Journal of Electronic Research and Application, 2025, Volume 9, Issue 6
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

Research Status and Development Trends of Lattice-Foam Composite Lightweight Porous Metallic Materials

Kerong Zhang[1]*, Jirui Yue[1], Yankuo Yin[1], Keqing Zhang[2]

[1]Xizang Minzu University, Xianyang 712082, Shaanxi, China
[2]Inner Mongolia Medical University, Hohhot 010110, Inner Mongolia, China

**Author to whom correspondence should be addressed.*

Abstract: This paper reviews the research status and development trends of lattice-foam composite structural materials. It introduces the characteristics and applications of lattice metallic materials and metallic foam materials among ultra-light porous materials, and points out their respective shortcomings. Subsequently, it elaborates on the research progress of lattice-foam composite structural materials at home and abroad, including the research achievements of research teams such as Xi'an Jiaotong University and the University of Virginia in the United States. Then, the key technologies in the preparation process of lattice-foam composite structural materials are discussed in detail, such as the rapid prototyping technology for special-shaped parts of porous materials, the friction stir welding technology for metallic foams, and the large-area joining and composite technology between the core and face sheets of composite structures. Finally, the research on lattice-foam composite structural materials is summarized and prospected.

Keywords: Lattice-foam composite structure; Ultra-light porous material; Preparation technology; Joining technology

Online publication: December 16, 2025

1. Introduction

As discontinuous metal matrix structural materials, ultra-light porous materials have broad application prospects in aerospace, architecture, military industry, energy, transportation and other fields. They are divided into two categories: lattice materials and foam materials, each with unique properties and characteristics, but also with certain limitations [1,2]. To overcome these shortcomings, research institutions at home and abroad have proposed a new type of lightweight porous metallic material that combines lattice structures with foam structures. This material integrates the advantages of both and exhibits better performance and application potential. Therefore, the research on lattice-foam composite structural materials holds significant scientific significance and application value.

2. Overview of lattice metallic materials and metallic foams

2.1. Lattice metallic materials

Lattice metallic materials are advanced lightweight and multi-functional materials with high porosity and periodic structures, among which corrugated structures are a typical type. Corrugated structures possess a series of advantages such as light weight, high strength, high rigidity, heat insulation, and sound insulation, thus being widely applied in various fields. However, they exhibit poor transverse deformation resistance and are prone to distortion, which limits their application under conditions involving large torsional loads or transverse tensile/compressive loads.

2.2. Metallic foams

Metallic foams are multi-functional materials with a large number of interconnected or closed pores, featuring excellent properties including light weight, sound absorption, heat insulation, flame retardancy, and impact energy absorption. Compared with lattice metallic materials, metallic foams have advantages such as isotropy, low cost, and ease of processing. If applied in manufacturing fields such as aircraft components and vehicle bodies, they will generate significant economic benefits. Aluminum foam is the most widely used and extensively studied type of metallic foam. It is often used as a core material combined with traditional dense metals to form composite components with a "sandwich"-like structure, so as to achieve optimal mechanical properties. However, currently, the finished aluminum foam plates at home and abroad generally have dimensions within 2000mm × 2000mm. The cost of preparing larger-sized plates increases sharply, and numerous defects are likely to occur, which restricts their application in the manufacturing of large-scale components.

3. Research status of lattice-foam composite structures

3.1. Domestic research status

Among domestic research institutions, the research team led by Lu from Xi'an Jiaotong University is in a leading position in the research of lattice-foam composite lightweight materials. The third-generation ultra-light porous materials (lattice-foam composite materials) proposed by this team are obtained by bonding lattice metallic materials with cut aluminum foam, resulting in multi-functional composite porous materials with good appearance. They have successfully prepared various types of lattice-foam composite materials such as foam-filled corrugated sandwich panels and foam-filled grid sandwich panels, and applied for related patents [3,4]. In addition, other scholars from the university have conducted research on some properties of lattice-foam composite structures. Regarding other domestic institutions, some scholars have proposed different types of lattice-foam composite structural materials and studied their properties [5,6], as shown in **Figure 1**.

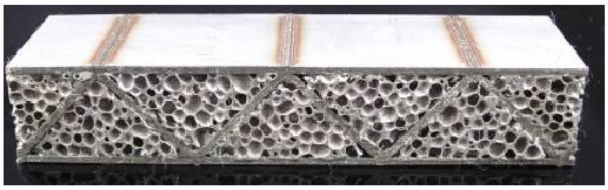

Figure 1. Lattice-foam composite structural sandwich panel.

3.2. Overseas research status

In overseas research, as early as 2000, Italian scholar Torre proposed a composite corrugated structural sandwich panel filled with phenolic resin foam [7]. However, this was not a true structural and functional study on lattice-foam composite materials. Since then, overseas research on lattice-foam composite structures has been scarce. Scholars such as Vaziri *et al.*, Shukla *et al.* from the University of Rhode Island (USA), and the research team from the University of Virginia (USA) have separately proposed lattice sandwich structural materials filled with different substances and studied their properties [8,9]. In general, current research on lattice-foam (or solid-filled) composite structures at home and abroad is extremely limited. Only the University of Virginia in the United States and Xi'an Jiaotong University in China have carried out research on a certain scale. Furthermore, most of the structures studied by overseas institutions use polyester materials as fillers, while those developed by Lu's team mainly adopt metallic foam fillers, this is more conducive to exerting the advantages of composite materials as structural materials [10,11]. **Table 1** presents a summary and comparison of the research status of lattice-foam composite structures at home and abroad.

Table 1. Summary of the research status of lattice-foam composite structures at home and abroad

University or scholars	Characteristics of composite structure	Main research directions
Xi'an Jiaotong University	Metal lattice-metallic foam filled	Deformation resistance, impact resistance
University of Virginia	Metal lattice-polymer filled	Impact resistance
Other domestic scholars	Metal (or composite material), lattice-metallic foam (or polymer) filled	Mechanical properties
Other overseas scholars	Metal lattice-polymer filled	Functional characteristics such as heat insulation and sound insulation

4. Key preparation technologies for lattice-foam composite structures

4.1. Rapid prototyping (RP) of special-shaped porous material components

The aluminum foam filled between lattice metals features an irregular (special-shaped) structure. Currently, there are generally two methods for the preparation and compounding of aluminum foam in lattice-foam composite materials at home and abroad, both of which have limitations [12,13]. In recent years, rapid prototyping (RP) technology has been successfully applied to the preparation of special-shaped components of non-metallic porous materials for medical use and has begun large-scale commercialization. Many research institutions have conducted and successfully completed experiments on preparing porous metallic materials using RP technology [14–17]. The indirect rapid prototyping technology for porous materials first involves fabricating a master mold with specific pores via rapid prototyping; this master mold is then used as a preform to produce porous materials through processes such as precision casting or infiltration casting [18,19]. The technological process of indirect porous material preparation is shown in **Figure 2**. RP technology enables the customized production of aluminum foam finished products or preforms that perfectly match the gap shape of the lattice structure. However, research on the rapid prototyping of porous metals with small, disordered pores is still under continuous exploration and development.

Figure 2. Process flow of porous aluminum production via the indirect method.

4.2. Joining and compounding technologies for lattice-metallic foam composites

4.2.1. Friction stir welding (FSW) technology for metallic foams

In traditional preparation methods of lattice-foam composite materials, bonding or free expansion diffusion bonding is mostly used to join foam materials and lattice materials, resulting in low strength at the interface between the two materials. Friction stir welding (FSW) is a novel welding method that achieves metallurgical bonding of joints without the need for a special environment or high energy input. Nevertheless, brazing or diffusion welding is generally employed for welding porous materials, and there are almost no reports on FSW of metallic foams at home and abroad. Since fusion welding methods such as laser welding and TIG welding share many similarities with FSW, and FSW possesses unique advantages in welding difficult-to-weld materials, the application of FSW technology to the joining of metallic foams is feasible [20,21].

4.2.2. Joining and compounding technology for composite cores and face sheets

Another key challenge in preparing large-scale corrugated sandwich panels filled with aluminum foam lies in the large-area joining technology between the composite core and face sheets. The primary issue encountered in joining stainless steel and aluminum foam is the formation of brittle intermetallic compounds during Al/Fe welding. The application of roll bonding/diffusion bonding for finished metallic foam sandwich panels is limited. In contrast, transient liquid phase (TLP) bonding can significantly reduce the required pressure by introducing an activation effect, effectively solving the problem that aluminum foam cannot form plastic joints due to its poor pressure resistance. However, there are very few domestic and foreign reports on TLP welding between aluminum foam and stainless steel sheets. Nevertheless, its application in the large-area joining of lattice-foam cores and stainless steel face sheets holds great promise [22].

5. Conclusion

Research on lattice-foam composite structural materials remains limited globally, with substantive work primarily concentrated at the University of Virginia in the United States and Xi'an Jiaotong University in China. These materials combine the respective advantages of lattice metallic structures and metallic foams, offering substantial potential for advanced engineering applications. Their fabrication relies on several key enabling technologies, including rapid prototyping of complex porous geometries, FSW for metallic foams, and large-area joining methods for integrating composite cores with face sheets. Looking ahead, further studies should focus on extending rapid prototyping techniques to the fabrication of small, irregular porous metal structures, refining FSW processes for metallic foams, and advancing large-area joining technology. Such developments will improve the performance, reliability, and manufacturability of lattice-foam composite materials, thereby supporting their broader adoption across diverse application domains.

Funding

Key Project of Xizang Natural Science Foundation (Project No.: XZ202201ZR0053G); 2023 Teaching Reform Project of Inner Mongolia Medical University (Project No.: NYJXGG2023025); "14th Five-Year Plan" Project of Educational Science Research in Inner Mongolia Autonomous Region (Project No.: NGJGH2021278)

Disclosure statement

The authors declare no conflict of interest.

References

[1] Evans A, 2001, Lightweight Materials and Structures. Materials Research Bulletin, 26(10): 790–797.

[2] Wadley H, Dharmasena K, Masta M, et al., 2013, Impact Response of Aluminium Corrugated Core Sandwich Panels. International Journal of Impact Engineering, 2013(62): 124–128.

[3] Han B, Yu B, Lu T, et al., 2015, Foam Filling Radically Enhances Transverse Shear Response of Corrugated Sandwich Plates. Materials & Design, 2015(77): 132–141.

[4] Tian P, Zhao G, Lu T, 2009, Numerical Analysis of Dynamic Response of Metal Grid Sandwich Plates with Filling Materials under High-Speed Impact. Chinese Journal of Applied Mechanics, 26(4): 788–792.

[5] Zhang J, Qin Q, Wang T, 2013, Compressive Strengths and Dynamic Response of Corrugated Metal Sandwich Plates with Unfilled and Foam-Filled Sinusoidal Plate Cores. Acta Mechanica, 224(4): 759–775.

[6] Qin Q, Zhang J, Wang Z, 2014, Indentation of Sandwich Beams with Metal Foam Core. Transactions of Nonferrous Metals Society of China, 24(8): 2440–2446.

[7] Torre L, Kenny J, 2000, Impact Testing and Simulation of Composite Sandwich Structures for Civil Transportation. Composite Structures, 50(3): 257–267.

[8] Vaziri A, Xue Z, Hutchinson J, et al., 2006, Metal Sandwich Plates with Polymer Foam-Filled Cores. Journal of Mechanics of Materials and Structures, 1(1): 97–127.

[9] Yazici M, Wright J, Shukla A, et al., 2014, Experimental and Numerical Study of Foam Filled Corrugated Core Steel Sandwich Structures Subjected to Blast Loading. Composite Structures, 2014(110): 98–109.

[10] Yungwirth C, Radford D, Aronson M, et al., 2008, Experiment Assessment of the Ballistic Response of Composite Pyramidal Lattice Truss Structures. Composites Part B: Engineering, 39(3): 556–569.

[11] Wadley H, Dharmasena K, Masta M, et al., 2013, Impact Response of Aluminum Corrugated Core Sandwich Panels. International Journal of Impact Engineering, 2013(62): 114–128.

[12] Zhang Q, Lu T, Yan L, et al., 2011, Preparation Method of a Lattice Metal-Aluminum Foam Composite Material. Chinese Patent, CN 201110233384.8.

[13] Wang W, Zhang Q, Yang X, et al., 2014, An Aluminum Foam-Corrugated Plate Composite Sandwich Panel and its Preparation Method. Chinese Patent, CN 201410409859.8.

[14] Sallica-Leva E, Jardini A, Fogagnolo J, et al., 2013, Microstructure and Mechanical Behavior of Porous Ti–6Al–4V Parts Obtained by Selective Laser Melting. Journal of the Mechanical Behavior of Biomedical Materials, 2013(26): 98–108.

[15] Traini T, Mangano C, Sammons R, et al., 2008, Direct Laser Metal Sintering as a New Approach to Fabrication of an Isoelastic Functionally Graded Material for Manufacture of Porous Titanium Dental Implants. Dental Materials, 24(11): 1526–1533.

[16] Yadroitsev I, Shishkovsky I, Bertrand P, et al., 2009, Manufacturing of Fine-Structure 3D Porous Filter Elements by Selective Laser Melting. Applied Surface Science, 255(10): 5523–5527.

[17] Xie F, He X, Cao S, 2013, Structural and Mechanical Characteristics of Porous 316L Stainless Steel Fabricated by Indirect Selective Laser Sintering. Journal of Materials Processing Technology, 213(6): 838–843.

[18] Ryan G, Pandit A, Apatsidis D, et al., 2008, Porous Titanium Scaffolds Fabricated using a Rapid Prototyping and Powder Metallurgy Technique. Biomaterials, 29(27): 3625–3635.

[19] Vandrovcova M, Douglas T, Mróz W, et al., 2015, Pulsed Laser Deposition of Magnesium-Doped Calcium Phosphate Coatings on Porous Polycaprolactone Scaffolds Produced by Rapid Prototyping. Materials Letters, 2015(148): 178–183.

[20] Pogibenko A, Konkevich V, Ryazantsev L, 2001, The Weldability of Alminum-Based Foam Materials. Welding International, 15(4): 312–316.

[21] Nowacki J, Moraniec K, 2015, Welding of Metallic AlSi Foams and AlSi-SiC Composite Foams. Archives of Civil and Mechanical Engineering, 15(4): 940–950.

[22] Zu G, Yao G, Li X, et al., 2010, Transient Liquid Phase Diffusion Welding Method for Aluminum Foam Materials. Chinese Patent, CN 201010298238.X.