ANALYSIS OF HONEYCOMB STRUCTURE EVALUATED IN STATIC AND IMPACT LOADING

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Abstract. The aim of this research is to analyse the theory of honeycomb structures, their pros and cons among other structures. To implement it in the physical realm, a honeycomb structure was analysed and evaluated with various modifications in SolidWorks to determine the efficiency of the structure. Honeycomb structures were evaluated for static structural and deformation with varied inclinations to the perpendicular axis to the base, and it was determined that the original structure was the most efficient, as it suffered the minimum stress of all the structures. Different cell geometries, such as triangles, squares, and pentagons, were tested, and it was discovered that the hexagonal structure had the best strength-to-weight ratio of all the configurations. For further analysis, the hexagon cell geometry was changed by adding chamfers and inner radius to see if there were any differences in the overall structure. It was found that the construction with a radius of 0.5 mm was more efficient at managing stress than the original structure due to its higher stress to weight ratio. The structure was optimised, and a model was built. The findings indicate that the optimised structure with the inner radius had a strength/weight ratio of 4.3% more than the original structure. The stress after impact test revealed a 5% reduction in stress compared to the original construction. The displacement was also determined using the static structural analysis of the same weight and was found to be less than 4% of the original structure.

Keywords: honeycomb structure, cell geometry, static, impact loading.

Introduction

The honeycomb structure is a relatively old structure concept that can be found in a variety of modern products and structures [1], it has a one-of-a-kind structure that is found in nature. The honeycomb structure implemented in engineering is partially based on the original structure seen in nature that is made by bees to store honey. It has a high weight-to-strength ratio and is quite resistant to external forces [2-4]. In this research, we will investigate and analyse how honeycomb structures are used in construction and engineering, as well as try to improve them through various modifications and suggestions.

In engineering, hexagonal shape is the preferred shape because it is most efficiently filling a plane with no wasted spaces between them, maximizing the area inside the polygon and reducing the material required for its wall construction. This property reduces wastage of material and extra space in construction also minimizing the weight. Honeycomb structure provides better strength against impact and vibration compared to the other structures [5-7]. Mainly it is used in sandwich structures between two outer stiff and strong layers.

The invention of the honeycomb sandwich, due to its low weight and increased axial stiffness, is one of the most lauded structural engineering breakthroughs in the industry, with applications in transportation, cars, aircraft, and railroads, among others. Sandwich Panels or Sandwich Structures are a subset of structural composites that are optimized for material savings and excellent stiffness-to-weight and strength-to-weight ratios. Sandwich panels are composed of three major components: two face sheets or skin sheets that are separated by a thicker but lighter core. The face sheets are constructed from a moderately stiff and robust material that provides sufficient stiffness and strength to sustain significant loading forces. The core material is lightweight and engineered to give adequate shear strength to sustain transverse shear loads while also providing sufficient shear stiffness to prevent the panel from buckling [6; 8-10].

Honeycomb structures are generated by interlocking of various shaped cells perpendicular to the plane formed by face sheets, resulting in a material with a low density and good out-of-plane shear and compression characteristics. The strength and stiffness of a honeycomb structure are determined by the cell shape and material used to construct it [11]. Due to its high strength-to-weight ratio and high bending stiffness, honeycomb structure composites have a broad range of applications.

In the past decade, one of the main engineering challenges was to develop and introduce in the mass production more efficient materials in all industrial areas. At the moment there is an intensive search

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for: new lightweight and reinforced metal-matrix composite [12; 13] for automotive and aerospace applications [14; 15]; composite for the construction sector [16-18] special metallo-ceramic-matrix with reduced density composites; innovative design of reinforced metallo-polymer composites; as well, innovative reinforced metals-crystals-polymer [19; 20] composite fibers with protection properties from electromagnetic field for office application [21-24]. Composite nanofibers have a unique tendency decreasing the diameter, increase the mechanical properties [25; 26].

Materials

Honeycomb structures are used to provide a basic sense of the dimensions of honeycomb cells and the area used for modelling. SolidWorks was used to create the design. Because of its light weight and great axial flexibility, the honeycomb structure is favoured over most conventional structural methods and materials [27; 28]. Tables 1 and 2 represent the dimensions of the modelled honeycomb structure and mechanical properties, respectively. As stated in the research, modern car manufacturers such as Toyota, Nissan, Mitsubishi, and Honda have all shifted to aluminium panels in the external body panels of their vehicles [29]. It demonstrates that the composition and mechanical properties of the 7000 series aluminium panels are best suited for the construction of body panels because they are light weight, heat treatable, and their strength can be controlled by heat treatments, and thus can serve in a variety of applications [30-32]. For the research, 7075-T6 alloy has been chosen. Figure 1 represents the 3D geometry of the honeycomb structure with the thickness of all walls 0.12 mm and the side of the hexagon is 3.46 mm.

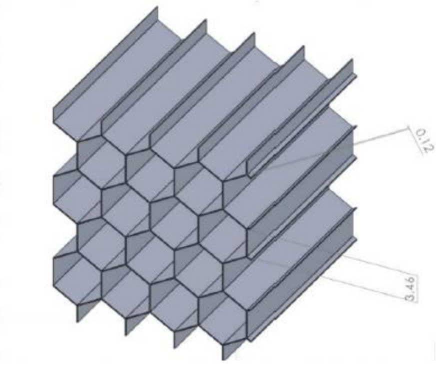


Fig. 1. **Modelled honeycomb structure**

Table 1

Dimensions of the modelled honeycomb structure

Cell (mm)	6
Specimen dimensions (mm^2)	25x25
Thickness (mm)	0.12
Height (mm)	30

Table 2

Mechanical properties of Aluminium 7075-T6

Properties	**Value**
Elastic Modulus (GPa)	70
Ultimate Tensile Strength (MPa)	560
Yield Tensile Strength (MPa)	480
Poisson’s Ratio	0.32
Compressive Strength (MPa)	280

Analysis of Honeycomb Structure

The modelled honeycomb structure (Figure 1) will be examined in this section with 0.2 mm thick aluminium sheets on both sides of the core and then modelling a static examination of the same in SolidWorks under 50 N of force. After receiving the results, a comparison with an aluminium sheet of similar dimensions will be made using the same static study to determine whether the honeycomb structure is useful or not.

The honeycomb structure is built with the same dimensions of the aluminium sheet. It weighs around 47 gm, which is more than 19.34 times heavier than the honeycomb construction.

The calculated required force 967 N is applied on the block of aluminium by fixing one face and applying the force on the opposite face of the sheet. The stress and displacement results obtained from the study simulation are shown in Figures 2 and 3.

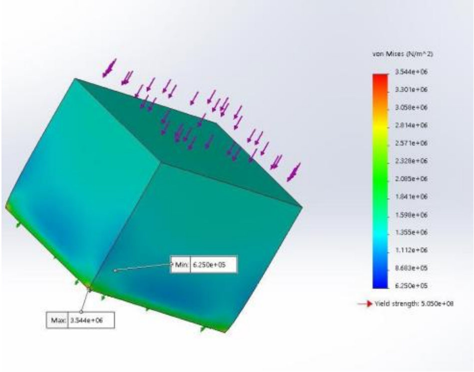


Fig. 2. **Static stress of aluminium sheet**

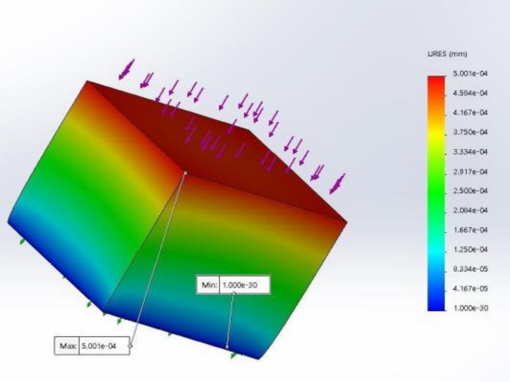


Fig. 3. **Static displacement of aluminium**

The honeycomb variant weighs around 2.43 gm, has a cell size of 6 mm, and overall dimensions of 25*25 mm^2. This honeycomb model is created in SolidWorks using 0.2 mm thick aluminium sheets on both sides of the core and then simulated under 50 N of force. One side of the structure is fixed and the force is applied from the opposite side. Static stress and static displacement results of the honeycomb model with 0.2 mm aluminium plates are shown in Figures 4 and 5.

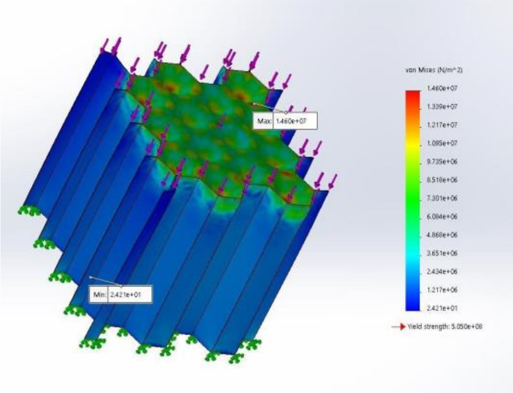


Fig. 4. **Static stress of honeycomb**

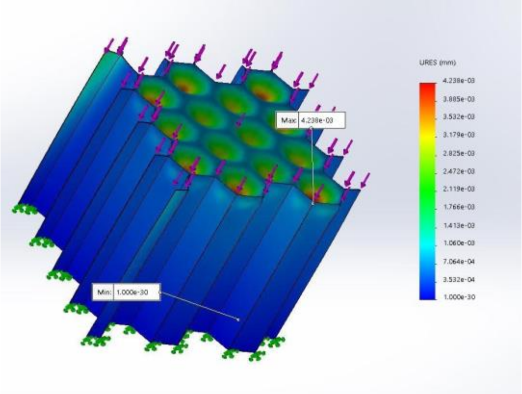


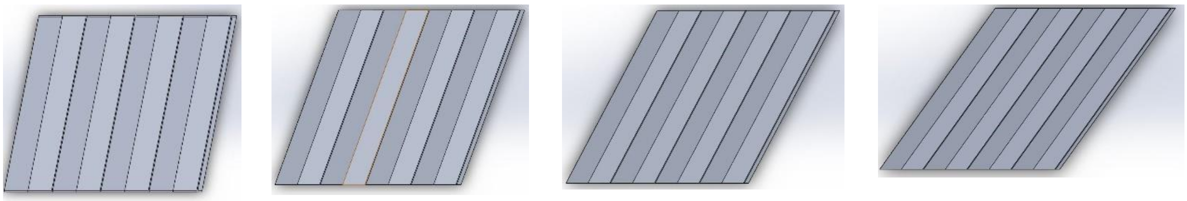
Fig. 5. **Static displacement of honeycomb**

To properly understand the honeycomb structure’s benefit, the strength-to-weight ratio of both structures must be determined. The strength-to-weight ratio is defined as the ability of a structure to bear a load divided by its weight. According to both assessments (1), the strength to weight ratio is defined as the ratio of the yield strength ($N \cdot m^{-2}$) to the structure’s weight (gm), which is calculated with the measured weight of the honeycomb structure in SolidWorks.

$$\frac{5.050e+08\,\frac{N}{m^2}}{2.43\;gm} \text{ is greater than } \frac{5.050e+08\,\frac{N}{m^2}}{47\;gm} \tag{1}$$

The strength-to-weight ratio of the honeycomb construction is approximately 19.34 times greater than the aluminium sheet (which was used in simulation). It can be stated that the honeycomb structure is significantly more convenient than conventional structures like beams and bars.

The strength top weight ratio of the honeycomb is about 11.2 times that of the conventional structure observed from previous study. Change some of the structure’s factors and dimensions within its initial constraints to get the best efficient design. As a result, honeycomb panels with y-axis angles of 10º, 20º, 30º and 40º were designed (Figure 6) for static study to obtain stress and displacement results by applying 50 N force per simulation, and the values are presented in Table 3.



10º 20º 30º 40º

Fig. 6. **Honeycomb structures with different inclinations with y-axis**

Table 3

Values of stress vs angle of the y-axis

Angle with the y axis	Maximum stress, MPa	Minimum stress, MPa	Maximum displacement, mm
0	1.46E + 07	2.42E + 01	4.28E-03
10º	3.31E + 07	1.82E + 01	1.25E-02
20º	2.31E + 07	1.84E + 01	2.24E-02
30º	3.22E + 07	1.28E + 02	3.50E-02
40º	4.42E + 07	1.63E + 01	1.62E-02

Figure 7 shows comparison of the cell shape geometry used for optimization as per previous simulation. Table 4 represents the results of each simulation under the same boundary condition.

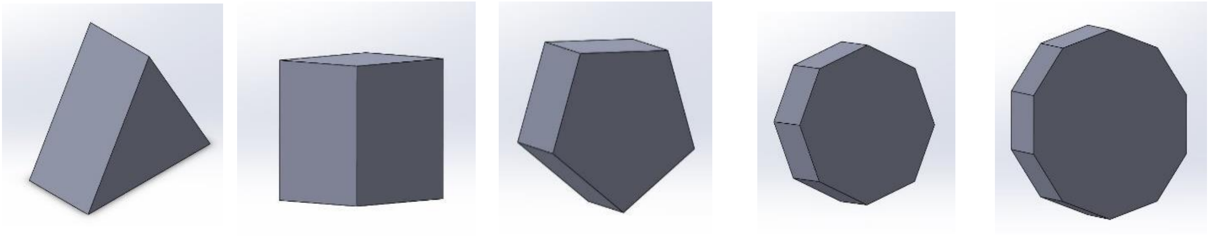


Fig. 7. **Cell shape geometries used for optimization**

Table 4

Static study of cell shape geometries

Cell shapes	Weight of structure (g)	Maximum stress (MPa)	Maximum displacement (mm)	Strength/weight ratio
Triangle	19.16	1.68E + 07	4.29E-03	26356993.74
Square	3.00	1.11E + 07	4.16E-03	168333333.30
Pentagon	12.56	1.98E + 07	4.12E-03	40207006.37
Hexagon	2.43	1.46E + 07	4.24E-03	207818930.00
Octagon	9.55	1.33E + 07	2.66E-03	52879581.15
Decagon	11.86	1.34E + 07	2.49E-03	42580101.18

The regular hexagonal panel cell shapes are modified by adding a 45-degree fillet at a distance of 0.5 mm from each hexagonal vertex. The thickness between two cells is held at 0.12 mm, and the total area of the structure is 25 x 25 mm^2, with a height of 25 mm and with an aluminium sheet of 0.20 mm on each face of the panel. Figure 8 shows the static stress results of the honeycomb panel with fillet edges. From the outcomes, it can be observed that the maximum stress on the body is 1.585e + 07 N·mm^{-2}. The calculated weight of the geometry is 3.11g.

The regular hexagonal panel cell shapes are modified by adding a radius of 0.50 mm instead of straight fillets 0.5 mm from each hexagonal vertex. To compare the outcomes, all other dimensions are presented in the honeycomb structure with fillet edges. Figure 8 illustrates the Von Misses stress with the addition of a fillet, while Figure 9 illustrates the static stress values for a honeycomb panel with an added radius to each edge. The results indicate that the maximal stress on the body is 7.797e + 06 N·mm^{-2}. The weight of the estimated model is 2.55 g.

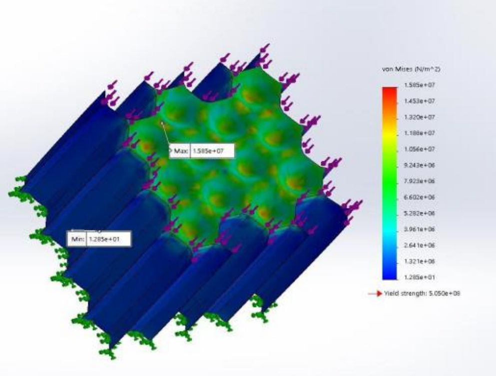


Fig. 8. **Static stress of honeycomb panel with added fillet**

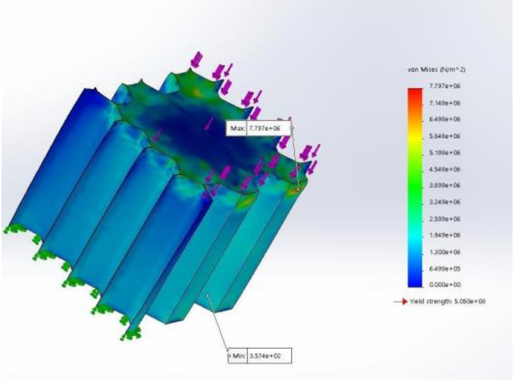


Fig. 9. **Static stress study of honeycomb panel with added radius**

Figure 10 is the optimal design, which has a mass of 2.33 g and it is less than that the initial structure. The resultant stress was 6.505e + 06 N·mm^{-2}, which is less than the original. This will be able to increase the strength-to-weight ratio of the object which makes this an efficient structure.

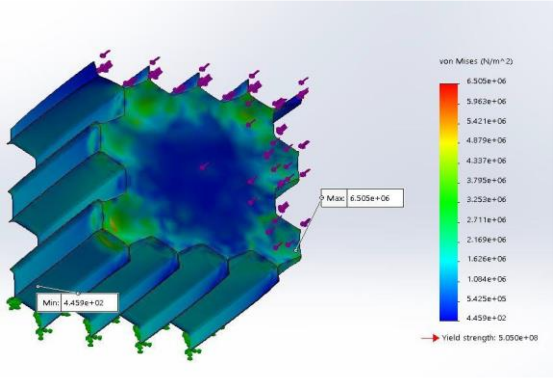


Fig. 10. **Static study of optimal structure**

To examine the physical consequences on the optimized structure, a simulation study of the 'impact test' on the body should be carried out. Impact testing is useful to determine the amount of stress, strain and the displacement on the body when it is dropped from a height, or it strikes a hard surface or body at a velocity. Initial velocity considered is 20 m·s^{-1}, the impact target is a rigid structure, and the coefficient of friction is zero. Given below Figure 11 represents the direction of impact on the geometry.

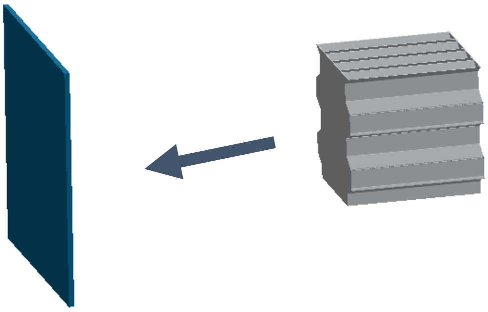


Fig. 11. **Impact test of honeycomb structure**

Figures 15 to 17 show the stress, displacement, and strain resultants of the optimized structure during impact load respectively. The maximum stress is 4.797e + 08 N·m^{-2} developed from the impact testing, which is less than the yield strength, this indicates that the structure is not likely to fail or experience failures with this velocity, this means that the structure is safe. The maximum displacement of the structure is 2.820e-01 mm, which is negligible for this speed of impact. The maximum equivalent strain experienced by this body is 1.702e-02, which denotes the state of strain in the solid.

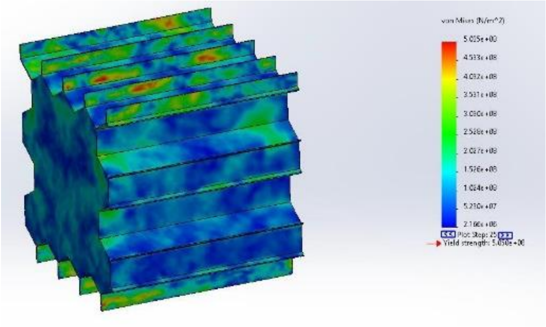


Fig. 12. **Stress distribution of the original hexagonal structure after impact load**

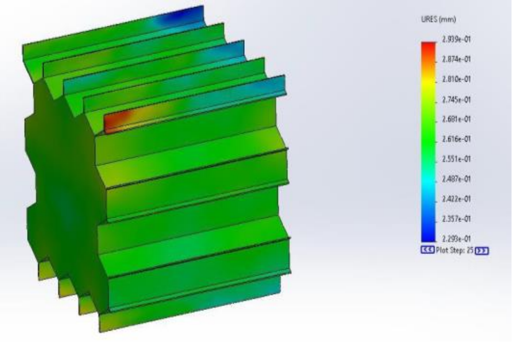


Fig. 13. **Displacement distribution of the original hexagonal structure after impact load**

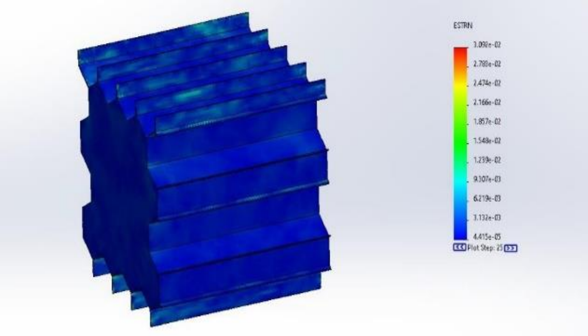


Fig. 14. **Strain distribution of the original hexagonal structure after impact load**

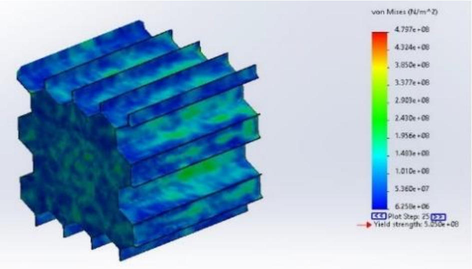


Fig. 15. **Stress distribution of the structure with radius after impact load**

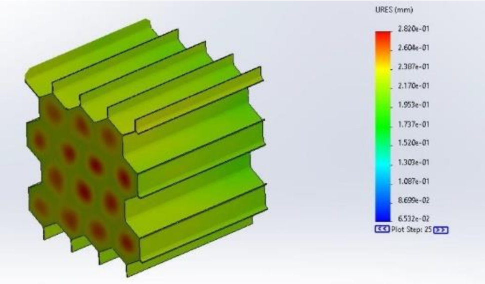


Fig. 16. **Displacement distribution of the structure with radius after impact load**

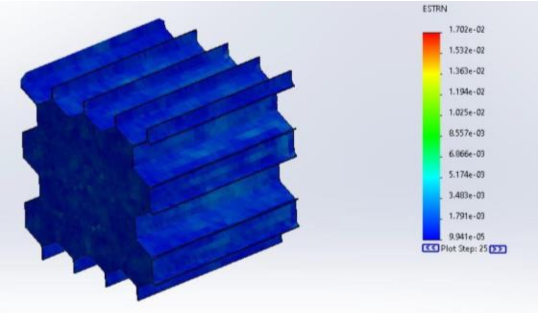


Fig. 17. **Strain distribution of the structure with radius after impact load**

Results and discussion

Table 5 shows the results that the shape which bears maximum stress is the hexagon which has fillet on each side. The maximum weight is seen in the structure with the hexagon with the inner radius and the minimum weight is seen in the original structure. The comparison of weight and stress to the original structure is given in Table 6, the results show that the strength/weight ratio of the structure with the inner radius was 4.7% less than the original structure. Strength-to-weight ratio of the structure with the inner radius was 4.3% more than the original structure. This already indicates that the honeycomb structure is best for using in areas where less weight should be maintained. Comparison of the impact load results of the original hexagonal structure with the optimised structure is shown in Table 7. Static analysis was also used to determine the displacement, which was lower by 4.1% than the original construction. The stress generated by the impact was 5% less than the stress generated by the original structure.

Table 5

Comparison of shape variant maximum stress and weight

Shape variant	Maximum stress, MPa	Weight, g
Original hexagon	1.46E + 07	2.43
Hexagon with fillet	1.585e + 07	3.11
Hexagon with inner radius	7.797e + 06	2.55

Table 6

Total percentage of weight and stress compared to original structure

Shape variant	% Change in weight	% Change in maximum stress
Original hexagon	0	0
Hexagon with fillet	5 increases	46 decreases
Hexagon with inner radius	4.1 decrease	55.4 decrease

Table 7

Comparison of parameters of original hexagonal structure with hexagonal structure with inner radius due to impact

Structure	Maximum stress, MPa	Maximum displacement, mm	Maximum strain
Original hexagonal structure	5.04E + 08	2.94E-01	3.09E-02
Hexagonal structure with inner radius	4.80E + 08	2.82E-01	1.70E-02

Conclusions

1. The honeycomb structure is analyzed by varying the structure's properties. To compare it to the original structure, the structure cell shape was altered. Fillets and radius were added to the cells to study the structure. The findings indicated that the construction with the fillet had 5% better strength-to-weight ratio than the original structure. The honeycomb structure with an inner radius proved to be more efficient than the original (conventional) form. The weight remained the same, but the maximal stress on the body was cut in half.
2. When a load was applied to the honeycomb wall, honeycombs with cores angled to 0 degrees with the vertical exhibited least stress and deformation.
3. The hexagon shape was found to be the most useful of all shapes; the honeycomb structure hexagon had the lightest weight of all the cell shapes; this was due to the hexagon's efficient packing system, which enables cost savings through reduced material usage; the structure, while light, had the best strength-to-weight ratio of any cell geometry. The structure with the radius on its sides demonstrated a significant reduction in overall stress distribution (55.4%) when compared to the original structure, whereas the structure with fillets on its sides demonstrated decrease in overall stress distribution (46%), which was not desirable and thus was discarded from further optimization.
4. SolidWorks optimized the structure by varying the radius and thickness of the walls, as well as lowering stress and managing mass, and identified a structure with a lower maximum stress than the non-optimized structure while maintaining the same weight. Maximum stress was reduced by 46% in the new optimized structure compared to the original hexagonal structure.

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Author contributions

Conceptualization, J.V.S. and V.J.; methodology, J.V.S. and A.D.; software, J.V.S. and A.D.; validation, S.P.K. and J.V.S.; formal analysis, J.V.S. and A.D.; investigation, J.V.S. and A.D.; data curation, S.P.K. and A.G.A; writing – original draft preparation, J.V.S. and S.P.K.; writing – review and editing, J.V.S.; visualization, S.P.K.; project administration, S.P.K. and J.V.S; funding acquisition, J.V.S. and S.P.K. All authors have read and agreed to the published version of the manuscript

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