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Experimental and numerical studies on the quasi-static and dynamic crushing responses of multi-layer trapezoidal aluminum corrugated sandwiches

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ABSTRACT

The axial crushing responses of bonded and brazed multi-layer 1050 H14 trapezoidal aluminum corrugated core (fin) sandwich structures, with and without aluminum interlayer sheets in 0°/0° and 0°/90° core orientations, were both experimentally and numerically investigated at quasi-static and dynamic strain rates. Multi-layering the core layers decreased the buckling stress and increased the densification strain. The experimental and simulation compression stress–strain curves showed reasonable agreements with each other. Two main crushing modes were observed experimentally and numerically: the progressive fin folding and the shearing interlayer aluminum sheets. Both, the simulation and experimental buckling and post-buckling stresses increased when the interlayer sheets were constraint laterally. The multi-layer samples without interlayer sheets in 0°/90° core orientation exhibited higher buckling stresses than the samples in 0°/0° core orientation. The increased buckling stress of 0°/0° oriented core samples without interlayer sheets at high strain rate was attributed to the micro-inertial effects which led to increased bending forces at higher impact velocities.

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1. Introduction

Sandwich structures are the structural components which are conventionally used in diverse structural applications. The main advantage in using these structures is derived from the relatively high strength to weight ratios combined with the relatively high energy absorption capabilities. A variety of metallic core materials have been subjected to experimental and numerical investigations, particularly aiming to improve the impact resistance of sandwich structures, including aluminum foams [1–9] and honeycombs [10–15]. Corrugated structures have been developed as light-weight core materials, providing light-weight and high crushing strength to the sandwich structures as similar with foams and honeycombs. Corrugated structures are manufactured easily into intricate geometries and have homogeneous macro-structure [16]. There have been apparently numerous experimental and numerical investigations and reviews in the literature on the quasi-static/dynamic mechanical and impact/blast loading responses of sandwich structures with periodic cellular metal cores, including honeycomb, corrugated and lattice truss topologies, for example see the review by Wadley in 2006 [17]. The most widely investigated topologies include V-type [18,19], U-type [20,21], X-type (diamond) [22] and Y-type [19,23,24] corrugated and pyramidal truss [16,25,26] structures. The previous experimental and accompanying numerical investigations were on the single layer corrugations; while, the effect of layering on the overall performance of multi-layer corrugated metal core sandwiches has not been investigated. In this study, the crushing responses of multi-layer 1050 H14 trapezoidal aluminum corrugated core sandwich structures were determined at quasi-static (10^{-3} and 10^{-1} s^{-1}) and dynamic strain rates (40 s^{-1}), both experimentally and numerically. In the previous studies, comparative studies were performed on the indentation and projectile impact behavior of layered corrugated aluminum and aluminum foam core sandwich panels [5,27]. This study is an extension of the pervious study and aims at determining and modeling the quasi-static and dynamic compression deformation behavior of multi-layer trapezoidal aluminum corrugated sandwiches. The comparisons between the mechanical responses of single- and multi-layer corrugated structures with and without aluminum sheet interlayers in two different core orientations were also presented. The effects of sandwich specimen assemble methods, namely adhesive bonding and brazing, on the crushing response were also assessed.

2. Sandwich structure construction

Multi-layer corrugated core sandwich structures were constructed by sequentially assembling 1050 H14 aluminum trapezoidal

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zig-zag corrugated aluminum fin layers (Fig. 1(a)), aluminum interlayer sheets and aluminum face sheets. The height, width and thickness of the fins in the corrugated aluminum layer are sequentially 9, 5 and 0.135 mm as shown in Fig. 1(b). The core layers are commercially produced by a local factory using a sheet metal forming press in the specified fin geometry for the heat exchangers. The zig-zag form of fins improves the heat conduction between layers. The thicknesses of aluminum interlayer sheets and face sheets were 0.5 mm and 1.5 mm, respectively.

The tested multi-layer corrugated core sandwich specimens consist of bonded/brazed seven corrugated fin layers in 0°/0° orientation, six interlayer sheets and two face sheets (Fig. 2(a) and (b)). The bonded panels were assembled using a Henkel Thomsit R710 polyurethane adhesive. Sandwich samples were also assembled through brazing in order to assess the effect of brazing on the crushing behavior. The brazing process was performed by the corrugated fin producer at 600 °C for 10 min under atmospheric pressure following the surface cleaning and flux slurry spraying. An aluminum 4343 alloy sheet was used as filler between layers with an amount of about 7 wt%. Multi-layer samples without interlayer sheet in 0°/0° and 0°/90° fin layer orientations were prepared using adhesive bonding (Fig. 2(c)). Single-layer sandwiches composing of a fin layer and two face sheets were prepared using the same adhesive and tested for comparison. The density of multi-layer corrugated sandwiches with interlayer sheets varies with the number of fin layers as shown in Fig. 3. The density of adhesively bonded sandwiches reaches almost a constant value of 0.35 g cm^{-3} after about 20 fin layers. The use of adhesive increases the density of multi-layer corrugated sandwich by 0.05 g cm^{-3}. The densities of tested brazed and polyurethane bonded sandwiches with interlayers were similar; ~0.39 g cm^{-3}, while the sandwiches without bonding layer were ~0.36 g cm^{-3}. The density of the corrugated fin layers without interlayer sheets was 0.115 g cm^{-3}, corresponding to a relative density of 0.042.

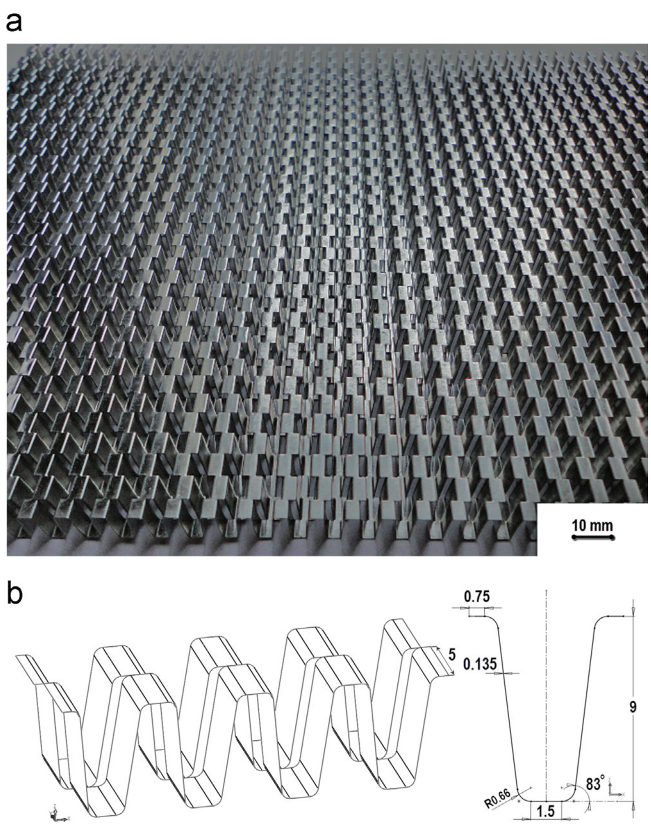

Fig. 1. (a) The picture of a corrugated fin layer and (b) isometric view and geometric variables of corrugated fin.

3. Experimental methodology

The quasi-static tensile stress–strain curves of 1050 H14 aluminum were determined at the strain rate of $10^{-3}\,s^{-1}$. The test specimens were machined in accord with ASTM E 8M-04 Standard [28]. The gage length and thickness were 60 and 1.5 mm, respectively. The displacements of test specimens were recorded using a video extensometer. The stress–strain behavior of 1050 H14 alloy after brazing was determined by testing the heat-treated tensile test specimens. These samples were heat treated at 600 °C for 10 min with the same heating and cooling rates applied in the brazing process.

The quasi-static compression tests on the adhesively bonded and brazed rectangular sandwich specimens ($50\times50\times70$ mm^3) were conducted at 10^{-3} and $10^{-1}\,s^{-1}$. The dynamic compression tests (40 s^{-1}) on the adhesively bonded and brazed rectangular sandwich specimens were performed in a FRACTOVIS drop weight tower. The main parts of the drop weight tower test machine, striker, platen, photocells and the bottom plate, are shown in Fig. 4(a). The striker was attached to a 45 kN piezoelectric force transducer. The striker velocity was measured by the photocells of drop weight tower. In a typical test, the specimen was placed on the bottom plate and the striker with an initially attained velocity crushed the specimen. The total mass of impact system

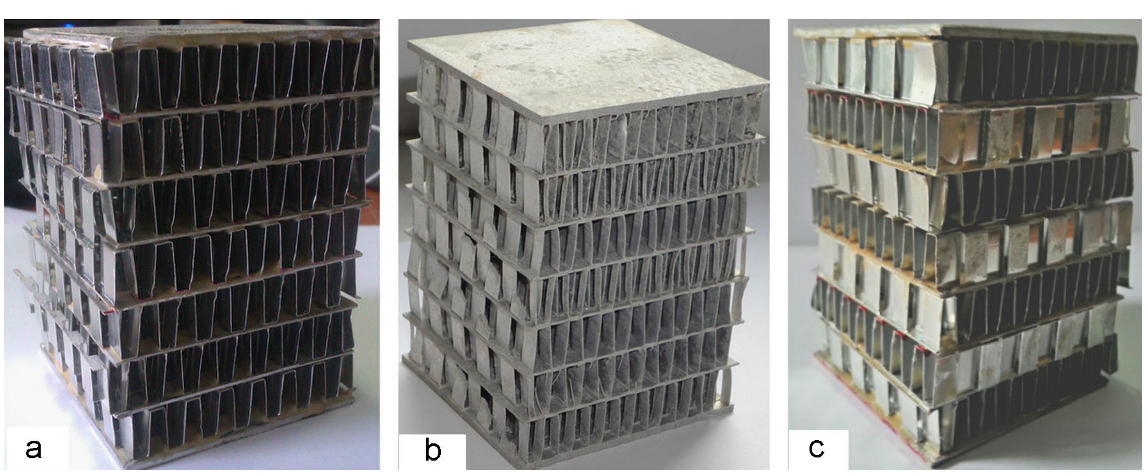

Fig. 2. Multi-layer corrugated sandwich specimens: (a) bonded 0°/0° oriented; (b) brazed 0°/0° oriented and (c) bonded 0°/90° oriented.

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