INDUCTION AND REMOVAL OF THERMAL EMF DURING STATIC AND ALTERNATING TWISTING

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Polycrystalline copper wires and tubes were plastically deformed in unidirectional and alternating twisting, and the induced thermal emf was determined. As the relative shear increases during unidirectional twisting, the thermal emf increases, passing through three stages analogous to the stages of hardening. A change in the sense of the deformation in any of the stages is accompanied by a corresponding removal of the thermal emf and the subsequent restoration of this emf to the value corresponding to the unidirectional twisting. Five stages were found in the increase of the thermal emf. The effects of the grain size and the deformation rate on the magnitude of the induced thermal emf were determined.

INTRODUCTION

Since the thermal emf induced by plastic deformation is highly sensitive to structural changes, it can be used to study various aspects of plastic deformation. For example, the thermal emf induced by plastic deformation correlates with the part of the absorbed energy expended on the work of deformation [1, 2]. A stable relation is observed between the differential thermal emf and the degree of deformation; the magnitude and sign of the induced thermal emf are related to the slip and twinning mechanisms [3], the dislocation density, etc.

We are concerned here with the use of the thermal-emf method to study characteristic details of the deformation mechanism such as the incomplete reversibility of macroscopic shear in the case of alternating twisting [4], the accumulation of macroscopic shear and its dissipation [5], the selectivity of the slip system [6], etc.

![Fig. 1](image1)

**Fig. 1.** Change in the induced thermal emf with increasing shear during static twisting of the wires (curve 1) and tubes (curve 2).

![Fig. 2](image2)

**Fig. 2.** Removal of the thermal emf after a change in the direction of the twisting during various stages of deformation. 1) Overall curve corresponding to static twisting in the different directions; dashed curves) removal and restoration of thermal emf after a change in the twisting direction.
Fig. 3. Induced thermal emf as a function of the number of cycles of alternating twisting of fine-grain copper. Broken lines 1-3 correspond to deformations at amplitudes of 0.00518, 0.0104, and 0.0153.

Fig. 4. The same as in Fig. 3 but for a coarse-grain copper. Curves 1-4) Deformation at amplitudes of 0.00318, 0.0088, 0.0291, and 0.0910, respectively.

Fig. 5. Effect of grain size on the dependence of the induced thermal emf on the degree of deformation during static twisting. 1) Sample having a grain size of 0.1 mm; 2) 0.001 mm.

EXPERIMENTAL METHOD

The V-shaped samples having arms 150-170 mm long were prepared from polycrystalline copper wire (0.50-0.75 mm in diameter) and tubes (inside diameter of 3.0 mm and outside diameter of 4.5 mm). The samples were annealed at 600-650°C; then one of the arms was subjected to unidirectional or alternating twisting on a special deformation apparatus; the induced thermal emf was measured (within 1.10^{-4} \mu V/deg). The deformation amplitude was varied. The frequency was 0.95 Hz. Four series of experiments were carried out.

Series A. Wire and tubular samples were deformed to destruction by unidirectional twisting, and the induced thermal emf was measured at relative-shear intervals of 0.25. We also varied the grain size (from 0.1 to 0.001 mm) and the deformation rate (from a relative shear of 0.25 to 0.75 per minute).

Series B. The wire samples were deformed by unidirectional twisting to relative shear values of 0.25, 0.50, 0.75, 1.00, 1.50, and 1.85, and the final values of the induced thermal emf were measured. Then the sign of the twisting was changed in each case, and the sample was deformed to destruction, with the thermal emf varied at relative-shear intervals of 0.02-0.20.

Series C. Fine-grain wire samples (0.10 mm in diameter) were deformed by alternating twisting to destruction at relative-shear amplitudes of 0.0032, 0.0104, and 0.0153, and the induced thermal emf was measured after 5, 10, and 50 cycles.

Series D. The samples of this series were subjected to the same treatment as in series C, but these samples were coarse-grain samples (grain size of 0.5-0.6 mm); the deformation amplitudes were 0.0032, 0.0088, 0.0291, and 0.0910.

DISCUSSION OF RESULTS

In the experiments of series A we studied the relationship between the induced thermal emf and the shear; the results are shown in Fig. 1, where curve 1 corresponds to the deformation of wire samples, while dashed curve 2 corresponds to the deformation of the tubular samples. Since these tubular samples became unstable rapidly and were destroyed, we were not able to study the entire deformation process in their case.

Curve 1 shows that the thermal emf induced in unidirectional twisting increases with an increase in the strain hardening. This curve can be thought of as consisting of three stages, corresponding to the stages on the hardening curve for single crystals. A difference between the two curves is that the first hardening stage is not observed in our case. However, we can assume that only a single slip system is actively participating in the shear in the individual grains during the initial stage of the deformation of a polycrystalline material. The induced thermal emf reflects the distortions in this system.