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TEM analysis of the interfaces between the components in magnesium matrix composites reinforced with SiC particles

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Abstract

A microstructural analysis of the interfaces between the components of cast composites based on magnesium and magnesium alloys (MgAl8, MgZn6 and MgRE3; RE: rare-earth elements) reinforced with SiC particles is presented. Transmission electron microscopy (TEM) investigations allowed to establish the adhesive character of the bonds between the SiC particles and Mg matrix as well as MgAl8, MgZn6 matrix alloys, while the composites based on Mg alloys containing rare-earth elements exhibited a reaction layer between the components. Occasionally, the interfaces between the components contained precipitates derived from the instability of the conditions or parameters of the production processes. Energy-dispersive spectrometry and electron diffraction analyses allowed to identify the precipitates as the SiO_2, MgO and Fe-containing compounds.

Keywords: TEM; Metal matrix composites; SiC particles; Structure

1. Introduction

Cast metal matrix composites with ceramic particles are among the most recent structural construction materials. Interfaces between the matrix and the reinforced phase play a significant role in determining their mechanical and tribological properties. The microstructure of these materials depends on the wettability of the reinforcing phase by the molten matrix and the interaction of the components during the production. Reactions in many metal–ceramic systems may cause the formation of transition layers at the component interfaces. These layers, although enabling a bond to be obtained between the ceramic and the metal matrix, they are not tough enough so as to carry loads and thus they often contribute to lowering the properties of composites [1–3].

In the case of magnesium matrix composites reinforced with SiC particles, the adhesive character of bonding between the components have been determined. That type of internal bond is related to a high wettability of SiC by molten Mg, a distinct geometrical similarity between the components, and a very high stability of SiC in liquid Mg. However, it should be noted, that an improper selection of the process parameters during the production and the presence of alloying elements would inhibit the formation of the adhesive bonding between the Mg matrix and SiC particles [4,5].

In this paper, a microstructural analysis of the interfaces between different kinds of magnesium alloys and silicon carbide particles in comparison with Mg–SiCp composites are presented.

2. Experimental

Technically pure magnesium and Mg–5 wt.% Al, Mg–6 wt.% Zn and Mg–3 wt.% of rare-earth elements introduced in the form of mischmetal (Ce, La, Nd, Pr and others) were prepared. The α-SiC particles of the 6H type with a maximum diameter of 32 μm have been used as the reinforcing phase. The composite samples have been obtained by means of a simple casting technique, involving mechanical mixing of the liquid metal with the introduced particles and subsequent casting in metal moulds under protective atmosphere.

The microstructure of the interfaces between the components and the identification of the precipitates at the interfaces were examined by transmission electron microscopy (TEM). Specimens for TEM investigations have been cut in the form of 3 mm discs. They were next dimpled and electrolitically polished using a double-jet Fischione polisher. Eventually, foils have been ion milled with a Gatan Duo Mill 600. TEM observations were performed with a Philips

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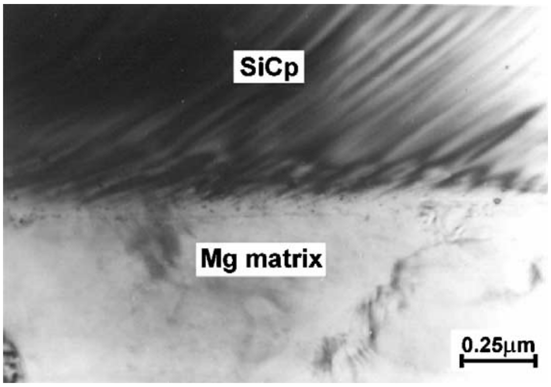

Fig. 1. TEM microstructure of the interface between Mg and SiC particle.

CM20 microscope operating at 200 kV equipped with an X-ray energy-dispersive (EDX) spectrometer.

3. Results and discussion

The composites on the base of the technically pure magnesium reinforced with SiC particles are characterised by stable, strongly connected and precipitate-free interfaces between the components. Such a typical interface between Mg and SiC is presented in Fig. 1. It should be noted that SiC particles tend to be covered with a SiO_2 film, due to the natural process of oxidising, even at ambient temperature. In the case of magnesium matrix, superficially oxidised particles inhibit the formation of an adhesive bonding between the components. At short times of mixing the liquid composite suspension, the oxide film may remain on the particles, forming an intermediate layer at the component interface (Fig. 2). The SiO_2 phase was identified by electron diffraction pattern inserted in Fig. 2.

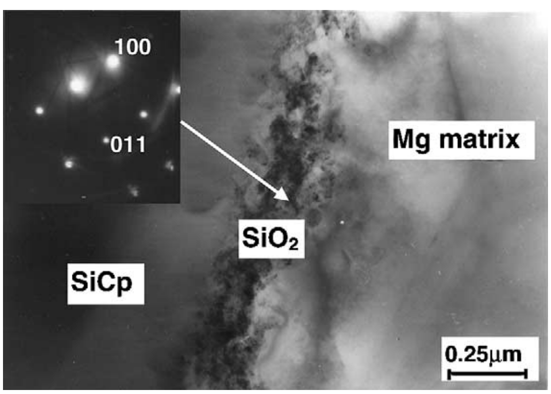

Fig. 2. TEM image of the precipitates along the Mg/SiC interface and electron diffraction pattern from the SiO_2 layer ([0 $\bar{1}$ 0] zone axis) as an insert.

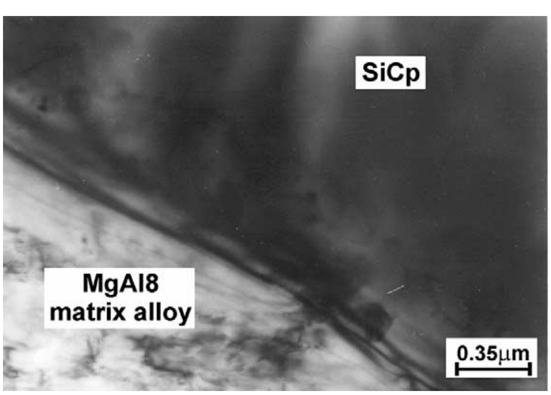

Fig. 3. TEM micrograph of the interface between the components in MgZn6–SiCp composite.

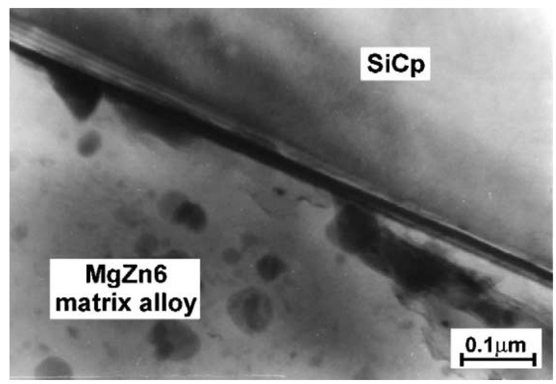

Fig. 4. TEM microstructure of the interface between the MgZn6 matrix and SiC particle.

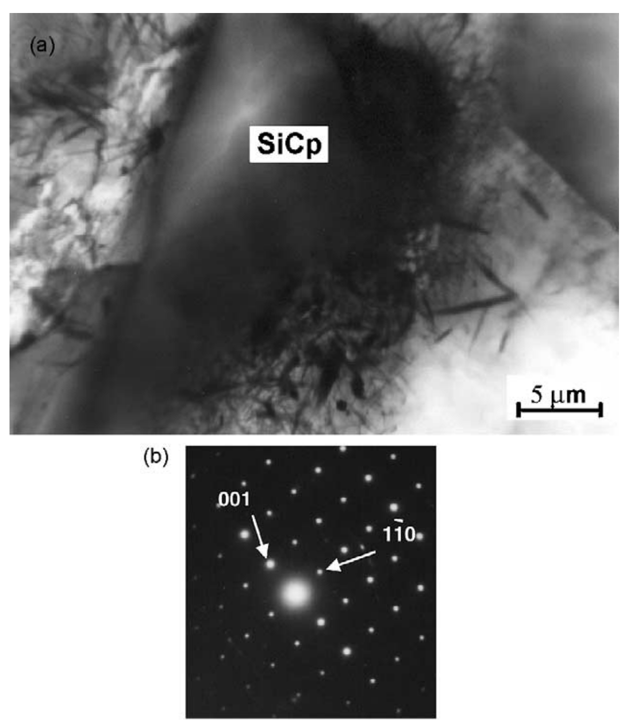

Fig. 5. (a) TEM microstructure of the interface between components in the MgRE3–SiCp (RE: rare-earth elements) composite and (b) electron diffraction pattern of the precipitates identified as Ce_3Si_2 phase; zone axis [1 1 0].

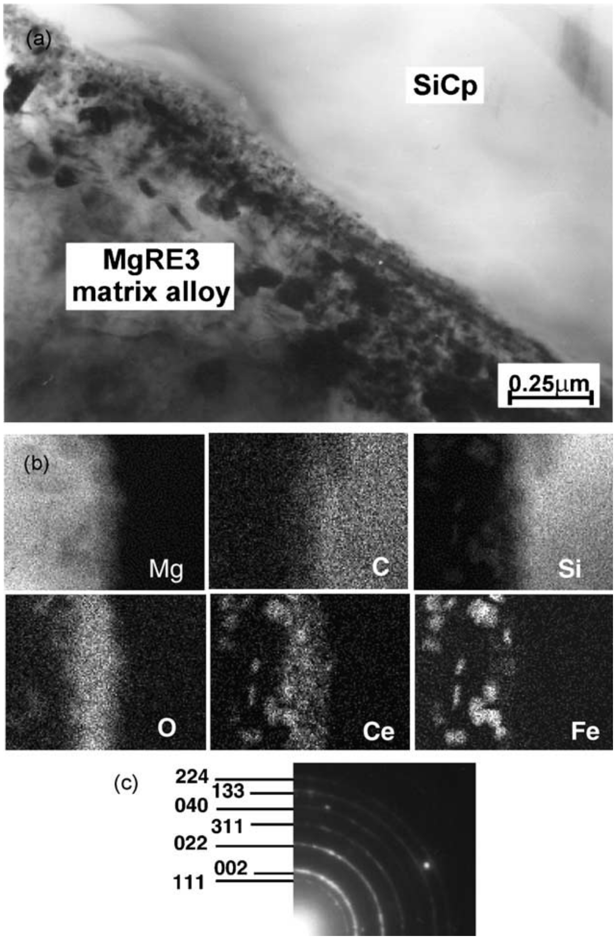

Fig. 6. (a) TEM microstructure of the interface between MgRE3 (RE: rare-earth elements) matrix and SiC particle. (b) X-ray maps showing the distribution of Mg, O, Ce and Fe at the interface. (c) Corresponding ring diffraction pattern (indexation is consistent with the MgO phase).

Investigation of Mg–8 wt.% Al alloys reinforced with SiC particles revealed the same character of bonding between the components as in the case of pure magnesium. Although aluminium is likely to react with SiC, forming a very unfavourable carbide Al_4C_3, it does not exhibit this tendency in that Mg alloy. Fig. 3 shows a typical TEM image of the interface between the components in the MgAl8–SiCp composite.

Consistent interfaces free of precipitates were also observed in the Mg–6 wt.% Zn–SiCp composite. A typical TEM microstructure of the interface between the components in the MgZn6–SiCp composites is shown in Fig. 4.

Another group of composites on the base of the Mg alloys with the addition of rare-earth elements were also investigated. The characteristic features of these materials are a good wettability of the SiC particles by the molten matrix and the appearance of reaction layers between the components of the composite. The formation of thick layers of feather-shaped morphology at the component interface was observed (Fig. 5a). The TEM–EDX analysis revealed an intensive increase of the amount of silicon and rare-earth elements present in these layers. Selected-area diffraction pattern allowed to identify the precipitates as Ce_3Si_2 phase (Fig. 5b).

Impurities, which were introduced due to an imperfect technological process, were located mostly along the interfaces (Fig. 6a). X-ray maps performed from the part of the area shown in Fig. 6b reveal the presence of Mg, O, Ce and Fe in the reaction layer. The reaction layer consists mainly of fine MgO crystals confirmed by the ring diffraction pattern presented in Fig. 6c. The compounds containing impurities promote mechanisms to destroy the composite.

4. Conclusions

The magnesium matrix composites reinforced with SiC particles are prone to the formation of adhesive interfaces between the components due to a good wettability of the reinforcing phase by the molten matrix and a high stability of SiC in liquid magnesium. The analyses of the interfaces between the components showed that some undesirable factors which affect the microstructure should be eliminated by changing the technology process. The most disadvantageous factors in the considered materials, which inhibit the formation of the adhesive bonding between the Mg matrix and SiC particles, seem to be: (i) the introduction of oxidized SiC particles and impurities like O_2, Fe, etc. and (ii) the addition of rare-earth elements.

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