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Manufacturing of Al Composites Reinforced with SiC and AlN

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ABSTRACT: *In-situ* processing of Al alloy composites using gas-bubbling method was investigated. The composites reinforced with SiC and AlN particulates have been formed *in-situ* using gas-bubbling method with CH₄, N₂, and NH₃ gas as gaseous precursors. Experimental studies showed that the reinforcing particles formed *in-situ* were small in size and uniformly dispersed in matrix. Thermodynamic and kinetic models were developed to understand the reaction mechanism.

1. INTRODUCTION

Discontinuously reinforced Al alloy composites (DRACs) have broad applications in tribological, electronic packaging, recreation, and automotive industries as well as defense and aerospace industries. However, DRACs manufactured by conventional solidification and powder metallurgy technologies are still not economically favorable. Necessary use of expensive small-size reinforcing particulates make it difficult to lower further the cost of DRACs. Moreover, since the potential interfacial problems and limitation of particles size, it is difficult to improve further the properties of DRACs. Because of these, the DRACs are still not profitable for structural applications.[1] Development of novel *in-situ* processing technologies, in which expensive reinforcing particulates are formed directly in alloy melts through *in-situ* chemical reactions from raw materials, may overcome these disadvantages. Since expensive reinforcing particulates are

directly synthesized from inexpensive raw materials, the cost of DRACs can be lowered. Also, since the reinforcing particulates are formed *in-situ*, they are in equilibrium with matrix alloy and interfacial properties can be improved. In our investigations [2-7], SiC and AlN reinforced Al alloy composites were synthesized using *in-situ* gas-bubbling method in the temperature range of 1223K – 1573K.

2. EXPERIMENTAL

The *in-situ* reaction was performed in an alumina crucible in a vertical tube furnace under Ar gas atmosphere in the temperature range of 1223K - 1573K. Al, Al-Mg and Al-Si alloys were used as the matrix alloys. CH₄, N₂, and NH₃ gases were used as the reactive gaseous precursors, which were bubbled into Al alloy melt through an alumina tube. In order to lower the effect of O₂ and moisture, deoxidization operation was applied when N₂ was used as the bubbling gas. Following the bubbling, the melts were cooled to ambient temperature in the furnace. The samples were characterized by OM, SEM, EDS, and XRD.

3. RESULTS AND DISCUSSION

The SiC reinforced Al alloy composites were formed *in-situ* in Al-Si-CH₄ system by bubbling CH₄-Ar gas mixture through Al-Si alloy melt in temperature range of 1223-1423K. Figure 1 shows a typical optical micrograph of the composite, in which bright domains are Al, dark particles are SiC, and the remaining regions with darkness in between Al and SiC are Si. As is seen from the figure that SiC particles are small in size (10-20 microns) and uniformly dispersed in the matrix alloy. XRD analysis further evidenced that the composite was composed of Al, Si, SiC, and a small amount of Al₄C₃. Thermodynamic modeling showed that the undesirable Al₄C₃ could be avoided by well-control of the content of Si in melt.[2,3] At high concentration of Si, Al₄C₃ can not be formed. The average rate of SiC formation is about 12.5 g·m⁻³·sec⁻¹ at 1473K. Kinetic studies [4] showed that the overall kinetic process is divided into five stages including: (1) methane dissociation to carbon particles and hydrogen, (2) carbon particle transfer from the bulk gas phase to liquid, (3) carbon particles entering the liquid, (4) reaction of carbon and silicon in liquid to form SiC monomer, and (5) SiC nucleation and growth. The second step, i.e. mass transfer rate of solid carbon in gas bubble was thought to be the rate-controlling step.

Thermodynamic analysis [5,6] showed that AlN is stable in pure aluminum, Al-Mg, and Al-Si alloys from room temperature to 1700K, covering the whole temperature range of fabrication,

secondary processing, and application of DRACs. With gas-bubbling method, AlN reinforced DRACs were synthesized with Al and Al-Mg as starting alloys by bubbling N₂. Figure 2 shows a typical SEM micrograph of the AlN-Al composite synthesized in Al-N₂ system, in which bright particles are AlN particles and dark region is Al. The AlN particles are small in size (<10 microns) and are uniformly dispersed in Al matrix. The trace oxygen and moisture in N₂-bubbling gas are very deleterious to the formation of AlN. Directly bubbling N₂ of commercial grade did not lead to the formation of significant AlN. When further de-moistured and de-oxidized N₂ was bubbled, AlN was formed at a low rate. At 1473K, the average rate of AlN formation is about 10.05 g·m⁻³·sec⁻¹.

Bubbling NH₃ has led to formation of AlN particles in Al and Al-Si melt at a very high rate. The rate of AlN formation was about 114 g·m⁻³·sec⁻¹ at 1473K. The alloy composition did not show obvious effect on the rate of AlN formation. The improvement of rate of AlN formation is due to contribution of H₂ dissociated from NH₃. H₂ functions as the oxygen getter and lowers the oxygen content in the reaction sites, thereby increasing significantly the permissible oxygen content in NH₃ precursor, as shown in Figure 3. Also, H₂ may enhance the adsorption of N₂ at gas bubble-metal melt interface, thereby improving the rate of AlN formation [3,7]. Kinetic studies showed that the overall kinetic process is similar to that in Al-Si-CH₄ system. However, the rate of AlN formation is controlled by the diffusion of adsorbed nitrogen in liquid boundary layer. Figure 4 shows a typical SEM micrograph of AlN-Al composite synthesized in Al- NH₃ system, in which the bright particles are AlN particles, the dark region is Al. The AlN particles are equiaxed, small in size (2 microns) and are uniformly dispersed in Al matrix.

Acknowledgements

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4. REFERENCES

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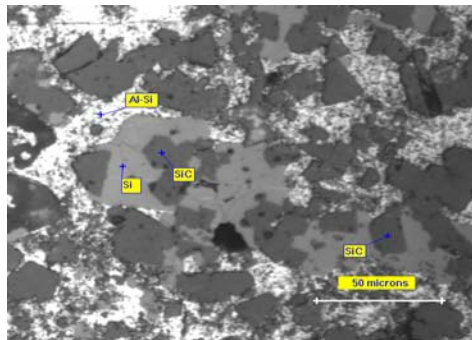


Figure 1 Optical micrograph of a SiC/Al-Si composite formed *in-situ* in Al-Si-CH₄ system.

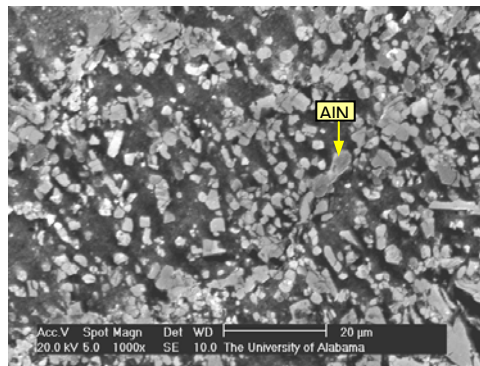


Figure 2 Typical SEM micrograph of a AlN/Al composite formed *in-situ* in Al-N₂ system.

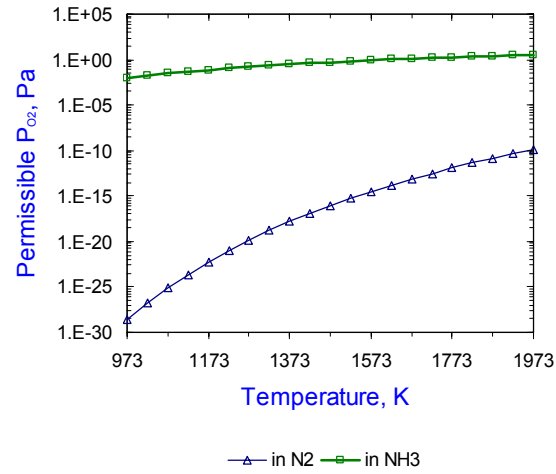


Figure 3 Permissible oxygen content in N_2 and NH_3 for formation of significant AlN in Al melt.

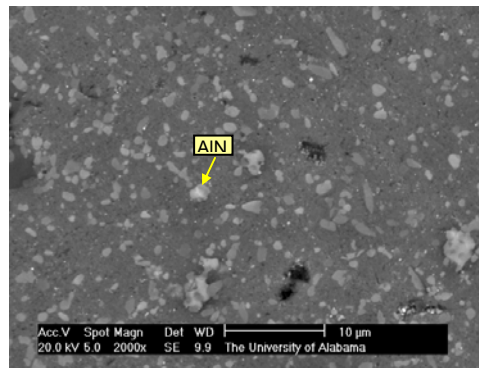


Figure 4 Typical SEM micrograph of a AlN/Al composite formed *in-situ* in Al- NH_3 system.