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Hybrid structures in Titanium-Lattice/FRP: effect of skins material on bending characteristics

Costanzo Bellini[a]*, Rosario Borrelli[b], Francesco Di Caprio[b], Vittorio Di Cocco[a], Stefania Franchitti[b], Francesco Iacoviello[a], Larisa Patricia Mocanu[a], Luca Sorrentino[a]

[a]*Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Cassino, Italy*
[b]*Manufacturing Processes on Metallic Materials Lab., CIRA, Capua, Italy*

Abstract

Lattice structures represent a valuable solution for applications demanding both high mechanical properties and lightweight. However, the skin is required to obtain uniformity of the load distribution and avoid stress concentration. The characteristics of the skin materials can influence the mechanical properties of the structure; therefore, in the present work the bending properties of various kinds of lattice-cored structures, with different skin materials, were investigated by means of experimental tests. In particular, flat lattice panels were produced by the Electron Beam Melting process. Then, composite material skins were added to these cores through the autoclave-vacuum bagging process. Three types of reinforcement were adopted for the skin: carbon, aramid, or glass, and the produced sandwich specimens were subjected to a three-point bending test in order to evaluate the flexural characteristics. The experimental tests showed that the specimens with the carbon skin were able to reach the maximum load, but presented the lowest ultimate transversal displacement. On the contrary, the aramid skins were characterized by the highest applied displacement and the lowest failure load.

Keywords: Additive manufactured lattice core; Composite material skin; Mechanical behaviour

* Corresponding author. Tel.: +39 0776 299 3617.
E-mail address: costanzo.bellini@unicas.it

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1. Introduction

The regulations in the transportation field are increasingly demanding more performances in terms of mechanical properties, lightweight, and reliability. These requirements can be satisfied by innovative hybrid structures that combine metallic lattice-like materials and composite materials. In fact, both types of material present high specific stiffness and strength; therefore, their synergic combination, in the form of cored structures, further increases the specific mechanical performances, especially under bending load conditions. The high specific mechanical properties of lattice structures are due to their particular morphology; in fact, they are made of several beams methodically positioned in space, as explained by Bellini et al. (2021). The lattice structures can be catalogued according to the geometry of their cell, that is a group of beams whose repetition forms the structure, as stated by Bellini et al. (2022). In the past, they were not so widespread since the relevant manufacturing processes were not enough developed. Today, additive manufacturing technologies offer new possibilities for lattice structures; in fact, they found applications in different fields, such as biomedical, aerospace, aeronautical, and automotive. To produce lattice core different traditional processes can be taken into consideration, such as machining, filament winding, and casting, as stated by Bellini and Sorrentino (2018), Fan et al. (2010), Queheillalt et al. (2008), but also innovative ones, like additive manufacturing, due to the increasing reliability that characterizes these processes, coupled to the capacity of producing very complex shape parts, as suggested by Dong et al. (2017). Moreover, even if the manufacturing process may introduce damage to the material, today there are post-processing techniques that are able to reduce this issue, as indicated by Benedetti et al. (2021) and Razavi et al. (2021). The technical solution investigated in this work, that is the construction of lattice cored structures with FRP (Fibre Reinforced Polymer) skins, is quite convenient from the point of view of processing, compared to honeycomb. As explained by Bellini et al. (2021), the common honeycomb cores must be shaped by the milling process if complex shape parts are to be produced, but this operation may damage the core itself; moreover, the honeycomb core may crush by the autoclave pressure, while lattice core is stronger.

Several research groups have investigated the mechanical characteristics of lattice structures created by additive manufacturing technologies and have published their findings in different publications. To establish the producibility limitations, Leary et al. (2016) created lattice structures using various geometrical factors such as beam diameter and cell type. Experiments were carried out by the same team in order to calculate the mechanical characteristics of the structures generated. Lampeas et al. (2019) created a simulation model for the additive manufacturing process, which was used to investigate the relationship between failure mechanism and process parameters. Epasto et al. (2019) conducted mechanical experiments on lattice structures made with various unit cell sizes and observed that the lattice with the largest cell had the worst mechanical behaviour. Using X-ray computed tomography, Liu et al. (2017) investigated process-induced flaws in a lattice structure, then evaluated the structures and linked the faults to the failure cause. To improve crush behaviour, Mahbod and Asgari (2019) proposed lattice frameworks with functionally graded porosity.

The aim of the present work consists in evaluating the effect of the skin material on the bending properties of hybrid structures presenting additively manufactured metal cores and FRP skins. There are several works concerning the comparison among the mechanical performance of different types of FRP, such as the work of Figlus et al. (2019), but very few are relevant to cored structures. This work is organized in several steps: first of all, there is the definition of the case study. In particular, the cell was identified in terms of type and dimensions, together with the geometry of the specimens to be tested and the materials to be considered for this work, that were titanium and different types of fibre composites. Then, the specimens were produced according to a two-step process: in the first one, the cores were manufactured through the EBM (Electron Beam Melting) process, an innovative powder bed additive manufacturing process. After, the skins were added by co-curing the prepreg layers on the cores. Finally, the produced specimens were tested, and the obtained results were presented and discussed.

2. Materials and methods

The characteristics of the lattice core are very important since they influence the mechanical peculiarities of the whole structure. As concerns the cell type, the octet-truss lattice was chosen. This cell is a centred face cubic cell, formed by 12 struts with an octahedron inside, as visible in Fig. 1. After several tests aimed at evaluating the possibility of removing the waste powder from the lattice, the cell side was chosen equal to 6 mm, while the truss diameter to 1 mm. The produced lattice core had a section of 30 mm x 9 mm and a length of 270 mm, while the skin thickness was equal to 1 mm for all types of material considered. The titanium powder adopted in the present research activity was made of the Ti6Al4V alloy, that is the most used titanium alloy in the aerospace and aeronautic field. As concerns the skins, three different types of fibre were taken into consideration: carbon, aramid and glass fibres. All the prepreg had an epoxy resin as matrix, and a satin weave fabric as reinforcement, except the carbon one that was a plain weave.

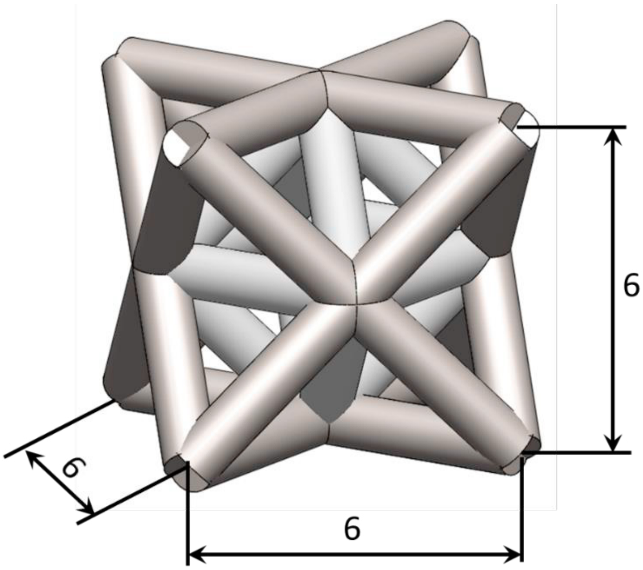

Fig. 1. The octet truss cell and its dimensions.

As concerns the manufacturing process of the cores, after having defined all the geometric parameters, the first step consisted in the creation of a virtual geometrical model. For this purpose, the Materialise Magics software was adopted, that was able to draw a lattice structure in a specific volume. Therefore, only the dimensions of the parallelepiped representing the core, the type of the cell, and the strut diameter were necessary. Once the CAD model was ready, it was exported in the slicing software of the 3D printer. The 3D printer adopted for this work was the ARCAM A2X, coupled with the Build Assembler slicing software. Then, the machine was prepared for the manufacturing run: the powder reservoirs were filled, and the process parameters were set. After the vacuum was drawn in the manufacturing chamber, the electron beam was calibrated, and the manufacturing chamber was preheated at 700 °C. As the imposed temperature was reached, the specimens were built according to the typical sequence of a powder bed additive manufacturing process. Once the process has ended, the chamber was cooled down to room temperature and the specimens were taken from the powder block and dusted in a pressurized air chamber, using also sandblasting machine. For a deeper cleaning operation, an ultrasound bath was used.

Then, further steps were required to create the composite skins. For this purpose, the prepreg-vacuum bag process was chosen: FRP prepreg plies were prepared and layered on the mould, together with the lattice core, as visible in Fig. 2a. The number of prepreg plies was chosen in order to obtain a thickness of about 1 mm for all the face sheets, so 5 plies were necessary for carbon skins, 4 for aramid ones and 9 plies for glass ones. This similarity was important to perform a meaningful comparison between the different types of specimens. All the layered specimens were covered with the release film and the breather fabric, and then the mould was closed with the vacuum bag, as shown in Fig. 2b. After the vacuum was drawn, the mould was positioned in the autoclave for the curing process.

The produced specimens, some of which are visible in Fig. 3, were tested according to the ASTM C393, that is the standard for the evaluation of the flexural behaviour of sandwich structures. In fact, the flat specimens considered in this work can be assimilated to a sandwich structure. Indeed, 3D printing is usually exploited for complex shape parts, but a flat shape was chosen for this mechanical behaviour analysis. The test scheme consisted in the typical three-point bending flexure: the specimen was placed on two supports and it was loaded in the centre by a loading nose. The span length was chosen equal to 216 mm, while the loading speed to 5 mm/min. After the start of the test, each specimen was loaded until the fracture.

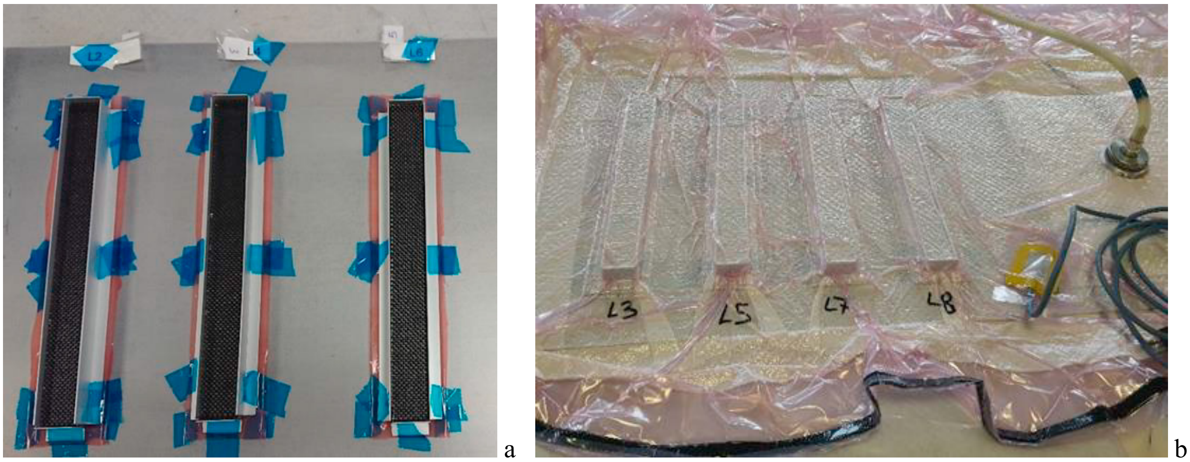

Fig. 2. The manufacturing process for hybrid parts: a) prepreg plies are laid on the flat mould, together with the core; b) vacuum bag is prepared for autoclave curing.

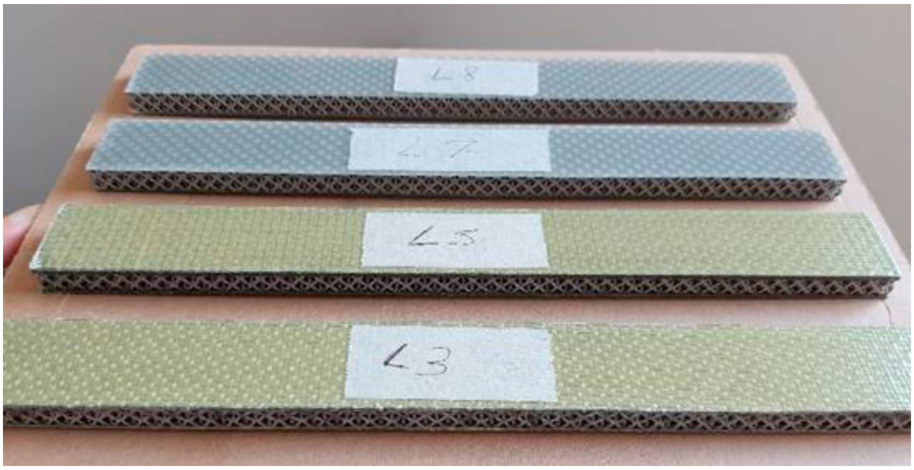

Fig. 3. Glass fibre and aramid fibre specimens.

3. Results

The data obtained from the experimental test campaign are reported in Fig. 4, in terms of load vs displacement. In particular, a single curve was plotted for each type of specimen, that was representative of the results relevant to the five specimens tested for each material. From the experimental data, it can be noted that the highest strength belonged to the carbon skin structure, that reached a maximum load of about 3000 N, while the lowest one was obtained by the aramid skin structure, with a value of less than 2100 N. As concerns the maximum displacement, the highest value was reached by the aramid specimen, and it was 21 mm, while the lowest value belonged to the carbon specimen, and it was 7 mm. The curves of the carbon and the glass specimens were characterized by a linear load increase, and the latter presented a sudden load drop to zero after the maximum point. The highest flexural rigidity, evaluated as the slope of the load increase section, was obtained by the carbon specimen, while the lowest by the glass one, even if the aramid specimen presented a minor slope in the second tract of the load increase.

However, another parameter should be considered in the present study: the weight, that is an important specification for the structures to be designed for aeronautic applications, as stated by Koziol (2019), and a performance index was defined for both the maximum load and the rigidity as the ratio between the property and the weight. As it can be seen from Table 1, where the values of all the above-mentioned quantities are reported, the same conclusions made before can be derived also for the performance index, because the weight was almost the same for all the specimens, and the carbon specimen was deemed the most performant. However, being the glass specimen the heaviest one, the difference from the aramid one is emphasised.

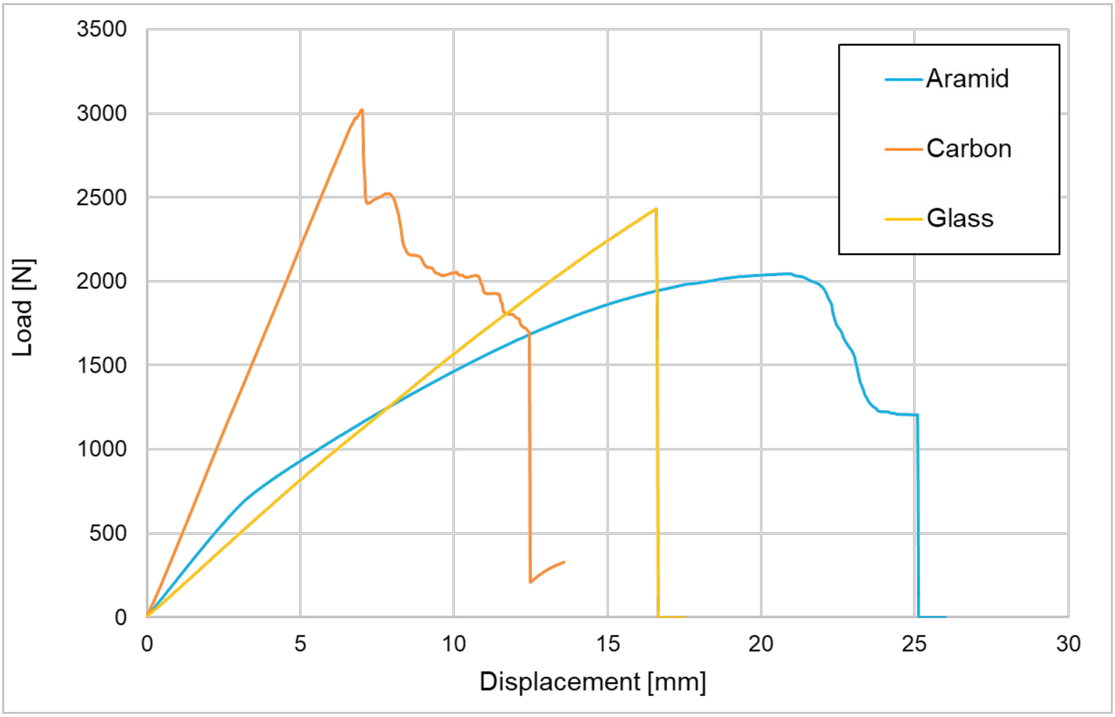

Fig. 4. Load-displacement curves for all the tested specimens.

Table 1. Performance indexes of the different specimens.

Specimen	Weight [g]	Max Load [N]	Performance index (Load) [N/g]	Rigidity [N/mm]	Performance index (Rigidity) [N/mm g]
Kevlar	94.01	2046.5	**21.77**	217.84	**2.32**
Carbon	97.03	3021	**31.14**	440.67	**4.54**
Glass	98.22	2433	**24.77**	146.76	**1.49**

4. Conclusions

The aim of the present work is to explore the effect of the skin material on the bending behaviour of metal lattice core structures. In particular, three different types of FRP (Fibre Reinforced Polymer) skins were considered: carbon, aramid and glass fibre, and the core was made of titanium alloy. The specimens were produced in a two steps process: at first, the cores were realized through EBM (Electron Beam Melting) process, and then the composite material skins were added through autoclave vacuum bagging. The three-point bending test carried out on all the produced specimens highlighted a better flexural behaviour of the carbon skin ones, that presented the highest maximum load and the maximum rigidity. In fact, the maximum load of the carbon specimens was 32% and 19% higher than that of the aramid and glass ones, respectively. As concerns the rigidity, that one of the carbon specimens was 51% and 67% higher than that of the aramid and glass ones, respectively.

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