UTILIZATION OF STEREOLOGY FOR QUANTITATIVE ANALYSIS OF PLASTIC DEFORMATION OF FORMING PIECES

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Resume
Mechanical working leads to final properties of forming pieces, which are affected by conditions of production technology. Utilization of stereology leads to the detail analysis of three-dimensional plastic deformed material structure by different forming technologies, e.g. forging, extruding, upsetting, metal spinning, drawing etc. The microstructure of cold drawing wires was analyzed. Grain boundaries orientation was measured on the parallel section of wire with a different degree of deformation and direct axis plastic deformation was evaluated in bulk formed part. The strain of probes on their sections was obtained using stereology by measurement of degree of grain boundary orientation which was converted to deformation using model of conversion of grain boundary orientation degree to deformation.

Available online: http://fstroj.uniza.sk/journal-mi/PDF/2012/06-2012.pdf

Article info
Article history:
Received 20 May 2011
Accepted 2 December 2011
Online 9 December 2011

Keywords:
Mechanical working;
Stereology;
Grain boundary;
Orientation;
Deformation.

ISSN 1335-0803 (print version)
ISSN 1338-6174 (online version)

1. Introduction

Mechanical working leads to final properties of forming pieces, which are affected by conditions of production technology. Recently the forming is in generally practice based on macroscopic effects of deformation, but these do not correspond fully with microscopic structural changes [1]. To obtain an exact knowledge about the material structural change in the whole volume of part it is necessary to use one of microscopic or macroscopic methods [2], for instance methods based on acoustic emission, microhardness measurement, dislocation analysis, slip band observation, micromeshes method or macroscopic screw method [3]. A quantitative description of microstructure changes induced by plastic deformation is essential to the development of analytical expressions relating structure parameters and strain in each place of material bulk. In the polycrystalline material (metal, alloy) the principal microstructural parameter is grain boundary – the interface between individual grains. In case of isotropic structure, the grains have isometric dimension and mean grain size or size distribution of grains and specific surface area of grain boundaries is sufficient. In case of anisotropic structure the grains have anisometric dimension and it is necessary to describe their orientation. There are a few ways how to measure the grain orientation. Vector or tensor measurement is for instance an distribution function orientation of normals to the internal grain surface described by a microstructural anisotropy tensor [4].

Another way is scalar measurement of anisotropy – to determine the degree of orientation. Anisotropic microstructure is decomposed into isotropic, planar and linear oriented components using stereology methods [5]. But this measurement requires a prior knowledge of axes of orientation, which are in most of mechanical working processes known. Therefore measurement of orientation degree in volume of plastic deformed parts and conversion of grain boundary orientation degree to deformation was used. Bulk forming leads to grain boundaries deformation. To obtain a value of strain is possible by measurement of degree grain boundaries deformation. On a metallographic cut it is possible to observe grain boundary orientation which was caused by grain boundary deformation, but orientation is not the same as deformation. It is necessary to use conversion of grain boundary orientation degree to deformation. Application of stereology methods to statistic reconstruction of plastic deformed material structure led to the detail analysis of material structure changes. The degree of deformation heavily influences the materials properties due to deformation strengthening [6] and materials behaviour during forming depends on the materials properties [7] as it is for instance during wire drawing. The quantitative description of real state enables to optimize technological parameters of production.

2. Experimental material

A cold drawing wire was used for analysis. The semi-product for wire was hot rolled wire from ASTM 1006 (ČSN 411301) steel. This hot rolled wire was cold drawn in two steps with increasing of diameter reduction and simultaneous decreasing of length. The diameter of semiproduct was 5,5mm, diameter of the wire after first drawing was 4,7mm and diameter of the wire after second drawing was 3,99mm. For the analysis a one continuous part of wire which consists of a material from in front of the second drawing die, from inside the second drawing die and from behind the second drawing die was used. The longitudinal section of the sample was made. The schema of longitudinal section of the sample with fifteen places for the analysis is in Fig. 1. As Fig. 1 shows, places for the deformation analysis are near the surface of wire diameter (S), in the wire centre (C) and in the middle of wire radius (M) in five positions (1-5) along the wire – one position in front of the drawing die, three positions inside the drawing die and one position behind the drawing die. Diameters of the wire in these five positions and from these values calculated deformation on the second drawing die - transverse section strain ε_S and true axial strain φ are in Table 1.

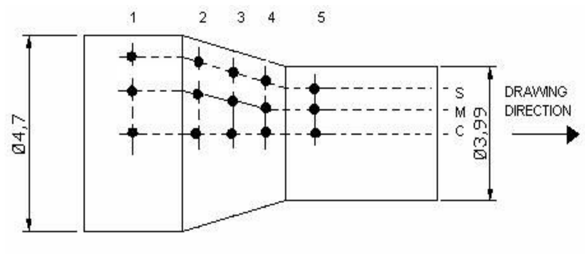

Fig. 1. Scheme of longitudinal section of the sample with places for the analysis

Table 1
Diameters of the wire and calculated deformation on the second drawing die

Position	Wire diameter (mm)	Transverse section strain ε_S	True axial strain φ
1	5.5	-	-
2	4.6	0.042	0.043
3	4.4	0.123	0.131
4	4.2	0.201	0.225
5	3.99	0.279	0.327

The structure of wire was observed with a proper magnification of light microscope on a metallographic cut of longitudinal section on the each analyzed places. The metallographic cut was mechanical grinded and polished, chemical etched in 3% HNO_3 alcohol solution.

3. Experimental methods

The strain of probes on their sections was obtained by stereological measurement of degree of grain boundary orientation which was caused by grain boundary deformation. A linear grain boundary orientation was analyzed. The test lines method was used [5]. Test lines were placed perpendicular and parallel to the grain boundary orientation direction caused by straining. 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 parallel section was the total relative surface area (area to unit test volume) $(S_V)_{TOT}$ of grains estimated according an equation (1) and linear oriented part of relative surface area $(S_V)_{OR}$ of grains estimated according the equation (2). Degree of grain boundaries orientation O was estimated as $(S_V)_{OR}$ to $(S_V)_{TOT}$ ratio [5].

$$(S_V)_{TOT} = \pi/2\ (P_L)_O + (2-\pi/2\ )\ (P_L)_P \qquad (1)$$

$$(S_V)_{OR} = \pi/2\ ((P_L)_O - (P_L)_P) \qquad (2)$$

It is possible to convert a grain boundary orientation degree to corresponding deformation. Dependence of linear true strain to linear degree of grain boundary orientation based on similar comparison orientation – deformation of idealized globular grain shape [8] was used (see Fig. 2).

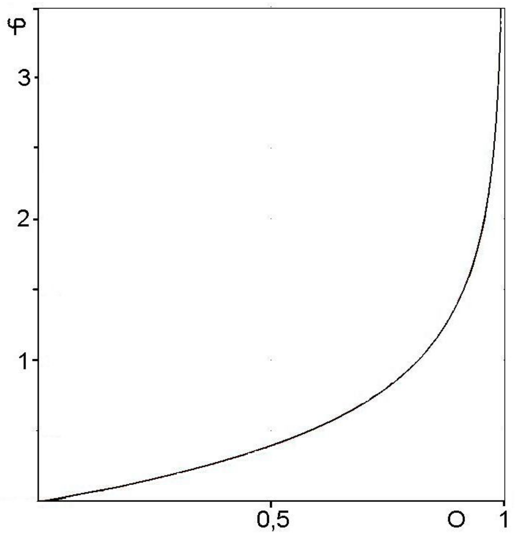

Fig. 2. Dependence of true strain to degree of grain boundary orientation [8]

4. Results and discussion

From the pictures of the structure on each analyzed places can be seen the structural changes caused by deformation. Examples of microstructures of wire in front of drawing die in place M1 is in Fig. 3, structure of wire behind the drawing die in place S5 is in Fig. 4.

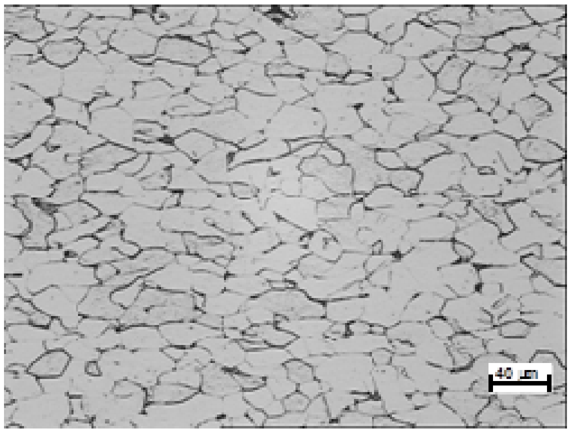

Fig. 3. Structure of wire in front of drawing die (place M 1)

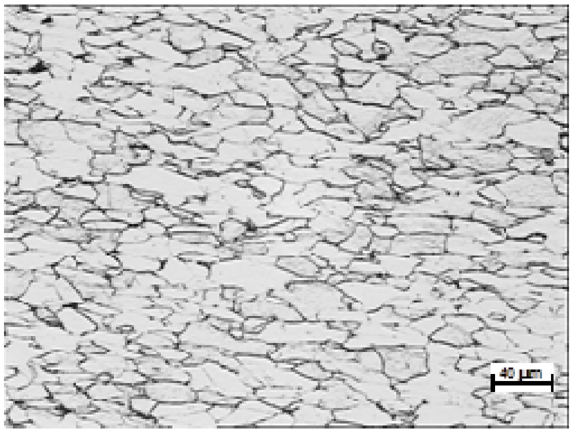

Fig. 4. Structure of wire behind the drawing die (place S5)

Measured and calculated degree of grain boundary orientation *O* on each analysed place and corresponding deformation φ converted according [8] are in Table 2.

From the results we can see very good qualitative coincidence between macroscopic deformations and microscopic structure orientation. With increasing of deformation, grain boundaries orientation increases too. Orientation is not equal in cross section of wire. The smallest is near the surface of wire, the greatest in the middle of wire radius in all places along the wire. The same course has also converted deformation. It means that in the middle of wire radius deformation make heavily influences on the materials properties due to deformation strengthening during wire drawing.

Table 2
Grain boundary orientation "O" on each analysed places and corresponding deformation "φ"

Place	O 1	2	3	4	5
S	0.32	0.33	0.37	0.40	0.48
M	0.39	0.41	0.42	0.50	0.52
C	0.35	0.36	0.39	0.49	0.51

Place	φ 1	2	3	4	5
S	0.316	0.326	0.371	0.405	0.504
M	0.394	0.417	0.429	0.530	0.558
C	0.348	0.359	0.394	0.517	0.544

In case simple deformation only degree orientation can be applied, because the values of strain from the conversion model are very similar to the degree of orientation values. On the other hand from comparison macroscopic and microscopic deformation can be seen that microscopic deformation is about two times smaller than macroscopic deformation. The conversion model using idealised globular grain shape has only partial success. However experimental result of measurement of linear deformation showed only qualitative coincidence between true strain of microstructure and macroscopic deformation calculated from dimensions of samples. It indicates that the conversion model of grain boundary orientation degree to true strain can be relatively effectual in case of using more optimally grain shape model, e.g. etrakaidecahedron (also known as "Kelvin cell"), which more objective describes grain shape [9].

4. Conclusions

The utilization of stereological metallography allows very simple and effective experimental estimation of plastic deformation degree by measurement of grain boundaries orientation in various places of plastic deformed parts. Scalar measurement of anisotropy – to determine degree of orientation of grain boundaries by its decomposing into isotropic, planar and linear oriented components is possible in most of mechanical working processes, because prior knowledge of the axes of orientation are known. This method can be used not only in case of bulk forming pieces, but also allowed an detail analysis such technological processes which were macroscopic described as for instance metal spinning [10] or a deformation surface layer as for instance surface rolling [11] or deformation under the machined surface at drilling holes [12]. Results of grain boundaries orientation can be used for verification of forming numerical model by comparing these results with numeric simulated ones [1]. To build up true conversion models of grain boundary orientation degree to deformation needs to fit them using comparison of results of the models with experimental results.

Acknowledgements

The results presented in the paper are based on the investigation of international research project "Multivariate optimization of the metal spinning processes – research and development" project MANUNET-2008-SK-001 and VEGA Grant No. 1/0412/12.

References

[1] M. Martinkovič, R. Sobota, M. Kapustová: In Annals of DAAAM and Proceedings of DAAAM Symposium, Ed.: B. Katalinic, DAAAM International Vienna 2008, pp. 0819-0820

[2] M. Forejt, M. Píška: Teorie obrabění a tváření a nástroje *(Theory of machining, forming and tools),* CERM, Brno 2006 *(in Czech).*

[3] F. Li, J.F. Lin, X.J. Liu, C. Li: J. Eng. Manufact. 223(7) (2009) 935-941.

[4] C.S. Hartley: Metall. and Mater. Trans. A37(12) (2006) 3531-3539.

[5] S.A. Saltykov: Stereometričeskaja metallografia *(Stereometric metallography),* Metallurgia, Moskva 1970 *(in Russian).*

[6] H. Petryk, S. Stupkiewicz: Mater. Sci. Eng. A444(1-2) (2007) 214-219.

[7] R. Prasannavenkatesan, B.Q. Li, D.P Field, H. Weiland: Metall. and Mater. Trans. A36(1) (2005) 241-256.

[8] M. Martinkovič: In.: Development of materials science in research and education DMSRE 2009, Ed.: M. Koman, E. Miklos, Slovak Society for Soli State Chemistry and Physics 2009, pp. 50-51.

[9] P.R. Rios, M.E. Glicksman: Mater. Res. 9(2) (2006) 231-236.

[10] J. Gašparová, J. Šugárová, D. Kalincová: In Trends in forestry, wood processing and environmental technology and its applications in the manufacturing process 2006, Ed.: M. Ruzinska, FEVT-TU Zvolen 2006, pp.13-18.

[11] D. Kalincová: Mater. Eng. / Mater. Inž. 16(1) (2009) 1-4.

[12] J. Jurko, A. Panda, M. Dzupon, L. Pandova, M. Gajdos: Chem. Letters / Chem. Listy 105(S) (2011), 600-602.