and continuing to fly high powered rockets for years to come.

About our Team

FIGURE 10: TREVOR TOFT LOCATED IN THE MIDDLE

We are MACH Rocketry. Our team is designing and building high powered rockets for our senior project. We are Mechanical Engineering students at the University of Colorado Denver and are striving towards tremendous goals. Our team consists of 6 highly motivated and intelligent individuals looking to push the boundaries of Amateur Rocketry.

PEAK of FLIGHT

Standard Missile Rocket Plan

Download the ***RockSim*** design file and decals for the Standard Missile at: https://www.apogeerockets.com/Peak-of-Flight-Rocket-Plans

Standard Missile Parts List

20119 - (1) PNC-3.90” (98MM)
10569 - (1) 4” Dual-Deployment Conversion Kit
11021 - (1) 34” 3.9” (98MM) LOC body tube
11010 - (1) 54MM LOC body tube 17” long
13433 - (3) 54mm to 98mm Centering rings
29623 - (1) 1/4-20 Forged Eyebolt
29621 - (4) 1/4” inch quick links
29097 - (1) 48” to 60” Main Parachute
29093 - (1) 24” to 36” Droque Parachute
29334 - (2) 12” X 12” Parachute Protector
(1) .25” Baltic Birch Plywood for fins and strakes

A design by Barry C. Kane

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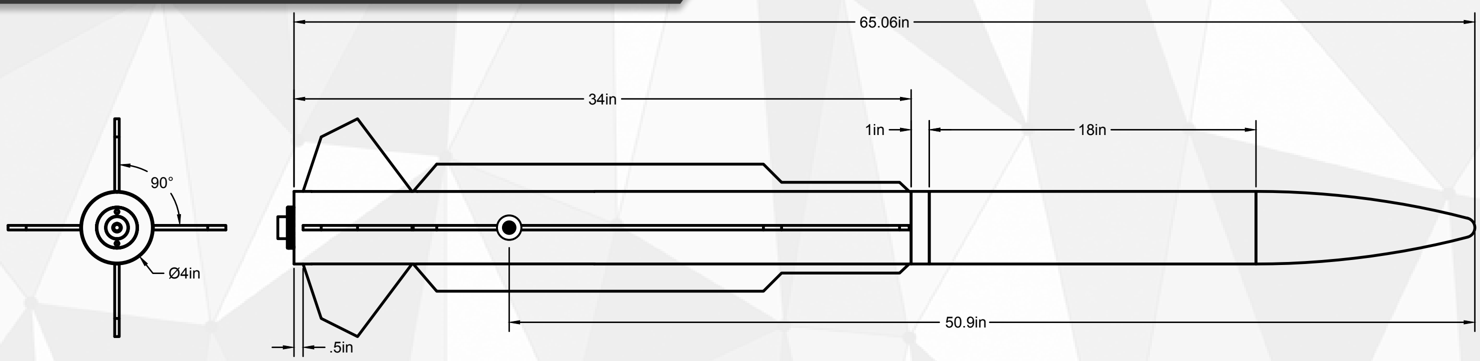
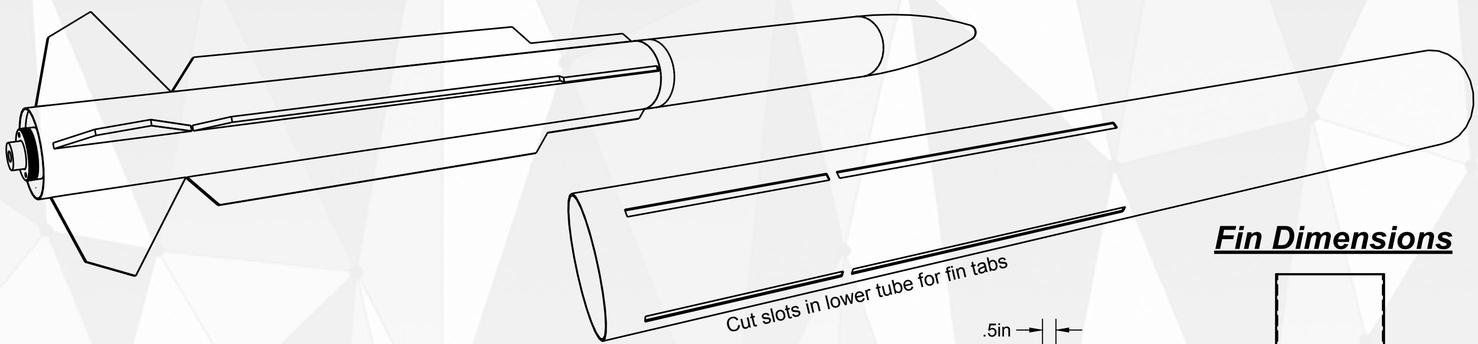
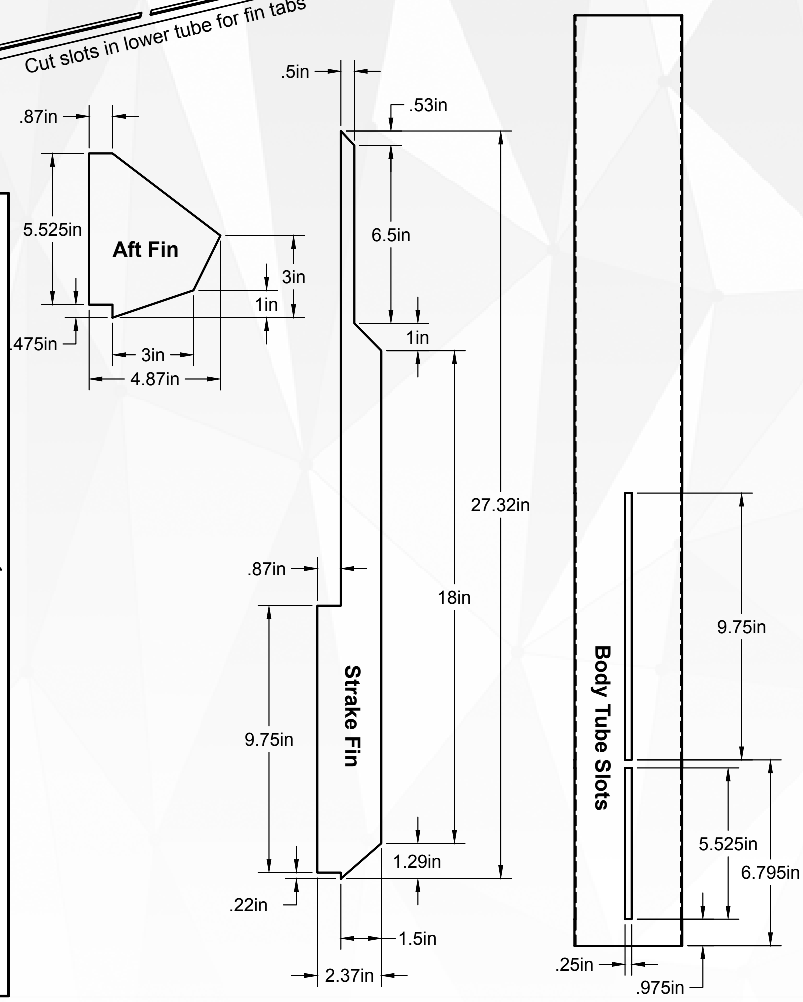
Standard Missile Rocket Plan





Fin Dimensions



Decal Sheet

DANGER: EJECTION →

DANGER: EJECTION →

← DANGER: EJECTION

← DANGER: EJECTION

RIM-66C/D SM2MR

MANUFACTURER: RAYTHEON
SCALE: 1/5
LENGTH: 66 INCHES
DIAMETER: 4 INCHES
WEIGHT: 124 OZ PROJ. / ______ ACT.
MOTOR MOUNT: 2.14 IN / 54 MM

CG: 44.617 / ________ ACT.
CP: 49.789
STABILITY: 1.29

USS PORT ROYAL
CG-73