A Review Paper on Mechanical Behavior and Engineering Applications of Cellular Structures

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Abstract - *Cellular solids are used widely in a variety of engineering applications, in particular, honeycomb cell structures are very prevalent. The continuing desire for stronger, light weight structural materials for use in aerospace and aircraft applications has made these industries the traditional leaders in the development of honeycomb structures for technological use. Auxetic structures are those who exhibit negative poisson's ratio (NPR) effect. These materials extend laterally when stretched longitudinally and contract laterally when compressed longitudinally. Auxetic structures are scale independent i.e. they exhibit NPR effect at macroscopic level as well as at molecular level. NPR materials are popular due to their unconventional material behavior. They are mainly popular for their indentation resistant property and high strain energy absorption capacity. The aim of this paper is to study the research done on auxetic structures in terms of their mechanical properties and in terms of their engineering applications, also various important conclusions are drawn out of each paper discussed below*

***Key Words*: Auxetic Structures, Cellular Solids, Honeycomb structures, Indentation resistant, Negative Poisson's ratio, material behavior**

1. INTRODUCTION

Resource consumption in the world is rising rapidly along with population growth and their needs. Reports suggest the consumption of resources is to grow five times in the next thirty years but question remains whether earth can provide these resources continuously at an escalating level. One way of achieving better efficiency in resources is by "de-materialisation" meaning reduction in the amount of energy and materials required for various engineering applications without compromising on their performance levels. The aforementioned policy has led engineers across the world to change their thought process, they are now more focused on using the material resources smartly and efficiently i.e. to get maximum output from minimum input so to speak.

The cellular structures are known for using optimum material to serve their purpose and so these are one of the most valued structural engineering concept used by engineers now-a-days. The popularity of these structures are due to their unconventional properties such as less material per unit volume, low weight, high strength, durability which is discussed in the paper.

2. LITERATURE REVIEW

Yanping Liu et al. [1] studied various geometrical structures and models, particular properties through which one can obtain negative poisson's ratio behavior. He found out that if auxetic structures are built at a molecular level then it is expected to enhance various mechanical properties such as high modulus, high strength etc. He also predicted that this scale-independent structures can be used in many other fields such as textiles to design auxetic fabrics.

Li Yang et al. [2] established an analytical model of a 3D re-entrant honeycomb auxetic cellular structure in which he obtained mechanical properties such as Modulus, Poisson's ratio, yield strength which were based on base material used and geometrical parameters only. He proposed that by changing only the geometrical parameters the material properties could be changed. He compared the analytical results with FEA and experimentations and verified the same. He also concluded that by incorporating complexities such as higher - order coupling effects like warp locking gives less accurate analytical results.

T. Mukhopadhyay et al. [3] developed an analytical solution for predicting the equivalent in-plane elastic moduli (longitudinal and transverse Young's modulus, shear modulus, Poisson's ratio) of irregular auxetic honeycombs with spatially random variations in cell angles. He also developed a finite element code which could accept number of cells in two perpendicular directions, random structural geometry and material properties of irregular auxetic honeycomb and thereby obtaining five in-plane elastic moduli of the structure. The results of finite element simulations and the analytical approach are found to be in good agreement. He also found out that though the effect of spatially random variations in cell angle on E_1 and ν_{12} is negligible E_2, ν_{21} and G_{12} reduce significantly with the increase in degree of random variation of the cell angles. Thus the auxetic property of honeycomb reduces considerably for ν_{21} with the increase in degree of structural irregularity.

Aniket Ingrole et al. [4] did a comparative study of in-plane uniaxial compression loading behavior of regular honeycomb, re-entrant auxetic honeycomb, locally reinforced auxetic-strut structure and a hybrid structure of combining regular honeycomb and auxetic-strut structure was conducted on 3D printed samples. The deformation and failure modes of the different cells were studied and it was found that the new auxetic-strut structure showed better mechanical properties than the regular honeycomb and auxetic structure. It was also confirmed that the new hybrid structure could absorb high impact energy.

Hu et al. [5] studied the effect of cell wall angle on the in-plane impact behavior of hexagonal honeycombs. Here they have kept the density of the honeycomb as constant but they have varied cell wall angles and observed crushing strength of the structure by impacting them with different impact velocities of the ballistic objects. The important conclusion was that the crushing strength of honeycombs is enhanced with increasing impact velocities for both x directional impact and y directional impact. The crushing strength ratio of y directional impact to x directional impact is sensitive to cell wall angle at lower impact velocities, while it approaches 1 for various cell wall angle at high impact velocities.

F Cote et al.[6] manufactured stainless steel square honeycombs and studied their out-of-plane compressive response as a function of the relative density, the ratio of specimen height to cell size , and the degree of constraint associated with bonding of the honeycomb to face-sheets. They concluded that for relative densities less than 20%; the compressive strength is insensitive to the ratio of the specimen height to cell size and to the presence or absence of bonding to face-sheets.

Chulho Yang et al. [7] with their knowledge in auxetic structures, designed different possible 3D CAD models of auxetic structures such as re-entrant hexagonal cells and arrowheads and used additive manufacturing technique (3D printing) to build prototypes. They conducted impact analysis test on the prototypes through dynamic simulations of FEA models. The 3D printed prototypes were then tested and the results were compared to the FEA results. The results showed that the auxetic material could be effective in reducing the shock forces. Each structure and material combination demonstrated unique structural properties such as stiffness, Poisson's ratio, and efficiency in shock absorption. They concluded that the auxetic structures showed better shock absorption performance than non-auxetic ones.

Chang Qi et al. [8] studied the dynamic behaviour of honeycomb sandwich panels (HSP) subjected to in-plane projectile impact by means of explicit nonlinear finite element simulations using LS-DYNA. Three different honeycomb cores were incorporated in the sandwich panels such as rectangular honeycomb, hexagonal honeycomb and re-entrant auxetic honeycomb. The ballistic resistances of HSPs with the three core configurations were first analysed. They concluded that the re-entrant auxetic honeycomb had the best ballistic resistance due to the negative poisson's ratio behaviour. They also performed parametric study to understand the influences of both macroscopic (face-sheet and core thicknesses, core relative density) and mesoscopic (unit cell angle and size) parameters on the ballistic responses of the auxetic HSPs. They concluded that the ballistic resistant ability of the HSPs increase with increase in the macroscopic parameters. They also observed that mesoscopic parameters show nonmonotonous effects on the panels' ballistic capacities. They also found out that the blunter projectiles results in higher ballistic resistance capacity of the HSPs. Another important conclusion was the type of honeycomb core did not matter when the impact velocity of the projectile exceeded the ballistic limits of honeycomb cores.

Zhengyue Wang et al. [9] this paper reviews the latest achievements in auxetic materials, including their properties, structures and applications. They have discussed various possible textile fabric applications. They have also suggested application in medical field such as “smart band-aid” and “smart bandages” in which the area of the wound when swells, the negative poisson’s ratio effect of the band-aid plays a role by secreting liquid gel(liquid gel which is pre-accumulated in the cellular structure of the fabric) on the wound. They also suggested safety belts of cars with high-performance auxetic fabrics to decrease the concentration of impact pressure due to increased contact area with the human body. Also auxetic fabrics for obese people can be a boon as when the belly grows, the auxetic fabric becomes wider in both the waist direction and direction perpendicular to it. In this case, the belly does not have to bear too much pressure as the auxetic fabric can naturally form a dome shape, which perfectly fits the belly shape.

D. Prall et al. [10] developed 2D geometric cellular model which consist of circular node and ligaments which are joined tangentially to the nodes, thus naming the structure as “chiral” structure. They then studied in-plane mechanical properties of this structure namely E1,E2, ν12, ν21 and they confirmed from the properties that the chiral structure is isotropic(two dimensional isotropic with negative poisson’s ratio) since $E_1=E_2$ and $\nu_{12}= \nu_{21}$. They also showed that the honeycomb exhibits a Poisson's ratio of -1 for deformations in-plane. This Poisson's ratio is maintained over a significant range of strains.

Petr Koudelka et al. [11] produced three types of auxetic structures by 3d printing them. These were namely 2D missing-rib cut, 2D re-entrant auxetic, 3D re-entrant auxetic structure prepared from acrylic material suitable for high-resolution direct printing. The samples were subjected to in-plane quasi-static compression, from which stress-strain relations were established. For a proper strain evaluation, they applied digital image correlation to measure full field displacement on the sample surfaces. They also conducted an FEA analysis of these three structures and compared the results obtained experimentally with the ones obtained through FEA. The results were within 20% of uncertainity and hence they concluded that such FE models can be successfully used in material engineering to design highly optimised structures for a given range of strain rates, with maximized strain-deformation energy.

3. CONCLUSIONS

Rapid advance in additive manufacturing techniques is a harbinger that the fabrication of functional cellular structures will be achieved with desired cellular microstructures tailored to specific application in mind. So it is necessary to develop a detailed understanding of the relationship between mechanical response and cellular microstructure.

1)In-plane and Out-plane Compressive, Tensile, response of various 2D, 3D topologies such as regular hexagonal honeycomb, re-entrant auxetic honeycomb, chiral structure honeycomb, missing-rib cut honeycomb were investigated and according to their cellular structures different mechanical properties were observed.
2)Also in-plane impact energy absorbing capacity of honeycomb structures(non-auxetic and auxetic) were investigated and was found out that auxetic structures show more energy absorbing capacity than regular hexagonal honeycomb structures.
3)Various applications of cellular structures were discussed by the authors and some were really interesting and innovative. The idea of using auxetic fabric clothing for plus size person was mind boggling. Smart band-aid was another interesting application of auxetic structures. Auxetic fabrics with increased air permeability under extension can be used for summer wear and functional sportswear.
I personally feel that an idea in hand is worth ten ideas in head. Further advances in this section of structural engineering would be the production of cellular structures on a nanoscale and picoscale. This will bring more reliable and sophisticated results in their analysis. Further point I would like to see in the near future is the amount of biodegradable materials usage in the production of cellular structures as per the engineering application.

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BIOGRAPHIES

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