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ESTIMATION AND UTILIZATION OF STRUCTURE ANISOTROPY IN TUBE DRAWING

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Abstract: Anisotropy of microstructure in case of forming of metal depends on technology parameters of processes. In case of deformation of metals grain boundaries orientation can be observed. In the polycrystalline material (metal, alloy) the main microstructural parameter is grain boundary – surface interface between individual grains. In case of isotropic non deformed structure the grains have isometric dimension mean grain size or specific surface area of grain boundaries can be measured. In case of anisotropic plastically deformed structure the grains have anisometric dimension, it is necessary to describe their anisotropy. Application of stereology methods to statistic reconstruction of three–dimensional plastic deformed material structure by bulk forming led to detail analysis of material structure changes. The microstructure of cold drawing tubes from STN 411353 steel was analysed. Grain boundaries orientation was measured on perpendicular and parallel section of tubes with different degree of deformation. The anisotropic microstructure was decomposed into isotropic, planar and/or linear oriented components – specific surface area of grain boundaries and these parameters were measured using stereology. Degree of grain boundary orientation is estimated as ratio of oriented specific surface area to total specific surface area. So the degree of grain boundary orientation depends on grain deformation, these results can be used for estimation of local plastic deformation in arbitrary places in volume of tube drawing which is not the same. This analysis can leads to optimization of technology parameters of the process.
Keywords: mechanical working, tube drawing, stereology, grain boundary, orientation, deformation

INTRODUCTION

Anisotropy of microstructure in case of forming of metal depends on technology parameters of processes. In case of deformation of metals grain boundaries orientation can be observed. In the polycrystalline material (metal, alloy) the main microstructural parameter is grain boundary – surface interface between individual grains. In case of isotropic non deformed structure the grains have isometric dimension mean grain size or specific surface area of grain boundaries can be measured.

In case of anisotropic plastically deformed structure the grains have anisometric dimension, it is necessary to describe their anisotropy [1]. The anisotropic microstructure is decomposed into isotropic, planar and/or linear oriented components – specific surface area of grain boundaries and these parameters are measured using stereology [2]. Degree of grain boundary orientation is estimated as ratio of oriented specific surface area to total specific surface area. These results can be used for estimation of local plastic deformation in arbitrary places in volume of forming pieces.

Real state of grain shape is quit impossible to describe, therefore model of conversion of degree of grain boundary orientation to deformation based on an idealized shape (tetrakaidecahedron) of grains has been proposed.

EXPERIMENTAL MATERIAL AND METHODS

— Material

The semi–product for cold drawing seamless tubes was hot rolled steel tubes from STN 411353 steel (recrystallization was passed, grain boundaries deformation was minimized) with the following dimensions: outside diameter 70mm, wall thickness 6,3 mm, length 4000 mm. These steel tubes were cold drawn in a one step with increasing of diameter reduction and simultaneous increasing of wall thickness reduction.

The tube dimensions after deformation were as follows: outside diameter 50mm, wall thickness 3,75mm, length 9255mm. True macroscopic deformation was calculated from these dimensions (see Table 1). The probe was cut from the tube. The section plains were oriented in three main directions of the tube deformation (see Figure 1) – parallel (perpendicular to φ_3), orthogonal (perpendicular to φ_1) and tangential (perpendicular to φ_2) in relation to the main tube's axes.

The cuts were metallographically prepared – mechanically grinded and polished, chemically etched in 3% HNO_3 alcohol solution. On these plains the structure of the steel material was observed with the proper magnification of a light microscope. An example of the steel structure in the initial state and in the state after deformation is shown in Figure 2.

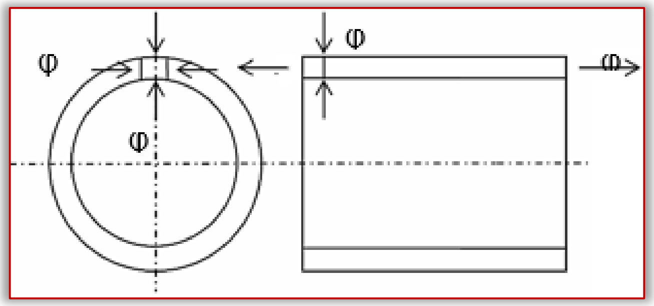

Figure 1: The scheme of tube deformation

— Orientation measurement

There are only three principal schemes of elementary bulk deformation, which allows very good evaluation of the strain analysed in place of the forming body. They are basic indicators for analysis and evaluation of the deformation state caused by external load. The scheme of deformation presented in Figure 3 relates to tube drawing, $\varphi_1 > 0$, φ_2, $\varphi_3 < 0$ and $\varphi_1 = -\varphi_2 - \varphi_3$. True (logarithmic) strain φ is defined from its dimension before deformation l_0 and after deformation l and from relative strain δ as:

$$\varphi = \int_{l_0}^{l} \frac{1}{l} dl \,; \qquad \delta = \int_{l_0}^{l} \frac{1}{l_0} dl \,; \qquad \varphi = \ln(1+\delta) \qquad (1)$$

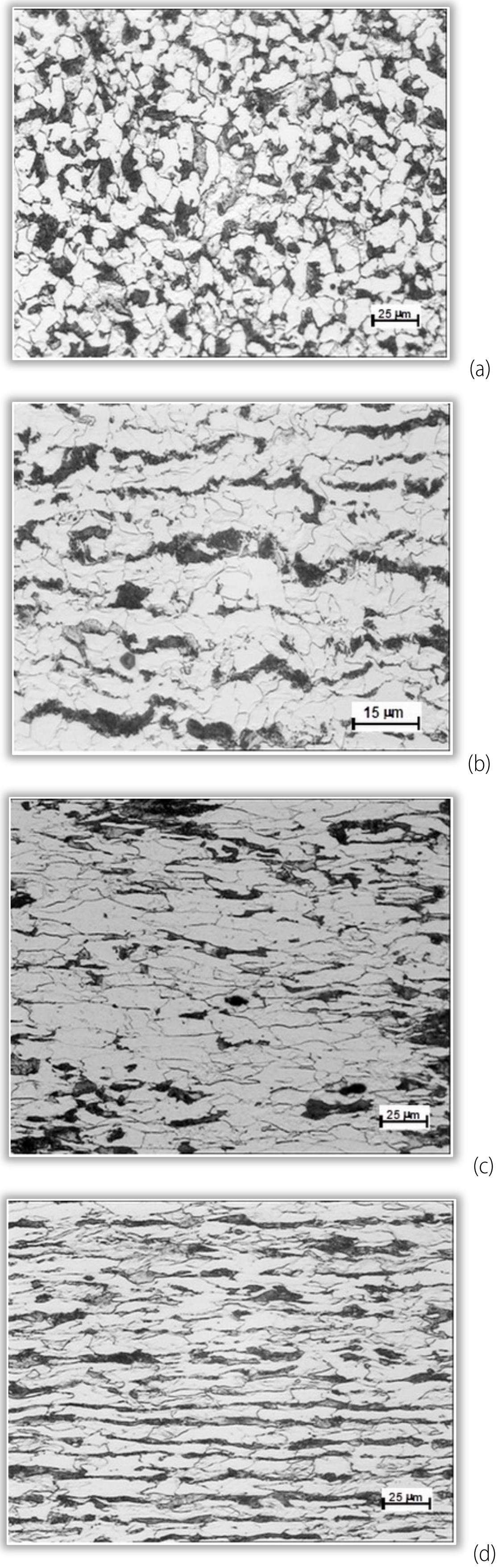

Figure 2: An example of structure in the middle of wall thickness: undeformed in the initial state a) and after deformation, b) in the orthogonal plane, c) in the tangential plane, d) in the parallel plane

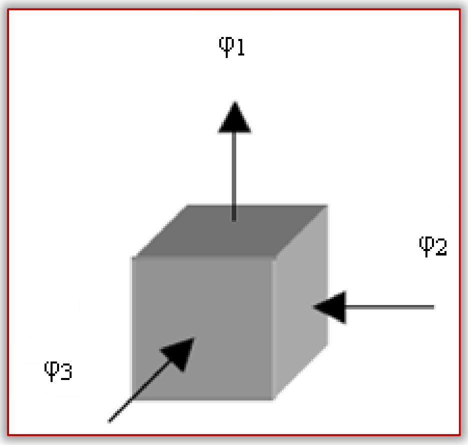

Figure 3: Principal schemes of elementary bulk deformation in case of tube drawing

Direction of the grain boundary's orientation is the same as the direction of deformation. If the deformation scheme is known, grain boundaries can be decomposed into isotropic, planar and linear oriented components. Saltykov stereology methods with oriented test lines were used [1].

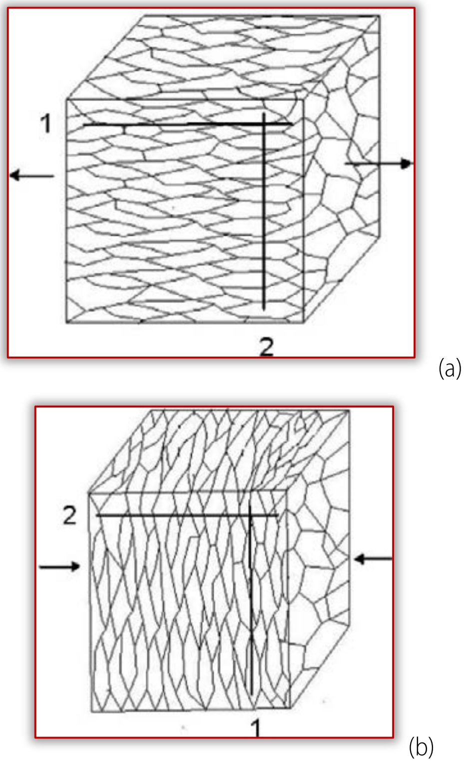

Figure 4: Anisotropic structure due to various types of deformation– linear a), planar b)

In the case of linear deformation (Figure 4a – direction of deformation is marked by arrows), grain boundary orientation can be observed in a plane parallel to drawing direction – linear orientation, in the case of planar deformation (Figure 4b) in a plane perpendicular to the deformation plane – planar orientation. On a metallographic cut, test lines are placed perpendicular and parallel to the grain boundary orientation direction affected by the straining.

From the specific number (number to unit of length) of parallel test lines (1 in Figure 4) intersections with grain boundaries $(P_L)_P$ and the perpendicular lines (2 in Figure 4) $(P_L)_O$ was total specific surface area (area to unit test volume) $(S_V)_{TOT}$ of grains estimated – according to equation (2) in the case of planar orientation and according to equation (4) in the case of linear orientation.

The planar oriented part of the specific surface area $(S_V)_{OR}$ of grains was estimated according to equation (3), the linear oriented part according to equation (5). The physical dimension of all the values is mm^{-1}. Degree of grain boundaries orientation O was estimated as $(S_V)_{OR}$ to $(S_V)_{TOT}$ ratio.

$$(S_V)_{TOT} = (P_L)_O + (P_L)_P \quad (2)$$

$$(S_V)_{OR} = (P_L)_O - (P_L)_P \quad (3)$$

$$(S_V)_{TOT} = \frac{\pi}{2}(P_L)_O + \left(2 - \frac{\pi}{2}\right)(P_L)_P \quad (4)$$

$$(S_V)_{OR} = \frac{\pi}{2}\left[(P_L)_O - (P_L)_P\right] \quad (5)$$

— Conversion of orientation to deformation

However grain boundaries orientation is proportional to deformation, it is not the same. Therefore a conversion of orientation to deformation must be developed. It is completely impossible to describe actual shape of the grain in material structure exactly. Therefore deformation of various idealized grain shapes can be investigated. For instance crystals can be modeled by regular polyhedron – tetrakaidecahedron [2].

One method is based on dependence of the ratio of relative surface area of grain boundaries in deformed state S_V and undeformed state S_{V0} to strain [3]. The method requires knowledge of the parameter of structure in case of zero value of initial deformation, which is unknown in most of cases and this parameter is not the same in the whole volume of pieces and it depends on grain size. Our conversion method is based on the analysis of orientation – deformation relationship of a grain. Dependence of true strain φ on the value of orientation O was derived from three basic equations – definition of deformation (1), definition of degree of orientation (2–5) and invariability of volume ($V_0 = V$ – initial volume is equal to volume after plastic deformation, $\varphi_1 + \varphi_2 + \varphi_3 = 0$).

The solution of the system includes one free parameter – grain size. Solution of the system of equations for used idealised grain shapes is independent of the initial dimension of the grain – strain depends only on the shape of grain and it does not depend on its dimension. As a result the method enables estimation of local plastic deformation from the estimation of microstructure anisotropy in an arbitrary place on the body with an arbitrary state of initial deformation. The solution and the result are relative complicated, so detailed description is in [4].

DISCUSION AND CONCLUSION

Degree of orientation of grain boundaries was measured in three places across the wall thickness – near the outside surface (Out), in the middle (Mid) and near the inside surface (In).

Test lines were placed perpendicular and parallel to the grain boundary's orientation direction which was affected by straining (see Figure 4). From the specific number (number to unit of length) of parallel test line intersections with grain boundaries $(P_L)_P$ and perpendicular ones $(P_L)_O$ the linear orientation O_L of grain boundaries affected by φ_1 (in the tangential plane) was calculated from equations (4) and (5), planar orientation O_P of grain boundaries affected by $\varphi_2 - \varphi_3$ difference (in the orthogonal plane) was calculated from equations (2) and (3).

The relative measurement precision was always smaller than 10% with reliability 90%. True strain φ_1 and the difference between true strains φ_2 and φ_3 was determined using the procedure described in [4]. True strain φ_2 and true strain φ_3 were calculated from values of true strain φ_1, true strains $\varphi_2 - \varphi_3$ difference and invariability of volume ($\varphi_1+\varphi_2+\varphi_3=0$). The results of the measurement of grain boundaries orientation in different places of the steel specimens and the calculated true deformations are shown in Table 1.

Table 1: The measured of the grain boundary's orientation and the calculated deformation

Place	Deformed state						True macroscopic deformation		
	O_P	$\varphi_2-\varphi_3$	O_L	φ_1	φ_2	φ_3	φ_1	φ_2	φ_3
Out	0,103	–0,166	0,645	0,867	–0,546	–0,351	–	–	–0,337
Mid	0,212	–0,329	0,694	0,975	–0,652	–0,323	0,839	–0,519	–0,320
In	0,238	–0,364	0,7	0,993	–0,678	–0,315	–	–	–0,301

We reported the problem of estimation and utilization of structure anisotropy in tube drawing. One can easily understand that there is a correlation between the change in the grain orientation and grain deformation and this correlation can be mathematically demonstrated [3, 4]. The analysis of local deformation could be performed experimentally on the basis of performed results.

One method [3] requires knowledge of the parameter of structure in case of zero value of initial deformation, which is in most of cases unknown. Our method can be used in case when knowledge of the parameter of structure in case of zero value of initial deformation is unknown.

The utilization of stereology metallography allow very simple and effective experimental estimation of plastic deformation degree by measurement of microstructure parameters of oriented grains caused by deformation in various places of bulk formed parts. Estimation of these parameters and consequential conversion of its values to true strain lead to determination of deformation in three main axes and an effective strain. Such results are very needful not only for effective technology application, but for instance for verification of bulk forming numerical model by comparing of these results with numerical simulated results of effective strain using finite elements method [5, 6].

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