Chapter 7

PAPER PUBLICATIONS

1. **Phase I: Optimization of magnesium content into the commercially pure aluminium (CPA)**

   H. N. Panchal and V. J. Rao, *"Influence of Mg on micro-mechanical behaviour of as cast Al-Mg System"*, Physics of Metals and Metallography, 2019, Vol. 120, No. 9, pp. 881–887.

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2. **Phase II: Effect of variation of MnO_2 content by changing its addition sequence into the commercially pure aluminium (CPA)**

   H. N. Panchal and V. J. Rao, *"Preparation of $Al - MnO_2$ Composite using Stir Casting Method"*, Proceedings of International Conference on Recent Advances in Metallurgy for Sustainable Development (IC-RAMSD 2018), ISBN : 978-93-88879-64-4, February 1^{st} - 3^{rd}, 2018, The M. S. University of Baroda, Vadodara, India, pp. 139-142.

3. **Phase III: Effect of variation of MnO_2 by changing its addition sequence into the commercially pure aluminium (CPA) along with optimised magnesium metal from phase I**

   H. N. Panchal and V. J. Rao, *"Fabrication of in situ aluminium matrix composite by change in addition sequence of MnO_2 particles"*, Engineering Research Express, 2022, Vol. 4, No. 2, pp. 881–887.

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STRENGTH AND PLASTICITY

Influence of Mg on Micro-Mechanical Behaviour of as Cast Al–Mg System

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Abstract— In the present work, a study was carried out for various possible Mg concentrations in order to optimize Mg amount in Al–Mg system as far as metallurgical and mechanical properties are concerned. In molten Al, variations of amount of Mg were made from 0.05–7 wt % Mg using a resistance heating furnace. Intermetallics like Al–Mg, Mg–Si, Al–Si, etc.,—were formed at processing temperature. During solidification, these intermetallics were pushed towards the grain boundaries and formed clusters, which was studied using SEM–EDS analysis. Heavier phases revealed as dark regions whereas lighter phases as less dark or bright regions. Due to such pushing effects of intermetallics during solidifications of bath in metallic die, development of grain boundaries started in the form of remarkable thickening of it into the Al matrix. This phenomenon was found to be more pronounced, as the Mg concentration was increased. Hence, in case of 7 wt % Mg, it was found that maximum amount of intermetallics gathered at grain boundaries. Segregation tendencies of various intermetallics and excess free Mg were found non uniform for a higher range of Mg. Ultimate tensile strength, specific strength, and hardness properties were studied and they were found to be highest in Al–3 wt % Mg system along with low density and ductility values. Therefore, in the present study, 3 wt % Mg is considered to be an optimum level of Mg concentration based on its micro-mechanical behaviour.

Keywords: aluminum, magnesium, specific strength, intermetallics

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1. INTRODUCTION

Al alloys are widely used in aerospace and automobile industries due to their low density, good mechanical properties, better corrosion resistance, better wear resistance, low thermal coefficient of expansion as compared to conventional metals and alloys. The excellent mechanical properties and relatively low production cost make Al alloys an attractive candidate for a variety of applications from both scientific and technological viewpoints [1]. At present, these Al–Mg alloys offer an attractive performance and weight-saving alternative for wide ranges of applications like sport industries, automobile industries, aerospace industries, etc., as they provide beneficial characteristics over existing materials with effective control on the economical factors. Alloying elements are selected based on their effects and suitability. Other typical alloying elements such as Cu, Mn, Si, Zn, Fe, Ni, Pb, and Sn are also frequently used in Al [2].

In principle, as a major alloying element, Mg is the most effective element to strengthen the alloy system and it alters the capability in die casting because of its soluble nature in Al. Mg can provide effective strengthening and increment in the work-hardening characteristics of Al [3]. It can also enhance the corrosion resistance and weldability [4, 5]. The moment silicon reacts with Mg to form the hardening phase Mg_2Si, it provides strengthening. Traditionally, Mg does not exceed 5–7 wt % in Al–Mg system sometimes along with Mn [6]. However, optimum strength and hardness values were claimed at 1 wt % Mg [7] and even at 5 wt % Mg [8] as reported. In some literature sources it was found that the optimum value of Mg is 8 wt % for which the Al–Mg system exhibited good thermo-mechanical properties, more specifically, when Mg was added between 4–8 wt %. Beyond 8 wt % Mg content, the higher porosity in the Al–Mg system was observed, resulting in lower thermo-mechanical properties [9]. Also, it is always desirable to understand the effect of Mg addition on the microstructure and mechanical properties of Al–Mg system. Hence, to optimize the Mg content in Al as far as metallurgical and mechanical properties are concerned, the present study was carried out.

Mg can vary most of the mechanical properties of Al [10]. Hardness and wear property of Al can increase with Mg addition due to formation of intermetallics [11].

A variety of studies in present Al–Mg system can be made as it is one of the highly flexible alloy systems.

Preparation of Al – MnO_2 Composite using Stir Casting Method

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Abstract

MnO_2 particles were incorporated into liquid Al to prepare Al-MnO_2 composite. The MnO_2 particles reacted with the Al to produce Al-Mn intermetallic and *in-situ* Al_2O_3 particles in the matrix. The aim of the present study is to investigate the micro-mechanical behaviour of cast Al-MnO_2 composites synthesized by dispersing MnO_2 particles in molten aluminium, which get reduced to form Al_2O_3 particles. Microstructure, hardness and tensile properties of the composites were found higher than those of the base material due to redistribution of the alloying elements and dispersion of Al-Mn intermetallic and *in-situ* Al_2O_3 particles.

Keywords: Intermetallic, Al-MnO_2, stir casting, Al_2O_3 particles, MMPCs

1. INTRODUCTION

Aluminium-based metallic systems have got wide acceptance due to their higher specific strength, specific modulus and wear resistance as compared to unreinforced alloys and thus capable to reduce the weight of components made out of them, leading to significant impact on fuel economy in dynamic systems [1-4].

A variety of ceramic powder particles have been dispersed in different metallic systems to develop metal–matrix particulate composites (MMPCs). Mostly investigations have been carried out to estimate tribological behaviour. The incorporated non metallic particles include Alumina [1, 3-8], Silicon Carbide [7,9-11], Silica [5, 12], Zirconia [6, 13] and soft solid particles such as Graphite [14,19], B_4C [20], Mica [21], MoS_2 [22], etc. directly into liquid commercially pure aluminium or aluminium alloys either by powder metallurgy or through a casting route for enhanced micromechanical behaviour considerably. In recent years, it has been found that the interest in the development of *in situ* MMPCs increased, where the reinforcing phases are formed within the matrix. By using this approach, Al-TiB_2 [23], Al-Al_2O_3 [24], Al-MnO_2 [25], Al-TiC [26], etc. *in situ* particulate-composites have been produced. Generally oxides, nitrides, carbides, borides, etc. are commonly use as non metallic particles to serve the purposes of *in situ* MMPCs. The significant increase found in both mechanical properties like bulk hardness, strength, etc. and tribological properties in aluminium based *in situ* composites which make them qualify to be candidate materials for many engineering applications [27].

The main advantages of *in situ* particle formation in the matrix are having a wide variety of shapes and sizes and strong interfaces between the particles and the matrix [28]. The studies undertaken here in the present work is intended to evaluate the micro mechanical behaviour of Al–MnO_2 system synthesized by dispersing MnO_2 particles into molten aluminium by a liquid metallurgy technique (stir casting method). The interesting feature of this system is the strengthening effect on matrix material by alloying with manganese when MnO_2 particles get decomposed at 535 °C by molten aluminium and generation of hard particles during processing. The influences of both externally added MnO_2 reinforcing particles and generated Al_2O_3 *in situ* particles on metallurgical and mechanical behaviour of *in situ* MMPCs were investigated.

2. EXPERIMENTAL PROCEDURE

In this method, ceramic particles i.e. MnO_2 are incorporated into molten Al so as to produce the reinforcing phases by chemical reaction between the added non metallic particles and the Al melt. Present work considers the preparation of Al–MnO_2 *in-situ* MMPCs by addition of MnO_2 particles into Al melt. Thermodynamic calculations show that the MnO_2 particles would decompose at 535 °C to manganese and oxygen. Liberated manganese would react with liquid Al at around 700 °C superheating temperature and formed Al-Mn intermetallic compounds, while oxygen would react to form tiny rounded Al_2O_3 *in situ* particles in the melt. Attempts were made to add 2.5 and 4 wt % MnO_2 after proper fluidity of liquid aluminium achieved and stir casting method used for getting proper distribution of dispersoids in the bath. In present work, commercially pure Al and laboratory grade MnO_2 powder (refer table 1 for chemical composition) were chosen as matrix material and externally added reinforcing particles respectively. The method of preparation of the composites has been described elsewhere [25].

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PAPER

Fabrication of *in situ* aluminium matrix composite by change in addition sequence of MnO_2 particles

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Keywords: In-situ composite, Commercially pure aluminium, XRD, Mn_3AlC, $MnAl_6$, Al_2O_3

Abstract

In-situ composite of commercially pure aluminium (CPA) matrix and 1 to 4 wt% MnO_2 reinforcement particles were fabricated using stir casting method. 3 wt% Mg was added to improve the wettability of generated *in situ* phases in CPA matrix. MnO_2 additions were carried out in two sequences named as A and B. In sequence A, MnO_2 was added after melting of CPA with 3 wt% Mg while in sequence B, MnO_2 added before melting of CPA with 3 wt% Mg. The sequence of addition of MnO_2 has been studied in terms of recovery of Mn, mechanical properties and microstructures of fabricated composite. Maximum recovery of Mn obtained in case of sequence B. Improved results in microstructure and mechanical properties were found in sequence B compared to sequence A. Formation of *in situ* phases such as $MnAl_6$, $MgSiO_3$, Al_2O_3, cemented carbide Mn_3AlC and small quantity of $MgFeSiO_3$, were confirmed by Xy diffraction analysis in final composite materials.

1. Introduction

A study of light metal and its alloy reinforced with variety of ceramic particles have been made in the past by various researchers. Metal matrix composites reinforced with non metallic particles have been recognized the promising candidate for different mechanical and thermal properties in different sectors. Wear resistance, high temperature hardness and strength, fracture toughness, tensile strength, specific strength, etc are very important properties which are mostly concerned behind the development of such composites. Addition of small amount of ceramic particles of micron size in the light metal matrix composites shows drastic changes in properties. Addition of non metallic particles such as alumina [1–8], silicon carbide [7, 9–11], silica [5, 12], zirconia [6, 13] and soft solid particles such as graphite [14–18], B_4C [19], Mica [20], etc directly into liquid commercially pure aluminium or aluminium alloys either by powder metallurgy or through a casting route help to improve mechanical behaviour considerably. Stir cast and *in situ* cast are two major methods to develop Al base MMC composite materials. The number of systems like $Al - TiB_2$ [21], $Al - Al_2O_3$ [22], $Al - MnO_2$ [23], $Al - TiC$ [24, 25], $Al - Al_3Zr$ [26], $Al - Fe_3O_4$ [27], $Al - TiAl_3$ [28], etc are the examples of *in situ* particulate-composites have been produced by different researchers claiming improved properties. Stir casting is the casting method in which the molten bath was agitated using mechanical impeller of different designs. Due to stirring action at controlled RPM, uniform distribution of stable oxides, carbides, nitrides, etc are possible by controlling wettability phenomena. Whereas in *in situ* casting the newly generated phase can alter the property of MMC. In short, stir casting is the method to directly incorporate ceramic particles into the molten bath of MMCs whereas in *in situ* method, such dispersoids are indirectly generated within the molten metal. In present research work of *in situ* MMC, MnO_2 powder was used. Thermodynamically unstable phases like the oxides of Mn decompose at 535 °C [29] and release pure manganese and nascent oxygen. These generated pure manganese and available oxygen makes formation of intermetallics and very fine uniformly distributed stable oxide and carbide phase like $MgFeSiO_3$, Al_3Mg_2, Al_2Mg_3, Mn_3AlC, $MnAl_6$ and Al_2O_3. It was due to the presence of aluminium, manganese,