Determination of Strain Distribution in Cold Extruded Workpiece – An Experimental Approach

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Keywords: extrusion, gear-like elements, strain distribution, recrystallization, grain size.

Abstract. In this paper experimental findings of strain distribution in cold extruded gear-like element workpiece with straight parallel flank are presented. The material of extruded workpiece was Al99,5 and a special tool was made to conduct the experiments. Strain distribution within a workpiece is one of the basic information in every metal forming process needed to obtain the state of stress in the workpiece. The experimental technique presented in this paper is based on the relationship between recrystallized grain size and prior deformation. In order to apply this technique it was necessary to define a calibration curve, establishing a relationship between grain size and prior deformation. The strain values were defined in selected points of cross section of the extruded workpiece. Flow curve for Al99,5 was obtained using the Rastegaev experiment.

Introduction

Manufacturing of gears and gear-like elements by means of metal forming technologies offers many advantages when compared with other technologies: high productivity and accuracy, material saving, lower cost and better mechanical properties. Considerable amount of work has been carried by a number of researchers investigating the manufacturing of gears and gear-like elements by metal forming processes, especially by forging and extrusion [1-8].

In the Metal forming laboratory of Faculty of technical sciences, University Novi Sad investigation of cold extruded gear like elements was conducted. Theoretical analysis, which was performed by Upper bound method, gave some of the main process parameters (total load, average punch pressure). However that method does not provide information about strain distribution within the workpiece and hence a special experimental technique was used. This technique was applied on the gear like element with straight parallel flank as shown in Figure 1. The material to conduct this experiment was Al99,5.

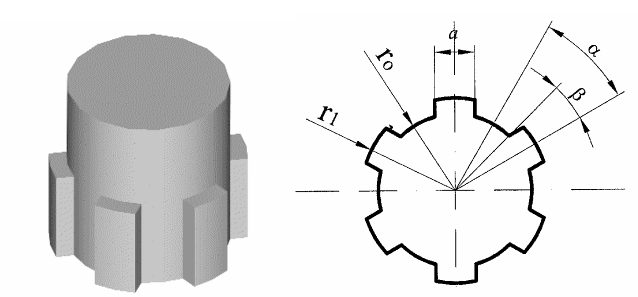


Fig.1. - Gear-like element with straight parallel flank [9]

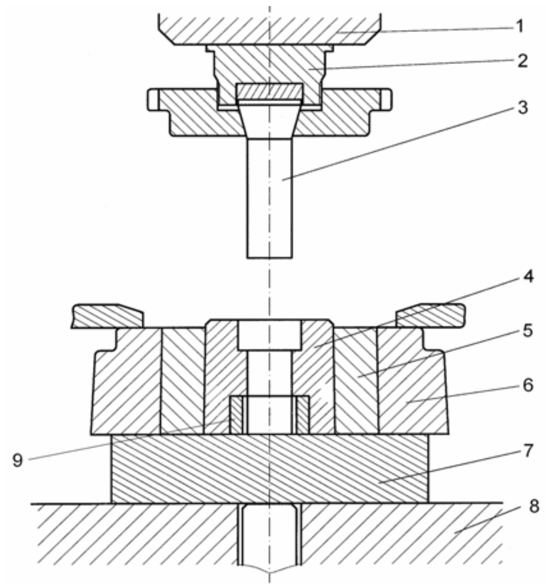
The most important part in this procedure is the definition of the relationship between the recrystallized grain size and the prior deformation. To apply this technique it is necessary to determine the calibration curve which gives the relationship between grain size and effective strain. Similar technique was used earlier on steel [10] as well as on aluminum [11].

Experiment

Specimen Preparation. All specimens for the determination of calibration curve and for the extrusion experiment were subjected to heat treatment. In order to homogenize the microstructure, Al99,5 specimens were heat treated for 16 hours at 600°C and then air-cooled. All specimens were deformed by upsetting by an amount of $\varphi = 0.25$. In order to obtain uniform distribution of the deformation through the specimen, the upsetting was performed by the method described by Rastegaev. All the specimens were then heat treated at 500°C for 1 hour and air-cooled. This procedure of the heat treatment resulted with homogenous microstructure with very uniform grain size distribution. Some of these specimens were used to determine the calibration curve and the others were used for extrusion of gear like-elements.

Determination of Calibration Curve. The specimens used to establish the calibration curve were deformed to a true strain between 0.1 and 1.2 by an increment of 0.1 using the Rastegaev's method of upsetting. This was followed by heat treatment at 500°C for 1 hour. From these specimens, small sections were prepared for metallography. After wet grinding and polishing, anodic oxidation in 40% HBF_4 solution was used to reveal the grain boundaries. Microphotographs were made using light microscope with camera at 100x magnification. Comparing these photographs with etalon photographs, grain sizes for each amount of logarithmic strain were determined.

Extrusion. For the experimental investigation special tooling was used as shown in Figure 2. The billet was placed into the die and the punch pressed it downwards. In this way material was forced to flow into the geared profile of the die insert. Die insert was replaceable in order to enable extrusion of different gear-like elements. Experiment was carried out on Sack & Kiesselbach 6.3 MN hydraulic press (Fig. 3).



1 – upper plate
2 – punch holder
3 – punch
4 – die
5, 6 – inner and outer ring
7 – lower plate
8 - press
9 – replaceable die insert

Fig. 2. - Experimental tooling

Fig. 3. - 6.3 MN hydraulic press, Sack und Kieselbach

Determination of Strain Distribution. After the extrusion process, the gear like element was heat treated at 500°C for 1 hour. The extrudate was cut at the half of the tooth height. This was used for metallography as shown in Figure 4. Similar technique to that of metallography, was used for the preparation of the specimens for the calibration curve (i.e. wet grinding, polishing, anodic oxidation in Barkers reagent).

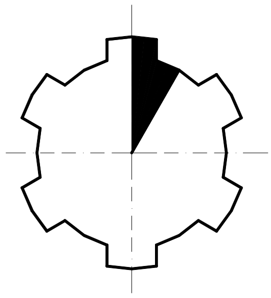


Fig. 4. Representative section for metallography

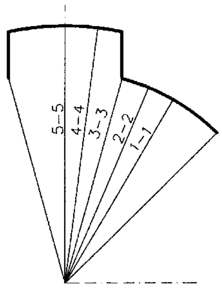


Fig.5 Characteristic directions

Prepared specimen was photographed along 5 different directions as shown in Figure 5 with a magnification of 100x. Comparing with etalon photographs, the grain size was determined for each of photographed position. Calibration curve was used for determination of effective strain.

Results

The strain distribution for one twelfth of the gear-like element is shown in Figure 6. The experimental values of strain indicate that the lowest values take place in the center of the workpiece, in the middle of a tooth and in the zone between the teeth close to the surface. Moving from the center of the workpiece towards outer surface, the effective deformation increases. The highest values can be seen at the root of a tooth.

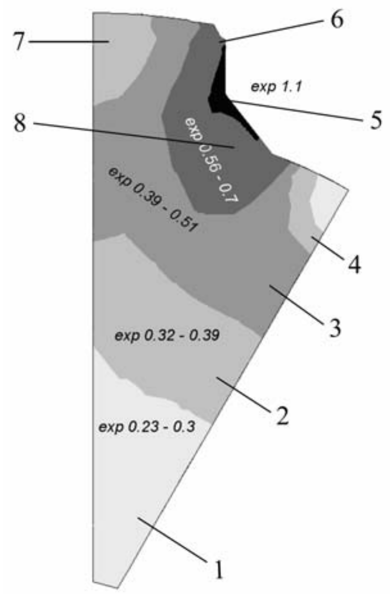
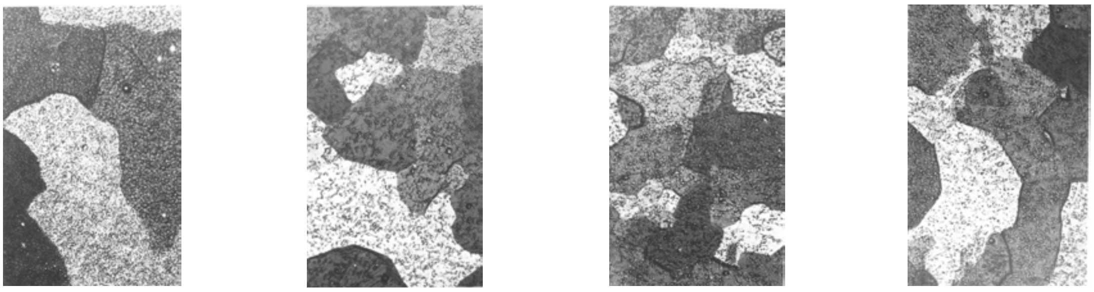
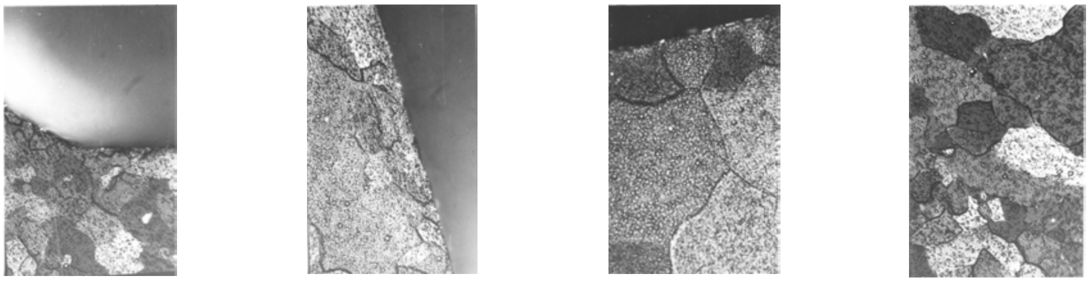


Fig. 6. Locations were strain values were determined by experimental method

The existence of two zones with different grain size can clearly be seen in the photographs in Figure 7 at locations 5, 6 and 7. Zone close to the surface has small grain size which corresponds with higher strain values.



location 1 $\varphi = 0.27$ center of the element	location 2 $\varphi = 0.32$	location 3 $\varphi = 0.51$	location 4 $\varphi = 0.32$



location 5 $\varphi = 1.1$ (0.7) root of a tooth	location 6 $\varphi = 0.7$ (0.32) side of a tooth	location 7 $\varphi = 0.5$ (0.3) top of a tooth	location 8 $\varphi = 0.7$

Fig. 7. Photographs of the recrystallized grains at the specimen cross-section

The highest values of effective strain occur at the root zone of the teeth in location 5 as shown in Figure 7. The grain size in this zone corresponds to the effective strain of $\varphi_e > 1$. Along the side of the tooth the effective strain is $\varphi_e = 0{,}7$. At the top of the teeth the value of effective strain is 0,5 in position 7 as also shown in figure 7. The zones under the surface zones have lower values of the effective strain.

The obtained values of effective strain are useful information about process, which can be used for determination of stress state, if stress-strain curve of the material is known.

Summary

In this paper an experimental approach to establish the strain state within workpiece is presented. The analyzed part was the gear like element produced by cold extrusion. Material of the workpiece was Al 99,6.

Information about strain values which was obtained by this experimental method is very valuable for process analysis. This method showed the critical locations within the workpiece volume with the highest strain values. If the stress-strain curve is known, strain values can be used to determine stress state at the cross section of the workpiece.

Acknowledgement

Results of investigation presented in this paper are a part of the research project TR 6333B, financed by Ministry of science and environmental protection of Republic Serbia.

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