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Cyclic compression behavior and energy dissipation of aluminum foam–polyurethane interpenetrating phase composites

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ABSTRACT

This paper presents a study of the mechanical behavior of aluminum foam–polyurethane interpenetrating phase composites (AF–PU composites) with different corresponding porosity and pore size under cyclic compressions. The dissipated energy of AF–PU composite is described by the area of the compression cycle. Cyclic frequency, strain amplitude, temperature aging and cycle numbers were taken as reacting influence parameters to evaluate the damping capacity of AF–PU composites with different corresponding porosity and pore size. These cyclic tests demonstrate that AF–PU composites can make up the disadvantage of pure aluminum foams (AF) that are not suffered by the recoverable deformation in the stage of plastic plateau, and AF–PU composites with high porosity and large pore size have a good potential applied in hysteretic damping devices for seismic resistant structures under the condition of large strain level and preloading several cycles.

1. Introduction

Porous aluminums or aluminum foams (AF) have been attracted considerable attention due to their potentials of excellent stiffness-to-weight ratio, low density and efficient energy absorption for applications in construction, automotive and aerospace [1–4]. However, most of AF used for energy absorption under compressive or impact loadings are irreversible, so they are rarely applied in hysteretic dampers which suffer cyclic loads for many times. To achieve the purpose of strengthening the shape recovery properties of AF, many researchers have carried out some investigations on the synthesis and characterization of shape memory foams (SMF) based on the Cu–Zn–Al system in virtue of the fact that Cu–Zn–Al system alloys have very good associated shape memory properties [5–7]. Unfortunately, there are two major disadvantages of Cu–Zn–Al foams that cannot be widely used in hysteretic dampers: firstly, in order to attain those high recovery properties, Cu–Zn–Al foams would be performed heat treatments at intermediate temperature (usually at around 100–130 °C) [7], which is not suitable for hysteretic dampers applied in building and automotive; secondly, the associated high costs of raw materials and alloy processing would prevent Cu–Zn–Al foams from massive quantities [6].

A composite could be another alternative which consists of open cell aluminum foam with polymers to improve the recovery properties of AF [8,9]. This composite is formed by introducing polymers into the open pores of AF called as ‘skeleton’. Taking advantage of super-elasticity of polymeric material, these composites would acquire the better reconversion after the loading disappears, even though the plastic deformations of AF in composites came out. This type of composite is the so-called interpenetrating phase composite (IPC), in which each constituent phase forms a completely interconnected and contiguous network [10–12].

In this study, we selected one of polymers, polyurethane (PU) as an addition of filler material, injected into AF to constitute aluminum foam–polyurethane composites (AF–PU composites). It is significant to inspect whether AF–PU composites can stand cyclic loads or not, and studying the performance of AF–PU composites during repeated loading/unloading cycles is also important because that would increase the reliability of AF–PU composites applied in hysteretic damping devices. AF–PU composites should conform the characteristics of IPCs that any one of the constituent phases is removed and the remaining phases would form a self-supporting open-celled foam [11]. Therefore, the mechanical parameters affecting the performance of AF and PU, respectively, also affect the mechanical behavior and structural stability of

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AF–PU composites. Different relative densities and pore size are two main factors influencing mechanical behavior of AF [13–19] and the usual influence parameters on the absorbed mechanical energy of PU are frequency, temperature and vibration amplitude [20–24]. In order to understand what kind of AF–PU materials are the most suitable for applying hysteretic damping devices in seismic resistant buildings, we will investigate the damping capacity of AF–PU composites with different corresponding porosity and pore size under different cycling frequency, vibration amplitude, temperature aging and cycle numbers.

2. Experiments

2.1. Specimen preparation

These open-cell aluminum foams were fabricated by the conventional infiltration preparation method in the present study [3,4]. In order to decrease the volumetric change of PU, all of AF should be wrapped in PU. These specimens were prepared using the procedure illustrated in Fig. 1. The open-cell aluminums were formed by means of filling salt particles into mold and pulling a vacuum on the bottom of mold to drive the molten aluminum into the open pore beds of bonded salt particles, then leaching salt particles in water. Thus, the sample porosities and pore size are controlled by the quantities and the size of salt particles, respectively. The density of 1.14 g/cm^3 PU was obtained by mixing A and B materials in the mass ratio of 10:1, and then a uniform pressure of around 1 MPa was applied to press this PU into the open-cell aluminum. Finally, the specimens of AF–PU composites were produced after they had been heated at 100 °C for three hours at least. Three types of specimen were shown in Fig. 1d including AF, AF–PU composite and PU. There are a total of 40 specimens divided into 6 groups according to pore size and details on the sizes of specimens used for this study are indicated in Table 1.

In order to eliminate the effect of the irregular external layer, the cylindrical AF–PU specimens were carefully polished their surfaces after PU were inside of the open-cell aluminum foams. The size of AF–PU specimens were satisfied the requirement of AF that there are at least 7 pores in every direction of specimen. The pore size and porosity displayed in second and third column of Table 1 are the characteristics of corresponding AF in AF–PU composites as well as they are mentioned in below.

2.2. Compressive test

Quasi-static compression tests were performed by using an MTS C45 universal testing machine at room temperature (23 °C) under displacement control at the crosshead speed of 0.02 mm/s. Cyclic compression tests were conducted by using an MTS 831 elastomer test system (shown in Fig. 2) importing a sinusoidal deformation wave also at room temperature, but some specimens were subjected to different temperature aging conditions explained in following. The control parameters of cyclic test were the frequency of excitation, the maximum peak to peak strain amplitude and the number of cyclic compression. For the purpose of reducing surface friction, some of silicon greases were covered on the surface of specimens. The variations of load and displacement were automatically recorded by the machine.

Table 1
Main characteristics of aluminum foam–polyurethane composites (AF–PU) under study.

Specimen	Pore size (mm) Mean (min–max)	Porosity (%)	Diameter (mm)	Height (mm)
a	5[4.5–5.4]	74, 75	44	35
b	4[3.5–4.4]	75, 73	44	32
c	3[2.5–3.4]	73, 66	44	32
d	2[1.5–2.4]	74, 73	25	11
e	1[0.5–1.4]	73, 72	44	31
f	1[0.5–1.4]	71, 70, 69, 67, 66	25	11

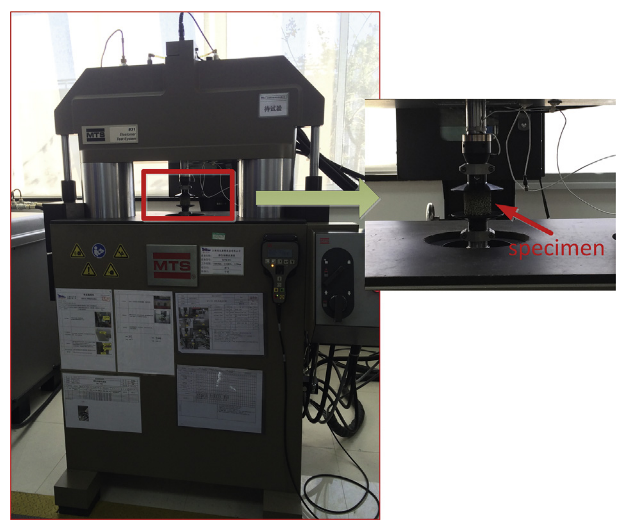

Fig. 2. Cyclic compression tests using MTS 831 elastomer test system. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

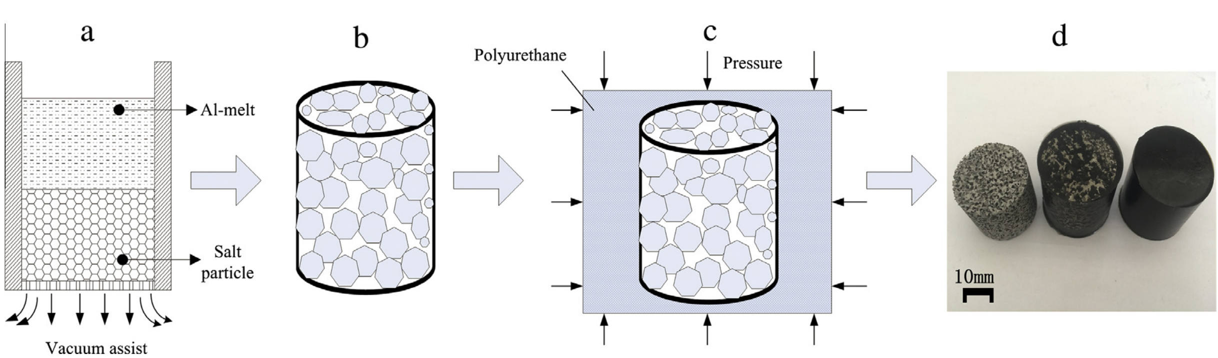

Fig. 1. Fabrication process of aluminum foam–polyurethane composites (AF–PU): (a) fabrication of open-cell aluminum foam, (b) production of open-cell aluminum foam, (c) method of manufacturing AF–PU, and (d) image of specimens from left to right: aluminum foams (AF), aluminum foam–polyurethane composites (AF–PU), polyurethane (PU). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)