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Manufacturing of Al-TiB_2 Nanocomposites by Flux-Assisted Liquid State Processing

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Abstract

Aluminum matrix nanocomposite (AMNC) materials are of great interests for various structural and functional applications for automotive, aerospace, and military. In this study pure aluminum (Al) with one and two volume percent (vol.%) of titanium diboride (TiB_2) nanoparticles were produced via flux-assisted liquid state processing. Adding flux during nanoparticle feeding can significantly improve nanoparticle incorporation into molten Al. TiB_2 nanoparticles as small as 100 nm were successfully incorporated into pure Al using potassium aluminum fluoride ($KAlF_4$) flux. TiB_2 nanoparticles were fairly distributed and dispersed in the Al-2 vol.% TiB_2 nanocomposite. Vickers hardness of the Al-2 vol.% TiB_2 nanocomposite was higher than the as-received pure Al. While $KAlF_4$ flux is proven to enhance the nanoparticle incorporation efficiency in Al system, further study is needed to thoroughly remove the flux remnant from Al matrix, to enhance the effect of the TiB_2 nanoparticle reinforcement.

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Keywords: Solidification processing; Aluminum matrix nanocomposite; TiB_2 nanoparticle; Flux-assisted processing

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1. Introduction

One of the great challenges of this century is the high demand for lightweight metals with promising physical, chemical, and mechanical properties for various structural and functional applications [1, 2]. In lightweight metals family, aluminum is one of the most abundant lightweight metals in Earth and is used in many industries such as

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aerospace, automobile, and naval. Pure Al with low strength and high ductility is less appealing for certain applications where high strength and lightweight are needed. Although alloying pure Al with other metals such as Cu and Zn [3] would result in higher strength, there is a limit to how much these elements can be added. On the other hand, Al matrix nanocomposites can offer excellent properties to compete with high strength and high density metals [4]. AMNCs are a class of materials in which the matrix is pure Al or its alloy and the nano-reinforcement (i.e. nanoparticle) can be represented by different metals, ceramics or organic compounds [5-9]. High performance AMNCs materials have great potentials to improve energy efficiency and system performance in numerous applications. While many researchers strived to develop AMNCs with significant enhanced mechanical property, limited success have been reported to produce bulk AMNCs with uniform dispersion of the nano-reinforcements [10-12].

1.1. Production of Metal Matrix Nanocomposites

There are several approaches for manufacturing of the AMNCs, such as solid state processing (i.e. powder metallurgy), Liquid state methods (i.e. pressure infiltration and squeeze casting), and semi-solid state processing (e.g. semi-solid powder processing). Among the aforementioned processes, liquid state solidification processing is promising for an economical manufacturing of bulk metal matrix nanocomposite specifically for those with crystalline materials as matrix. However, efficient feeding and dispersion of nano-reinforcements in crystalline matrix is still a great challenge [13].

1.2. Nano-reinforcement Feeding and Incorporation

Direct feeding of nano-reinforcements to molten metals has several potential problems such as partial nano-reinforcement burning and loss during feeding [14, 15]. These challenges reduce the incorporation efficiency and therefore less effect on mechanical property improvement. On the other hand, surface oxide formation during liquid state processing at high temperatures poses a barrier for effective incorporation and dispersion of nano-reinforcements due to a reduced wetting between nano-reinforcements and matrix. Using a flux agent, protection gas or vacuum processing can significantly mitigate this barrier and improve nano-reinforcement incorporation efficiency [16]. Achieving a uniform dispersion of nano-reinforcements within crystalline matrix is crucial to enhance the mechanical property of metal matrix nanocomposites [17, 18].

2. Materials and Method

For this study TiB_2 was chosen as the nano-reinforcement since it is an extremely hard ceramic. High purity Al (99.99%) ingot and in-house synthesized TiB_2 nanoparticles with an average size less than 100 nm were used as matrix and nano-reinforcement, respectively. TiB_2 nanoparticles (2 g) and $KAlF_4$ flux (13 g) were mechanically mixed at solid state for 3 hours. Mixed powders were dehydrated at 120 ºC for 1 hours in a vacuum oven. An electrical resistance furnace was used to melt the Al ingots (39 g) at 800 ºC under argon (Ar) gas protection. Then, the mixed powders were added to the melt surface and melt was mechanically stirred at 200 rpm for 10 minutes with a one-inch dimeter titanium (Ti) mixing blade. The melt was naturally cooled down to room temperature under Ar gas protection. The final product was (in the shape of a disk with 1.5 inches in diameter and 1.0 inch in height) carefully extracted from the graphite crucible. Al-X vol.% TiB_2 (X=1 and 2) nanocomposites were produced (three study samples were prepared from top, middle, and bottom of each nanocomposite sample). Figure 1 shows the schematic of the experimental setup.