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High velocity impact responses of sandwich panels with metal fibre laminate skins and aluminium foam core

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A B S T R A C T

In this paper, high velocity impact responses of newly designed sandwich panels with aluminium (AL) foam core and metal fibre laminate (FML) skins, which are comprised of aluminium sheets and plain woven E glass fibre composite plies are investigated. Gas gun impact tests were conducted to investigate the high velocity impact response of the panels subjected to the impact from a steel ball bearing at an impact velocity of around 210 m/s. The effect of the thickness of the foam core and FML skin on the impact resistance of the panels is also investigated via experimental study. A finite element model is developed for effective numerical modelling of the impact behaviour of the sandwich panels using the commercially finite element software ANSYS LS-DYNA for more extensive study of the impact response of the sandwich panels. The simplified Johnson Cook material model, the composite damage material model based on the Chang-Chang criteria, and the crushable foam material model are used to model the aluminium sheets, composite plies and the AL foam respectively. Three types of contact algorithms, i.e. the erosion contact type, the tie-break contact type and the general 3D contact type are employed to define the various contacts during the impact and to model the delamination between the FML layers and debonding between the FML skin and the AL foam. The finite element model is validated by comparing the simulated impact behaviour to that from experimental for a sandwich panel subjected to high speed impact and demonstrated to be effective and accurate. The effect of the shape of projectile and impact angle on the impact behaviour of the sandwich panels is studied using the developed finite element model. The research findings are summarized and concluded finally.

1. Introduction

Many engineering structures might be subjected to high velocity impact in their service life, such as aircraft wing structures in aeronautical engineering and structural components in aviation industry. Composite sandwich panels have been used widely in these structures, and research and development of light weight composite sandwich panels with good impact resistant capability have attracted lot of research interest.

A sandwich panel is a special class of composite structures that is fabricated by attaching two thin but stiff skins to a light but thick core. The core material, usually in the form of soft foam, honeycomb or truss core, is normally of low strength and it provides the sandwich panels with high bending stiffness with overall low density. The skins are usually thin metallic or composite face sheets of high strength. Metal foam is a type of highly porous material with light weight and superior energy absorption capability. Among the various metal foam, such as aluminium (AL) foam, steel foam, nickel foam, lead foam, titanium foam, magnesium foam and copper foam, AL foam is of a lighter weight, higher impact resistance and energy absorbing capability with a good balance between the mechanical behaviour and the availability [1].

Research on AL foam sandwich panels with various types of skins have been reported and high velocity impact tests on AL foam cored sandwich panels were conducted. Radford *et al.* [2] studied the impact behaviour of AL foam sandwich panels with stainless steel face sheets subjected to impact from a cylindrical projectile with an impact velocity varying from 160 m/s to 570 m/s using gas gun facilities. It was found that increasing the core thickness could enhance the shock resistance of the sandwich panels. Hou *et al.* [3] conducted high velocity impact tests on AL foam sandwich panels with AL 5005H34 face sheets of varying thicknesses. It was found that sandwich panels with thicker skins and a thicker core with a greater density was prone to produce a higher ballistic limit, and that a more severe delamination occurred between the core and back face for

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the panels with thicker skins. Villanueva and Cantwell [4] conducted intermediate velocity impact testing on a range of AL foam sandwich structures with plain composite and fibre-metal laminate skins using a hemispherical headed projectile launched from a gas gun. It was found that the sandwich panels exhibited excellent energy absorbing capability. Vaidaya *et al.* [5] conducted impact tests on AL foam sandwich panels with face sheets made of various materials such as S2-glass, E-glass, aramid, and carbon fibre reinforced vinyl ester resin at an initial impact velocity up to 100 m/s. The AL foam sandwiches with S2-glass skins demonstrated the strongest impact resistance than other face sheets with reduced damage sizes. It was concluded that a strong top skin is essential for the good impact resistance of the AL foam sandwich panels.

FMLs, which combine the merits of both metal sheets and composites, are of high strength and stiffness, low density, improved toughness, corrosion resistance, fatigue properties and amplified impact resistance capability [6-9]. FMLs generally consist of thin, high strength alloy sheets, frequently AL alloy sheets, alternately bonded to plies of fibre-reinforced epoxy. Among the commercially available FMLs, i.e. ARALL (Aramid Fibre Reinforced AL Laminate), CARALL (a new ARALL), and GLARE (glass fibre reinforced metal laminate), GLAREs have been currently used extensively than others especially in aerospace industry [10] and been demonstrated to exhibit the best impact resistance among others [9]. Hitherto the research on high velocity impact behaviour of AL foam sandwich panels is still very limited and very rare research on the behaviour of AL foam sandwich panels with FML skins has been reported so far.

To resist high velocity impact, a sandwich panel should have a skin with high strength and stiffness for penetration resistance and a low density and thick core for energy absorption. Considering the excellent mechanical characteristics of AL foam and FMLs, in particularly the GLARES, sandwich panels made of FML skins and AL foam core are expected to exhibit characteristics such as light weight, greatly enhanced impact resistance with reduced damages sizes, and excellent energy absorption capability. Recently a new type of sandwich panels with AL foam core and FML (GLARE) skins, which are made of a combination of aluminium sheets and E-glass fibre/epoxy laminated plies have been developed for enhanced impact resistance by the authors [11]. The research also demonstrated the good bonding capability between aluminium foam and the E-glass/epoxy composite plies and good impact resistance of the sandwich panel under low velocity impact. However the high velocity impact response of the new sandwich panel has not been calibrated and this is the aim of this investigation. In this paper experimental studies were conducted using gas gun facilities to investigate the high velocity impact response of the panels from a steel ball bearing. Due to capability of the impact facility, the impact velocity was chosen at around 210 m/s, which is close to the taking-off and landing speed for the majority of civil planes nowadays. The effects of the parameters, including the foam core thickness and the stacking and thickness of the FML skins, which have affected the impact resistance of the panels significantly are also investigated via experimental study.

Finite element method has been demonstrated to be a robust, cost-effective and time-efficient method for an extensive investigation of the structural behaviour of complicated engineering structures including laminated composites [12-14]. However, only several finite element analyses on AL foam sandwich panels have been reported so far with all focusing on AL foam sandwich panel with AL skins [15,16]. Rajaneesh *et al.* [17] also modelled the perforation of AL foam sandwich panels with carbon fibre reinforced face sheets, but the modelling was for low velocity impact only. So far very rare numerical analyses have been reported on the high velocity impact response of the AL foam sandwich panel with FML skins.

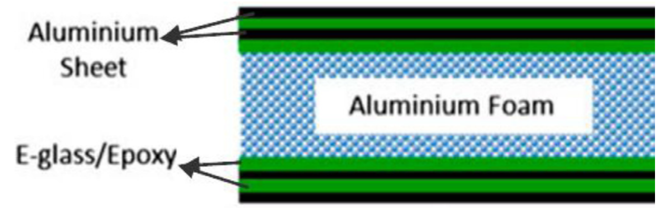

Fig. 1. The schematic of the cross-section of the AL foam sandwich panel with “2/2” FML skins.

In this paper, a finite element model is developed using the commercial finite element analysis software LS-DYNA [18], and validated by comparing the simulated impact behaviour of the sandwich panel to that obtained from experimental study. It is then employed to investigate the impact behaviour of the newly developed sandwich panel and the effect of shape of the projectile and impact angle on the impact behaviour of the sandwich panels is studied.

2. Experimental study

2.1. Specimens

AL foam is employed as the core and FMLs as the skins for the newly developed sandwich panels considering their material characteristics and advantages. The sandwich panels were fabricated in the Composite labs of UNSW Canberra using the methods described by Liu, *et al.* [11]. The size of the sandwich panels is 120 mm × 120 mm with varying thicknesses. The FML comprises of aluminium sheets and plain woven E glass fibre composite plies considering their excellent impact resistance [9], and AL 5005 is used as the AL sheets due to the availability. To determine the effect of the skin thickness on the impact resistance of the panels, the E glass fibre composite plies of three types of stacking sequence, namely "1/1", "2/2" and "3/3" are fabricated. The stacking sequence "n/n" stands for 'n' layer of 1 mm-thick AL alloy sheet and 'n' plies of plain woven E-glass composite (0°/90°). The AL foam is of a density of 300 kg/m^3 with varying thickness from 20, 25 and 30 mm so as to determine the effect of the core thickness on the impact resistance. A sandwich panel denoted as "1/1–20” stands for a sandwich panel with a 20 mm-thick AL foam core and FML skins with a stacking sequence of "1/1”. The cross section of a sandwich panel with "2/2” skins is shown in Fig. 1. To study the effect of the core thickness on the impact resistance of the sandwich panels, the "1/1–20” panels, "1/1–25” panels and "1/1–30” panels, which were of the same skins (1 layer FML) but varying thickness of the core were tested, with an average areal density of 1.18 g/ cm^2, 1.33 g/ cm^2 and 1.48 g/ cm^2 respectively. The panels of "1/1–20”, "2/2–20” and "3/3–20”, which were of the same core thickness of 20 mm but different skins were tested to investigate the effect of skins on the impact behaviour of the sandwich panels. The average areal density of "2/2–20” and "3/3–20” panels was 1.77 g/cm^2 and 2.35 g/cm^2 respectively. Three specimens for each type sandwich panel were tested with a total number of 15 specimens. For details of the fabrication of the panels, one may refer to Liu *et al.* [11].

2.2. Material properties of AL foam

AL foam cubes of 50 mm × 50 mm × 50 mm purchased from Foamtech®, South Korea were tested using the 100 kN Shimadzu AG-X testing machine under a loading rate of 2 mm/min to obtain the mechanical properties of the AL foam, which will be used for numerical modelling. The tested compressive stress-engineering strain curve of the AL foam is shown in Fig. 2.