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Effect of Reinforcement in Energy Absorption Characteristics of Honeycomb Structures Under Blast Loading

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Abstract

During recent decades demand for cellular structures has increased due to raised concern for protection of important buildings and components from blast loads. These types of cellular materials possess important features that includes less weight, higher energy absorption capabilities, higher strength to weight ratio in comparison with monolithic counterpart. Cellular material includes honeycomb, corrugated, web type structure, open and closed cell metal foam etc. However, in the present investigation, honeycomb sandwich panel are rein forced and are analysed for blast response mitigation. Further, obtained response of reinforced honeycomb structure is compared with the conventional honeycomb sandwich panel on the basis of mass. The Finite Element (FE) software LS-DYNA®, commonly used for dynamic explicit analysis, is used for numerical simulation and blast response investigation. Total three different reinforced configurations are developed and compared with conventional honeycomb i.e. honeycomb without any reinforcement. From FE analysis, it is noticed that reinforcing the honeycomb structure enhances the energy absorption capabilities significantly due to reinforcement which in turns increases the density of honeycombs.

Keywords: Reinforced Honeycomb, Blast, LS-DYNA, FE Simulation

1. Introduction

Honeycomb sandwich structure consists of a core of identical cells which fit into the spaces of one another in a precisely compact manner so as to fill a plane and is sandwiched between relatively thin metal face plates. Hexagonal honeycomb structure has found its application in various industrial fields like aerospace, manufacturing of transportation vehicles and high-speed trains, packaging materials, walls of cargo containers and even in some military utilities. This wide spread preference is attributed to their lightweight, high specific stiffness and an ability to absorb energy under impulsive loading such as blast [1-3]. The energy dissipation is mainly attributed to large plastic deformation of the sandwich element. The honeycomb structure is preliminarily used for resisting out of plane compressive impact loads since it has maximum load carrying capacity in this direction. With the addition of reinforcement, the relative density of the core structure increases. This increase in density results in significant increment in the crushing strength on these structures [4]. Honeycomb structures can also be used as sacrificial blast walls to protect important buildings and their components from blast loads. Sandwich structure can be used to reduce the damage level to the parent structure with the dispersion of transmitting impulse.

There exist several experimental and theoretical studies in which response of monolithic plate is compared with sandwich panel subjected to blast load. Dharmasena et al. performed explosive test to study mechanical properties of honeycomb sandwich panel and solid plate having equal areal density [5]. There exist several researches on the energy absorption characteristics of sandwich panel composites [6-10]. The core structure attenuates the velocity, thereby reducing the deflection at the back face of the sandwich composite [11]. Recently, researchers are keen to understand the effect of reinforcement in honeycomb structures so that they can be more effectively used as packing materials, automobile and aerospace components etc. [12-16]. Researchers are trying to explore various reinforcement patterns so that they can be effectively utilized as an alternative to traditional method of reducing the size of honeycomb cell or improving the material of core.

There exists certain literature in which performance of sandwich panel has been improved by stiffening the sandwich structure by providing various stiffener configurations.

Dynamic response of stiffened sandwich panel has been found to be significantly enhanced as compared to

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unstiffened sandwich configuration [17-19]. The improved structure showed better bearing strength as compared to conventional structure [12]. Wang et al. [20] investigated different types of reinforced honeycomb structures. To compare the mechanical behavior and energy absorption properties of reinforced honeycomb reinforcement patterns performed better in load carrying capacity and energy absorption capability. Mou et al. [12] experimentally analyzed the behavior of reinforced honeycomb paperboard to be used as a packing material. Based on the literature present on the response of honeycomb sandwich components, the numerical simulation has been performed to investigate the enhancement in strength of regular honeycomb structure by using reinforced configurations. Different geometric configurations have been used to reinforce the honeycomb sandwich panel.

2. Geometric Configuration of Honeycomb Sandwich Panel

Three different reinforced honeycomb structures have been considered in the present analysis to compare its response with conventional unreinforced honeycomb configuration (H_1) as shown in Fig. 1. First one is simplest configuration having horizontal rib in regular hexagon (H_2). Second configuration consist of general triangular type of (H_3) and the last type of configuration (H_4) is reinforced with circle in addition to configuration H_3 as shown in Fig. 1. The dimensions of general hexagonal are characterized as thickness of cell, t, l_0 is the length of unit cell and radius of inside circle $R_0 = l_0/2$. The overall size of the sandwich panel considered in this investigation is 250 mm × 250 mm × 25 mm. One fourth size of the panel has been modeled using symmetrical boundary conditions to reduce the simulation time of the FE analysis. Both face-sheet and back-sheet is of thickness 5 mm, whereas thickness of honeycomb core i.e. t is 0.3 mm. The detailed specifications of the unit cell under consideration are illustrated in Fig. 1 (c) Based on these configurations, comparative analysis has been done using LS-DYNA® to investigate enhancement in honeycomb sandwich structure with respect to conventional design so that these can be used for blast load mitigation.

Mechanical properties of the foil material used to model honeycomb sandwich panel are as follows; density of the foil is 2680 kg/m^3, Young's module 69.3 GPa, Poisson ratio 0.33, and yield stress as 215 MPa. The effect of strain rate has not been considered in the present case. The foil material used for the analysis was assumed to behave as an ideal elastic plastic constitutive model. To model elastic plastic with kinematic hardening material characteristics MAT_003 (MAT_PLASTIC_KINEMATIC) code of LS_DYNA® material library has been used.

3. Geometric Configuration of Honeycomb Sandwich Panel

Performance of all the configurations of the honeycomb sandwich panel has been numerically investigated in the present study. The BT4 (Belytschko-Tsay-4node) shell elements with 5 integration points through shell thickness

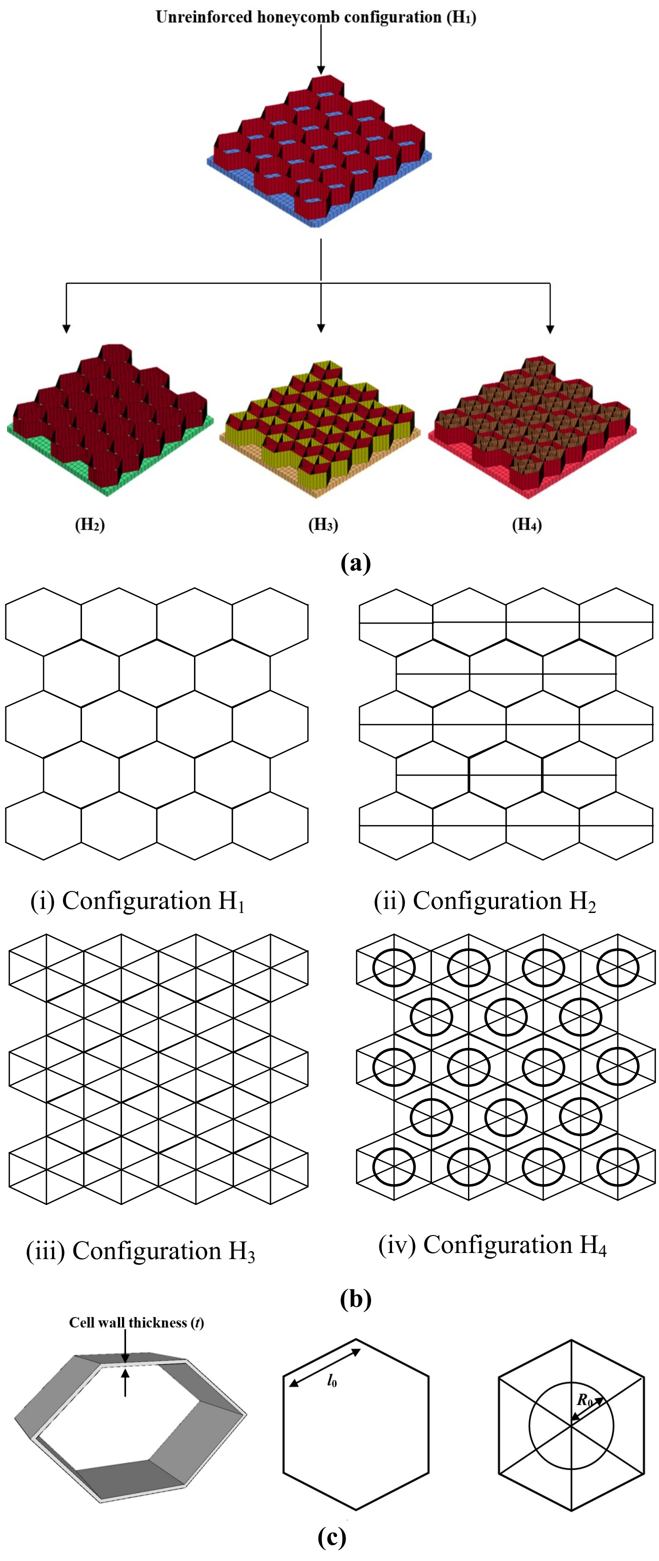

Fig. 1. Schematic of honeycomb structure with different inside cells (a) Isometric view; (b) Top view; (c) Detailed specifications of unit cell

has been used to model honeycomb cells, reinforcement, face and back-sheet of the sandwich panel using LS-DYNA®. Based on the mesh convergence study, the hexagonal honeycomb core is meshed with 30 layers along the width of the core and ten integration points along the thickness of the core. The face and back-sheet are discretized using 60 × 60 elements in the plate. To define the contact between honeycomb and plates tied nodes to surface is used that avoids penetration of cell walls. Symmetric boundary condition is implemented in this model with fixed boundaries at X = Y = L, whereas X-symmetry and Y-symmetry conditions are used at Y = 0 and X = 0, respectively.

The sandwich panel configurations have been subjected to blast load resulting from 1 kg TNT detonated at 500 mm standoff distance from the centre of the plate. To evaluate the effectiveness of different configurations, CONWEP loading scenario which is developed by U.S. Army has been used. This equation 1 is developed based on Kingery and Bulmash equations and the pressure obtained P(t) using this method depends on TNT weight, standoff distance, incidence angle θ. Where, P_i and P_r are incident and reflected pressures, respectively.

$$P_t = P_r \cos^2\theta + P_i\left(1+\cos^2\theta - 2\cos\theta\right) \quad (1)$$

The blast pressure time history resulting from 1 kg TNT in at 500 mm distance is represented in Figure 2. Impulse is the area under pressure time curve of air blast and is calculated using equation 2 as shown below:

$$i_s = \int_{t_a}^{t_a+t_0} P_s(t)dt \quad (2)$$

4. Validation of FE model

Deformation behaviour of sandwich plate has been investigated using LS-DYNA® to study the response of honeycomb sandwich plate subjected to CONWEP blast loading. To validate the blast model literature titled "Mechanical response of metallic honeycomb sandwich panel structures to high-intensity dynamic loading" authored by Dharmasena et al. [5] is referred.

For this validation, honeycomb sandwich plate of size 610 mm × 610 mm × 61 mm consisting square honeycomb core was considered as represented in Fig. 3. The honeycomb core has 0.76 mm thickness and 51 mm width with spacing between the core web of 30.5 mm. The size of both top and bottom plate was 610 mm × 610 mm × 5 mm. The TNT of weight 1 kg was placed 100 mm vertically above top plate in z-direction. For complete sandwich structure was made of high ductility stainless steel alloy material. Assuming symmetry of the solution one-quarter model of full plate was used for simulation.

The sandwich plate model has been analysed using LS-DYNA® software and the results were compared with the experimental results of Dharmasena et al. [5]. The central point deflection of the back face with respect to distance from centre of the plate obtained in numerical and experimental results of Dharmasena et al. [5] are presented in Fig. 4. It can be observed from the figure that results of numerical simulation and experimental results are comparable. Peak pressure from experimental and FE result are 366 and 365.34, respectively which are nearly equal with percentage variation of 0.18%. However, there exist small difference in displacement-time history with maximum percentage deviation of 0.66% and 2.3% for facesheet and backsheet respectively. Thus, it can be said that finite element model is validated and can be further used for analysis.

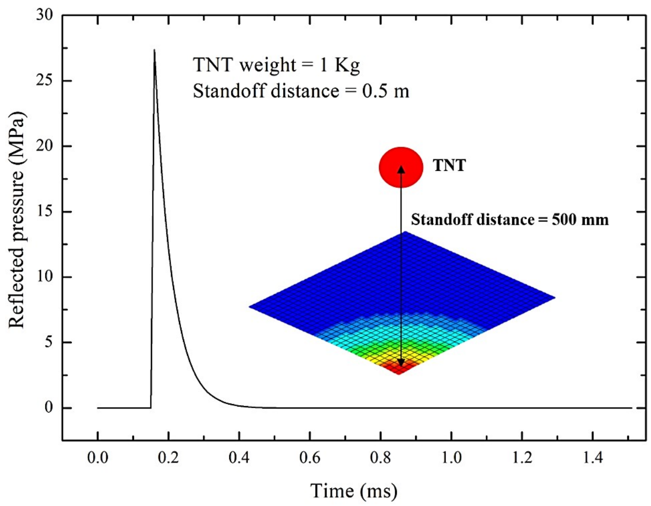

Fig. 2. Blast pressure time history of the present analysis models

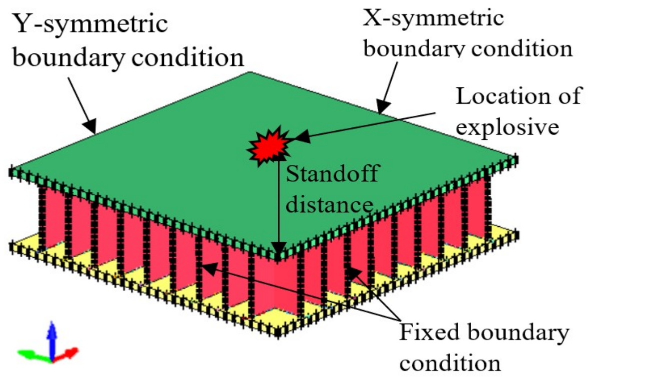

Fig. 3. One-fourth symmetrical FE model of the sandwich plate with explosive

5. Results and Discussions

Numerical analysis has been performed to compare the response and energy absorption capability of different reinforced geometrical configurations under impulsive loading such as blast. Fig. 5 shows reduction in central point displacement of reinforced honeycomb configurations as compared to regular hexagonal honeycomb. This indicates that with the use of different geometries of reinforced honeycomb configurations, blast resistance capability of sandwich panel enhances. The peak central point displacement is 13.8, 13.1, 11.02 and 9.89 mm for configurations H_1, H_2, H_3 and H_4, respectively. A reduction of 28% in central point displacement has been observed when H_4 configuration is compared to regular honeycomb configuration H_1.

Further, energy absorption study has been conducted to evaluate effect of reinforcement in honeycomb sandwich panels. The energy imparted on the sandwich panel is evaluated based on equation 2 is found to be 1480 Pa-s using area under pressure time curve shown in Fig. 2. To calculate energy absorbed by individual components (i.e. face-sheet, back-sheet and honeycomb) of different sandwich configurations, force displacement plots at each

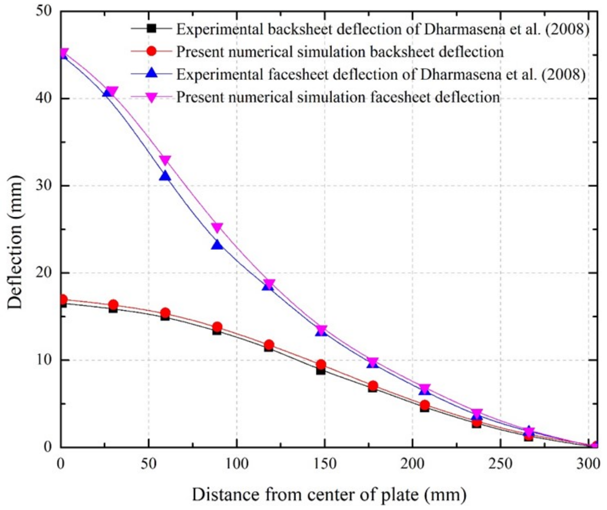

Fig. 4. Deflection-distance from center of facesheet and backsheet of honeycomb sandwich panel for 1 kg TNT.

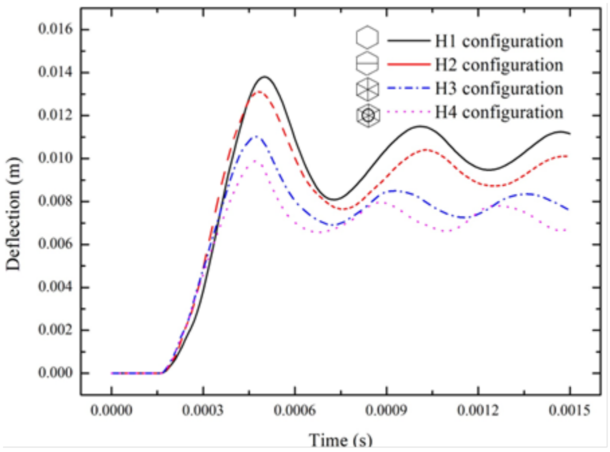

Fig. 5. Center point displacement time history of reinforced honeycomb configurations

interface of the sandwich panel as reported in Fig. 6-8 has been used. The results showing energy absorption for each configuration are represented in Table 1. It can be observed from Table 1, increase in energy absorption with provision of reinforcement. Configuration H_4 absorbs maximum energy amongst all the configurations under considerations.

It is also clear from Fig. 6-8 that with the use of reinforcement in configurations as shown in Fig. 1 (b), energy absorbed by these configurations is significantly increased from H_1 to H_4.

Table-1. Energy absorption of all the components of sandwich panel configurations

Configuration	Energy Absorption Top Plate (J)	Energy Absorption Core (J)	Energy Absorption Bottom Plate (J)	Total Energy Absorption (J)
H_1	506.69	360.5	355.1	1222.3
H_2	601.25	486.7	529.2	1617.15
H_3	689.8	560.3	548.2	1798.3
H_4	736.1	588.2	724.3	2048.6

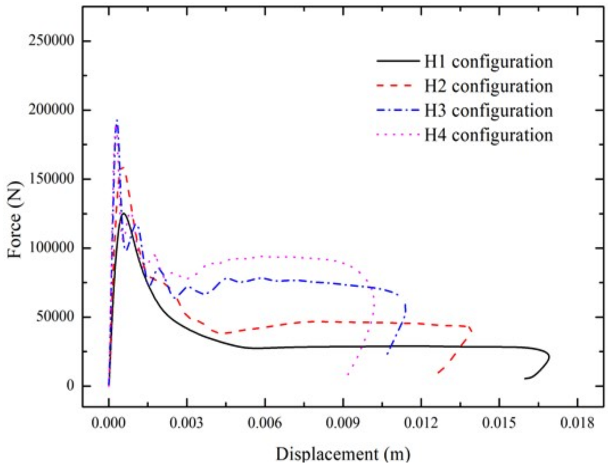

Fig. 6. Force-displacement curve for face-sheet of all the configurations of honeycomb sandwich panel

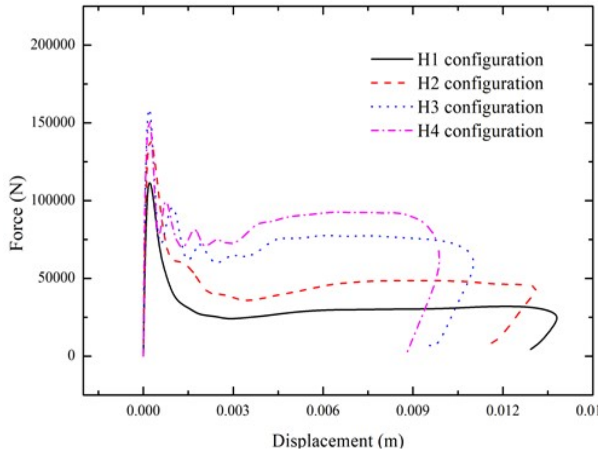

Fig. 7. Force-displacement curve for back-sheet of all the configurations of honeycomb sandwich panel

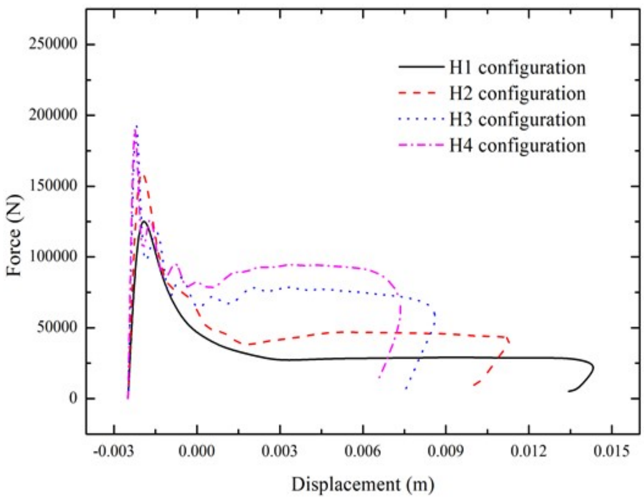

Fig. 8. Force-displacement curve for core of all the configurations of honeycomb sandwich panel

6. Conclusions

Honeycomb sandwich structures are widely used as energy absorbing structural elements. Numerical analysis has been carried out to study the effect of different geometries of reinforcement in enhancement of honeycomb sandwich panel to resist blast load. The honeycomb sandwich panel has been simulated in finite element software LS-DYNA® and blast load of 1 kg TNT at 500 mm standoff distance has been applied. All the components of sandwich panel are considered to be made of aluminium. However, significant reduction in deformation of sandwich panel from the analysis, it is found that provision of reinforcement improves the performance of honeycomb sandwich panel. In addition to blast resistance, energy absorption characteristics are also studied. It is also obtained from the present study that configuration H_4 performed best. The results of analysis also indicate that energy absorption in the honeycomb sandwich panel is due to plastic deformation.

Disclosures

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