QUANTITATIVE ANALYSIS OF DRAWING TUBES MICROSTRUCTURE

Maroš Martinkovič

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Abstract

Final properties of forming pieces are affected by production, at first conditions of mechanical working. 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 analyzed. Grain boundaries orientation was measured on perpendicular and parallel section of tubes with different degree of deformation. Macroscopic deformation leads to grain boundaries deformation and these ones were compared.

Keywords: bulk forming, quantitative metallography, stereology

1. Introduction

Final properties of forming pieces are affected by production, at first conditions of mechanical working. 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 experimental results can lead to design material microstructure model, whose numerical parameters allow quantitative and semiquantitative dependences technological parameters - microstructure – properties and consecutive optimalization of the process and products properties. Recently the volume forming is not based on exact knowledge about materials structural change in the whole volume of part. It was based on macroscopic effects of deformation, but these are not corresponding fully with microscopic structural chances [1]. For example at deformation of steel sheet specimen with 38% overall determined from outside size was observed the deformation of crystal grain in the range from 16 to 31% dependent on the area of specimen [2]. Degree of deformation heavily influences the materials properties due to deformation strengthening and materials behaviour during forming depends on the materials properties as it is during seamless tubes production. During seamless tubes drawing the semi-product (tube) is formed on mandrel and in draw die so that its cross section decreases, its wall thickens and it elongates. The technological parameters of process were not based on any quantitative model of materials structure after plastic deformation. But for example at process recrystallization annealing the grain size increases in dependence also on deformation degree, which is various in tubes wall cross section. The quantitative description of real state could provide the knowledge to reach more optimal volume deformation which requires less energy. There are several microscopic methods to obtain degree of strain in material structure [3], but measurement of grain boundaries orientation was not used to recent time.

2. Experimental material and methods

2.1. Material

The semi-product for cold drawing seamless tubes was hot rolled steel tubes from STN 411353 steel. These steel tubes were cold drawn in three steps with increasing of diameter reduction and simultaneous increasing of wall thickness reduction. The main dimensions of tubes – semi-product and cold drawn tubes after each step are in Table 1.
The main dimensions of semi-product and cold drawn tubes after three drawing

From each tube the probe was cut. The section plains were oriented in two main directions – parallel and orthogonal to main axes of tubes. The cuts were metallographic prepared - mechanical grinded and polished, chemical etched in 3% HNO\textsubscript{3} alcohol solution. On these plains the structure of steel material was observed with proper magnification of light microscope.

2.1 Quantitative analysis

The strain of probes on their sections was obtained by stereological measured by measurement of degree of grain boundaries orientation which was cased by grain boundaries deformation [5]. Two types of grain boundaries orientation were analysed - planar on orthogonal section and linear on parallel section. The method of oriented test lines was used. Test lines were placed perpendicular and parallel to the grain boundaries orientation direction effected by straining [4]. From the relative number (number to unit of length) of parallel test lines intersections with grain boundaries ($P_L^P$) and perpendicular lines ones ($P_L^O$) on orthogonal diction was total relative surface area (area to unit test volume) ($S_V^\text{TOT}$) of grains estimated according equation (1) and planar oriented part of relative surface area ($S_V^\text{OR}$) of grains estimated according equation (2). Degree of grain boundaries orientation was estimated as ($S_V^\text{OR}$) to ($S_V^\text{TOT}$) ratio.

\begin{align*}
(S_V^{\text{TOT}}) &= (P_L^O) + (P_L^P) \\
(S_V^{\text{OR}}) &= (P_L^O) - (P_L^P)
\end{align*}

From the relative number (number to unit of length) of parallel test lines intersections with grain boundaries ($P_L^O$) and perpendicular lines ones ($P_L^P$) on parallel section was total relative surface area (area to unit test volume) ($S_V^{\text{TOT}}$) of grains estimated according equation (3) and linear oriented part of relative surface area ($S_V^{\text{OR}}$) of grains estimated according equation (4). Degree of grain boundaries orientation was estimated as ($S_V^{\text{OR}}$) to ($S_V^{\text{TOT}}$) ratio.

\begin{align*}
(S_V^{\text{TOT}}) &= \pi/2 (P_L^O) + (2 - \pi/2) (P_L^P) \\
(S_V^{\text{OR}}) &= \pi/2 ((P_L^O) - (P_L^P))
\end{align*}

3. Results and discussion

Macroscopic deformation of drawing tubes was calculated from their dimensions with comparison with basic state. The results of deformation of diameter in three places, thickness and length are shown in Table 2.

![Fig. 1. Structure of semi-product on orthogonal section in the middle](image1)

![Fig. 2. Structure of semi-product on parallel section in the middle](image2)
Structure of 1st drawing on the bottom on orthogonal section is on Fig. 3, on parallel section is on Fig. 4.

Fig. 3. Structure of 1st drawing on the bottom on orthogonal section

Fig. 4. Structure of 1st drawing on the bottom on parallel section

Structure of 2nd drawing in the middle on orthogonal section is on Fig. 5, on parallel section is on Fig. 6.

Fig. 5. Structure of 2nd drawing in the middle on orthogonal section

Fig. 6. Structure of 2nd drawing in the middle on parallel section

Fig. 7. Structure of 3rd drawing on the bottom on parallel section

Structure of 3rd drawing on the bottom on parallel section is on Fig. 7.

The direction of deformation on parallel section was assumed along main axes of tubes, on orthogonal section parallel to tangent line of tube cross section. These directions are along longer side of pictures. Measured and calculated degree of grain boundaries orientation on each analysed places are in Table 3. The relative measure precision was always smaller then 10% with reliability 90%.

From the results we can see very good qualitative coincidence between macroscopic deformations and microscopic structure orientation. Negative value of deformation means, that the dimension was decreased. On the other hand negative degree of orientation means, that orientation has reverse direction than assumed – radial not tangential. On orthogonal section two deformations (deformation of diameter–tangential and deformation of thickness – radial) which counterwork lead to grain boundaries orientation. The grain boundaries deformation in basic state – semiproduct was not zero, however recrystallization was passed. From these
follow that on orthogonal section planar deformation increased from top to bottom and degree of the orientation too. The same results were achieved on parallel section between linear deformation and the orientation.

4. Conclusions

The utilization of sterology metallography allow very simple and effective experimental estimation of plastic deformation degree by measure of grain boundaries orientation in various places of bulk formed parts. Such results are very needful not only for effective technology application, but for instance for verification of bulk forming numerical model by comparing this results with numeric simulated ones. But not only in this case is it necessary to build up conversion of grain boundary orientation degree to deformation. It can be based on similar comparison orientation – deformation of idealized shape grain. Some models were made with partial successful, but to recent time still remains a lot of work.

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References