Scripta METALLURGICA Vol. 14, pp. 1033-1034, 1980 Pergamon Press Ltd.
Printed in the U.S.A.

35

COMMENTS ON "THE ELECTROPLASTIC EFFECT IN ALUMINUM"

Marc A. Meyers
Department of Metallurgical and Material Engineering
New Mexico Institute of Mining and Technology
Socorro, New Mexico 87801

(Received November 29, 1980)
(Addendum Received March 24, 1980)

Varma and Cornwell (1) (VC) have recently reported some intriguing experimental results with the prupose of elucidating the electroplastic effect (2,3). They compared the effect in mono and polycrystalline aluminum, observing that the load drops associated with the former were about three times higher than the latter. It is the purpose of this note to explore an additional explanation for the larger load drops exhibited by monocrystalline aluminum: machine-specimen interactions could be responsible for the effect since the monocrystalline specimens were three times as long as the polycrystalline ones. This is proven through the more rigorous analysis shown below. The slope of the load-extension curve reflects the deformation of both specimen and machine. If one considers the machine-specimen system as two springs associated in series (4), then the slope of the load-extension curve in the elastic range can be expressed as

$$\frac{1}{S} = \frac{1}{K} + \frac{L}{AE} \tag{1}$$

where K is the machine stiffness and L, A, and E the specimen length, cross-sectional area, and elastic modulus. One can express the slope in terms of changes in load ΔP and length ΔL:

$$\frac{\Delta L}{\Delta P} = \frac{1}{K} + \frac{L}{AE} \tag{2}$$

If at a certain load level the specimen is unloaded, the unloading proceeds elastically with a slope equal in magnitude to the elastic loading line. If there is an instantaneous change in length of the specimen, the drop in load will be expressed by Eq. 2, with the appropriate change in sign. Upon unloading, the machine stiffness is unchanged.

$$\Delta L = (-\Delta P)\left(\frac{1}{K} + \frac{L}{AE}\right) \tag{3}$$

The electroplastic engineering strain can be expressed as:

$$\varepsilon_{ep} = \frac{\Delta L}{L} = \left(\frac{-\Delta P}{L}\right)\left(\frac{1}{K} + \frac{L}{AE}\right) \tag{4}$$

The average load drops obtained from Figs. 1 and 4 of VC, at a 30 V level, are -11.9 N for the polycrystal and -44.67 N for the monocrystal, respectively. Substituting these values, in addition to the specimen dimensions and elastic modulus into Eq. 4, one has, for the monocrystal,

$$(\varepsilon_{ep})_{sx} = 5.88 \times 10^2\left(\frac{1}{K} + 5.22 \times 10^{-8}\right) \tag{5}$$

and polycrystal:

$$(\varepsilon_{ep})_{px} = 4.68 \times 10^2\left(\frac{1}{K} + 3.1 \times 10^{-8}\right) \tag{6}$$

0036-9748/80/091033-02$02.00/0

VC used an Instron tensile testing machine, but do not report the value of its stiffness. From a systematic investigation on the significance and variation of machine stiffness conducted by Hockett and Gillis (5), the value of K = 1,200 N/m was taken. This applies to a 10,000 lb capacity Instron operated at a cross-head velocity of 1.27 in/min (0.032 m/min). Substituting this into Eqs. 5 and 6, one obtains:

$$(\varepsilon_{ep})_{sx} = 0.49$$

$$(\varepsilon_{ep})_{px} = 0.39$$

The values of ε_{ep} depend strongly on K and this results in an uncertainty in the calculation of the strains. However, one can conclude from the above derivation, that the electroplastic strain is far from three times higher in the monocrystal than in polycrystal. Additional factors that have not been considered in the above analysis and that might bring the two values even closer, are the differences in cross-sectional area and strain rates between the two specimens Indeed, Okazaki et alii (2) report that the effect is dependent on both strain rate and specimen cross section. In view of the above, it is felt that the conclusions arrived at by VC should be revised.

References

1. S.K. Varma and L.R. Cornwell, Scripta Met. 13, 733 (1979).
2. K. Okazaki, M. Kagawa, and H. Conrad, Scripta Met. 12, 1063 (1978).
3. K. Okazaki, M. Kagawa, and H. Conrad, Scripta Met. 13, 277 (1979).
4. G.E. Dieter, Mechanical Metallurgy, 2nd Ed., p. 359, McGraw-Hill, NY (1976).
5. J.E. Hockett and P.P. Gillis, Mechanical Testing Machine Stiffness, U.S.A.E.C. Contract W-7405-Eng. 36, Los Alamos Sc. Lab. Report LA-DC-11155.

ADDENDUM

In simple words, my criticism can be restated as: it is meaningless to compare load drops from tensile specimens having widely different lengths and cross-sectional areas. Hence, I proposed a normalized parameter, the electroplastic strain. It is highly dependent on the machine stiffness, K. Since VC did not report this value, I used stiffness from a literature source (as I clearly stated). If, for instance a stiffness of 12,000 N/m were used, one would obtain electroplastic strains of 0.049 and 0.039 for the mono and polycrystal, respectively.

I assumed that the load drop resulted from an "instantaneous" increase in length of the specimen. The assumption of instantaneous increase in length is justified by the fact that it is orders of magnitude higher than the rate of extension of the specimen imparted by the tensile testing machine. The various second and third-order effects such as stress-relaxation and strain-rate could be discussed ad nauseam but detract from the primary objective of this note.

In summary, my analysis is correct and invalidates the conclusions of VC. Hence, they should (a) calculate the electroplastic strains using the stiffness of their testing machine-grip system and (b) repeat their experiments using mono and polycrystalline specimens with identical dimensions.