MECHANICAL RESPONSE OF PYRAMIDAL LATTICE TRUSS CORE SANDWICH STRUCTURES BY ADDITIVE MANUFACTURING

Ge Qi[1], Bin Ji[2], Han Han[2], Bing Wang[1], Li Ma[1*]

[1] Center for Composite Materials, Harbin Institute of Technology, Harbin, PR China.
[2] Aerospace System Engineering Shanghai, Shanghai, PR China
* Corresponding author (mali@hit.edu.cn)

Keywords: Sandwich structures, Pyramidal truss, Additive manufacturing, Mechanical properties

ABSTRACT

It has been demonstrated that stretching-dominated materials are much more weight-efficient and can facilitate multifunction integration than the conventional bending-dominated cellular solids, however, with some difficulty in fabrication. In this study, metallic pyramidal lattice truss core sandwich structures are fabricated from EOS Aluminium AlSi10Mg, utilizing additive manufacturing method. Out-of- and in- plane compression as well as shear tests were carried out in order to measure the stiffness and strength properties of the structures. The out-of-plane compressive strength is determined by buckling of struts, and samples fail in macro buckling in in-plane tests. The shear strength of the samples is dominated by the node failure. The measurements indicate that lattice truss materials fabricated by additive manufacturing method is characterized by excellent process stability, providing new opportunities for cellular solids.

1 INTRODUCTION

Lightweight sandwich structures, comprising of two thin but stiff face-sheets and ultra-low-density cellular material cores, possess superior mechanical characteristics, including excellent strength-to-weight ratios and high stiffness-to weight ratios, which are the most popular choices in engineering applications, ranging from aerospace industries to food technology [1]. Cellular material cores can be divided by topology configuration, as either stochastic foams, such as metallic foam or micro-architectured lattice materials, such as the hexagonal honeycomb and lattice truss materials. A large amount of research has been conducted on the cellular solids based on both theoretical analysis and experimental tests. It is proved that the stretching-dominated lattice truss materials are much more weight-efficient for structural applications than the conventional bending-dominated cellular solids [2, 3]. Additionally, the open and connected interior space can facilitate multifunction integration, such as thermal management, morphing capabilities and catalyst support.

Despite their fascinating properties, there are few examples that fully leverage the lattice truss core sandwich structures in extensive industrial or general public use [4]. An inevitable reason is that the manufacturing complexity of lattice truss cores results in certain restrictions for application, due to the complicated and precise geometric shapes. As the innovation of product and process, there is a growing consensus that additive manufacturing methods, which is colloquially referred to as 3D printing techniques, will provide tremendous flexibility in achieving controlled composition, architecture feature as well as function, compared with conventional manufacturing technologies [5]. It implies that lattice truss materials with a variety of topologies, such as tetrahedral, pyramidal as well as Kagome, can be fabricated with a rapid processing cycle and less manpower at both macro- and micro-scales.

In this investigation, pyramidal lattice truss core sandwich structures via additive manufacturing method. The properties were presented utilizing a series of experimental testing and failure modes as well as strength of the structures were given.

2 MATERIAL AND EXPERIMENTAL TESTS

Metallic pyramidal lattice truss core sandwich structures are designed and fabricated from EOS Aluminium AlSi10Mg, utilizing additive manufacturing. A schematic illustration of the pyramidal cell is shown in Fig. 1 together with a coordinate system. The struts have circle cross section, including constant and variable configurations, with relevant geometric parameters.

The lattice truss sandwich structure prototype were modelled for different sizes of unit cells with the use of a 3D modelling computer-aided-design (CAD) software package Pro/ENGINEER. Then, STL-files for the 3D models were imported into EOSINT M systems (Hangxin Technology Co., Ltd) and dissected into slice wise information, based on which, metal powder was attached, melted and built layer by layer for fabrication. Fine aluminium alloy powder EOS Aluminium AlSi10Mg (Hangxin Technology Co., Ltd) are employed in this study for processing. The corresponding geometric parameters defining each of the samples in the tests are summarized in Table 1. A series of experimental tests, including out-of- and in-plane compression, as well as in-plane shear, were carried out in order to determine the stiffness and strength properties of the structures.

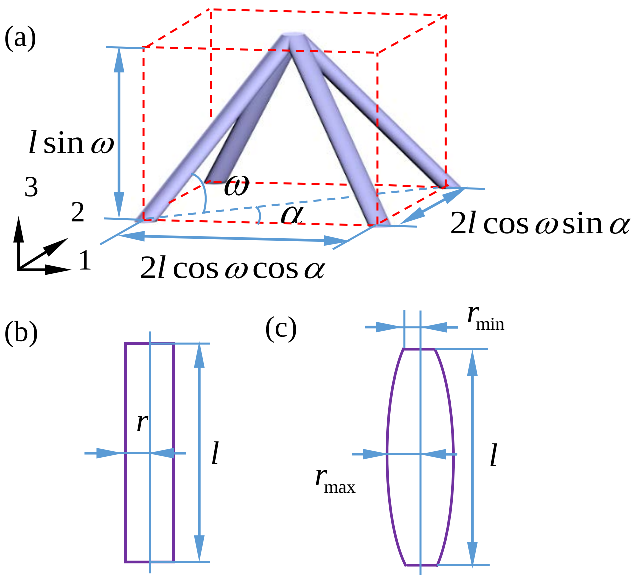


Figure 1: A schematic illustration of (a) a pyramidal cell and geometries of (b) constant as well as (c) variable cross section strut.

Type	ω	α	l	r
O-C	45°	45°	21.213	1.000
O-V	45°	45°	21.213	r_{max} =1.421 r_{min} =0.397
I-M	35°	30°	5.230	0.4
I-S	45°	45°	21.213	1.000

Table 1: Dimensions for the pyramidal lattices in this study (unit: mm)..

3 RESULTS

The measurements show that pyramidal lattice truss core sandwich structures by additive manufacturing own great mechanical properties and the results present good consistency and repeatability.

For out-of-compression testing, the failure modes of the single-layered is shown in Fig. 2, while the response curves are shown in Fig. 3. For the sample O-C, the buckling of struts could be viewed with the compressive of 3.18MPa, corresponding to the literature [6]. On the basis of this, variable cross section samples with spindle-shape struts might be stronger than their constant cross section counterparts, attributing to higher second area moments in the middle of the struts. However, the thinner and softer struts at the nodes resulted to earlier failure with a lower level of compressive strength of 2.75MPa.

(a)

(b)

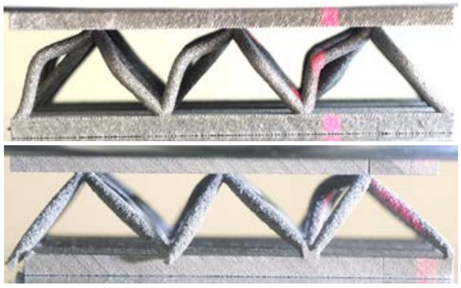
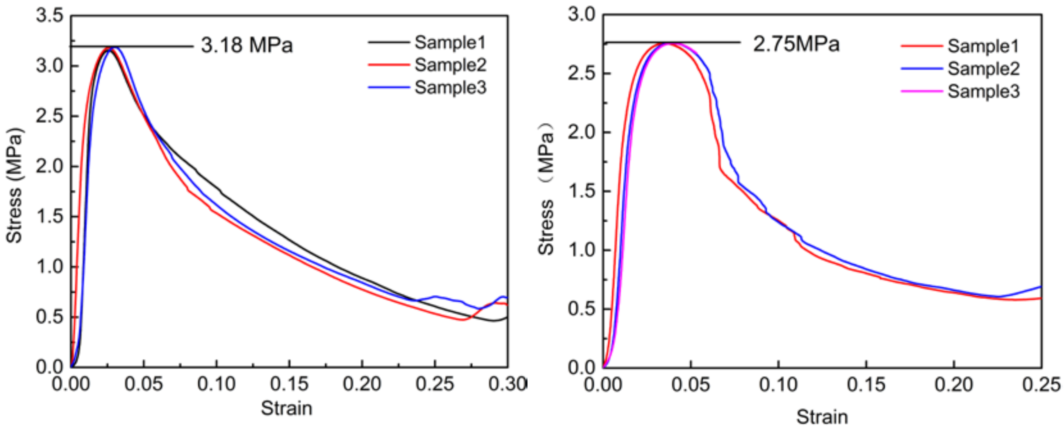


Figure 2: Optical image of (a) sample O-C and (b) sample O-V.



(a) (b)

Figure 3: Response curves of (a) sample O-C (b) sample O-V.

Then, Fig. 4 taken during the in-plane compression tests revealed that failure were caused by macro buckling. The multi-layered lattice truss sandwich columns failed due to macro buckling and the ultimate load is 48.78kN.

(a)

(b)

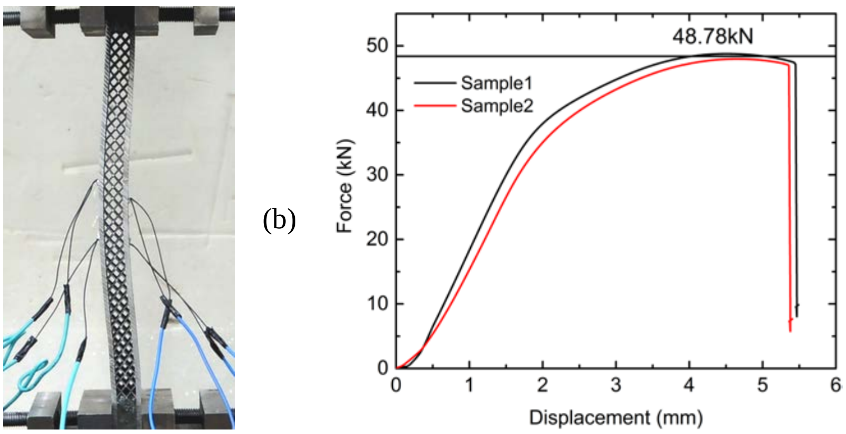


Figure 4: In-plane measurements of sample I-M. (a) Photograph of the failure mode; (b) Response curves of the tests.

Failure mode of in-plane shear testing presented debonding failure between nodes and face-sheets, as shown in Fig. 5(a) and the stress-strain curves are given in Fig. 5(b). The shear strength of the samples in this study is 1.78MPa, implying that additive manufacturing method could not increase the node strength directly and more design and fabrication work should be done to improve it.

(a) (b)

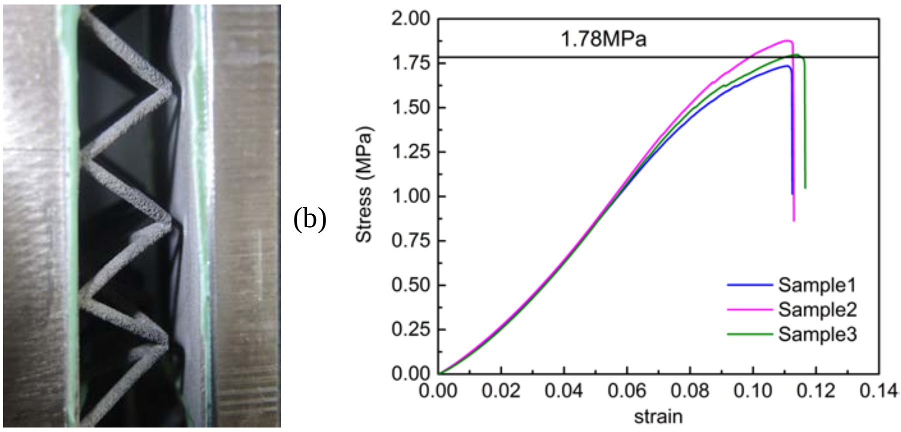


Figure 5: Shear measurements of sample I-S. (a) Photograph of the failure mode; (b) Response curves of the tests.

4 CONCLUSIONS

Metallic pyramidal lattice truss core sandwich structures are fabricated utilizing additive manufacturing method. The experimental investigations including out-of- and in- plane as well as shear tests demonstrates that additive manufacturing is characterized by excellent process stability and high parameters control accuracy. Meanwhile, concise fabricating process with almost little manual cost increases the potential for engineering application.

ACKNOWLEDGEMENTS

The present work is supported by the National Science Foundation of China under Grant Nos. 11672085 and 11432004.

REFERENCES

[1] Gibson LJ, Ashby MF. Cellular solids: structure and properties. Cambridge University Press; 1997.

[2] Deshpande VS, Fleck NA. Foam topology bending versus stretching dominated architectures. Acta Mater 2001; 49: 1035–40

[3] Evans AG, Hutchinson JW, Fleck NA, Ashby MF, Wadley HNG. The topological design of multifunctional cellular metals. Prog Mater Sci 2001; 46: 309–27.

[4] Stansbury JW, Idacavage MJ. 3D printing with polymers: Challenges among expanding options and opportunities. Dent Mate, 2016, 32:54-64.

[5] Compton B G, Lewis J A. 3D-printing of lightweight cellular composites. Adv Mater, 2014, 26:5930-5.

[6] Zhang G, Wang B, Ma L, et al. Response of sandwich structures with pyramidal truss cores under the compression and impact loading. Compos Struct, 2013, 100: 451-463.