ACTA STEREOL 1994; 13/2: 473-478
PROC 6ECS PRAGUE, 1993
ORIGINAL SCIENTIFIC PAPER

QUANTITATIVE DESCRIPTION OF THE PLASTIC DEFORMATION OF GRAINS IN POLYCRYSTALLINE MATERIALS

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ABSTRACT

Polycrystals are characterized by an intricate microstructure, which consist, among others, of grains with their boundaries. Grain geometry is of a stochastic nature and the relationships between the shape and size of grains have received less attention in analyzing the plastic deformation of polycrystals in the past due to technical difficulties involved in any measurements of these effects. A single phase stainless steel of 316L type has been studied and the interest was focused on the changes in the grain geometry during deformation in the tensile test. Also, a computer model has been used to verify the validity of stereological measurements of deformed microstructures. Detailed measurements of grain geometry have been carried out with the use of a system for image analysis. The analysis involved such parameters as grain area, grain shape factors etc. The same measurements were carried out on live images and model microstructures obtained by controlled distortion of the images characteristic for undeformed material.

Key words: size and shape of grains, plastic deformation effect, computer simulation.

INTRODUCTION

Many models of the plastic deformation of polycrystals commonly assume that the plastic strain accommodated by each of the grain of the aggregate is equal. Both the Taylor (1938) and Ashby (1970) models explicitly assume that upon tensile deformation each grain on average elongates by an amount equal to the macroscopic tensile strain. A number of other models assume that the grain in the polycrystal are of equal size. Since real polycrystals always contain a distribution of grain sizes and shapes, such an assumption can be justified only if the grains deform in a uniform way, independent of their size. Few experimental investigations have been made to check the validity of this basic assumption. The data obtained more recently by Rhines et al. (1981) suggest that the contrary may be true.

Grains in polycrystals form a population that can be described by their shape and size distribution functions. Therefore plastic deformation cannot, in general, be considered in the framework of single-grain-in-the-matrix model. The differences in size and shape of individual grains may play an important role as well as interactions between the neighboring grains.

The geometry of the initial microstructures of a polycrystal can be described by a set of distribution functions $f(x_i)$, where x_i is grain area, grain perimeter, grain shape factor, etc. These distribution functions, $f(x_i)$, change into $f_\epsilon(x_i)$ as a result of distortion introduced in the way characteristic of the plastic deformation process taking place in the material. Apart from the applied load, which is an "external factor", it depends on:

1. the operating mechanism of plastic deformation,
2. interactions between the grains,
3. the shape and size of a given grain.

The aim of this work was to study the relationships between $f(x_i)$ and $f_\epsilon(x_i)$ in the case of a low temperature deformation. In particular, an attempt has been made to check the degree of plastic deformation distribution homogeneity.

METHODOLOGY

Plastic tensile deformation characteristically changes geometry of sections of grains in polycrystals strained at different temperatures. At a low temperature, grains observed on sections parallel to strain axis become elongated. In the present work detailed measurements of grain geometry have been carried out with the use of a system for image analysis. The analysis involved such parameters as grain area A, grain maximum diameter d_{max}, grain equivalent diameter d_{eq}, grain perimeter p, number of sides of given grain n (see Fig.1) (Bucki et al., 1991). The measurements were carried out on microstructures of 316L type austenitic stainless steel annealed at 1000°C for 1 hour and deformed to a total elongation of 24% and 50%, as well as on binary images of numerically distorted microstructures, which simulate totally uniform deformation of grains.

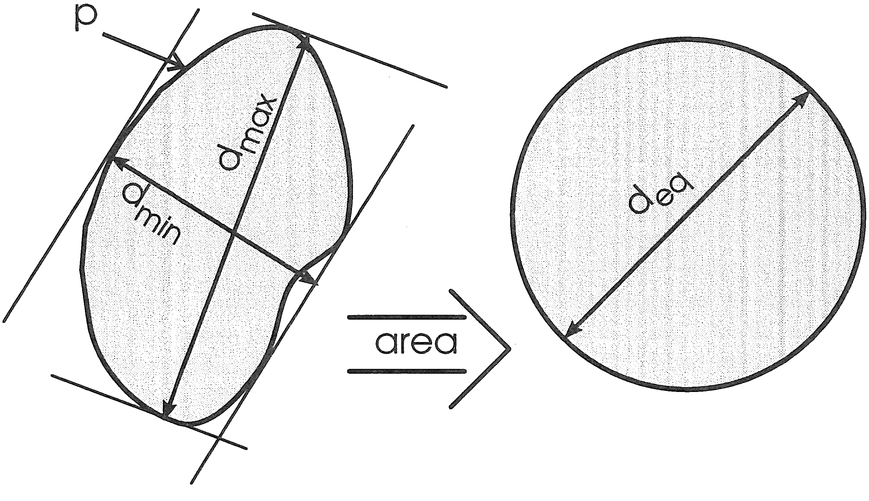

Fig.1. Explanation of parameters describing the shape and size of individual grain.

The changes in the shape of grains, as a result of straining, were quantified by means of the following parameters:

1. $\alpha = d_{max}/d_{eq}$,
2. $\beta = p/d_{eq}$,

The parameter α describes elongation of the grains, parameter β is a sensitive measure of grain boundary convexity (Kurzydłowski et al., 1990).

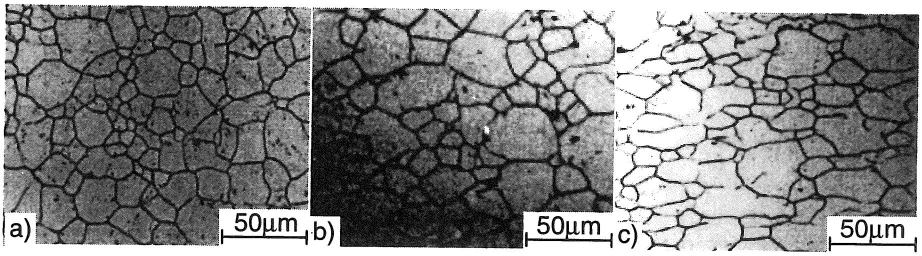

Fig.2. Structures of 316L type steel: a) before straining, after straining to total elongation of b) 24% and c) 50%.

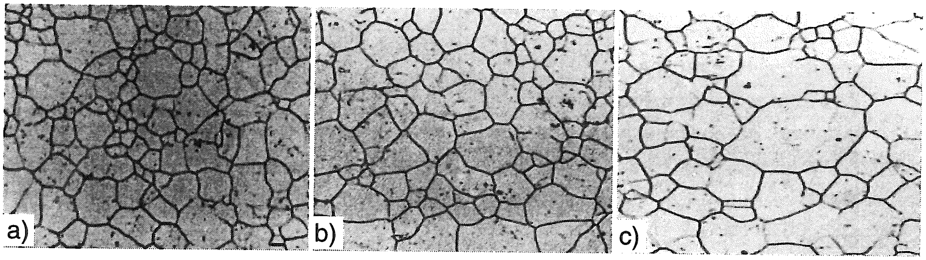

Fig.3. Structures strained in the computer: a) 0% of elongation, total elongation of b) 24% and c) 50%.

RESULTS

Fig.2 shows the structures of 316L type stainless steel annealed in 1000°C before and after straining. Fig.3 shows the simulated microstructures elongated to 24% and 50%.

Table 1 and Fig. 4-6 summarize the results of the measurements of geometrical parameters for the real and simulated microstructures. These results indicate that for the same macroscopic elongation, the elongation of grain sections in real material is less pronounced than the elongation of grain sections in the simulated microstructure. Also, there is a systematic increase in the coefficient of variation of the number of grain sides as a result of plastic stringing in the material while this coefficient remains unchanged in the simulated microstructures, which were subjected to a totally uniform deformation simulated with using a computer software. Various values of CV(n) for 316L steel show that during plastic deformation grains change their neighbors or, in other words, there are topologically transformation taking place during deformation of polycrystals.

DISCUSSION

Kurzydłowski et al. (1992) have shown that plastic deformation of grains in an austenitic stainless steel strained at a room temperature is considerably uniform. This conclusion was based on the measurements of grain area distribution function for as annealed and deformed microstructures.

In the present work a different method has been used to evaluate changes in the geometry of grains as a result of strain at a low temperature. This new method is based on quantification of shape of grains in terms of their elongation (α shape factor), convexity (β shape factor) and number of grains (CV(n)). It has been found, with the help of these parameters that:

1. grains in deformed polycrystals depart from their equilibrium geometry to a lesser degree than it is observed for the totally uniform distribution of plastic strain in the simulated structures;
2. There is a systematic change in the number of sides which indicates rearrangements of the neighboring grains.

These two observations suggest that in the condition of a low temperature deformation, grain boundaries play an active role and their final geometry is not entirely conditioned by the imposed macroscopic deformation. This effect can be explained in terms of the interactions between the lattice dislocations and grain boundaries, which act as a barrier for their movement. It may also be an indication of some recovery processes taking place in the microstructure, possibly due to adiabatic heating effects.

Table 1. Mean values of shape factors E(α), E(β) and the coefficient of variation CV(n) for 0%, 24% and 50% of total deformation of the material.

	initial microstructure	24%	50%
α	1.29	1.31	1.38
	1.29	1.43	1.54
β	3.69	3.71	3.75
	3.69	3.89	4.06
CV(n)	0.278	0.306	0.331
	0.278	0.274	0.275

Data of computer simulation are in shaded cells.

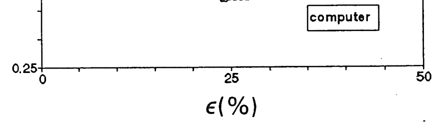

Fig.4. Coefficient of variation CV(n) as a function of elongation ϵ.

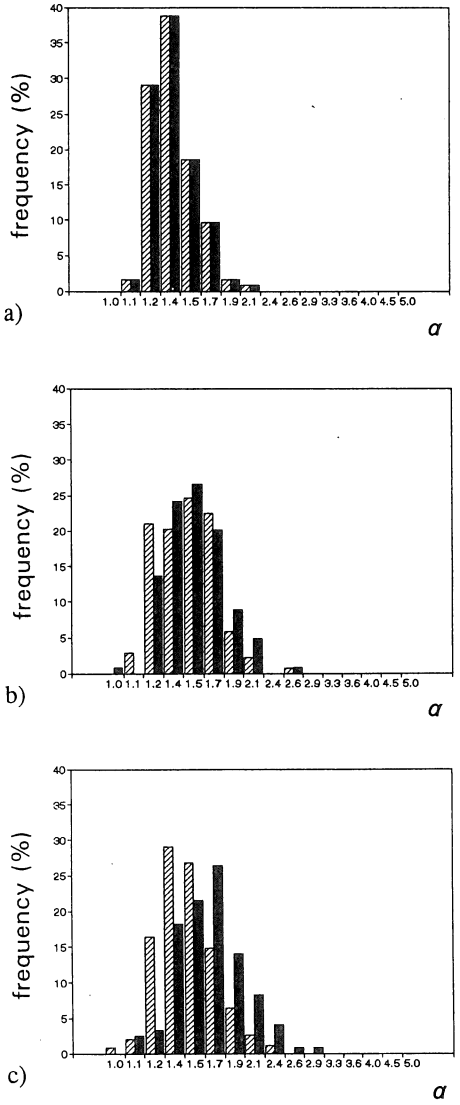

Fig.5. Plots of distribution functions of $\alpha = d_{max}/d_{eq}$ for undeformed material (a), deformed to total elongation of 24% (b) and 50% (c) (▒ - stands for data of 316L steel, ■ - stands for data of computer structures).

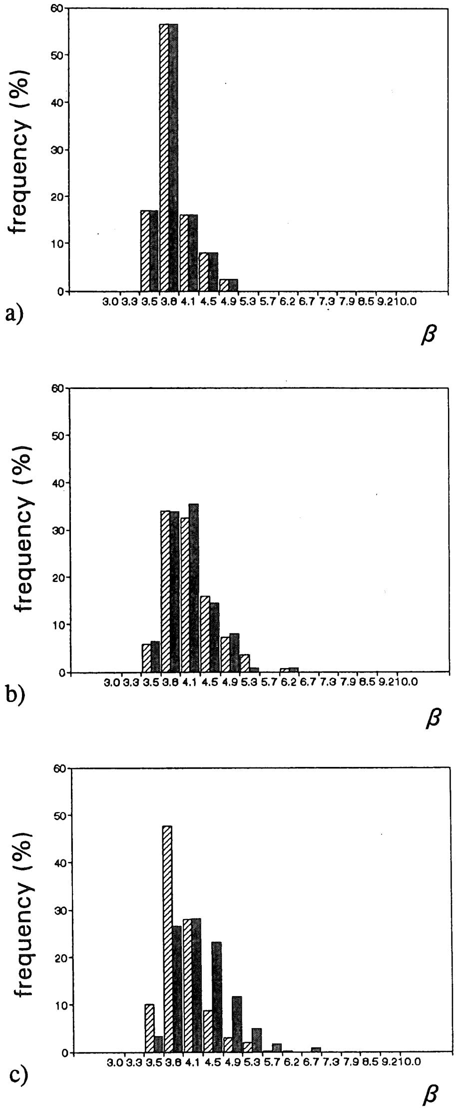

Fig.6. Plots of distribution functions of $\beta = p/d_{eq}$ for undeformed material (a), deformed to total elongation of 24% (b) and 50% (c) (▒ - stands for data of 316L steel, ■ - stands for data of computer structures).

ACKNOWLEDGEMENTS

This work was supported by grant from Polish Committee for Scientific Research and from U.S.-Poland Maria Curie-Skłodowska Joint Found II.

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