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The low velocity impact response of curvilinear-core sandwich structures

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ABSTRACT

The low velocity impact response of lightweight aluminium sandwich panels, based on a curvilinear aluminium alloy core, has been investigated to evaluate their energy-absorbing characteristics and to identify the associated failure mechanisms. Finite element models are then developed to predict the dynamic response of these lightweight structures. Here, an elasto-plastic model, capable of accounting for strain-hardening effects, material rate-dependence, as well as the relevant damage criteria, was employed to predict the dynamic response of the targets. The finite element models were then validated by comparing their predictions against the corresponding experimental results. Good agreement was obtained, indicating that the models are capable of predicting the dynamic behaviour of these all-metal sandwich structures under low velocity impact conditions.

Once the finite element model had been validated, it was used to assess the effect of varying key test parameters, such as the projectile diameter, the material properties of the metal substrate as well as the angle of obliquity on the impact response. Here, it has been shown that the perforation energy increases as the impact angle is increased and also as the projectile diameter increases. An investigation of seven different all-metal sandwich structures has shown that an aluminium alloy offers the highest specific perforation resistance under conditions of low velocity impact loading.

1. Introduction

Sandwich panels, consisting of thin skins bonded to a low density core material, are finding widespread use in a wide range of applications, such as lightweight marine structures, impact-resistant land-transportation panels and high-performance load-bearing aerospace structures. Traditionally, most sandwich panels are based on either a lightweight polymer foam or metal foam or a honeycomb core. When skins are bonded, the resulting structures offer exceptional specific strength-to-weight ratios and stiffness-to-weight ratios, buoyancy, dimensional stability, thermal and acoustical insulation characteristics. A number of research studies have focused on the properties of sandwich panels based on corrugated cores. Curvilinear corrugated-core sandwich structures offer superior mechanical properties and various types of such sandwich structure have been studied in detail [1–10].

Curvilinear corrugated-core sandwich design has been used in the production of boxes and cardboard since the late 1800s [11]. They have been widely used in the packaging industry as a result of their low weight, recyclability and low cost. In the past, attempts have been made to predict the load-carrying capacity of corrugated box structures, most notably by McKee et al. [12]. Talbi et al. [11] analysed the geometric and mechanical properties of corrugated board components. They also studied the behaviour of these corrugated structures when subjected to transverse shear and torsion. Allaoui et al. [13] noted that corrugated cardboard is very sensitive to atmospheric conditions. Shear buckling of the core of a corrugated paperboard structure was investigated by Isaksson and Gradin [14]. It was shown that the structural strength of the panel decreases rapidly below a critical thickness of fluting. Tian and Lu [15] studied the minimum weight of a corrugated panel based on fibre reinforced composites subjected to a uniform axial compressive load in order to design an optimal corrugated panel. Haj-Ali et al. [16] presented a refined nonlinear finite element approach for analysing corrugated fibreboards. In their work, the anisotropic and nonlinear material stress–strain behaviour of the corrugated structured was modelled. It was found that the proposed refined modelling approach was able to accurately predict the overall

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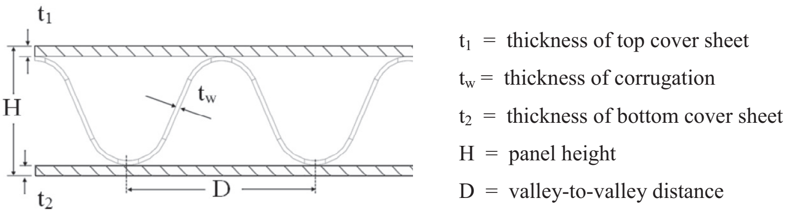

Fig. 1. Schematic of the cross-section of the curvilinear sandwich panel.

mechanical behaviour and ultimate failure in a wide range of corrugated systems.

Metallic corrugated core sandwich structures offer potential for use in a wide range of applications, such as those involving impact/blast load mitigation. There is a limited amount of experimental and numerical data in the literature relating to the dynamic response of sandwich structures based on corrugated topologies. Rubino et al. [17] investigated the impact response of clamped stainless steel Y-framed and corrugated core sandwich plates loaded by aluminium foam projectiles. At low values of projectile momentum, the sandwich panels deflected less than their monolithic counterparts. However, at higher values of projectile momentum, the sandwich panels failed in a tearing mode, whereas the monolithic panels remained intact. Kılıçaslan et al. [18] conducted an experimental and numerical study on the impact response of layered trapezoidal corrugated aluminium core and aluminium sheet interlayer sandwich structures. Here, rate effects were attributed to micro-inertial effects that increased the critical buckling load of the fin at high rates of loading. Radford et al. [19] conducted impact tests on triangular corrugated, pyramidal and aluminium foam core sandwich plates. It was observed that the corrugated and metal foam core sandwich plates offered the best dynamic performance. Tilbrook et al. [20] investigated the dynamic crushing characteristics of sandwich panels based on prismatic lattice cores. Here, the quasi-static and dynamic compression deformation behaviour of stainless steel corrugated and Y-frame sandwich cores were tested. At velocities below 30 m/s, micro-inertial stabilisation against elastic buckling was observed to occur. At higher velocities the propagation of plastic waves within the core resulted in the front face stresses increasing with velocity, whilst the rear surface stresses remained roughly constant. Liang et al. [21] developed lightweight structural concepts for naval applications, with a view to replacing traditional designs with optimised metallic corrugated core sandwich panels. The optimum designs of metallic corrugated core sandwich panels were modelled under blast loading. The authors showed that parameters, such as the corrugation angle and core thickness, are important when designing the core structure.

Recently, Mohr and Marcadet [22] developed a phenomenological ductile fracture initiation model to predict ductile fracture for high strength metallic materials. Here, an extended Mohr–Coulomb criterion is proposed, which makes use of the Hosford equivalent stress in combination with the normal stress acting on the plane of maximum shear. The validation with experimental results indicates that the proposed Hosford–Coulomb model can be used to accurately predict the onset of ductile fracture in advanced high strength steels. Also, Roth and Mohr [23] undertook extensive experimental and numerical work to investigate effect of strain rate on ductile fracture initiation in advanced high strength steel sheets. The extended stress-state dependent Hosford–Coulomb fracture initiation model is proposed to evaluate the strain rate effect on the onset of ductile fracture, which is also successfully validated against the experimental results. These state of the art theories could be used to simulate ductile fracture of metallic materials.

In the present work, a range of metallic curvilinear corrugated-core sandwich structures has been developed [24]. These panels are made in a continuous process by adhesively-bonding two face sheets to a core consisting of a wave-formed aluminium alloy. These panels are finding use in a range of applications in the construction sector, the transport industry and other load-bearing mechanical engineering applications.

The aim of this study is to investigate the dynamic response of such curvilinear corrugated-core sandwich structures, when subjected to low velocity impact loading. The impact response of these structures is subsequently modelled and the resulting models are then used to investigate other loading conditions and material systems.

2. Experimental procedure

The corrugated-core sandwich structures investigated in this study were based on an EN AW-5182 H48 aluminium alloys supplied by Metawell® in Germany [24]. The sandwich panels were manufactured by adhesively bonding two flat alloy skins to a curvilinear alloy core material. Fig. 1 shows the basic design of the sandwich panels investigated here. Two panel configurations, with different face sheet thicknesses and core sizes, were tested, details of which are given in Table 1.

Low velocity impact tests were conducted using an Instron CEAST 9350 falling-weight impact tower. A piezoelectric load sensor was imbedded at the tip of an impactor holder, which makes the impactor replaceable. An impact mass of 5.32 kg, with a 25.4 mm diameter spherical steel head, was used for all tests. Loading data were acquired as voltage output and then transferred into a module 64K DAS (Data Acquisition Station) at a frequency of 100 kHz. Impact velocity was acquired by a photoelectric sensor. During the impact test, the impactor holder was released and dropped vertically passing through the photoelectric sensor beam. At the tip of impactor right at the surface of specimen, the impact velocity was detected. The error of the measured velocity is within 0.01 m/s. Each impact velocity was acquired by a certain height, which was calculated from the required impact energy. The tests were conducted by a varying impact velocity between 1.9 and 5.4 m/s. This range of velocities correlates the strain rate from 100 to 150 s^{-1}. Displacement was calculated by Pro Analyst software, basically considered from load–time relation.

Square test panels, with an edge length of 155 mm, were clamped by a cylindrical ring with inner and outer diameters of 76 and 100 mm, respectively. A clamping force of 200 Newtons was applied

Table 1
Panel dimensions and areal density for the aluminium alloy panels.

Type	t_1 (mm)	t_w (mm)	t_2 (mm)	H (mm)	D (mm)	Areal density (kg/m^2)
Alu hl/H6	0.5	0.2	0.5	6.0	9.0	3.8
Alu hl/H10	0.8	0.3	0.5	10.0	13.4	5.2