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Original Research Article

An investigation into fabrication and characterization of direct reaction synthesized Al-7079-TiC in situ metal matrix composites

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ABSTRACT

The present study was attempted to highlight a novel direct reaction synthesis in which traditional casting plus rapid solidification techniques were implemented to produce Al-7079-TiC in situ composites with homogenous microstructure and improved dispersion strengthening by the reinforcing phases. Casted samples were effectively characterized by scanning electron microscopy followed by energy dispersive spectroscopy and X-ray diffraction. Ingot metallurgy showed a homogenous distribution of TiC particles inside the grain. This particle behavior acted as an excellent nucleation sites for the Al dendrites to grow unvaryingly. TiC reinforcements have semi coherent relationship with α-Al matrix. It was observed that eutectic boundary includes the second phases based on η ($MgZn_2$) and Mg $(Zn, Cu, Al)_2$. Almost 90% of the in situ reinforced TiC were homogenously distributed along the center of the grain. Thermal history conditions have shown an exothermic behavior during casting. Experimental results revealed the evolution of TiC particles in super-heated melt region, i.e. dissolution of titanium continued by reaction of titanium with diffused carbon in the Al matrix to form TiC particles. Further they acted as nucleation sites for the α-Al dendrites to grow homogenously. This study presents optimum process temperature for the Al-TiC in situ synthesis.

1. Introduction

During the past decade aerospace and automobile industries are becoming more challenging due to the specific property requirements where conventional alloy systems are not sufficient. Attempts to improve the performance characteristics of aluminum alloys with a high strength second phases are required for high strength to weight ratio [1]. Metal matrix composites (MMCs) incorporate a broad variety of metal systems (e.g. titanium, aluminum, magnesium, copper and nickel alloys) using various reinforcements in the form of fibers (Al_2O_3, SiC, graphite), whiskers (SiC) and particulate reinforcing phases (SiC, Al_2O_3, B_4C, TiC, TIB_2) [2,3]. High quality

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composites can be accomplished by avoiding destructive interfacial reactions and interfacial compatibility [4]. Among the current methods for processing composites, the most popular methods are in situ reinforced composites. In this process, the reinforcements are formed inside the melt prior to solidification by direct reaction synthesis in the absence of air, so that interface wettability and quality of the composites can be achieved [5].

Several processing routes have been implemented traditionally for the production of MMCs by several processing routes such as spray deposition, powder metallurgy, mechanical alloying and various melting routes, i.e. stir casting, compocasting, squeeze casting, rheocasting, etc. [6].

The identification of process parameters such as stoichiometry, temperature, pressure and stirring time is essential for the good dispersions of the reinforcement in the liquid metal whereby detrimental matrix reinforcement reactions and porosity can be minimized [7]. Apart from the inherent advantages of in situ reaction synthesis, this melting route provides near net shape components directly by die casting [8]. The advantages following this reaction synthesis was reported by several researchers [3,5–7]. In this technique reinforcements are well distributed and impurity free interfacial bonding exists between reinforcing phases and the matrix, fabrication cost is less compared to ex situ reinforcements, quality of product is outstanding because the formation of reinforcements is in the absence of air.

Feng et al. [9] compared monolithic Ti-1100 alloy with in situ (TiB-TiC)/Ti-1100 through ingot melting process by reacting Ti with B_4C. The yield strength of the composites has been increased by effective reinforcement load transfer. Flux assisted synthesis of in situ cast Al-Cu-TiB_2 was investigated by several researchers [10–12]. In situ TiB_2 reinforcement were formed by an exothermic reaction inside the matrix in the presence of K_2TiF_6 and KBF_4 halide salts. TiB_2 reinforcements not only increased hardness and elastic modulus but also it acted as a good grain refiner for the matrix [12]. By varying the weight percentage of TiC at different ratio in the high strength Al-alloys, these can be engineered for frictional applications; dry sliding and abrasive wear behavior has been conducted in this Al alloys, which lead to good wear resistance by optimizing various casting parameters such as temperature, holding time, addition of reinforcing phases, etc. [13].

Additionally, in situ Al-TiC has been developed by a novel technique by passing carbonaceous gas into the melt which lead to a fine decomposition reaction in which titanium diffuse into the carbon and precipitating out as titanium carbide. These composites showed improved mechanical properties compared with the parent matrix by dispersion strengthening and grain refinement [14,15]. For a homogenous cast, self-propagation high temperature synthesis (SHS) of preforms of Al, Ti, C powders were measured with respect to the molar ratio. With increase in the Al powders in the preform, SHS reaction gets delayed. Blending of Al powders should be in the range of 20–40% for the formation of TiC inside the Al-matrix [16]. Titanium also acts as a good grain refiner along with boron or carbon. It was reported that reactive slag process of making in situ reinforcement could produce composite using cheap materials (commercial pure aluminum, titanium oxide, cryolite and graphite); TiC produced was in whisker form which improved mechanical properties considerably [17].

The increase in wear resistance by adding carbide reinforcement has been reported by many researchers [13,18–20]. For instance Kim et al. [21] reported that sliding wear resistance has got negligible effect on size of the reinforcements (TiC, TiB_2, SiC, B_4C) but strongly depends on volume fraction of the reinforcement. Additionally, attraction of TiC with Al matrix is due to its superior wettability, high hardness, relative thermal stability and low density. Al-TiC MMCs are now widely used for defense, aerospace and structural applications [22]. Other than reinforcement reaction, there is a formation of second phase inside the alloy matrix. The precipitation sequence for this age-hardenable Al-Zn-Mg-Cu alloys were proposed as follows:

$$\begin{aligned}&\alpha\text{-supersaturated solution } (\alpha\text{-sss})\\ &\quad\rightarrow \text{Guinier-Preston zones (GP zones) (vacancy rich clusters)}\\ &\quad\rightarrow \text{metastable } \eta' \rightarrow \text{equilibrium phase } \eta\ (MgZn_2)\ [23].\end{aligned}$$

Ghiaasiaan et al. [24] reported the quantitative metallographic secondary phases in 7XXX alloys. In the complex Al-Zn-Mg-Cu alloy system various precipitation phases could evolve such as sigma phase $Mg(Zn, Cu, Al)_2$, η phase ($MgZn_2$), θ phase (Al_2Cu). However, melting characteristics of the in situ Al-TiC in situ by direct reaction synthesis has been reported very rarely.

This study is approaching toward developing cost effective in situ metal matrix composite by reaction synthesis with Al-7079 as cast base matrix. Al 7079 is basically used in aircraft industry for aircraft parts such as wing panels and bulkhead assemblies [25]. In the direct reaction synthesis of Al-TiC MMCs, Ti and C powders are added into the melt separately for in situ reaction, and reinforcement (TiC) is formed inside the melt in the absence of air [6,7,18,26]. According to processing methods particulate reinforced MMCs are classified as ex situ and in situ MMCs. Later one is preferred because of less interfacial defects and homogenous distribution along with better wettability between the reinforcement and matrix [4,27,28]. The role of temperature controlled reaction is more important in in situ MMCs which ultimately influences mechanical properties.

MMCs reinforced with TiC have vast thermal, physical, mechanical and electrical properties. With regard to the mechanical properties of TiC reinforcements [29,30], density = 4.93 g/cm^3, expansivity = 7.60×10^{-6} °C^{-1}, strength = 55 MPa at 1090 °C, and elastic modulus = 269 GPa at 24 °C. According to the previous studies [31,32], it has been demonstrated that Al-TiC metal matrix composites produced using in situ reaction synthesis has shown better results in mechanical properties as compared to the matrix alloy along with an excellent wettability. The present study is focused on the in situ formation of TiC reinforcements at different temperature along with free energy of formation of TiC particulates inside Al-7079 matrix. The MMC is further analyzed for the effect of volume fraction of TiC along with precipitates inside the matrix and shall examine the effects of TiC upon microstructure, strengthening mechanism, hardness, etc. with a similar unreinforced alloy.