Enhancement of Mechanical Properties Through Design Modification in Mechanical Metamaterials

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Abstract - Mechanical metamaterials draws everyone's attention and expands its scope due to their exceptionally controllable mechanical properties, along with the advancement in additive manufacturing technology, which facilitates the easy fabrication of the metamaterial. The experimental survey presented in this document involves the design of the hybrid type model (Anti-tetra chiral) and its two variants with modified dimensions, simulation for the designed models for compressive loading conditions using loads 50N, 75N and 100N for each variant of varied dimensions. Inconel 718 material is considered for the simulation study. After simulations, the results obtained are transformed into graphical representation to further analyse the compressive strength that each model can withstand..

Key Words: Mechanical Metamaterials, Hybrid model, additive manufacturing technology

1. INTRODUCTION

Metamaterials are the engineered materials that gain their properties from structure rather than their composition, this led to a drastic increase in study of metamaterials as their properties not exhibited by most materials, which are obtained naturally [1]. Mechanical properties of materials have been one of the most fundamental and widely studied areas in materials, owing to its crucial importance for real-life applications. The unit cell of desired pattern is first designed and multiplied unit patterns of small to large scales are used to get the desired metamaterial design. The properties of the materials such as stiffness, Poisson's ratio, energy absorption capability, or compressibility can be altered to desired extent using internal structures [2]. The properties of the materials can be enhanced by using optimized parameters of the unit cells such as the shape of the unit cell, size and unit cell orientation, etc. Therefore, by changing the internal geometry of the material we can control its properties. Currently, the most studied and widely used mechanical metamaterials are those with negative Poisson's ratios, which have energy absorption and impact resistance properties. They demonstrate outstanding performances in elastic modulus adjustment, indentation resistance, and energy absorption. Negative Poisson's ratio metamaterials with a rotation mechanism are also called auxetic metamaterials. Auxetic material is an unusual material, which expands in one direction when they are stretched in another direction. This unusual auxetic effect is due to the negative Poisson's ratio. Auxetic metamaterials are the materials, which have a negative Poisson's ratio [3-6]. When we look at traditional convectional materials with a positive Poisson's ratio we cannot alter or modify their mechanical properties but materials with negative Poisson's ratio exhibits enhanced mechanical properties such as high fracture toughness, impact resistance, energy absorption, increased hardness etc. [8-9]. The development of additive manufacturing technologies now makes it possible to produce lightweight metallic and non-metallic porous materials with properties that are highly controllable. This means that their structure is designed in a controlled way [9].

The aim of the research is to investigate the influence of the basic unit cell on the compression behaviour of a basic lattice structure fabricated from Inconel 718 material to use it in the most suitable applications for the parts of daily use or in engineering practice in future.

2. EXPERIMENTAL METHODS

2.1 DESIGN OF MECHANICAL METAMATERIAL MODEL

The model designed is modified for various dimension to check for any changes could be seen in their mechanical properties such as compressibility, stiffness etc. The type of model that is designed here is of hybrid type model (Anti-tetra chiral). The unit cell of the hybrid model is shown in figure 1. For this unit cell, the rib thickness is kept constant and the diameter of the circle is varied to get similar model with varied dimensions. The sketch where the dimensions are modified in hybrid model is shown in figure 2.

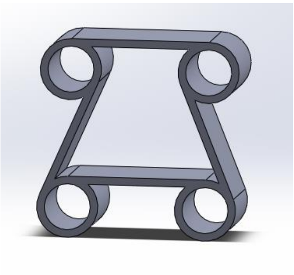

Fig. 1. Unit cell of Hybrid model (Anti Tetra chiral)

The other two models with modified dimensions similar to the initially designed model is shown in figure 3. The diameter for both the models are modified in their diameter in either extremes by 18.75% respectively. So that their strength in

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withstanding load can be determined and compared with each other, the simulation for these three models are carried out in ansys software.

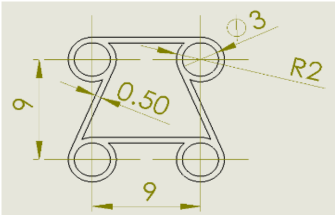
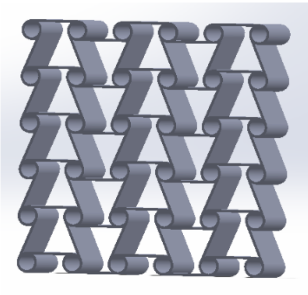
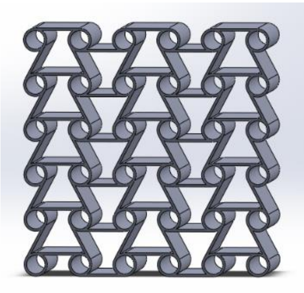


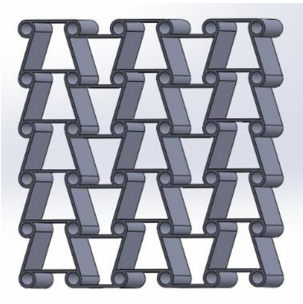
Fig. 2. Sketch of unit cell of Hybrid model for which the dimensions are varied



a) Hybrid with dia 4mm



b) Hybrid with dia 4.75mm



c) Hybrid with dia 3.25mm

Fig .3. Hybrid model designed with varying diameter a) the actual model with 4mm diameter b) variant model with 4.75mm diameter (increased 18.75%) c) variant model with 3.25mm diameter (decreased 18.75%).

2.2 SIMULATION STUDY

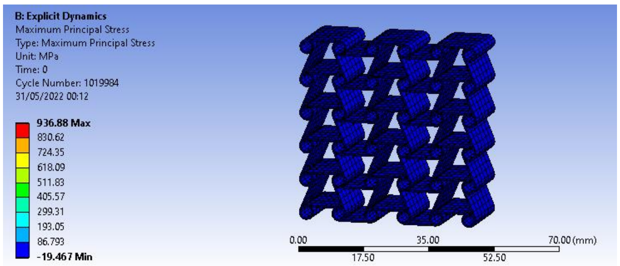
The simulation for the designed models were done using ansys software, the compression test was done on all three models for 50N, 75N and 100N load. Inconel 718 material is considered for the simulation study and its properties are tabulated in Table 1.

Table -1: Properties of Inconel 718.

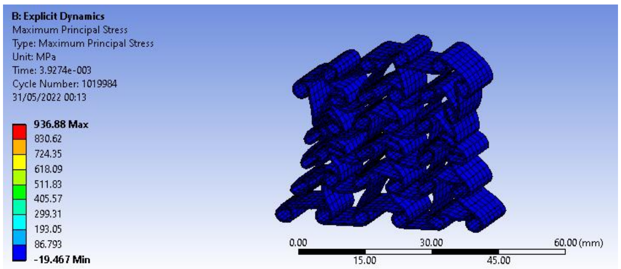
Properties	Values
Density	8.192 g/cm³
Young's Modulus	2.05 Gpa
Poisson's Ratio	0.284

The following figures shows the simulated results for compressive load of 100N.

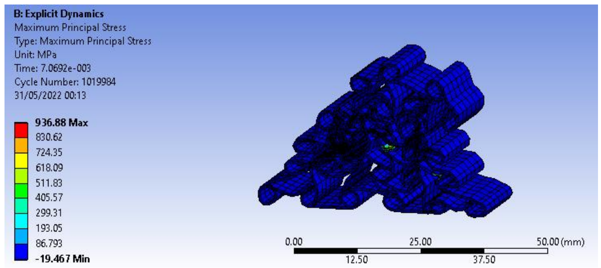
1. Simulation of compression test using 100N load



a) With no load

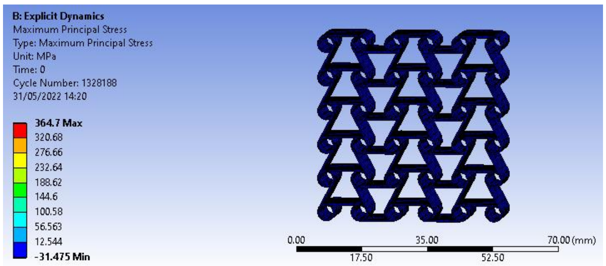


b) With intermediate load

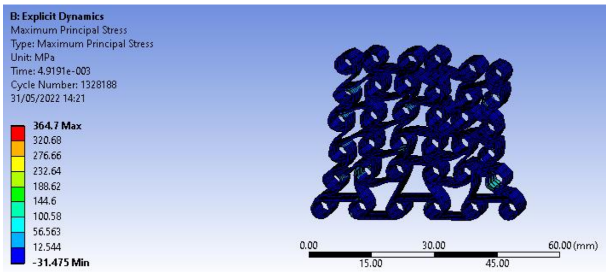


c) With full load

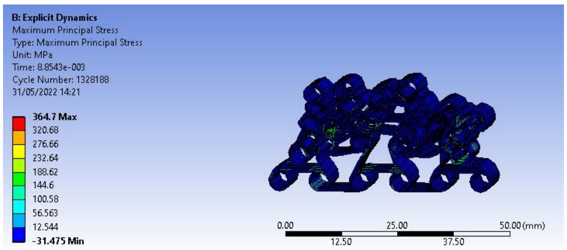
Fig .4. Deformation of the simulated model for 100N load of Hybrid model with circle diameter 4mm. (a), (b), (c) are the simulated models with no load, intermediate load and full load respectively.



a) With no load

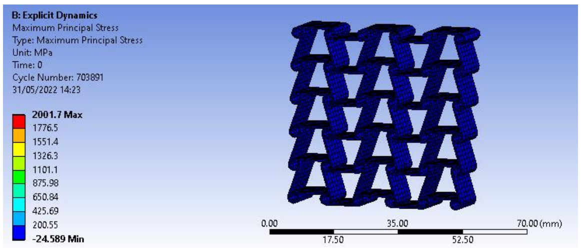


b) With intermediate load

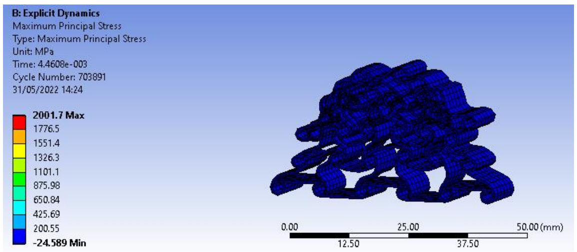


c) With full load

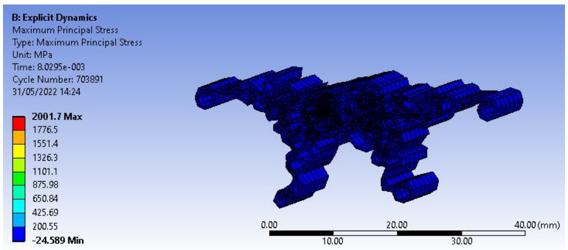
Fig .5. Deformation of the simulated model for 100N load of Hybrid model with circle diameter 4.75mm. (a), (b), (c) are the simulated models with no load, intermediate load and full load respectively.



a) With no load



b) With intermediate load



c) With full load

Fig .6. Deformation of the simulated model for 100N load of Hybrid model with circle diameter 3.25mm. (a), (b), (c) are the simulated models with no load, intermediate load and full load respectively.

The above figure shows the simulation results for 100N. Similar iterations were carried for 50N and 75N load and appropriate results were obtained.

3. RESULTS AND DISCUSSION

The compression test for the hybrid models shown in the figure2 were completed using ansys software. After simulation the results of deformation stress and strain for given model are obtained. The stress versus strain graphs are plotted for each model for different loads. In addition, the test results are compared using the graphs that are plotted.

The following figures below shows the stress vs strain graphs plotted.

1. Graphs of 50N load

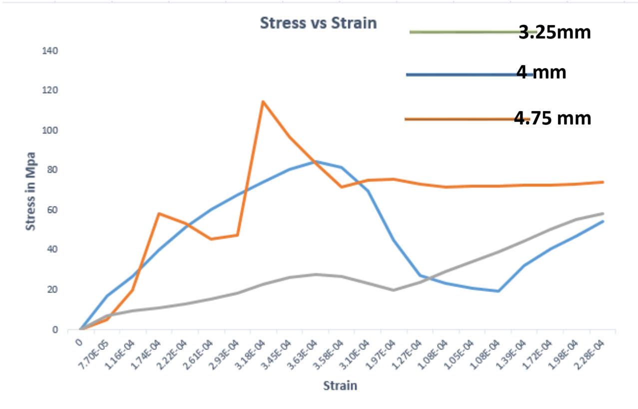


Fig .7. Stress-Strain graphs plotted for the values obtained after simulating for compression of 50N load for 4mm, 4.75mm and 3.25mm diameter of circle respectively.

2. Graphs of 75N load

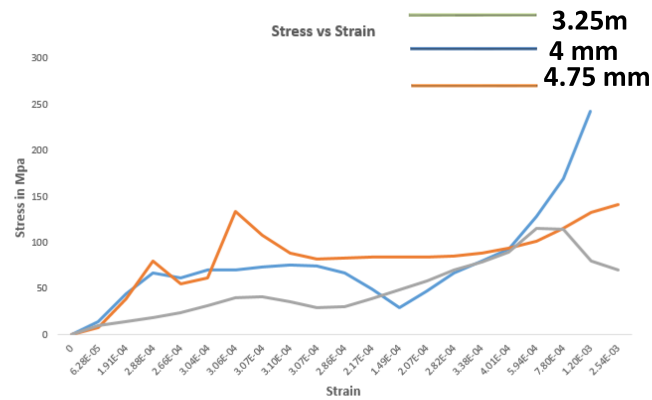


Fig .8. Stress-Strain graphs plotted for the values obtained after simulating for compression of 75N load for 4mm, 4.75mm and 3.25mm diameter of circle respectively.

3. Graphs of 100N load

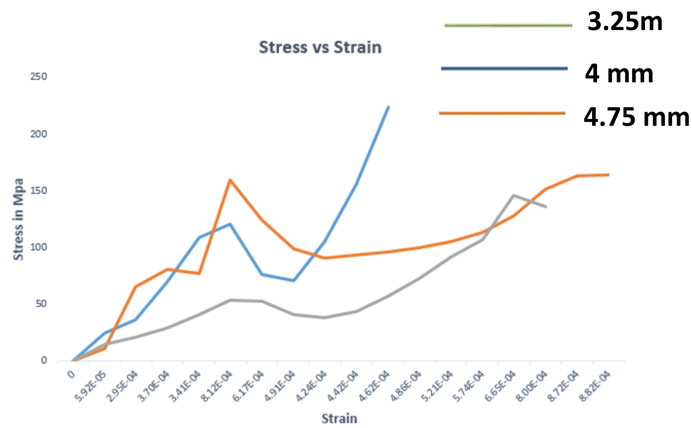


Fig .9. Stress-Strain graphs plotted for the values obtained after simulating for compression of 100N load for 4mm, 4.75mm and 3.25mm diameter of circle respectively.

From the graphs plotted we can get the inference of which model could withstand more stress when subjected to compression load. When 50N load is applied, the actual model (diameter 4mm) can withstand a stress of 84.531Mpa, the modified model (diameter 4.75mm) can withstand 114.41Mpa, and the other variant (diameter 3.75mm) can withstand 58.316Mpa. Similarly, when 75N load applied the actual model (diameter 4mm) can withstand a stress of 75.701Mpa, the modified model (diameter 4.75mm) can withstand 134.31Mpa, and the other variant (diameter 3.75mm) can withstand 116.07Mpa. In the same way when 100N load applied the actual model (diameter 4mm) can withstand a stress of 120.57Mpa, the modified model (diameter 4.75mm) can withstand 159.65Mpa, the other variant (diameter 3.75mm) can withstand 53.762Mpa. Therefore, by comparing all three models the modified model (diameter 4.75mm) could withstand more stress when compared to other two models.

4. CONCLUSION

The hybrid model was designed and the variants are derived from varying dimensions of their circle diameter to either extremes by 18.75% respectively. Then these three models were simulated using ansys software, by taking the material properties of Inconel 718 material the simulation were carried out for compression test by applying various loads of 50N, 75N and 100N for each model. The test results were obtained in the form of deformation, stress and strain. Then using these values the stress-strain graphs were plot and the results were compared. Therefore, when compared the modified model (diameter 4.75mm) showed the greater stress withstanding capability than other two models.

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