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Mechanical Behavior of Innovative Reinforced Aluminum Foam Panels

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Abstract. Metals foams are attracting great interest in aerospace, automotive and military fields. Particularly, the closed-cells aluminum foams are characterized by peculiar properties, such as low specific weight coupled with high energy absorption capacity, high specific stiffness and strength and reduced thermal and electrical conductivity. For the above reasons, aluminum foams can be effectively used as core of sandwich structures, replacing the traditional honeycomb and polymer-based foams. However, under specific loading conditions, the foam core was proved to collapse because of the bubble-cell structure, so affecting the mechanical performance of the sandwich constructions. Different solutions have been studying in literature to reinforce the foam-based core; for example, the authors in previous studies investigated the possibility to use a metal grid inside the core as a corrugated skeleton, to improve its behavior under compression. Therefore, based on these premises, the aim of this work is to improve understanding of the mechanical behavior of innovative reinforced aluminum foam panels through an experimental approach consisting of three-point bending tests. In particular sandwich structures with and without a corrugated grid structure, acting as skeleton inside the core, were manufactured. The bending properties were estimated also considering two different types of steel grid employed for the corrugated structure and for reinforcing the skins.

Introduction

Metal foams are a relatively new class of structural materials with low densities and novel physical, mechanical, thermal, electrical, and acoustic properties. They offer potential for lightweight structures, for energy absorption, and for thermal management and acoustic control [1]. Closed cells metal foams are made by cellular structures consisting of solid metal containing a large volume fraction of gas-filled pores, with properties depending on the nature of the metal and their morphology [2]. These characteristics make metal foams very attractive in engineering fields, especially in aerospace and automotive sectors [3].

Several metallic materials can be processed to make metal foams such as magnesium, lead, zinc, copper, bronze, titanium, steel and even gold. Among them, the aluminum alloys are largely employed for obtaining foams characterized by relatively high properties, such as low specific weight coupled with high energy absorption capacity, high specific stiffness and reduced thermal and electrical conductivity [4].

Aluminum foams can be manufactured through several ways and the gas-releasing particle decomposition in semi-solids, also known as powder compact melting technique (PCMT), was proved to be a consolidated process route [5]. Aluminum powders (typically Si-based Al alloys) are mixed with a foaming agent material (typically titanium hydride that starts to decompose at about 465°C), both in form of fine particles, to produce the so-called foamable solid precursor. Then, raising the temperature sufficiently to cause gas release and partial or full melting of the metal, allowing bubble growth. Under these conditions, the released gas forces the melting precursor material to expand, modelling a highly porous structure. Cooling, then, stabilizes the foam.

Aluminum foams manufactured through PCMT can be effectively used as core of sandwich structures, so replacing the traditional honeycomb and polymer-based foams. Compared to honeycomb, metal foams were proved to be more versatile and more performant to face mechanical transverse loads [6]. Moreover, more complex geometries can be obtained through metal foams that are difficult to model with honeycomb structures. Respect to polymeric foams, the metallic ones are characterized by a relatively higher stiffness to weight ratio and the thermal conductivity is at least an order of magnitude greater than their non-metallic counterparts, so they can provide fire protection, flame arrest, etc. [7].

Several studies were carried out in the last decades on the mechanical behavior of sandwich structures made of aluminum foam as core and polymer matrix composites or metallic solids as skins [8,9]. To the authors' best of knowledge, very few works have been carried out on reinforced aluminum foam samples with the skins constituting the sandwich made of lightweight metallic grid. This solution was proved to be capable of providing lightness and relatively higher thermomechanical properties [10]. For instance, Viscusi et al. [11] studied the bending behavior and the failure mechanisms of grid-reinforced aluminum foam cylinders through an experimental/numerical approach; Formisano et al. [12] investigated the collapse modes of innovative sandwich panels with aluminum foam as the core and stainless-steel wire mesh grid as the skins under three-point bending. The main results from these studies are that, under specific load conditions, the foam core can collapse because of the bubble-cell structure, so affecting the integrity and the mechanical performance of the sandwich constructions.

Different solutions have been studying in literature to reinforce the foam core keeping the lightweight conditions. For instance, Duarte et al. [13] studied the processing and the characterization of in-situ carbon steel bar reinforcing aluminum foams. In this study, the authors discussed the issues concerning the manufacturing procedure of the samples, also indicating the potential of reinforcing these materials. In line with this topic, Durante et al. [14] investigated the possibility of integrating a corrugated skeleton, made of stainless-steel grid, inside the foam constituting the core of a metal grid-reinforced sandwich, for the improvement of the compression strength of the samples.

Therefore, based on these preliminary results, the aim of this paper is to study more in details the mechanical behavior of innovative reinforced aluminum foam panels through an experimental approach. For this purpose, metal sandwich panels consisting of a core in aluminum foam, skins in stainless-steel wire mesh grid and a corrugated grid structure, acting as skeleton inside the core, were manufactured without the employment of a mold; the wire mesh grid was used as mold, in the sense that the aluminum alloy core foamed inside the mesh grid, incorporating it [15]. The grid used as mold can also offer the possibility of manufacturing sandwiches with complex geometries by using localized heating, with consequent customized production and cost-efficiency.

The bending behavior of these reinforced sandwiches was analyzed experimentally by comparing the mechanical performances of samples with and without the corrugated structure, using two different metal grids and by varying the span length.

Experimental Procedure

In this section, both the materials and the manufacturing processes developed to produce the innovative reinforced aluminum foam panels are described. Moreover, the mechanical tests carried out for the experimental campaign are detailed.

Materials and Manufacturing Processes. The sandwiches consist of a core in aluminum foam and skins in stainless-steel mesh grid. The same grid was also used to reinforce the core foam through a corrugated skeleton. The gas-releasing particle decomposition in semi-solids process was used for the foam production.

The foamable solid precursor, consisting of AlSi10 powder mixed with 0.8 wt. % of TiH_2 particles, was supplied by *Alulight Company*. As for the reinforcement used for the skins and the corrugated skeleton, a 0/90 stainless-steel wire mesh grid was employed, an elastoplastic material with isotropic hardening. Two different grids varying in mesh size (referred below as large and narrow grids) were used in this activity with the scope to study the core/reinforcement coupling and the effects on the bending performances.

The main properties of both the grid and the foam are reported in [11].

A piece of grid was cut creating a parallelepiped mold. The corrugated skeleton was realized with the same grid and placed into the parallelepiped together with the precursor of aluminum foam.

At this point, the foaming processes occurred for all the types of sandwich structures: i) without the skeleton and with narrow grids as skins (referred as N_S); ii) with both the corrugated skeleton and the skins made of narrow grids (referred as N_S+C) and iii) with both the corrugated skeleton and the skins made of large grids (referred as L_S+C). The charge was placed and left into a preheated 3 kW power muffle furnace. Time and temperature of foaming were estimated according to an experimental campaign of foaming tests; in particular, a temperature of 665°C was set for a time of 18 minutes. The amount of precursor used for all the types of structures was chosen to obtain a theoretical value of foam density equal to 0.6 g/cm^3.

Afterwards, the sandwich structures were extracted and cooled up to the room temperature; finally, they were milled along the lateral surfaces, to eliminate the wire mesh on these faces. In doing so, sandwiches with a thickness of 16 mm, a length of 250 mm and a width equal to 50 mm were manufactured. More details on the manufacturing process are reported in [15].

A schematization of the layout configurations of the sandwich structures along with the geometrical details of the involved grids is shown in Fig. 1.

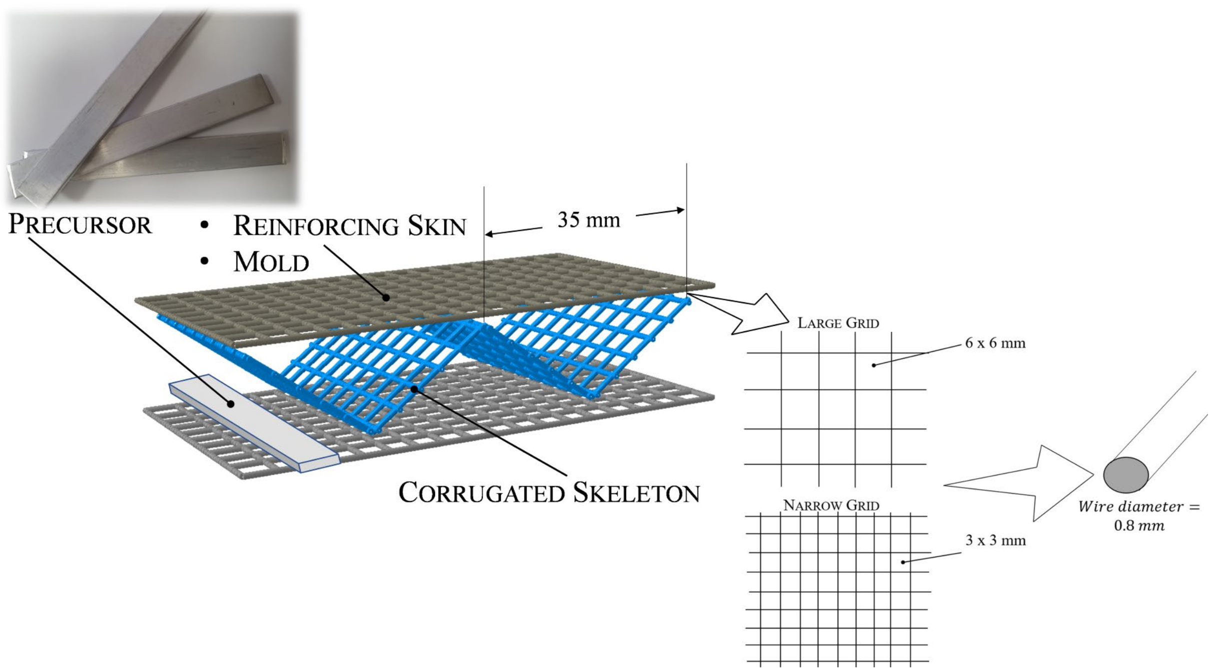

Fig. 1. Schematization of the layout configurations of the sandwich structure along with the geometrical details of the involved grids.

Mechanical tests. The mechanical behavior of the sandwiches was evaluated through three-point bending tests (see a detail of the test in Fig. 2), carried out according to ASTM C393 standards, by using an MTS Alliance RT/50 testing machine equipped with 50 kN load cell. A crosshead speed of 4 mm/min was set; the radiuses of the supports and the loading nose, namely, the cylindrical indenter, were 5 mm. The tests were performed by imposing two span lengths, namely 100 and 200 mm.

The load-deflection curves obtained from the tests were compared to highlight the influence of both the skeleton and the mesh size of the grid on the mechanical properties of the sandwiches. Three samples were tested for each type of specimen for the repeatability of the results.

Fig. 2. Three-point bending test (detail).

Results and Discussion

The tests on each sample typology showed a significant repeatability of the results, proving the effectiveness of the manufacturing method and the beneficial effects of the reinforcement on the mechanical behavior of aluminum foams [12].

Figs. 3 and 4 report the results obtained from the tests for a span length of 100 and 200 mm, respectively.

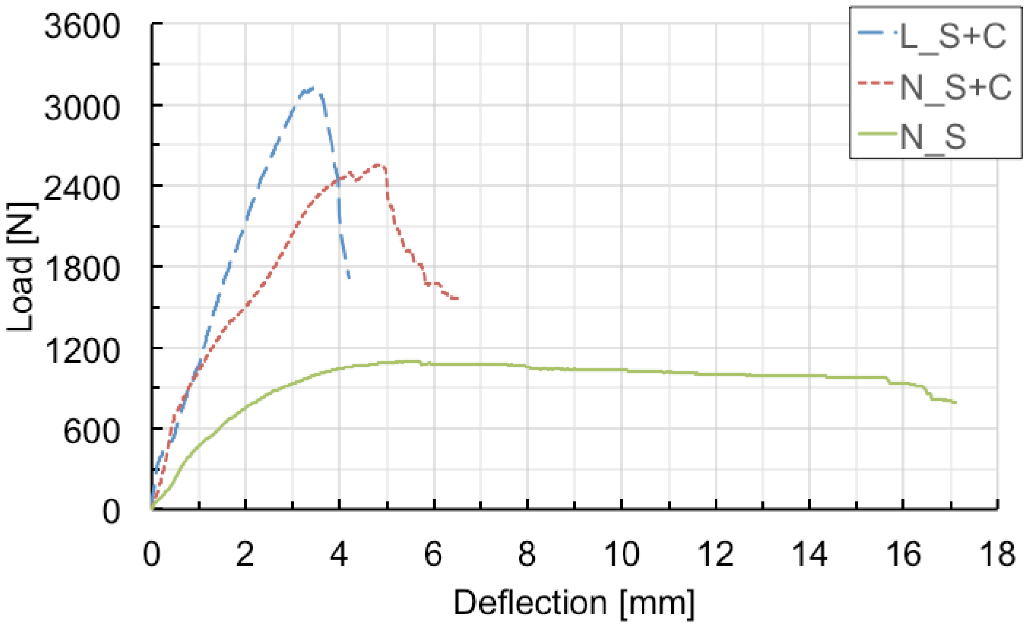

Fig. 3. Load-deflection curves from the three-point bending tests with a span length of 100 mm.

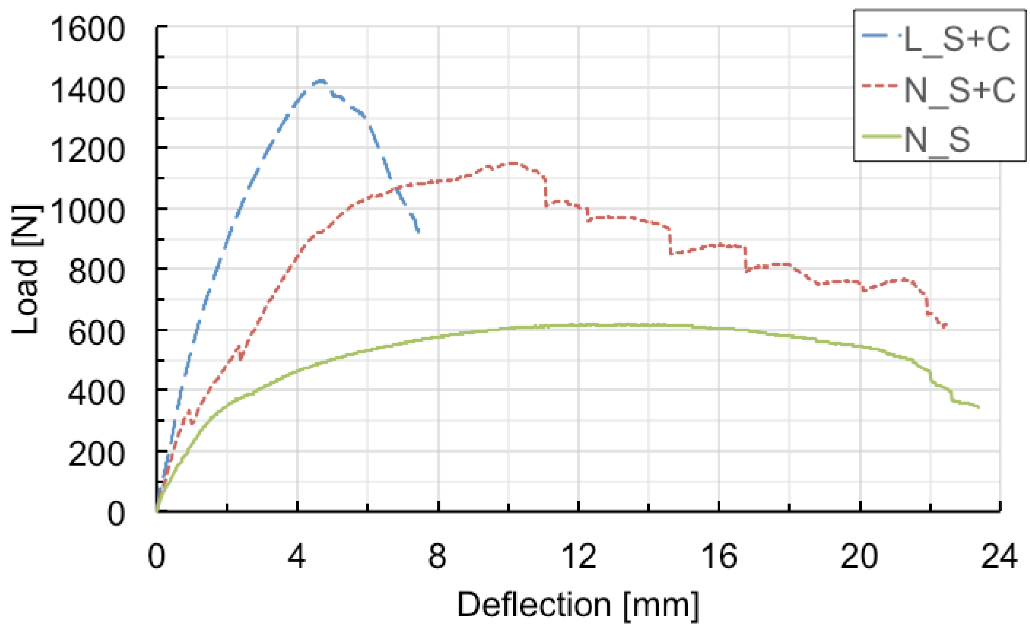

Fig. 4. Load-deflection curves from the three-point bending tests with a span length of 200 mm.

The L_S+C sandwiches experience face yielding for both the span lengths, with one only fracture starting from the face opposite to the indenter and propagating up to the central plane of the core.

Similar behavior was noted for the N_S sandwiches, with a beginning of indentation for the test with the shortest span, due to a highest maximum force. For these last types of sandwiches, the maximum value of the forces was significantly lower, compared to the corrugated ones, highlighting a huge contribution of the internal skeleton to the foamed core.

The failure mechanisms for the N_S+C corrugated sandwiches were more complex: for the tests with the longest span, a scrolling between the grid of the skeleton and the foam generated by shear stress determined a core collapse; for the test with the shortest span, a mix of indentation and shear failure occurred. These failure mechanisms, consequence of a poor filling of the meshes of the grid, occurred for lower force values, compared to the ones for the L_S+C sandwiches, characterized by a full fill of the meshes of the grid. Also the slope of the load-deflection curves for both the corrugated structures (L_S+C and N_S+C) is influenced by the different filling of the mesh grid.

In particular for N_S+C configuration, the stepping in the load deflection curve, after the peak load, is due to the progressive scrolling and detachment between the grid and the foam.

For both the corrugated sandwiches, the force to span ratio is higher in the tests carried out at short span, where the properties of the core are more relevant.

Conclusions

The aim of this work was to study the bending behavior of innovative sandwich panels consisting of a core in aluminum foam, skins in stainless-steel wire mesh grid and a corrugated grid structure, acting as skeleton inside the core. The effects of both the skeleton and the mesh size of the grid were highlighted. Based on the results presented and discussed in the previous sections, the following considerations can be drawn:

- The innovative PCMT method is effective in manufacturing the above-described reinforced structures in a one step process.
- The bending behavior of foam panels, already improved using the mesh grid as skins, can be further improved considering a corrugated grid structure as core reinforcement. The best results are obtained with the large grid.

- The influence of the corrugated skeleton is more evident in bending tests with a short span.

Future works can involve the FE (Finite element) modelling of the reinforced sandwiches, paying particular attention to the interaction between the reinforcement and the closed-cells aluminum foams. To this end, the modelling must be based on experimental results, along the lines of those above discussed. In doing so, the FE model can represent a potential tool to predict the mechanical behavior of these innovative reinforced sandwiches.

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