SEVERE PLASTIC DEFORMATION WITH ASYMMETRIC ROLLING

Summary of the PhD theses

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Budapest
2011.

This dissertation, the comments of the reviewers and the log recorded on the defence are on show in the Dean's office of the Faculty of Mechanical Engineering of the Budapest University of Technology and Economics

Possible applications of the results

The results of my researches show what microstructure and mechanical properties can be expected after four-step differential speed rolling of Al 7075 aluminium alloy according to different deformation routes.

The other part of my results help planning forming processes, with that it allows to obtain information about the evolving microstructure with the use of the developed techniques.

Publications

[I.] Bobor K. Krállics Gy. *Characterization of metal-forming processes with respect to non-monotonity*, Journal of Physics Conference Series **240,** 2010, 012126

[II.] Bobor K. Krállics Gy. *Characterization of severe plastic deformation techniques with respect to non-monotonity*, Review on Advanced Materials Science **25,** 2010, 32-41

[III.] Bobor K. Krállics Gy. *Study of non-monotonity of forming processes using finite element analisys*, Materials Science Forum **659,** 2010, 373-379

[IV.] Bobor K. Krállics Gy. *Könyöksajtolás különböző alakítási útjainak vizsgálata nem-monotonitás szempontjából*, OGÉT 2010, XVIII. Nemzetközi Gépészeti Találkozó, konferenciakötet, 71-74

[V.] Bobor Kristóf, Májlinger Kornél, *Felületi réteg kialakulása öntöttvas motorblokkok hengerfuratának falán lézerkezelés hatására*, OGÉT 2010, XVIII. Nemzetközi Gépészeti Találkozó, konferenciakötet, 283-286

[VI.] Bobor Kristóf, Májlinger Kornél, Szabó Péter János, *Formation of Surface Layer on Cast Iron Cylinder Bore due to Nanosecond Laser Impulses*, Periodica Polytechnica Mech. Eng. **53,** 2009:2, 75-80

Introduction

Nano- and ultra-fine grained materials

In the past decades the nanotechnology and the nanotechnology researches have become some of the most important areas of both the engineering and physical sciences. Some of the important areas of the nanotechnology researches are the investigation and produce of the so-called ultra-fine grained (UFG) and nanograined (NG) materials which have an average grain size of 100-1000 nm or less than 100 nm, respectively. The NG and UFG materials differ in several properties from the conventional ones:

- High strength and hardness
- Superplastic formability
- Low ductile-to-brittle transition temperature
- Good corrosion resistance
- Good electric and magnetic behavior

Although numerous methods exist to produce such materials, nowadays this can be done typically under laboratory circumstances. One of the most applied procedures is the so-called severe plastic deformation (SPD) method. Such procedures belong to the group of SPD processes, whereby the deformation, even more the type of deformation is emphasized. The shear and the so-called non-monotonic deformation are characteristic for these processes. Among others the equal channel angular pressing, the high pressure torsion, the multiply forging and the differential speed rolling belong to these methods.

Differential speed rolling

Three different methods belong to the asymmetrical rolling techniques. In the first case the friction between the work piece and the lower or the higher roll is different, while by the other two cases the peripheral speed of the rolls are different. The latter can be realized in two ways. In one case the speed of the rolls are equal but their diameters are different, while in the other case their diameter are equal but the speeds are different. This latter is called differential speed rolling. In the present work I deal with this technique in details.

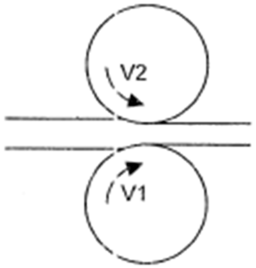

Figure 1: The technique of the differential speed rolling

The difference between the conventional and the differential speed rolling is that besides the stretching-upsetting type of the deformation, in the latter case, the material takes a significant amount of shear strain. This shear promotes the evolution of the special microstructure similar to the previously mentioned SPD processes. Due to this, the material deformed by differential speed rolling differs in its texture, grain and grain boundary structure and mechanical properties from one deformed by conventional rolling. Four deformation routes (UD, RD, TD, ND) can be found in the literature (2 Figure). By the route UD the specimen is not rotated between two deformation steps, while by the other three cases it is rotated with 180° degrees. By the route RD the rotation axis is the rolling direction, by the route TD the transverse direction and by the route ND the normal direction.

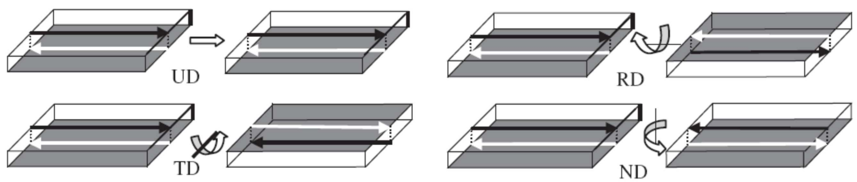

Figure 2: Different deformation routes of the differential speed rolling

amount of deformation, but different mechanical scheme, the value of υ_1 is the highest by those of which are realized through simple shear deformation.

- From two forming processes, whereat the value of υ_1 is higher, the evolution of the ultra-fine grained microstructure can be expected by smaller amount of deformation.

3. I proved that the symmetrical and differential speed rolling, according to the routes UD, RD, ND and TD differ from each other in the respect of non-monotonity. After the investigated four-step rolling, this difference reaches the 25-100% in different points of the cross section. [II.][III.]

- Compared to the symmetrical rolling, higher non-monotonity is characteristic for the differential speed rolling, and the value of υ_1 is more evenly distributed through the cross section after the multi-step rolling.
- After multi-step differential speed rolling, the distribution of the value of υ_1 is symmetrical through the cross section in case of UD and ND routes and asymmetrical in case of RD and TD routes.

4. I proved that through four-step differential speed rolling (10 rpm – rpm) according to the UD, ND, RD and TD routes in Al 7075 aluminium alloy an ultra-fine grained (400-500 nm) microstructure can be produced. Furthermore I determined that the four different deformation routes influence significantly the evolved microstructure and the mechanical behavior of the material.

- The strength quantities are approximately equal for all four routes, while the toughness was the highest for UD and ND routes and lowest for TD route.
- The dislocation density was the highest for UD and ND routes $5{,}6 \cdot 10^{14}$ and $5{,}5 \cdot 10^{14}$ m^{-2}, and the lowest for TD route $3{,}4 \cdot 10^{14}$ m^{-2}.

dimensional material flows in plain strain and axisymmetric cases, and it can be extended for three dimensional problems. I used Maple and Matlab software for the study of the forming processes.

I investigated conventional and SPD techniques, as well as the multi-step differential speed rolling according to the four deformation routes, in respect of non-monotonity

Theses

1. I introduced a numerical method based on the combined Euler-Lagrange description wherewith the continuous velocity field and the velocity gradient field can be calculated in case of steady state two dimensional streaming of incompressible material. By the calculation of the streamlines I applied cubic smoothing spline to eliminate the effect of the errors (noise) from the finite element calculations. [III.]

- The effect of the errors can be eliminated with choosing the p smoothing parameter between 0.7 and 0.9 without to become the description of the deformation inaccurate.

2. I introduced a calculation method, which is appropriate to quantitative characterization of the monotonity of forming processes and is related to the evolution of ultra-fine grained microstructure. The value of the introduced υ_1 quantity is changing in the 0-2 interval in case of unit equivalent plastic deformation. [I.][II.][III.][IV.]

$$\nu_1 = \int_0^t \left| \boldsymbol{w} - \boldsymbol{\omega} \right| \frac{d_{\mathrm{eq.}}}{d_{\max}} \cdot dt$$

$\boldsymbol{w}$ - angular velocity vector of rigid body rotation,
$\boldsymbol{\omega}$ - rotation vector of the principal axis of rate of deformation tensor
$d_{\mathrm{eq.}}$ - equivalent strain rate, $d_{\max}$ - highest values of equivalent strain rate

- The higher the value of υ_1 is, the more the deformation process differs from the monotonic one. From two deformation process with the same

Analysis of the monotonity of forming processes

According to Smirnov-Aljajev, a forming process develops monotonically if no component of the rate of deformation tensor changes its sign, namely the eigenvectors of the rate of deformation tensor are parallel to the same material lines during the whole deformation process and the Lode parameter remains constant. The non-monotonic deformation is characteristic for the severe plastic deformations realized through simple shear. Through the investigation of the deviation from the monotonic deformation, the non-monotonity, beside the conventional stress and strain quantities extra information can be achieved about the evolved microstructure.

Aim of the research

My work is related to the researches of the Department of Materials Science and Engineering of the Budapest University of Technology and Economics, the scope of which is the study of the properties of bulk nano- and ultra-fine grained materials and their production. The aims of my researches are related to the investigation of differential speed rolling and the monotonity-analysis of forming processes. These can be summarized as follows:

- To develop a procedure which makes the application of such continuum mechanical calculations possible, using finite element analysis results, wherewith the monotonity analysis of forming processes can be performed.
- To develop a calculation method based on continuum mechanical basis and quantity wherewith the quantitative characterization of the deformation type of forming processes is possible in respect to the monotonity. Thereby information can be achieved about the expected microstructure
- To characterize the four deformation routes of the differential speed rolling in respect to monotonity
- To determine the differences between the four deformation routes of

the multi-step differential speed rolling in respect to the evolved microstructure and mechanical behavior for Al 7075 aluminium alloy.

Investigated materials and applied test methods

In the investigation, Al 7075 aluminium alloy was used, which is a widely used material of the industry. This is a high-strength precipitation-hardening alloy whose strength is comparable with many steels. Good fatigue behavior, mean machinability and corrosion resistance characterize it. The highest strength state can be reached with precipitation-hardening of the alloy. Its main alloying element is the Zinc, the table below contains its chemical composition.

Table 1.: The chemical composition of Al 7075 alloy

Al	Zn	Mg	Cu	Cr	Fe	Si	Mn	Ti
88 – 92	5,1 – 6,1	2,1 – 2,9	1,2 – 2,0	0,18 – 0,28	max 0,50	max 0,40	max 0,3	max 0,20

The rolling experiments and the related heat treatments and production of samples were conducted in BAY-NANO Institute in Miskolc. The rolling mill can be seen in the figure 3. The rolls are driven by two separate controllable electric motors, the speed of which can be adjusted between 0 and 10 rpm. The diameters of the rolls are Ø140 mm.

From the material (10x40x3000 mm) delivered from the producer specimens with the geometry of 10x40x3000 mm were prepared. Before the forming the specimens were annealed at 450°C for 2 hours and cooled in furnace.

The specimens were rolled in four steps from the initial thickness of 10 mm to the final 2.5 mm with symmetrical and differential speed methods according to the routes UD, ND, RD and TD. The work pieces were not heat-treated during and after the deformation. Thereafter the mechanical properties and microstructure of the deformed material were investigated.

The tensile tests were performed at the Department of Materials Science and Engineering of the Budapest University of Technology and Economics on a MTS 810 type 250 kN testing machine. The yield stress, tensile strength, elongation to failure and the specific work for failure were determined.

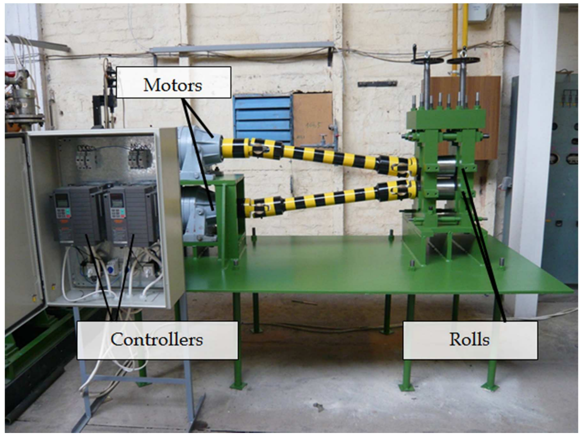

Figure 3: The rolling mill

The x-ray diffraction analysis of the microstructure was performed in the laboratory of the Department of Materials Physics of Eötvös Loránd University where the average crystallite size and the dislocation density were determined through line profile analysis. The microscopic investigations were performed at BAY-NANO Institute with dark and bright field transmission electron microscope technique.

For the analysis of deformation in respect of monotonity, I introduce a quantity which permits the investigation of forming processes in arbitrary coordinate system. The value of this quantity is related to the evolution of the ultra-fine grained microstructure. In order to allow the use of this method in case of finite element calculations, I developed a procedure based on the combined Euler-Lagrange description. A cubic smoothing spline was applied to eliminate the effect of the errors (noise) from the finite element calculations. The method is appropriate for the description of two