# Letters

## *Comment on "Microyield and fracture in Polycrystalline MgO"*

It was predicted by us that plastic deformation of grain boundaries by grain-boundary dislocations can precede plastic deformation of the crystal by lattice dislocations. This should lead to a grain-size dependence of the yield stress of well annealed pure metals or solid solutions similar to the Hall-Petch relationship, if it can be assumed that the average size of planar sections of grain boundaries are proportional to the grain size [1, 2]. This model explains several facts which cannot be adequately explained in the classical way assuming that dislocation pile-ups in the crystal are generating slip.

1. The Hall-Petch relationship is also found for metals of very high-stacking-fault energy, in which pile-ups were never found or expected.
2. The sensitivity of $k_y$ to the state of segregation of the grain boundaries as well as the existence of an upper limit value of $k_y$, as it can be demonstrated best with bcc interstitial alloys, can be better explained if the mechanical properties of the grain boundaries are considered.
3. The occurrence of discontinuous or continuous yielding depends on the density of dislocation sources that initiate yielding. The latter can be expected if grain-boundary sliding can simultaneously initiate a large number of dislocation sources.

We pointed out that our model cannot be applied quantitatively if the proportionality between grain diameter and average slip distance in grain boundaries is lost. This is the case in highly segregated boundaries as well as in imperfect boundaries which for example contain a high density of ledges, jogs and immobile grain-boundary dislocations. The same may be valid for ceramic materials in which owing to the atomic order, non-thermally activated grain boundary deformation should be more difficult than lattice deformation on particular slip systems. In addition, it is expected that a much longer period of time is required to form planar grain-boundaries in ceramics than in metals.

It follows from this that the results in the paper under discussion[3] correspond to what we would have expected from our model. Our quantitative treatment of the phenomena is claimed to be valid only for well annealed, textureless pure metals or solid solutions with a small degree of segregation at the grain boundaries.

### References

1. G. BÄRO and E. HORNBOGEN, "Quantitative Relation Between Properties and Microstructures", eds. D. G. Brandon, and A. Rosen (Israel University Press, Haifa, 1969) p. 457.
2. G. BÄRO, E. HORNBOGEN, and H. GLEITER, *J. Mater. Sci.* **8** (1973) 726.
3. M. N. SINHA, D. J. LLOYD, and K. TANGRI, *ibid* **8** (1973) 116.

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## *Reply to "Comment on 'Microyield and fracture in polycrystalline MgO' "*

The Bäro-Hornbogen [1] (B-H) model of yielding by grain-boundary dislocations predicts a $d^{-\frac{1}{2}}$ dependence of $\sigma_y$ in "well-annealed materials with no dislocation sources in the grain interior". In our well-annealed MgO samples it was shown clearly that even though the first evidence of slip was associated with grain boundaries, the stress required to activate the grain-boundary sources was essentially independent of grain size for the grain size range investigated. In view of these experimental facts, our conclusion that the results do not agree with the B-H model is justified and consistent with their original paper [1] and their present comments [2]. Recent electron microscopy of the polycrystalline MgO used in the previous study has supported the assumption of a well-annealed structure. Fig. 1 shows a typical micrograph of the grain boundary structure present in the material. It is apparent that the grain boundaries are very clean and straight in comparison with typical grain bound-

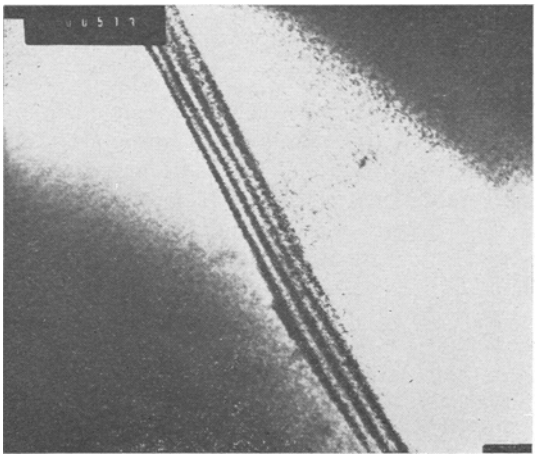

*Figure 1* Typical grain boundary structure in polycrystalline MgO (× 22000).

aries in metals. In addition, the dislocation density within the grains is very low (less than $10^6$) and the material is free of any precipitation. Hence the structure should be ideal for operation for the B-H mechanism.

Though we have some reservations about the B-H model, we have not taken issue with it because this would not have formed an organic part of our paper and also because a paper primarily devoted to the explanation of Hall-Petch relationship is in preparation. However, we may take this opportunity to mention one disagreement which is pertinent to this discussion.

The key assumptions common to the usual explanation of the Hall-Petch relationship and the B-H model are:

(*a*) that the stress field at the head of a blocked pile-up of $n$ dislocations is $n\sigma$ where $\sigma$ represents the difference between the applied stress and an appropriate friction stress and

(*b*) that $n$ is proportional to the length of the pile-up.

Thus the two treatments are essentially analogous. The main variation in the two treatments is in defining the pile-up length. In the usual H.P. explanation, this length is assumed proportional to the grain diameter, $d$, and in the B-H model the pile-up length, $l$, is taken to be "the length of the straight and periodic array of the grain boundary."

Thus a natural consequence of the above is the $d^{-\frac{1}{2}}$ dependence of $\sigma_y$ in the case of a pile-up of lattice dislocations against a grain boundary (Equation 5 of B.H. paper [1]) and the $l^{-\frac{1}{2}}$ dependence in the B-H model of yielding by grain-boundary dislocations (Equation 9 of B-H paper [1]). This, however, does not justify the statement that from a comparison of Equations 5 and 9 "it is found that $l$ should be proportional to $d$".

## References

1. G. BÄRO and E. HORNBOGEN, "Quantitative Relations Between Properties and Microstructures", eds. D. B. Brandon and A. Rosen (Israel University Press, Haifa, 1969) p. 457.
2. G. BÄRO and E. HORNBOGEN, *J. Mater. Sci.* **8** (1973) p. 1213.

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