A PARAMETRIC STUDY OF THE IMPACT BEHAVIOR OF A HONEYCOMB SANDWICH STRUCTURE

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1 Introduction

Researchers have investigated the behavior of composite parts under high velocity impact through analytical methods, numerical methods, and experiments. Chen et al. [1] used a smoothed particle hydrodynamics technique (SHP) in conjunction with a macro-homogeneous, anisotropic material concept for simulating impact damage and penetration of composite structures. Van Hoof [2] conducted experiments to examine the deformation response of materials used in ballistic helmets. In addition, a numerical analysis was conducted and compared with the experiment.

Fujii et al. [3] experimentally investigated the impact perforation behavior of various carbon-fiber-reinforced plastic laminates impacted by steel spheres with a velocity of 500-1230 m/s. Chambers et al. [4] evaluated the impact damage in CFRP using embedded fiber Bragg grating (FBG) sensors, C-scan, and microscopic analysis. Gower et al. [5] carried out experimental and numerical studies to determine the ballistic response of laminated Kevlar29 and 129. Naik et al. [6] investigated the ballistic impact behavior of plain weave E-glass/epoxy and twill weave/epoxy composites.

Talebi et al. [7] studied the projectile nose angle of impact and penetration into high strength fabric. Normal and oblique impacts on thin woven laminates were investigated by J. Lopez-Puente et al. [8] through experimental and numerical analyses. Will et al. [9] studied the effect of stacking sequence of CFRP filament wound tubes subjected to projectile impact.

Beside most papers have been focused on composite laminates, some researchers have investigated the behavior of sandwich materials under impact. Aktay et al. [10] investigated several numerical models for honeycomb core crush behavior. The detailed honeycomb mechanical model was shown to be mesh-dependent and time-consuming. A model based on SPH was proposed and shown to be useful in crush modeling of the core.

Heimbs et al. [11] investigated the properties of Nomex honeycomb core through virtual testing to reduce the cost of experiment. He, in another study [12], performed many tests on the strain rate effects of Nomex honeycomb core. Buitrago et al. [13] did an experimental and numerical study on the behavior of honeycomb core sandwich structure under high velocity impact. A combination of shell and solid elements were used to model the behavior of honeycomb core.

There is, however, a lack of study on the oblique impact on the behavior of sandwich structures. Therefore, the objective of this paper is to conduct a parametric study on the behavior of aluminum honeycomb sandwich panel using numerical analysis. The parameter is the oblique angle of the impactor's flight direction and vertical axis. First, the vertical impact was validated by using published data in [13]. Then, the parametric study was conducted by changing the oblique angle numerically.

2 Finite Element Analysis

2.1 Test

In the work of Buitrago et al. [13], the impact behaviors of aluminum honeycomb sandwich structures were investigated. Square sandwich specimens were used with dimensions of 140 mm x 140 mm x 24 mm thick. The skin was plain-wave woven laminates of carbon-fibers AS4 and epoxy resin 8552. The typical thickness of the prepreg is 2 mm. The core was a 3003 aluminium honeycomb of 20 mm thick and 77 kg/m^3 density. The cells were hexagonal, with a size of 4.8 mm and a wall thickness of 60 μm. The specimens were impacted

by spherical steel projectiles of 1.7 g and 7.5 mm in diameter. The impact velocity was ranged from 92 m/s to 548 m/s.

The properties of the composite skins and the honeycomb core are given in Table 1. To determine the properties through thickness direction of the core, a flat-wise compression tests were performed, according to ASTM C365 Standard. The load-displacement curve, which is shown in Fig. 1, was used to determine the compressive and crush strengths and the compressive modulus given in Table 2. Each composite faces included 10 plies with the same orientation of 0 degree.

Table 1. Properties of plain-wave prepreg

E_1(GPa)	E_2(GPa)	G_{12}(GPa)	ν_{12}	
68.5	68.5	3.7	0.12	
X_t(MPa)	X_c(MPa)	Y_c(MPa)	Y_c(MPa)	S_{12}(MPa)
795	860	795	860	98

Table 2. Compressive behavior of core

σ_{comp} (MPa)	σ_{crush} (MPa)	E_{comp}(MPa)
3.76	1.8	400

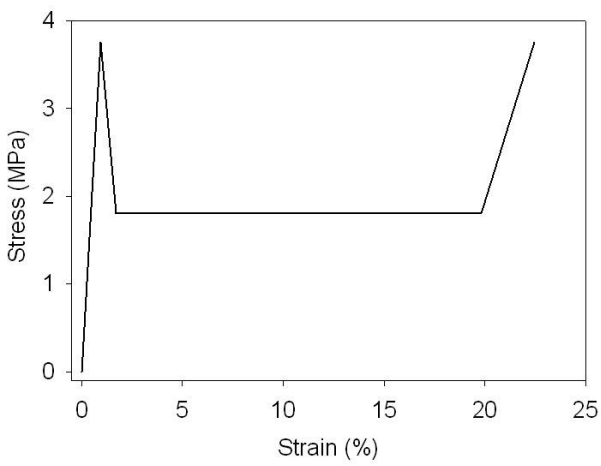


Fig. 1 Compressive load-displacement curve

The ballistic limit was defined as the minimum impact velocity required for the projectile to completely penetrate the sandwich plate. The experimental ballistic limit estimated was 139 ± 4.2 m/s. The curve of residual velocity vs. initial velocity obtained by the tests is shown in Fig. 2.

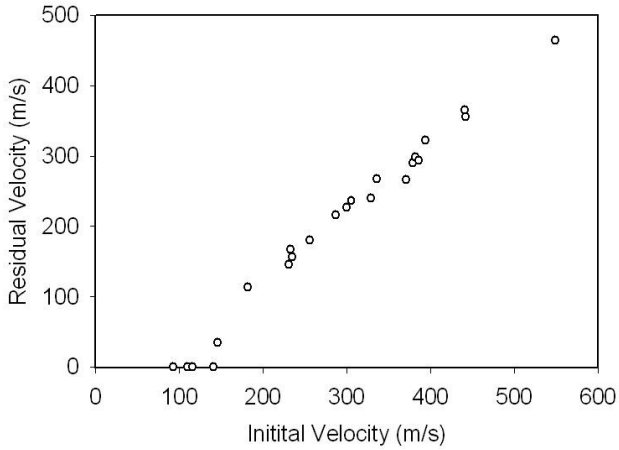


Fig. 2 Residual velocity versus impact velocity

2.2 Finite element model

Finite element models were built to investigate the behavior of honeycomb core sandwich structures under vertical and oblique impacts. The model for vertical impact was first built to validate the numerical model. The parametric study, then, was conducted by changing the impact angle in the oblique impact's model. The explicit finite element code LS DYNA was used for the analysis.

Two major modeling methods for honeycomb sandwich structures were classified in the work of Lambs et al. [14] into the macro-modeling and meso-modelling methods. The former does not consider the core's geometries in detail and model it with its effective properties. The latter has a detailed representation of the cell wall so that the behavior of cells can be investigated closely. In this study, a combination of these two modelling methods was used to simulate the impact behavior of the sandwich structures.

2.2.1 Vertical impact's model

The vertical impact's model was built to simulate the test of Buitrago et al. Because of the symmetry of the problem, only a quarter of specimen was built to reduce the computational time. Composite faces were modeled with shell elements. Impactor was built with solid elements. Core was modeled with shell and solid elements. In the region closed to the impact position, each core wall was modeled by shell element to accurately capture the behavior of the core. Far from this region, the core was modeled using solid element with effective modulus. The

modulus was obtained by using the equations in Gibson and Asby [15].

Material model 3 (MAT_PLASTIC_KINEMATIC) in LS-DYNA [16] was used for modeling aluminum core wall. This model is suitable to model isotropic and kinematic hardening plasticity with the option of including strain rate effects. However, the strain rate effect was ignored in the current analysis. Material model 22 was applied to model the composite laminates.

Material model 22 is an orthotropic material with optional brittle failure for composite. Chang-Chang criteria [17] were adopted in this material type as follows. Denoting a fiber shearing term τ as Equation (1), the failure modes are evaluated using three equations (2), (3), and (4).

$$\tau = \frac{\dfrac{\sigma_{12}^2}{2G_{12}} + \dfrac{3}{4}\alpha\sigma_{12}^4}{\dfrac{S_{12}^2}{2G_{12}} + \dfrac{3}{4}\alpha S_{12}^4} \qquad (1)$$

Matrix cracking:

$$\left(\frac{\sigma_2}{S_2}\right)^2 + \tau \geq 1 \qquad (2)$$

Compression criteria:

$$\left(\frac{\sigma_2}{2S_{12}}\right)^2 + \left[\left(\frac{C_2}{2S_{12}}\right)^2 - 1\right]\frac{\sigma_2}{C_2} + \tau \geq 1 \qquad (3)$$

Fiber breakage:

$$\left(\frac{\sigma_1}{S_1}\right)^2 + \tau \geq 1 \qquad (3)$$

In these equations, S_1, S_2, S_{12}, C_2, and α are longitudinal tensile strength, transverse tensile strength, shear strength, transverse compressive strength, and shear stress parameter, respectively. In this model, the immediate degradation model was used to reduce the material's properties. When the failure criteria are satisfied, the relevant properties drop to zero.

The finite element model for vertical impact is shown in Fig. 2. Two edges of the lower face were constrained in vertical displacement to simulate the support.

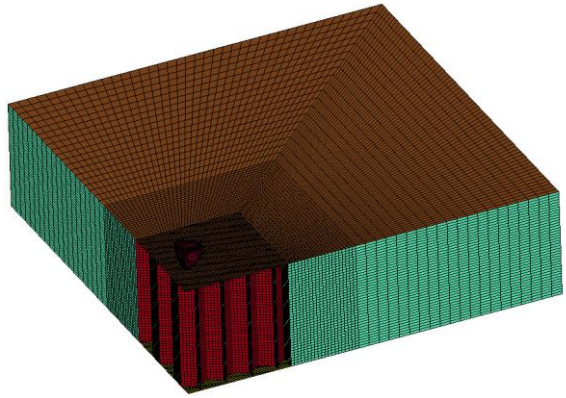


Fig. 2 FE model for vertical impact

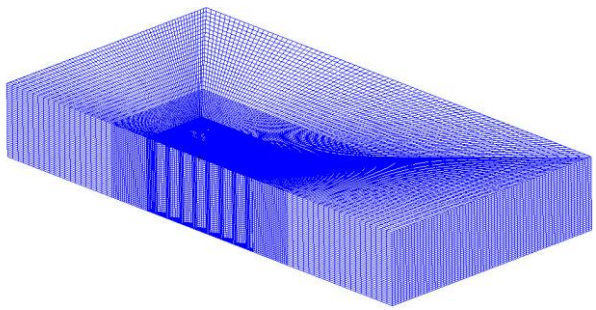
2.2.2 Oblique impact's model

A half model was built to investigate the effects of oblique impact on honeycomb sandwich structures. The oblique angle was chosen to be 15, 30, and 45 degree. The finite element model and oblique angle are shown in Fig. 3 (a) and (b), respectively.

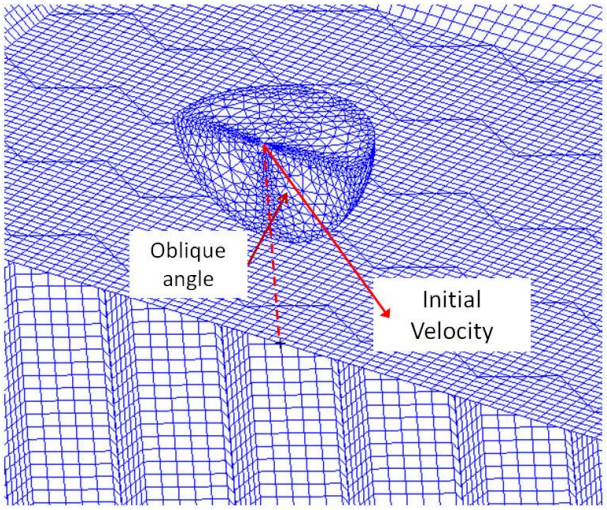
3 Results and Discussion

The impact velocity obtained by the current model was found to be higher than the experimental test by Buitrago et al. [13]. The analysis result obtained at a velocity of 160 m/s at the time of 0.1 μs is shown in Fig. 4. At this time, the impactor started to rebound. The experimental ballistic velocity was 139 ± 4.2 m/s. However, even at 160 m/s, the panel was not fully penetrated. The material model must be improved.

The oblique impacts required a higher velocity to penetrate the honeycomb sandwich panel than the vertical impact.



(a) Oblique impact's model



(b) Oblique angle

Fig. 3. Oblique impact's model and oblique angle

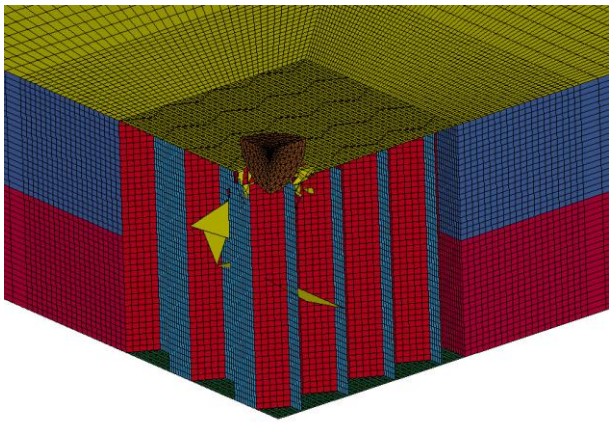


Fig. 4. At time of 0.1 μs, 160 m/s initial velocity

4. Conclusions

In this study, a parametric study of the high velocity impact behavior of a sandwich structure was numerically conducted. The considered sandwich structure consists of two composite faces and an aluminum core.

The finite element model for vertical impact on the structure was validated by existing test data. The predicted results, however, did not match well the test data. The model should be improved to match the test. Oblique impact showed the trend that oblique angle needed a higher velocity to penetrate the panels.

Acknowledgements

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