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Effective Elastic Modulus of Regular Hexagon Hierarchical Honeycomb Structure

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Abstract- cellular solids such as foams are widely used in engineering application due to their superior mechanical behavior and light weight high strength characteristic .therefore it is important to understand the mechanical properties and the variation of these properties with the presence of hierarchy the investigation of effective elastic modulus builds upon prior work and investigated for regular hexagon hierarchy and result validate by FEA in this work hierarchy is consider by replacing every three edge vertex of a regular hexagon with smaller regular hexagon. This gives a hierarchy of 1st order and repeating this process with 1st order hierarchy gives 2nd order hierarchy. Our result shows that effective elastic modulus of 1st and 2nd order hierarchy can be up to 2 and 3.5 times of regular hexagonal honeycomb with the same relative density.

Keywords- effective elastic modulus, hierarchical, FEA, regular hexagon, honeycomb.

1. INTRODUCTION

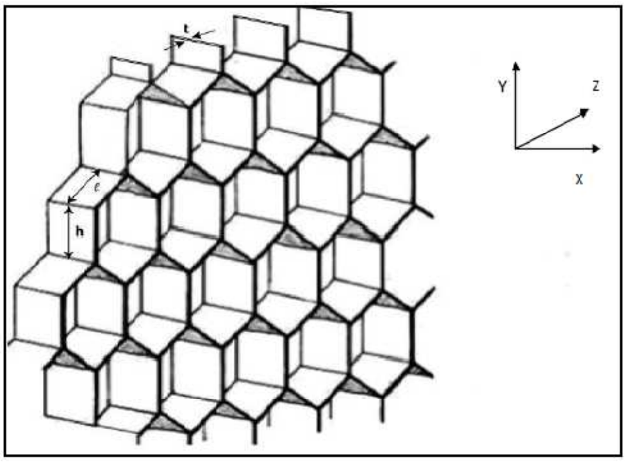
Cellular structure is constituted by the solid struts that are interconnected. The thickness of the cell walls is found by the value of the relative density [1]. The high value of relative density greater the thickness of the cell wall this leads to cellular structure to have smaller pore spaces .when the relative density is more than 30% , the solid is no longer count in cellular structure, but rather solid containing isolated pores[2]. These properties are measured in same way as those used for fully dense solid .the low density feature of cellular structure the design of light stiff components for instance sandwich panels. Cellular structure also known for thermal insulators [3,4].

The utilization of cellular structure in packaging has some other advantage in that the low relative density makes the packaging weight less than different solid .this show lowers the manufacturing, handling and transportation cost[5].

There are natural or man- made materials that show structure in more than one length scale. The concept behind the structural hierarchy developed from different field, especially structure biology and polymer science [6]. The hierarchical cellular structure is known to be large contributors in identifying the bulk mechanical properties. The main objective of introducing hierarchy to the cellular structure is to further to enhance the property of the structure without compromising the elastic property of material. Hierarchical structure circumventing us everywhere in nature and can be viewed in several biological systems and organic materials [7]The mechanical behavior of this structure is generally governed by the replication at different length scales and level of hierarchy [8]. Different types of hierarchical cellular structure have been studied Taylor and Smith explored their work on effects of hierarchy on the elastic properties of honeycomb in-plane [9]. The mechanical properties of 2 D hierarchical cellular structure made up on sandwich walls have also been proven by Fan et al. [10], Polymeric and glass foams are mainly used for thermal insulators and as the insulators of booster rockets of space shuttles, modern building, refrigerated trucks, railway cars and even ships all advantage from the low thermal conductivity of cellular structures.

2. METHODOLOGY

The most general three-dimensional honeycomb structure is shown in fig.1 In the direction of X-Y plane (in-plane) strength and stiffness of the honeycomb are the lowest for the reason that stresses in this plane make the cell walls bend. And another side the out plane direction, i.e. Z plane stiffness is higher since they require the compression or axial extension of the cell walls[3].



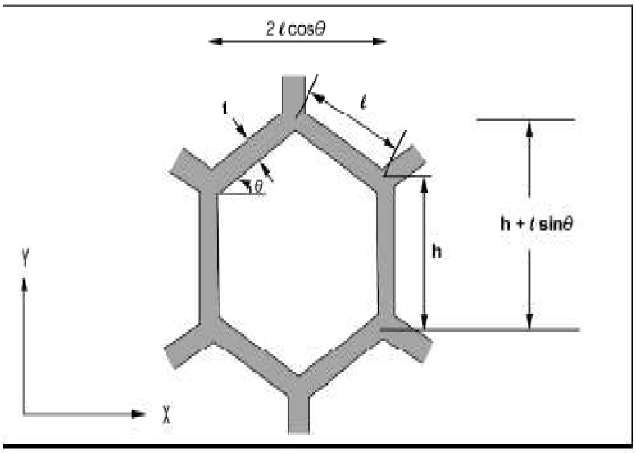


Fig.1: three dimensional hexagonal honeycomb structure [2]

Fig.2: Undeformed single unit cell [3]

The most significant characteristic of a cellular structure is its relative density ρ^m/ρ_s, where ρ^m the density of the cellular is structure, and ρ_s is the density of the solid from which the cells are made for geometry analysis mass distribution is same for solid and cell. From the fig.2 relative density of the irregular hexagon structure is

$$\frac{\rho^m}{\rho^s} = \frac{t}{l}.\frac{(\frac{h}{l}+2)}{2cos\theta(\frac{h}{l}+sin\theta)} \quad (1)$$

When the cells are regular hexagons, then θ=30^0 and h=l=a, the relative density reduce in form of

$$\frac{\rho^m}{\rho^s} = \frac{2t}{\sqrt{3}l} \quad (2)$$

Same as the relative density of the first order regular hexagon hierarchical (fig.3) structure

$$\frac{\rho^m}{\rho^s} = \frac{2t}{\sqrt{3}a}(1 + 2.\alpha_1) \quad (3)$$

Where $\alpha_1 = \frac{b}{a}$

Therefore the range of values for the 1st order hierarchy is $0 \leq b \leq a/2$, and thus $0 \leq \alpha_1 \leq 0$.

For Regular 2nd order hierarchy (fig.4)

$$\frac{\rho^m}{\rho^s} = \frac{2}{\sqrt{3}}\frac{t}{a}(1 + 2.\alpha_1 + 6.\alpha_2) \qquad (4)$$

Where $\alpha_2 = \frac{c}{a}$

There is two limitations: $0 \le c \le b$ and $c \le a/2\text{-}b$

Linear elastic deformation:- From Hooke's law, the effective elastic modulus parallel to the Y direction is $E_2 = \sigma_2 / \epsilon_2$, giving [2]:

$$\frac{E2}{Es} = \left(\frac{t}{l}\right)^3 \frac{\left(\frac{h}{l}+\sin\theta\right)}{cos^3\theta}$$

(5)

R.oftadeh et.al derived a equation for defining effective elastic modulus of anisotropic hierarchical structure [11].

We use here only regular hierarchical structure and we get Effective elastic modulus of first order hierarchical structure can be evaluated from following equation for the case of regular hexagon

$$\frac{E_1}{E_S} = \left(\frac{t}{a}\right)^3 f(\alpha_1)$$

(6)

Where

$$f(\alpha_1) = \frac{\sqrt{3}}{(0.75 - 3.525\alpha_1 + 3.6\alpha_1{}^2 + 2.9\alpha_1{}^3)}$$

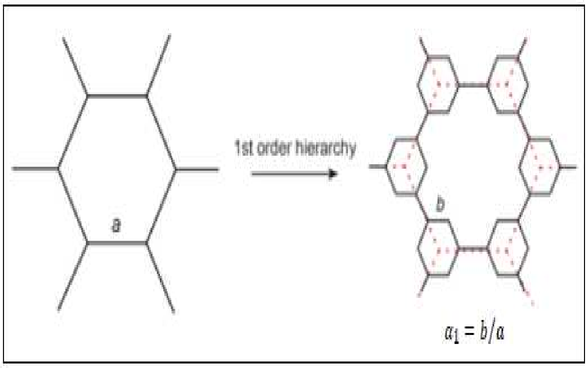
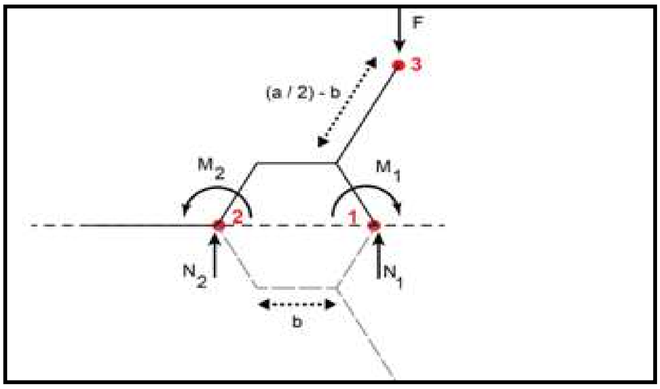


Fig.5: free body diagram of 1st order

Maximize the equation (6) with respect to α_1 for fix relative density of 1st order hierarchical structure we get $\alpha_1 = 0.3$,using this value with equation (6) and (3) which results



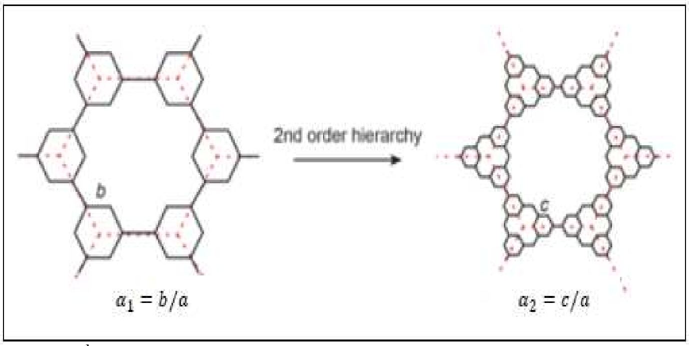


Fig.4 2nd order hierarchical structure

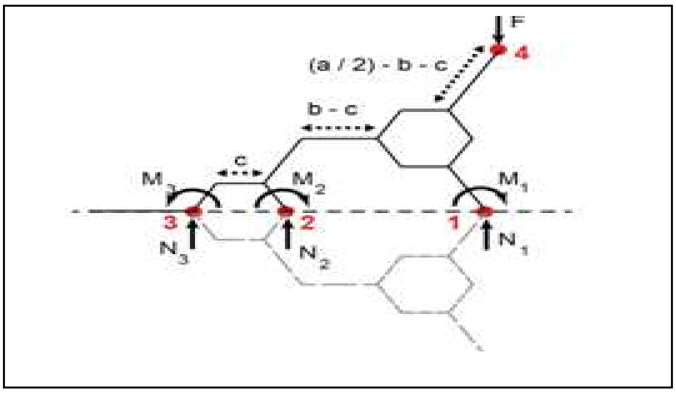


Fig.6: free body diagram of 2nd order

Effective elastic modulus of the structure is the function of relative density in the form of equation (7)

$$E_1/E_S = 2.97\rho^3$$

(7)

Effective elastic modulus of the regular hexagon honeycomb without hierarchy is

$$E_0/E_S = 1.5\rho^3 \qquad (8)$$

Where E_0 is the effective elastic modulus of the regular hexagon honeycomb (isotropic) structure which is same for X and Y direction.
Effective elastic modulus of 2nd order hierarchical structure can be evaluated from following equation for the case of regular hexagon

$$\frac{E}{E_s} = \left(\frac{t}{a}\right)^3 f(\alpha_1, \alpha_2) \qquad (9)$$

Maximize the equation (9) we get the value of we get α_1 =0.3, and α_2=0.1, putting this in equation (9) & (4) which result effective elastic modulus of the 2nd order hierarchy is the function of relative density in form of equation (10)

$$\frac{E}{E_S} = 5.26\,\rho^3 \qquad (10)$$

From equation (7), (8) & (10) conclude that the effective elastic modulus of the2nd order hierarchy is 1.5 times higher than the first order and 3.5 times higher than the regular hexagonal honeycomb structure without any order of hierarchy.

3.Result

1st and 2nd order hierarchical honeycomb structure has been modeled by using CATIA V5, with the different value of α_1 and α_2 respectively. The model was created by using 1mm dimension in depth (out plane) and the thickness of the cell wall is calculated from the equation (3) and (4) by fixing the relative density and side length(4cm)of single unit cell which is in this present work is 8%. In addition at the top and bottom

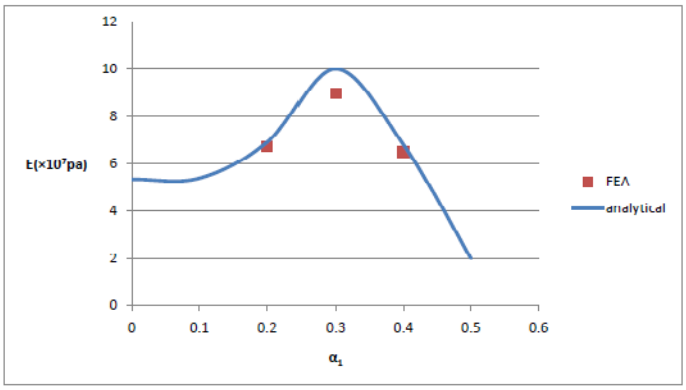


Fig.7 graph between effective elastic modulus v/s length ratio for analytical and FEA result for 1st order hierarchical structure

Attach a sheet of the same thickness as the cell for uniform displacement.

To calculate the effective elastic modulus the first and second-order hierarchical honeycomb structure displacement was applied in the Y- direction by applying on the top face and bottom face was fixed from avoiding the movement in X and Y direction, at same from rotation. Displacement was applied 0.2 % of densification strain. For analytical and FEA simulation aluminum alloy is used which is also available in ANSYS14.5 which contains following property (table 1).

Table 1 material property

density	2770 kg/m^3
Young modulus	7.1×10^{10} Pa
Compressive yield strength	2.8×10^{10} Pa
Poisson' ratio	0.33

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Analytical and FEA result (fig.7) shows that when length ratio increasing the effective elastic modulus of first

order is maximum for 0.3 length ratio, and for same relative density effective modulus of 1st order hierarchical structure is

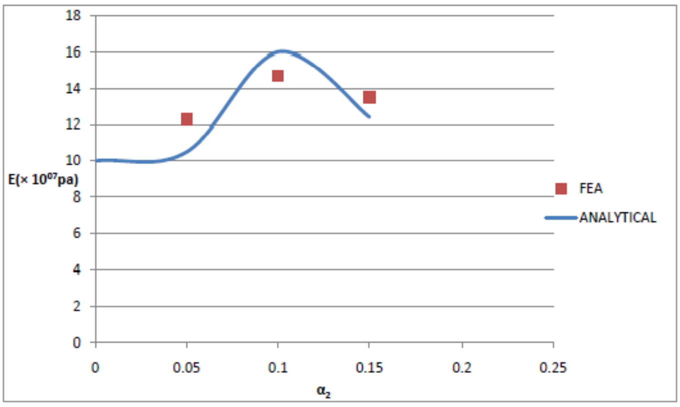

Fig.8 graph between effective elastic modulus v/s length ratio for analytical and FEA result for 2nd order hierarchical structure nearly two times of regular hexagon honeycomb structure without hierarchy.Incresing the length ratio after 0.3 effective elastic modulus of the 1st order hierarchy is decreases. Same as for 2nd order hierarchical structure Analytical and FEA result (fig.8) shows that at $\boldsymbol{\alpha_1=0.3}$ for 2nd order length ratio the maximum effective elastic modulus is at 0.10 and for the same relative density effective elastic modulus of the 2nd order hierarchical structure is nearly 1.5 times of 1st order hierarchy and 3.5 times of regular hexagon structure without any hierarchy ,length ratio for 2nd order hierarchy is decrees after 0.1length ratio of 2nd order hierarchical structure.

4. CONCLUSIONS

The main purpose of introducing hierarchy to cellular structures is to further enhance the mechanical behavior of the structures without compromising the elastic Properties of the material. From previous research, it has been proved that increasing the Levels of hierarchy in cellular structures produces better performing structures that are lighter in weight. The effective elastic modulus of the cellular structure is controlled by the thickness of the cell.

In this work the effective elastic modulus for regular hierarchical structure is done by fixing the relative density which is 8% and their behavior validates with FEA result , model of different structure is prepared using CATIA V5 and FEA is done through ANSYS 14.5 .after investigation we find the analytically maximum effective elastic modulus of 1st order regular hierarchical structure is maximum at 0.3 length ratio, and for 2nd order maximum effective elastic modulus is at the 0.1 length ratio for second order both result validate by FEA result.

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