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ON THE DEVELOPMENT OF THE NEW TECHNOLOGY OF SEVERE PLASTIC DEFORMATION IN METAL FORMING

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Abstract. The information about the effect of the plastic deformation mechanism on the formation of the sub-microcrystalline structure of steels is reported. It is shown that the development of the new technological schemes for metal forming with severe alternating deformation is promising. A rolling method by two passes, which provides severe alternating deformation with minor changes of the billet dimensions is proposed. The results of computer simulation showed that with the use of new rolling method the uniformity of deformation along the height and the value of the deformation degree in the plane of symmetry of the billet are increased.

Keywords: severe plastic deformation; alternating deformation; forging; rolling; structure.

1. Introduction

According to the experts in many countries of the world, development and research of the new severe plastic deformation (SPD) methods is still an attractive and urgent task. The interest to the problem caused by the fact that due to severe, and in some cases severe and alternating deformation it is possible to obtain metals with ultrafine-grained (UFG) and nanocrystalline (NC) structure, with a high level of mechanical and functional properties [1-5].

2. The influence of deformation mechanism on the formation of the submicrocrystalline structure in steels and alloys

The founder of the SPD method is P.W. Bridgman. In the work [1] the apparatus, which implements severe alternating deformation in the volume of the billet was presented (Fig. 1). Two disc shaped billets are placed in between dies and anvil, then they are compressed under the pressure of hydraulic press with the load force *P*. The shearing strain was applied manually by alternating rotation of the anvil by the angle α=35-60° with the necessary number of stages *n*.

The alternating strain amplitude determined by $\varepsilon_{ui} = (1/\sqrt{3})\cdot\alpha\cdot r/h$, and the accumulated strain – $\varepsilon_u = \sum_{i=1}^{n}\varepsilon_{ui}$, where the value of the radius *r* changes from zero to d/2 on the edge. The aim of the research was to gather information on the grain structure evolution for steels and alloys in dependence of the amplitude ε_{ui}, the number of alternating plastic deformation stages *n* and the stress state value $\dfrac{\sigma}{T} = \dfrac{4\sqrt{3}P}{\pi d^2\sigma_s}$.

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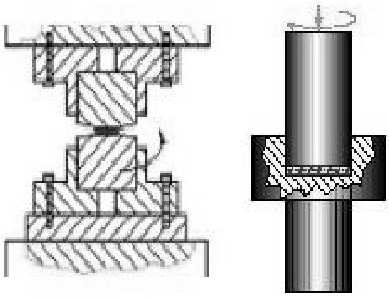
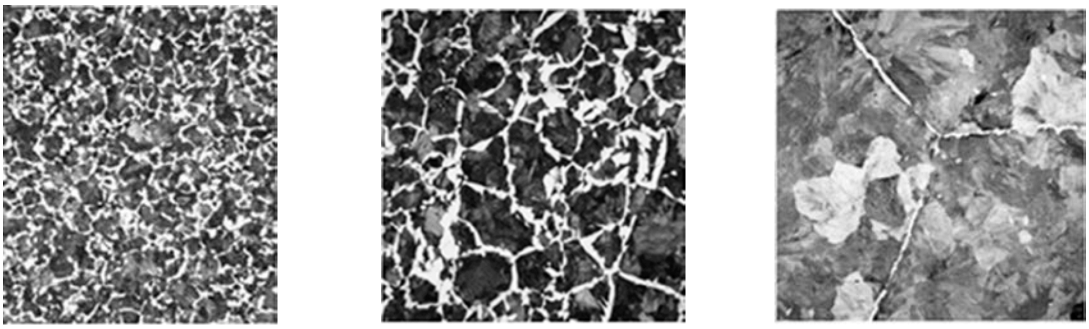


Fig. 1. Scheme of the SPD method on the Bridgman anvil.

The advantage of the SPD method on the Bridgman anvil is the possibility of establishing the dependence of the structure and properties of the metal on the characteristics of the stress state: $\frac{\sigma}{\sigma_s}$ relative mean normal stress, where $\sigma = \frac{1}{3}\sigma_i$, $\sigma_s = \left(\frac{\sqrt{3}}{2} s_{ij} s_{ij}\right)^{1/2}$, $s_{ij} = \sigma_{ij} - \sigma\delta_{ij}$ – components of the stress deviator; $\mu_\sigma = 2\frac{\sigma_2 - \sigma_3}{\sigma_1 - \sigma_3} - 1$ – Lode index. A feature of this method is insignificant shape change of the billet, since the shape of the finished product is close to the shape of the billet, but the structure and properties of metal change drastically.

In the Belarusian Academy of Sciences and later at the Ufa academic center was designed and developed method of equal channel angular pressing (ECAP) [3, 4]. The results of fundamental research of the process are as follows: during the process of ECAP, the billet passing through the matrix channel undergo shear deformation without changing its cross-section dimensions. Based on this principle, it can be concluded, that the deformation applied to the billet in a single pass, mainly depends on the angle φ between the matrix channels. Since the passage of the billet through the ECAP matrix channel does not affect the cross-sectional dimensions, high deformation degree can be achieved by multiple pressing of the billet. The disadvantages of ECAP are the limited cross-sectional dimensions and the length of the billet, as well as the difficulty during pressing high-strength and low-plastic materials.

In the work [6], the authors showed that one of the traditional methods of severe alternating deformation, providing the fine-grained structure is helical rolling of the billet (Fig. 2).



a) b) c)

Fig. 2. Microstructure of 32HG steel for continuous cast and rolled billets (resolution 100 μm):
a – rolled billet after the reduction by the helical rolling method with the elongation ratio λ = 1,56; b – billet after the longitudinal rolling with the elongation ratio λ = 5,94;
c – initial continuous casting billet.

The rolling of the continuous casting billet (Fig. 2c) from a diameter of 150 mm to 120 mm on a three-roll mill is characterized by a high deformation degree (on the surface $\varepsilon_u = 4{,}73$, in the axial zone $\varepsilon_u = 0{,}51$) with a relatively small reduction (elongation ratio $\lambda = 1{,}56$). Due to the severe alternating deformation, a fine-grained structure is formed (Fig. 2a). A rolled billet with the diameter 120 mm, obtained by longitudinal rolling on the mill «650» with the elongation ratio $\lambda = 5{,}94$, has a size of austenitic grain 5-6 times larger (Fig. 2b) than during helical rolling.

3. Development of the forging and the longitudinal rolling methods of billets under severe alternating deformation conditions

Forging in special dies allows processing long billets under the severe alternating deformation conditions. Ingot 1 upsetted in two stages, first in the section-shaped dies 2, then in the flat dies 3. In the section-shaped dies 2 bulges and recesses on the billet are formed. In the flat dies 3 the billet is smoothed and takes former sizes (Fig. 3).

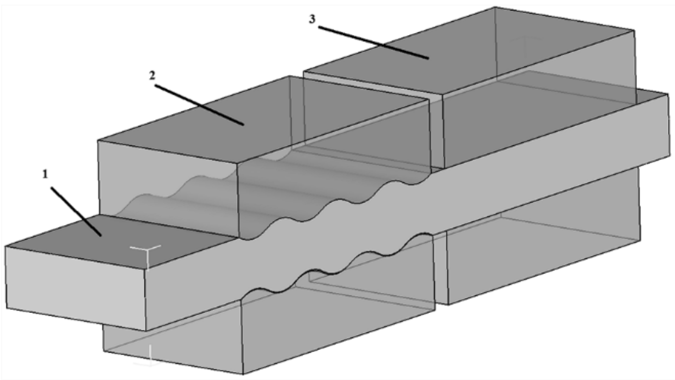
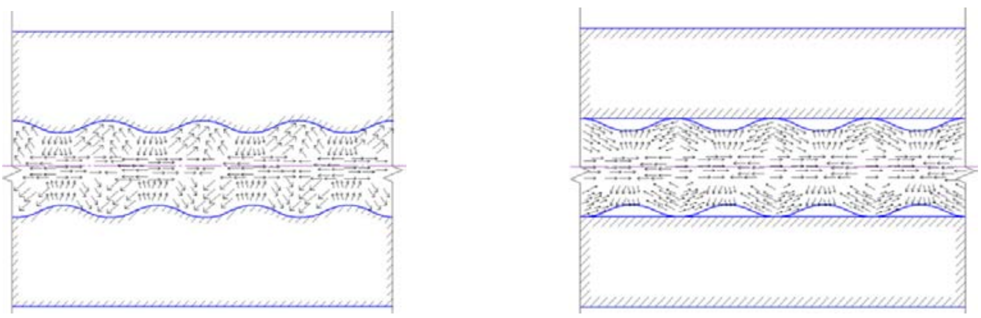


Fig. 3. The design of dual SPD press.

On the section-shaped dies cylindrical form bulges displace metal particles into recesses on the dies. In the flat dies metal particles are displaced from the billet bulges into recesses. Fig. 4 shows vector velocity fields during billet upsetting in section-shaped (Fig. 4a) and flat (Fig. 4b) dies, which indicate the alternating nature of the metal flow. Thus, the severe alternating deformation is implemented. Calculation of the die impression and the upsetting value *Δh/h₀* is carried out from the condition of uniform deformation distribution along the cross section of the billet with taking into account die impression filling on the first stage and smoothing the billet surface on the second stage in such way, that height has reached its initial value.



a) b)

Fig. 4. The vector field of the metal particles velocities during reduction by section-shaped (a) and smooth dies (b).

A similar severe alternating deformation method is proposed to implement during rolling of thick slabs in the double SPD stand (Fig. 5) [7]. Rolling occurs without the billet widening due to the presence of non-driven edging rolls. The surface shape of rolls in the first stand made in the form of alternating annular blockers and collars with the same radius. The rolls are setup in such way, that the gap between collars apexes equals to the value $a=h-\Delta h$, and between blockers apexes to the value $b=h+\Delta h$, where h – height of the rolled billet, Δh – absolute reduction in the plane of the collars.

As in the case of the billet upsetting in dual press, during rolling in a double SPD stand the billet undergoes alternating deformation, and the distribution pattern of the vector velocities field of the metal particles will be the same as shown in Fig. 4.

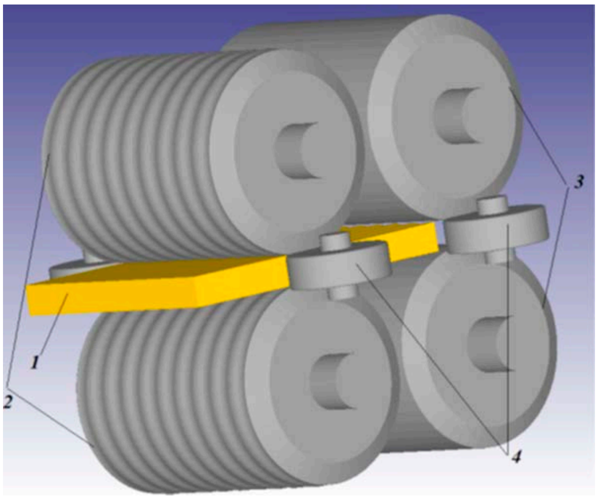


Fig. 5. The solid model of the double SPD stand:
1 – billet; driven horizontal rolls with section-shaped 2 and smooth 3 barrels, 4 – non-driven edging rolls.

Computer simulation of the proposed rolling method was carried out with the aim of determination of optimal blocker and collar sizes of rolls with section-shaped barrel, as well as the reduction value of the billet on the collars Δh in such way, that during rolling in the first stand the blocker was filled with metal, and during rolling in second stand with smooth rolls the surface of the billet was smoothed at the minimal elongation ratio and the fulfillment of the condition of uniform strain in billet sections on blockers and collars. As a result, the calculation methodology of the radius r and the distance e between the lines of the circle centers of collars and blockers, the rational value of the relative reduction of the billet $\frac{\Delta h}{h}\cdot 100\%$ in the first and second stands, which accordingly equal 15% and 20%, was developed.

To assess the efficiency of the new rolling method a comparative analysis of rolling of the thick sheet with height h=65 mm made of slab with height H_0=300 mm in the rolls with smooth barrel by the existing technology for eleven passes and by the proposed rolling technology with the reduced size billet with height H_0=160 mm for sever passes was performed. The criterion of efficiency was the accumulated deformation degree in the plane of symmetry, homogeneity of deformation along the height and the value of energy consumption for the production of rolled thick sheet with height h=65 mm. In Fig. 6 curve 1 shows the accumulated deformation degree of the billet with a height H_0=300 mm during rolling by the existing technology for eleven passes. Curves 2 and 3 show the accumulated deformation degree of the billet with a height H_0=160 mm during rolling by the proposed technology for seven passes, calculated for two sections – under the blocker and the collar of roll accordingly. As can be seen from curves 2 and 3 in Fig. 6, the total deformation degree for seven passes in the plane of symmetry is 1.15-1.2 times higher than by the existing rolling technology of high billets for eleven passes. Rolling by the new technology allows to reduce strain heterogeneity by 6 times in comparison with the existing technology. This effect was achieved due to the use of severe alternating deformation during rolling by the new method.

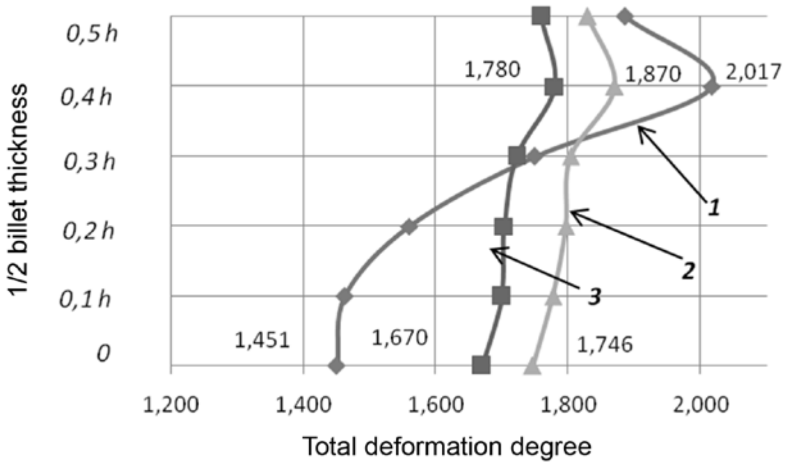


Fig. 6. The distribution of the total deformation degree $\sum \varepsilon_u$ along the billet height by the existing technology for eleven passes and by the proposed technology for seven passes.

According to the results of the comparative analysis of computer simulation it was concluded that the rolling of the billet using new technology can reduce the number of passes from nine to seven. In addition, the new rolling technology of thick plates made of continuous casting billet with height 160 mm instead of 300 mm allows to reduce energy consumption by 1.8 times.

4. Conclusion

The existing SPD methods solve only scientific problems and most of these methods allow processing billets with limited sizes due to specific tool design. In this regard, development of the new SPD methods, which allow processing long billets is relevant. In this work was proposed to use method of slabs rolling in a double SPD stand with high degree and uniformity of strain in fewer passes with simultaneous reduction in energy consumption compared to the existing flat rolling technology.

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