WEB ISSN 2535-003X
PRINT ISSN 2535-0021

COMBINED AND CONSECUTIVE SPD PROCESSING TECHNIQUES

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Abstract: *This work presents the analysis of the stress-strained state of billets processed by such SPD processing techniques as "ECAP-Conform", "drawing with shear" and "rotary forging" with a special geometry of anvils. We analyze the influence of processing by these SPD techniques, as well as by their combination with conventional metal working methods, on the structure formation and enhancement of properties in Al and Cu-based alloys, as well as in low-carbon steel. We demonstrate the critical role of the induced non-monotonous deformation in the formation of a combination of enhanced physical and mechanical properties in the investigated metallic materials during treatment by combined and consecutive SPD techniques.*

1. Introduction

The severe plastic deformation (SPD) is one of the effective techniques for fabrication of ultra-fine and nanostructured metallic materials [1,2]. An important factor for intensification of the process of the initial structure refinement is implementation of non-monotonous character of plastic deformation. Non-monotonous deformation should be divided into the induced one and the applied schemes' inherent one, e.g. the shear-inherent one. The induced non-monotonous deformation as a rule provides more effective formation of the ultra-fine (UFG) structure of the grained type [3]. Recently there have been developed new methods of SPD providing high degree of non-monotonous deformation during one operation (the combined methods), e.g. such as multi equal-channel angular pressing Conform (ECAP-Conform), drawing with shear, rotary forging with a special geometry of the die-set, which provides high level of the accumulated strain [4-6]. The analysis of efficiency of application of these schemes is presented below.

2. Multi ECAP-Conform technique

The process is implemented in the following way (Fig. 1): billet 1 is fed to the input channel, which is formed by a rectangular shaped graving of rotation working wheel 2 and stationary holder 3. The pressing force, leading to moving of billet 1 through the working channel, is ensured by rotation of working wheel 2 and appeared active friction forces between the graving of wheel 2 and billet 1. The working channel in the output has two graduated bendings, which provides consecutive triple shear deformation of billet 1 under the circumstances of continuous treatment.

The results of investigation of the strained state are presented in Figure 2.

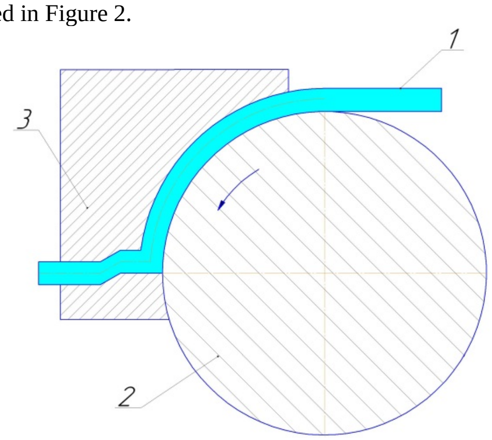

Figure 1 *- Scheme of multi ECAP-Conform: 1 – billet, 2 – working wheel, 3 – holder [5].*

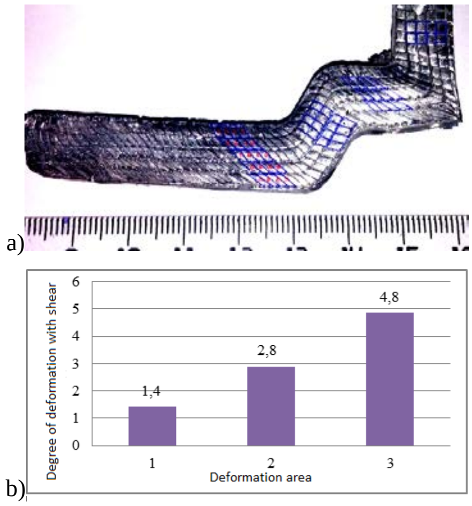

Figure 2 – *Investigation of the strained state: a – the sample after deformation (the grid method); b – diagram of the accumulated strain value*

The results of numerous trials of aluminum semi-products, fabricated on the pilot-industrial equipment, showed that the ultimate tensile strength (UTS) increased from 170±4 to 268±10 MPa, i.e. by 57%, and the electric conductivity – by 4.9%, as compared with the as-received state (T1).

3. Rotary forging

Rotatry forging is one of the efficient methods of reduction treatment of metals by pressure (see the principal scheme in Fig. 3). It is possible to achieve high values of the accumulated strain in the billets by using specific regimes of rotary forging and to form this way the ultra-fine grained structure in them [3]. Thus, the rotary forging is a promising technique of severe plastic deformation (SPD).

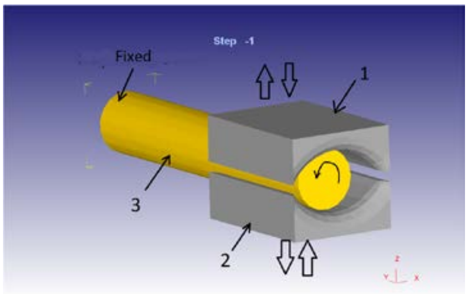

Figure 3. *The principal scheme of modeling of rotary forging: 1 – upper anvil, 2 – lower anvil, 3 – billet*

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Rotary forging of commercially pure copper grade M2 at room temperature showed that special anvils allow to form the structure with the fragment size of 1-5 µm (Fig. 4) during the process of plastic deformation, meanwhile the strength grows till 350 MPa.

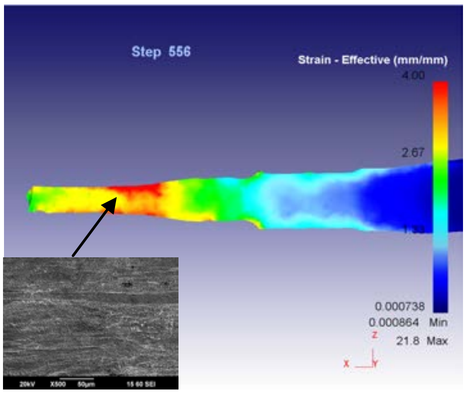

Figure 4 *– patterns of the strained state and structure of commercially pure copper grade M2 after rotary forging with the special geometry of anvils with the total reduction 80% (Deform-3D)*

Computer modeling shows that the special geometry of anvils provides the increase of the accumulated strain level in two times (e>3) as compared with the conventional rotary forging treatment (e=1.6).

4. The method of SPD – drawing with shear

This method includes operation of reduction treatment, combined with shear. Implementation of the method includes deformation of the metal according to the drawing scheme due to the applied tractive force through two consecutively located conical wire-drawing dies 1 and 2 with simultaneous rotation of one of the dies (2) (see Fig. 5).

The distinctive feature of the method is that rotation of one of the dies provides additional deformation with shear (torsion) due to a non-symmetric conic channel of the dies and the eccentricity designated around the axis of rotation. The shear occurs in the constrained conditions, because the deformation zone is limited by the shaping tool and at the hydrostatic pressure close to the yield stress.

The specific feature of the method is fabrication of heterogeneous strain state and heterogeneous structure in the cross section of the billet (Fig. 6)

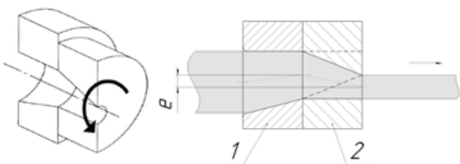

Figure 5. *Scheme of the SPD method – drawing with shear [7], e- eccentricity*

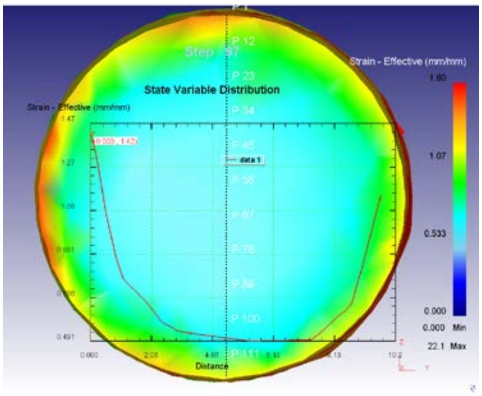

Figure 6. *Pattern of the strain state of the cross section of the billet from steel grade 10 after one cycle of drawing with shear at room temperature (Deform-3D).*

Investigation of structure of the billet from steel grade 10 in the cross section after one cycle of drawing with shear at room temperature showed that the heterogeneous type of structure is being formed. This structure possesses super fine grains in the periphery area with formation of the superhard layer 100 µm in width with Hv equal to 700 MPa.

Mechanical properties of steel grade 10 after one cycle of drawing with shear at room temperature is higher by 10% as compared with the reduction treatment via conventional drawing with the same reduction ratio.

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Acknowledgements: the authors acknowledge the financial support by the Ministry of Education and Science of Russian Federation under Grant agreement No. 14.586.21.0025 (unique identification number RFMEFI58616X0025).