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Quasi-static localized indentation tests on integrated sandwich panel of aluminum foam and epoxy resin

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ABSTRACT

By carrying out quasi-static localized indentation tests, the mechanical properties and energy absorption capacity of the integrated sandwich panel of aluminum foam and epoxy resin with different immersed resin thickness, boundary conditions and indenter type were studied. It was also compared with traditional aluminum foam sandwich panel. The experiments indicated that with the increase of immersed resin thickness, the specimen's energy absorption capacity and yield load increase significantly; in the condition of fully fixed, energy absorption capacity and yield load of specimens are higher than the condition of simply supported, which have been greatly improved compared to the traditional sandwich panel; elastic modulus of specimen under cylindrical indenter is higher than specimen under square indenter, but the elastic modulus in the yield and destruction phase are highly similar to each other. The specimens maintain good stability under indentation, no peeling-off or cracking happens between the composite layer and core.

1. Introduction

Aluminum foam is a new type of structural functional materials with high porosity and larger aperture, which is similar to common foam material. For its special porous structure, its process of plastic strain lasts longer in the state of compression [1–3]. Thus sandwich panels can absorb lots of energy before collapsing into a more stable configuration and protect other structures from damaging [4]. As a result, aluminum foam is getting widely used in the field of damping and energy absorption such as architecture, aerospace, transportation, automotive manufacturing, military, packing and so on [5–9]. Sandwich panel combined with aluminum foam and other metal panels has became a research hotspot for its light-weight, high specific stiffness, etc. [10]. Traditional preparation methods of aluminum foam sandwich panel are bonding [11] or welding [12]. However, with its low bond strength and poor performance at high temperatures or corrosive conditions, it can easily cause stripping between the core and the surface for the bonding sandwich panel; the welding method combines welding flux and aluminum together that may cause corrosion. Worse, the welding area is only limited to the aperture, which also decreases the structural strength [12].

In recent years, the aluminum foam sandwich panel's mechanical properties in the condition of quasi-static and impact load have been widely concentrated and studied. Through quasi-static localized indentation tests, Mohan [13] studied the mechanical properties of aluminum foam sandwich panel with different materials in the surface layer under the flat and spherical indenter, and it was found that sandwich panel has core indentation, core crushing and surface bending failure modes. Olurin and Andrews [14–15] had studied the metal foam on the quasi-static localized compression, it was obtained that the plastic deformation of metal foam mainly located in the area below the indenter. Li and Meng [16] studied dynamic response of the foam material under the impact load, and got the relationship between momentum and stress amplitudes when the stress wave passing through the foam materials. Villanueva [17] studied the energy absorption capacity of aluminum foam sandwich structures with different fiber plies, and the studies indicated that the blended laminated panel has a better energy absorption capacity than the single panel.

Sandwich panel's core often fails by localized indentation when subjected to impact and blast loads. To provide an aluminum foam sandwich structure, having a simple productive process and strong impact energy absorption, which is also not easy to crack, a kind of integrated sandwich panel of aluminum foam and epoxy resin is proposed. The upper and lower sides of the structure are aluminum-resin composite layers, and the middle core is aluminum foam (Figs. 1 and 2). This composite sandwich panel's core and

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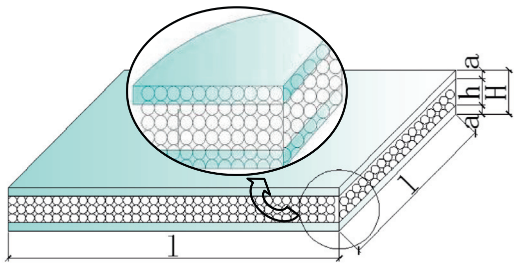

Fig. 1. Schematic diagram of the specimen. Notes: *H* is the specimen's height, *a* is the immersed resin thickness, *h* is the core's thickness, *1* is the length of specimen edges.

Fig. 2. Test specimen picture.

surface layers are connected into a whole without any obvious interface. The overall performance is greatly improved.

By quasi-static localized indentation tests, integrated aluminum foam sandwich panels were tested and the influence of different resin immersing thickness, shapes of indenters and boundary conditions on its energy absorption function were analyzed.

2. Experiment

2.1. The experimental material

Continuous casting aluminum foam with opening cell was used as main material for sandwich panel, which is produced by Beijing Qiangye Metal Foam Limited Company. Its average relative density is 0.9 g/cm^3, main aperture is 2.5 mm and porosity is 80%. The aluminum foam has relatively regular, round aperture and excellent impact resistance, which is conductive to energy-absorbing.

The DY.E.44 resin and DY.EP resin firming agent were selected, both are produced by Norsun Chemical Limited Company. Dibutyl phthalate was chosen as plasticizers.

2.2. Manufacture of the specimens

First, according to the test purpose, aluminum foam panels were made into 150 mm × 150 mm specifications, and the grease was washed away from aluminum foam with alcohol, then they were put in a ventilated place to make them dry naturally. Second, groove molds were prepared to make aluminum foam panels, and the height of the mold is same with the height of resin immersed in the panel. Third, the resin and firming agent were put in a water bath and the water was kept heating at 60 °C. If the temperature is too high, the reaction rate would be so fast that no bubbles would come out. If too low, the flow ability would be poor which made it difficult to stir. Fourth, stopped heating when both of them have a good liquidity, in a beaker they were mixed at the ratio of 1:1, and 5% of the plasticizer was added and stirred rapidly until the polymer was color uniformed and bubble free.

Table 1
Specimen number and parameter.

Group number	Specimens size *l*/mm	Immersed resin thickness *a*/mm	Boundary conditions	Aluminum panel	Indenter shapes
1	150 * 150	2.5	Fully fixed	No	Cylindrical
2		4	Fully fixed	No	Cylindrical
3		0	Fully fixed	Yes	Cylindrical
4		0	Fully fixed	No	Cylindrical
5		2.5	Simply supported	No	Cylindrical
6		2.5	Fully fixed	No	Square
7		2.5	Simply supported	No	Square
8		2.5	Fully fixed	No	Spherical
9		2.5	Simply supported	No	Spherical

Fifth, they were fully filled into the mold which has a specific thickness, refer to the second point, and shaved. Then the treated aluminum foam sandwich panels were put into the molds slowly and smoothly, panels were immersed fully by the resin from the bottom of the aluminum foam. Sixth, panels were solidified for three days at room temperature, and then the molds and the excess resin at the edge of the aluminum honeycomb were removed. Seventh, the resin was poured on the other side by the same procedure. Finally, all the specimens were marked the number. Specimen number and parameters are shown in Table 1.

2.3. Experiment equipment and load

A test on the specimen was conducted with the WDW3100 micro-controlled electronic universal testing machine which is produced by Changchun Kexin Test Instrument Co. A specimen together with the specially designed supporting frame was placed on the indenter bottom of machine. The indenter moved down to indent the specimen at a velocity of 1 mm/min for all tests. The test was conducted according to GB/T1453-2005 from *Test Method for Flatwise Compression Properties of Sandwich Constructions or Cores.* The test data were all collected automatically by the computer.

In these tests, a cylindrical indenter with a diameter of 45 mm (area is 1590 mm^2), a square indenter with a side length of 40 mm (area is 1600 mm$^{2)}$ and a spherical indenter of 50 mm diameter were made (Fig. 3). To eliminate friction, the shanks of all indenters were chamfered at an angle of 5°. To conduct the localized indentation tests, square sandwich panel specimens with a side length of 150 mm were either simply supported or fully fixed by a specially designed frame (Fig. 4).

3. Results

3.1. Process of destruction

As integrated sandwich panel of aluminum foam and epoxy resin has its unique porous structure, at the beginning of the test, the load increases linearly with the extent of indention and the elastic deformation of its frame begins. The specimen presents slight cracks for the resin's high brittleness in the composite layer.

When the increasing load reaches the yield load of the core material, the foam cell beneath the indenter started to be crushed and tearing of the cells at the periphery of the indenter began. The collapse of foam cell leads to plastic deformation of its inner frame. By the plastic deformation, the material transforms the released-energy into the needed-energy of deformation. The core gradually indented from compression, which showed as the process of the continuous expanding of crack into an approximately circular