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Laminate squeeze casting of carbon fiber reinforced aluminum matrix composites

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ABSTRACT

Carbon fiber reinforced aluminum matrix composites show an excellent combination of lightweight, mechanical properties, ease of processing and low costs. However, standard liquid infiltration squeeze casting often requires complex preforms in order to control fiber configuration and distribution. It also requires relatively high pressures to overcome the pressure drop across the preform, which can lead to preform compaction and damage and can limit the maximum component thickness that can be thoroughly infiltrated. Therefore, a laminate squeeze casting process is investigated as alternative whereby alternate layers of fiber fabrics and aluminum sheets are hot consolidated. Liquid infiltrates the fiber fabrics from their two respective neighboring aluminum layers, thereby reducing the infiltration distance from the entire component height to only half the thickness of individual fiber layers. This results in a rapid and thorough infiltration. Composites with fiber contents between 7 and 14 vol% are successfully fabricated. Despite complete melting of the aluminum layers at 850 °C, optical and scanning electron microscopy investigations show that hydrostatic pressure practically preserves the laminate configuration during fabrication and no fiber agglomeration occurs. The composites show good fiber–matrix bonding. No noticeable fiber damage is observed despite some carbide formation primarily at interfaces. A composite hardness over 50% higher compared to the reference 6061 matrix alloy is achieved at a carbon fiber content of 7.4 vol%.

1. Introduction

A great deal of research is been dedicated to lightweight metal matrix composites for highly demanding applications including defense, aerospace and transportation [1–2]. Aluminum matrix composites are among the most popular of such composites due to major advantages in both processing and final properties. The ease of processing aluminum matrix composites results primarily from the low melting point of aluminum and the high fluidity and infiltration rates that can be achieved. During use, carbon fiber reinforced aluminum matrix composites can show superior temperature resistance, strength, stiffness, lightweight, thermal and electrical conductivity, fatigue, creep and wear resistance compared to their conventional polymer matrix composite and unreinforced aluminum alloy counterparts [1,3].

Liquid infiltration squeeze casting has been attracting huge interest from both the manufacturing society and the research community for the fabrication of fiber–aluminum matrix composites [4]. Current standard processes use complex performs in order to control local fiber configuration and distribution. The preforms often require complex weaving and stitching techniques, equipment and long production times resulting in major additional production costs [5,6]. Also, high infiltration pressures are needed to overcome the strong flow resistance and pressure drop as the liquid aluminum flows relatively long infiltration distances across the entire perform from one end to another. Excessive pressure at the liquid inlet side can cause local perform compaction and damage [5,7,8]. Also, the pressure drop can lead to insufficient liquid pressure at the far end of the preform resulting in a lack of appropriate thorough infiltration and wetting. The result can be poor wetting, poor fiber–matrix interface bonding, remaining porosity and limitations in the maximum component thickness that can be safely manufactured.

Therefore, the present work investigates the fabrication of aluminum matrix composites by squeeze casting using a laminate configuration of carbon fiber fabric and aluminum sheets or foils. The work focuses on investigating the process feasibility as well as the resulting microstructure and hardness at both macro- and micro-scales. The microstructure characterization is done using optical microscopy and scanning electron microscopy. The quality of the fiber–matrix interface bond is investigated and correlated to

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the indentation resistance. The effect of fiber volume fraction is investigated. The obtained composite properties are compared with those of the reference 6061 aluminum alloy fabricated under identical process conditions.

2. Methods

A comparison of the standard liquid infiltration squeeze casting process and the laminate squeeze casting method is graphically illustrated in Fig. 1a and b. Aluminum is molten and infiltrates the preform from one end (top) to the other (bottom) under the squeeze pressure in the case of the standard liquid infiltration method in Fig. 1a. In contrast, an alternate configuration of aluminum and carbon fiber fabric layers allows liquid aluminum to infiltrate the sandwiched carbon fiber fabric layers from their two respective neighboring aluminum layers under the squeeze pressure upon heating in the case of the laminate squeeze casting technique illustrated in Fig. 1b.

For composite sample fabrication, cylindrical die and punch were made of stainless steel 304 that provided sufficient strength, temperature and oxidation resistance; the setup is shown in Fig. 2. AS4 Hexcel carbon fiber fabric and 0.7 mm thick Aluminum 6061 sheets were cut to 78 mm diameter discs, placed in the die in a laminate configuration as illustrated in Fig. 1b, and then heated in a Lindberg furnace to 850 °C. The heating time was 1 h. Die and sample were maintained at 850 °C for 40 min. The die was then placed in a hydraulic press for squeezing at 20 MPa. The pressure was maintained until cooling below the solidus temperature of the aluminum matrix to allow molten aluminum to infiltrate and wet the carbon fiber fabric layers.

AS4 Hexcel carbon fiber fabric features continuous 3000 (3 K) filament tows with 94% carbon content. The elastic modulus and the strength of carbon fiber are over 3 and 14 times higher than values for aluminum, respectively, while its density is only about 2/3 that of aluminum, making it an excellent lightweight strengthener. The chemical composition of the 6061 aluminum matrix is shown in Table 1 and some relevant properties of both 6061 and AS4 Hexcel carbon fiber are summarized in Table 2.

Metallography samples are ground, polished and etched for 2 min using a Keller solution. The microstructure investigation is done using a XJP-3A optical microscope for fiber configuration and distribution as well as for porosity analysis. The chemical

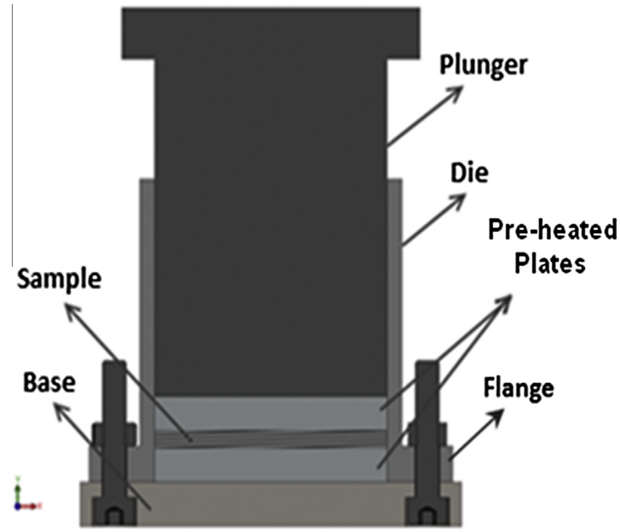

Fig. 2. Squeeze casting set-up.

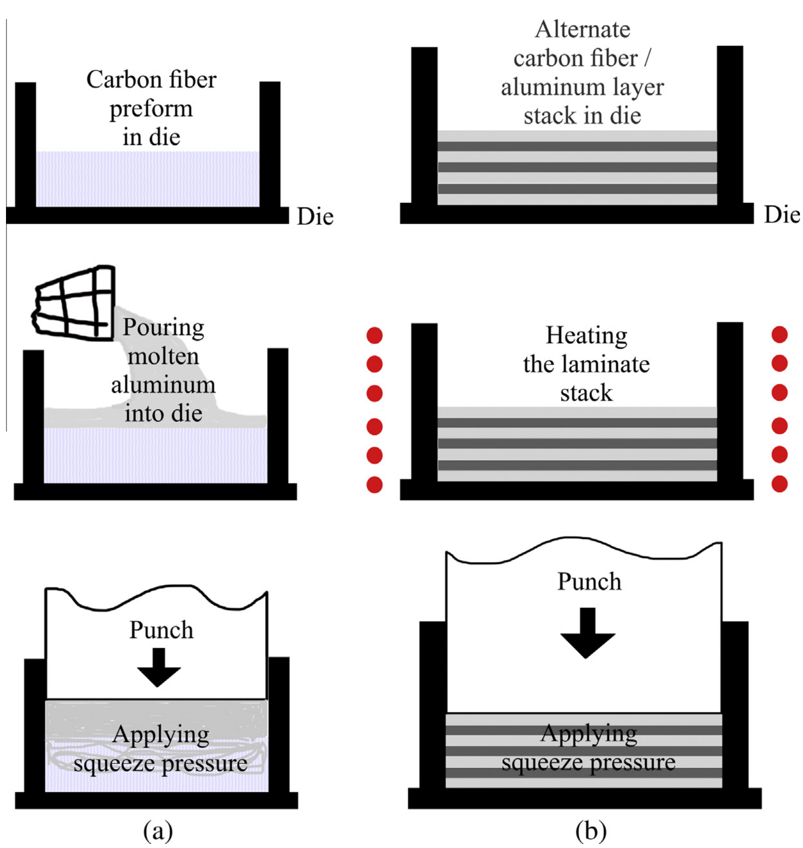

Fig. 1. Graphical illustration of conventional (a) and laminate (b) squeeze casting processes.