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Impact responses of sandwich panels with fibre metal laminate skins and aluminium foam core

Chengjun Liu[a], Y.X. Zhang[a,*], Jing Li[b]

[a] *School of Engineering and Information Technology, The University of New South Wales, Canberra, The Australian Defence Force Academy, Northcott Drive, ACT 2600, Australia*
[b] *School of Civil Engineering, and Transportation, South China University of Technology, Guangzhou 510641 China*

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ABSTRACT

Low velocity impact responses of a newly developed sandwich panel with aluminium foam core and fibre metal laminate (FML) skins, comprised of aluminium sheets and plain woven E glass fibres, are investigated in this paper. Drop weight impact tests were conducted and the effect of the thickness of foam core and FML skin on the impact response of the panels was investigated via the experimental study. A finite element model is also developed and validated against the experiments to prove the effectiveness and accuracy for analyzing the impact responses of the sandwich panels under low-velocity impact. The research findings are summarized and concluded finally.

1. Introduction

Sandwich structures integrate the strength of the skins and the stiffness of the core with usually a significantly reduced weight than their metal counterparts. Sandwich panels with aluminium foam (Al) core and FML skins exhibit the advantages of both aluminium foam and FML skins, and has a high potential to be applied in the engineering components such as the automotive structures where impact is a concern [1,2].

Researches on the impact velocity impact response of Al foam sandwich panels with varying skins have been reported. Several researches studied the effect of face sheet on the low velocity impact response of Al foam sandwich panels and the skins of higher stiffness were found to be more impact resistant when subjected to low velocity impact. For example, Kiratisaevee and Cantwell [3] investigated the low-velocity impact response of the Al foam sandwich structures with both unidirectional and plain woven glass reinforced thermoplastic-matrix FML skins, and found that FML skins of higher stiffness offered a greater dent resistance. Vaidya et al. [4] conducted drop weight impact tests on Al foam sandwich panels with face sheets like S2-glass, E-glass, Kevlar, and carbon fibre reinforced vinyl ester resin, and found that the panels of higher stiffness skins, specifically the vinyl ester resin reinforced S2-glass, was optimal for resisting low velocity impact. Mohan et al. [5] experimentally investigated the low velocity impact responses of sandwich panels with Al foam core and three types of face sheets, including carbon fibre reinforced polymer composite, Al alloy 1100 sheet and stainless steel sheet, and the results showed that the face sheets of the highest stiffness, namely the stainless steel sheet, was strong enough to withstand the pre-designated impact loading without penetration damage. Crupi et al. [6] also found that the collapse of these sandwich panels was strongly influenced by the rigidity of the skin.

Failure modes of Al foam sandwich panels with FML skins under low velocity impact have also been studied. Villanueva and Cantwell [7] found that the glass fibre reinforced Al foam sandwich panels absorbed large amounts of impact energy through buckling and crushing in the core and fibre fracture in the top surface of the composite skins. Reyes [8] revealed that sandwich panels with Al foam core and FML skins absorbed much of the impact energy from global contact and bending when subjected to low velocity impact. Strain rate effect of Al foam in sandwiches subjected to low velocity impact was also studied. Kiratisaevee and Cantwell [9] found that the Al foam core and FML skin materials were insensitive to loading rate. Li et al. [10] found no strain rate sensitivity for the Al foam in the drop weight impact process, although the energy absorbed in the low velocity impact testing was greater than that in the quasi-static testing.

Finite element modelling is a very powerful and robust tool for an intensive investigation of the responses of structures especially when subjected to extreme loadings such as impact. However very rare numerical work on the low speed impact behaviour of Al foam sandwich panels with FML skins has been reported so far. Rajaneesh et al. [11] modelled the low velocity impact response of sandwich plates subjected

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* Corresponding author.
E-mail address: y.zhang@adfa.edu.au (Y.X. Zhang).

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to an impact from an impactor of 2.65 kg with an initial impact velocity of 6.7 m/s using 3D finite element models in LS-DYNA. The sandwich plates modelled had an Alporas foam core with face plates made of either Al or carbon fibre reinforced plastic. Zou et al. [12] modelled Al foam sandwich panels subjected to low velocity impact loading. These studies demonstrated the effectiveness of the finite element method in the modelling of the impact response of the Al foam sandwich panels. However, these models did not consider the debonding in the panels and thus could not model debonding failure.

In this paper, the impact response of a newly developed sandwich panels with Al foam sandwich panels with FML skins [13] is studied extensively so as to calibrate the impact resistance of the panels. Drop weight impact tests were conducted on sandwich panels subjected to single impact and multiple impacts and the experimental program and results are reported. To study the effect of foam thickness on the low velocity impact behaviour of the sandwich panels, sandwich panels with four core thicknesses, i.e., 20 mm, 25 mm, 30 mm and 35 mm were tested. To study the effect of stacking sequence on the skin on the low velocity impact behaviour of the sandwich panels, panels with two skin combinations were tested. The failure modes and energy absorption capability of the panels are studied. In addition, a finite element model is developed in this paper for simulation of the impact responses of the sandwich panels when subjected to drop weight impact. The finite element model is used to model the impact response of the tested panels, and the agreement between the numerical results and experimental results demonstrates the effectiveness and accuracy of the developed model.

2. Experimental programs

2.1. Specimens

The rectangular sandwich panels are of a dimension of 150 mm × 150 mm with various thicknesses. Totally five groups of sandwich panels with varying core thicknesses and FML skin stacking sequences as shown in Table 1 were tested to evaluate the effect of the core thickness (Group 1, 2, 3 and 5) and the skin stacking on the impact resistance of the panels (Group 4 and 5). As shown in Table 1 the Al/(0°/90°) represents a stacking sequence of one layer of Al sheet and one ply of plain woven E glass prepreg, and it is marked as “1/1”. In the same way, the (Al/(0°/90°))$_2$ is denoted as “2/2”, standing for 2 layers of Al alloy sheet and 2 plies of woven E glass prepregs. A sandwich panel with 20 mm thickness foam core and the “1/1” FML skin is denoted as “1/1-20”. The panels were manufactured in the composite lab and tested in the Impact Dynamics lab at UNSW Canberra. Three specimens were tested for each group of panel. For the details of the sandwich panels and detailed manufacturing process, one may refer to the Ref. [13].

2.2. Material properties

The Al foam used as the core of the sandwich panels is of a density of 300 kg/m^3 and cut from the same batch of foam block to keep the porosity reliably stable. To obtain the mechanical behaviour of the Al foam, Al foam cubes of size 50 mm × 50 mm × 50 mm were tested using the 100 kN Shimadzu AG-X testing machine under a compressive loading rate of 2 mm/min. The tested compressive stress-engineering strain curve of the Al foam is shown in Fig. 1.

Table 1
Specifications of the sandwich panel specimen.

Specimen type	Skin stacking sequence	Skin thickness (mm)	Foam thickness (mm)	Panel thickness (mm)
Group 1	Al/(0°/90°)	1.37	35	37.06
Group 2	Al/(0°/90°)	1.27	30	32.09
Group 3	Al/(0°/90°)	1.26	25	27.34
Group 4	(Al/(0°/90°))$_2$	2.25	20	25.54
Group 5	Al/(0°/90°)	1.25	20	22.28

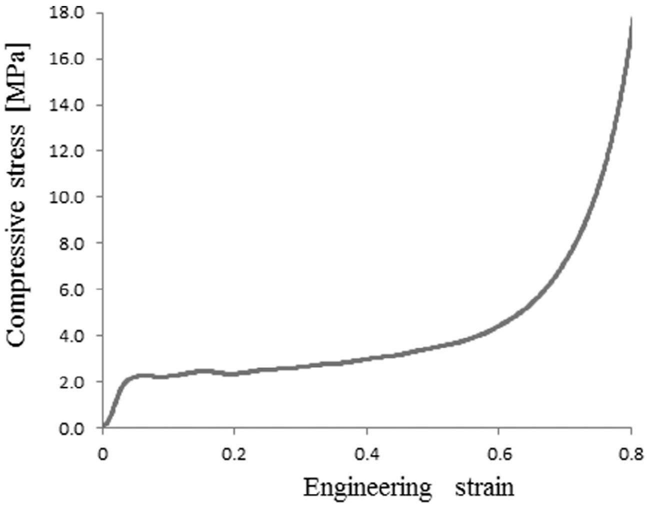

Fig. 1. Compressive stress-engineering strain curve of the Al foam.

2.3. Test setup

The drop weight impact facility as shown in Fig. 2 was used to conduct the low speed impact tests. The facility consisted of a vertical guiding rail, an electro-magnet and an impactor. The rail presented a dovetailed cross-section and fitted the linear bearing of the impactor to allow the impactor to slide down under its gravity force. The drop weight impactor was controlled by the electro-magnet fixed on the

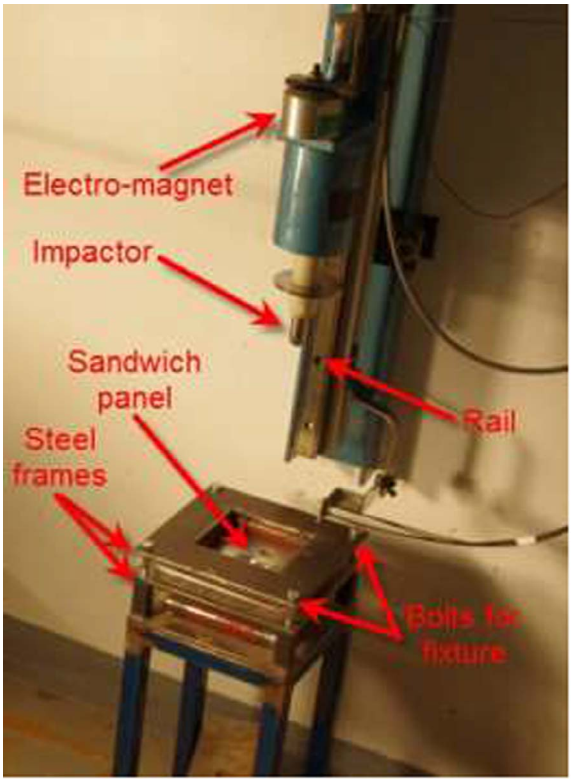

Fig. 2. The set-up of the drop weight impact facilities.