

EFFECT OF LIQUID METAL PROCESSING PARAMETERS ON MICROSTRUCTURE
AND CORROSION BEHAVIOR OF Al BASE METAL MATRIX COMPOSITES

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Abstract

This paper presents the effect of processing parameters such as Al alloy composition, melt temperature, particle characteristics, stirring rate, solidification rate as well as composite surface treatment on the microstructure and corrosion behavior of liquid metal processed alumina/Al and SiC/Al metal matrix composites. Melt temperatures above or below the liquidus, depending on the alloy, and high stirring rates facilitate particle incorporation. Particle pretreatment and high solidification rates prevent particle segregation. Corrosion tests in NaCl solutions revealed particle/matrix interfaces to be preferred sites for pitting corrosion and microcrevice formation. These preferred sites arise as a consequence of specific processing conditions. The use of conversion coatings reduces MMC corrosion rates.

Introduction

Metal matrix composites (MMC) are anticipated to have a significant niche in industries such as defence, aerospace, automotive and sports equipment. In recent years, particulate reinforced MMCs have been extensively developed because of a combination of factors which include ease of fabrication and availability of inexpensive ceramics as particulates. These MMCs present isotropic properties which permits their processing using conventional metal working techniques. Although MMCs encompass a very wide range of matrix/reinforcement combinations, the aluminium alloy/SiC (or alumina) particle combination seems to be one of the most interesting for industrial applications. These composites can be produced by a variety of techniques and even though the powder metallurgy route has been used quite extensively, the molten metal route is considered to be cost effective for large scale production.

The properties of liquid metal processed MMCs are controlled by the alloy composition, particle related parameters and process related parameters such as particle wetting by the molten metal, particle matrix interfacial reactivity etc. (1-3). Variations in these processing conditions bring about microstructural changes, usually in the form of local compositional variation, second phase precipitates, and formation of matrix/reinforcement interaction products. These microstructural changes in turn affect the corrosion behavior of MMCs (4-7). This paper presents the effect of processing parameters such as matrix alloy composition, melt temperature, stirring rate, solidification rate, particle characteristics (such as composition, size and volume fraction) as well as composite post treatment on the microstructure and corrosion behavior of Al base MMCs.

Experimental

Al-7%Si-X%Mg (AlSiMg) was prepared in a coated steel crucible inside a resistance furnace, homogenized, degassed and subsequently transferred to the compositing crucible shown in figure 1. The overall procedure for composite preparation consisted of transferring the AlSiMg or AA 2014 alloy (Al-4.5Cu-1Si-0.8Mn-0.5Mg) melt to the preheated compositing crucible. The alumina or SiC particles were weighed, dried at 250 C, and added to the stirred melt in the region of the vortex. The melt was stirred for varying times and the composite slurry poured into moulds with different heat extraction rates to simulate variations in solidification rates. The principle processing parameters and their conditions are given in Table I. The microstructure of the composites were determined following conventional metallographic practices. The composite surface treatment consisted of anodization in 16% sulphuric acid at 23 C and 27 mAcm⁻² for 30 min followed by sealing. Specimens from the various composites, both untreated and surface treated were prepared for the corrosion measurements. The corrosion tests consisted of (a) electrochemical measurements in 3.5% NaCl and (b) 28 day immersion test in NaCl. The former consisted of anodic potentiodynamic polarization from -1400 mV to +100 mV at 10 mVs⁻¹ in a standard corrosion cell with a SCE reference electrode. Polarization was carried out in both deaerated and aerated electrolytes. Specimens from both types of corrosion tests were examined in a scanning electron microscope.

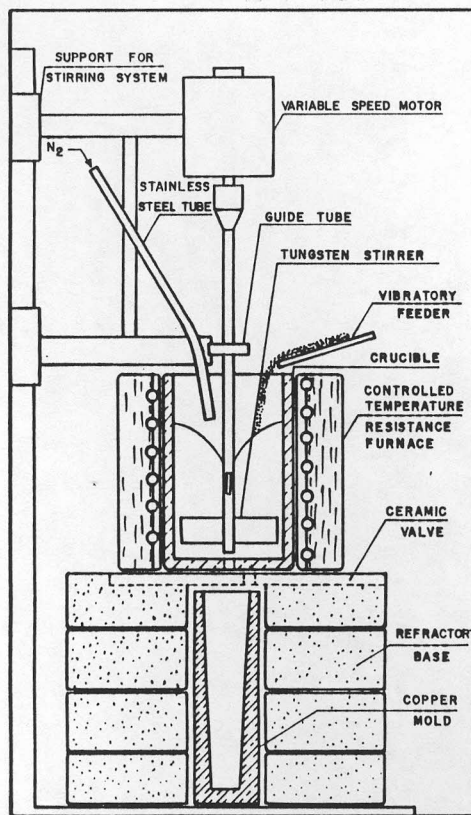


Figure 1. Schematic illustration of equipment used to prepare composites.

TABLE I - Principle composite processing parameters and their conditions.

Parameter	Conditions
Matrix alloy	Al-7%Si-0.7%Mg; AA2014
Mg in Al-7%Si (%)	0.3; 0.5; 0.7; 1.0
Reinforcement Type	Alumina; SiC
Content (vol%)	5; 10; 15; 20
size (μm)	20; 50; 100
Melt temperature ($^{\circ}\text{C}$)	680; 710; 740
Stirring rate (rpm)	500; 750; 1000
Cooling rate	Rapid (Cu mold); slow (Alumina crucible)

Results and Discussion

Effect on Microstructure

Upon addition of 5 vol% alumina to the Al-7%Si alloy containing upto 0.5%Mg, it was observed that the particles were not retained in the metal. Further increase in Mg content to $\geq 0.7\%$ helped retain the particles in the melt under identical conditions. The particles were found to be non-uniformly distributed and as agglomerates (figure 2). Increase in stirring rate helped incorporate particles more uniformly and at lower Mg contents (figure 3). Particle size and content had a significant effect on composite processing. Processing conditions that were optimized for particles of a specific kind and size were not suitable to incorporate particles of a different size, type or volume fraction. Conditions such as melt temperature, stirring rate, solidification rate etc. that were optimized for AlSiMg composites were not appropriate for making AA 2014 composites. Increase in particle content from 5% to 10% resulted in a significant increase in melt viscosity. After prolonged stirring, further increase in viscosity was observed, in alumina composites due mainly to formation of spinel at the alumina/AlSiMg alloy interface. Increase in the melt temperature to 720C and agitation speed to 1000 rpm helped increase the ease of incorporation of 20 μm size SiC or alumina particles. Particle incorporation in AA 2014 was possible when the melt was ~ 650 C. The wide solidification range of this alloy and increased viscosity of the melt permitted particle entry. Cooling rate of composite also affected particle distribution.

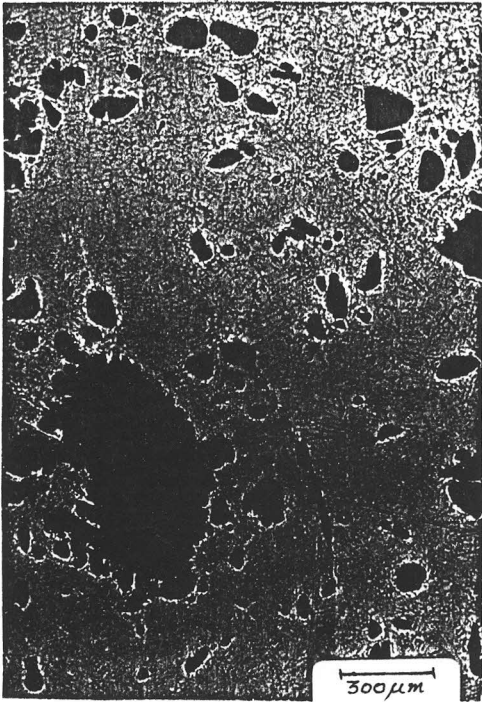


Figure 2. Optical micrograph of AlSiMg-Alumina (10 vol%) composite.

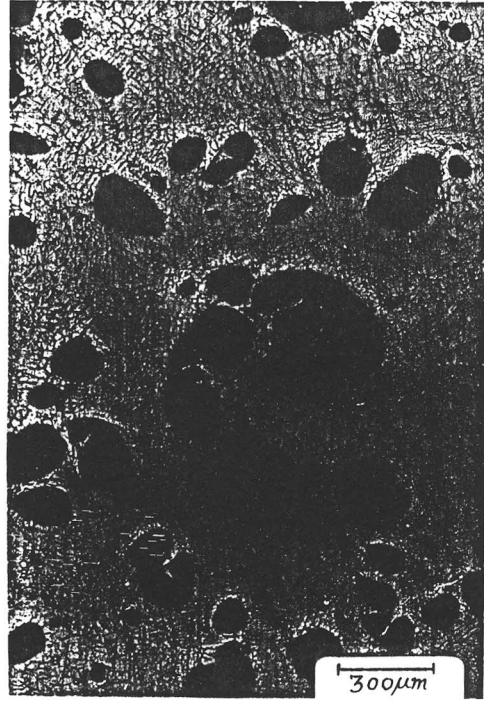


Figure 3. Optical micrograph of AlSiMg-Alumina (10 vol%) composite.

Close to the mould wall, where cooling rates were high, particle distribution was uniform. A certain distance from the wall, where cooling rates were lower, the particles were entrapped by converging dendrites. At even slower cooling rates, particle pushing by the solidification front took place. Where composites were allowed to solidify in the crucible, particle settling due to gravity was also observed.

TABLE II - Corrosion and pitting potentials of alumina and SiC composite specimens in aerated and deaerated 3.5% NaCl. All potentials in mV vs SCE.

Specimen	Aerated		Deaerated	
	E_c	E_p	E_c	E_p
Alloy AlSiMg	-760	-695	-1140	-719
CA-05-20	-736	-608	-1220	-688
CA-05-100	-740	-675	-1240	-625
CA-20-100	-760	-620	-1070	-599
CC-10-50	-733	-688	-1130	-678
CC-05-100	-755	-600	-930	-713
CC-10-100	-744	-721	-1100	-728
Anodized				
CC-10-50	-725	-458	-	-
AA 2014 + CC-05-100	-700	-500	-	-

CA - Alumina composite; CC - SiC composite; CA (or CC) - AB - XY = AB - volume (%), XY - Particle size (μm)

Corrosion effects

Composite specimens for corrosion measurements were obtained under processing conditions optimized insofar as particle distribution was concerned. The polarization curves of the different composites in both aerated and deaerated NaCl were similar. The pitting potential E_p denoted by the potential at which the current increases was read from these curves. In deaerated NaCl, the E_p of the different composite specimens were 300-500 mV higher than the corrosion potential E_c . In aerated NaCl, the differences dropped to ~100mV as shown in Table II. It can also be noted that E_p of the alloys increased upon addition of the particles. Other particle related parameters did not alter E_p or E_c . The E_c and E_p of AA 2014 are higher than those of AlSiMg, due primarily to presence of Cu in the former. The E_c of the anodized specimens were significantly higher than those of the as cast specimens, indicating increased resistance of the anodized specimens to pitting.

TABLE III - Average weight loss after 28 days in 3.5% NaCl of pH 7.0

Specimen	weight loss m.d.d.	Specimen	weight loss m.d.d.
Alloy AlSiMg	5.28		
CC-05-20	2.37	CA-05-20	4.75
CC-05-50	3.41	CA-05-50	6.95
CC-05-100	5.6	CA-05-100	4.45
CC-10-50	4.67	CA-10-50	4.61
CC-10-100	6.12	CA-10-100	4.39

The results of prolonged immersion measurements are shown in Table III. The weight losses are due to extensive localized and general corrosion of the matrix. Slight increase in corrosion rate with increase in SiC particle content was observed, whereas no significant change was observed upon increase of the alumina content. This behavior could be attributed to the difference in the conductivity of the particles.

The morphology of the composite specimens exposed at 50 mV above E_p for 15 min revealed (a) crystallographic pits in the matrix (figure 4) and (b) microcrevices in the vicinity of the reinforcement (figure 5). The pits in the SiC composites were deeper than those in the alumina composites. Prolonged exposure to NaCl resulted in dimpled regions and formation of hemispherical pits.



Figure 4. Scanning electron micrograph of AlSiMg-SiC composite exposed to NaCl at 50mV above E_p .

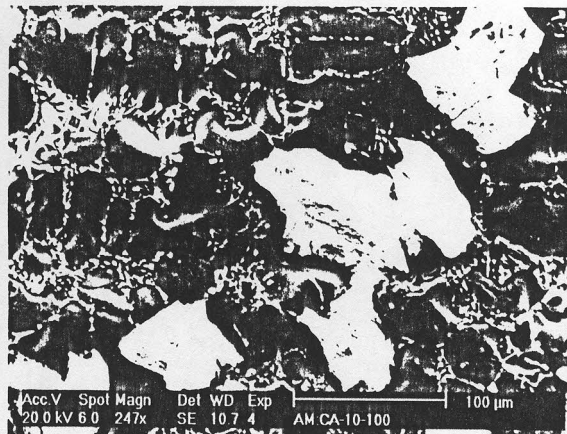


Figure 5. Scanning electron micrograph of AlSiMg-Alumina composite after prolonged exposure to NaCl.

General Discussion

The main requisites of particle reinforced composite fabrication are adequate particle entrainment, uniform particle distribution and controlled interfacial interaction. Processing parameters such as melt composition, temperature, stirring rate and particle characteristics need to be adjusted and optimized for a specific alloy/particle combination. For the AlSiMg alloy, increase in processing temperature and hence melt fluidity, facilitate processing. On the other hand, for the Cu bearing AA 2014 alloy, low temperature processing helps to incorporate the particles. Higher cooling rates help prevent particle pushing and formation of agglomerates. The formation of interfacial products, alters local matrix composition and increases the number of heterogeneities which reduces the corrosion resistance of the composite. The Al base MMCs corrode by pitting in Cl containing aqueous solutions. The pits usually initiate at surface heterogeneities and in cast composites are one or a combination of the following: casting defects, second phase precipitates, reinforcement and reinforcement/matrix interaction products. The number of intermetallic precipitates that form in composites are considerably higher than those in the unreinforced alloy. Thus candidate sites for pit initiation in the composites are significantly higher. The driving force behind the corrosion reaction in aerated media is the cathodic oxygen reduction reaction. Besides pits, microcrevices have been observed at the interfacial region, and these are due to changes in composition, brought about by specific composite processing conditions.

Conclusions

1. Particle incorporation in Al alloy melts depends on alloy composition and processing parameters. $>0.7\%Mg$ in Al-7%Si held above the liquidus improves particle incorporation. On the other hand, SiC particles entered the AA 2014 alloy at ~ 660 C. High stirring rates help retain particles in the melt and high cooling rates prevent particle segregation.
2. The composites corrode by pitting of the matrix at regions close to the heterogeneities. These are significantly higher in composites than in monolithic alloys.
3. A significant number of heterogeneities in the form of intermetallic precipitates and reinforcement/matrix interaction products are the result of specific composite processing parameters.

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