FRACTURE BEHAVIOR OF Al 1100/Al 2024 LAMINATE COMPOSITES

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ABSTRACT

Laminate composites consisting of Al 1100/Al 2024 were fabricated by roll-bonding. Composites were cycled between 300 K and 600 K for up to 3000 cycles while isothermal treatments at 600 K were given to some composites. Thermal cycling led to an interfacial diffusion zone and overaging of Al 2024. Isothermal treatment resulted in a precipitate free zone at the interface and along the grain boundaries as well as overaging in Al 2024. This difference was explained in terms of an excess vacancy concentration resulting from cycling. Fracture (tensile) surfaces of all composites were very similar, with flat fracture in Al 2024 and slant fracture (fully in external layers and partially in internal layers) in Al 1100. This was due to the thickness direction constraint in the internal Al 1100 layers. Thermal cycling and isothermal treatment resulted in change from a fully ductile to a ductile plus intergranular fracture in Al 2024.

KEYWORDS

Laminate composites, fracture, Al 1100, Al 2024, thermal cycling, isothermal treatment, interfacial diffusion zone, precipitate free zone, overaging.

INTRODUCTION

In some earlier work on aluminum - stainless steel laminate composites, we have reported the improved mechanical properties obtainable in such composites (Chawla and Collares, 1978; Chawla and Liaw, 1979). Such metallic composites, however, show problems with regard to the thermal stress generated due to any temperature changes (Chawla and Nielsen, 1982a, 1982b). In order to eliminate the problem of thermal stresses and yet maintain the idea of a laminate composite consisting of alternating hard and soft layers, we turned to Al 2024/Al 1100 system. In this paper we report the fracture behavior of these composites in tension as a function of thermal cycling and isothermal treatment.

EXPERIMENTAL

Laminate composites consisting of alternate layers of Al 1100 and Al 2024 were fabricated by roll-bonding (Chawla and Collares, 1978). Altogether 7 sheets were used with Al 1100 being always the external facings which gave 45% volume fraction of Al 2024. The as rolled composites were given T-4 heat treatment to obtain precipitation hardening in Al 2024. This was the initial state. Composite samples were cycled between 300 K and 600 K for 500, 1000, 1500, 2000 and 3000 times, each cycle taking 10 minutes. Isothermal treatments were given at 600 K for time intervals equivalent to the respective thermal cycles, to wit, 612, 1225, 1839, 2453 and 3679 minutes. Tensile tests were done in an Instron machine. Microstructural examinations were carried at various stages using scanning electron microscope.

RESULTS AND DISCUSSION

We denote, in what follows, Al 1100 as component 1 and Al 2024 as component 2. The diffusion free (at least at the SEM resolution level) interfacial region in the initial state is shown in Fig. 1. Al 2024 shows fine precipitates. The situation of this interfacial region after 500 cycles is shown in Fig. 2 where we now see precipitation at the interface and a diffusion zone extending from component 2 into 1. During thermal cycling, there occurred an excess of vacancies in each cycle (Jacobs and Pashley, 1968) which favored heterogeneous precipitation at the interface (a kind of supergrain boundary) and diffusion of species from 2 to 1. A microprobe analysis confirmed this diffusion zone. Al 2024 also showed precipitate coarsening as a result of overaging. All thermally cycled composites showed similar microstructural changes with a tendency toward saturation. The microstructure of a sample isothermally treated for 612 min is shown in Fig. 3. Here, we see precipitation at the interface and a precipitate free zone (PFZ) in Al 2024 along the interface. During isothermal treatment too there occurred a segregation of elements to the interface. In this case, however, there was not created too much of an excess vacancy concentration. Thus, although the interface does trap any migrating species, it does so by creating a PFZ (Jacobs and Pashley, 1968) and the diffusion zone is conspicuous by its absence. Al 2024, in this case, also showed coarse precipitates in the grain interiors and at grain boundaries with PFZ's along the boundaries. All composites isothermally treated for different time intervals showed similar microstructural changes with a tendency toward saturation. It should be pointed out that compared to thermally cycled composites, the isothermally treated samples showed a larger degree of overaging in Al 2024.

The engineering stress-strain curves of thermally cycled and isothermally treated composites are presented in Figs. 4 (a & b). In relation to that of the composite in the initial state, we note a general lowering of the stress-strain curve with cycling or isothermal treatment and the tendency toward saturation. The strength degradation was more after isothermal treatment than on cycling due to the existence of PFZ's and a greater degree of overaging in Al 2024 in the former case.

The fracture surface of composite in the initial state is shown in Fig. 5. Notice the flat fracture in Al 2024 and partially slant fracture in the internal Al 1100 layers and a highly slant fracture in the external Al 1100 layers where there was no constraint in the thickness direction. Figures 6 (a & b) show regions of fracture surfaces of Al 1100 and Al 2024, at higher magnifications, respectively. The fracture occurred by nucleation, growth and coalescence of microcavities in both 1 and 2, although as expected it was much more ductile in 1 than in 2.

The fracture surfaces of cycled and isothermally treated composites (Fig. 7 a, for 500 cycles and Fig. 7 b, for 612 min) were similar outwardly to that of the composite in the initial state. Higher magnifications of individual laminae showed that although Al 1100 continued to have a ductile fracture, Al 2024 showed an ever increasing tendency for cleavage faceting and intergranular fracture, Figs. 8 (a & b), more in isothermally treated than in cycled composites.

CONCLUSIONS

Thermal cycling between 300 K and 600 K or isothermal treatment at 600 K did not result in interfacial delamination in roll bonded Al 1100/Al 2024 composites. Thermal cycling, however, resulted in an interfacial diffusion zone and overaging of Al 2024, the former tending to attenuate the gradients in plastic deformation while the latter tended to degrade the strength but improve ductility. Isothermal treatment resulted in a precipitate free zone at the interface and along the grain boundaries of Al 2024. This together with the precipitate coarsening in Al 2024 during isothermal treatment resulted in a greater lowering of strength and increase in ductility than in the cycled composites.

Fracture (tensile) surfaces of all composites were very similar, in general, with flat fracture in Al 2024 and partially slant fracture in internal Al 1100 layers and fully slant fracture in the external Al 1100 layers (lack of constraint in the thickness direction). Thermal cycling and isothermal treatment resulted in a change from a fully ductile to a ductile plus intergranular fracture in Al 2024.

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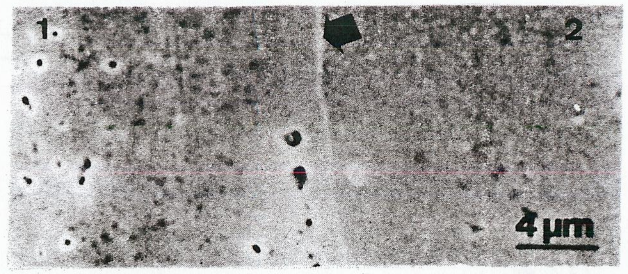

Fig. 1: Diffusion free interface in the initial state. Arrow indicates the interface.

Fig. 2: Interface after 500 cycles. Notice the diffusion from Al 2024 to Al 1100. Arrow indicates the interface.

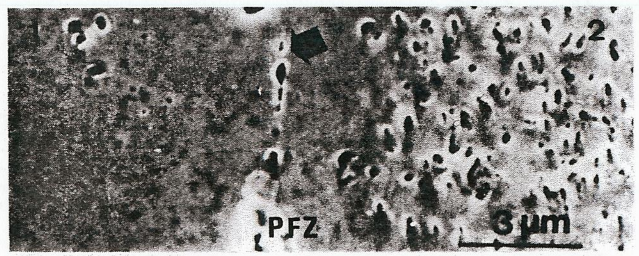

Fig. 3: Interface after isothermal treatment (612 min). Notice the precipitates at the interface and precipitate free zone (PFZ). Arrow indicates the interface.

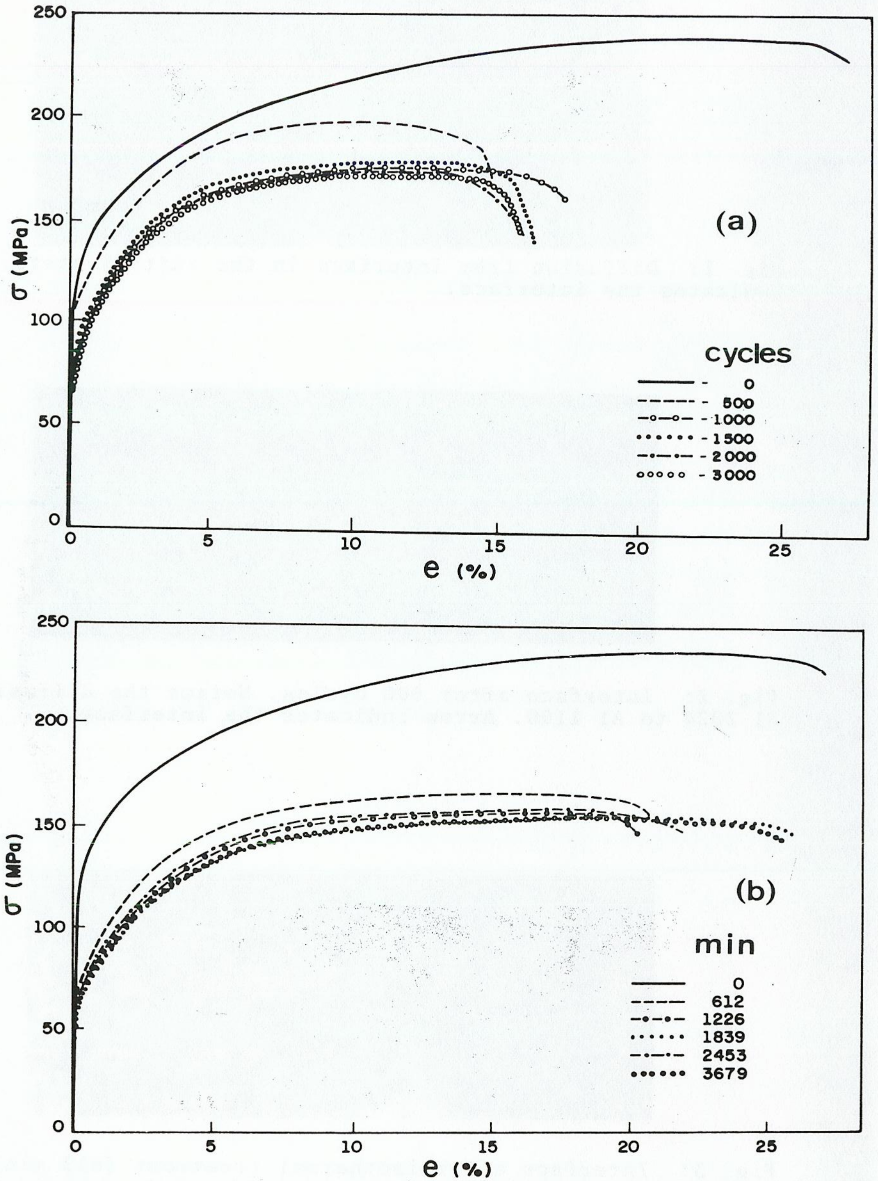

Fig. 4: Stress-strain curves of (a) thermally cycled composites and (b) isothermally treated composites. The strength degradation is more after isothermal treatment than cycling treatment.

Fig. 5: Fracture surface of a composite in initial state. Flat fracture in Al 2024 and slant (partial and total) in Al 1100.

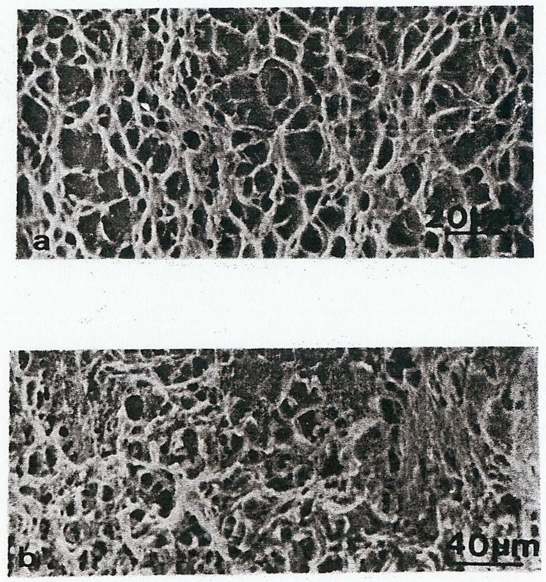

Fig. 6: Fracture surface of Al 1100 (a) and Al 2024 (b). Fracture occured by nucleation, growth and coalescence of microcavities, more ductile in Al 1100 than in Al 2024.

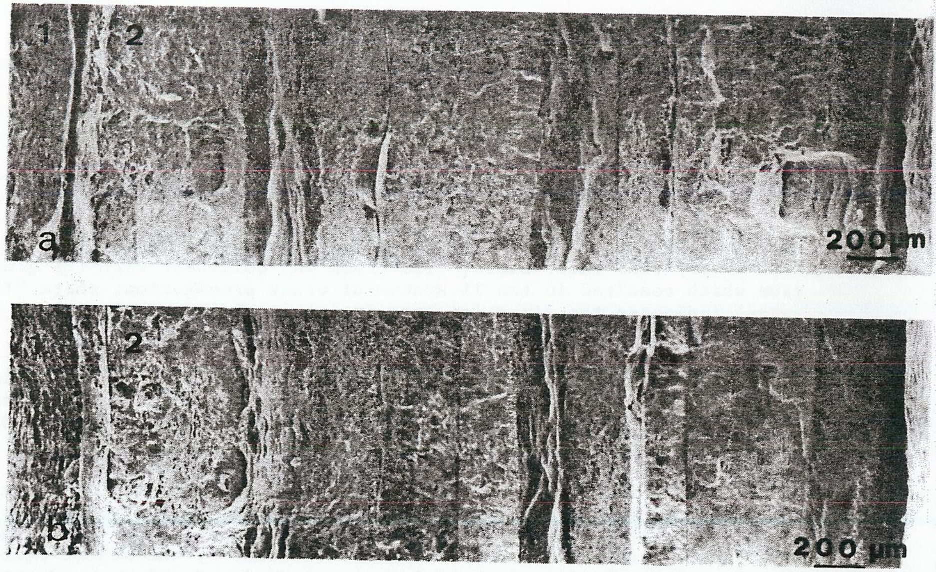

Fig. 7: Fracture surface of cycled (a) and isothermally (b) treated composites, similar to that of the composite in the initial state.

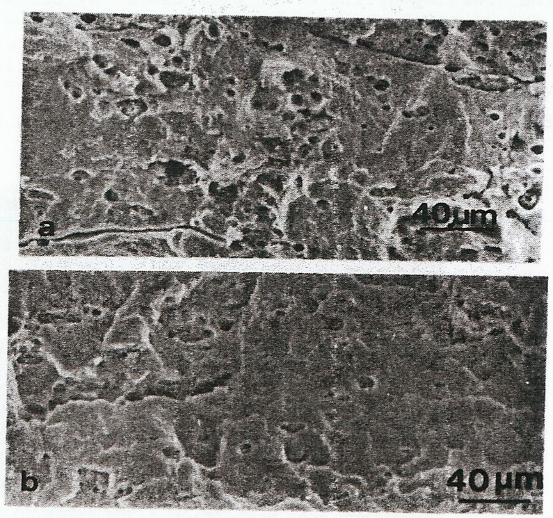

Fig. 8: Fracture surface of Al 2024, 500 cycles (a) and Al 2024, 612 min (b). Notice the tendency for cleavage faceting and intergranular fracture, more in isothermally treated than in cycled composites.