International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2022): 7.942

Synthesis and Study of Mechanical Properties of Cast Al (Mg) - MnO_2 Composites

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Abstract: ***Metal Matrix composites (MMCs) represent a new generation of engineering materials in which a strong ceramic reinforcement is incorporated into a metal matrix to improve its properties including specific strength, specific stiffness, wear resistance, corrosion resistance and elastic modulus. Thus, they have significant scientific, technological and commercial importance. Therefore, the development of aluminium matrix composites is receiving considerable emphasis in meeting the requirements of various industries. Incorporation of hard second phase particles in the alloy matrices to produce MMCs has also been reported to be more beneficial and economical due to its high specific strength and corrosion resistance properties. In the present investigation is to reinforce Al1100-Mg alloy with different wt. % of MnO_2 (1, 3, 6, 9 and 12) was added by melt stirring method. Micro structural studies using Scanning Electron Microscopy (SEM) and Mechanical properties have been investigated for cast base alloy and composites.***

Keywords: Aluminium matrix composites MMC, SEM, *Mechanical properties*

1. Introduction

Many of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics and polymeric materials. The synthesis and characterization of aluminium based composite materials are ideal for structural applications where high strength-to-weight ratios are required.

Aircraft and spacecraft are typical weight sensitive structures in which composite materials are cost-effective. Traditionally, the Al-MMCs are produced by directly adding reinforcements into the Al matrices [1]. Aluminium matrix composite materials reinforced with SiC [2] and Al_2O_3 [3,4] particles offer higher wear-resistance, higher modulus and better dimensional stability than conventional aluminium alloys.

The fabrication of the molten aluminium mechanical stirring method enables these materials to be cast into shapes or ingots for further processing. Conventional stir-casting technology has been employed for producing particulate reinforced metal matrix composites (PMMCs) for decades. The casting methods and associated techniques used to fabricate composites based on aluminium alloys have been amply studied [5, 6].

An economical way of producing metal matrix composite is the incorporation of the particles into the liquid metal and casting. In cast aluminium alloy based composites, a moderate improvement in strength over the unreinforced alloy is obtained. On the other hand when particulate reinforcement is added to improve stiffness, strength and tribological properties, a substantial decrease in ductility is observed. Inferior ductility of these materials limits their performance and application. The ductility is affected by various factors such as the matrix micro structure, heterogeneous reinforcement distribution, porosity content and the strength of the interfacial bond between the matrix and the reinforcement.

2. Experimental Methodology

2.1. Stir-Casting and Its Experimental Set-Up:

In this study, Al 1100 of 99.67% purity and commercial magnesium of 99.92% purity was used as the matrix for the synthesis of particle reinforced metal matrix composites.

Table 1: Chemical composition of the commercial Al 1100 and magnesium used in the investigation

Material	Chemical composition (wt. %)	
	Al-Ingot	Mg-Ingot
Fe	0.132	0.020
Mn	0.051	0.002
Cu	0.043	0.016
Zn	0.022	0.002
Si	0.073	0.006
Mg	0.005	Balance
Al	Balance	0.023

The chemical compositions of the commercial Al 1100 and magnesium ingots, in weight percent, are as shown in the Table.1.

A batch type stir-casting furnace cum pouring set-up has been used for solidification processing of Al 1100 based composites. Melting of the Al 1100 was carried out in a clay graphite crucible (No-6) has a cylindrical tapered shape with an average inner diameter of 80 mm and a hole of 10 mm in diameter at the centre of its bottom. The graphite crucible is placed inside the furnace and the bottom hole of the crucible is plugged tightly by inserting a graphite stopper in it through the bottom of the furnace. The stopper is held in place with the help of a lever arrangement as shown in Fig.1. In this study, Al

1100 was used as the matrix material and it was alloyed with 2 wt.% magnesium to impart wetting to the MnO_2 particles is added as reinforcements in amounts of 3, 6, 9 and 12 wt.%. About 600 g of commercially pure Al 1100 was melted and superheated to a 900°C in a clay-graphite crucible inside the furnace. The weighed amount of MnO_2 particles was added into melt at the rate of 6-8 g/min. A magnesium lump of 2 wt. % was added to improve the wettability of the melt. A coated pitched blade stirrer was used to disperse the MnO_2 particles in the melt. A non-contact type speed sensor was used to measure the constant stirring speed of 300 rpm. The temperature of the melt was measured by using a digital temperature indicator connected to a chromel-alumel thermocouple. When the desired time of the stirring elapsed pour the melt-particle slurry into split type graphite coated and preheated permanent steel mould of three cavities of 12 mm for tensile specimen.

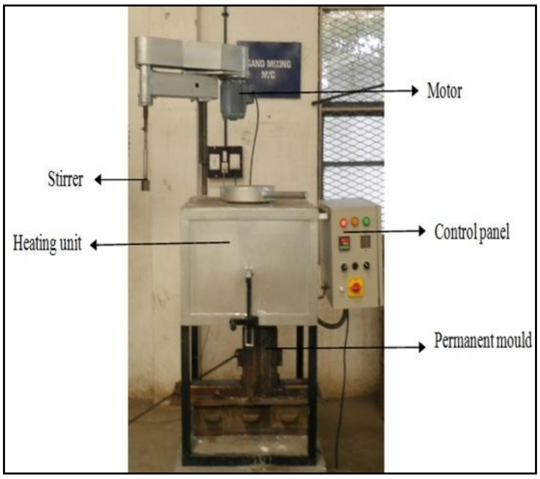

Figure 1: Experimental set-up for stir casting used for solidification processing of different cast composites and cast unreinforced base alloy.

The surfaces of the substrate materials which are to be plasma coated were examined for dimensional accuracy and surface finish before being degreased in a vapor bath (70-80^{0}C) of tetra chloro ethylene. The surfaces were then grit blasted by TiO_2 at a pressure of 455 kPa. Plasma spraying process was carried out with the help of proprietary Sulzer Metco Equipment.

3. Results and Discussions

3.1. Morphology of MnO_2 Particles

The size and particle shape of the MnO_2 particles in the powder has been observed under SEM and the results are shown in Fig.2 the size is in the range between 1 µm and 25 µm and the shape of the smaller particles are spherical while the larger particles have somewhat irregular in shape.

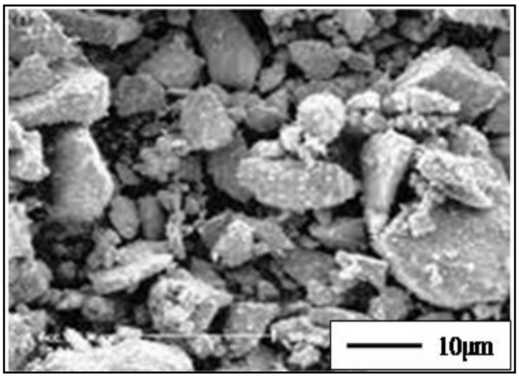

Figure 2: SEM micrographs showing Size and particle shape of the Manganese dioxide powder.

The powder has been examined for their X-ray diffraction (XRD) pattern using X-ray diffractometer in the two theta range of 5^0 to 80° using CuK_α radiation target and nickel filter, step size and dwell time were suitably adjusted, which was used for identification of various phases with the help of inorganic JCPDS (joint committee on powder diffraction standards) x-ray diffraction data card which shows the MnO_2 particles are fairly pure as shown in fig. 3.

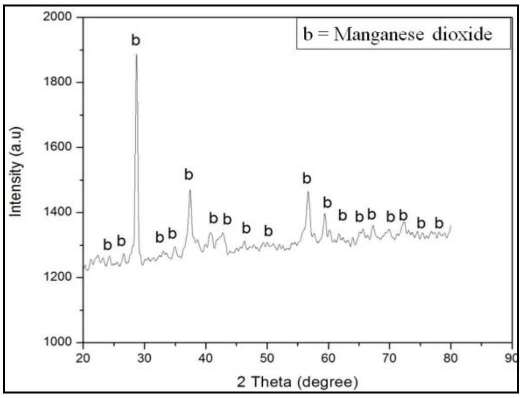

Figure 3: SEM micrographs showing Size and particle shape of the Manganese dioxide powder

The powder have been used to develop cast particle reinforced Al 1100 metal matrix composites, by solidification of slurry obtained by dispersion of externally added MnO_2 powder into molten Al 1100-Mg alloy. When it is added to molten aluminium alloy during processing of composite, MnO_2 particles may be reduced to elemental Manganese by aluminium, which gets oxidized to alumina. The elemental Manganese is released for alloying the remaining molten aluminium. Since surface forces play a dominant role in retaining particles of alumina, which has a poor wettability by molten aluminium, magnesium (2 wt%) is added to molten aluminium to improve wettability and retain the particles inside the melt.

3.2. Cast composites and microstructure studies

Different composites have been synthesized by adding powder as given in Table 2 and these composites have been designated by using the letters AM to indicate Al 1100-Mg alloy followed by a letter P indicates the percentage of MnO_2 powder of 3, 6, 9 and 12 wt.% respectively. The composite designated as AMP3 the first latter A and the following latter M indicating base metal Al 1100 and the alloying element of Mg (2 Wt.%) followed by latter P3 indicating addition of 3 wt.% of MnO_2.

Table 2: Nominal Composition of the Composites

Designation of composites	Magnesium (wt%)	Particle (wt%)
AM	2	0
AMP3	2	3
AMP6	2	6
AMP9	2	9
AMP12	2	12

The scheme of sectioning the cast alloy and composite were initially cut into square/rectangular pieces of suitable dimension. Then these samples were polished by using silicon carbide emery papers (water proof) of 220, 400, 600, 800, 1000, 1200, 1600 and 2000 grit sizes and the final polishing of the specimens was carried out on a fine velvet polishing cloth using polishing grade II alumina suspension prepared by standard metallographic procedure for metallographic examination under SEM and studies were carried out with an electron beam accelerating potential of 15 kV.

In the present study In-situ aluminium matrix composites, during processing at a high temperature it is expected that these oxides will react with molten aluminium and get reduced to metallic Manganese, which will alloy with molten aluminium. The reaction will also produce alumina by oxidizing aluminium. After reaction, the resulting slurry may be solidified to get a composite based on Al-Mn alloy containing in-situ generated alumina. The resulting composite is Al (Mg, Mn)-Al_2O_3 (MnO_2) indicating a matrix of Al-Mg-Mn alloy reinforced with oxide particles consisting of un-reacted MnO_2 and alumina (Al_2O_3) resulting from reduction of MnO_2 by molten aluminium. MnO_2 oxides will react with molten aluminium and following phases expected that alumina, MnO_2, $MgAl_2O_4$, MgO, $MgMn_2O_4$ $MnAl_2O_4$, and $MnAl_6$.

All the four SEM microstructures in Fig. 4 (a) AMP3, (b) AMP6, (c) AMP9 and (d) AMP12 respectively contain similar phases but their weight fraction varies depending upon the amount of Manganese dioxide additions. The composite, AMP12, has more distributed phases than that in composite AMP3. It is observed that the porosity in the composite increases with increasing addition of MnO_2 particles. This is often attributed to attachment of particle with bubble during processing. This attachment takes place during particle transfer by stirring. It may also happen during solidification as the dissolved gases start nucleating on the heterogeneous surfaces of particles. Often these bubbles are not able to float out rapidly due to increased density because of attached particles and get entrapped during solidification, enhancing the porosity in cast composite. Thus, porosity increases with increasing addition of MnO_2 powder in cast composites. The particle distribution in the composites, developed by addition of MnO_2 powder, shows individual particles and no significant clustering as shown in Fig. 4.

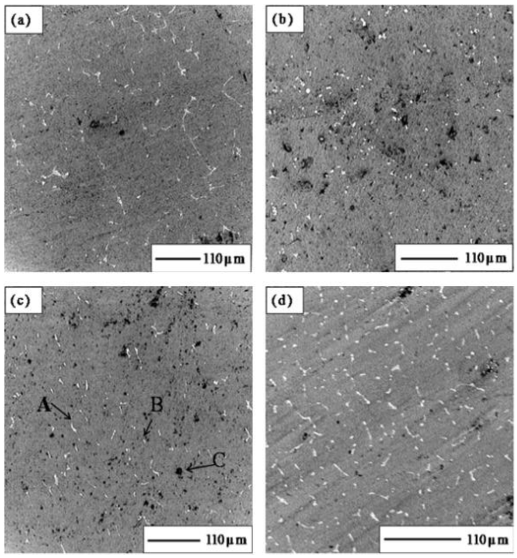

Figure 4: SEM micrographs of different cast composites developed by increasing amounts of MnO2 powder designated as (a) AMP3 (b) AMP6 (c) AMP9 and d) AMP12 respectively.

3.3 Mechanical Properties

3.3.1Brinnell Hardness

Average Brinell hardness has been measured for unreinforced alloy and cast in-situ composites developed by addition of MnO_2 Powder, with 10 mm hardened steel ball indenter of 500 kg load. Variation of hardness in cast and extruded AM alloy based composites with increasing addition of MnO_2 composites particle are shown in Fig.5. The hardness increases in composite with the addition of MnO_2 particles due to three reasons. (i) Formation of in situ Al_2O_3 particles in the matrix as observed in Fig 4 as a result of reaction between aluminium and MnO_2. These alumina particles are very fine, uniformly distributed and firmly bound with the matrix. (ii) Addition of Mn alloying element in aluminium matrix due to reduction of MnO_2 by aluminium. (iii) Further reinforcement of matrix by formation on Al-Mn precipitate.

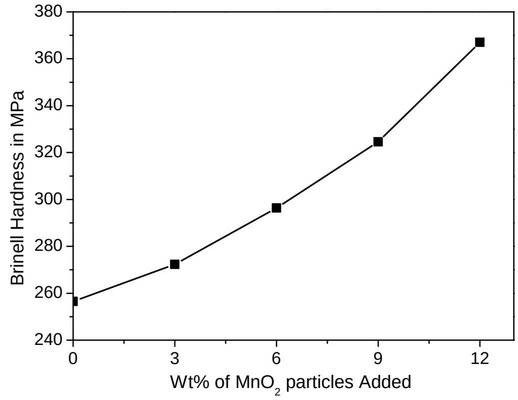

Figure 5: Variation of average hardness in cast alloy and composites developed by increasing addition of MnO_2 powder

3.3.2 Tensile Properties of Cast Composites

The tensile tests were carried out at ambient temperature for cast composites and unreinforced alloys. The specimens shape and dimension of the tensile specimens, conforming to ASTM–E8M specification, at least three tensile specimens of 5.0 mm gauge diameter and 25 mm gauge length, were machined from the each cast composites.

The stress-strain behavior of the cast alloy and composites developed by addition of different amounts of MnO_2 powder has been determined by tensile tests and the results are shown in Fig. 6. The stress-strain behavior of cast Al-Mg alloy of composition similar to that of the matrix of the composites is also shown for comparison; there is significant improvement in the strength and decrease in ductility with powder addition compared to those observed in the base alloy. Compared to the base alloy, there is increased strain hardening in the composites. When one compares the stress-strain behavior of composites AM shows the highest ductility, while AMP12 shows highest in strength and slightly decrease in ductility compared to all other composition.

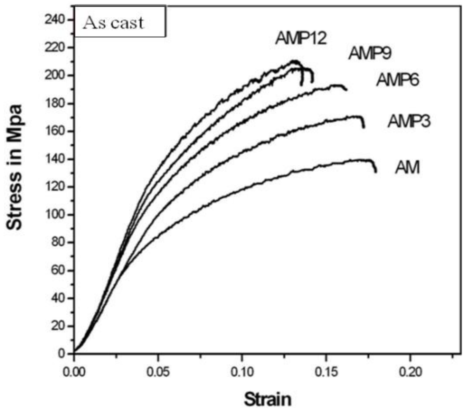

Figure 6: Tensile stress-strain behavior of cast alloy and composites developed by addition of 0, 3, 6, 9 and 12 wt. % of MnO_2 powder.

The yield strength, tensile strength and percent elongation in cast composites developed by addition of 0, 3, 6, 9 and 12 wt. % MnO_2 powder have been determined from stress-strain behavior shown in Fig.6 and the results are shown in Fig.7. The yield strength and tensile strength increases with increasing addition of MnO_2 powder marginally with 3, 6 and 9 wt.%, improves most with 12 wt.% addition of powder is as shown in Fig.7. Whereas percentage elongation in cast composite decreases with the increasing the wt. % of MnO_2 powder addition.

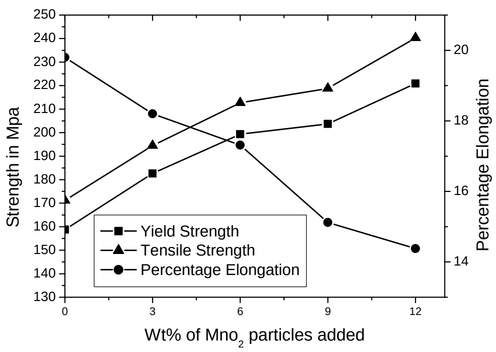

Figure 7: Comparison of yield strength, tensile strength and percentage elongation in cast alloy and composites with increasing addition of MnO_2 powder.

4. Conclusions

1) The Liquid metallurgy route (stir casting technique) was successfully adopted in the preparation of Al 1100–MnO_2 composites containing 0, 3, 6, 9 and 12 wt. % of MnO_2 powder reinforcement with particle size of 1-25μm.
2) Fine Al_2O_3 particles are formed as a result of reduction of MnO_2 particles by aluminium and Manganese (Mn) is released in the matrix after the reduction of MnO_2 by aluminium.
3) SEM analysis shows Porosity in cast composites increases with increasing addition of MnO_2 powder, comparatively more dark spots observed at AMP12 composites.
4) The hardness of the cast composites is found to increase with increase in reinforcement content, for the 12 wt% of MnO_2 powder added composite the highest hardness of 367 MPa.
5) The strength of the cast composites is found to increase with increase in reinforcement content for the 12 wt% of MnO_2 powder the highest yield strength of 198.6 MPa and tensile strength of 212.5 MPa.

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