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Three-point bending performance of a new aluminum foam composite structure

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Abstract: A new composite structure based on aluminum foam sandwich and fiber metal laminate was proposed. A layer of glass fiber was provided at the interface between the metal panel and the aluminum foam core in this composite structure, using adhesive technology to bond the materials together by organic glue in the sequence of metal panel, glass fiber, aluminum foam core, glass fiber and metal panel. The experimental results show that the new composite structure has an improved comprehensive performance compared with the traditional aluminum foam sandwiches. The optimized parameters for the fabrication of the new aluminum foam composite structure with best bending strength were obtained. The epoxy resin and low porosity aluminum foams are preferred, the thickness of aluminum sheets should be at least 1.5 mm, and the type of glass fiber has little effect on the bending strength. The main failure modes of the new composite structures with two types of glues were discussed.

Key words: composite structure; three-point bending strength; aluminum foam sandwich; glass fiber

1 Introduction

The properties of aluminum foam are superior to traditional aluminum because of its porous structure. As a functional material, open-cell aluminum foam has excellent electromagnetic shielding capacities, good noise reduction and closed-cell aluminum foam possesses high shock absorption capacity. As a structural material, aluminum foam has low density and high specific strength. Because of the existence of the internal trapped gas, the closed-cell aluminum foam has better mechanical properties with respect to open-cell aluminum foam. Many researches have been carried out on closed-cell aluminum foam as a structural material [1−5], and most studies on the mechanical properties of pure aluminum foams were focused on energy absorption performance in quasi-static compression or dynamic compression tests. One problem is that comprehensive mechanical properties of closed-cell aluminum foam are not good enough to meet the requirements of industrial applications. Therefore, the aluminum foam sandwich (AFS) has been developed for its improved strength while retaining the excellent properties of aluminum foam.

Metal panels and aluminum foam core constitute the aluminum foam sandwich. The main ways to manufacture AFS are by powder metallurgy route and adhesive route. KITAZONO et al [6] reported that the adhesive prevents local buckling of the cell walls by infilling the open cell surface, so the adhesive coating can increase the mechanical properties of aluminum foam. Although some researches [7,8] showed that the metallurgical bonding interface is stronger than that of adhesive bonding, the lower cost and the simpler process have given adhesive technology a better application prospect.

Fiber metal laminates (FML), made by aluminum plates and fiber-reinforced resin layers laminated alternately, were developed by Delft University in the Netherlands and the Fokker Aircraft Company in the 1970s. There are two types of fiber metal laminates, named Arall (Aramid Reinforced Aluminum Laminate) and Glare (Fiberglass Reinforced Aluminum Laminate), the fibers in which are aramid fiber and glass fiber, respectively. Glare overcomes the shortcomings of

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sensitivity to gap and impact in Arall and improves the biaxial stress fatigue properties, so it gets a better application prospect [9]. The base materials in Glare are aluminum alloy sheet, glass fiber and epoxy resin. Glare combines the advantages of both metal and composite materials, especially for low density, high strength, high fatigue resistance, high impact resistance, excellent corrosion resistance, flame retardance and relatively low cost. This gives it a broad application and great potential in the aviation industry. The first successful application of Glare was in the skin structure and leading edge of the wing and empennage in the Airbus A380 aircraft. The application area reached 380 m^2 and achieved a mass reduction of 794 kg [10].

Based on the AFS with adhesive bonding and Glare plate, a new aluminum foam composite structure which is named as glass fiber reinforced aluminum foam laminate (GRAFL) was proposed, which was fabricated by adding a layer of glass fiber to the interface between the metal panel and the aluminum foam core of AFS. Adhesive technology was used to bond the materials together in the sequence of metal panel, glass fiber, aluminum foam core, glass fiber and metal panel, as shown in Fig. 1. The new composite structure is a material with the integration of structure and function, and it has very wide application prospects in the fields of ship manufacturing, aerospace, automobile manufacturing and transportation. The anti-bending performance is an important property index of the composite sheets, and the response to three-point bending of AFS with adhesive bonding was investigated in many studies [11−15] through experimental and theoretical analysis, which discussed various failure modes related to the geometric and material factors. The main failure modes of AFS are face yield, indentation and core shear in the literature previously mentioned. In this work, the influence of the thickness of panels, the glass fiber, the porosity of aluminum foam, and the type and amount of glues on the three-point bending performance of the new composite structure were studied. The parameters of materials which gave the best mechanical properties were obtained, and the performance of the new aluminum foam composite structure was compared with that of AFS. Moreover, the main deformation and failure modes of the new composite structure were discussed.

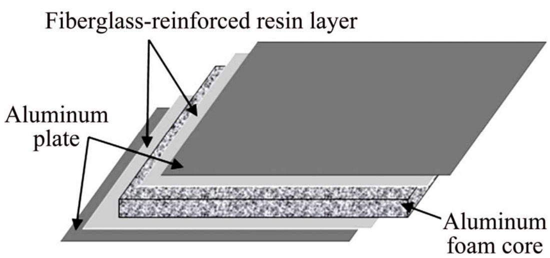

Fig. 1 Schematic diagram of new aluminum foam composite structure

2 Experimental

The aluminum foam core, two metal panels and glass fiber sheets were all in the size of 200 mm × 50 mm. The aluminum foams with a thickness of 10 mm were prepared by melt foaming process. The aluminum foam sheets used in the experiments were carefully selected, the pores of which were relatively uniform. So, the differences between the aluminum foams were not considered except for porosity. Commercial aluminum panels were used as metal panels because of their light weight. Three aluminum panel thicknesses were adopted, namely 0.5, 1 and 1.5 mm. Three glass fibers were used for comparative analysis. Their grades and tensile breaking strength are shown in Table 1. The thicknesses of fibers 1, 2 and 3 are 0.2, 0.1 and 0.21 mm, respectively. Fibers 2 and 3 are high-strength glass fibers, so the monofilaments of fibers 2 and 3 have superior mechanical properties compared with fiber 1. Two kinds of commercial adhesive were used in the experiments, namely Kafuter K-801 AB glue and Kafuter epoxy glue with epoxy curing agent. Kafuter K-801 AB glue, which is a kind of modified acrylate adhesive, is also called green−red glue. Kafuter epoxy glue mixing with epoxy curing agent is called epoxy resin in this work. The epoxy resin is used as binder in the Glare plate, but it needs 3 to 5 h to reach initial curing, the aluminum foam and panels are easy to dislocate with each other in the curing process. The green-red glue can reach initial curing in 3 to 5 min, therefore, green-red glue was chosen as a comparison for its easy use.

Table 1 Grades and strength of glass fibers used in experiments

Composition	Tensile breaking force (N/25mm)	
	Zonal	Meridional
EW-140	450	650
SW100A-100a	550	550
SW210A-92a	1350	1600

The aluminum foams and aluminum panels were firstly sanded with sandpaper, to remove the oxide film on the surface. Moreover, the surface became rough after sanding which was conducive to the good adhesion of glue. Then, the sanded panels were washed using ethanol to further remove impurities. Equation (1) was used to calculate the porosity of aluminum foams, and the specific porosities of aluminum foams were selected for the experiments. The mass of adhesive was obtained by subtracting the mass of other materials from the total mass after bonding and drying.