Fracture Mechanisms in Lamellar Eutectic Composites

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Introduction

This paper is concerned with the effects of growth speed and test temperature on the deformation and fracture of two lamellar eutectic composites. Al-37.5a%Ag and Ag-32.2a%Mg. The experimental program consisted of producing directionally solidified alloys at several growth rates, R, performing post-solidification heat treatments, and determining the tensile properties of these alloys as a function of test temperature in the range -196°C to 300°C. In addition, some limited creep studies on the Ag-Mg alloys are reported.

Experimental Procedure

Small ingots of each alloy were cast under argon from starting materials of 99.999%Ag and Al and 99.995%Mg. Ingots were then hot swaged to 0.187 in. dia. and 5.5 in. long samples were directionally solidified in graphite crucibles within a resistance-wound furnace, under argon.

For both alloys the interlamellar spacings, $\lambda = t_1 + t_2$ (where t_1 and t_2 are the thickness of adjacent lamellae of the two phases) varied with $R^{-\frac{1}{2}}$. The eutectic grain size d, of Ag-Mg was about 0.06 cm, independent of growth speed, but increased with R for Al-Ag.

Ordering of the Ag_3Mg phase in the Ag-Mg alloy was induced by reheating to 500°C for 1 hr. in vacuum, followed by a slow cool to room temperature. Disordered samples were quenched from 500°C. This treatment disordered only the Ag_3Mg phase; complete long range order

was retained in the CsCl type AgMg phase.

One group of Al-Ag samples was stress relieved for two hrs. at 200°C and air cooled. Another set was annealed at 525°C for two hrs., water quenched, and aged at 165°C for five hrs., and quenched again. The latter treatment caused precipitation of γ' Ag_2Al in the Al-rich phase.

Tensile tests were conducted on an Instron machine at a constant strain rate of 3.3×10^{-4} sec.$^{-1}$. Creep tests were also carried out, under constant load in argon, for the Ag-Mg alloy.

Results and Discussion

1. Ag-Mg

Typical load displacement curves for both the ordered and disordered Ag-Mg eutectic are shown in Fig. 1. Both conditions exhibited substantial ductility at all test temperatures but ordering raised yield strength and strain hardening rates and reduced ductility. In creep tests under argon at several temperatures, ordering increased rupture life but again decreased rupture ductility, see Fig. 2.

Electron fractography revealed that tensile fracture surfaces in either heat treatment condition exhibited dimples, the maximum size of which was limited by plate thickness, see Figs.3 a) and b). Longitudinal metallographic sections confirmed that most of the fracture path occurred transverse to lamellae, for both conditions at room temperature. However, there was some tendency for delamination of phases in ordered material tested at -196°C.

Creep fracture surfaces differed from those in tension as

shown in Figs. 4 a) and b) for disordered and ordered samples. There was a tendency for flat, cleavage-like facets in ordered material.

2. Ag-Al

Although aging of this eutectic had a significant influence on yield stress (some 20,000 psi increase at all growth speeds) there was no marked effect on fracture behavior. Accordingly, we shall discuss fractographic features from aged samples as representative of both conditions.

Crack paths in this alloy tended to lie between 30° and 60° to the tensile axis, Fig. 5 a), with secondary cracks which followed eutectic grain boundaries or interphase boundaries lying nearly parallel to the tensile axis. Scanning electron microscopy revealed that interlamellar failure was accompanied by dimple formation, Fig. 5 b). Note the change in crack appearance at the eutectic grain boundary, G, in Fig. 5 b). It is apparent that cracks tend to run for short distances along interphase boundaries (or a path at 90° to these boundaries). Individual lamellae appeared to cleave, as noted by nearly featureless regions in Fig. 5 b). These observations indicate that when plasticity is high in lamellar eutectics that mixed fracture modes are likely: cracks will propagate along interphase boundaries and eutectic grain boundaries, as well as transverse to the lamellae.

Acknowledgement

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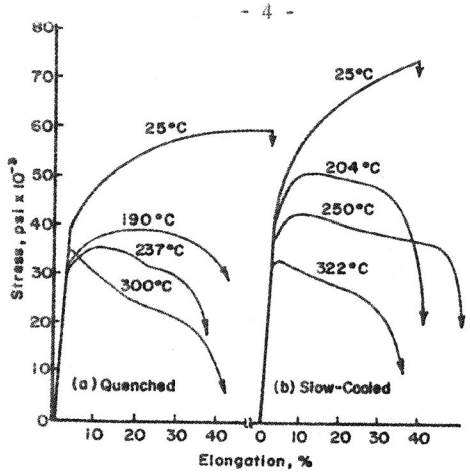

Fig. 1 Typical load-elongation curves, Ag_3Mg - AgMg

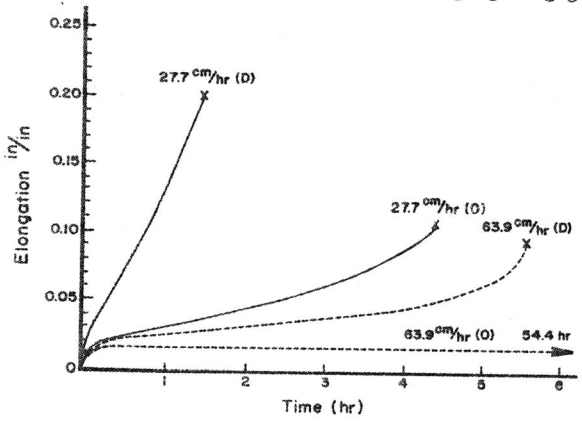

Fig. 2 Creep curves for Ag_3Mg - AgMg at 238°C

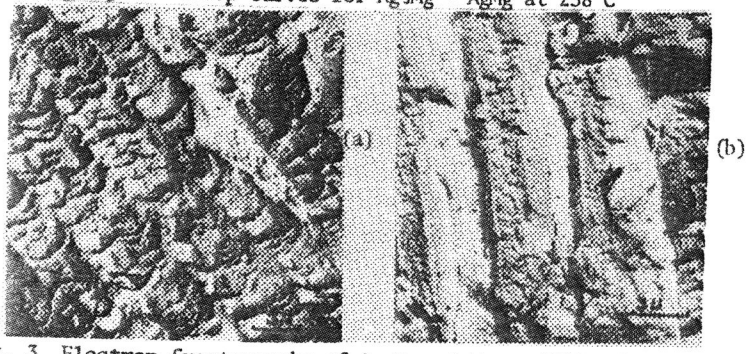

Fig. 3 Electron fractographs of Ag_3Mg - AgMg at 25°C a) disordered b) ordered

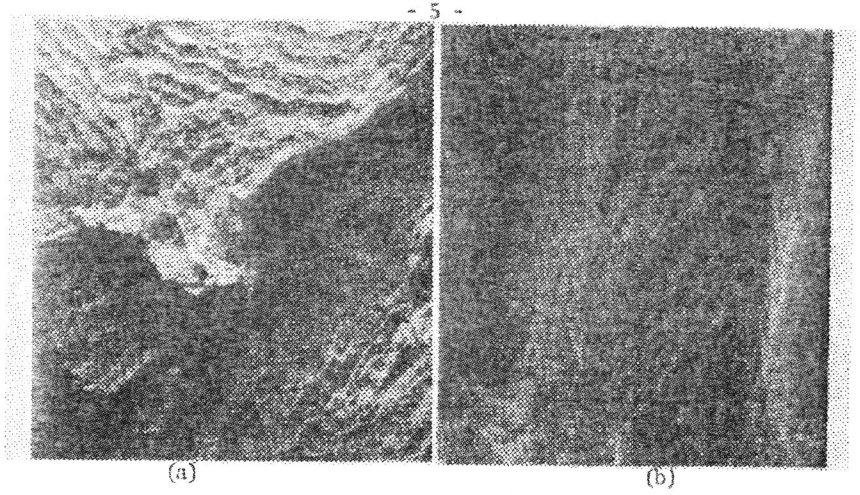

Fig. 4 SEM fractographs, creep-rupture of Ag_3Mg - AgMg at 226°C
R = 3.4 cm/hr, x200 a) disordered, σ = 35 ksi b) ordered, 36 ksi

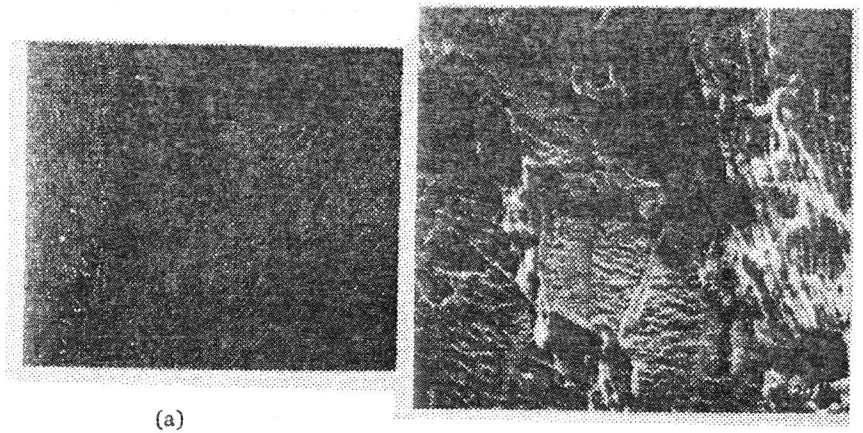

Fig. 5 Fracture modes in Al-Ag_2Al; eutectic grain boundaries marked G.
a) crack path, -196°C, R = 31.7 cm/hr, x121
b) SEM fractograph, -196°C, R = 3.5 cm/hr