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TITLE: The Microstructure and Texture of Torsion-Reverse Torsion Experiments

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THE MICROSTRUCTURE AND TEXTURE OF TORSION-REVERSE TORSION EXPERIMENTS

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ABSTRACT

It has been known for many years since Backofen's experiments that reversing a torsion test to zero net strain does not restore the texture of the material to its initial state. Instead, a weak shear texture remains. The grain shape is restored, however, which leads to the prediction on the basis of the Taylor model that the texture development should be reversible. Recent experiments with short thin-walled tubes (Lindholm design) tested in torsion and reverse torsion have confirmed both the persistence of a shear texture at zero net strain and the restoration of the grain shape. Calculations of theoretical texture development using a code based on the Bishop and Hill analysis have confirmed the reversibility of texture development when Taylor based models are used. This code includes the effect of Relaxed Constraints and uses a non-linear strain rate sensitivity to resolve the ambiguity of slip system choice. Calculations performed with the Asaro-Needleman code do leave a small residual texture at zero net strain. The conclusion is that there is sometimes an irreversible component of texture development that is not accounted for by the geometry of plastic deformation.

Introduction

Backofen's (1) experiments showed many years ago that performing a torsion test and then reversing the twist to zero produced a shear texture very similar to a normal torsion texture. He also showed that the grain shape was restored to its initial equiaxed character at zero net strain. The aim of this paper is to confirm Backofen's experimental results and to point out the disagreement with theoretical calculations of texture development that are based on grain shape change alone. Even the Asaro-Needleman polycrystal model (2) which takes full account of the elasto-plastic constitutive response of a polycrystal only predicts a slight residual texture at zero net strain.

Experimental

Torsion tests were performed with short thin-walled tubes of the Lindholm design (3) as shown in Fig. 1, which permit large strains to be attained before fracture terminates the test. The experiments reported here arose from a study of large strain plasticity in a range of aluminum alloys by Rollett (4) where it was found that strain hardening continues to large strains at a low level known as Stage IV work hardening. By conducting torsion-reverse torsion tests it was established that Stage IV is still present after the strain reversal although a significant transient of low or negative strain hardening occurs at the reversal. The example material studied here was an Al-1Mg alloy manufactured for research purposes by ALCOA and containing 1%Mg, 0.15%Fe and 0.07%Si. The Fe and Si was present in the form of coarse second phase particles which formed stringers after the extrusion processing of the alloy.

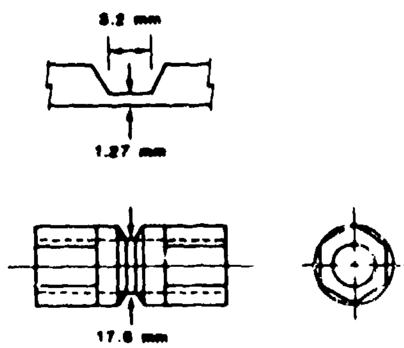


Fig. 1. Diagram of the Lindholm tube (3) torsion specimen.

Results

The strain hardening characteristics of Al-1Mg are shown in Fig. 2 where the stress-strain curve rises monotonically with strain and the derivative of the curve decreases. The plot shows that a linear hardening hardening regime, known as Stage IV, exists at strains beyond about 1; this hardening is interrupted by the reversal at a shear strain of 3.5 over a transient of about 0.5 shear strain.

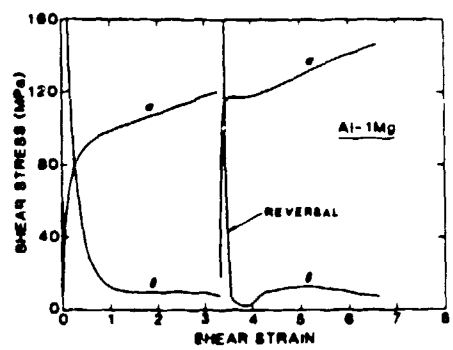


Fig. 2. Shear Stress (σ)- Shear Strain (γ) curve for Al-1Mg. The hardening rate ($d\sigma/d\gamma$) is plotted on the same axes and shows a transient reduction from the level established in the forward test after the strain reversal at γ=3.5.

The microstructure of the material is shown in Fig. 3 in a section that includes the torsion axis and the shear direction. The initial unstrained material has been imaged in a scanning electron microscope under channeling contrast conditions, Fig. 3a. In this image, the stringers of iron-containing particles show up as lines of bright spots. After the torsion-reverse torsion test, a specimen was prepared for optical microscopy in the usual manner and given an anodizing treatment. The bright-field image, Fig. 3b, reveals that the stringers are aligned in the same direction as they were initially although they are not as straight as before. The polarized light image, Fig. 3c, shows grains that are essentially equiaxed albeit heavily strained. Two other materials, 99.99% Al and Al-2%Mg, also showed a restoration of grain shape at zero net strain.

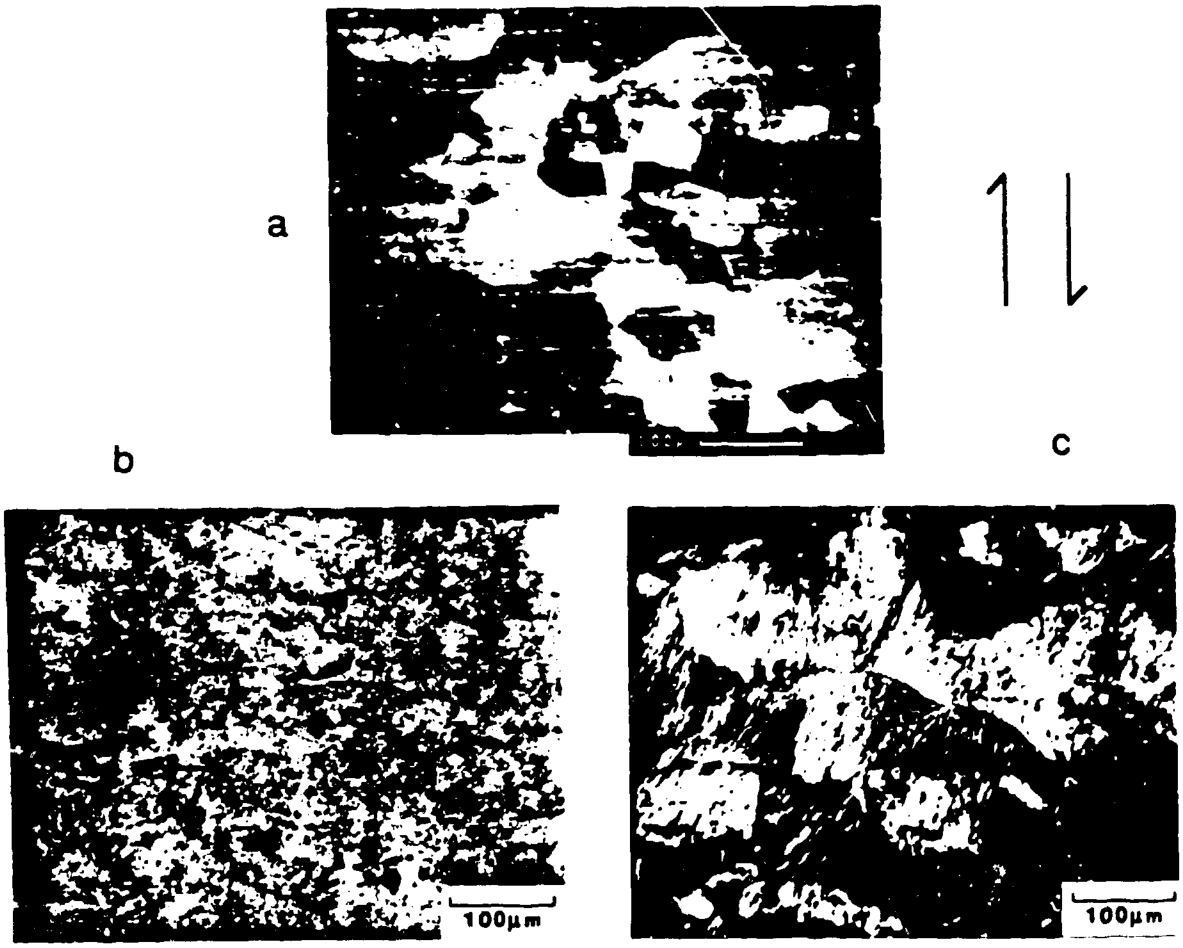


Fig. 3. Microstructures of Al-1Mg, a) initial microstructure imaged in SEM under channeling contrast b) bright field optical image after torsion-reverse torsion to a shear strain of 3.5, followed by a return to zero, showing stringers and c) polarized light image of anodized specimen showing restoration of grain shape. The arrows indicate the sense of the first shear.

The experimental textures are shown in Fig. 4 as {111} pole figures taken with conventional X-ray techniques out to 80° with the torsion axis vertical and shear direction horizontal. The pole figures show the initial texture of the material (4a), the texture at γ=3.5 (4b) and for the same material after complete reversal of the strain (4c). The forward torsion texture shows the B partial fiber with a weak A fiber whereas the reverse torsion texture shows only the C component of the B fiber, see Canova et al. (5) for a definition of partial fibers in torsion.

Theoretical textures were simulated with the Los Alamos Polycrystal Plasticity code (LAPP, version 4.8) and the Asaro-Needleman code (2). The LAPP code uses the Bishop and Hill (6) analysis to find the active vertex of the single crystal yield surface for each grain of the polycrystal and then uses a rate-sensitive formulation to

Fig. 4. {111} pole figures (in equal area projection) for Al-1Mg, a) initial texture, b) tested in torsion to γ=3.5 and c) in torsion to γ=3.5 followed by reverse torsion to γ=0.

eliminate the ambiguity of choice of active slip systems (7). At large strains in torsion the grain shape is elongated to lath shapes which permits the introduction of Relaxed Constraints (8,9). The results of simulating torsion test to a shear strain of 3.5 followed by a reversal to zero strain are shown in Fig. 5. This figure shows that texture development based on the Taylor model is exactly reversible.

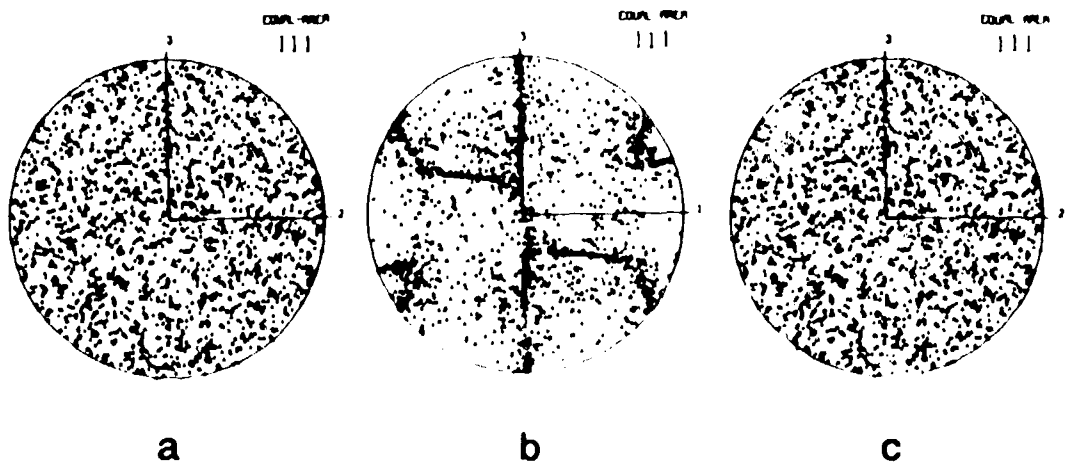
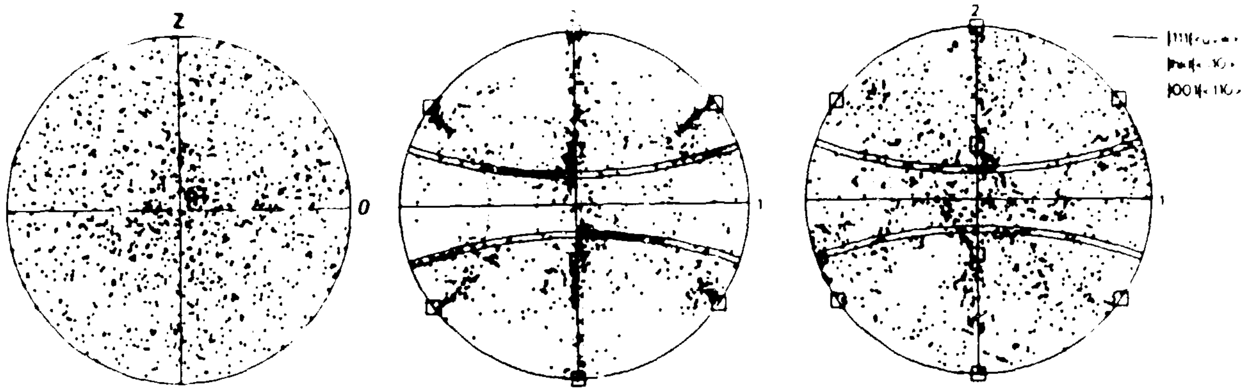


Fig. 5. {111} pole figures (in equal area projection) showing texture development simulated by the LAPP code, a) initial texture, b) γ=3.5 and c) γ=0.

The Asaro-Needleman code (2) is a rate-dependent crystal plasticity model that fully accounts for the elasticity of the material and which has been fully described elsewhere. Figure 6 shows the results of running the same simulation as for the previous figure: in this case a slight texture is apparent after complete reversal. Detailed examination of the texture evolution suggested that a nearly random texture was reached before zero net strain.



a b c

Fig. 6. {111} pole figures (in stereographic projection) showing results of simulation of torsion-reverse torsion with the Asaro-Needleman code, a) initial texture, b) γ=3.5 and c) γ=0.

CONCLUSION

The conclusion of this study of torsion-reverse torsion tests is that texture development is not reversed on reversing strain in a way that is analogous to strain hardening. This irreversibility of texture development cannot be modeled simply on the basis of change in grain shape as in the Taylor model. It is known that at large strains, grains break up into subgrains with surprisingly large misorientations between them (10,11). This break-up of the grains may be connected with the retention of texture upon strain reversal.

REFERENCES

1. W.A. Backofen, Trans. AIME, **188** (1950), 1454-1459.
2. R.J. Asaro and A. Needleman, Acta Met., **33** (1985), 923-953.
3. U.S.Lindholm, A. Nagy, G.R. Johnson and J.M. Hoegfeldt, Trans. ASME, J. of Eng. Mat. & Tech., **102** (1980), 376.
4. A.D. Rollett, Ph.D. thesis, Drexel University (1987).
5. G.R. Canova, U.F. Kocks and J.J. Jonas, Acta Met., **32** (1984), 211-226.
6. J.F.W. Bishop and R. Hill, Phil. Mag., **42** (1951), 1298-1307.
7. G.R. Canova and U.F. Kocks, ICOTOM-7, Holland (1984), 573.
8. H. Honneff and H. Mecking, ICOTOM-5, Aachen, W. Germany (1978), 265.
9. C. Tomé, G.R. Canova, U.F. Kocks, N. Christodoulou and J.J. Jonas, Acta Met., **32** (1984), 1637-1653.
10. P. Heilmann, W.A.T. Clark and D.A. Rigney, Acta Met., **31** (1983), 1293-1305.
11. A.D. Rollett, Ph.D. thesis, Drexel University (1987).