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EFFECTIVE ELASTIC PROPERTIES OF HONEYCOMB SANDWICH MICROSTRUCTURE: THE EFFECT OF INCLUSION ARRANGEMENT

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ABSTRACT

This paper presents a homogenization analysis to obtain effective elastic properties of honeycomb sandwich microstructure considering the inclusion defect arrangement. 3D finite element models were developed using voxel-type element with variation of inclusion arrangement where one is regular and three are random arrangement. Aluminium was used as constituent material. Periodic boundary condition was applied to the unit cells in the homogenization analysis. The results suggest that the Young's moduli and Poisson's ratio of honeycomb sandwich microstructure are not sensitive to the inclusion arrangement between regular and random, but quite significant difference was found in shear moduli. Effective elastic properties were found higher for honeycomb with inclusion compared to the case without inclusion except for ν_{12}. This work provides a new insight into the arrangement factors in microstructure that contributes to the effective elastic properties.

Keywords: homogenization analysis, honeycomb microstructure, effective elastic properties.

INTRODUCTION

Sandwich panels are generally used because of their high strength-to-weigth and high strength-to-weight capability particularly in aerospace industry [1]. Sandwich panels are consists of a lightweight core and two thin sheets that covered both faces of a core. A core material can be made either by honeycomb or foam.

Honeycomb core is typically fabricated by repetitive stamping or stacking process. Due to inaccuracy in fabrication process, honeycomb core might be subjected to manufacture defects [2, 3]. Variation of defects in honeycomb core can be occurred in fabrication process such as delamination, inclusion, voids and porosity, debond and fiber breakage [3]. Several studies have been conducted to investigate the effect of honeycomb core defects on mechanical properties so far. Chen and Ozaki [4] studied on the effect of missing cell walls in a honeycomb structure on stress concentration. They found that the bending stress is greater than the tensile stress in the cell wall immediately at the defect tip. Wang *et al*. [5] also investigated the influence of missing or fractured cell walls on in-plane effective elastic stiffness and initial yield strength of square and triangular cell metal honeycombs using finite element analysis. The result indicates that the effective elastic stiffness and initial yield strength of triangular cell honeycombs are least sensitive to defects among those considered under compression load. The effect of minor geometrical defect in honeycomb cell walls on effective elastic properties also has been studied recently [6]. However, the effect of inclusion defect on the mechanical properties has not been investigated so far.

Therefore, this study was undertaken to analyse the effective elastic properties and mechanical response of honeycomb sandwich microstructure considering the defect of inclusion and its arrangement. Finite element method integrated with homogenization theory was employed to simulate the multiscale analysis in the present study.

MODELLING AND METHODS

Geometrical models

Three dimensional model of periodic honeycomb microstructure was developed using Catia V5R19 as shown in Figure-1 (a), whereas the dimension for one cell of honeycomb model is shown in Figure-1(b). Two types of inclusion arrangement were created which are regular and random. Figure-2 shows the unit cell for honeycomb with regular arrangement that hold the periodicity condition. Next, three additional random arrangement models were created as shown in Figure-3. These models were developed by assigning the identical number for each honeycomb cell and then, by employing the random permutation approach, the inclusion was created at the selected cell numbers. Each unit cell was developed with 5 mm thick.

Discretization of finite element with voxel-type was applied on all geometrical models using Voxelcon (Quint Corp., Tokyo). Element size of 0.4 mm was selected as optimum size after undergo the convergence test. Figure-4 shows some portion of honeycomb microstructure model after discretization.

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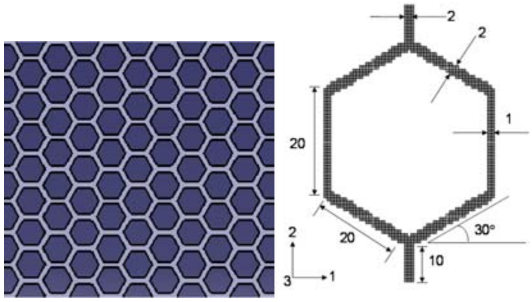


(a) Periodic microstructure (b) Dimension for one cell

Figure-1. Honeycomb microstructure (in mm).

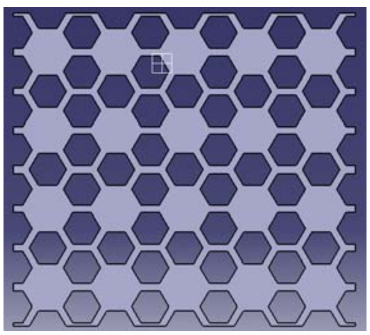
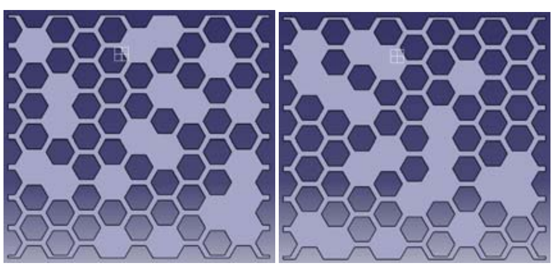
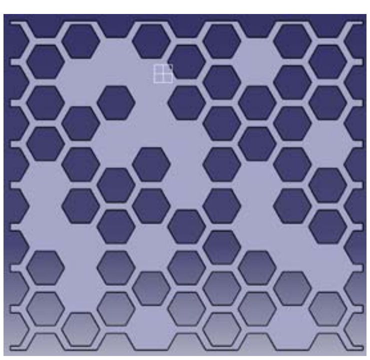


Figure-2. Unit cell of honeycomb with regular arrangement.



(a) Random 1 (b) Random 2



(c) Random 3

Figure-3. Unit cell of honeycomb with random arrangement.

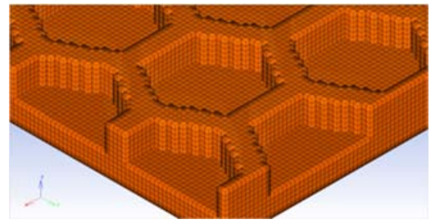


Figure-4. Discretization of honeycomb microstructure.

Homogenization method

Homogenization method [7, 8] was employed to calculate the effective properties of honeycomb microstructure. Since the homogenization method is quite established and has been used extensively [9, 10], only the outline of this theory is hightlited in this paper.

Equation (1) is analyzed for honecomb microstructure model with periodic boundary condition, where D is the elastic tensor.

$$\int_Y D_{ijmn} \frac{\partial \chi_m^{kl}}{\partial y_n} \frac{\partial \delta u_i^1}{\partial y_j} dY = \int_Y D_{ijkl} \frac{\partial \delta u_i^1}{\partial y_j} dY \quad \forall \delta u_i^1 \tag{1}$$

Here, χ is a periodic function with respect to the microstructure, known as the characteristic displacement to represents the microscopic perturbation of displacement due to the heterogeneity. Once the characteristic displacement is obtained, the macroscopic homogenized elastic tensor is computed using equation (2).

$$D_{ijkl}^H = \frac{1}{|Y|} \int_Y \left(D_{ijkl} - D_{ijmn} \frac{\partial \chi_m^{kl}}{\partial y_n} \right) dY \tag{2}$$

where D^H is homogenized (effective) elastic properties, Y is the region of the microstructure model and $|Y|$ is the volume of microstructure model. Then, equation (3) which is the macroscopic equation, coincides with the classical micromechanics theory is written as,

$$\int_\Omega D_{ijkl}^H \frac{\partial u_k^0}{\partial x_l} \frac{\partial \delta u_i^0}{\partial x_j} d\Omega = \int_\Gamma t_i \delta u_i^0 d\Gamma \quad \forall \delta u_i^0 \tag{3}$$

t denotes the traction applied on the surface Γ of domain Ω. Hence, macroscopic response such as displacement can be obtained based on equation (3).

Constituent material for the present honeycomb model was set as aluminium that having the Young's modulus, E of 69 GPa and Poisson's ratio, ν of 0.334.

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Macroscopic analysis

Then, the macroscopic response of honeycomb microstructure was analysed based on the effective elastic properties obtained in homogenization analysis for each model. Two types of simple macroscopic problem was analyzed which are (1) simple cantilevear beam and (2) simply-supported beam. In both cases, a force of 100 N was applied at the beam end with no support (1), and at the center of beam span (2). The effect of inclusion arrangement in honeycomb microstructure on macro-displacement in vertical axis was then investigated critically. The beam size was created with 9.4 m (L) × 1.7 m (W) × 0.3 m (H).

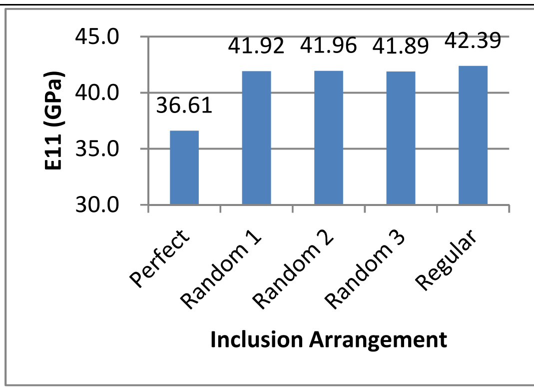
RESULTS AND DISCUSSIONS

Effective elastic properties

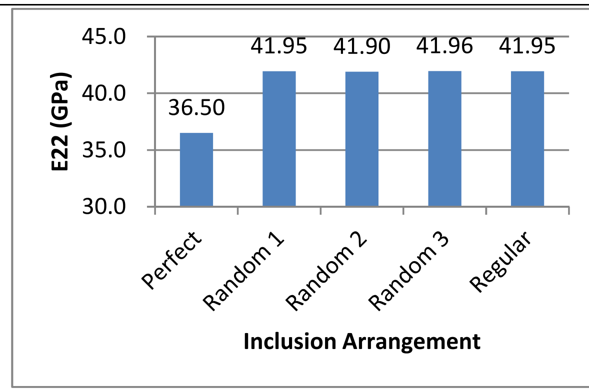
Figure-5(a-c) shows the effect of inclusion arrangement in honeycomb microstucture on the Young's modulus in axis-1, 2 and 3, respectively. The bar graph for 'Perfect' in this figure represents the honeycomb microstructure without inclusion defect. Obviously, inclusion defect in honeycomb microstructure increased the stiffness in all axes because the volume fraction was also increased. However, no significance different was found in the Young's moduli due to inclusion arrangement between regular and all random arrangements.

On the other hand, Figure-6(a-c) shows the influence of inclusion arrangement in honeycomb microstructure on the Poisson's ratio for axes-1, 2, 2, 3 and 3, 1, respectively. In contrary, Poisson's ratio in axes-1, 2, ν_{12} was found higher for honeycomb without inclusion compared to honeycomb with inclusion. But the kind of inclusion arrangements did not affect much on ν_{12}. Meanwhile, ν_{23} and ν_{31} were slightly lower for the case without inclusion compared to those which have inclusion. Similar to ν_{12}, ν_{23} and ν_{31} were also not sensitive to the inclusion arrangements. The average value for ν_{23} and ν_{31} were obtained at 0.2499 and 0.2303, respectively.

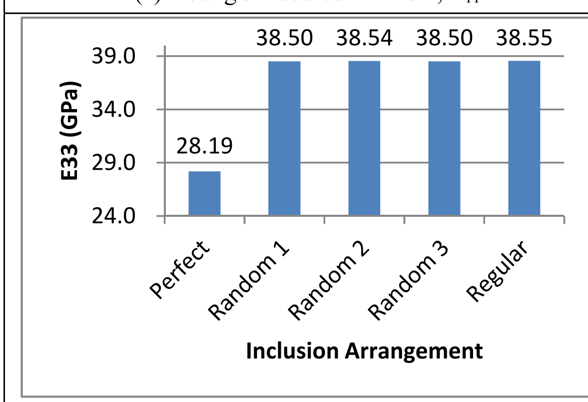
Furthermore, the effect of inclusion arrangement on the shear moduli of honeycomb microstructure is shown in Figure-7. Similarly, the shear moduli of honeycomb microstructure without inclusion defect was found lower



(a) Young's modulus in axis-1, E_{11}



(b) Young's modulus in axis-2, E_{22}



(c) Young's modulus in axis-3, E_{33}

Figure-5. Effect of inclusion arrangement on Young's moduli.

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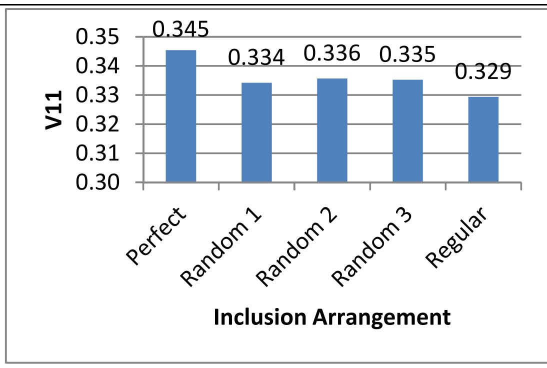
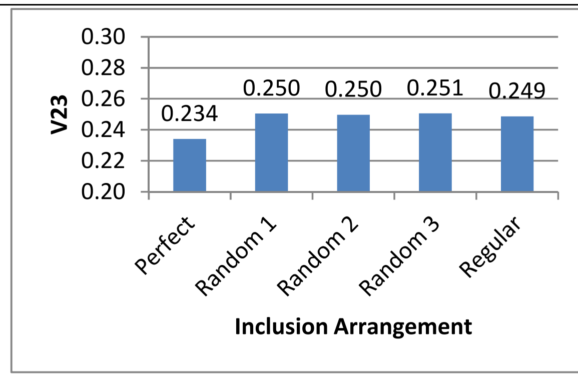
than the microstructure with inclusion. However, the bar graph shows that the shear moduli are quite sensitive to the arrangement of inclusion between regular and random. Shear moduli at G_{12} and G_{13} for honeycomb with regular arrangement were obtained slightly lower compared to that with random arrangement, whereas shear modulus at G_{31} was found quite higher for regular arrangement compared to the latter.

Macroscopic response

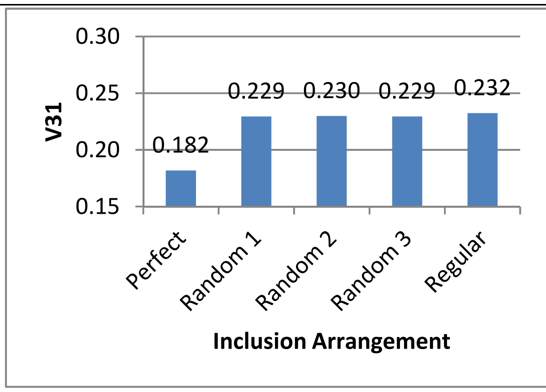
The effective elastic properties obtained in homogenization analysis were then used as nine elastic constants to develop the elasticity matrix of orthotropic material. Figure-8 shows the displacement for vertical axis in (a) contour and (b) along the beam span length under simple cantilever beam problem. Since the stiffness of honeycomb microstructure without inclusion was lower



(a) Poisson's ratio in axes-1, 2, ν_{12}



(b) Poisson's ratio in axes-2,3, ν_{23}



(c) Poisson's ratio in axes-3,1, ν_{31}

Figure-6. Effect of inclusion arrangement on Possion's ratio.

than that with inclusion, hence the displacement in vertical axis was found highest for the case without inclusion. Obviouly, the maximum displacement was at the bμeam end, where the load was applied, which is 7 μm as shown in Figure-8(b). Honeycomb structure with regular arrangement was slightly stiffer than that with random arrangement. Similarly, the same trend of macroscopic response was obtained for the case of simply-supported beam analysis. However, the maximum displacement in *z* axis for honeycomb microstructure without inclusion was lower compared to case (1), which is 0.45 μm.

CONCLUSIONS

This study presents about the influence of inclusion factor in the honeycomb microstructure on the effective elastic properties and macroscopic response. The existence of inclusion defect was found increased most of the

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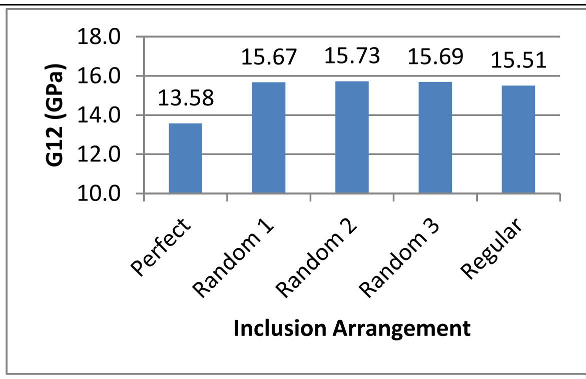
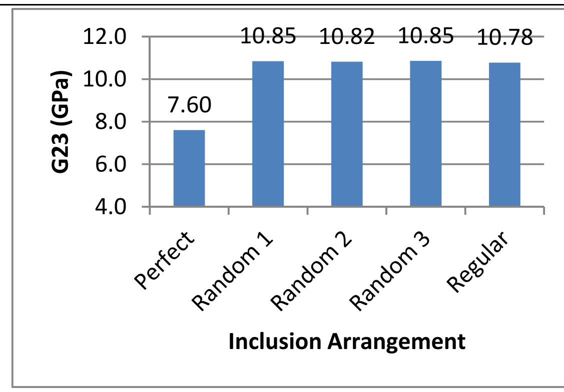
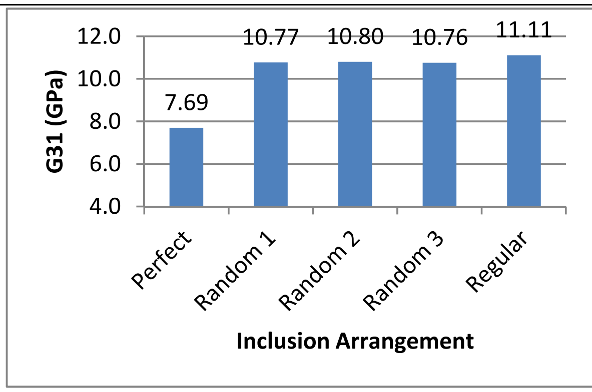


(a) Shear modulus in axes-1,2, G_{12}



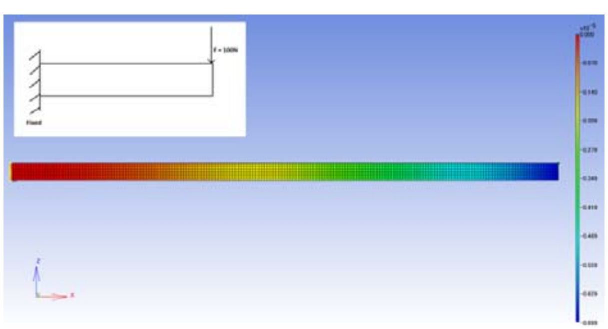
(b) Shear modulus in axes-2,3, G_{23}



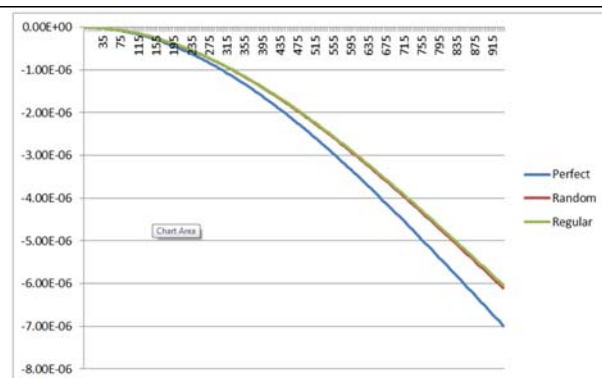
(c) Shear modulus in axes-3,1, G_{31}

Figure-7. Effect of inclusion arrangement on shear moduli.

effective elastic properties of honeycomb sandwich mcrostructure except for ν_{12}. However, types of inclusion arrangement either regular or random were not significant on the effective elastic properties, but quite sensitive to shear moduli. Macroscopic response of honeycomb sandwich beam was proportional to the effective elastic properties where the highest vertical displacement was obtained in the case without inclusion defect.



(a) Contour of z-displacement



(b) z-displacement along the beam span length

Figure-8. Z-displacement for cantilever beam analysis.

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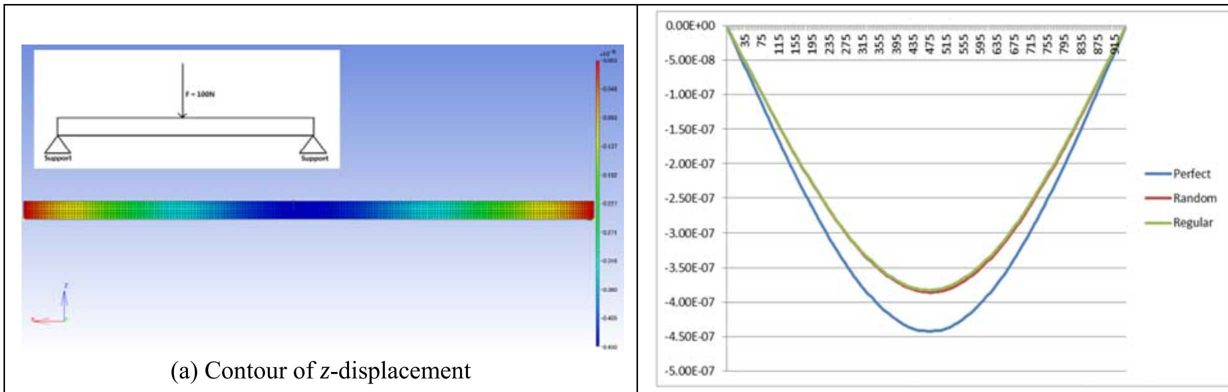

(a) Contour of z-displacement

(b) z-displacement along the beam span length

Figure-9. Z-displacement for simply supported beam analysis.

REFERENCES

[1] C.C. Foo, G.B. Chai, L.K. Seah. 2007. Mechanical properties of Nomex material and Nomex honeycomb structure. Composite Structures. 80, pp. 588-594.

[2] M. Balaskó, E. Sváb, G. Molnár, I. Veres. 2005. Classification of defects in honeycomb composite structure of helicopter rotor blades. Nuclear Instruments and Methods in Physics Research. 542, pp. 45-51.

[3] B. Keskes, Y. Menger, A. Abbadi, J. Gilgert, N. Bouaouadja, Z. Azari. 2007. A fatigue characterization of honeycomb sandwich panels with a defect. Materiali in Tehnologije. 41, pp. 157-161.

[4] D.H. Chen, S. Ozaki. 2009. Stress concentration due to defects in a honeycomb structure. Composite Structures. 89, pp. 52-59.

[5] A. Wang, D.L. McDowell. 2003. Effects of defects on in-plane properties of periodic metal honeycombs. International Journal of Mechanical Sciences. 45, pp. 1799-1813.

[6] K.S. Basaruddin. 2015. Stochastic Homogenized Properties for Honeycomb Microstructure Based On First Order Perturbation. Applied Mechanics and Materials. 695, pp. 516-520.

[7] J. Guedes, N. Kikuchi. 1990. Preprocessing and postprocessing for materials based on the homogenization method with adaptive finite element methods. Comput. Methods Appl. Mech. Eng. 83, pp. 143-198.

[8] S. J. Hollister, N. Kikuchi. 1994. Homogenization theory and digital imaging: a basis for studying the mechanics and design principles of bone tissue. Biotechnol. Bioeng. 43, pp. 586-596.

[9] N. Takano, M. Zako, F. Kubo, K. Kimura. 2003. Microstructure-based stress analysis and evaluation for porous ceramics by homogenization method with digital image-based modelling. Int. J. Solids Struct. 40(5): 1225-1242.

[10] T. Matsuda, S. Kanamaru, N. Yamamoto, and Y. Fukuda. 2011. A homogenization theory for elastic-viscoplastic materials with misaligned internal structures. Int. J. Plast. 27(12): 2056-2067.