Interfacial Tailoring for the Improvement of Toughness Properties in SiC-Particle Reinforced Aluminium Matrix Composites
NDE by Heat wave detection

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Abstract

Metal Matrix Composites (MMCs) are rapidly becoming strong candidate materials for many high temperature structural applications. The main objective is to increase the service temperature of structural components by using MMCs as an alternative to existing super-alloys. Fundamental to the satisfactory performance of metal matrix composites is their integrity, the heart of which is the matrix-reinforcement interface. On its turn, the nature of the interface depends on the processing history of the MMC. At the micro-level, the development of local concentration gradients in the vicinity of the reinforcement may result to considerable variations from the mean values. Thermal treatments and mechanical post processing are the main reasons for the existence of the aforementioned concentrations gradients. Mechanical deformation in particular plays a crucial role in the micro-structural events of segregation and precipitation at the matrix-reinforcement interface. The amount and size of segregation depend very much on (i) the heat treatment temperature and the cooling rate, (ii) the concentration of solute atoms and (iii) the binding energy between solute atoms and vacancies.

At present, the relationship between the strength of metal matrix composites and the details of the thermo-mechanical forming processes is not well understood. One objective of the present study is to define the features which affect the interfacial strength of a practical aluminium alloy/silicon carbide composite system, and are directly related to the forming processes currently being used by the industry. This work deals with interfacial segregation which takes place either under thermodynamic equilibrium or non-equilibrium conditions. 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. Micro-compositional changes which occur during the thermo-mechanical forming processes of these materials can cause substantial changes in mechanical properties such as ductility, fracture toughness, or stress corrosion resistance.

The material used in this study was Al-Mg-Si alloy reinforced with SiC paricles in various volume fractions. In order to obtain a quantitative assessment of the effects of the presence of the SiC particles on the mechanical properties of the matrix-reinforcement interface, the MMCs, were tested in tension, fatigue as well as micro-hardness. In addition, the fracture toughness has been evaluated and the stress field around the crack opening was monitored non-destructively using lock-in thermography.
The heat wave, generated by the thermo-mechanical coupling and the intrinsic dissipated energy during mechanical loading of the sample, is detected by a thermal camera [1]. The coefficient of thermo-elasticity allows transforming temperature changes into stress (Figure 1). The linearity between temperature change and stress is described by the relationship (equation 1):

$$\Delta T = -K_m \cdot T \cdot \Delta\sigma \,, \; K_m = \frac{\alpha}{\rho \cdot C_p} \qquad (1)$$

Where, K_m is the thermo-elastic coefficient of the material, α = Linear thermal expansion coefficient (K^{-1}), ρ = Density (kg m^{-3}) and Cp = Specific heat (J kg^{-1} .K^{-1}).

In the experiments the frame rate of the thermal camera was 140 Hz with a frame resolution of 1000 frames, the processing and acquisition times were 7 sec and 30 sec respectively, and the lock-in frequency was 20 Hz.

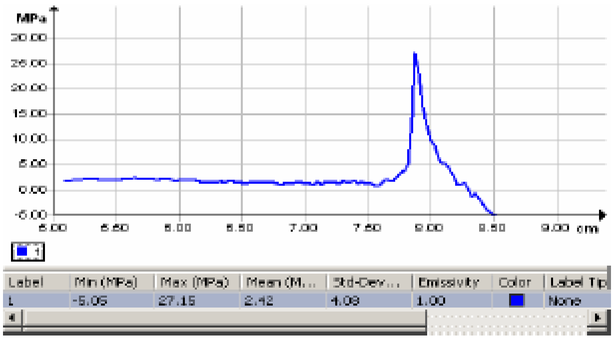

Figure 1: Stress field measurement from thermographic data.

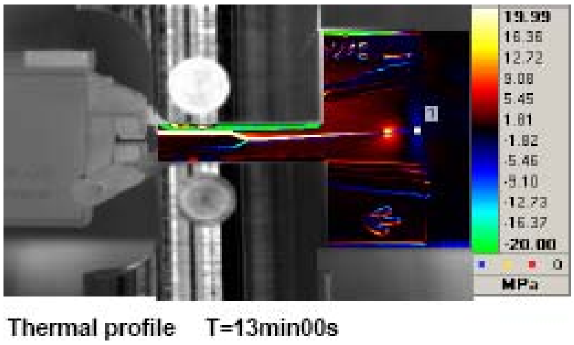

Figure 2: Lock-in thermography monitoring of fracture toughness testing

As can be seen in figure 2, the increased temperature at the vicinity of the crack tip can be directly related to the stress concentration which results in the crack propagation. The constant temperature contours as monitored by lock-in thermography were related to equal stress contours, as indicated by equation (1) for different heat treatments and reinforcement volume fractions and were correlated to the interfacial strength of the MMCs.

Finally, a semi-empirical analytical model has been applied to predict the interfacial fracture strength of aluminium, in the presence of segregation. The model is successful in predicting possible trends in relation to segregation and interfacial fracture strength behaviour in metallic alloys [2].

References

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