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Procedia Manufacturing 10 (2017) 760 – 770

Procedia MANUFACTURING

45th SME North American Manufacturing Research Conference, NAMRC 45, LA, USA

Simulation of Elastic Properties of Solid-Lattice Hybrid Structures Fabricated by Additive Manufacturing

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Abstract

The lattice structure is promising in a variety of engineering applications because of its unique mechanical properties. To satisfy certain functional requirements, lattice structures combined with the skin and solid are preferred in many cases. Additive Manufacturing (AM) has reduced the difficulty in fabricating Solid-Lattice hybrid structures, which brings more potential for applications. However, analyzing such a complex structure is challenging for traditional methods. In this paper, a new simulation model is proposed to reduce the computational cost and avoid poor mesh quality in simulating elastic properties of Solid-Lattice hybrid structures by Finite Element Analysis. The connecting area of the lattice strut and the solid is investigated to determine the best parameter for the new simulation model. A structure is designed and the experiment is conducted to validate the proposed method. A comparison between the new simulation model and the traditional one shows that the computational cost is dramatically decreased and the mesh quality is improved by the proposed method. And both of the simulation results are close to the experimental result which can be used to predict the mechanical performance of Solid-Lattice hybrid structures.

Peer-review under responsibility of the organizing committee of the 45th SME North American Manufacturing Research Conference

Keywords: Additive Manufacturing; Finite Element Analysis; Lattice Structure; Mechanical Property

1. Introduction

Additive Manufacturing (AM) is a technology that can fabricate three dimensional models directly which makes the process planning much easier [1]. It works by adding material in layers, which are the cross-sections of the

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Peer-review under responsibility of the organizing committee of the 45th SME North American Manufacturing Research Conference
doi:10.1016/j.promfg.2017.07.072

model derived in Computer Aided Design (CAD) system. Unlike traditional manufacturing technologies, AM doesn't require a careful and detailed analysis to determine the tools, processes and the order of fabrication, which can significantly shorten the time from design to production. And because of the layer by layer manufacturing principle, structures with complex geometries can be fabricated by AM without drastically increasing the manufacturing cost. Due to these advantages, manufacturing constraints have been released during the design stage, which gives designers more space to further improve the performance of their products.

Lattice structures are widely used in many engineering applications because of the ability to distribute materials at vital parts to improve specific mechanical performance, such as strength to weight ratio, heat transfer, thermal isolation, energy absorption and biocompatibility. Traditional manufacturing methods have greatly limited the complexity of lattice structures. However, AM provides an alternative approach to fabricate complex lattice structures with its layer by layer manufacturing principle. Based on the capability of AM, the design methods for meso-level lattice structures (feature size from 0.1mm to 10mm) have drawn lots of attention. As shown in Fig. 1, lattice structures in meso-level can be divided into three main types according to the degree of order [2]. The first type is called periodical lattice structures which has a uniform size and shape of the unit cell over the whole design space. This type of lattice structures can be subdivided into the homogeneous periodic lattice structure and the heterogeneous periodic lattice structures. The second type of lattice structures is called pseudo-periodic lattice, or conformal lattice. For this type, the size and shape of each unit cell can be different due to special design purpose, but they all use the same general topology. Pseudo-periodic lattice structures are capable of keeping the integrity of their unit cells on the boundary, which potentially has better performance than a periodic lattice structure [3]. Apart from periodic and pseudo-periodic lattice structures, the third type of lattice structure is called disordered cellular structures. In this structure, unit cells with different sizes and shapes are randomly distributed, which makes the properties of disordered cellular structures hard to control. Therefore, lattice design methods are more focus on periodic and conformal lattice structures.

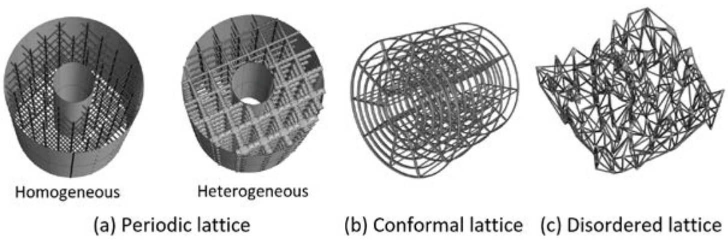

Fig. 1. Three types of lattice structures

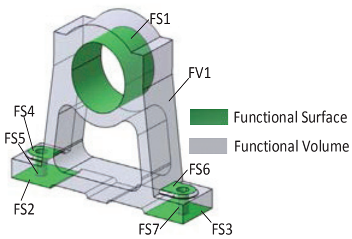

Fig. 2. An example of FSs and FVs [2]

Currently, researchers have proposed several design and optimization methods of lattice structures. But most of them only focus on the performance of the lattice itself while neglect the functional roles of skin or solid materials. This restricts the applications of lattice structure, because skin and solid materials are crucial for certain functions, such as assembly, shape maintenance, aerodynamic performance and strength requirement. An innovative method has been proposed to consider both the solid volume and skin structure in the design of periodic lattice structures [2]. Functional volumes (FVs) and functional surfaces (FSs) have been introduced to represent the geometrical elements for specific functional purposes, as shown in Fig. 2. A FV is defined as a geometrical volume that has certain purposes. FVs can be further divided into two types: FVs with solid materials and FVs with lattice structures. And a FS refers to a key surface of the structure that has functional behaviors. By defining FVs and FSs first, solid materials and lattice structures can be appropriately selected for each FV and FS according to their functional requirements.

Previous research is mainly concentrated on the mechanical properties of lattice structures. But the analysis related to the combination of lattice and solid structures hasn't been fully investigated. One possible approach is to use Finite Element Analysis (FEA) to simulate the mechanical performance of the hybrid structure. Typically, 3D elements such as tetrahedron elements are used to mesh the hybrid structure. But for the lattice part, mesh size should be small enough to ensure the quality of the mesh, which will result in high computational cost. In this paper, a new simulation model is proposed to reduce the computational cost of analyzing the elastic properties of Solid-