Communications

The Occurrence of Transgranular Cleavage-Like Fracture in an Al-Zn-Mg Alloy During Tensile Testing

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The fracture of high-purity Al-Zn-Mg alloys is generally regarded to be ductile. However, observations presented in this communication indicate that regions of transgranular cleavage-like fracture can also occur. This form of failure is shown to require the presence of water, and to be dependent on strain rate and yield strength.

The tests were carried out on tensile specimens of gage dimensions 25 mm × 6.4 mm × 0.25 mm taken longitudinally from sheet of a high-purity Al-5.5 wt pct Zn-2.5 wt pct Mg alloy. The specimens were solution treated for 1 h at 470°C in dry argon, water quenched, held at room temperature for 15 min, and then aged in silicone oil baths for either 72 h at 130°C (0.1 pct offset yield strength of 390 MN/m^2) or 24 h at 160°C (300 MN/m^2).

The fracture surfaces of specimens aged at 130°C and tensile tested at a strain rate of 0.002 min^{-1} in laboratory air were predominantly intergranular and dimpled, resulting from ductile fracture in the precipitate-free zones; regions of transgranular ductile fracture were also evident. In addition, approximately 1 to 5 pct of the fracture surface exhibited transgranular regions having a cleavage-like appearance, Fig. 1. It can be seen from the SEM stereo-pairs that the region is not flat but consists of a series of parallel facets, each exhibiting cleavage-like steps. Comparison of stereo-pairs from opposite fracture surfaces established that the fractographic features were matching and that the facets were interlocking. At higher magnifications, the facets were found to exhibit parallel markings, approximately 1.5 μm apart, which were

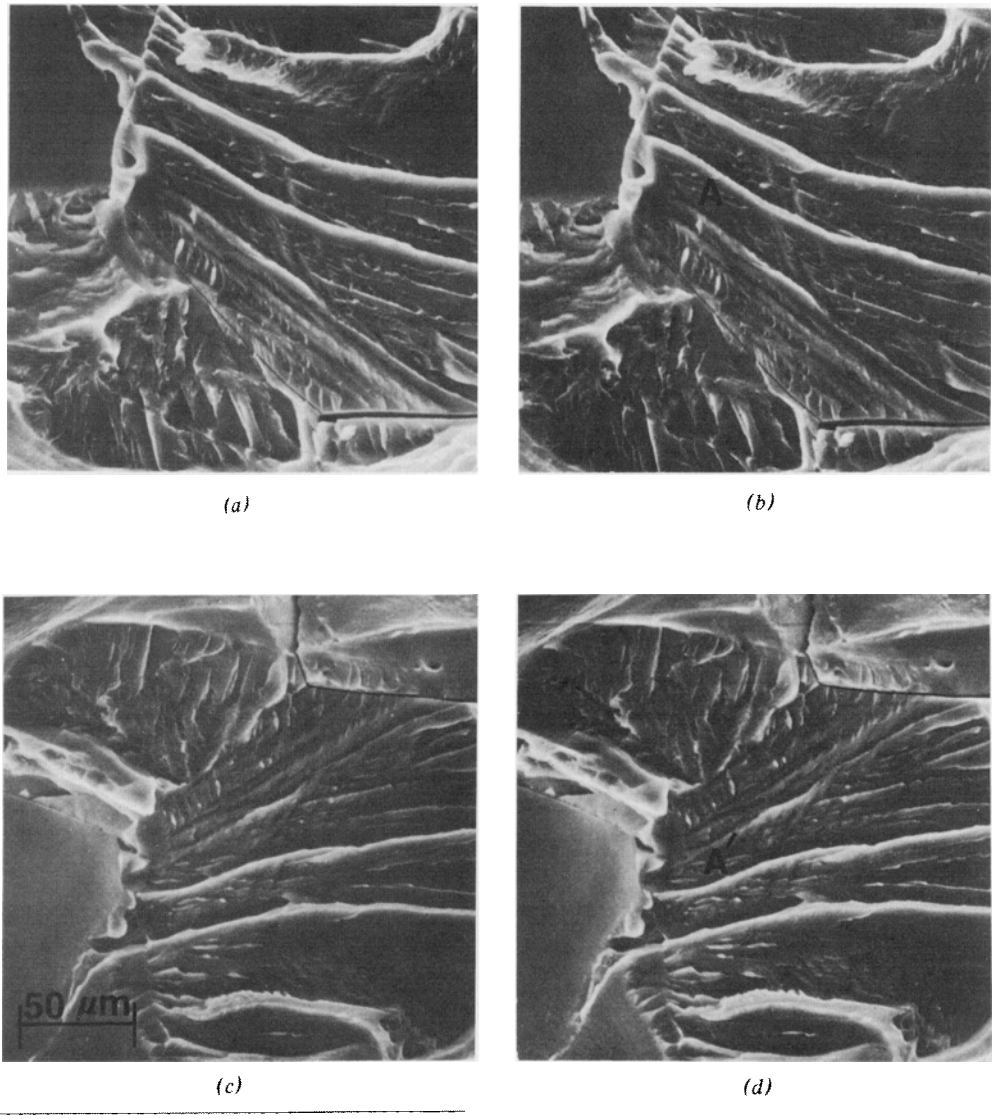

Fig. 1–SEM stereo-pairs of the opposite fracture surfaces of a specimen aged at 130°C and tested in laboratory-air at a strain rate of 0.002 min^{-1}.

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also matching on the opposite faces, Fig. 2. These markings, similar in appearance to fatigue striations, were detectable on all cleavage-like facets, although in some cases it was necessary to tilt and rotate the specimen to produce sufficient contrast.

Attempts were made to identify the orientation of the cleavage-like facets using several etch-pit techniques.[1,2] The pits were generally too irregular to permit proper orientation determination, but in some instances pits of fairly regular shape were obtained, and these suggested that the surfaces were either {100} or {110}.

Similar cleavage-like regions were observed in 130°C-aged specimens tested at 0.002 min^{-1} in both moist argon and 3 pct aqueous NaCl solution. However, there was no evidence for this type of failure in these specimens when tested at this strain rate in dry argon or at a strain rate of 0.2 min^{-1} in laboratory air. Tests on specimens aged at 160°C did not generally produce the cleavage-like fracture, except for one isolated instance in a specimen tested at 0.002 min^{-1} in laboratory air after immersion for 8 h in aqueous $NaCl + AlCl_3$ solution (pH $\simeq$ 2).

The necessity for the presence of moisture or an aqueous solution suggests that the cleavage-like fracture may involve the entry of hydrogen into the lattice. The occurrence of striations suggests that the fracture process is discontinuous, so that it may be speculated that failure involves cycles of hydrogen diffusion to the region ahead of the crack followed by cleavage through this zone, the crack becoming arrested when it passes into the unembrittled lattice. The observed strain-rate dependence is consistent with this hypothesis, and the general absence of the phenomenon in specimens of lower strength is also in general agreement with a hydrogen-embrittlement phenomenon.

Similar cleavage-like fractures have also been reported in Al-Zn-Mg alloys failed by stress-corrosion cracking and by corrosion-fatigue. In the former, fracture is generally intergranular but isolated cleavage-like regions have been observed.[3] This effect was confirmed in the present work in studies of the 130°C-aged alloy tested at constant load (70 pct of 0.1 pct offset yield strength) in the 3 pct aqueous NaCl solution. The cleavage-like regions were indistinguishable from those observed in tensile specimens and, in particular, exhibited striations of the type shown in Fig. 2. In the case of corrosion-fatigue, the fracture surfaces are predominantly cleavage-like, in contrast to those in dry environments;[4,5] the cleavage-like surfaces have been observed to be primarily {100},[4,5] although {110} and {111} have also been reported.[6,7] Significantly, several workers have attributed this type of fatigue failure to hydrogen.[6,8] Thus it appears that water-induced cleavage can occur whenever these alloys are subjected to large tensile stresses, regardless of whether the loading is monotonic, static or cyclic, and that its contribution to overall failure depends on the existence of competing fracture processes.

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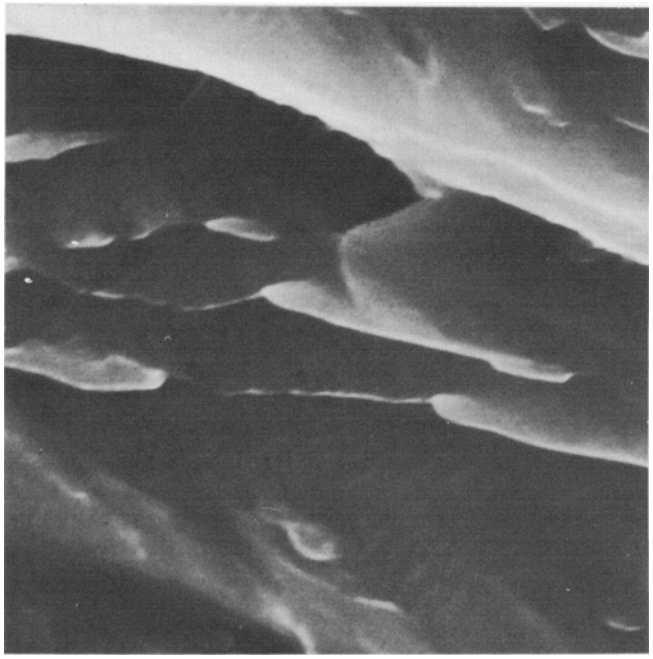
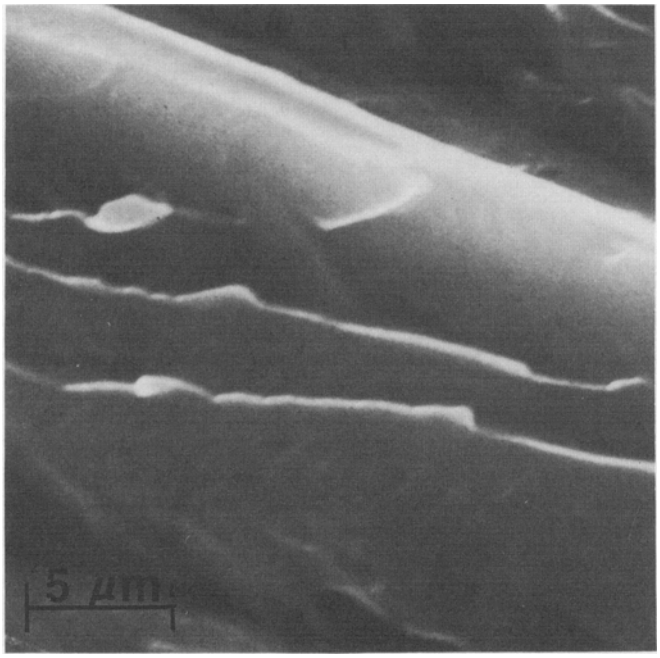


(a)



(b)

Fig. 2—Scanning electron micrographs of regions A and A′ in Fig. 1 illustrating the matching parallel markings. The lower micrograph was reverse printed to facilitate matching of the fractographic features.

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