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Significant improvement in structural features, mechanical and physical properties of a novel CAR processed Al foam by nano-SiC_p addition

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ABSTRACT

A brief outline was prepared to study the effect of nano-SiC_p reinforcement on the structural features, mechanical and physical properties of the continual annealing and roll-bonding (CAR) processed aluminum foam. Nanoindentation, drop weight impact and operational modal tests were applied to evaluate mechanical and physical properties of the nanocomposite foam. Scanning electron microscopy and elemental distribution images were utilized to analyze the results. Findings showed that the application of nano-SiC_p results in matrix strengthening and remarkable improvements in dynamic compressive properties (strength increase of 48%), energy absorption (35% increase) and damping behavior (77% increase in damping ratio) of the nanocomposite foam.

1. Introduction

Closed-cell metal foams, particularly aluminum foams, are widely used in structural engineering applications and building constructions because they provide lightweight structures with high ratios of stiffness and strength to weight, remarkable energy absorption capabilities and suitable damping properties [1,2]. These characteristics of metallic foams strictly depend on pore architecture (diameter, uniformity and shape) and cell skeleton properties (thickness and strength) [3–5]. Addition of ceramic particles, specifically SiC, Al_2O_3 or TiB_2, to the metallic matrix offers one of the existing strategies to obtain the desired quality [2,6]. For instance, Kennedy et al. [7] verified that these particles were able to increase maximum expansion of P/M Al foams by decreasing the critical cell wall thickness before rupturing phenomenon. However, long-term stabilization was exclusively observed in the foams comprising the SiC particles due to appropriate wetting behavior between the particles and Al melt. This feature hindered the SiC particles moving into the cells and significantly reduced the drainage, leading to expansion of the resultant foam over a longer foaming time.

Up to now, there has been an ongoing effort in order to develop the most cost-effective and innovative routes in manufacturing of aluminum composite foams [8,9]. Preparation of a foamable precursor using accumulative roll-bonding (ARB) or continual annealing and roll-bonding (CAR) processes followed by subsequent foaming heat treatment is one of the recent attempts of this progression [2,10,11]. Over the last decade, Kitazono et al. [12–14] have traced the advance of the ARB process in production of foamed sheet Al alloys. However, the main attention has been paid on optimizing the process parameters such as number of ARB cycles in production of precursors as well as heating rate, time and temperature of the foaming heat treatment. Recently, the authors have applied the CAR process as a fabricating method to achieve a uniform dispersion of 0.75 wt% nano-SiC particles through the foam structure. It resulted in fabrication of a nanocomposite foam with superior improvement in macrostructure, pore distribution and cell wall smoothness [2].

The present study, to the best of our knowledge, is the first of its kind that focuses on how nano-SiC_p reinforcement influences the physical and mechanical properties of the nanocomposite aluminum foams produced by the CAR process.

2. Experimental procedure

2.1. Materials

The base material used in this study was AA1050 aluminum

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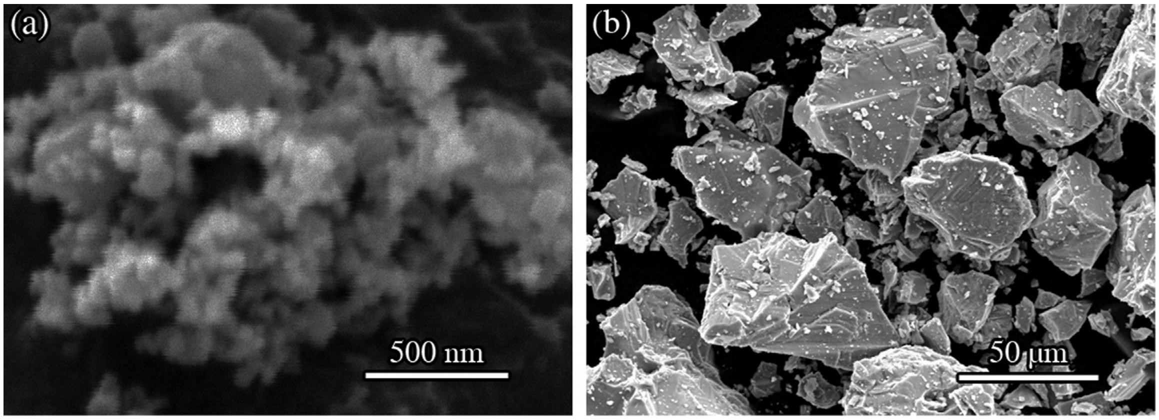

Fig. 1. SEM micrographs of (a) nano-SiC, and (b) micro-TiH_2 particles.

sheets with chemical composition of Al – 0.16 Si – 0.28 Fe – 0.11 Cu (wt%). The sheets were initially annealed at 380 °C for 2 h to release the residual stresses. Nano-SiC and micro-TiH_2 particles with mean diameters of 50 nm and 30 μm were utilized as foam stabilizer/reinforcement and blowing agent, respectively. Fig. 1 shows scanning electron microscope (SEM) micrographs of the both particles.

2.2. Precursor preparation and foaming process

The CAR process as a manufacturing method of foamable precursors was carried out in two steps to fabricate Al/0.75 TiH_2 and Al/0.75 TiH_2/0.75 nano-SiC (wt%) precursors. Stepwise details have been clarified in Fig. 2. The first step included surface preparation of 5 aluminum strips (acetone degreasing followed by scratch brushing) and manually dispersion of both powders between the strips. Then, the Al strips were stacked, fastened together and roll-bonded (reduction thickness of equal to 66%) at room temperature using a laboratory rolling mill with no lubricants. The second step was initiated by cutting the precursors in halves prior to inter-pass annealing at 275 °C for 45 min. In this step, the same procedure as the first step was repeated up to 8 CAR cycles with two exclusions: no further addition of the powders, and applying a constant thickness reduction of 50% for roll-bonding process. Foaming operation was performed in a preheated furnace at 750 °C for 340 s. Stainless steel molds with ceramic bottoms and metallic caps were utilized to facilitate inserting/removing the specimens into/from the furnace.

2.3. Microstructural characterization and nanoindentation test

Microstructural observations and elemental distribution images were carried out using a MIRA TESCAN SEM. The pore characterization was carried out based on 2-D image analysis. Therefore, the mean diameter and shape factor (circularity) of the pores were measured using the Clemex image analyzer software. The

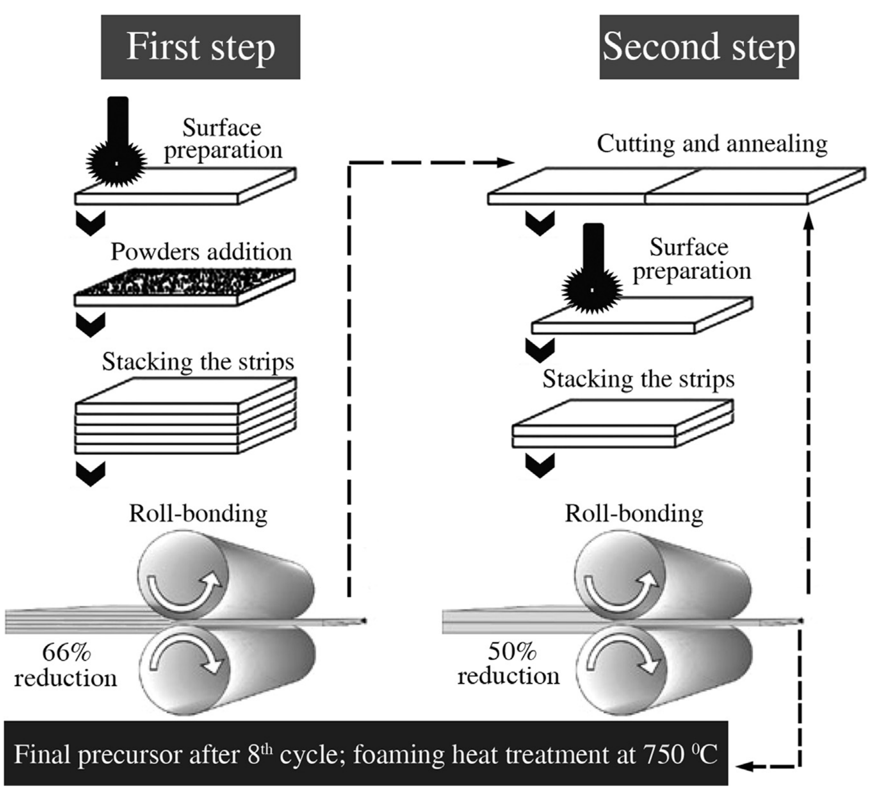

Fig. 2. Schematic illustration of foam manufacturing via CAR process.