Manufacturing of AA2024 Composite reinforced with alumina nanoparticles using Semisolid Casting

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Abstract— In this study Al2024/ Al_2O_3 nanocomposite was manufactured by rheocasting technique in semisolid state. Al 2024 was used as a matrix alloy and 50 nm Al_2O_3 particles were used as reinforcement. To evualte microstructural evolution of manufactured nanocomposite, AA 2024 alloy was cast in same manner. The microstructures were examined by optical and scanning electron microscopy to evaluate the effect of alumina nanoparticles on microstructure. Microhardness revealed that the semi-solid state processing does not allow obtaining an even dispersion of nanoparticles within the matrix. Casting defects associated with low particle wettability (porosities and particle agglomeration), leading to an enhanced exploitation of nanoparticles strengthening effect.

Index Terms—Nanocomposite, semisolid processing, rheocasting

1 Introduction

Metal Matrix Composites are being increasingly used in aer space and automobile industries owing to their enhanced properties such as elastic modulus, hardness, tensile strength at room and elevated temperatures, wear resistance combined with significant weight savings over unreinforced alloys [1-3].
The advantages of particulate-reinforced composites over others are their formability with cost advantage [4].
Most of the researchers tried to reinforce aluminium metas and their alloys with ceramic particles to improve their properties [5]. These composite materials presented great applications in thearea of commercial as well as industrial components [6].

Stir casting is one of the low cost process out of available manufacturing techniques for AMCs, with advantage of low cost; it alsooffers a wide range of material and processing conditions and canmanufacture composites with up to 30% volume fraction of rein-forcement with better bonding of metal matrix with reinforcementparticles because of stirring action [7–10]. Due to all these advan-tages stir casting process is employed in the present research forthe manufacturing of composites.
For aluminium alloy composites, it has been generally agreed that increasing the ceramic particle content can enhance mechanical properties [11-12]. Therefore, the application of Al_2O_3 or SiC particle reinforced Al based composites in the automotive and aircraft industries is gradually increasing for pistons, cylinder heads, connecting rods etc. [13-14].
Aghajanin et al [15] studied the Al_2O_3 particle reinforced AMCs, with varying particulate volume fraction and reported the improvement in elastic modulus, tensile strength, compressive strength and fracture properties with an increase in the reinforcement content.
The interface between the matrix and reinforcement plays a critical role in determining the properties of MMCs. Stiffening and strengthening rely on load transfer across the interface. Toughness is influenced by the crack deflection at the interface and ductility is affected by the relaxation of peak stress near the interface [16].

A. Mahdy [17] shows that the primary solid particles already formed in the semi-solid slurry prevent their gravity segregation and reduce their agglomeration.

El-Mahallawi et al. [18-20] studied the influence of nano dispersions on mechanical properties of semisolid Al casts using nanoparticles as reinforcement agents, results showed enhancement in hardness values.

Thus the aim of the present work is to fabricate sound nanocomposite of Al 2024/ Al_2O_3 using rheocast, also study effect of alumina nanodispersion in Al 2024/ Al_2O_3, which could be enhanced by mechanical properties.

2 MATERIALS AND METHOD

2.1 Materials

Materials used in this study are as following; (1) cast Al 2024 alloy, and (2) cast Al 2024 reinforced with 50 nm α-Al_2O_3 nanoparticles.Typical chemical composition of wrought Al 2024 alloy is shown in Table 1.

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TABLE 1

Chemical composition (wt. %) of the aa 2024 matrix

Element	Cu	Mg	Mn	Fe	Si	Zn	Cr	Al
wt%	4.39	1.26	0.57	0.50	0.50	0.25	0.10	Bal.

2.2 Casting Procedure

Al 2024 wrought alloy was melted in an electric heat resistance furnace, using a carbide crucible, and a three-blade graphite stirrer driven by speed motor of 900-1200 rpm, which was used for stirring. The melt was degassed with hexachlorethane degasser tablets, to get rid of gases. At temperature (650 ºC) the reinforcing Al_2O_3 particles were introduced into the slurry. The nano Al_2O_3 particles packaged in aluminum foil (1% of charge weight). The packages were preheated for 1 hour at 200°C before being introduced to the molten aluminum alloy. Another charge of Al 2024 wrought alloy was melt at same conditions but without adding reinforcement. The melt (either unreinforced or reinforced) was cast in a stainless steel mould producing as cast Al 2024 and nanocomposite AA 2024/Al_2O_3 plates.

2.3 Materials characterization

Microstructural analyses, metallographic samples were prepared for examination by optical microscopy (OM) and scanning electron microscopy equipped with energy dispersive spectroscopy (SEM EDS). sections were cut from the cross-section of cast plates, then wet grounded using silicon carbide abrasive discs of increasing fineness (from 120 to 4000 grit) and finally polished using 3 µmand 1 µm diamond paste. Samples for OM and SEM analyses were etched with Keller's reagent.

Mechanical properties of the investigated materials were measured at ambient temperature by Vickers microhardness.Vickers microhardness measurements were peformed on the cross section of samples, under 4.9 N load and for a dwell time of 10s. 20 microhardness indentations were performed every 500 µm.

Tensile samples were prepared according to ASTM B557M specifications as shown in Fig.1, for reperesentative characterizeation minmuim 6 samples of each cast were used.

Fig. 1. Tensile specimens according to ASTM B557M specifications

3.1 Microstructural analyses

Optical micrographs of AA 2024 cast without reinforcement are shown in Fig.2. Dendrite structure was reveled within the matrix alloy at different magnifications, considering voids and cavities produced thoroughly. The proeutectic alpha globules, in the aluminum alloy 2024, which are reasonably spherical although have a large size distribution. The eutectic areas are noticeably coarse this structure, this effect is assumed to be related to copper diffusion from the concentration on the grain boundaries and eutectic areas into the grains, this was reported by Curle [21].

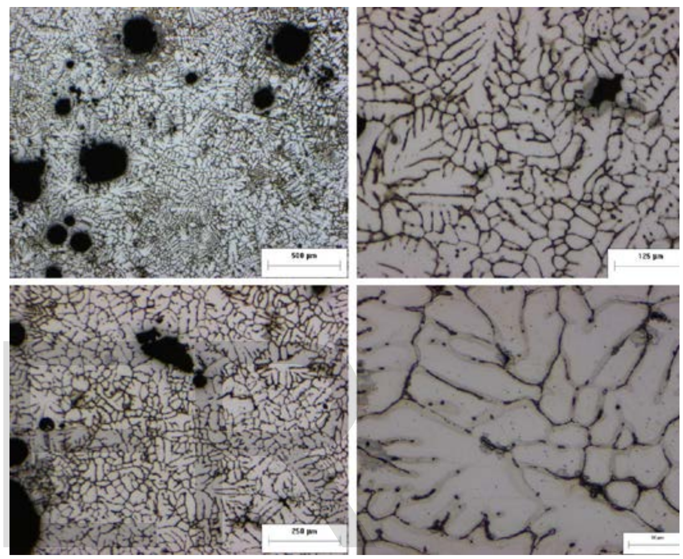

Fig. 2. Micrograph of dendrite structure reveled in AA2024 condition at different magnification

Due to the semi-solid processing, the α-dendrites are characterized by a quasi-globular morphology, more accentuated in the composite as shown in Fig.2.

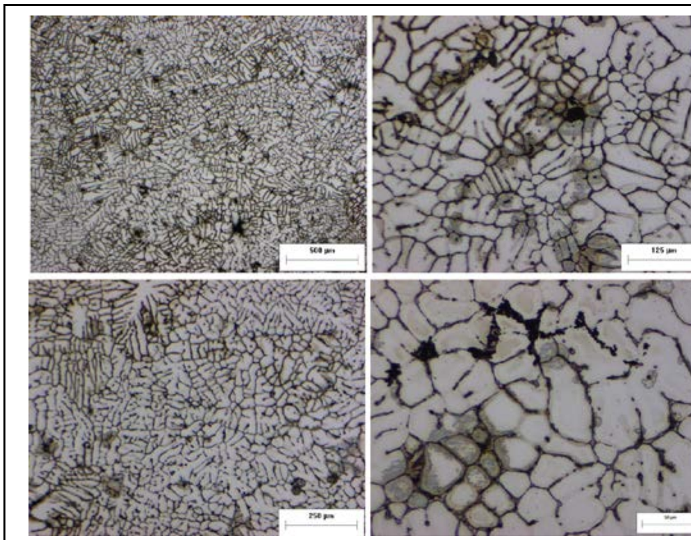

Fig. 2. Micrographs of rheocast AA2024 reinforced with Al_2O_3 at different magnification

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Addition of Al_2O_3 nano-particles to aluminium alloys could reduce the grain size of the aluminium matrix. Similar behavior has been reported by Kim et al. [22] described in detail the combined role of nanoparticles dispersion and semi-solid processing in producing equiaxed particles in favour of dendritic structures. This has been attributed to their combined effect on causing the growth and heat flux directions to be the same, and hence promoting the nucleation of the equiaxed grains in a random matter. In this case, the last traces of the remained liquid (including the nanoparticles) are blocked among the branches and preferentially solidified, capturing the nanoparticles within the grain itself, rather than only on the grain boundary.

Composition of cast AA 2024 was investigated through SEM-EDS analyses as shown in Fig. 3 (a, b). EDS analysis revealing the presence of small particles containing Al, Cu and Mg (probably the Al_2Cu and Al_2CuMg phases) in the interdendritic regions.

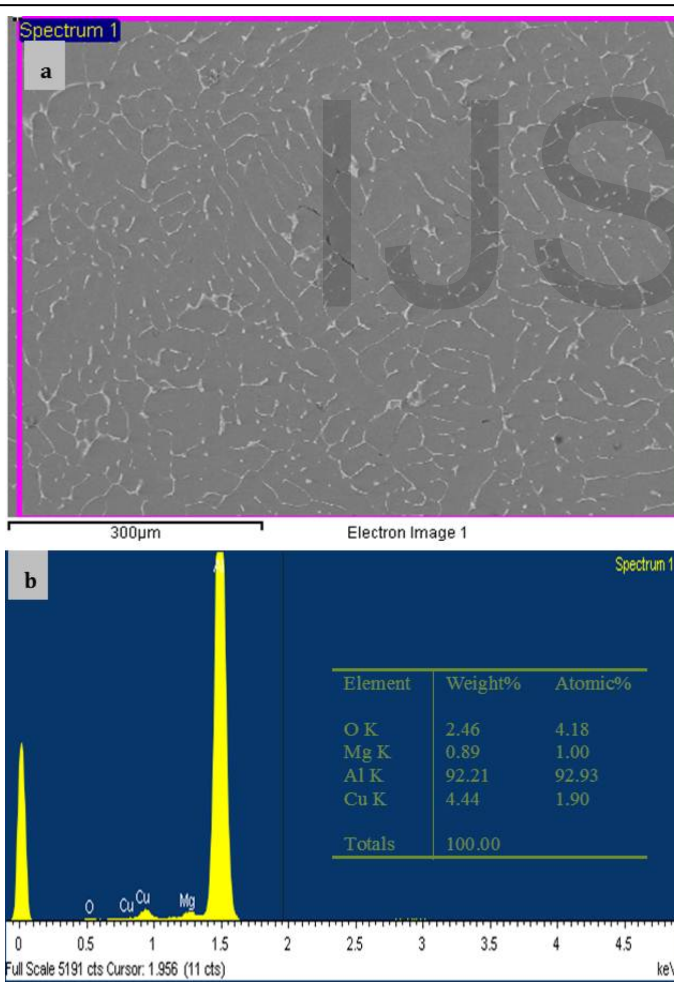

Fig. 3. SEM micrographs of rheocast AA 2024 (a), accompanied with EDS pattern (b).

The nanoparticles were found at the cavities and pores as shown in Fig. 4, this pores and cavities are the last parts to solidify. This action have been explained by the tendecy of these alloys to exhibit a pushing mechanism for the foreign particles, rather than the engulfment mechanisms shown when the particles are homogeneously incorporated within the grain boundaries during solidification. It has been shown that as the slurry of the melt contains more liquid phases remaining and when the heat extraction by the die is non-uniform [16].

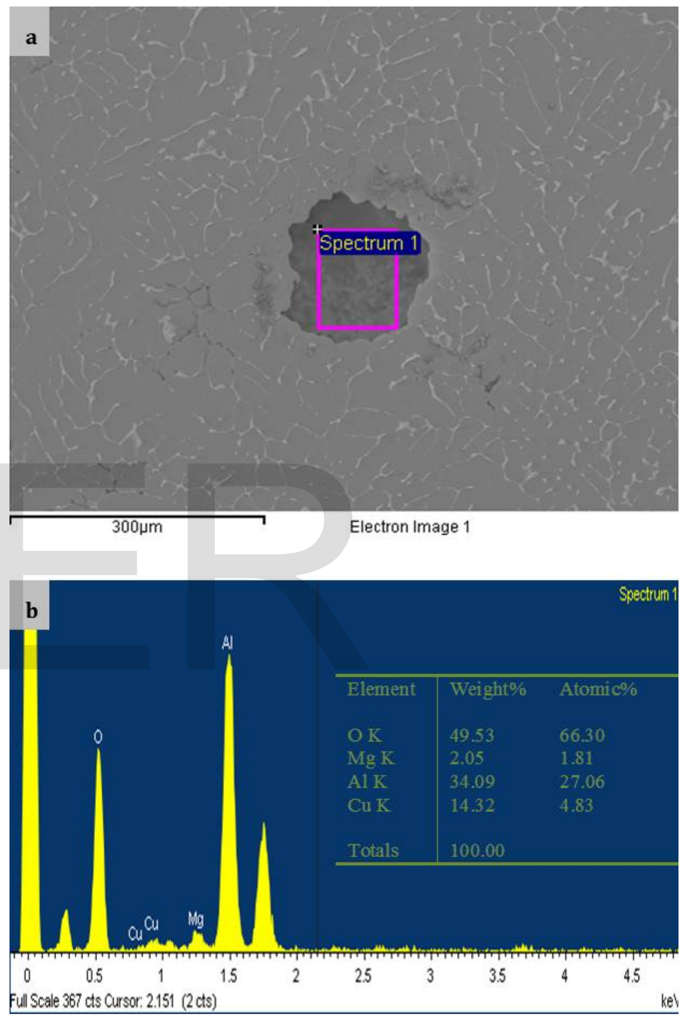

Fig. 4. SEM micrographs rheocast AA 2024/ Al_2O_3 (a), accompanied with EDS pattern that confirm Al_2O_3 existance (b)

It should still be stated that Al_2O_3 nanoparticles appeared mostly agglomerated around the pores and at the end of dendrite arms. The results obtained by examining the cross-section polished samples confirmed that the particles would be pushed by the solidification front during the dendrite solidification, as reported earlier [18,19].It is difficult to obtain uniform dispersion of the ceramic particles in liquid metals due to poor wettability in the metal matrix, and the large surface-to-volume ratio of the added particles.

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3.2 Mechanical properties

Fig. 5 shows the variation of the tensile properties of the nanocomposite as well as the AA 2024 unreinfrced matrix. The tensile tests results reveled that ultimate tensile strength of the nanocomposite is greater than the AA 2024 monolithic alloy.

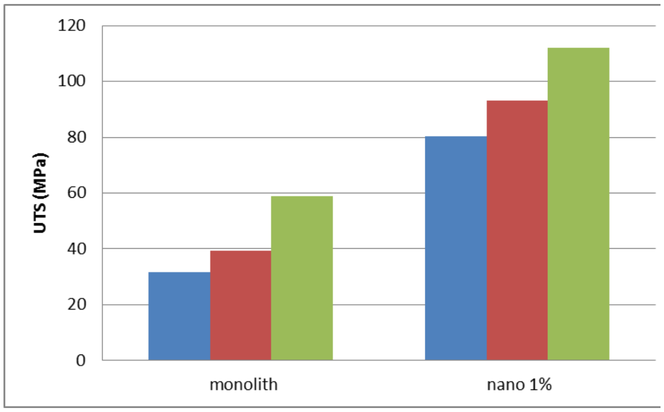

Fig. 5. Ultimate tensile stress (MPa) of monolithic and nano reinforced composite AA2024

These results are in confidence with the microstructural observations from optical micrographs and previous researches [17-22].

Microhardness values measured on the cast material of the unreinforced alloy and nanocomposite are shown in Fig. 6. No significant variance is evident between the hardness values of monolithic and nano reinforced samples.It is reasonable to relate this microhardness enhancement to microstructure observed by optical microscopy, as there is no difference of the structure could probaply affect hardness as nano particles were clustered in pores and non homogenous dispered within the matrix.

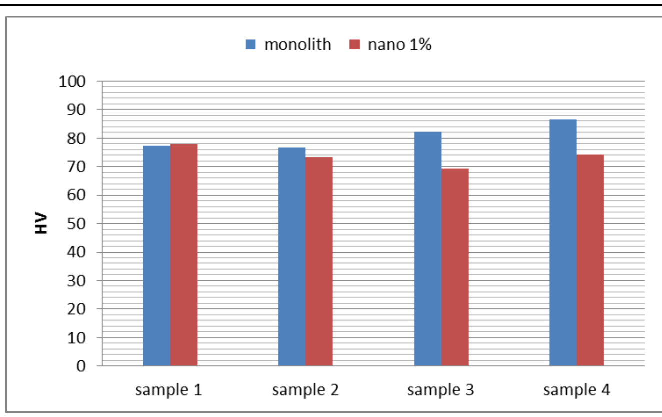

Fig. 6. Hardness vlaues of monolithic and nano reinforced composite AA2024

Conclusion

Manufacturing of AA 2024 composite reinforced with alumina nano particles was successful achived using semisolid casting. The obtained results revealed that the introductionof Al_2O_3 nanodispersions with the stirring effect induce a refining role, as significant refining was observed in the microstructure of the alloy that make enhancement in the mechanical properties of the Al_2O_3 nanodispersed AA 2024 alloy.

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