Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 47 (2023) 623–629

Structural Integrity Procedia

www.elsevier.com/locate/procedia

27th International Conference on Fracture and Structural Integrity (IGF27)

In-plane flexural behaviour of a hybrid titanium lattice/FRP short beam

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

A solution to meet higher performances in terms of mechanical properties and lightweight is the adoption of innovative hybrid structures made of metallic lattice core and composite material skins, because both of them are characterised by high specific strength and stiffness. Flexural load is a stress configuration commonly present in structural frame parts of vehicles; however, the out-of-plane load arrangement has often been considered, while in-plane one has been never analysed. Therefore, in this work, attention was paid to this latter configuration, and a short beam specimen was considered. A comparison between the mechanical answer of two types of skin materials, CFRP (Carbon Fiber Reinforced Polymer) and AFRP (Aramid Fiber Reinforced Polymer), was carried out. For both CFRP and AFRP a similar maximum load was recorded, even if that one of the latter was slightly higher, as well as the maximum displacement at break was the same for both types of specimens. As concerns the shape of the load-displacement curves, a sudden load drop after the attainment of the maximum load was observed. The increasing load section of the curves was characterised by an initial linear part (even if a slight deviation from linearity was noted) followed by a first minor load drop, probably due to the fibres' breakage. The subsequent part showed a non-linear load increase with other load drops: also in this case, this trend was caused by fibres' breakage.

Keywords: Additive manufacturing; composite material; hybrid structures; in-plane mechanical behaviour.

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

10.1016/j.prostr.2023.07.060

1. Introduction

The requirements for mechanical characteristics, lightweight, and security are being raised under regulations in the transportation sector. Innovative hybrid architectures that mix metallic lattice-like materials and composite materials can meet these needs. Since both types of materials exhibit high specific stiffness and strength, their synergistic combination, in the form of cored structures, improves specific mechanical performances, particularly under bending stress situations. According to Bellini et al. (2021), lattice structures are constructed of several beams that are methodically positioned in space, which is why they have high specific mechanical qualities. According to Bellini et al. (2022), the lattice structures can be categorised based on the geometry of their cell, which is a collection of beams whose repetition creates the structure. These structures were not so common in the past because the associated production techniques were not sufficiently advanced. Lattice structures today have new possibilities because of additive manufacturing technology; in fact, they have found use in a variety of industries, including biomedical, aerospace, aviation, and automotive. According to Fan et al. (2010), Bellini and Sorrentino (2018), and Queheillalt et al. (2008), different traditional processes, such as filament winding, machining and casting, as well as more advanced ones, like additive manufacturing, can be used to produce lattice cores. This is because these latter processes are becoming more reliable and have the ability to produce very complex shape parts, as indicated by Dong et al. (2017). Furthermore, although the production process may result in material damage and part defects, post-processing methods are currently available that might mitigate this problem, as stated by Razavi et al. (2021) and Benedetti et al. (2021). There are several additive manufacturing techniques, but only some of them are suitable for metal materials. Among them, the EBM (Electron Beam Melting) was used in this study. In comparison to honeycomb, which represents one of the most widespread materials for the production of cores, the technical method studied in this work - building lattice cored structures with FRP (Fibre Reinforced Polymer) skins - is relatively straightforward in terms of processing. According to Bellini et al. (2021), the common honeycomb cores must be milled into complex shapes in order to make the parts, but this operation may harm the core itself. On the contrary, lattice core can be produced in the final shape. In addition, the honeycomb core may be crushed by the pressure in an autoclave, while the lattice core is more robust.

The mechanical properties of lattice structures produced by additive manufacturing processes have been studied by several research groups, and their findings have been reported in a variety of publications. Leary et al. (2016) used several geometrical parameters, such as beam diameter and cell type, to form different lattice structures in order to determine the producibility restrictions. The same team conducted experiments to determine the mechanical properties of the structures produced. A numerical model for the simulation of additive manufacturing processes was developed by Lampeas et al. (2019) to examine the association between failure mechanism and process variables. Mechanical tests were performed on lattice structures created using different unit cell sizes by Epasto et al. (2019), who found that the biggest cell size resulted in the worst mechanical behaviour. Liu et al. (2017) analysed process-induced defects in a lattice structure employing X-ray computed tomography, subsequently evaluated the mechanical behaviour of the structures and connected the flaws to the failure cause. Mahbod and Asgari (2019) developed lattice frames with functionally graded porosity to enhance the mechanical answer to crushing.

The current study's objective is to assess how the skin material affects the bending characteristics of hybrid constructions with FRP skins and additively built metal cores. Many papers compare the mechanical behaviour of various forms of FRP, like that of Figlus et al. (2019) and Koziol (2019); however, relatively few of these studies are pertinent to cored structures. Flexural load is a stress configuration commonly present in structural frame parts of vehicles. However, the out-of-plane load arrangement has often been considered, that is a load parallel to the skins' thickness direction, while the perpendicular direction, that is the in-plane one, has never been analysed. Therefore, in this work attention was paid to this latter configuration, and a short beam specimen was considered. A comparison among the mechanical answer of two types of skin materials, CFRP (Carbon Fibre Reinforced Polymer) and AFRP (Aramid Fibre Reinforced Polymer), was carried out too.

The organisation of this article has been divided into various parts, starting with the definition of the case study in the "materials and methods" section. The cell was specifically identified in terms of its kind and dimensions, as well as the geometry of the specimens that would be tested and the materials that would be taken into consideration for this task, which included titanium and various fibre composites. The specimens were then created using a two-step procedure: in the first, the cores were made using the EBM process. Then, the prepreg layers were layered on the cores and co-cured in an autoclave. Finally, the manufactured specimens were tested by considering a three-point bending load procedure, and the findings were presented and discussed in the "results" section.

2. Materials and Methods

In this study, the three-point bending test was used to evaluate the short-beam flexural characteristics of two different types of sandwich structures. The difference between them was in the material of the skins: in one case, it was AFRP, while in the other, it was CFRP. Both types of structures had a lattice titanium core, and short beam specimen was considered for the flexural loading test. The lattice core was constructed using the octet-truss cell as the unit cell since it is one of the most popular due to its superior mechanical qualities. The cell is made up of two lattice solids: the inner one is an octahedron and the outer one is a cube with centred faces. The cell had an edge length of 6 mm and was composed by 36 trusses with a diameter of 1 mm, as visible in Fig. 1, while the specimen core had a section of 10x9 mm^2 and a length of 30 mm. Ti6Al4V alloy powder served as the base for the lattice, while the skins were made of CC202-ER450 prepreg or AA285-ER450 prepreg for the CFRP and AFRP specimens, respectively. The connection between the composite material skin and the titanium lattice was assured by structural adhesive, that was the Hexcel Hexbond ST 1035 epoxy film adhesive.

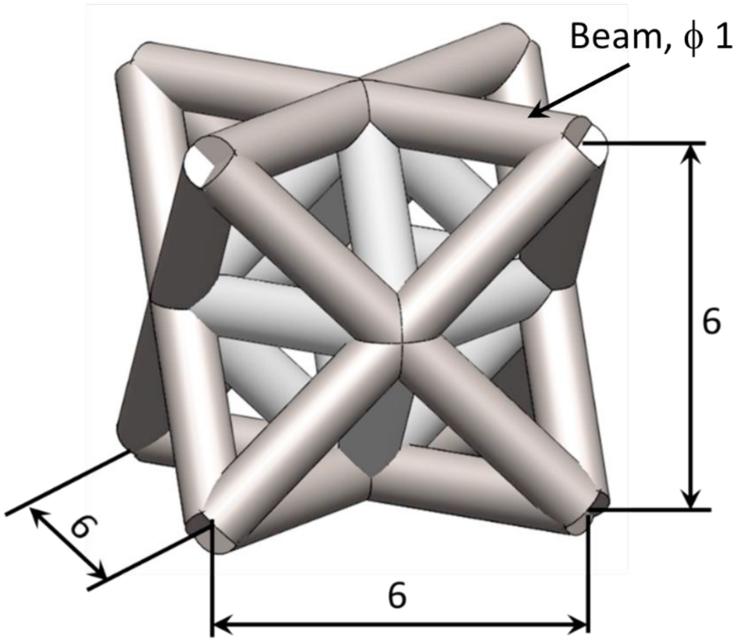


Fig. 1. Geometrical characteristics of octet truss cell (dimensions in mm).

The EBM process, which is one of the most used additive manufacturing techniques in the aerospace industry because of its unique properties deeply described in Franchitti et. al (2018), was utilised to create the lattice core. The initial phase was building a digital geometric model. The Materialise Magics software, which was capable of modelling a lattice structure in an isolated volume, was used for this purpose. Therefore, all that was required were the parameters of the parallelepiped that represented the core, the cell type, and the beam diameter. The Magics Materialise software was used to import the finished CAD model and design the build. The software Materialise Build Assembler and EBM control 3.2 were used for slicing and setting the process themes, respectively. The ARCAM A2X EBM system was then set up for the manufacturing run, and the hoppers were filled with powder. The production chamber vacuum was drawn before the electron beam calibration, and then the platform was preheated. The specimens were produced in accordance with the standard procedure of a powder bed additive manufacturing process as soon as the pre-heating temperature (about 700°C) was met. After the procedure was complete, the chamber was cooled to room temperature and the samples were removed from the powder block and cleaned using sandblasting equipment and a pressurised air chamber (Powder Recovery System). An ultrasonic bath was employed for a more profound cleaning procedure.

The composite skins had to be made after that, which required additional stages. The prepreg-vacuum bag procedure was selected for this purpose; FRP prepreg plies and the lattice core were made and stacked on the mould. The number of prepreg plies was determined to be 5 for carbon skins and 4 for aramid skins in order to achieve a thickness of approximately 1 mm for all of the face sheets. The ability to compare the various specimen kinds in a meaningful way required this similarity. All of the stratified specimens got covered with breather fabric and release film before the vacuum bag was used to seal the mould. The mould was placed in the autoclave for the curing process after the vacuum was drawn.

The produced specimens, some of which are visible in Fig. 2, were tested according to the three-point bending scheme: the specimen was placed on two supports and it was loaded in the centre by a loading nose. This test is commonly used for sandwich structures, but usually the out-of-plane properties are determined. As aforesaid, in this work the in-plane characteristics are studied, therefore the load was applied perpendicularly to the skin direction, as visible in Fig. 3. The span length was chosen equal to 20 mm, while the loading speed to 2 mm/min. After the start of the test, each specimen was loaded until the fracture.

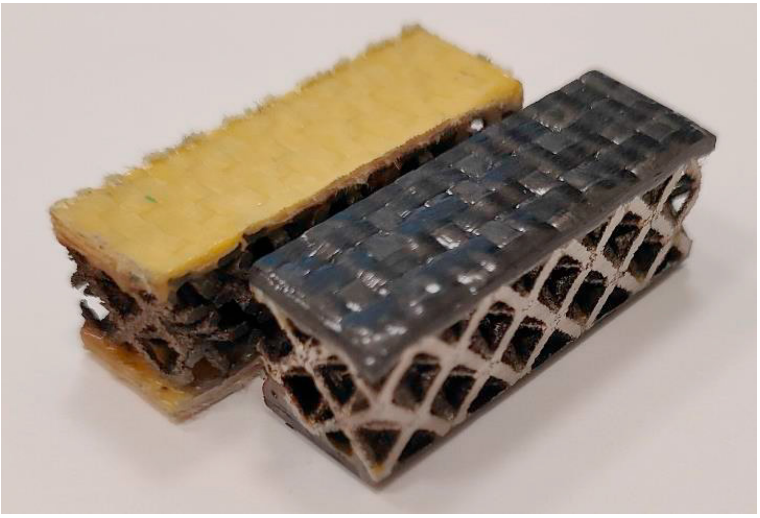


Fig. 2. Carbon fibre and aramid fibre short beam specimens.

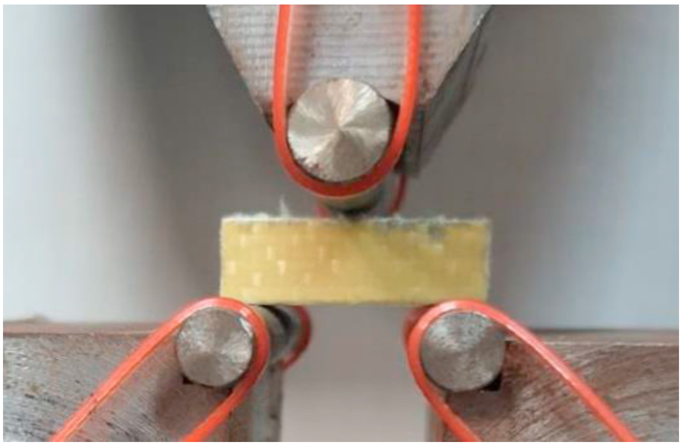


Fig. 3. Three-point bending test.

3. Results

The load-displacement curves found for both the CFRP and AFRP short beam specimens are reported in Fig. 4. It should be noted that each type of specimen is only represented by one curve in the chart of this figure in order to minimise overcrowding and improve readability. The experimental data acceptable repeatability, which was lower than 10%, made this simplification practicable. For both CFRP and AFRP a maximum load of about 4000 N was recorded, even if that one of the latter was slightly higher. The maximum displacement at break was the same for both types of specimens, and it was equal to 1.8 mm. As concerns the shape of the curves, a sudden load drop after the attainment of the maximum load can be observed. The increasing load section of the curves was characterised by an initial linear part (even if a slight deviation from linearity can be noted) followed by a first minor load drop, probably due to the breakage of some fibres. The subsequent part showed a non-linear load increase with other load drops: also in this case, this trend is caused by the breakage of more other fibres.

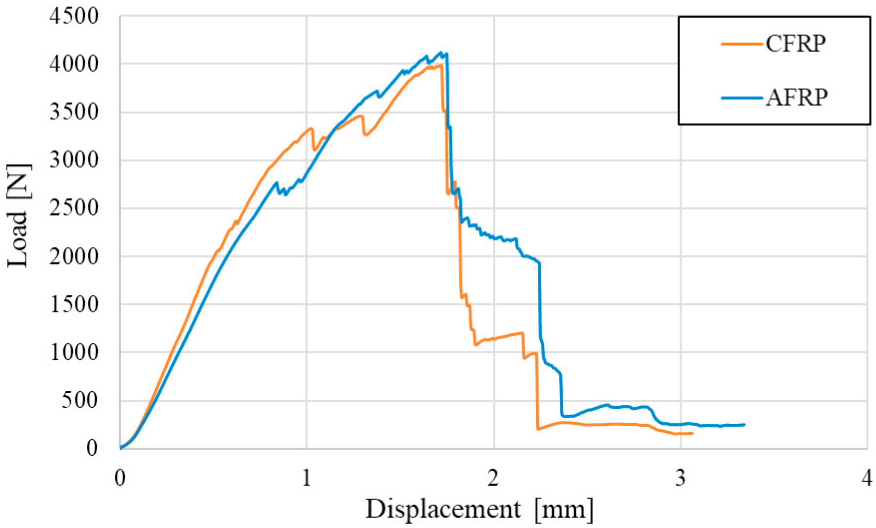
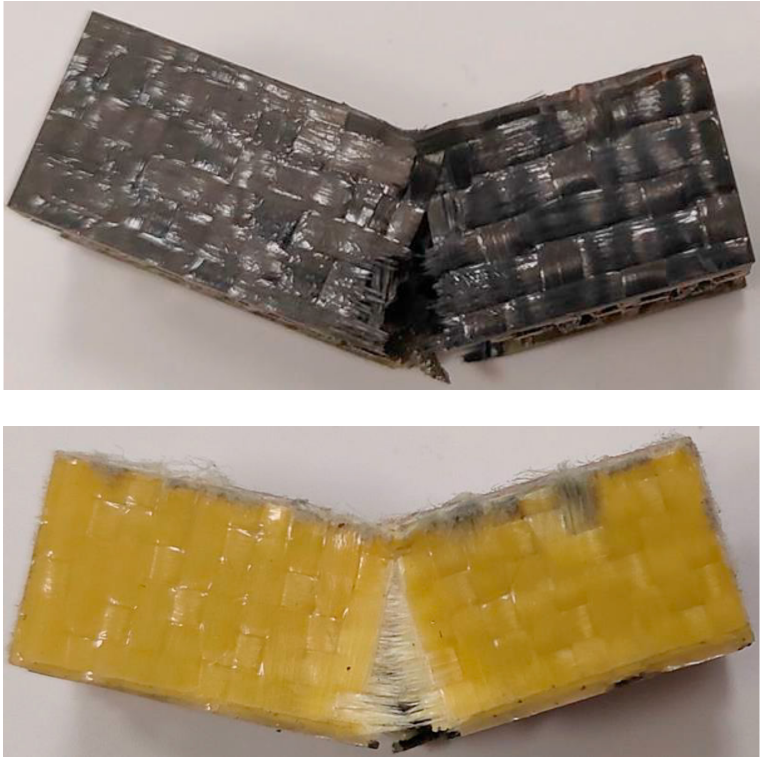


Fig. 4. Three-point bending test results.

Some images of the fracture zone were taken to inspect the fracture mode. As concerns the carbon specimens, visible in Fig. 5a, the fibre failure was observed only in the lower part of the specimens, while fibre wrinkling was noted in the upper zone, just below the loading nose. The most interesting thing to highlight is that a sharp fibre fracture was observed in the lower part. As concerns the aramid specimen, visible in Fig. 5b, also in this case the fibre tensile failure was observed, as for the carbon one, in the lower zone, together with fibre wrinkling in the upper one. The fracture surface of the carbon laminate was sharp and clean, while for the aramid a kind of fraying of the fibres was observed.

4. Conclusions

A study about the in-plane flexural behaviour of different FRP (Fibre Reinforced Polymer) -titanium structures is presented in this work. In particular, two different types of FRP skins were considered: carbon and aramid fibres, while the core, presenting a lattice structure, was made of titanium alloy. The lattice cores were made through EBM (Electron Beam Melting) process, an additive manufacturing technique, while the skins were added through autoclave vacuum bagging. The experimental tests evidenced very similar mechanical properties for CFRP and AFRP structures, with a similar load-displacement trend, even if the aramid one demonstrated a higher residual load capacity. However, different damage mechanisms were observed for the tensile failed fibres: the carbon fibre specimen presented a sharp fibre fracture, while for the aramid ones a frying was observed.



a

b

Fig. 5. Fractured samples: a) carbon specimen, b) aramid specimen.

Acknowledgements

This research was supported by POR FESR Lazio 2014-2020, Strategic Projects-AoS Aerospace [AMHybridStructures project, 28143, rif. G06734/2020].

References

Bellini, C., Borrelli, R., Di Cocco, V., Franchitti, S., Iacoviello, F., Mocanu, L. P., Sorrentino, L., 2021. Failure Energy and Stiffness of Titanium Lattice Specimens Produced by Electron Beam Melting Process. Material Design and Processing Communications 3, e268.

Bellini, C., Borrelli, R., Di Cocco, V., Franchitti, S., Iacoviello, F., Sorrentino, L., 2021. Damage Analysis of Ti6Al4V Lattice Structures Manufactured by Electron Beam Melting Process Subjected to Bending Load. Material Design and Processing Communications 3, e223.

Bellini, C., Borrelli, R., Di Cocco, V., Franchitti, S., Iacoviello, F., Sorrentino, L., 2022. Titanium Lattice Structures Manufactured by EBM Process: Effect of Skin Material on Bending Characteristics. Engineering Fracture Mechanics 260, 108180.

Bellini, C., Sorrentino, L., 2018. Characterization of Isogrid Structure in GFRP. Frattura ed Integrità Strutturale 46, 319–331.

Benedetti, M., du Plessis, A., Ritchie, R. O., Dallago, M., Razavi, S. M. J., Berto, F., 2021. Architected Cellular Materials: A Review on Their Mechanical Properties towards Fatigue-Tolerant Design and Fabrication. Materials Science and Engineering R: Reports 144, 100606.

Dong, G., Tang, Y., Zhao, Y. F., 2017. A Survey of Modeling of Lattice Structures Fabricated by Additive Manufacturing. Journal of Mechanical Design, Transactions of the ASME 139 (10), 100906.

Epasto, G., Palomba, G., D'Andrea, D., Guglielmino, E., Di Bella, S., Traina, F., 2019. Ti-6Al-4V ELI Microlattice Structures Manufactured by Electron Beam Melting: Effect of Unit Cell Dimensions and Morphology on Mechanical Behaviour. Materials Science and Engineering A 753, 31–41.

Fan, H. L., Zeng, T., Fang, D. N., Yang, W., 2010. Mechanics of Advanced Fiber Reinforced Lattice Composites. Acta Mechanica Sinica 26, 825–835.

Figlus, T., Kozioł, M., Kuczyński, Ł., 2019. The Effect of Selected Operational Factors on the Vibroactivity of Upper Gearbox Housings Made of Composite Materials. Sensors 19 (19), 4240.
Franchitti, S., Borrelli, R., Pirozzi, C., Carrino, L. Polini, W., Sorrentino, L. Gazzerro, A., 2018. Investigation on Electron Beam Melting: Dimensional accuracy and process repeatability. Vacuum 157, 340-348.
Koziol, M., 2019. Evaluation of Classic and 3D Glass Fiber Reinforced Polymer Laminates through Circular Support Drop Weight Tests. Composites Part B: Engineering 168, 561–571.
Lampeas, G., Diamantakos, I., Ptochos, E., 2019. Multifield Modelling and Failure Prediction of Cellular Cores Produced by Selective Laser Melting. Fatigue and Fracture of Engineering Materials and Structures 42(7), 1534–1547.
Leary, M., Mazur, M., Elambasseril, J., McMillan, M., Chirent, T., Sun,Y., Qian, M., Easton, M., Brandt, M., 2016. Selective Laser Melting (SLM) of AlSi12Mg Lattice Structures. Materials and Design 98, 344–357.
Liu, L., Kamm, P., García-Moreno, F., Banhart, J., Pasini, D., 2017. Elastic and Failure Response of Imperfect Three-Dimensional Metallic Lattices: The Role of Geometric Defects Induced by Selective Laser Melting. Journal of the Mechanics and Physics of Solids 107, 160–184.
Mahbod, M., Asgari, M., 2019. Elastic and Plastic Characterisation of a New Developed Additively Manufactured Functionally Graded Porous Lattice Structure: Analytical and Numerical Models. International Journal of Mechanical Sciences 155, 248–266.
Queheillalt, D. T., Murty, Y., Wadley, H. N. G., 2008. Mechanical Properties of an Extruded Pyramidal Lattice Truss Sandwich Structure. Scripta Materialia 58(1), 76–79.
Razavi, S. M. J., Avanzini, A., Cornacchia, G., Giorleo, L., Berto, F., 2021. Effect of Heat Treatment on Fatigue Behavior of As-Built Notched Co-Cr-Mo Parts Produced by Selective Laser Melting. International Journal of Fatigue 142,105926.