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Influence of nano-SiC_p on the foamability and microstructure of Al/TiH_2 foam sheet manufactured by continual annealing and roll-bonding process

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ABSTRACT

In the present work, the continual annealing and roll-bonding (CAR) process was applied to produce a novel aluminum nanocomposite foam by applying 0.75 TiH_2 and 0.75 nano-SiC_p (wt%) between 5 pure Al strips, followed by 8 CAR cycles prior to foaming heat treatment in a preheated furnace at 750 °C. The effect of nano-SiC particles on the foamability and microstructural evolution of the precursors was investigated. The results obtained from the nanocomposite foams were compared with the corresponding ones of Al/0.75 wt% TiH_2 foamed sheets. Scanning electron microscopy (SEM) and elemental distribution images were utilized to compare the obtained results. The findings led to the conclusion that the application of nano-SiC particles results in an increment of pore nucleation sites, higher linear expansion and foam stability along with a smooth and regular cell morphology in the foamed nanocomposite sheets.

1. Introduction

Closed-cell metal foams, particularly aluminum foams, are introduced as a new category of advanced materials that are extensively used in the automotive, aerospace, aircraft, marine and construction industries because of their unique physical, mechanical, thermal, electrical and acoustic properties [1–3]. Consequently, these are interesting types of materials to be developed in the most cost effective and innovative routes. Direct foaming of metallic melts and indirect foaming of powder compacts are two well-known manufacturing methods which have attracted remarkable attention [4–10].

The melting routes are attractive for commercial purposes because the products are of relatively low cost and can be produced in large quantities. Contrarily, the weakest aspect of these routes is the restriction in the improvement of mechanical properties by the addition of reinforcements, specifically in the range of nano-size, owing to agglomeration phenomena [11–13]. The microstructure and mechanical properties of such foams have been widely studied on both macro- and micro-scales [14–16].

The powder metallurgy (P/M) processes offer some significant merits such as the possibility of near net shaping production, simplicity of process, flexibility in choosing the powder composition and the capability for use in small pieces. However, the P/M process is an expensive method and difficult to produce large volume components because of comprising small pores and cracks in the cell walls [12,13,17,18]. Recently, Kitazono et al. [17] proposed a novel and practical technique using accumulative roll-bonding (ARB) to manufacture a new type of closed-cell aluminum foam plate. In this method, a stack of two or even several strips is prepared having dispersed titanium hydride as a blowing agent among them. The stack is roll-bonded by an effective reduction, cut into two or several pieces followed by surface preparation. The new strips are stacked together and roll-bonded again. Through repetition of this process, the TiH_2 particles are well distributed throughout the thickness of the precursor. The precursor is heated to near its melting point and the cellular structure is achieved by releasing the gas from individual sources of distributed TiH_2 particles into the mushy state metallic matrix [17–19].

A review of the literature on this topic indicates that there is not much research on the cellular structures processed by the ARB or CAR processes and their microstructural evolution during foam formation can also rarely be found [17–24]. Kitazono et al. [17] produced an A1050 aluminum foam sheet using 0.5 wt% TiH_2 powder and 6 ARB cycles with a draft percentage of 50%. The results showed that the closed-cell Al foam contains about 40% porosity, while some cracks parallel to the rolling direction were observed and the size of the pores was reported between 1 and 4 mm. Complementary studies were continued by changing the composition of the metal matrix (Al—Si and Al—Mg) based on the strategy of filling the gap between the decomposition

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temperature range of TiH_2 and melting point of the base material [18–20]. As an example, a closed-cell Al—Si alloy foam was produced via 12 ARB cycles on a precursor with 0.5 wt% TiH_2, followed by the heat treatment at 630 °C for 1 min. The maximum porosity was measured 60%, whereas a few large pores were observable in the resulting structure [19]. Other investigators made an attempt to introduce new foam structures using alternative foaming agents such as dolomite [21,22] and carbonate calcium [23,24].

The present paper analyzes the development of a fabrication method to produce a nanocomposite foam reinforced/stabilized by nano-SiC particles using the CAR process. It studies the evolution of pore formation in the vicinity of nano-SiC particles, which could play a striking role in the shape and distribution of pores, cell wall smoothness and foam stability.

2. Experimental procedures

2.1. Materials

In the present study, an EN AW-1050A sheet with the chemical composition of Al – 0.16 Si – 0.28 Fe – 0.11 Cu (wt%) was used as the base metal. TiH_2 and nano-SiC particles with an average size of 30 μm and 50 nm were utilized as a blowing agent and foam stabilizer/reinforcement, respectively. Scanning electron microscope (SEM) images of the particles are shown in Fig. 1. It should be pointed out that TiH_2 particles have an angular morphology, whereas nano-SiC particles are more or less round. Five aluminum sheets were cut into 150 mm × 50 mm × 1 mm pieces, parallel to the rolling direction (RD), and four holes were drilled at both ends. The sheets were annealed at 380 °C for 2 h to improve the formability of the strips during the later roll-bonding process.

2.2. Precursor preparation

The manufacturing procedure of foamable precursors through the CAR process has been schematically summarized in Fig. 2. The first step included surface preparation of the five strips by degreasing in acetone and brushing the surfaces using a circular stainless steel brush on both sides to obtain 4.5 μm roughness. Then, either TiH_2 or nano-SiC powders (0.375 wt% with equivalent weight ratio) were uniformly dispersed between the two neighboring strips. The strips were then stacked over each other to achieve a 5 mm thick strip. The stacked strips were fastened at both ends with copper wire, and a 66% rolling reduction was applied in one pass at room temperature. The second step included an inter-pass annealing of the roll-bonded strips at 275 °C for 45 min to relieve residual stresses and to improve the ductility and bonding quality of the roll-bonded strips. Then, the strips were cut in halves, degreased in acetone, brushed using a wire brush, fastened to each other and roll-bonded with a reduction amount of 50% without adding the powders. The second step of the process was repeated up to 8 cycles in order to attain a uniform distribution of powders throughout the strips. Al/0.75 wt% TiH_2 precursors were similarly fabricated via the described procedure.

The CAR process was performed with no lubricants using a laboratory rolling mill with a diameter of 120 mm. The loading capacity and rolling speed were 20 tons and 32 rpm, respectively.

2.3. Foaming process

The precursors were cut into 22 × 12 × 2 mm^3 pieces before the foaming process. The high temperature foaming process was performed in an ordinary atmosphere using a resistance furnace preheated to 750 °C. Stainless steel molds with ceramic bottoms were designed to facilitate inserting/removing the specimens into/from the furnace. They also allowed the samples to expand only in the vertical direction. Both specimens with and without nano-SiC particles were put into the furnace at the same time to provide equal conditions during the foaming process.

The temperature-time curves of the foaming process were measured using a K-type thermocouple which was positioned between the ceramic bottom of the mold and the specimen through a hole in the mold wall. Temperature and porosity profiles corresponding to the two kinds of foamed specimens are presented in Fig. 3. After partial or complete foaming process, molds containing the specimens were cooled to room temperature by compressed air. The porosity level of the foamed specimens was measured using Archimedes' law.

2.4. Microstructural evaluation

Microstructural observations of the specimens were carried out using a scanning electron microscope (MIRA TESCAN) to study the distribution of particles and pores in the matrix. The cross section of the images was perpendicular to the transverse direction (TD).

3. Results and discussion

3.1. Microstructural investigations of the precursors

The SEM and elemental distribution (EDX) images show the distribution of powders used in foam precursor strips after 8 CAR cycles (Fig. 4). According to Fig. 4a and b which are corresponded to the precursors without and with 0.75 wt% nano-SiC after 8 CAR cycles, respectively, uniform dispersion of TiH_2 particles is evident in both specimens. TiH_2 particles have larger mean size in the Al/TiH_2 precursor (Fig. 4a). The powder size reduction takes place due to the nature of the roll-bonding operation [25,26]. TiH_2 particles are more brittle than the existing aluminum oxide films at contact surfaces, whereas larger particles crack or break to smaller sizes during roll-bonding. In addition, the presence of the hard nano-SiC particles in the precursor assist the oxide film to further break the micro-TiH_2

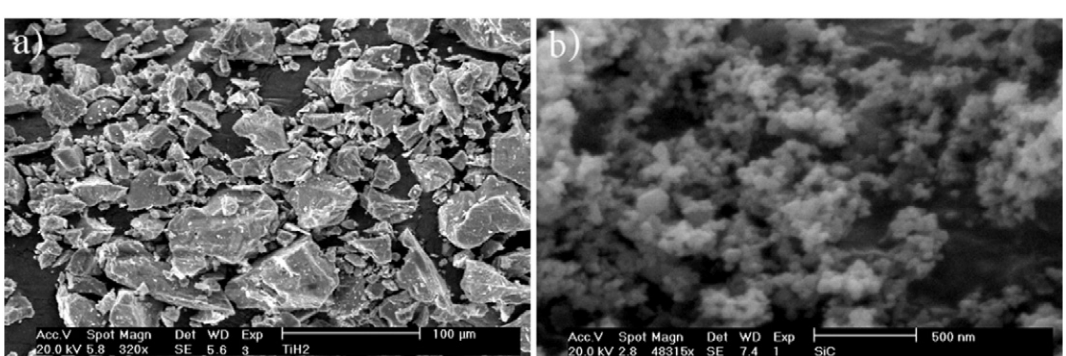

Fig. 1. SEM micrographs of (a) TiH_2, and (b) nano-SiC particles.