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WORK-HARDENING OF POLYCRYSTALLINE IRON UNDER COMBINED TENSILE-TORSION DEFORMATION

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For polycrystalline iron wires deformed torsionally by the method of Kovács and Nagy [1] using different axial tensile stresses an elongation in the wires was observed. As the magnitude of the applied tensile stress was increased, the relative change of the tensile strain per unit torsion deformation increased too. Such increase was found to depend on both the temperature and the grain diameter. This behaviour was interpreted on the basis of a cross-slip hardening mechanism.

Introduction

It is well known that in the course of twisting metal wires an axial elongation is produced [2]. This elongation is enchanced even by small axial tensile stresses (in the elastic range), and the elongation becomes homogeneous and easily measurable [3]. The dependence of this elongation on grain size was studied for copper and α-brasses [4], and was found to vary according to the operating mechanism of work-hardening.

The present work aims at studying the work hardening mechanism in iron as can be deduced from the effect of various constant tensile stresses on the elongation resulted during twisting. The effects of varying grain sizes and temperature were also studied.

Experimental procedure and results

In this work iron was used in the form of wires of 0.25 mm diameter. Precise chemical analysis has shown in wt% C 0.012, Si 0.018, Mn 0.92, P 0.014, S 0.010, Cu 0.02 and traces of Ni and Mo. 10 cm long pieces of wires were annealed in vacuum (10^{-4} mm Hg) to attain wires of different grain diameters. The annealed wires were subjected to uniform deformation by twisting in a conventional type twisting machine whose specifications were published elsewhere [4]. The degree of torsional deformation is given by the dimensionless quantity $\frac{ND}{L}$ where N is the number of turns of twist, D and L are the diameter and the initial length of the wire, respectively. Axial tensile stresses of 2,4,6 and 8 Kgm/mm^2 were studied by loading the investigated wires with different corresponding loads. The elongation resulted in the wires during twisting was measured by a travelling microscope accurate to 1×10^{-3} cm. The experiments were repeated at different temperatures of 100 °C, 27 °C and —10 °C by using a thermostatically adjusted heating furnace, or cooling unit. The results obtained for wires of different grain diameters, at different testing temperatures are given in Fig. 1 which shows that as the applied axial tensile stress is increased the tensile strain accompanying torsional deformation increased too. The value of the tensile strain per unit torsional deformation at a constant axial tensile stress (S) i.e.

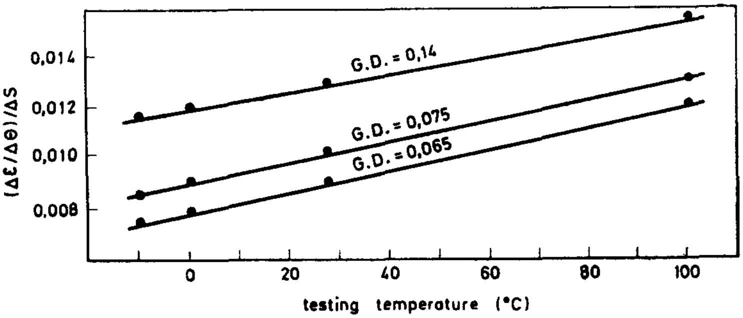

Fig. 1. Effect of axial tensile stresses on the magnitude of tensile strain associated with torsional deformation for wires of different grain diameter, at different temperatures

$$\left[\frac{\Delta(\Delta L/L)}{\Delta(ND/L)}\right]_s = \left[\frac{\Delta\epsilon}{\Delta\Theta}\right]_s$$

could be obtained from slopes of relations given in Fig. 1. Fig. 2 gives the effect of the applied axial tensile stress on $\left[\frac{\Delta\epsilon}{\Delta\Theta}\right]_s$ from which it is clear that $\left[\frac{\Delta\epsilon}{\Delta\Theta}\right]_s$ is linearly increased by increasing the applied axial tensile stress, and that the rate of such increase is enhanced by raising the testing temperature. Fig. 3 gives the effect of both testing temperature and grain diameter on $\left[\frac{\Delta\epsilon}{\Delta\Theta}\right]\Big/\Delta S$ as calculated by taking the slopes of lines of Fig. 2. It is clear that increasing testing temperatures increase linearly the value of $\left[\frac{\Delta\epsilon}{\Delta\Theta}\right]\Big/\Delta S$, and that the

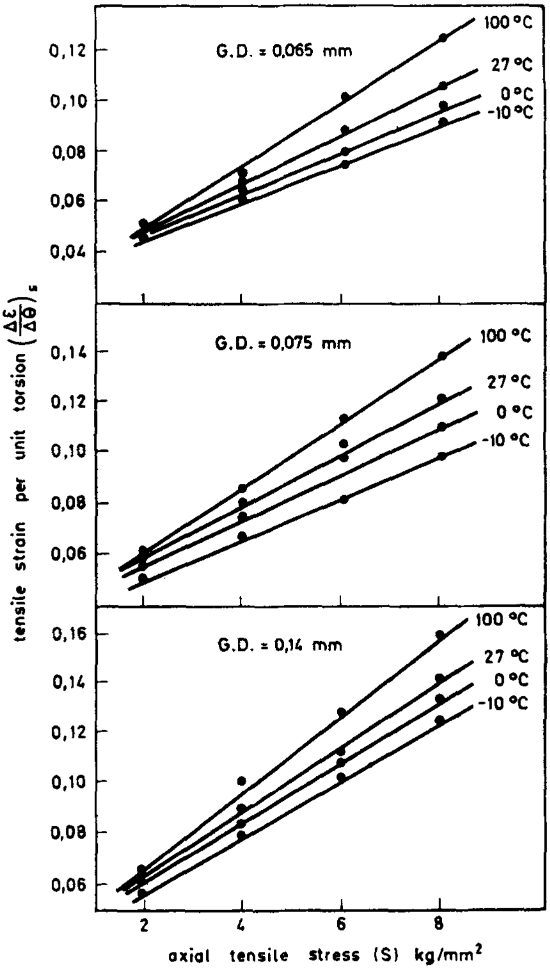

Fig. 2. Effect of axial tensile stress on the tensile strain per unit torsion for wires of different grain diameter and at different temperatures

rate of such increase is the same for all grain diameters studied. Also the value of $\left[\frac{\Delta\epsilon}{\Delta\theta}\right] \Big/ \Delta S$ at any temperature is increased by increasing the grain diameter.

Discussion

The pronounced behaviour of the combined tensile — torsion deformation is that the increase of the applied axial tensile stress is accompanied by an increase in the tensile strain per unit torsion. This implies that a stress dependent process causing an increase in the strain coefficient is taking place

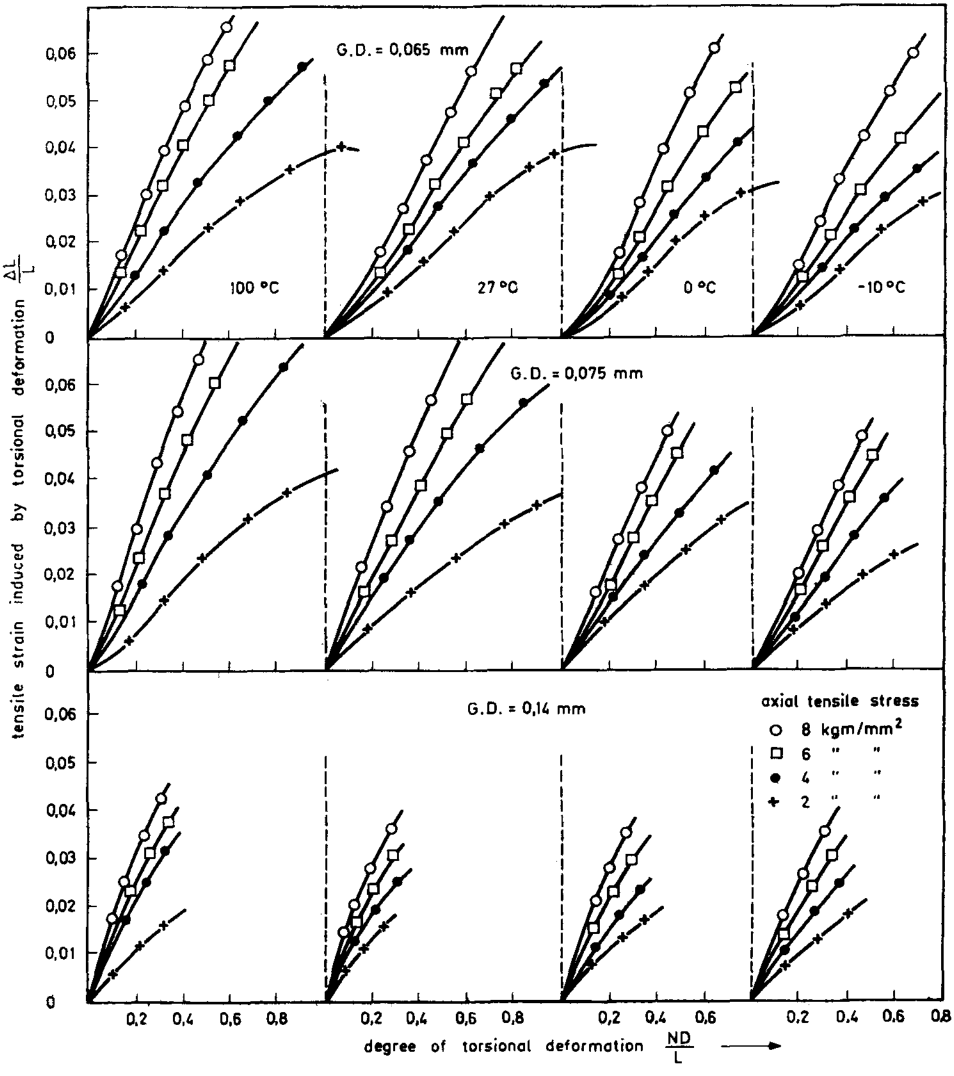

Fig. 3. Dependence of $\left[\frac{\Delta \epsilon}{\Delta \Theta}\right] / \Delta S$ on the testing temperature for wires of different grain diameter

during deformation. This process allows dislocations to move large distances leading to the observed increase in the tensile strain per unit torsion. Cross-slip is dominant in iron owing to its high stacking fault energy [5]. Because twisting facilitates cross-slip as suggested by HOLT [6], and since the activation energy of cross slip decreases by increasing the applied stress [7], it is expected that the application of tensile stress during torsion increases the probability of a cross-slip mechanism. This increased probability might be due to the elimination of jogs [8] formed through a deformation process. It has been found that the deformation of iron either by twisting or by tension leads of jog formation [9]. Of course the combination of both tension and torsion dislocations will lead to a large number of jogs. Because jogs have a tendency to cluster specially under stress [7], jogs of opposite sign will be annihilated, and those of the same sign coalesce leading to a decrease in the jog density. As a result the dislocation mobility will increase. It seemed likely that the large amounts of heat treatments initially given to the relatively large grained wires during their preparation caused their slip planes to be relatively clean for cross-slip, consequently the slip distance will increase by increasing both the grain diameter and the testing temperature.

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