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Optimization of composite materials using 3D printed cores

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Abstract

Application of 3D printed cores composites materials in rocket structure elements is considered. Different types of infill structures and filaments are tested, mainly PLA, PET-G. Comparison between the foam and 3D printed cores used in sandwich composites have been made. The project gave our team data, essential to develop the most optimal composite material intended to manufacture aerodynamic fins from it.

1. Introduction

In the light of working in AGH Space Systems student's society, where one of the main projects is designing, manufacturing and launching up to 10km Turbulence rocket, as well as research conducted towards manufacturing rotor blades for autorotation system in CanSat project, authors created this paper. On the basis of previous experience with manufacturing fibre laminate materials, the research aims at using 3D printed cores for sandwich composite material. The experimental part of testing aerostructure parts made of our material such as test flight and wind tunnel tests, against initial thoughts, are still on-going and not introduced.

3D printing technology is still rapidly developing and finds its use in more and more areas. For example, it has great potential in substituting foam cores for various laminate composites. In the wake of researching more uses of the printing technology, the authors propose reinforced 3D printed parts with glass, carbon or Kevlar fibres. In the previous projects, the team was making use of fibre cloth in the matrix of epoxy resin, sometimes, with the foam or aramid honeycomb cores. However, complex shapes such as trapezoidal tapered-swept fins, which are the most suitable for Turbulence are relatively difficult to manufacture due to the core of laminate being a flat mat or foam and require complicated milling processes or braiding machines. To counter difficulties created by previously mentioned method, using either FDM, SLS or SLA 3D printing technology, cores can be manufactured much cheaper, with the benefit of wanted shape/infill/weight allowing easy laminating directly on it and ending up with desired, accurate dimensions. Designing material for fins, constructors beside aerodynamic properties needed to stabilize the rocket, it is needed to take into consideration the aeroelastic flutter effect, which is dangerous for construction, and can lead to catastrophic failure, and to avoid its negative effects the part should be very rigid which can be denoted by values of Young's modulus. [1]

The paper is intended to gather useful data, compare different geometries of infills and to be a review for further investigation.

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2. Methodology

To investigate the shape of infill 5 samples of every shape were printed. PLA samples with 30% 1 shell and no top and bottom layers printed with 0.6mm nozzle with 60mm/s printing speed. The following varying infill patterns have been considered:

- Rectilinear,
- Fast honeycomb,
- Full honeycomb,
- Grid,
- Tri-hexagon,
- Cubic subdivision
- Gyroid,
- Triangles.

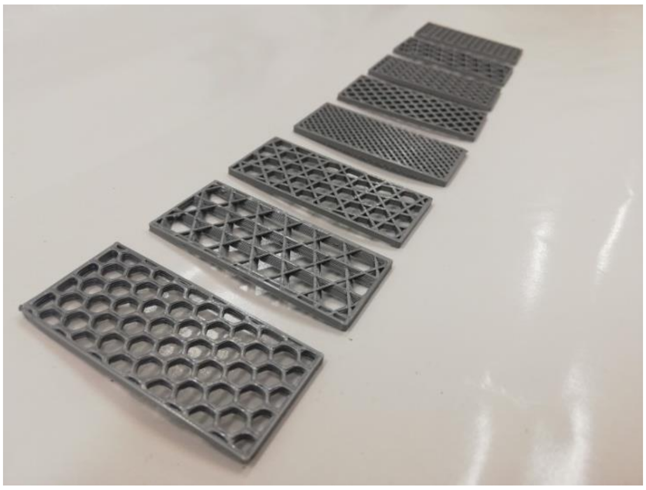

Figure 1: 3D printed samples.

To manufacture a sample first it was printed on a FDM printer on a glass heated bed that was then left to cool down. This is important as we do not want our samples to get deformed which would happen if they were touched while being heated up above their Glass transition temperature, which for PLA is 60°C.

Then sheets of fibers were laid flat on a mylar sheet and soaked in epoxy resin that was then flattened and squeezed using a plastic in a credit card shape to be sure we do not use too much resin, as this would lead to long curing times and greatly increased weight, which is crucial.

Next the sheets were aplied on cores, coated with extra layer of mylar, two flat stainless steel plates. The structure was cured in the vacuum bag for 24 hours, which was placed inside a heating chamber that maintained a constant 50°C. The resin content was 40 percent by weight. The testing samples total dimensions 25x54x2,5 were fabricated to satisfy the selected standard.

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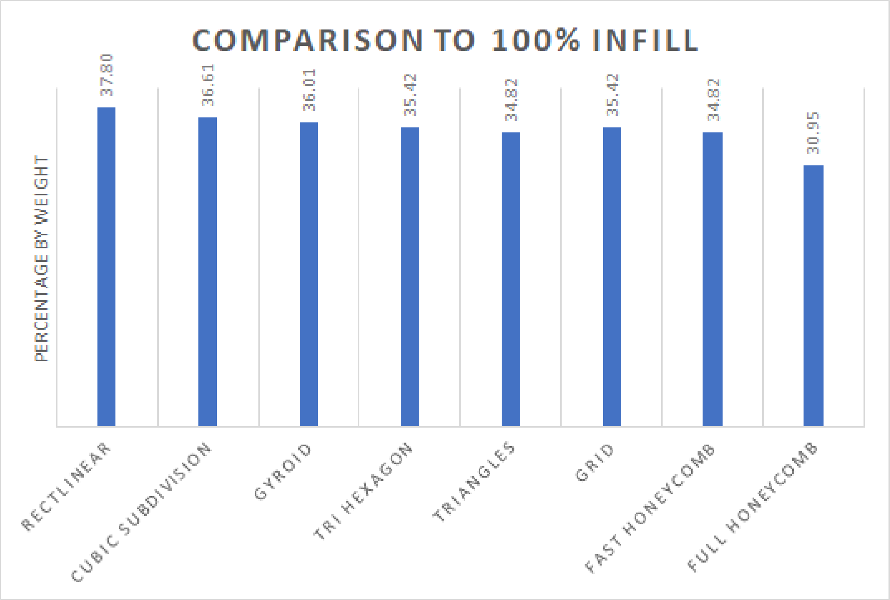

Figure 2: Weight comparison to infill shapes with same percentage - 30%.

Comparing the weight of the samples already gave interesting statistics. None of the samples was exactly 30%. The outer shell weights 0.2g, so even when it is considered the values don't correspond exactly, just give brief information. To compare the influence of infill percentages samples with 15, 30, 50, 100 were tested on the rectilinear infill type.

2.1. Three-points bending technique

To compare each of them, three-points bending tests were carried out. The tests were conducted using standard in EN ISO 178;2011. [5] The measurements were carried out with Zwick Roell 2.5kN bending testing machine and with Zwick – Materialprüfung machine. Two kinds of machines were used to verify their precision. TestXpert program, correlated with the machine in order to save the data.

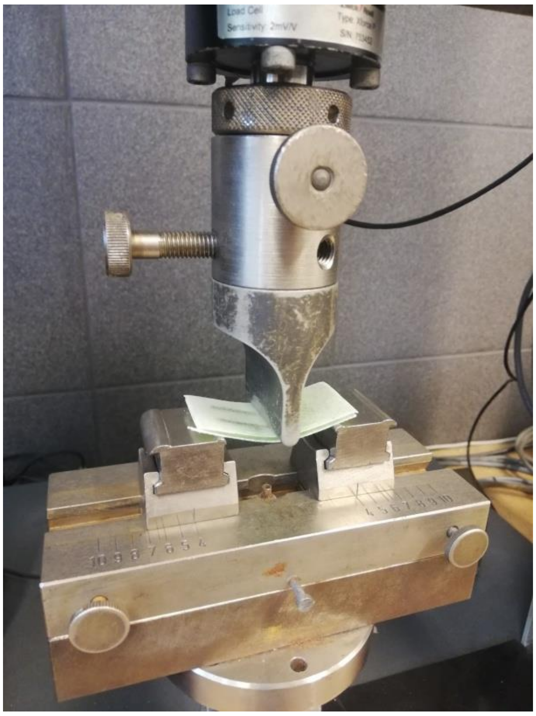

Figure 3: Bending test machine.

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To investigate the structure damage caused by bending tests, samples were researched using a light microscope. The photos of the delaminated areas and cracks have been made. The most interesting cases have been presented below.

Figure 4: Infill covered be resin.

2.2. Ultrasound method

Another method of investigation mechanical properties of the material is measuring the velocity of ultrasonic wave propagation. The velocity of the longitudinal and transverse waves propagation is connected with elastic and material constants such as Young Modulus.

The method is suitable for anisotropic materials like fiber composites, additionally, it is nondestructive and fast. Measurements of the time required to propagate the wave and geometric lengths enable calculating the velocity of the phase.

Samples were manufactured in the same conditions as previous ones and have the same geometric lengths. The measurements of ultrasonic wave propagation velocity in composite materials were made by the through transmission technique, using UZP-1 (INCO-VERITAS) machine. Unfortunately, the measurements of the transverse waves were impossible due to heavy dumping. Measurement of the time of the longitudinal wave propagation appeared to be possible with the nominal resonance of 10MHz and with the Canadian balm as a coupling medium. Only the measurements of times required to travel that thickness were unambiguous and repeatable.

Fully description of the transversely isotropic material demands determining 5 independent elastic constants C_{11}, C_{12}, C_{13}, C_{33}, C_{44}, or seven material constants E_{33}, E_{11}, G_{31}, G_{12}, μ_{31}, μ_{23}, μ_{12}. Because of lacking data, the authors could only compare samples based on average velocities of the ultrasonic wave propagation. [2]

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3. Results

3.1 Bending tests

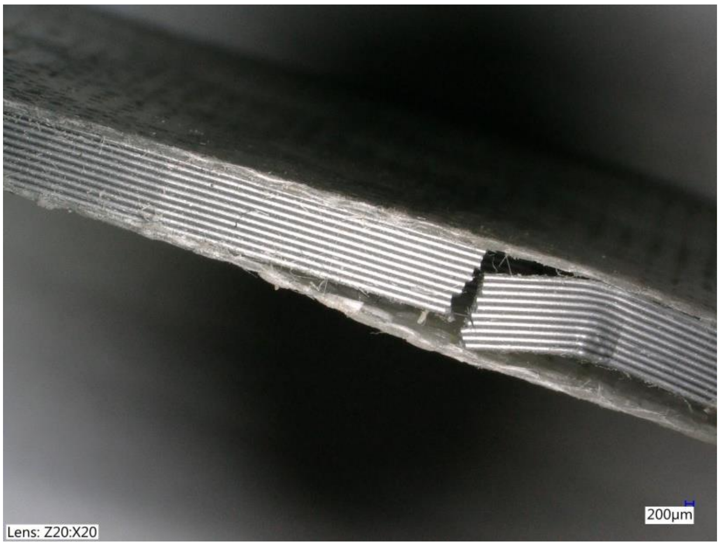

Figure 5: Bended sample number 3.

Performed bending tests allowed for determination of which infill ratio has the best properties when its weight is considered as we try to build lightweight structures. With that in mind it was noted that the most adequate is the infill ranging in 15-25% as the higher infills such as 50% only increased the stiffness slightly, but added a lot of weight.

All results are basing on following calculations which are true for flexural bending tests.

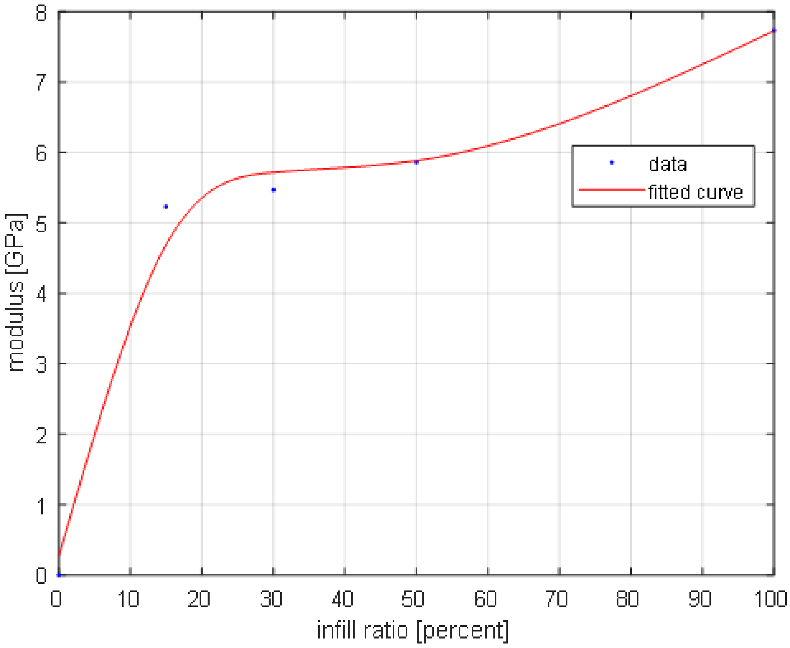

Figure 6: Point data of influence of infill percentage on Elastic Modulus.

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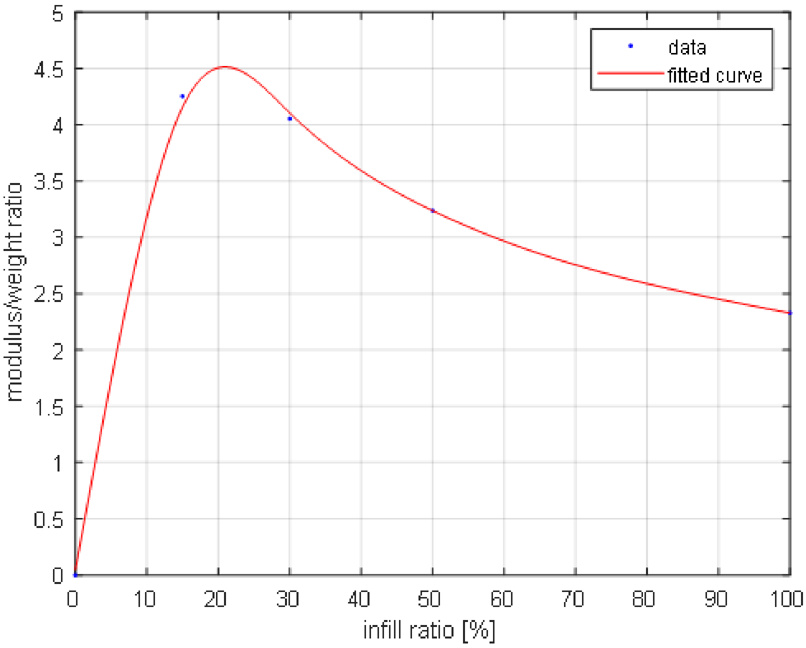

Figure 7: Ratio of Elastic Modulus to weight of various infill percentages that indicate the one with best properties.

Next part of bending tests shown which of the infill patterns is the most suitable one. Again, they have been checked with weight and tested for ultimate strength - until critical fracture.

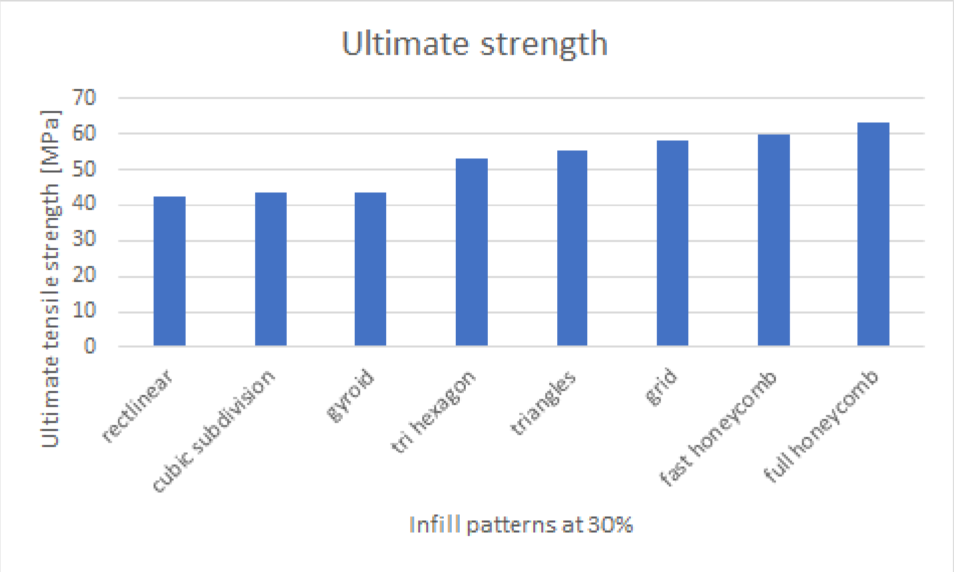

Figure 8: Influence of infill pattern on core’s ultimate strength.

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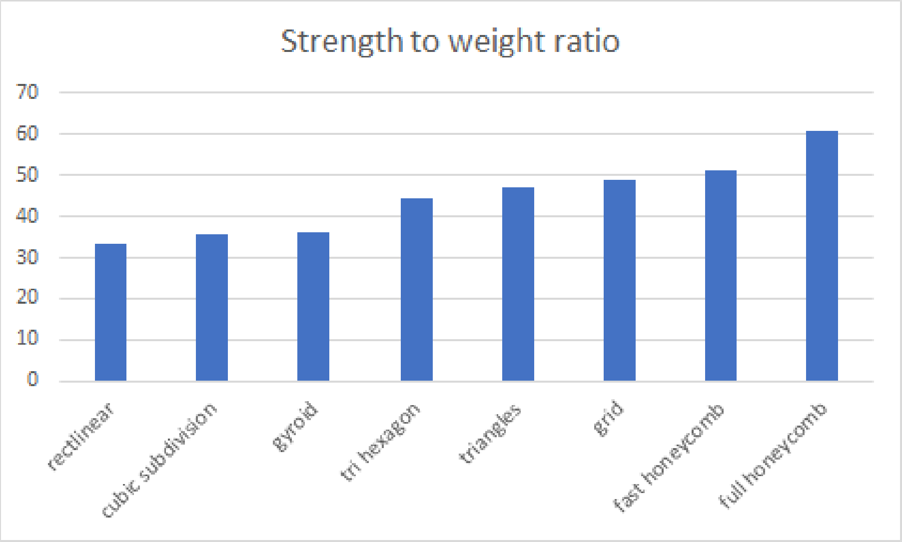

Figure 9: Comparison of infills with weight consideration

It is also worth noting that even though the honeycomb infill shape has the best properties, it takes the longest to print. This is due to the fact that the printer has capped acceleration and jerk rates, which means that the more complicated shape and more direction changes - like in hexagonal shape takes the longest. Slicing software usually does not take this into consideration which results in offset in the predicted in the slicer print time and real time. Most printers have the limitations embedded, which can be only changed in the firmware (for example Marlin) and some slicers (i.e. Cura) allow for modifications of accelerations that do not overwrite the maximum printer settings.

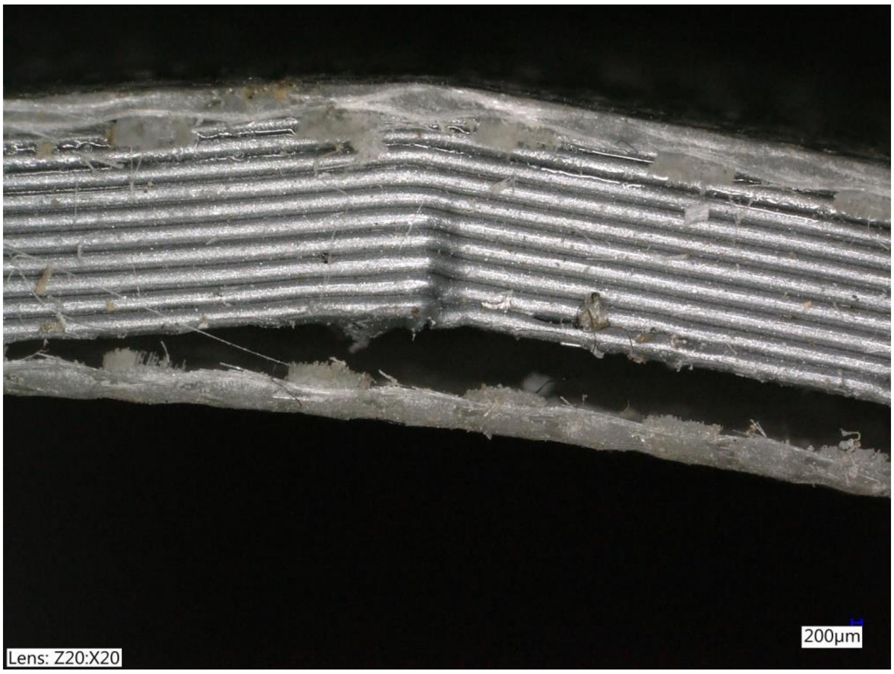

Figure 10: Delamination caused by strain. The adhesion between layers wasn’t enough strength to bond them while deformation.

3.2 Ultrasound method

The longitudinal sound spread speed was shown. The printed samples all shown rather similar results, with the correspondence to the bending test. However, just for comparison a PVC foam core with the same configuration of the composite was tested and performed noticeably weaker. This confirms that 3D printing is a good alternative to be used instead of foam cores. However, if the smaller thickness is required with the maximum possible strength and

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slightly higher mass, the 3D printed cores show superiority. It could be further improved when using a different filament, for example, Pa12+15% CF which has Elastic Modulus 3 times higher than PLA and has a potential of replacing foam completely. The only issue that needs to be rechecked and tested is fibre to core adhesion which would vary with different epoxies used or another type of matrices for composites. [3]

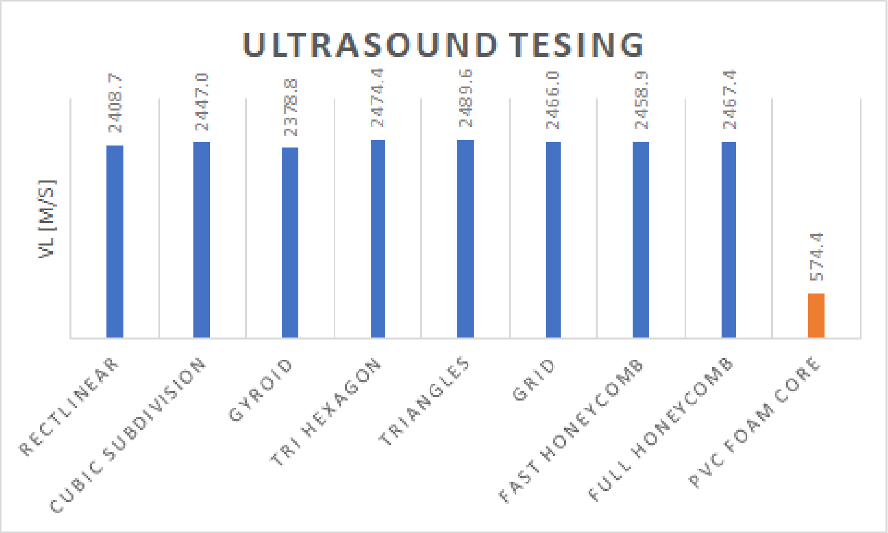

Figure 11: Wave propagation in tested samples.

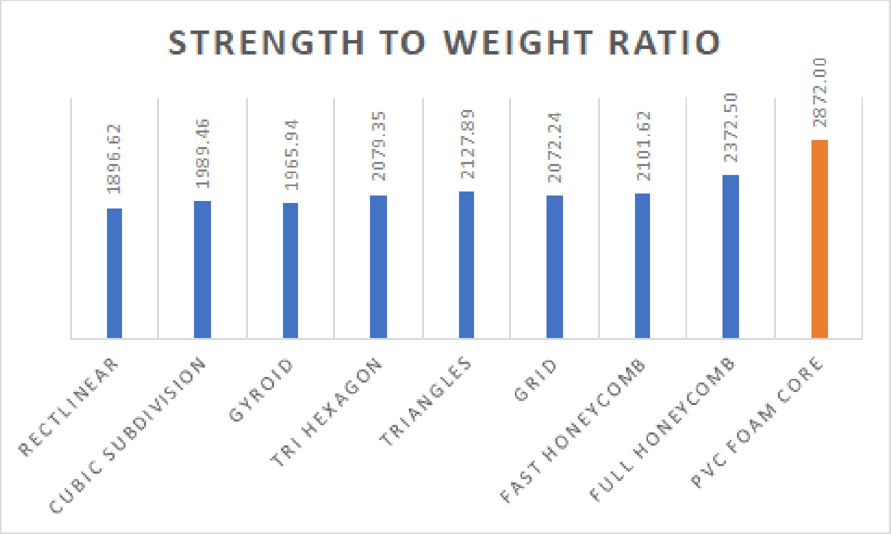

Figure 12: Strength to weight ratio of considered samples

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4. Conclusion and discussion:

4.1

Bending tests showed that honeycomb structure infills can resist the highest forces than the rest. The bending curves shapes are different in honeycomb case. After reaching the maximum force, honeycomb structure composites, are not bent. The samples stressed after that and broke after some extra time and extra force. This is a very important fact in aerospace engineering, which could let constructor avoid the same accident, and stop breaking of the part on time, by for example having special sensors. Moreover, this kind of structure has the least mass from the rest of the samples, which is, of course, fundamental in rocket engineering.

Figure 13: Stress propagation inside honeycomb core composite

Figure 14: Destructed sample with 100% infill.

During bending sample with 100% infill, core started to break simultaneously and fell apart into two pieces. This case occurred only in the sample with 100% infill.

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4.2

The average velocities have varying values, but the samples 1- 9 theoretically should act the same. This difference points that, the shape of the infills has an impact on the velocity of ultrasonic waves propagation, so also on the durability of the material. The most optimal for rocket construction is honeycomb structure, the researches proved that infills of these shapes have the biggest durability to weight ratio.

To compare the results with another sandwich specimens composite, the sample with the same properties and glass/epoxy face sheets but with the PVC foam core was manufactured and researched. The velocity of the propagation of the longitudinal ultrasonic wave through the thickness of that sample was average 574,4 m/s. It means that this material has above 16 times less Young's modulus. However, its strength to weight ratio shows a slight advantage. If the maximum dimensions matter - like in case of rocket fin where the higher thickness the drag is exponentially increased - the thinner the fin the better. With the help of 3D printed cores, we can maximize the strength to weight ratio.

Another thing worth noting is that the printing orientation has a huge influence on the strength of a part as has the best properties when the force acts along the printed layers. Unless the material has properties similar to PET-G that has very good layer to layer bonding properties and during failure acts like solid, injection molded part. On the contrary parts created with Pa12 could undergo high warping that could cause internal stresses by uneven cooling of the part and could be reduced using annealing process that is yet to be researched, as our preliminary results show that parts undergo rather big shrinkage during this process and lead to dimensional inaccuracy.

Based on the literature, we expected that the honeycomb cellular structure provides greatest stiffness and strengths in bending. [4] Our research confirmed it and proved that this kind of relationship is also proper id 3D printed cores.

One of the major design consideration of the Turbulence rocket was to create trapezoidal tapered-swept fins. This research helped us to design rocket fins, choose proper infill shape, and manufacture the most optimal part whilst maintaining the low weight.

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[5] EN ISO 178 :2011