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Microstructure and mechanical properties of Al/Fe-aluminide in-situ composite prepared by reactive stir casting route

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ABSTRACT

Iron aluminide particulate reinforced aluminium composites were prepared by a simple liquid metal stir casting route. The particulate intermetallic reinforcements were formed by in-situ reaction between molten aluminium and a rotating mild steel stirrer at 800 °C. X-ray diffraction studies were carried out to identify the types of iron aluminide particulates present in the as cast composite. Compositional variations of the composite samples were estimated with the aid of energy dispersive spectroscopy. The microstructural features of the composite were studied with respect to different heat treatment schedules and deformation conditions. Microhardness and nanoindentation measurements were also carried out to assess the micromechanical behaviour e.g., hardness and elastic modulus in micrometric length scale of the composite samples. Tensile tests and fractographic analysis were performed to estimate the mechanical properties and determine the mode of failure of the samples. The microstructure and mechanical properties of the composite samples were correlated and discussed.

1. Introduction

Aluminium matrix composites (AMC) due to their light weight and high strength possess high application potential in manufacturing advanced structural components for automobile and aerospace industries [1–4]. The strength property of AMC depends on shape, size, amount, spatial distribution and composition of reinforcements incorporated in the host matrix. A strong interfacial bond between the reinforcements and the matrix is essential for achieving high strength. A number of synthesis techniques based on powder metallurgy and liquid phase processing routes have been successfully employed in recent past for synthesizing particle reinforced AMC. However, the liquid phase techniques particularly stir mixing and casting is very attractive as they are very economical for fabricating large structural components with complex geometry. Ceramic particulates such as SiC, TiC and Al_2O_3, commonly used as reinforcements, exhibit poor wettability in molten aluminium. An external force in terms of vigorous stirring is required for incorporation of these ceramic particulates in the molten metal. Poor wettability of ceramic particulates results in formation of weak interfacial bonding of the particulates with the matrix; furthermore, mechanical stirring often causes inhomogeneous distribution of reinforcements in the matrix [5].

Recently transition metal tri-aluminide intermetallics are considered as suitable substitutes for ceramic particles, because they possess density and elastic modulus values comparable to that of the ceramic material and they can be formed by in-situ reaction (s) between the host matrix and suitable precursor element(s) or compound(s) added to the molten metal during processing [6]. Formation and incorporation of reinforcements in the matrix through in-situ reaction possess several advantages over the conventional processing techniques. The important advantages are the reinforcements, so formed by the in-situ reaction(s), remain well distributed and make strong interfacial bonding with the matrix. In this context, it would be worthwhile to mention that efforts were made to incorporate steel fibres and wires as reinforcements in aluminium for improving the mechanical strength and wear properties of the composite [7–11]. It has also been reported that iron powder can be directly incorporated in the melt either by stir mixing or by plasma synthesis technique [12–15]. In all the cases mentioned above, microstructural analyses have confirmed that iron aluminide intermetallics are formed at the metal–metal interface which makes strong bonding with the matrix. It has been also established that these intermetallic interfacial layers were formed by in-situ reaction between the added metal and metallic matrix.

Considering the importance of the reinforcement–matrix interface, a need is felt to evaluate the mechanical properties around these regions. However, since the area of the interface and inter reinforcement distance is only of the order of few micrometers, practical determination of mechanical property around these

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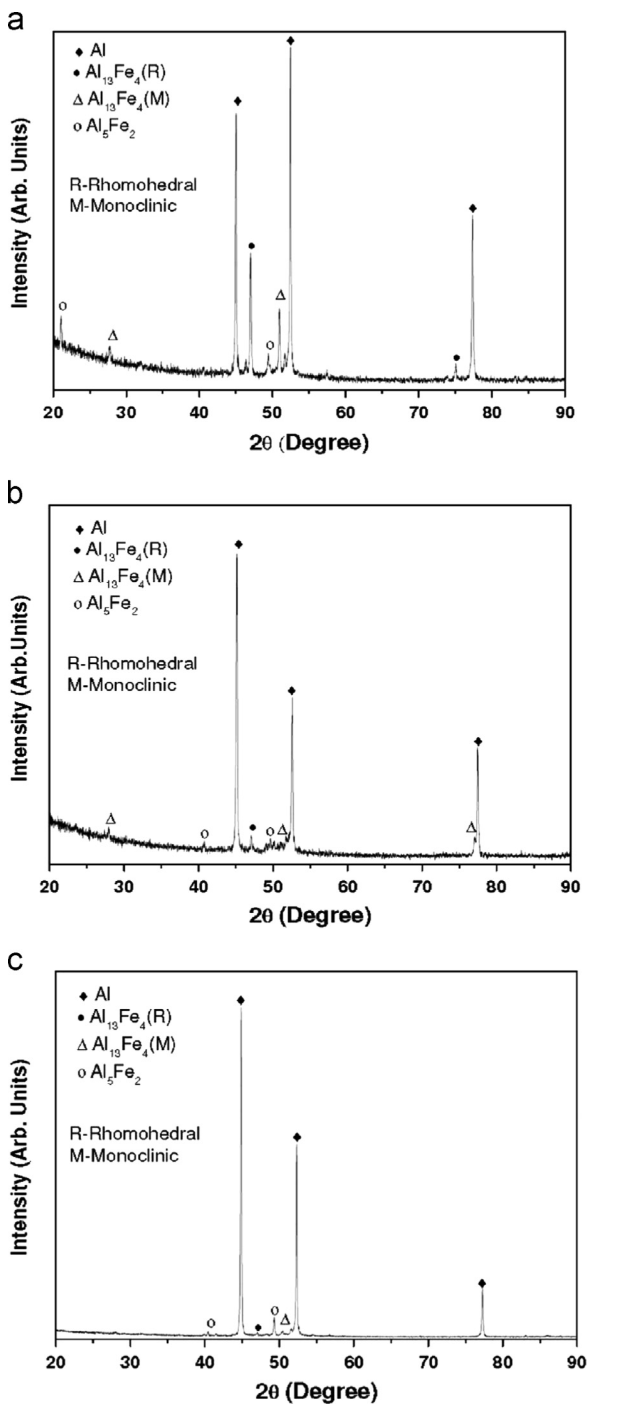

Fig. 1. XRD profiles of (a) as cast (b) normalized and (c) hot deformed samples showing the presence of $Al_{13}Fe_4$ and Al_5Fe_2 intermetallic phases in the composites.

regions using conventional techniques is impossible. Recent studies have shown that researchers have successfully employed the nanoindentation technique to determine the mechanical properties of the AMCs in the micrometric length scale [16,17].

Here it would worthwhile to mention that several researchers have dealt only with the fundamental aspects of microstructural feature mainly the evolution of intermetallic phases through in-situ reaction and their growth kinetics [7,18]. But, from the viewpoint of structural application, little effort has been made to assess the strength properties of the AMC's with respect to mechanical working and heat treatment conditions which are essential for shaping the composite materials for engineering applications.

Hence the present work aims at preparing the iron aluminide reinforced AMC by in-situ reactions between molten aluminium and a rotating mild steel stirrer and also study the microstructural features and mechanical properties of the composites with respect to different heat treatment schedules and deformation conditions.

2. Experimental procedure

Commercially pure aluminium (Fe-0.08 wt%, Si-0.06 wt%, Al-rest) was melted in an alumina crucible inside an electrically heated pot furnace at 800 °C. The temperature of the furnace was maintained constant by a PID controller with an accuracy of ± 1 °C. The molten aluminium was stirred continuously for 30 min with a mild steel stirrer (C-0.29%, Mn-0.5%, Si-0.2%, P-0.05%, S-0.04%, rest-Fe) rotating at a speed of 500 rpm. However, prior to stirring the mild steel stirrer was subjected to normalization treatment at 850 °C for 3 h and subsequently air cooled to room temperature. The stirrer consists of four blades with 20 mm width and 4 mm thickness. The blades were attached with central stirring rod with a gap of 5 mm. Molten Al reacts with the iron of mild steel stirrer to form iron aluminide intermetallic particles. The melt with the reaction product was poured into a rectangular cast iron mould of dimension 200 mm × 10 mm × 30 mm. The as-cast composite samples were subjected to (a) normalization treatment at 500 °C after holding for 1 h, 3 h and 6 h and (b) 10%, 20% and 40% hot deformation at 500 °C after 3 h holding.

XRD patterns of the as cast, normalized and deformed composite samples were recorded to identify the intermetallic phases present in the microstructure by using a Philips PW 1830 diffractometer with Co-K_α radiation operated at 35 kV/25 mA with a step of 0.005°/s.

Table 1
Energy dispersive spectroscopic data for three zones in the as cast composite.

	Zone A	Zone B	Zone C
Aluminium (wt%)	95.13	95.65	98.49
Iron (wt%)	4.87	4.35	1.51

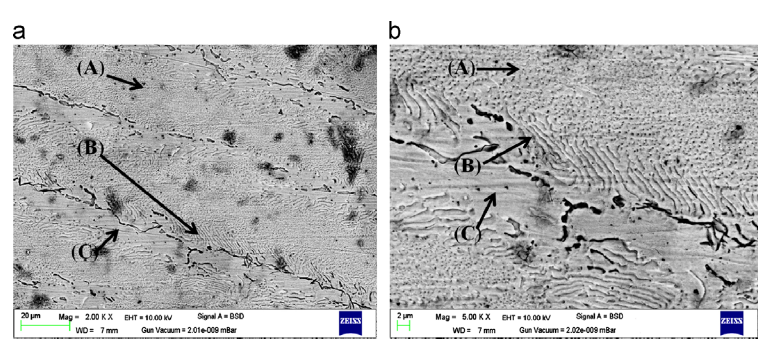

Fig. 2. SEM micrographs of the as-cast sample in the back scattered compositional mode (a) showing the presence of three distinct zones: (b) enlarged view of the three zones. (A) large dendritic grains with spherical particles (B) aggregate of wavy fibres (C) particle free regions.