

Numerical modelling and nanoindentation experiment to study the brazed residual stresses in an X-type lattice truss sandwich structure

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ABSTRACT

The lattice truss sandwich structures are considered as the most promising advanced lightweight materials used in modern industries and aircrafts. Most sandwich panel structures are fractured at brazed joints named node failure during static and dynamic testing, which is mainly influenced by brazing residual stresses. Finite element method (FEM) was used to study the brazing residual stresses in a stainless steel X-type lattice truss sandwich structure. And the nanoindentation experiment is used to verify the validity of FEM. The effects of braze processing parameters including applied load, face sheet thickness, truss thickness and truss length on residual stresses have been investigated. It is shown that the residual stresses are concentrated on the brazed joint, which has a significant effect on node failure. As the applied load increases, the residual stresses decrease first and then remain unchanged, and the optimal applied load is around 1 MPa. As the face sheet thickness increasing, the residual stresses are increased. Too thin face sheet can cause large residual stresses on the top surface of face sheet. With truss thickness and truss length increase, the residual stresses are decreased first and then increased. The optimized face sheet, truss thickness and truss length are found to be 2 mm, 1 mm and 26 mm.

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1. Introduction

Ultra-lightweight cellular metallic materials have become the focus of attention in recent years because they exhibit an attractive combination of properties, such as low density, high strength, high specific stiffness, damping capacity, noise absorption, and multi-functional application potential, etc. [1]. Therefore, these materials have been widely used in modern industries and aircrafts [2]. The lattice truss structures are considered as the most promising type of advanced lightweight materials, because they are highly efficient load supporting systems used as the cores of sandwich panels [3]. Tetrahedral [4], pyramidal [5], 3D-Kagome [6], metal textile [7] and woven structures [8] are the main topologies used to construct the lattice truss structures. The tetrahedral truss core panels exhibit particularly good bending performance and feasibility for achieving the minimum weight [9,10]. 3D-Kagome sandwich panels show greater load capacity under compression and shear loading than that of tetrahedral truss core panels and provide isotropy under shear loading [11,12]. Recently, Lu et al. [13,14] developed an ultra-light X-type lattice sandwich structure.

The open literatures on lattice structure were focused on their mechanical properties [15], fabrication technologies [16–18], failure mechanism [19], etc. Deshpande et al. [20] and Zok et al. [1] developed the micromechanical models for the stiffness and strength of pyramidal lattice truss cores. Fang et al. [21] designed a new Kagome cell and statically indeterminate square cell lattice materials, and investigated their in-plane mechanical properties such as stiffness, yielding, buckling and collapse mechanisms by analytical methods. Alkhader and Vural [22] explored the effect of topology and microstructural irregularity on deformation modes of cellular structures by a simple quantitative technique. Oruganti et al. [23] studied the thermal expansion behavior in fabricated cellular structures.

In the fabrication, investment cast [20,24], perforation and folding [25], tri-axial weaving of wires technology [26], extrusion and electrodischarge machining [27] are the main methods used to fabricate the metal lattice truss cores. Water-jet cutting combined with the snap-fitted method [28] and molding hot-press method [18] are also developed to fabricate the carbon fiber composite pyramidal truss structures. Very recently, Moongkhamklang et al. [29] developed a method to fabricate millimeter cell size cellular lattice structures with a square or diamond collinear truss topology.

The lattice truss core sandwich panels are fabricated by bonding lattice structures to face sheets [30]. During the brazing, residual stresses and defects would be generated inevitably [31,32], which

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have a great effect on fracture [33]. Most sandwich panel structures have been fractured at brazed joints named node failure during static and dynamic testing [34,35], which are mainly influenced by the residual stresses and defects resulted from the brazing [36]. But up to now, little attention has been paid to residual stress for the lattice truss structures. As the complexity of the lattice truss structures, it is very difficult to obtain their residual stress distribution by experiments. Finite element method (FEM) has been proved to be a powerful tool to predict the residual stress and deformation in complex structure [37,38]. Therefore in this paper, FEM has been used to simulate the brazing residual stress in an X-type lattice truss sandwich structure, which has been verified by nanoindentation experiment. Some braze processing parameters including the applied load, face sheet thickness, truss thickness and truss length are the key factors because they have great effect on residual stress and strength [39–41]. Therefore the effects of applied load, face sheet thickness, truss thickness and truss length on residual stresses have been discussed here, aiming to provide a reference for design and manufacture of the X-type lattice truss sandwich structure.

2. Brazing of X-type lattice truss structures

A slitting, expanding and flattening method is used to form a periodic diamond pattern sheet. Then the diamond sheet is continuously punched with a pair of specially designed punch to form the lattice structure cores. Punching at different locations can form different shape of lattice core. Punching continuously at the node rows of the expanded diamond sheet can form the pyramidal lattice structure, while punching continuously in the middle of two node rows can form the X-type lattice truss structure, as shown in Fig. 1 [13]. The trusses are arranged in triangle shape and X-shaped arrangement in the pyramidal and X-type core, respectively. Lu and co-workers [13,14] found that the mechanical strength of the X-type lattice sandwich structure is superior to the pyramid lattice structure. In this paper the residual stresses in an X-type lattice sandwich structure are studied by FEM.

The lattice structures are brazed to face sheets to form lattice truss core sandwich panels, and the filler metal is pre-located between the face sheet and lattice core. A clamping fixture should

be used to clamp the assembly tightly, which can generate an applied load to ensure the close contact between face sheet and the lattice core. Then the assembly is fixed and brazed in a vacuum furnace.

Before brazing, the vacuum-pumping below 10^{-4} Torr must be first ensured. The stacking is heated to 500°C at $10^{\circ}\text{C}/\text{min}$ and the temperature is held for about 60 min to volatilize the binder. Then it is heated to the brazing temperature of 1050°C and held about 25 min, which makes the carbide of the austenitic stainless steel achieve preferable solid-solution treatment. At last, the assembly is cooled to the ambient temperature in the furnace.

3. FE simulation

3.1. Geometrical model and meshing

Fig. 2 shows the sketch of the X-type lattice truss structures [13]. The truss thickness (t), length (l) and width (w) are 1, 22 and 2 mm. The inclination angle ω and β are 41° and 40° , respectively. The node size b is 3 mm. Finite element code ABAQUS is used to simulate the residual stress. A three dimensional FE model is built as shown in Fig. 3, and its meshing is shown in Fig. 4. In total, 95,218 nodes and 75,461 elements are meshed.

3.2. Residual stress analysis

At the high brazing temperature, the assembly is at stress-free state. Therefore, the as-brazed residual stress is simulated during the cooling from 1050°C to 20°C . For the present used materials, solid-state phase transformation does not occur. Therefore, the total strain rate can be decomposed into three components as

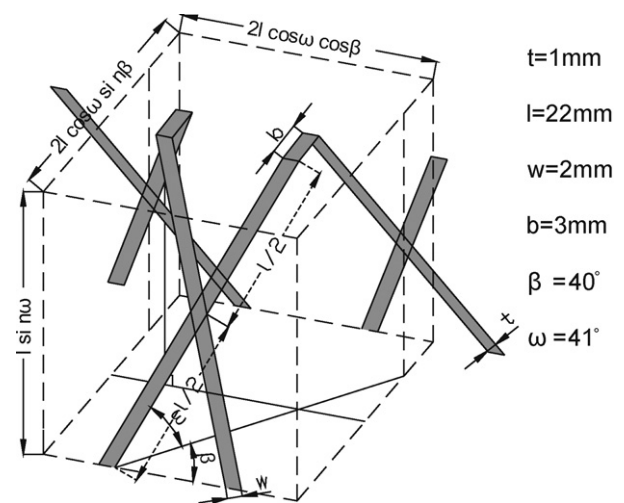


Fig. 2. Sketching of X-type lattice structure.

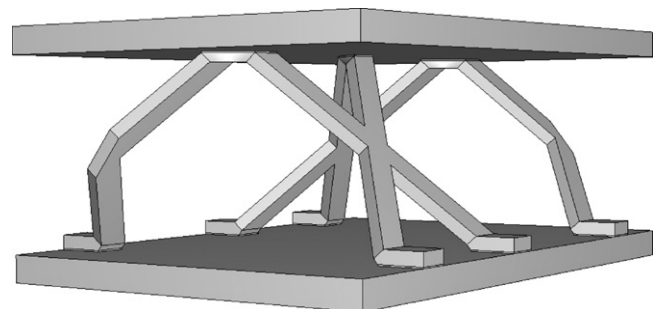


Fig. 3. Geometrical model.

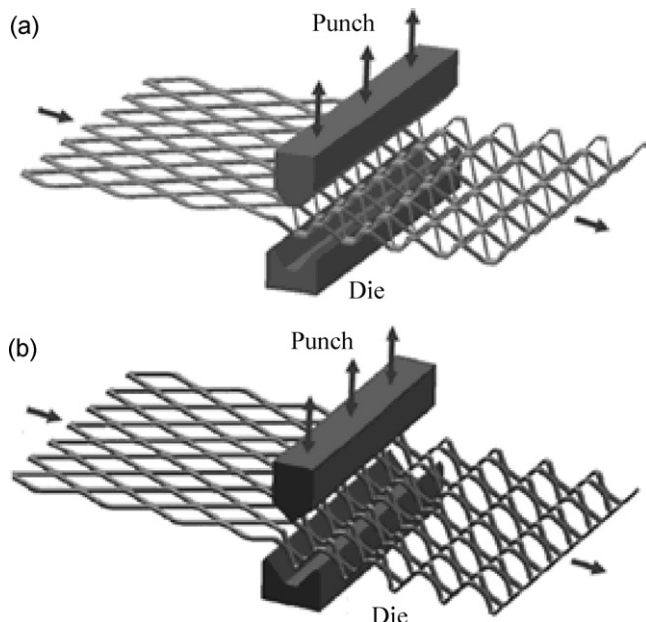


Fig. 1. Fabrication process of pyramidal (a) and X-type truss structures (b).

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