Numerical Modelling of Triangular Corrugated-core Sandwich Panel subjected to Impact Loading

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***Abstract*—In this paper, lightweight aluminium AL2024-O sandwich panels were tested using drop-weight impact tower with lateral impactor to evaluate impact responses and to identify the associated failure mechanisms under various impact loading conditions. The simulations of impact responses of triangular corrugated-core sandwich panels were presented, which were validated against the corresponding experimental data. The triangular corrugated-core sandwich panel configurations were studied by using commercial finite element (FE) code, Abaqus/Explicit. The FE code is used to develop numerical models by using plasticity with strain hardening, and ductile damage criteria, etc., to cover the most representative cases. A good agreement was obtained, which indicates the finite element models developed are capable of predicting the dynamic behaviour of the triangular corrugated-core sandwich panels subjected to uniform lateral impact.**

Keywords—corrugated-core; low velocity impact; finite element analysis; sandwich panel.

I. Introduction

Sandwich panels are considered as optimal designs for a wide range of engineering applications such as insulated structures, aerospace vehicles, marine constructions, etc. A composite sandwich panel is typically made from a lightweight foam, honeycomb or corrugated-core sandwiched between two composite skins. Such a combination offers exceptional specific strength-to-weight or stiffness-to-weight ratio, buoyancy, dimensional stability, and thermal and acoustical insulation characteristics. Recently, many researches have been study on various types of sandwich panels (Biancolini, 2005; Herrmann, Zahlen, & Zuardy, 2005; Kazemahvazi & Zenkert, 2009; Lin, Liu, Kuo, & Chen, 2007; Nyman & Gustafsson, 2000; Rejab & Cantwell, 2013; Xiong, Ma, Wu, Liu, & Vaziri, 2011; Yokozeki, Takeda, Ogasawara, & Ishikawa, 2006; Zenkert, 1995; Zhang Y, 2011). However, it was found that few of published worked involved in triangular corrugated-core sandwich panels in spite of a versatile applications.

In this paper, the triangular corrugated-core sandwich panels made by bonding two cover sheets to the core material, consisting of triangular with angled at 45^{o} formed sheet metal, were used, tested and modelled in order to study the influence of low velocity impact. Response of the sandwich panel was investigated by using the uniform lateral indenter.

II. Experimental Setup

The triangular corrugated-core sandwich panels in this study were based on AL2024-O aluminium alloy sheets from fabricated by bonding two cover sheets intpo core material, which consists of triangular formed sheet metal, using adhesive bonding technique. Fig.1 shows a design and dimension of the sandwich panel.

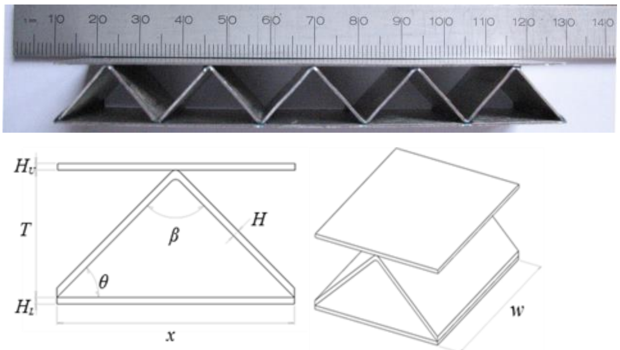


Fig. 1: Geometry of corrugated-core sandwich panel.

Generally, the unit cell is based on a triangular profile. The geometric parameters plotted in Fig. 1 are annotated as follows: θ and β are the internal angle of a unit cell for the corrugated-core sandwich panel; T is the height of the core; H_U and H_L are the upper and lower thickness of the skins, respectively; H is the average thickness of inclined core members and also called as wall thickness (H = 0.5mm in the study); x is the length of the core; and w is the width of a sample. Due to the predetermined mould design, the value of x is 20mm length while θ and β are set to be 45^o and 90^o, respectively. For preparation of the test specimens, the value of w was consistently cut into 25mm width. And then, five different numbers of corrugated cores have been cut according to the size of unit cells.

Low velocity impact tests on the panels started from 0.99m/s and increased gradually until 4.43m/s, were conducted by using an instrumanted drop-weight tower machine. A flat impactor of 1.247kg with dimension of 120mm x 80mm was used. The test specimens had the dimension 100mm. x 25mm. Details about the test configuration are shown in Fig. 2.

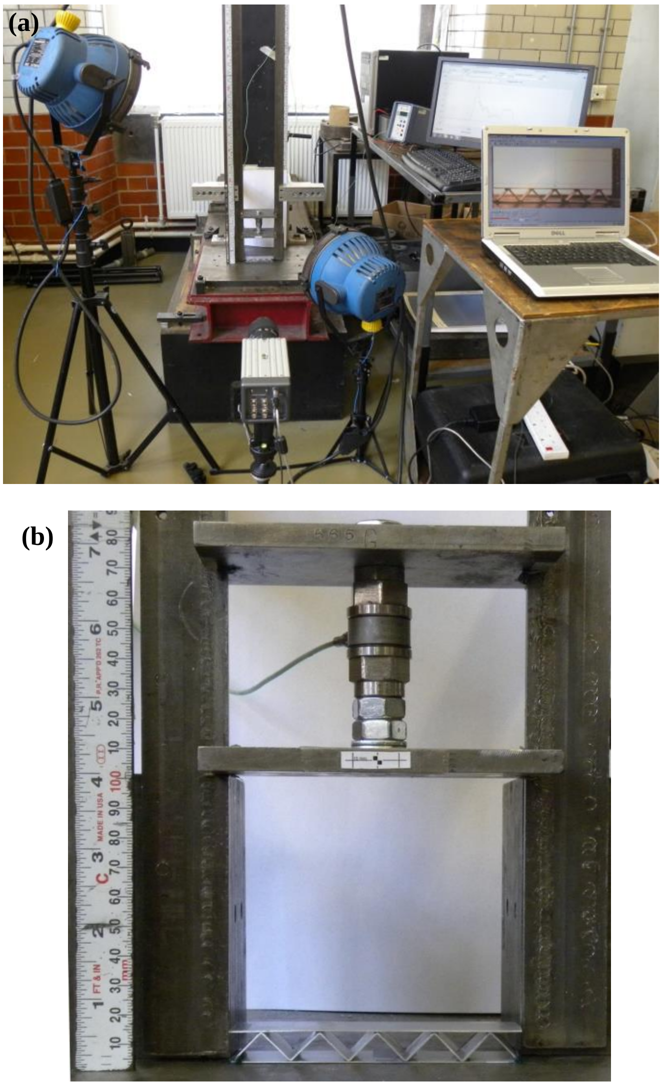


Fig. 2: (a) The instrumented drop-weight impact test set-up adopted for testing the corrugated-core sandwich panels (b) A closer view of the test set-up for a drop-weight impact test.

In order to get the materials properties for the input parameters used in finite element modelling, the aluminium sheets were tested by using Instron 4505 to conduct the uniaxial tensile test following the standard tensile test BS 10002-1.

III. NUMERICAL MODELLING

Abaqus/Explicit (Abaqus 6.13, 2013) was used to develop numerical simulations of the triangular corrugated-core sandwich panels under low velocity impact. The aluminium alloy was modelled as an elasto-plastic material with rate-dependent behaviour. For a rate-dependent material, the relationship follows the uniaxial flow rate definition as:

$$\dot{\bar{\varepsilon}}^{pl} = h(q, \bar{\varepsilon}^{pl}, \theta) \quad (1)$$

where h is a known strain hardening function, q is the von-Mises equivalent stress, ε^{-pl} is the equivalent plastic strain, and θ is the temperature. The isotropic hardening data for the AL2024-O aluminium alloy are given in Table 1. The density of the aluminium was taken as ρ = 2780 kg/m^3. The material properties of the AL2024-O can be found from the tensile test results, where the Young's modulus, E = 70.6 GPa and the Poisson's ratio, υ = 0.3.

Table 1: Isotropic hardening data for the AL2024-O aluminium alloy

Yield stress (MPa)	71	104	133	152	165	175	200	222
Plastic strain	0	0.009	0.018	0.028	0.037	0.046	0.093	0.137

The rate-dependent hardening curves can be expressed as:

$$\bar{\sigma}(\bar{\varepsilon}_{pl}, \dot{\bar{\varepsilon}}_{pl}) = \delta_y(\bar{\varepsilon}_{pl}) R(\dot{\bar{\varepsilon}}_{pl}) \quad (2)$$

Where $\bar{\varepsilon}_{pl}$ and R are the equivalent plastic strain and stress ratio (= $\bar{\sigma}$ / σ_y) respectively.

Damage initiation criteria

Ductile damage criterion is a phenomenological model for predicting the onset of damage due to nucleation, growth, and coalescence of voids. The model assumes that the equivalent plastic strain at the onset of damage, $\bar{\varepsilon}_D^{pl}$, is a function of stress triaxiality and strain rate:

$$\bar{\varepsilon}_D^{pl}(\eta, \dot{\bar{\varepsilon}}_{pl}) \quad (3)$$

where η = - p/q and η is the stress triaxiality, p is the pressure stress, q is the Misses equivalent stress, and $\dot{\bar{\varepsilon}}_{pl}$ is the equivalent plastic strain rate. The criterion for damage initiation is met when the following condition is satisfied:

$$\omega_D = \int \frac{d\,\bar{\varepsilon}_{pl}}{\bar{\varepsilon}^{pl}_D(\eta,\dot{\bar{\varepsilon}}_{pl})} = 1 \qquad (4)$$

where ω_D is a state variable that increases monotonically with plastic deformation. At each increment during the analysis the incremental increase is computed as:

$$\Delta\omega_D = \int \frac{\Delta\,\bar{\varepsilon}_{pl}}{\bar{\varepsilon}^{pl}_D(\eta,\dot{\bar{\varepsilon}}_{pl})} \geq 0 \qquad (5)$$

Shear failure criterion

The shear failure model is based on the value of the equivalent plastic strain at element integration points; failure is assumed to occur when the damage parameter exceeds 1. The damage parameter, ω, is defined as :

$$\omega = \frac{\bar{\varepsilon}^{pl}_0 + \sum \Delta\bar{\varepsilon}^{pl}}{\bar{\varepsilon}^{pl}_f} \qquad (6)$$

where $\bar{\varepsilon}^{pl}_0$ is any initial value of the equivalent plastic strain, $\sum \Delta\bar{\varepsilon}^{pl}$ is an increment of the equivalent plastic strain, is the strain at failure, and the summation is performed over all increments in the analysis. The strain at failure, $\bar{\varepsilon}^{pl}_f$, is assumed to depend on the plastic strain rate, $\dot{\bar{\varepsilon}}_{pl}$; a dimensionless pressure-deviatoric stress ratio, *p/q* (where *p* is the pressure stress and *q* is the Mises stress); temperature; and predefined field variables. However, in this model, the temperature parameter would be ignored as a small effect to the results.

Geometry and mesh design

The response of the corrugated-core sandwich panel under low velocity impact loading was modelled using the conventional shell element, S4R. The corrugated-core was modelled together with upper and lower skins, as in Fig. 3. The element size for each of the skins was of 12 x 50, giving a total of 600 elements. A total of 3500 elements were generated in the corrugated-core, as same as used in the quasi-static FE models. Overall, the total number of 4700 element meshes was used in this sandwich panel model.

Fig.3: The meshes of the sandwich panel modelling.

The impactor was modelled as a flat plate using the discrete rigid surface, R3D4, and positioned above the sandwich model with a 1 mm offset. The small offset was introduced so that the impactor and the sandwich model were not in contact at the beginning of the simulation.

Boundary conditions and loading

Fig. 4 shows the model assembly used to simulate the dynamic compression test. A point mass, equal to the mass of the experimental impactor, was assigned to a reference point located at the centre of the flat plate. The reference point also was used to record the displacement from this model.

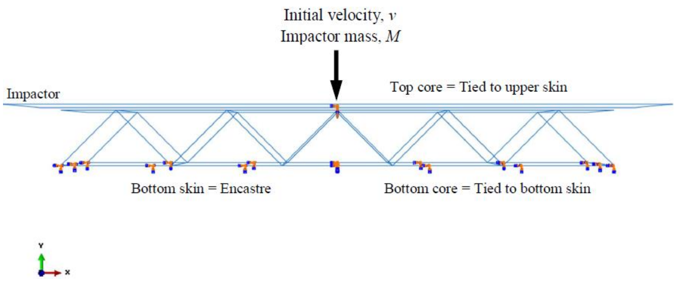


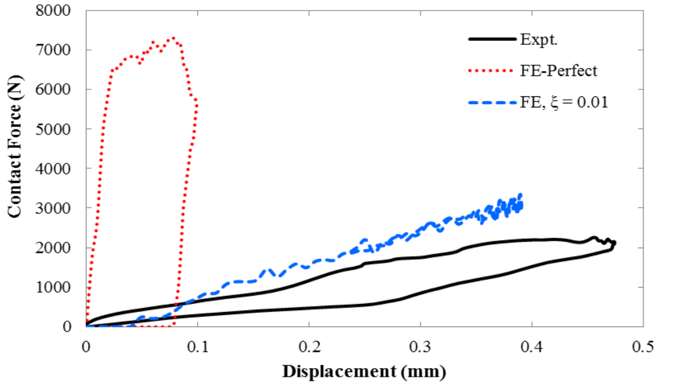
Fig.4: Loading direction, boundary conditions and assembly for the dynamic compression model.

An initial velocity was prescribed to the rigid plate, was equal to the impact velocity engaged in the experiments. An initial imperfection was also introduced in the sandwich structure modelling to accurately predict the buckling behavior. A surface-to-surface contact algoritham was used to define contact between the impactor and the sandwich model. Self-contact within the corrugated-core was also modelled. The interaction properties were set to ‘softened’ in the normal direction and a friction coefficient of 0.15 was assumed in the tangential direction. All nodes along the upper and lower core edges were tied to the skins. The lower surface of the bottom skin was fixed, to restrain from any movements.

IV. Result And Discussion

The FE results for the panels were compared to the experimental results to verify the numerical model. Fig. 5 shows the force-displacement traces of experimental and FE results, for an aluminium system. The Fig. 5.(a) and (b) show the impact response at low and beyond the energies to break the panels, respectively. In general, a small imperfection with a scale factor of 1% as used in quasi-static FE model, was applied to the thickness of the model, the FE results indicate good agreement with the corresponding experimental results. The deformation trends in the dynamic FE models mirror those observed in the quasi-static FE models, where buckling was dominating the initial damage mechanisms of the panel, as shown in Fig. 6.

(a)



(b)

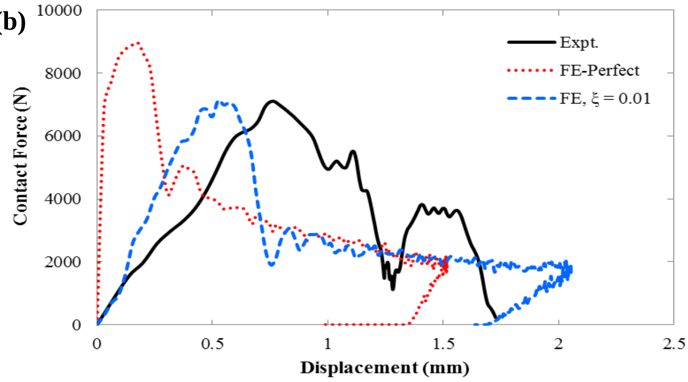
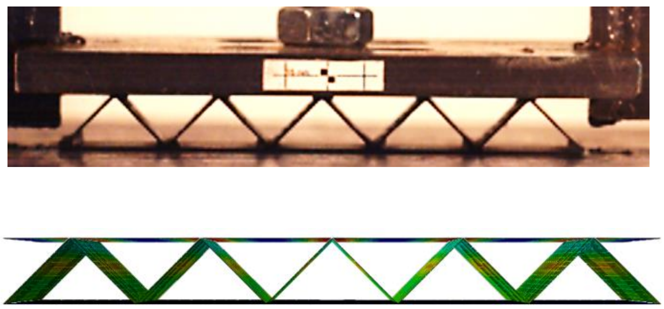


Fig. 5: The measured response for an aluminium corrugated-core structure compared to the numerical simulation. The force-displacement responses for the model with FE–ξ = 0.01 show reasonable agreement with the measured response. Note that in this FE analysis, an initial velocity of (a) 0.99 m/s and (b) 3.13 m/s has applied.

(a) t =20 µs ; δ = 0.062 mm ; F = 0.69 kN



(b) t =250 µs ; δ = 0.689 mm ; F = 4.19 kN

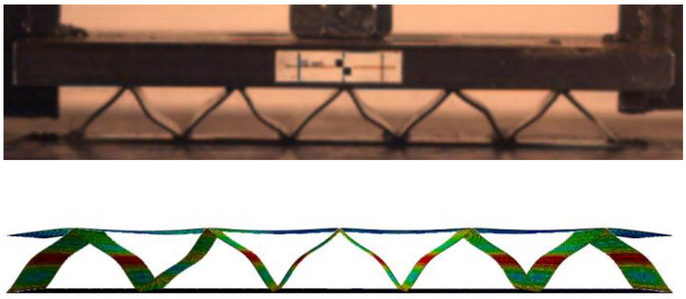


Fig. 6: Experimental and predicted deformation modes for an aluminium corrugated-core panel at a velocity of 3.13 m/s; (a) initial contact and (b) buckling of the struts.

V. CONCLUSION

Agreement between the experimental and predicted data is reasonably good, with the model tending to follow the experimental data. Only in some regions were observed not associated in particular the impact displacement, which seem offers slightly greater than measured data. Imperfection sensitivity factor improved the impact response of the simulation.

For the future work, the numerical modelling could be improved at high speed velocity impact, which relate to the realistic scenarios. The parametric study such as the projectile diameter, oblique impact, should be included in order to optimize the sandwich panels. Eventually, this study could be used for transportation applications, which the lightweight panels are significantly impacted to reduce fuel consumption.

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