The role of interlayers in diffusion bonded joints in metal–matrix composites

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Solid state bonded joints in a particulate metal–matrix composite containing 17 vol% SiC in Al–Li 8090 alloy had planar bond interfaces with particle–particle (P–P) interfaces and particle–matrix (P–M) interfaces aligned in and parallel to the bond interface. The insertion of a matrix interlayer into the MMC–MMC bond interface changed the type of particle interface and interface area fractions in the two new bond planes created. In these planes P–P interfaces became P–M interfaces and the P–M area fraction either increased or fell to zero depending on the particle symmetry with respect to the bond plane. The implications for the mechanical properties of diffusion bonded joints in MMCs are discussed.

1. Introduction

Solid state diffusion bonding is an attractive method for joining metal–matrix composites (MMC) since it avoids the microstructural degradation associated with fusion welding and provides more design flexibility than friction welding [1]. The MMC is, however, not always bonded to itself. Thin layers (< 5 μm) of the matrix alloy may be used at the bond interface to reduce the bonding pressure and ensure complete surface contact. Thicker multiple interlayers are used to produce compatible interfaces in dissimilar metal joints [2] and multilayer bonded laminates find application as light weight armour or containment walls [3]. MMC–metal combinations such as Ti–6Al–4V containing 20% SiC particulate bonded to Ti–6Al–4V alloy can produce erosion, abrasion, corrosion or creep resistant surfaces on a tough load bearing core. Since bonded interlayers are becoming an important feature of MMCs, the effect of inserting a matrix interlayer on the bond interface microstructure in an aluminium alloy particulate composite has been studied. Some results of this study and their implications for the mechanical properties of bonded joints in particulate reinforced MMCs are reported in this paper.

2. Experimental procedure

A particulate reinforced MMC containing 17 vol% SiC in an Al–Li 8090 alloy matrix was made by BP Research International and rolled to sheet at RAE. The 8090 alloy composition (wt%) was Al–2.4Li–1.2Cu–0.6 Mg. The sheet surfaces were mechanically polished to 1 μm diamond surface finish prior to diffusion bonding by vacuum hot pressing [4, 5]. 8090 alloy interlayers were in the form of foils 100 μm thick. Sections normal to the sheet surface and parallel to the rolling direction are shown for the diffusion bonded MMC in Fig. 1a and for the MMC–8090 interlayer–MMC joint in Fig. 1b. A statistical analysis of the particle interfaces present in the bond interfaces has been described in detail elsewhere [6, 7]. It was based upon linear intercept measurements over sample lengths $L = 400$ μm in the longitudinal direction along the bond line of polished and slightly etched sections similar to that shown in Fig. 1a. The P–P, P–M and M–M interface parameters used in this paper are [6] n the number of interfaces, x the interface length, Σx the total interface length in sample length L, percentage interface length in sample length, $R = \Sigma(x)/L \times 100$.

3. Results

3.1. Microstructure of diffusion bonded joints

The bond line A–A in Fig. 1a can be identified by the flat particle facets (P–P and P–M interfaces at A and B, respectively) which lie in and parallel to the bond interface. In the MMC the particle distribution was uniform on a macroscopic scale but on a microscopic scale some banding and clustering were apparent. The banding led either to regions completely free of particles or to regions containing a higher than average density of particles. A schematic diagram of this joint is shown in Fig. 2a and the same joint after insertion of an interlayer is shown in Fig. 2b with the corresponding P–P and P–M interfaces indicated. The introduction of the interlayer creates two new bond interfaces, A_1–A_1 and A_2–A_2, and converts P–P interfaces to P–M interfaces (Figs 1b and 2b).

3.2. Effect of interlayer on a symmetrical MMC–MMC bond interface

A symmetrical bond interface is one in which the total P–M interface length associated with particles at the bond line on one side of the bond plane is equal to the

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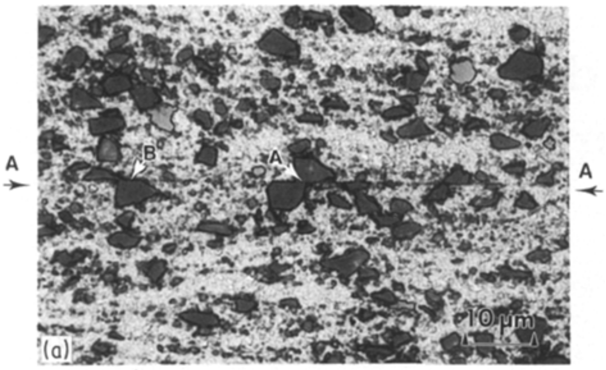

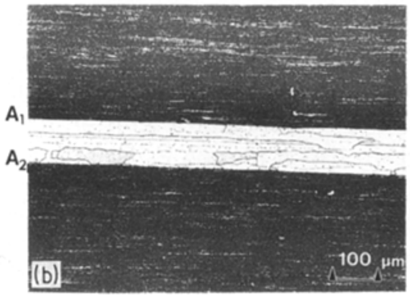

Figure 1 Optical micrographs of MMC diffusion bonded joint. (a) as bonded MMC–MMC interface at A–A, A is the P–P interface, B the P–M interface. (b) MMC–matrix bond interfaces at A_1–A_1 and A_2–A_2 after insertion of 8090 matrix interlayer.

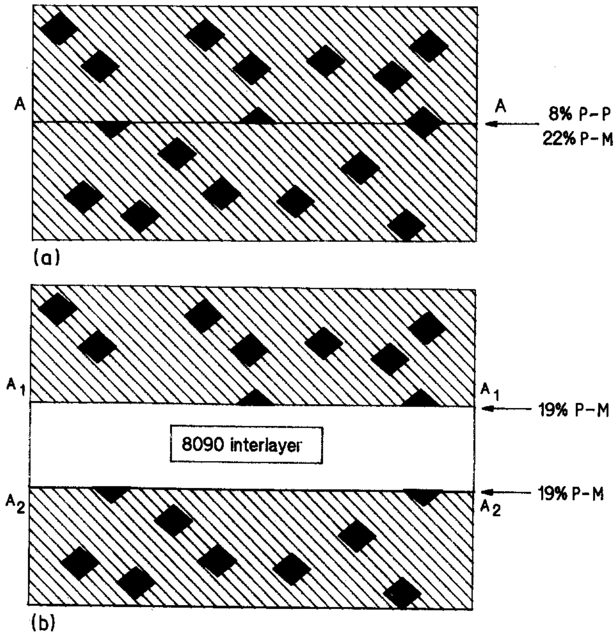

Figure 3 Schematic diagram of (a) symmetrical MMC–MMC bond interface at A–A (b) after insertion of matrix interlayer to produce two similar assymmetrical bond interfaces A_1–A_1 and A_2–A_2.

total P–M interface length associated with particles on the opposite side of the bond plane, as shown in Figs 2a and 3a. Insertion of the interlayer produces two new bond planes which are identical i.e have the same *R* value for P–M interfaces, but are assymmetrical i.e. have all the particles on one side of the bond line, as in Figs 2b and 3b. The total P–M interface length in each new bond plane is equal to the P–P + P–M interface length in the original MMC–MMC joint. No P–P interfaces are possible. This can be summarized as follows

MMC–MMC joint interface length L	MMC–interlayer–MMC joint interface length $2L$	
P–P interface →	P–M in interface A_1 P–M in interface A_2	(1)
P–M interface →	P–M in interface A_1 M–M in interface A_2	(2)

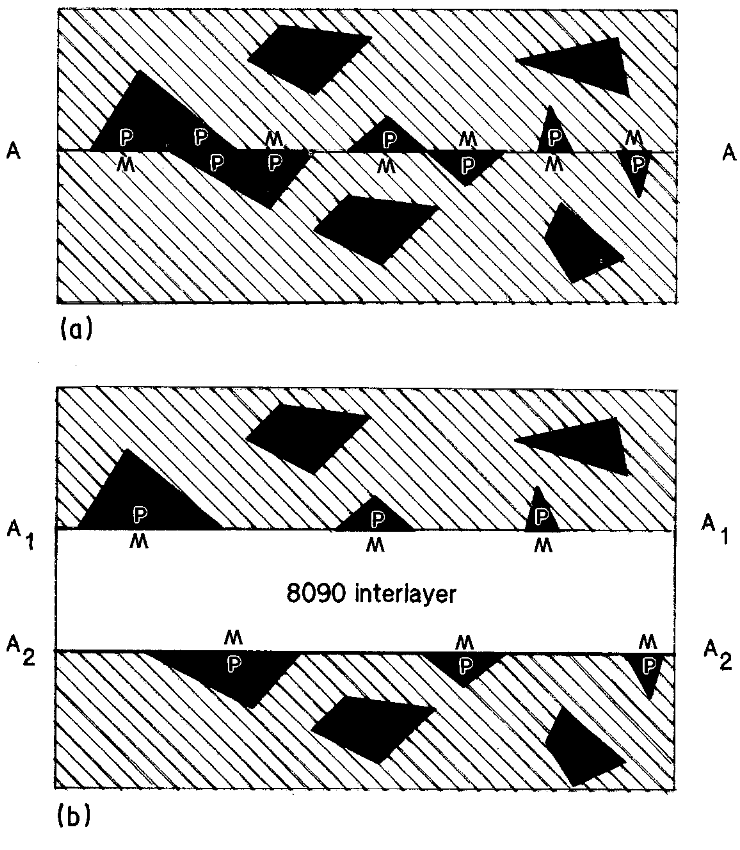

Figure 2 Schematic diagram of MMC diffusion bonded joint. (a) a symmetrical MMC–MMC bond interface at A–A, (b) after insertion of matrix interlayer to produce two identical assymmetrical MMC–matrix bond interfaces A_1–A_1 and A_2–A_2. P is a particle, and M the matrix.

It is, therefore, possible to predict the effect of inserting an interlayer into an MMC–MMC bond interface containing the random particle distribution determined for this MMC in the previous analysis [6, 7]. The R values for random 400 μm sample lengths were about 8% for P–P interfaces and about 22% for P–M interfaces. For a symmetrical MMC–MMC interface (Fig. 3a), inserting an interlayer would produce two identical bond planes each having $R = 19\%$ P–M interfaces (Fig. 3b). This can be represented by the relationship

$$\begin{array}{ccl} R = 8\%\ \text{P–P} + R = 22\%\ \text{P–M} & \rightarrow & R = 19\%\ \text{P–M in interface } A_1 \\ \text{MMC–MMC interface} & & R = 19\%\ \text{P–M in interface } A_2 \\ \text{(Fig. 3a)} & & \text{(Fig. 3b)} \end{array} \quad (3)$$

Thus the insertion of the interlayer leads to the elimination of P–P interfaces and a reduction in the R value for P–M interfaces in each bond plane compared with the initial MMC–MMC interface.

Similarly an interlayer may be inserted into a region of high particle density, for which $R = 50\%$ for P–P interfaces and $R = 1\%$ for P–M interfaces [6, 7]. Insertion of an interlayer would produce two bond lines each with $R = 50.5\%$ for P–M interfaces.

3.3. Effect of interlayer on an assymmetrical MMC–MMC bond interface

An assymmetrical bond interface is one in which the total P–M interface length associated with particles at the bond plane on one side of the bond plane is not equal to the total P–M interface length associated with particles on the opposite side of the bond plane, as shown in Fig. 4a. After insertion of the interlayer two new bond planes are formed which are asymmetrical and are not identical, since one has more P–M interface length than the other (Fig. 4b).

The interfaces present in a real material can be predicted as above. If the asymmetrical MMC–MMC bond interface has the same R values as given above for the random sample, but has all the particles associated with P–M interfaces on one side of the bond plane, then the change in particle interface lengths caused by the insertion of an interlayer can be represented by

$$\begin{array}{ccl} R = 8\%\ \text{P–P} + R = 22\%\ \text{P–M} & \rightarrow & R = 30\%\ \text{P–M in interface } A_1 \\ \text{MMC–MMC interface} & & R = 8\%\ \text{P–M in interface } A_2 \\ \text{(Fig. 4a)} & & \text{(Fig. 4b)} \end{array} \quad (4)$$

In this example the P–P interfaces are eliminated, but one new bond interface has an R value for P–M interfaces higher and the other an R value lower than the R value for P–M interfaces in the initial MMC–MMC interface.

Insertion of an interlayer into a region of high particle density, for which $R = 50\%$ for P–P interfaces and $R = 1\%$ for P–M interfaces would lead to two new bond planes, one with $R = 51\%$ and one with $R = 50\%$ for P–M interfaces. Thus when R(P–P) $\gg$ R(P–M) in the initial MMC–MMC interface, R(P–M) values in the new bond interfaces are about the same.

The other extreme occurs if prior to bonding one of the two polished MMC surfaces lies in a particle depleted band in the microstructure. Then an asymmetrical MMC–MMC bond interface is produced with only P–M interfaces at the bond line (Fig. 5a). After insertion of an interlayer all the P–M interfaces lie in one of the two bond planes whilst the other has no particle interfaces (Fig. 5b).

4. Discussion

The shear strength of solid state diffusion bonded joints in MMCs will depend upon the individual and total particle area fractions, their type and their respective shear strengths. It was concluded [6, 7] that particle interfaces aligned in the planar bond interface were potential defect sites and regions of higher particle density could be responsible for the lower bond shear strength in the MMC compared with the bulk material.

Assuming P–P interfaces at the bond line have lower strength than P–M interfaces the elimination of P–P interfaces and their replacement by P–M interfaces by the insertion of a matrix interlayer in an MMC–MMC joint may lead to increased bond interface strength. The increased number of bond planes and the ductile interlayer may increase the joint toughness and provide transverse crack stoppers. The local fracture behaviour may also reflect the increase or decrease in the symmetry of the bond interfaces, with a significant increase in ductility associated with particle free interfaces. Greater plastic flow may also be associated with short interface lengths compared with long interface lengths.

When the above factors are considered the relative bond strengths consistent with the present results and the previous analysis [6, 7] are

$$\begin{array}{ccccccc} \text{matrix–matrix} & > & \text{MMC–LPDB–MMC} & > & \text{MMC–matrix–MMC} & > & \text{MMC–MMC} \\ (190\,\text{MPa}) & & (>170\,\text{MPa}) & & (150\,\text{MPa}) & & (\sim 100\,\text{MPa}) \end{array}$$

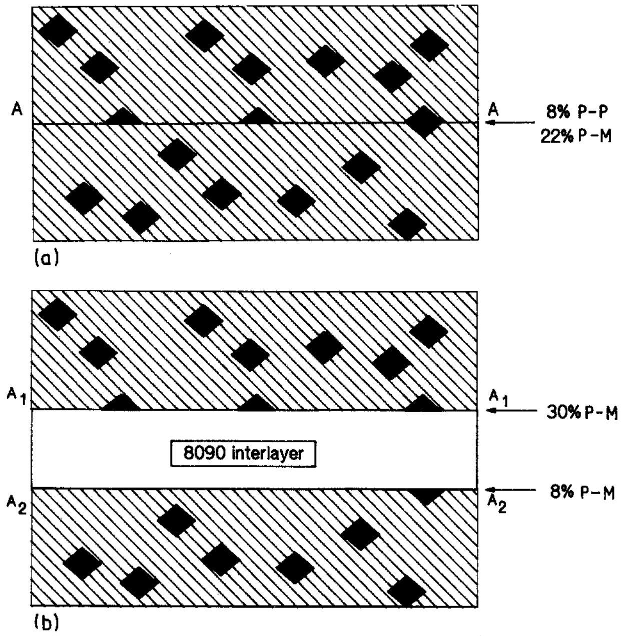

Figure 4 Schematic diagram of (a) assymmetrical MMC–MMC bond interface at A–A containing P–P and P–M interfaces, (b) after insertion of matrix interlayer to produce two dissimilar assymmetrical bond interfaces A_1–A_1 and A_2–A_2.

The predictions are in agreement with the preliminary shear strength values obtained for solid state and liquid phase (LPDB) diffusion bonded joints in this composite as shown above.

5. Conclusions
The insertion of a matrix interlayer into a solid state diffusion bonded joint changes the type and area fraction of particle interfaces at the two new bond interfaces created. P–P interfaces become P–M interfaces and the area fraction of P–M interfaces may increase or decrease and may become zero. These changes may affect the strength and fracture behaviour of diffusion bonded joints in MMCs.

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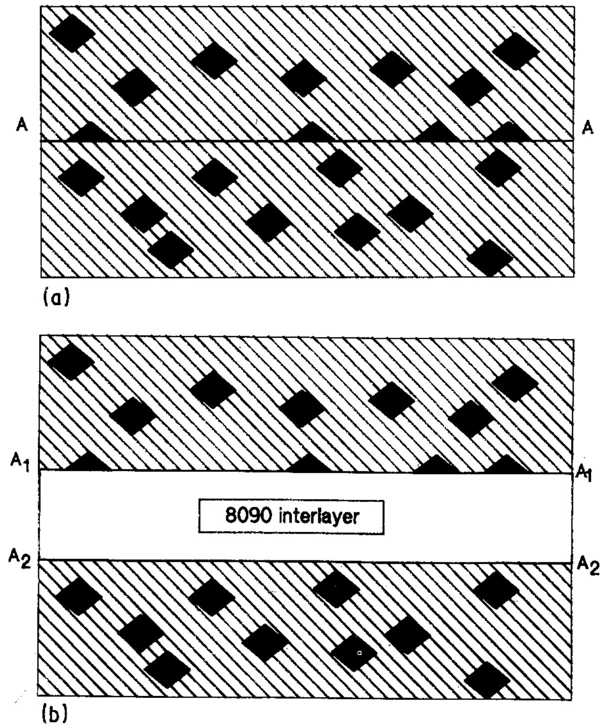

Figure 5 Schematic diagram of (a) assymmetrical MMC–MMC bond interface at A–A containing only P–M interfaces. (b) after insertion of matrix interlayer to produce two dissimilar bond interfaces A_1–A_1 and A_2–A_2.

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