

Microstructural study of aluminium matrix composites reinforced with SiC.

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Abstract: Rheocasting, as a semi-solid process, allows the production of aluminium matrix composites at relatively low temperatures (ca. 580°C), thus favouring a reduced reactivity at the reinforcement-metal matrix interface. When one considers the possibility of further processing (such as any treatment involving remelting, even if partial) of the material, this trait allows a more rigorous control of the interfaces. Composite samples have been produced using as matrix an Al-7Si-0.3Mg alloy reinforced with SiC_p (granulometry: 120 µm; V_r = 0.30). These were rheocast at 583°C, followed by forging and subsequent water-quenching. A structural characterisation (optical microscopy and XRD) of the as-received matrix material, as well as of the reinforced and non-reinforced rheocast material was performed. The phases identification will provide a basis for the understanding of the further processing where the rheocast material will be used as a raw material to produce functionally graded metal-matrix composites by centrifugal casting.

INTRODUCTION

Metal matrix composites are a class of materials which have long merited a strong interest from materials scientists, for they are tempting from the viewpoints of stiffness, strength, creep and wear resistance, lightness and thermal expansion characteristics^[1].

From all the methods to produce particle-reinforced aluminium matrix composites, those involving casting techniques are specially attractive, since they can often be implemented with only minor alterations to existing equipment^[2]. However, one of the main problems in fabricating composites in the presence of liquid aluminium resides in the difficulty to add the ceramic reinforcements to the molten metal, since proper dissemination of those throughout the melt is often impaired, even in processes during which adequate stirring is provided. Two obstacles to particle dissemination have been identified: the particles show a great tendency to form clusters that need to be broken up, and also tend to attach to gas bubbles entrained in the melt by the stirring operation^[3]. This results in a deficient distribution of the reinforcements in the cast material, with consequent degradation of the composite properties.

Further loss of properties is incurred due to poor wettability of the ceramic by the melt^[4]. Wettability is essential to form an adequate interface in the contact region between the aluminium matrix and the ceramic particle. Without the above mentioned interface, the stress transfer mechanisms between the surrounding matrix and the reinforcement element can not operate. An ideal interface should extend throughout the entire contact region and be exempt from any fragile compounds^[5].

In SiC-reinforced aluminium matrix composites, the most common of these compounds is Al₄C₃, the formation of which is favoured by low Si contents^[6, 7]. Other examples are Al₄SiC₄ and Al₈SiC₇, but these are interpreted as binary carbides, belonging to the Al₄C₃ isopleth; the first corresponds to Al₄C₃ · SiC and the second to 2 Al₄C₃ · SiC^[8]. However, some contaminants, when present, can also have a deleterious effect on the interface. Of these, some attention has recently been devoted to Fe^[9], which is thought to segregate towards the interface in the form of the fragile compound FeAl₃.

Since the first reports on the behaviour of semi-solid alloys were published in the seventies^[10, 11], the field of semi-solid processing has grown to a very complex and diverse state^[12]. Soon it was recognised that semi-solid processing offered an advantageous way to incorporate ceramic reinforcements, especially particles, into the metallic slurry, thus obviating some of the difficulties found when fabricating composites by conventional (liquid) casting techniques^[13]. Several processes have evolved, including composite rheocasting (also designated compocasting)^[14]. In rheocasting, the alloy is held at a temperature between *liquidus* and *solidus*, while being mechanically stirred by an impeller. Stirring gradually modifies the morphology of the solid grains present, which, from a dendritic form, gradually transform into rosettes, which with time suffer a ripening process, eventually culminating in spheroidization of the grains^[15].

During solidification, ceramic particles may be pushed by the advancing solidification front. This results in their location in the last freezing intergranular regions. Alternatively, the particles can be engulfed by the growing primary phase grains, ending in intragranular sites^[16]. Particle pushing, although very common, can constitute a serious problem, for particle segregation into the last freezing intergranular spaces can give rise to severe agglomeration and interparticle contact, with negative effects on mechanical strength^[17]. Some reports seem to indicate that an adequate reinforcement dispersion may be achieved through size optimisation of the primary phase solid crystals, combined with a very high primary solid content (ca. 45%)^[18].

EXPERIMENTAL PROCEDURE

Rheocast alloys and composites were prepared as indicated in Table 1, from Al-7Si-0.3Mg ingot material and SiC particles with 120 µm. While still in the semi-solid state, the rheocast materials were forged and subsequently water-quenched.

The particle content of the composite was evaluated by densitometry.

In addition, all The rheocast materials were subject to optical metallographic observation.

Samples of the non-reinforced rheocast material, as well as of the as-received matrix material, were analysed by XRD and flame-emission spectroscopy. XRD was also employed with the composite material.

Table 1 – Experimental parameters for the materials studied. Stirring time for the composite is given as two separate periods: the first for morphological conditioning of the primary phase, and the second for particle incorporation in the slurry.

Material	Temperature (°C) [% primary solid]	Stirring speed (rpm)	Stirring time (min)	Particle content (vol. %)
As-received	-	-	-	-
A10	583 [45]	650	10	-
A11	583 [45]	650	20	-
A12	583 [45]	650	30	-
A13	583 [45]	650	120	-
Composite	586 [40]	650	30 + 30	40

RESULTS

The typical microstructure of the non-reinforced rheocast alloys is presented in Figure 1. In Figure 2 the composite microstructure can be observed for two extreme cases.

The rate of contamination during stirring is displayed in Figure 3, as a result of chemical composition analysis obtained by flame-emission spectroscopy.

DISCUSSION

The examples in Figure 1 clearly show the observed microstructural evolution induced by rheocasting over time, with primary phase grains progressively acquiring a rosette-like morphology and coalescing to larger grain-sizes. Although the non-reinforced material, after 2 hours stirring, still hasn't achieved spheroidization, the microstructural evolution seems to be accelerated by the

addition of the SiC particles, for primary phase grains in the composite are clearly more advanced towards a globular shape after only 1 hour stirring (the last 30 minutes with the effective presence of particles).

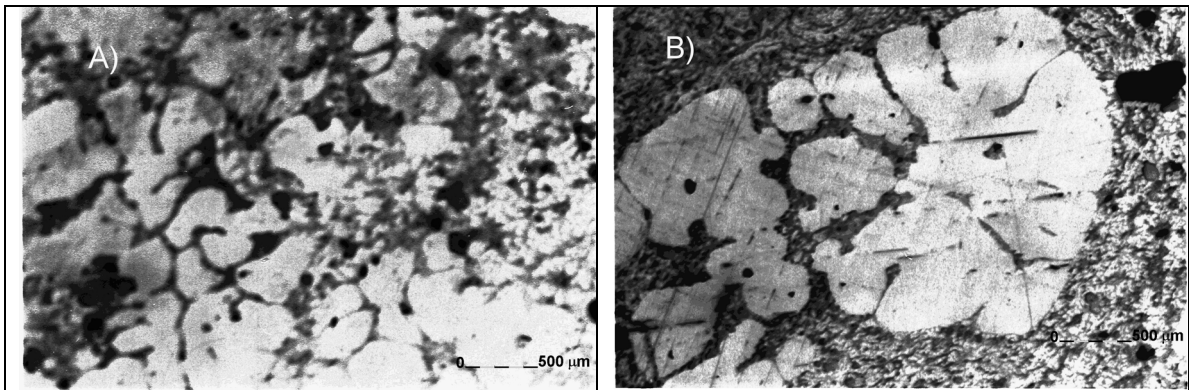


Figure 1 – Microstructure of non-reinforced rheocast alloys: A) A10 (10 min.); B) A13 (120 min.).

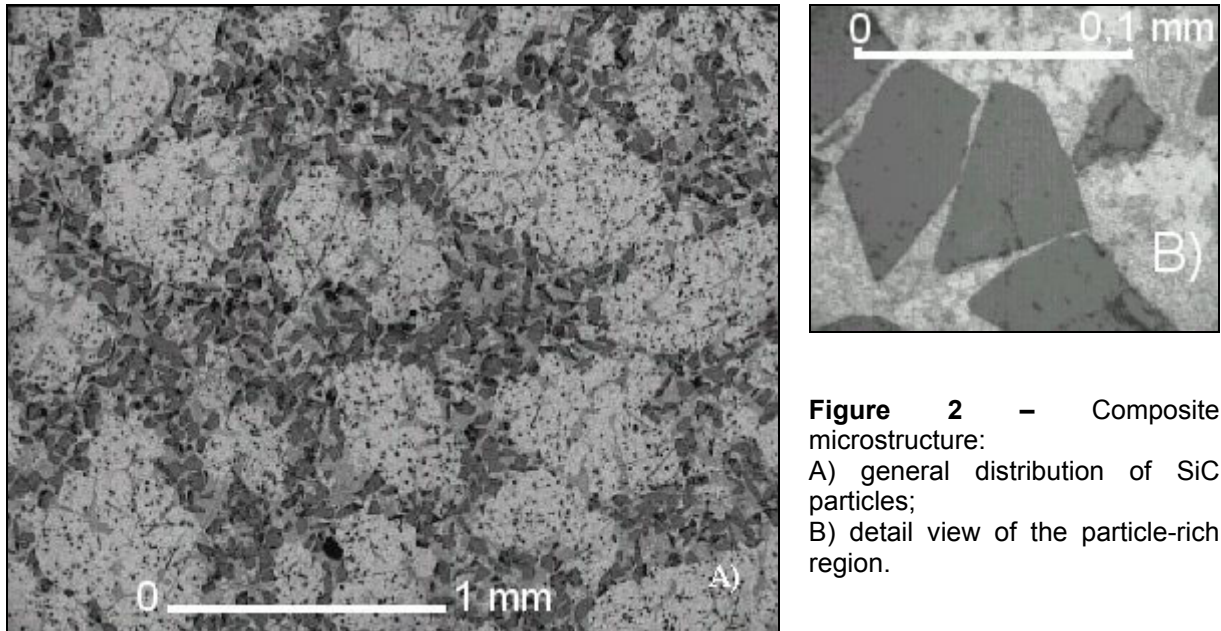


Figure 2 – Composite microstructure:
A) general distribution of SiC particles;
B) detail view of the particle-rich region.

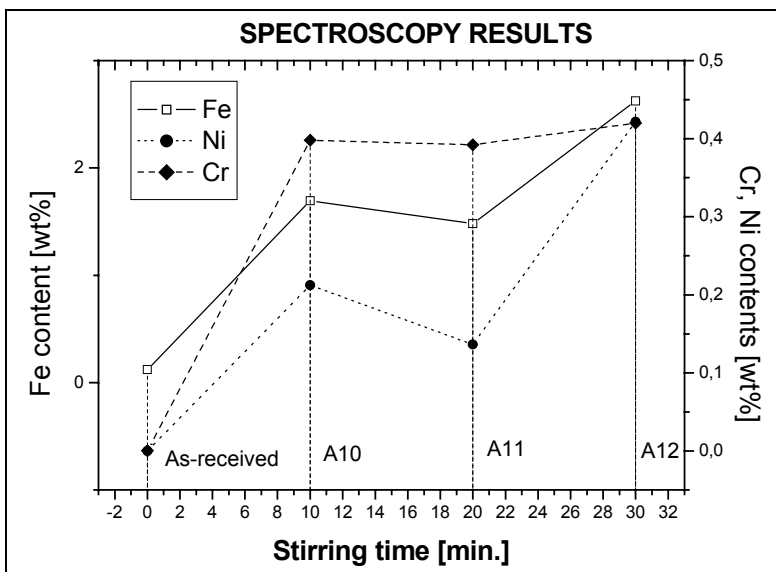


Figure 3 - Fe, Cr and Ni content evolution with stirring time in rheocast non-reinforced alloys, compared to the as-received ingot material.

Fig. 4 shows the XRD pattern of the rheocast composite where, besides the diffraction peaks of the aluminium matrix and the silicon precipitates of the base material, we identified the peaks of SiC reinforcement (as moissanite, JCPDS 29-1131), as well as α -Al₄SiC₄ (JCPDS 35-1072) and AlFe₃C_{0.5} (JCPDS 29-0044).

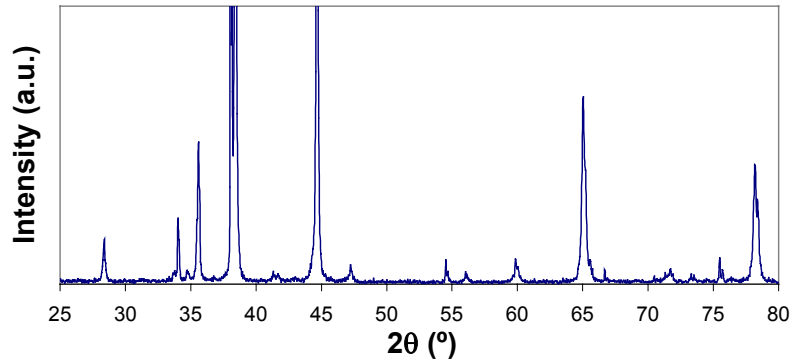


Fig. 4 - XRD of the rheocast composite

Also in the composite microstructure ample particle pushing is evident, with all the particles sited in the eutectic regions. Figure 2 B) puts in evidence that, even with such a large SiC volume fraction, interparticle contacts occur in isolated points only, which denotes that wetting of the particles was effective and the conditions well able to destroy any particle clusters.

A negative trait indicated by both the spectroscopic and XRD results is an important contamination of the rheocast material by Fe, Cr and Ni, which are practically non-existent in the as-received alloy. The source for these contaminants is to be found in the stirring impeller and the furnace walls, presently made of low-alloy steel. One interesting feature is that, whereas the contaminations by Fe and Ni seem to increase with time, Cr contamination does not seem time-dependent, for Cr content reaches its maximum already after 10 min. stirring time, and remains constant after that. This could indicate that Cr contamination occurs by dissolution into the slurry, while Fe and Ni contaminations proceed mainly through wear of the rheocaster parts in direct contact with the semi-solid.

The presence in the composite of Al₄C₃, as revealed by the Al₄SiC₄-peaks suggests further improvements could be obtained by using a higher Si-content in the matrix alloy.

CONCLUSIONS

The results obtained seem to show that, under certain conditions, rheocasting can be an appropriate processing route for the production of SiC-reinforced aluminium matrix composites. The contamination problems detected with this particular equipment are however a reason of concern, and have already prompted corrective actions, with the design of new ceramic parts for the rheocaster.

Also a higher Si-content alloy will be tested in the making of these composites.

With the implementation of those alterations, it is hoped to produce composite materials which will be further processed by centrifugal casting, aiming to obtain functionally-graded composites.

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