A Comparative Study of Microstructure, Mechanical and Tribology Properties of Cast in-situ Particulate: Al(Mg,Mn)-Al_2O_3(MnO_2) and Al(Mg,Ti)-Al_2O_3(TiO_2) Composites

Abstract

In-situ composites are a class of composite materials in which the reinforcing phases (such as Al_2O_3, TiB_2, TiC, etc.) are generated within the matrix material by some chemical reaction during the composite processing. This research paper concerns comparison between microstructure, mechanical and tribological properties of the resulting cast in-situ Al(Mg,Mn)-Al_2O_3(MnO_2) and Al(Mg,Ti)-Al_2O_3(TiO_2) composites have been investigated. It is generally observed that intermetallic phase Mn(Al_{1+x},Fe)_x in the cast in-situ Al(Mg,Mn)-Al_2O_3(MnO_2) composite is relatively finer in size and is sometimes blocky type compared to Ti(Al_{1+x},Fe)_x formed in cast in-situ Al(Mg,Ti)-Al_2O_3(TiO_2) composite. This has been attributed to difference in heterogeneous nucleation behavior of the alumina substrates for the formation of intermetallic phases. Superior mechanical properties, as indicated by ultimate tensile stress, yield stress and percentage elongation, are obtained in the cast in-situ Al(Mg,Mn)-Al_2O_3(MnO_2) composite compared to those obtained in cast in-situ Al(Mg,Ti)-Al_2O_3(TiO_2) composite. It is observed that the wear rate in cast in-situ Al(Mg,Mn)-Al_2O_3(MnO_2) composite is considerably lower compared to that of the cast in-situ Al(Mg,Ti)-Al_2O_3(TiO_2) composite, particularly at higher normal load of 39.2 N, in spite of a relatively higher porosity content and slightly lower hardness in cast in-situ Al(Mg,Mn)-Al_2O_3(MnO_2) composite.

Keywords: In-Situ Composites; Microstructure; Mechanical Properties; Dry Sliding

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1. INTRODUCTION

Metal Matrix Composite (MMCs) can be fabricated via both the ex-situ and in-situ processing routes. The in-situ processing routes are often favoured for making MMCs, as these routes overcome the technical challenges encountered in the ex-situ processing routes. The technical challenges include non-uniform distribution of particles, interphase formation and poor wetting of reinforcement with the matrix material [1]. Aluminium based tribological materials have received considerable attention due to their ability to reduce the weight of components made out of them, leading to significant impact on fuel economy in dynamic systems. A variety of nonmetallic particles have been dispersed in different metal systems to develop ex-situ discontinuous metal-matrix particulate composites (DMMPCs). Most investigators of ex-situ DMMPCs have found considerable increase in wear resistance owing to the reinforcement particles [2-6]. From the experience in composite containing externally added reinforcing particles, it is expected that the composites containing in-situ generated reinforcing particles may lead to important consequences in wear resistance and strength. Commonly used in-situ aluminium based composites processing by the reaction between metal oxide and Al-melt [7]. In-situ generated particle reinforced aluminium alloy-based composites have been developed by solidification of slurry obtained by dispersion of externally added oxide particles (MnO_2 / TiO_2) in molten aluminum at a given processing temperature of 730 °C. The oxides have been so chosen that during processing, alumina (Al_2O_3) is formed by reaction
of these oxide particles with molten aluminum. At the same time, the chemical reaction also releases alloying elements like manganese / titanium into the molten aluminum, enhancing the value addition to the product. A part of alloying element released forms solid-solution with aluminum and the remaining part, if any, reacts with aluminum to form intermetallic phases.

The present work is intended to investigate the characterizations, mechanical properties and wear and friction in cast in-situ Al(Mn)-Al2O3(MnO2) and Al(Mg,Ti)-Al2O3(TiO2) composites. The interesting feature of this system is matrix strengthening by alloying with manganese / titanium when MnO2 / TiO2 particles get reduced by molten aluminum during processing. The studies undertaken here are expected to lead to an understanding of a situation where progressive matrix strengthening both by alloying and by the generation of hard particles during processing, determine the overall mechanical and tribological behaviour.

2. EXPERIMENTAL PROCEDURE

Aluminium alloy-based composites containing in-situ generated alumina particles have been synthesized by stirring MnO2 / TiO2 particles into molten aluminium alloy followed by addition of small amounts of surface active element of magnesium (Mg) according to procedures detailed elsewhere [8,9,10]. Both in-situ composites materials have been tested for mechanical properties and wear and friction. Dry sliding wear tests have been carried out by using a pin-on-disc machine. Different loads of 9.8, 19.6, 29.4 and 39.2 N have been applied on the pin, normal to the sliding contact, during wear test of each in-situ composite. The track radius has been kept constant at 50 mm and the linear speed has been maintained at 1.05 m/s according to procedures detailed elsewhere [10,11,12].

3. RESULTS AND DISCUSSIONS

Figure 1 shows a typical unetched SEM microstructure of cast in-situ Al(Mg,Mn)-Al2O3(MnO2) and Al(Mg,Ti)-Al2O3(TiO2) composites containing intermetallic phases, reinforcing particles, and a small number of pores. It is generally observed that intermetallic phase Mn(Al1-x Fe)x in the cast in-situ Al(Mg,Mn)-Al2O3(MnO2) composite is relatively finer in size and is sometimes blocky type compared to Ti(Al1-x Fe)x formed in cast in-situ Al(Mg,Ti)-Al2O3(TiO2) composite. This has been attributed to difference in heterogeneous nucleation behavior of the alumina substrates for the formation of intermetallic phases. In case of cast in-situ Al(Mg,Ti)-Al2O3(TiO2) composite, the intermetallic phases form due to release of titanium to the matrix alloy due to chemical reduction of TiO2 particles by molten aluminium. The intermetallic phases display both blocky (with an average size of about 5 μm) and platelike (with an aspect ratio of about four) shapes. No significant difference in the size and distribution of pores is observed in the microstructure of the different cast in-situ composites. However, there are large pores around clusters of particles, observed at the top of the cast ingot.

Figure 2 shows the comparison of average Brinell hardness of cast in-situ Al(Mg,Mn)-Al2O3(MnO2) composite containing 2.726 wt% reinforcing particles and 1.973 vol% porosity and cast in-situ Al(Mg,Ti)-Al2O3(TiO2) composite containing 2.904 wt% reinforcing particles and 1.282 vol% porosity.

Figure 1. Unetched optical microstructure of cast in-situ composite (a) cast in-situ Al(Mg,Mn)-Al2O3(MnO2) composite; the intermetallic phase Mn(Al1-x Fe)x marked by (1) and the reinforcing particles marked by (2) and (b) cast in-situ Al(Mg,Ti)-Al2O3(TiO2) composite; the intermetallic phase Ti(Al1-x Fe)x marked by (1) and the reinforcing particles marked by (2).
The hardness in cast in-situ Al(Mg,Mn)-Al₂O₃(MnO₂) composite is slightly lower than that observed in the cast in-situ Al(Mg,Ti)-Al₂O₃(TiO₂) composite by about 3%. The porosity content of the cast in-situ Al(Mg,Ti)-Al₂O₃(TiO₂) composite is lower than that of the cast in-situ Al(Mg,Mn)-Al₂O₃(MnO₂) composite. Thus, the reduced hardness of the cast in-situ Al(Mg,Mn)-Al₂O₃(MnO₂) composite over that of cast in-situ Al(Mg,Ti)-Al₂O₃(TiO₂) composite could be attributed mainly to the relatively higher porosity.

Generally, the improvement in the mechanical properties is come from the solid solution strengthening of Mn / Ti solute and fine particulate strengthening of Alumina [7,10]. If one compares the mechanical properties in cast in-situ Al(Mg,Mn)-Al₂O₃(MnO₂) composites and that observed in cast in-situ Al(Mg,Ti)-Al₂O₃(TiO₂) composites on the basis of nearly similar particle contents and porosities, it is evident that the mechanical properties have significant difference in both of the systems. In the context of tensile properties, there are relatively higher tensile properties (ultimate tensile stress, yield stress and percentage elongation) in cast in-situ Al(Mg,Mn)-Al₂O₃(MnO₂) composite as shown in Fig. 3, compared to that observed in the cast in-situ Al(Mg,Ti)-Al₂O₃(TiO₂) composite as given in the same figure, in spite of relatively lower amount of reinforcing particles and higher porosity content in the former cast in-situ composite. Microstructural examination reveals that the precipitates of intermetallic phases is of irregular shapes, elongated and having sharp edge in the microstructure of the latter cast in-situ composites which are consequently acting as sites for stress concentration leading to relatively lower strength. The interfacial bonding between the matrix and the reinforcing particles may also be stronger in cast in-situ Al(Mg,Mn)-Al₂O₃(MnO₂) composite.

Figure 4(a) and (b) shows the variation of cumulative volume loss with sliding distance at different normal loads of 9.8, 19.6, 29.4 and 39.2 N and a fixed sliding speed of 1.05 m/s for these two different cast in-situ composites. Figure 5 shows the variation in wear rate of these two cast in-situ Al(Mg,Mn)-Al₂O₃(MnO₂) and cast in-situ Al(Mg,Ti)-Al₂O₃(TiO₂) composites with normal load. It is observed that the cumulative volume loss and wear rate in cast in-situ Al(Mg,Mn)-Al₂O₃(MnO₂) composite are considerably lower as shown in Fig. 4(a) and Fig. 5 compared to that of the cast in-situ Al(Mg,Ti)-Al₂O₃(TiO₂) composite as given in Figs. 4(b) and Fig. 5. Particularly at higher normal load of 39.2 N, in spite of relatively higher porosity content and slightly lower hardness in cast in-situ Al(Mg,Mn)-Al₂O₃(MnO₂) composite. However, from the comparison of results presented above, it clearly reveals the potential of both the cast in-situ composites Al(Mg,Mn)-Al₂O₃(MnO₂) and Al(Mg,Ti)-Al₂O₃(TiO₂). In the end, there is a need to emphasize the role for better foundry practice for solidification processing of cast in-situ composites since cast in-situ composites containing relatively non-wettability particles of alumina have a natural tendency to form stable pore-particle combination increasing the overall porosity of the cast in-situ composites.

Figure 3. Comparison of tensile properties for cast in-situ Al(Mg,Mn)-Al₂O₃(MnO₂) and Al(Mg,Ti)-Al₂O₃(TiO₂) composites.
Figure 4. The variation of cumulative volume loss with sliding distance for (a) cast in-situ Al(Mg,Mn)-Al2O3(MnO2) composite and (b) cast in-situ Al(Mg,Ti)-Al2O3(TiO2) composite.

Figure 5. The variation of wear rate with normal load for cast in-situ Al(Mg,Mn)-Al2O3(MnO2) and Al(Mg,Ti)-Al2O3(TiO2) composites.

4. CONCLUSIONS

However, from the comparison of results presented above, it clearly reveals the potential of both the cast in-situ composites Al(Mg,Mn)-Al2O3(MnO2) and Al(Mg,Ti)-Al2O3(TiO2). In the end, there is a need to emphasis the role for better foundry practice for solidification processing of cast in-situ composites since cast in-situ composites containing relatively non-wettabl particles of alumina have a natural tendency to form stable pore-particle combination increasing the overall porosity of the cast in-situ composites. The following main conclusions have emerged:

1. Microstructural examination reveals that the precipitates of intermetallic phase is considerably finer in the cast in-situ Al(Mg,Mn)-Al2O3(MnO2) composite than that in the cast in-situ Al(Mg,Ti)-Al2O3(TiO2) composite. This has been attributed to difference in heterogeneous nucleation behavior of the alumina substrates for the formation of intermetallic phases.

2. The hardness in cast in-situ Al(Mg,Mn)-Al2O3(MnO2) composite is slightly lower than that observed in the cast in-situ Al(Mg,Ti)-Al2O3(TiO2) composite by about 3%.

3. The tensile properties (ultimate tensile stress, yield stress and percentage elongation) in cast in-situ Al(Mg,Mn)-Al2O3(MnO2) composite are relatively higher compared to those observed in the
cast \textit{in-situ} \textit{Al(Mg,Ti)-Al}_2\textit{O}_3(TiO}_2 composite containing similar amount of reinforcing particles and porosity presumably because of finer intermetallic phases in the former coupled with irregular and elongated shapes with sharp edge of the intermetallic phase in the latter. The interfacial bonding between the matrix and the reinforcing particles may also be stronger in cast \textit{in-situ} \textit{Al(Mg,Mn)-Al}_2\textit{O}_3(MnO}_2 composite.

4. The cumulative volume loss and wear rate in cast \textit{in-situ} \textit{Al(Mg,Mn)-Al}_2\textit{O}_3(MnO}_2 composite are relatively lower compared to that of the cast \textit{in-situ} \textit{Al(Mg,Ti)-Al}_2\textit{O}_3(TiO}_2 composite containing similar reinforcing particles and porosity, particularly at higher normal load of 39.2 N, in spite of slightly lower hardness in cast \textit{in-situ} \textit{Al(Mg,Mn)-Al}_2\textit{O}_3(MnO}_2 composite. Thus, the reduced volume loss and wear rate of the cast \textit{in-situ} \textit{Al(Mg,Mn)-Al}_2\textit{O}_3(MnO}_2 composite over that of cast \textit{in-situ} \textit{Al(Mg,Ti)-Al}_2\textit{O}_3(TiO}_2 composite could be attributed to a relatively superior tensile properties and better interfacial bonding between the \textit{in-situ} formed reinforcing particles and the matrix.

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