Free vibration analysis of sandwich panels including the effect of irregularity in honeycomb core

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Outline

Sandwich Panel

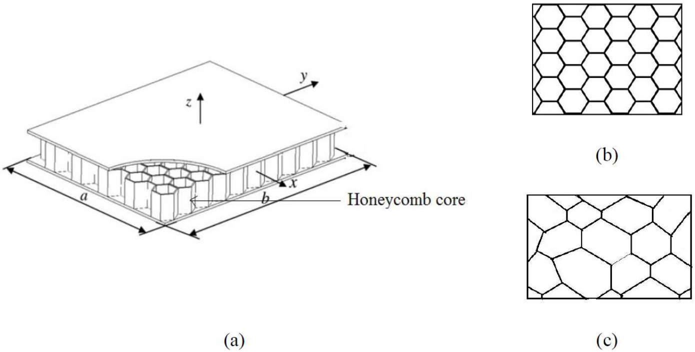
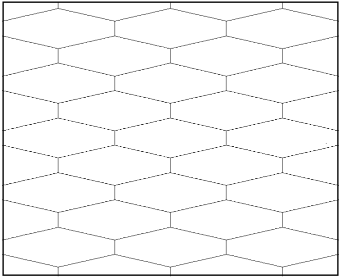
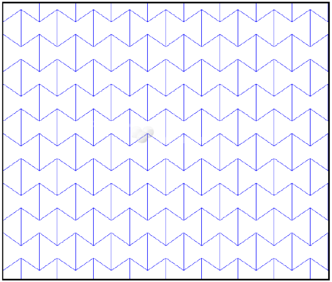


Figure: (a) Sandwich panel (b) Regular honeycomb (c) Irregular honeycomb.

Cellular solids/structures





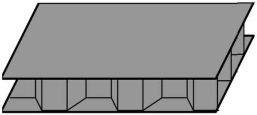
- Cellular structure: Cluster of cells
- Cell: An enclosed space/small compartment
- Interconnected network of solid struts/plates

Forms of irregularity

- Different forms of uncertainty associated with analysis, design and fabrication process of the structure: aleatoric, epistemic and prejudicial uncertainties.
- Spatial variation in structural geometry of honeycomb core
- Spatial variation in material property of honeycomb core
- Defects in the structure of of honeycomb core
- Uncertainty associated with the material and geometric property of face plates

Present study: Investigation of the effect of irregularity in honeycomb core for free vibration analysis of sandwich panel using a computationally efficient analytical framework.

Different forms of irregularity in honeycomb



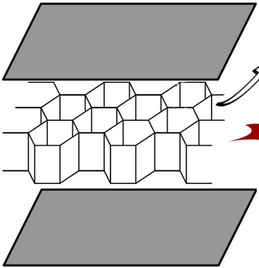


Fig. Sandwich panel

Fig. Imperfection in length of bond lines

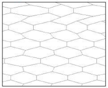


Fig. Randomly spaced over and under expanded cells

Different forms of irregularity in honeycomb

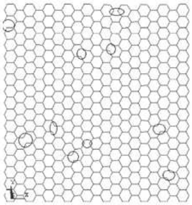


Fig. Randomly missing cell wall

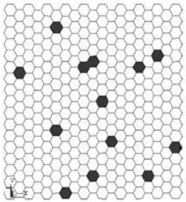


Fig. Random filled cell

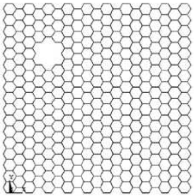
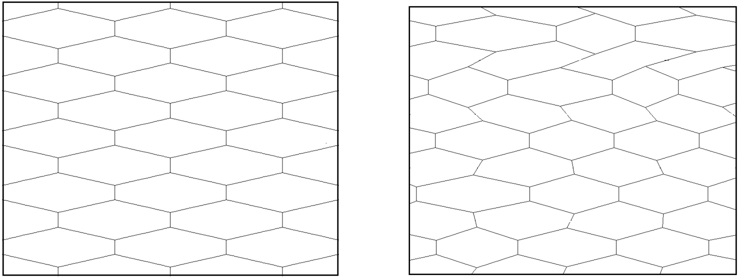


Fig. Missing cell cluster

Irregular honeycomb



- Random spatial irregularity in cell angle is considered in this study.

Whitney (1987)

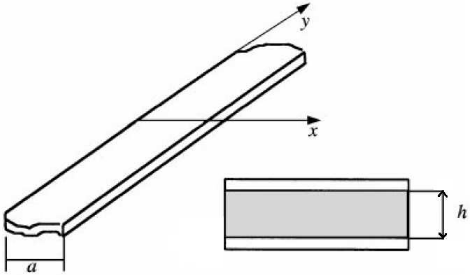
Whitney J. M. (1987) Structural Analysis of laminated Anisotropic Plates. Lancaster, PA: Technomic Publishing Company Inc.

Gibson and Ashby (1997)

Gibson L. J. and Ashby M. F. (1997) Cellular Solids: Structure and Properties. Oxford:Pergamon Press.

- Analytical formulae are available for natural frequency of sandwich panels in Whitney (1987).
- Literature are available for analysis of sandwich panels, wherein for evaluating the equivalent elastic properties of regular honeycomb core, formulae given by Gibson and Ashby (1997) have been utilized.
- Here we propose analytical formulae for elastic properties of irregular honeycomb. These formulae are then utilized to obtain natural frequency of sandwich panels with irregular honeycomb core in conjunction with Whitney (1987)'s approach

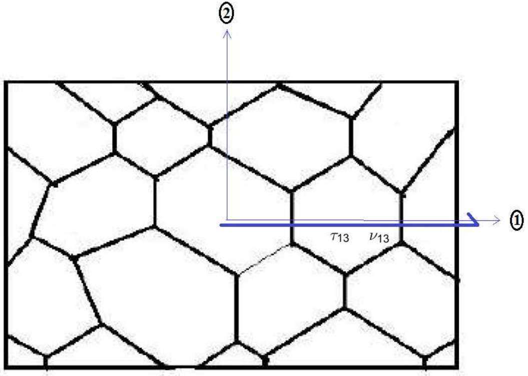
Formulae for natural frequency of sandwich panel having very high length-to-width ratio (Whitney (1987))



- For fundamental natural frequency: $\omega = \frac{\pi^2}{a^2}\sqrt{\frac{D}{\rho h}}\sqrt{1 - \frac{S\pi^2}{1 + S\pi^2}}$

  where, $S = \frac{D}{G_{13} h a^2}$ and D is the bending stiffness of laminate.
- Thus the fundamental natural frequency depends on G_{13} of the core.

Equivalent G_{13} for irregular honeycomb



- The derivation of G_{13} for irregular honeycomb is described as the out-of-plane shear modulus in the considered problem. However, G_{23} can be derived following similar analogy. Derivation of other out-of-plane shear moduli are straightforward following same way as discussed by Gibson and Ashby (1997) for regular honeycombs.

Minimum potential energy theorem (Gives upper bound of G_{13})

- The strain energy calculated from any postulated set of displacements which are compatible with the external boundary conditions and with themselves, will be a minimum for the exact displacement distribution:
  $\frac{1}{2} G_{13} \nu_{13}^2 V \leq \frac{1}{2} \sum_i G_s {\nu_i}^2 V_i$
  where, G_s is the shear modulus of cell wall material.
- $V (= LBh)$ and $V_i (= l_i th)$ represent the total volume and volume of i^{th} cell wall respectively.
- l_i, t and h are length of i^{th} cell wall, thickness of cell wall and depth of honeycomb core.
- ν_i and ν_{13} represent strain in i^{th} cell wall and global strain respectively. L and B denote overall length and width of entire irregular honeycomb:
  $\nu_i = \nu_{13} cos\theta_i$
  where, $cos\theta_i$ denote the inclination angle of i^{th} cell wall with direction-1.
- From the above equations,
  $\frac{G_{13}}{G_s} \leq \frac{t}{LB} \sum_i l_i cos^2\theta_i$

Minimum complementary energy theorem (Gives lower bound of G_{13})

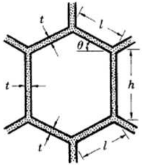
- Among the stress distributions that satisfy equilibrium at each point and are in equilibrium with the external loads, the strain energy is a minimum for the exact stress distribution.
- Expressed as an inequality, for shear in direction-1
  $\frac{1}{2}\frac{\tau_{13}^2}{G_{13}}V \leq \frac{1}{2}\sum_i \frac{\tau_i^2}{G_s}V_i$
- Using the condition of force equilibrium,
  $\tau_{13}LB = \sum_i \tau_i t l_i cos\theta_i$
- From the above two equations, it can be written:
  $\frac{G_{13}}{G_s} \geq \frac{t}{LB}\sum_i l_i cos^2\theta_i$

Expressions for lower and upper bound of G_{13} are noticed to be identical

- Thus considering the lower and upper bound of G_{13}, for irregular honeycomb

$$\frac{G_{13}}{G_s} = \frac{t}{LB} \sum_{i} l_i cos^2 \theta_i$$

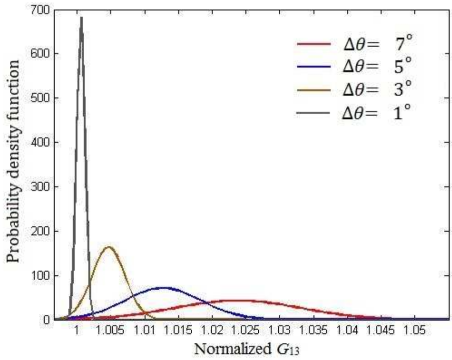
  - Note: The above expression can be reduced to the formula given by Gibson and Ashby (1997) in case of regular hexagonal honeycomb.



For a regular honeycomb as shown in figure:

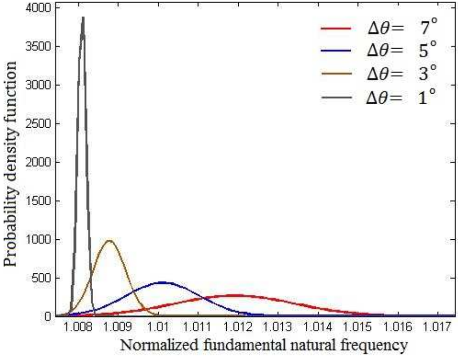
$$\frac{G_{13}}{G_s} = \frac{tcos\theta}{h + lsin\theta}$$

Variation of G_{13} with different degree of irregularity



- G_{13} for irregular honeycomb have been normalized with respect to that of regular honeycomb.

Variation of fundamental natural frequency for the sandwich panel with different degree of irregularity in honeycomb core



- Fundamental natural frequency for the sandwich panel with irregular honeycomb core have been normalized with respect to that of regular honeycomb core.

Conclusion and future research directions

- Derivation of out-of-plane shear modulus G_{13} for irregular honeycomb is discussed. Subsequently the effect of irregularity in honeycomb core for fundamental natural frequency of a sandwich panel is shown in an analytical framework.
- The mean value of out-of-plane shear modulus G_{13} is found to be increased upto 2.5 percent due to spacially random variation of cell angle to the extent of 7 degree. As a result the mean fundamental natural frequency is noticed to be increased upto 12 percent with respect to sandwich panel having regular honeycomb core.
- The formulae developed here can also be extended to predict equivalent out-of-plane elastic moduli of irregular honeycombs having spatial variation in material properties and thickness of cell wall.