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Compressive mechanical properties of closed-cell aluminum foam–polymer composites

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ABSTRACT

The compressive mechanical properties of two kinds of closed-cell aluminum foam–polymer composites (aluminum–epoxy, aluminum–polyurethane) were studied. The nonhomogeneous deformation features of the composites are presented based on the deformation distributions measured by the digital image correlation (DIC) method. The strain fluctuations rapidly grow with an increase in the compressive load. The uneven level of the deformation for the aluminum–polyurethane composite is lower than that for the aluminum–epoxy composite. The region of the preferentially fractured aluminum cell wall can be predicted by the strain distributions in two directions. The mechanical properties of the composites are investigated and compared to those of the aluminum foams. The enhancement effect of the epoxy resin on the Young's modulus, the Poisson's ratio and the compressive strength of the aluminum foams is greater than that of the polyurethane resin.

1. Introduction

Metal foams have found extensive applications in construction, automotive, aerospace, and naval industries due to their unique properties such as excellent stiffness-to-weight ratio, efficient energy absorption, shock wave attenuation, sound and vibration damping and absorption and low thermal conductivity [1,2]. Their cellular structure is the key factor of their interesting properties. Based on these metal foams, several composites [3–6] have been developed to further improve their properties. Recently, a new advanced type of composite containing a metal and a polymer has received significant attention [7–10]. It is known as the metal foam–polymer composite composed of two monomaterials of different material classes which are connected on a macroscopic level [11]. The coexistence of these two materials allows each to contribute its prominent properties.

Researchers have carried out some investigations on the properties of metal foam–polymer composites. Reinfried et al. [11] fabricated hybrid foams by combining expandable polystyrene with open-cell steel foams and investigated their compressive and damping properties. Garsot et al. [12] studied the compressive behaviors of three kinds of composites with polyethylene, polyamide and epoxy filled in the open-cell aluminum foams. Sharma et al. [13] did some research on the damping and basic dynamic properties of a type of multifunctional hybrid material obtained by injection molding a thermoplastic polymer through an open-cell aluminum foam. Stöbener and Rausch [7] developed a simplified process route targeted at the application in foam-filled structures with advanced pore morphology aluminium foam–polymer hybrids. Kishimoto et al. [14] produced some metallic closed cellular materials containing a polymer based on aluminum and steel foams, and performed some tests to determine their mechanical properties.

However, these current studies are insufficient to understand these new kinds of composites, and more investigations are needed to explore the properties of the metal foam–polymer composites. Among the material characteristics, the mechanical properties are crucial to evaluate a material [15,16]. The new metal foam–polymer composite has better mechanical properties as well as the initial advantages of the metal foam [12]. To understand the mechanical properties, deformation measurements are essential [17,18]. The use of an electronic universal testing machine and an extensometer clipped on the specimen cannot give an indication of the deformation distribution of the specimen. Based on the authors' knowledge, there are few reports on the investigation of metal foam–polymer composites using a full-field deformation measurement method which can also provide the Poisson's ratios [19,20]. Since the natural characteristic patterns arising from the

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material differences and the surface roughness can be considered as speckle patterns, the digital image correlation (DIC) method is well-suited for foam-based composites as well as foams [1,21–23]. In this study, we focused on the compressive mechanical properties of the closed-cell aluminum foam–polymer composites by the combination of an electronic universal testing machine and the DIC method which is a non-destructive and full-field optical technique [24–26]. The mechanical properties of the aluminum foam–polymer composites are compared to those of closed-cell aluminum foams without any polymer.

2. Experiments and methods

2.1. Specimen preparation

The closed-cell aluminum foams (ALPORAS, Shinko Wire Co., Ltd.) were fabricated by the space holder method [27]. The size of the ellipsoid-like shaped pores ranges from 1 mm to 9 mm in length. The specimens were prepared using the procedure illustrated in Fig. 1. An aluminum foam cube with the size of 40 mm × 15 mm × 30 mm was cut into two parts (P and O), each of which had a size of 20 mm × 15 mm × 30 mm. Several through holes were made in part P using a 1 mm diameter drill to provide channels for the polymer. A uniform pressure of around 0.1 MPa was then applied to press the polymer into the pores of part P. Finally, the specimen containing the polymer (aluminum–polymer composite) was produced after part P was heated at 80 °C. One surface of the specimen containing polymer and that of the specimen without any polymer were symmetric.

In this study, two kinds of polymer were chosen to be injected into the closed-cell aluminum foams. One was an epoxy resin mixed by epoxy and hardener, and the other was a polyurethane resin including 70% solvent. These two kinds of polymers are usually used in energy-absorbing systems. Specimen #1P contained the epoxy resin, and #1O without any polymer had a porosity of 89.0%. Specimen #2P contained the polyurethane resin, and #2O without any polymer had a porosity of 88.9%. Fig. 2 shows the surface images of the closed-cell aluminum foams with the epoxy resin, with the polyurethane resin and without any polymer recorded by a charge-coupled device (CCD) camera.

2.2. Compressive test

An electronic universal testing machine (Shimadzu, AG-100kND) was used to perform the compressive tests on the specimens. The upper rigid plate of the testing machine was movable, and the lower one was fixed. The symmetric surfaces on the specimens containing the polymer and without any polymer were treated as the front surfaces. The displacement was slowly applied to the specimens at the speed of 0.6 mm/min. The loading force and the displacement of the upper rigid plate were recorded by a computer. During the tests, the front surfaces were illuminated by two beams of a white light source. An optical CCD camera was used to capture the front surface images of the specimens for the deformation distribution measurement.

2.3. Deformation measurement method

Previously developed by a group of researchers at the University of South Carolina in the 1980s [28–30], the DIC method has been increasing in popularity for mechanical testing applications due to its relative ease of implementation. The full-field displacement can be obtained by processing two speckle images before and after deformation, which are, respectively, referred to as the reference image and the deformed image [31]. A reference subset in a square region with a pixel size of $(2M+1) \times (2M+1)$ is first considered in the reference image, where M is a positive integer. The aim of the correlation method is to find the deformed subset in the deformed image to match the reference subset (Fig. 3).

To evaluate the similarity between the deformed subset and the reference subset, a correlation function should be pre-defined. The position of the deformed subset can be determined by searching the peak position of the correlation coefficient distribution. In this study, the normalized sum of squared differences (NSSD) correlation function is adopted. The differences in the positions

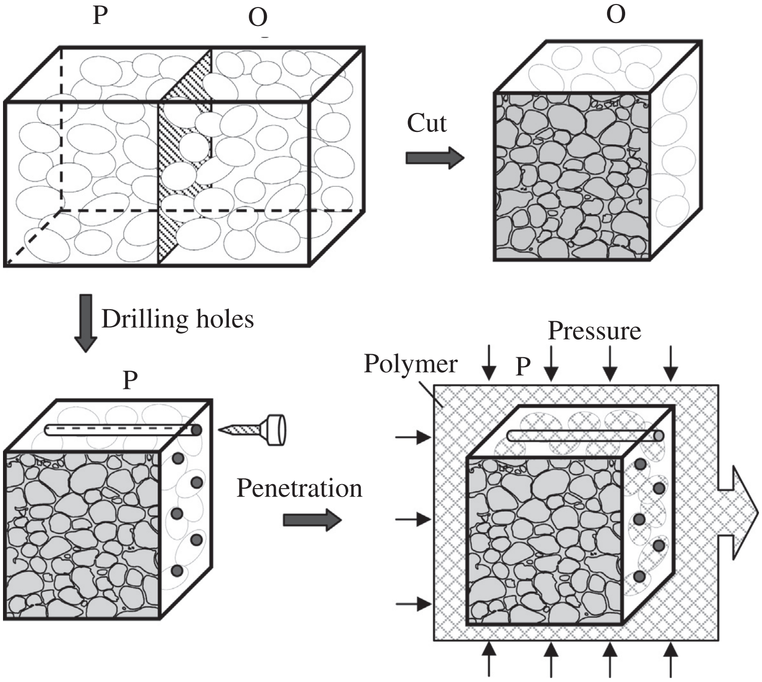

Fig. 1. Fabrication process of the closed-cell aluminum foams containing polymer (aluminum–polymer composite) and without any polymer.