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ON THE USE OF SOME GEOMETRICAL MEASUREMENTS TO STUDY THE PLASTIC DEFORMATION OF POLYCRYSTALLINE MATERIALS

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ABSTRACT

Different mechanisms of plastic straining and recovery bring about specific changes in the geometry of grains. Two parameters quantifying those changes are introduced . They allow to study the contribution of mechanisms of plastic deformation in a wide range of temperatures. An application example of the geometrical measurements is given. Measurements of the changes in geometry of grains in an austenitic stainless steel enables to detect the temperature range where grain boundary sliding and grain boundary recovery significantly contribute to the total strain of the material.
Key words: grain size, mechanisms of plastic deformation, shape of grains.

INTRODUCTION

Plastic deformation of polycrystals is a complex phenomenon involving different processes of straining and recovery. On a microscopic level there are three modes of deformation:
(a) intragranular dislocation slip (IS)
(b) grain boundary sliding (GBS)
(c) diffusional flow (DF)

The relative contributions of these modes of deformation to the total plastic strain ε_T depends on the applied strain rate $\dot{\varepsilon}_a$ and the test temperature T. The flow stress at a given strain is the lowest stress such that the sum of strain rates of the different deformation modes reaches the value of the applied strain rate.

The work hardening of polycrystals depends on the rate of the recovery processes taking place at:
(a) the grain boundaries (GBR)
and
(b) in the grain interiors (GIR).
These two types of recovery have different temperature characteristics; the grain boundary recovery is more effective in lower temperatures (Kurzydłowski et al., 1985).

It is essential to modelling of the polycrystal properties that the contributions of different deformation and recovery modes at a given experimental conditions are properly estimated.Such information is stimulating for theoretical analysis and required for verification of the existing models.

It is the aim of the present communication to show that the relevant data on the contribution of different plastic deformation and of recovery modes can be obtained from stereological analysis of metallographic measurements on plane sections.

METHODOLOGY

A macroscopic plastic deformation of polycrystals results in characteristic changes in the geometry and/or in the position of grains inside a polycrystal depending on the operating mechanism of plastic deformation. In the absence of GBS, the changes in the grain geometry are statistically compatible with the change in the geometry of the strained specimen. On the other hand, GBS preserves the grain shape and no correlation between changes in the geometry of grains and changes in the geometry of the specimen is observed. In this case the accommodation of the plastic strain results from changes in the grain positions.

The amount of plastic strain accommodated by GBS can be estimated from the analysis of the compatibility between the change in specimen shape and the change in grains shape.

Consider the characteristic situation of an uniaxial tensile test. In the absence of GBS the grains of the polycrystal increase their dimensions parallel to the straining axis. On any cross-section taken parallel to this axis, the initially equiaxed grains will become preferentially elongated. Such an elongation will, among others, change the value of ratio α defined as the ratio of the maximum dimension d_{max} to the equivalent diameter d_{eq}:

$$\alpha = d_{max}/d_{eq} \tag{1}$$

The parameter α is a stochastic variable. The initial value of α, depending on the shape of a given grain, is close to 1. With increasing total plastic strain α increases to the value given by the following equation:

$$\alpha(\varepsilon_T) \simeq (1 + \varepsilon_T)^{3/4} \tag{2}$$

The detailed analysis described elsewhere (Kurzydłowski, 1989 and Kurzydłowski et al., 1990), shows that statistically significant differences in the value of α are observed at a strain level $\varepsilon_T \geq 0.10$. If the value of α remains statistically unchanged after plastic deformation to a total strain $\varepsilon_T \geq 0.1$, a part of plastic deformation is accommodated by GBS which, as it has been pointed earlier, preserves the grain shape.

Diffusional flow, in general, produces changes in the geometry of grains which are similar to those observed after plastic deformation via IS. It is known however that these two mechanisms operate at different temperature ranges, namely IS at low and DF at high temperatures respectively. On the temperature scale these two mechanisms are separated by the range of temperatures in which GBS takes place. Thus, the measurements of changes in the α value (if performed systematically on the specimens strained over a wide range of test temperatures) can also permit to detect the range of temperatures where DF significantly contributes to the total strain.

The operating recovery mechanism (GBR vs GIR) can be determined from measurements of the changes in the β value, where parameter β is defined as the ratio of grain perimeter p to grain equivalent diameter:

$$\beta = p/d_{eq} \tag{3}$$

The parameter β is a stochastic variable. Its value depends on the shape of a given grain. Thus, the value of β changes with amount of plastic straining. It has been shown, however, that numerically the changes in the values of β as a result of plastic strain are not prominent (Kurzydłowski 1989 and Kurzydłowski et al., 1990). The parameter β is much more sensitive to changes in the geometry of grains caused by recovery process.

The recovery taking place in the grain interiors results neither in the change of grains shape nor in the change in curvature of grain boundaries. On the other hand, the recovery taking place at grain boundaries is accompanied by their migration which brings about changes in the grain boundary curvature (Kurzydłowski et al., 1990). Such changes, in turn, lead to a significant increase in the value of the parameter β.

The results of the above discussion are summarized in Table I.

Table I

Schematic representation of the effect of different modes of plastic deformation and recovery on the values of the parameters α and β measured on a plane section parallel to the axis of straining.

Deformation/Recovery Mode	Value of	
	α	β
IS	!!	!
GBS	0	0
DF	!!	!
GBR	!	!!
GIR	0	0

(0 means no effect, !, !! weak and strong effects, respectively)

It is seen from Table I that both parameters, α and β, can be used to determine the operating mechanism of plastic straining and the type of recovery.

APPLICATION

The described method has been used to determine the operating mechanism of plastic deformation and the prevailing type of recovery in a micro grained austenitic stainless steel strained in the temperature range from 21 to 900°C. The thermo-

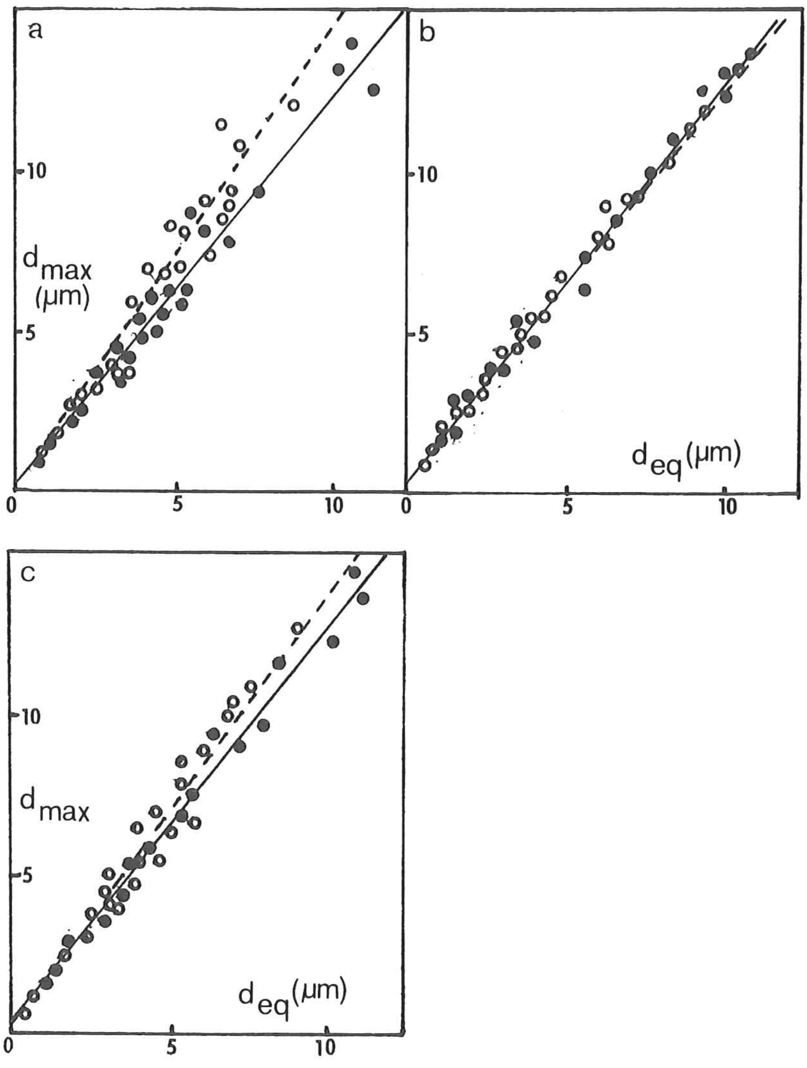

Fig.1.Plots of d_{max} vs d_{eq} for individual grains in micrograined 316L austenitic stainless steel deformed at constant $\dot{\varepsilon}=10^{-3}$ s^{-1}: (a) 21°C, (b) 400°C, (c) 900°C. (full line - undeformed shoulder sections, broken line - gauge sections deformed to a total plastic strain $\varepsilon_T=0.24$)

mechanical treatment and mechanical properties of the material are given by Kashyap et al. (1988). The gauge and shoulder sections of specimens deformed to a total plastic strain of 24% were polished using standard techniques. The specimens were electrolytically etched to reveal the grain boundaries without delineating the twin boundaries. Metallographic measurements were made, using an image analyzer, on images obtained from scanning electron micrographs. 35 and 60 grains were selected randomly from the images of each specimen.

Plots of d_{max} versus d_{eq} for individual grains from the specimens tested at temperatures: 21, 400 and 900°C, respectively are given in Fig.1a–c. The solid and broken lines in these figures represent least-squares fits to the data for undeformed and deformed sections.

The mean value of α for undeformed material is equal to 1.25, while
as a result of straining at 21°C it increases to 1.50. Straining to the same total strain at 400°C results in an increase which is significantly smaller then that observed for the specimen strained at 21°C.

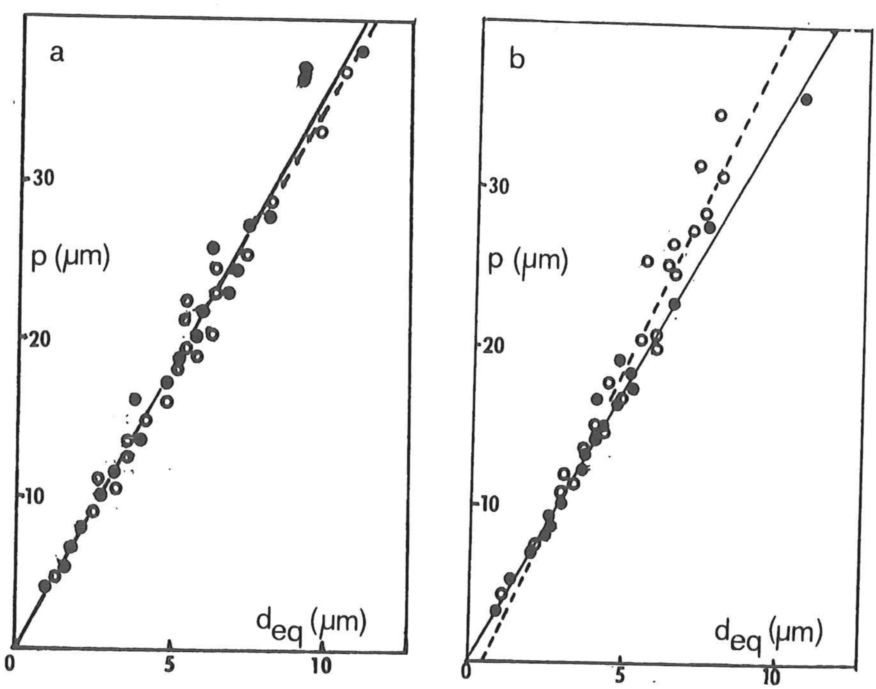

Fig.2.Plots of p vs d_{eq} for individual grains in micrograined 316L austenitic stainless steel deformed at constant strain rate $\dot{\varepsilon}=10^{-1}\ s^{-1}$: (a) 400°C, (b) 900°C. (full line – shoulder sections, broken line – gauge sections deformed to a total plastic strain $\varepsilon_T=0.24$)

The data for p as a function of d_{eq} are shown in Fig.2a,b. It has been shown that the mean value of β for undeformed material is equal to 3.65 and remains unchanged after staining at both 21 and 400 ^{o}C. It increases to 4.33 upon straining at 900^{o}C.

The presented results of measurements give better insight into the physics of plastic deformation in fine grained polycrystals. It can be deduced that at 400^{o} both IS and GBS sliding make significant contributions to the total strain. The mechanical tests performed on the steel have proved that its flow stress is weakly dependent on test temperature for temperatures higher than 200 and lower than 700^{o}C. The observation that in this temperature range GBS contributes to the total plastic strain has been used to correct the existing models of plastic flow in polycrystals (Kurzydłowski et al., 1989).

The measurements show also that grain boundary recovery is an effective process of polycrystal softening responsible for the drop in stress at high temperatures.

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