Quasi-static Compression Behavior of Bio-inspired Hybrid Lattices with Non-periodicity Prepared by a Rapid Casting Method

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Abstract: Inspired by the cross-lamellar structures commonly found in mollusks, a strengthening concept by adding crossed struts to the adjacent units in a cubic lattice structure was proposed, for the purpose of achieving strength gain by simple structure design. In this study, lattice structures were prepared by a rapid casting combing additive manufacturing and infiltration casting Quasi-static compression experiments were conducted to investigate the crushing behavior and mechanical performance of the non-periodic hybrid lattice (NPHL)with crossed struts. In addition, numerical simulations were employed to illustrate the stress distribution inside the structure under different strains. The anisotropy of NPHL in the elastic deformation range was investigated using the asymptotic homogenization method and validated by numerical simulations. Compared with the typical cubic lattices, the NPHL structures have a reduced tendency of loaded struts to buckle, altered crack propagation paths in the cubic lattice, and crushing behavior. At the same time, the NPHL structure has higher compressive strength, specific strength, and specific energy absorption.

Keywords: Non-periodic Hybrid Lattice, Rapid casting, Crossed struts, Energy absorption

1 Introduction

Porous materials are capable of possessing customizable properties due to their internal topology, and many works have investigated the structure-property relationship from microscopic to macroscopic perspectives with the help of experimental, numerical, and simulation tools. Many complex topologies are difficult to construct due to the limitations of traditional preparation processes, which limits the applications and research on porous materials[1]. The emergence of additive manufacturing technology provides great design space for selecting substrate materials and preparing complex configurations. Porous materials can be categorized into ordered and disordered based on their structure, and ordered porous materials have become the focus of research because of their superior mechanical properties. Porous materials are called lattice materials because of their periodic arrangement and structural characteristics in three-dimensional space [2]. Lattice materials are often put to use as mechanical metamaterials due to their excellent specific strength and counter-intuitive special properties that can be realized by topological design. The properties of lattice materials depend on the structural design of the representative volume element (RVE), and the initial design strategy was the body-centered cubic, face-centered cubic, and simple cubic crystal structures common in crystals[3]. Subsequently, the design strategy shifted to hybridizing multiple lattice structures or making simple topological changes to optimize performance further. With the development of bionics, new ideas have been given to the design strategy of lattice structures. In recent years, RVEs can be composed of pillars, plates, or shells [4], which are then periodically and repeatedly arranged in three dimensions to build lattice metamaterials. It is worth noting that the scale of RVEs can reach the micrometer level, which makes lattice materials have special properties that cannot be found in solid materials [5]. However, existing design strategies limit the topological transformation to a single unit cell, which greatly restricts the enhancement of the mechanical properties of lattice materials. In this study, three crossing patterns and two pillar placement strategies were designed based on the common cross-laminated structures in mollusk shells, three hybrid lattice structures were designed and samples were prepared and evaluated for their mechanical properties using a combination of selective sintering and percolation casting processes.

2 Experimental procedure

In this study, geometric modeling was carried out using Creo Parametric 3D modeling software. The sample preparation process is shown in Fig. 1: the samples were prepared using an indirect additive manufacturing technique that combines selective sintering (SLM) and percolation casting processes. The raw material was ZL111 alloy (2.71 g·cm^{3,} elemental composition: 8.0-10.0 Si, 1.3-1.8 Cu, 0.4-0.6 Mg, 0.1-0.35 Mn,0.1-0.35 Ti, wt%. Bal. Al). The raw material used for additive manufacturing was coated resin sand (75-250 μm). The prefabricated body required for the casting process was first prepared using additive manufacturing technology, and then molten aluminum at 750°C was poured into the prefabricated body that had been preheated at 200°C.

Subsequently, in order to eliminate casting defects, the samples were heat-treated at 400 °C for two hours. Finally, the samples were desanded to obtain the designed lattice material.

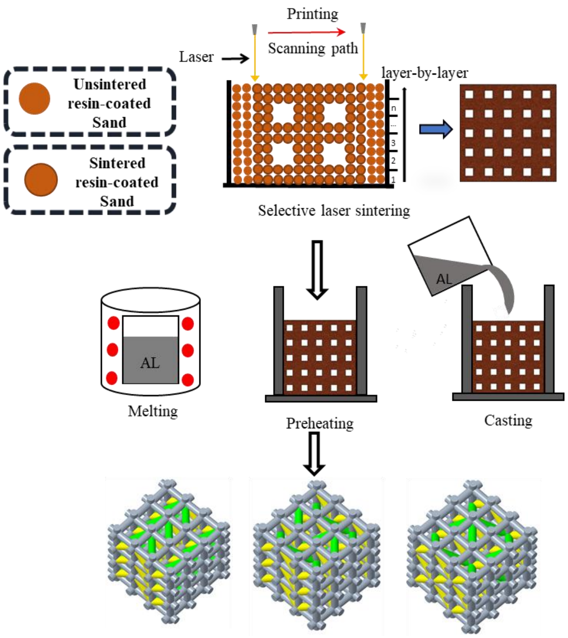

Figure 1 Schematic diagram of preparation process

Table 1 The elastic modulus E, yield stress σ_y, density ρ of specimens

Samples	E (MPa)	σ_y (MPa)	ρ ($g{\cdot}cm^{-3}$)
A	671.87	17.17	0.75
B	649.46	16.12	0.77
C	729.8	21.17	0.76
SC	444.62	10.54	0.48

3 Result and discussion

The stress-strain curves of the three samples are shown in Fig. 2. It can be seen that the compressive strength of the structure can be effectively enhanced by placing intersecting pillars within and on the lattice body. The three crossing strategies have similar enhancement of the compressive strength of the samples, but the enhancement is more than 70%.

Figure 2 Strain-stress curves of samples

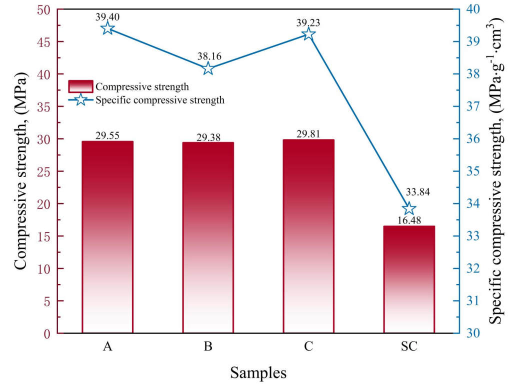

Figure 3 Compressive strength and specific compressive strength of samples

4 Conclusion

The non-periodic lattice structures formed by placing cross-pillars inside the simple cubic lattice have excellent compressive strength, and the strength enhancement effect is significant, with all three cross-strategies achieving strength enhancement of more than 70% for the SC lattice and specific compressive strength enhancement of more than 10%, with a maximum of 16%. In addition, the yield strength of Sample C increased by 68.82% and the modulus of elasticity increased by 64.14% compared to SC.

Acknowledgments

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