# Role of Segregation and Precipitates on interfacial strengthening mechanisms in Al-SiC MMC.

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**Abstract**: Metal Matrix Composites (MMCs) are rapidly becoming strong candidates as structural materials for many high temperature and aerospace applications. The main objective of using an MMC system is to increase service temperature of specific mechanical properties of structural components by replacing existing super-alloys. The satisfactory performance of metal matrix composites depends critically on their integrity, the heart of which is the quality of the matrix-reinforcement interface. The nature of the interface depends in turn on the processing of the MMC component. At the micro-level the development of local concentration gradients around the reinforcement can be very different to the nominal conditions. The latter is due to the metal matrix attempt to deform during processing. This plays a crucial role in the micro structural events of segregation and precipitation at the matrix-reinforcement interface. This research work deals with interfacial segregation that takes place by two mechanisms: equilibrium and non-equilibrium. A method of calculation has been proposed to predict interfacial fracture strength of aluminium in presence of magnesium segregation.

## INTRODUCTION

Equilibrium segregation occurs as a result of impurity atoms relaxing in disordered sites found at interfaces such as grain boundaries. Non-equilibrium segregation arises because of imbalances in point defect concentrations set up around interfaces during non-equilibrium heat treatment processing.

The kinetics of precipitation in the solid state has been the subject of much attention. Early work of Zener on growth kinetics has been developed by Aaron and Aaronsson for the grain boundary case and by Aaron et al. for intragranular precipitation. These approaches have been integrated to produce a unified description of the inter and intragranular nucleation and growth mechanisms. More recently successful attempts have been made to combine models of precipitate growth at interfaces with concurrently occurring segregation in aluminium alloys. Studies of the relation between interfacial cohesive strength and structure have only recently become possible. This is due to of remarkable advances in physical examination techniques allowing direct viewing of interface structure and improved theoretical treatments of grain boundary structure.

## AIMS&OBJECTIVES

The key objective of the research is to predict the interfacial strengthening mechanism at the matrix-reinforcement interface in a metal matrix composite. A major objective is to predict atomic movements in the materials on the 1 to 100 nm scale in the region of internal interfaces in MMCs. The work will build on the knowledge and skills acquired in the mathematical prediction of materials' behaviour when the following mechanisms are in operation:

- Interfacial Segregation
- Precipitation on interfaces and intragranular precipitation
- Combined grain boundary precipitation and segregation
- Relation of grain boundary and interfacial structure to cohesive strength.

Furthermore, another objective is to obtain a mechanistic model by using the mechanical testing data from fracture toughness $K_{IC}$ testing in order to relate it with the intergranular fracture energy Gk, and also calculate the intergranular fracture surface energy for second phase reinforced Al-Alloys.

The present work focuses on applying various micro scale modelling techniques to the aluminium alloy matrix composite, strengthened with varying amounts of silicon carbide particulate. The models will be used to predict the material state at critical points during heat treatment of the material as it is formed into tube.

Furthermore, advanced analytical electron microscopy techniques will be used in order to study microstructure and micro-compositional variations in regions within several hundred nm of the SiC/alloy interface. Changes in structure and micro composition as a function of heat treatment will be compared with predictions of the models for segregation and precipitation and effect on cohesive strength and mechanical properties of the interface.

For an aluminium alloy, precipitation hardening process is very important to produce good mechanical properties. The process consists of three steps. The first step is by solutionising the alloy followed by quenching to lower temperature and ageing. The ageing mechanism depends on the ageing time and ageing temperature. Besides that the ageing behaviour also determines the size and the particle distribution in the alloy which will effect the properties of the material.

The effect of stress and strain history on the micro-modelled mechanisms is likely to be of greatest importance to the segregation and precipitation phenomena and thus indirectly affect cohesive strength. The methods of incorporating stress into the description of the segregation process will be based on the Rauh-Bullough theory and will also use the concept of misfit-related impurity-boundary binding energies developed by Carolan and Faulkner.

## SUMMARY & FUTURE WORK

- Compositional variations at 100 – 300 nm can be reliably measured.
- Presence of Zinc and Magnesium at matrix-reinforcement interface identified
- A method of calculation has been proposed to predict interfacial fracture strength of aluminium in the presence of magnesium segregation

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- Fracture toughness ($K_{IC}$) determination for MMCs
- Relate $K_{IC}$ and Gk
- Obtain mechanistic model-$K_{IC}$ /Tensile test-Age hardening vs. έ hardening (n)
- Obtain energy model - $K_{IC}$ vs. Strain hardening / $K_{IC}$ vs. Energy

## REINFORCED ALUMINIUM ALLOY SYSTEM

***Quality of Matrix-Reinforcement interface***
- The nature of the interface depends on processing of the alloy system
- At the micro-level the development of local gradients around the reinforcement effect the microstructural events such as segregation and precipitation

### MATERIALS SPECIFICATION

- AlZnMgCu alloy (N707; weight %)
- Heat treatable and produced by spray deposition technology with fine homogeneous microstructure.

| Code | Zn | Cu | Mg | Zr | SiC |
|---|---|---|---|---|---|
| AZC-I | 10.5 | 1.0 | 2.3 | 0.18 | - |
| AZC-II | 10.9 | 1.15 | 2.5 | 0.22 | 7.8 |
| AZC-III | 11.0 | 1.15 | 2.5 | 0.22 | 11.5 |

### HEAT TREATMENT CYCLE

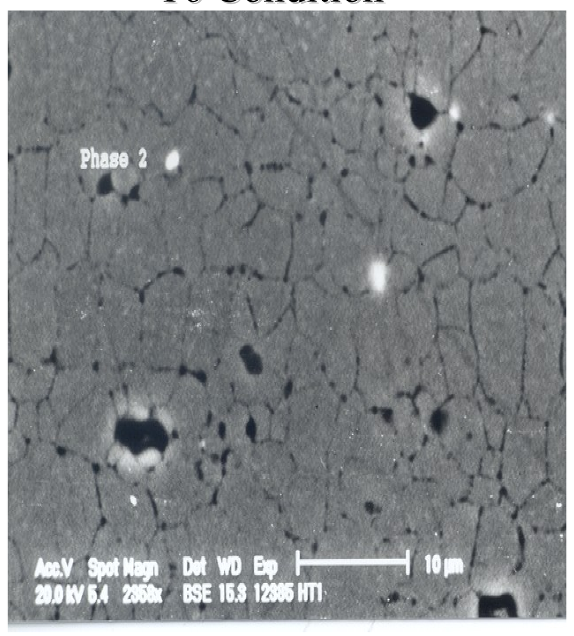
2. HT1(T6) (solution treatment) heating at 450°C for 1 hour per 2mm section thickness and water quench to room temperature.
3. Followed by precipitation treatment (artificial ageing) for 24 hours at 170°C and allowed to air cool.

### EXPERIMENTAL TOOLS

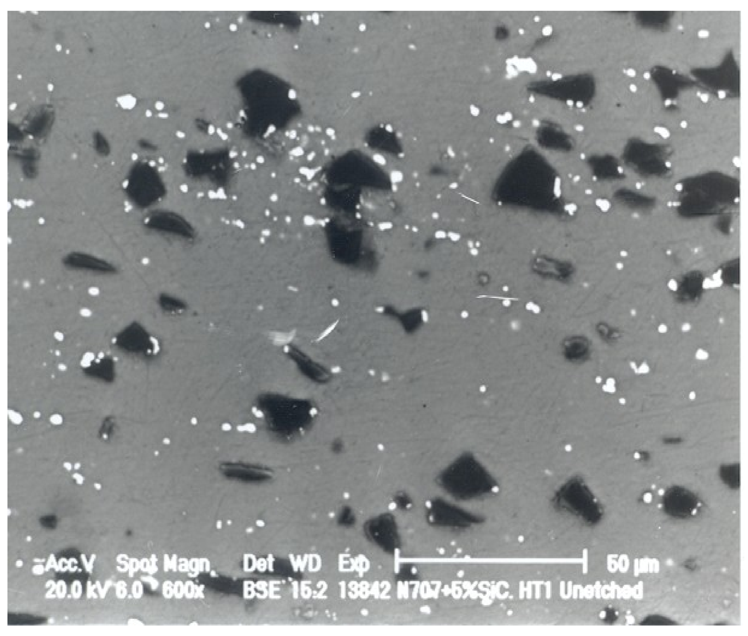
2. Electro polishing with 25% Nitric acid at -20°C
3. Ion beam thinning in vacuum with 5-6 KV argon beam at 7°C
4. Philips XL40 Scanning Electron Microscope and Jeol 100 CX System / Link 860 EDAX

## RESULTS

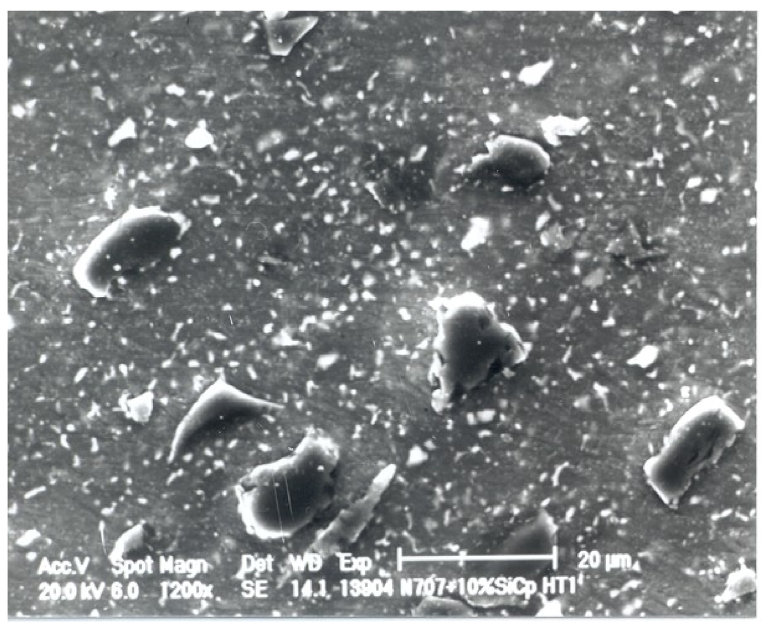
Monolithic Alloy in T6 Condition



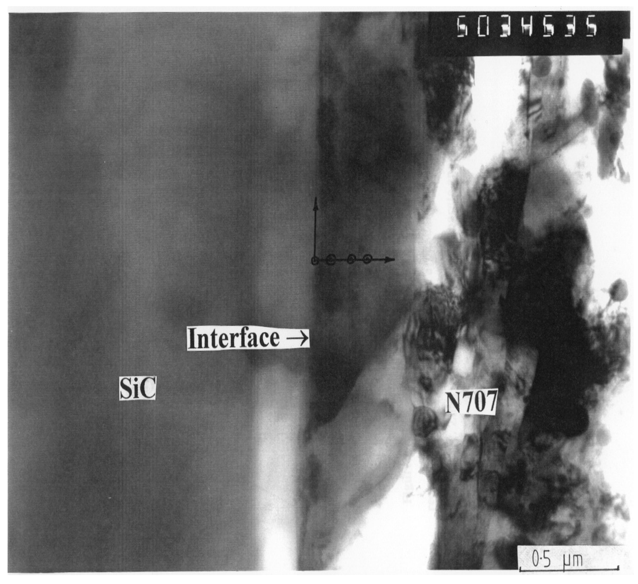

SiCp Reinforced Alloy (AZC-II) in T6 Condition



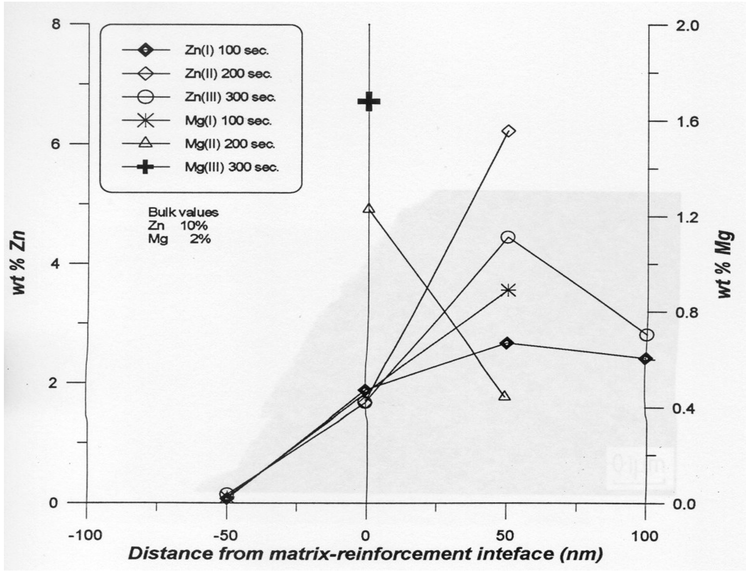
SiCp Reinforced Alloy (AZC-III) in T6 Condition



Compositional Variations Matrix-Reinforcement interface




Effect of prolonged beam analysis time on segregation behaviour (Zn & Mg)




Interfacial strength prediction in SiC Reinforced Aluminium alloy:

- Assuming Magnesium is the main segregation specie and
- SiC interface is treated as random grain boundary (Z=1)
- In the absence of Al-SiC data figures for pure aluminium are used for prediction

Interfacial Fracture Strength

| $r_{Al}$ x$10^{-10}$ m | $r_{Mg}$ x $10^{-10}$ m | $E_{Al}$ $Nm^{-2}$ | $\sigma_S$ $Jm^{-2}$ | $\sigma_F$ MPa |
|---|---|---|---|---|
| 1.43 | 1.60 | 7.1 x $10^{10}$ | 1.02 | 11.5 |
| 1.43 | 1.60 | 7.1 x $10^{10}$ | 1.02 | 260* |

*unsegregated

Prediction of intergranular fracture, Gk;

$$G_k = A\sigma_P \exp\left(n \ln\left(\sigma / \sigma_o\right)\right)$$

where A is the dislocation pile-up term, n is the strain rate hardening, $\sigma_P$ is the fracture surface energy and
New interfacial energy caused by segregation is given by, $\sigma_\alpha$ ;

$$\sigma_a = \sigma_P - ZRT \ln(1 - c + Bc)$$

where $\sigma_o = \sigma_P$ fracture surface energy, Z is the density of interface sites which are disorder enough to act as segregation sites, R is the gas constant, T is the absolute temperature, c is the segregate concentration and B is the Zuchovitsky constant.

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