in most cases the effect is only 3 to 10% [1]. This means that changes in the mechanical properties with ordering can be ascribed to changes in slip behaviour between ordered and disordered states.

The results agree in principle with those obtained by the authors in a study of the microplasticity of magnesium-lithium alloys [2]. It was found that an alloy with an hcp structure, in which the slip was planar, behaved in a way very similar to the disordered alloy in this experiment (which again showed only planar slip) in that a plot such as shown in Fig. 2 was a single straight line. In contrast, an alloy with a bcc structure, showing a large amount of multiple slip behaved in a way similar to the ordered material in this experiment (which showed profuse cross-slip) in that the plot in Fig. 2 showed two straight line regions with a sharp discontinuity.

In experiments on beryllium, Bonfield and Li [3] found a two stage behaviour in the stress-strain curve in the microstrain region. By means of electron microscopy studies they concluded that the transition coincided with appearance of multiple slip in the material. The experiments conducted here lend considerable support to the findings of Bonfield and Li and indicate that the microstrain behaviour of materials depends to a large extent on the number of slip systems which can operate.

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*Received 25 July*
*and accepted 30 July 1973*

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## *Cyclic stress-induced grain-boundary migration in polycrystalline zinc*

During the course of fatigue tests on polycrystalline zinc at room temperature, it was found that considerable grain-boundary migration often occurred, and some tests were carried out to observe this effect more closely.

Polycrystalline zinc, 99.95% pure, with a grain size after annealing of 0.15 mm was subjected to rotating bending fatigue at 3000 Hz. The surface of a specimen examined after $3.8 \times 10^6$ cycles (10% of the expected life at 35 MN $m^{-2}$, and occupying 17 h) showed a marked degree of grain-boundary migration. Almost every boundary had moved, the largest movement being 0.04 mm. The migrated boundaries were very irregular in appearance, often with microcracks running along the new boundary. A typical example of this is shown in Fig. 1. The migration led to a new network of boundaries giving a larger overall grain size, with many small grains being annihilated. Fig. 2 is a histogram of the angular distribution of the orientations of the migrated boundaries with respect to the principal stress axis, and shows clearly a peak in the region of 45°. This indicates that the stress cycling leads to a re-orientation of the grain boundaries to positions parallel to the planes of maximum shear in the specimen.

The surface regions through which the boundaries migrated were often marked by pitting of the type shown in Fig. 3, where pits formed rows behind the advancing boundary. A smaller proportion of grains showed pitting of a more random nature. Fine slip lines were seen in a

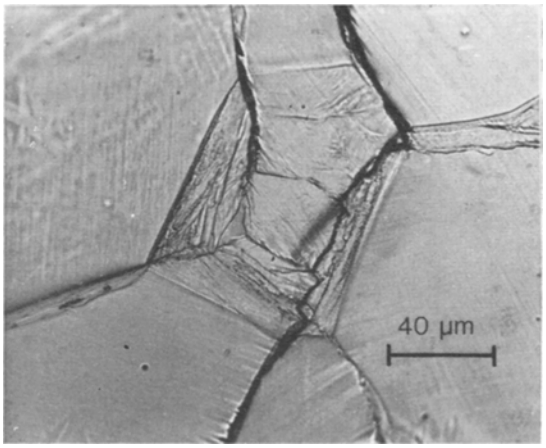

*Figure 1* A typical example of the damage produced in polycrystalline zinc after cycling for 17 h at a low stress.

few grains, being more intense near the grain boundaries. Some grains became polygonized during the cycling showing a very marked subgrain structure. The boundaries surrounding the polygonized grains were severely damaged. Microcracks occurred along the newly migrated boundaries and it is possible that the cracking was associated with the pits which accompanied the boundaries.

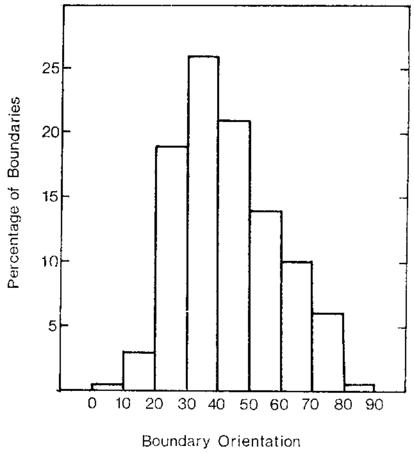

*Figure 2* The angular distribution with respect to the specimen axis of the migrated positions of the grain boundaries which moved as a result of stress cycling.

A further specimen stress cycled for $4.3 \times 10^3$ cycles at 75 $\text{MN m}^{-2}$ ($5\%$ of the expected life, occupying 1½ min) also showed grain-boundary migration, the maximum movement being approximately 0.02 mm. Slip was observed in most of the grains, often grouped into striations. Twinning was also present, many twins showing considerable damage at one of the interfaces. Microcracking along migrated boundaries was extensive.

Cyclic stress-induced grain-boundary migration has been observed in a number of materials at $T/T_{\mathrm{m}}$ of 0.4 and above [1-4]. Snowden [4], working with lead bicrystals, calculated that the pressure difference across a boundary necessary to cause migration is an order of magnitude less than the external applied stress. It is likely that the driving force for migration arises from the slip inhomogeneity at low stresses, which is typical of the deformation caused by stresses leading to failure in fatigue.

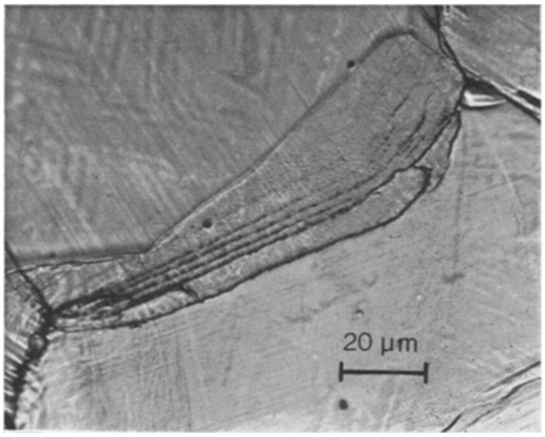

*Figure 3* An example of the type of pitting occurring in the wake of the migrating grain boundaries in polycrystalline zinc as a result of stress cycling.

Chen and Machlin [5] found that in the creep of copper bicrystals, grain-boundary sliding was necessary to produce cavities, and the most effective mechanism was that of a shear stress followed by a tensile stress. During the stress cycling of polycrystalline zinc most of the boundaries are likely to be subjected to stresses which are part shear and part tensile and this may provide the ideal conditions for void formation. Vacancies migrating to the voids create optically resolvable cavities. The formation of the cavities at the grain boundaries may lead to weakness and subsequent cracking.

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*Received 23 July*
*and accepted 10 September 1973*

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