Simulation of the macrostructure influence of forging ingots on the potential capabilities of obtaining high-quality forgings

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Abstract
The results of range expanding potential possibilities of technological process of forgings manufacturing by using shear deformations intensification in the volume of forging ingots with a triradiate cross-section configuration which are subjected to free forging and performed by finite element modeling are presented. The influence during modeling of hypothesis of isotropy and structural heterogeneity on the transformation intensity of dendritic structure from coarse into fine-grained by using flat and combined dies was shown.
Key words: FINITE ELEMENT MODELING (FEM), SHEAR DEFORMATIONS, FORGINGS MANUFACTURING, FORGING INGOTS MACROSTRUCTURE, HYPOTHESIS OF MODELING

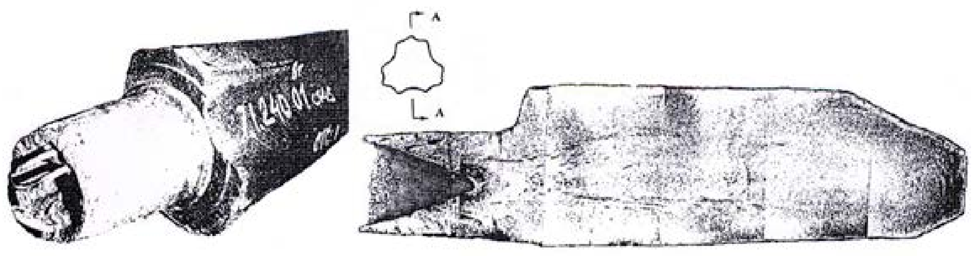
Formulation of the problem

Increasing the yield of usable metal and, consequently, the efficiency increase of production methods of finished products is one of the most important parts of the resource saving and metal capacity problem of national product. At the same time increasingly high demands are placed on the quality of the finished products.

With regard to the process of obtaining high quality forgings with a predetermined macrostructure and required distribution level of physical-mechanical properties of metal, including the part of results of the dimensions identification of allowed discontinuities when their nondestructive ultrasonic testing according to ASTM or DIN method, this problem is solved both by improving the shape of the original ingot and by the use of various technological methods which are based on such resources of physical and mechanical influence: thermal zonal factor or deformation effect of the die with working surfaces providing an intensification of shear deformation [1-3 and others].

From the standpoint of increasing working out of the axial zone of the ingot, i. e. transformation of coarse dendritic structure to a fine-grained, one of the leading roles in the mechanism of plastic deformation and closing of discontinuities (jointing, closing, cavities welding) of deformable metal [4-5] is given to shear deformations. At the same time prospective deformation effect from the intensification of shear deformations, which value is significantly less than the normal components of deformation tensor and in times more than deformation influence of latter [6]. However, implementation of the above approach requires on the one hand a detailed study on the mathematical models of possible industrial implementation of technological redistribution of forging ingots macrostructure and intensification of shear deformations, and on the other hand it requires carrying out of at least laboratory and industrial tests confirming (disprove) the results obtained from mathematical models.

As applied to the conditions of forgings production from a triradiate ingot in conditions of “Ufaley Metalware Plant”, the changes in the location of “vee zones” and of liquation areas were found by sulfur prints (Fig. 1). At the same time, the question of the influence of such ingot macrostructure on the potential opportunities for obtaining the high-quality forgings by transformation of coarse dendritic structure to the fine-grained due to the intensification of shear deformations remains poorly investigated and is relevant.



a) b)

Figure 1. The triradiate ingot mass of 8 tons (a) and sulfur print in section A-A (b)

Analysis of recent researches and publications

Describing the complex set of phenomena characteristic of plastic deformation of metals and alloys the researchers in an effort to create a detailed picture of the investigated processes come to the need of building more complex mathematical models that require application of thin and efficient modern mathematical apparatus not only to determine the deformation and temperature parameters, but also to describe the structural changes and properties of the deformable metal.

The experimental data are the basis for the creation of theoretical methods of calculation of plastic deformation processes, as well as the criterion for the correctness and accuracy of analytical solutions. In fact, reliability of the results obtained by finite elements method is due to the presence of pilot and experimental data about the peculiarities of the metal plastic flow.

Potential possibilities of overcome the many difficulties, not only hinders the solution space (volumetric) problems, but also their particular cases – in two-dimensional planes of symmetry and on the side face from the status of experimental and calculated level to the experimental and analytical were established by G. A. Smirnov -Alyaev and V. M. Rosenberg [7] due to the implementation of approach for the use of experimental data processing not only in the Euler or Lagrangian, but also in the combined Euler-Lagrangian representation (CEL-view). In this case, the CEL representation of processed experimental data significantly expands the possibilities of theoretical methods for simulation of metals plastic forming and in particular the method of finite elements.

The primary starting point for FEM simulation of free forging process were the obtained from layered samples of Pb-Sb-alloy under simulation conditions using the CEL method [8] in their gradual deformation of the experimental calculated components ξ_{ij} of the strain rate tensor T_ξ, reflecting the instantaneous ("frozen") picture of the deformed state at a fixed time τ.

Further studies have shown that the location and type (configuration) of the maximum deformation rate zones (instantaneous deformations) ξ_{22} and ξ_{33} agree well with the izohrom changing diagrams obtained on samples of the epoxy resin and the lead sample with an optically sensitive coating at their elastic and plastic deformation if the izohrom fields are interpreted as strain rates fields as well as the distribution diagrams of vertical and transverse strains obtained by the measurements results of the lead samples coordinate grid applied to the symmetry planes. The differences are observed for the peripheral layers of deformable workpiece, which is due to the edge effect of the polarization-optical method. However, the results with high degree of convergence correlate with the data obtained by A. A. Milenin at FEM simulation of stretching operation in rolling-impression dies.

In connection with the foregoing, the practical use of commercial software Deform 3D (the most common specialized complex for simulating the conditions of metal plastic deformation in the deformation process) appears advisable. At the same time from the position of identifying the best conditions for working out the cast structure of forge triradiate ingot which is subjected to plastic deformation the greatest interest atracts the distribution of shear deformations ξ_{ij} (tangential component T_ξ) in its cross-section.

Work objective

Based on the finite element method we should develop the simulation technique and estimation of influence of forging ingots macrostructure with triradiate cross-section on the potential of obtaining high quality forgings due to the intensification of shear deformations.

The presentation of research results

Below are the initial results of 3D-FEM simulation of plastic deformation of forging ingots with a triradiate cross-section made in Deform 3D software package for the following conditions:

– Dies type: flat and combined (flat top, and bottom with a cutout corner 135°);

– Ingot macrostructure: isotropic and with the presence of liquation;

– Degree of percentage reduction ε: 3.7 % and 11 %.

The results of primary calculations are shown in Fig. 2 and 3. In this case, Fig. 2 (left half) shows the pattern of shear deformations isolines ξ_{23} in cross-section subjected to compression in a flat die at a value $\varepsilon = 11$ % of triradiate ingot with taking into account its liquation and condition of its isotropy (right half), and Fig. 3 shows the picture of tangential component isolines T_ξ in cross section for similar conditions.

Comparison of isolines values with taking into account the liquation and isotropy conditions indicates the occurring differences in subjected to plastic deformation forge triradiate ingot while maintaining their overall distribution pattern.

The maximum values according to the absolute values of the tangential deformation (instantaneous) in the cross-section of the triradiate ingot take place in the areas of contact with deforming tool – die. At the same time the highest vertical and transverse deformations are characteristic of the central deformable layer of the workpiece.

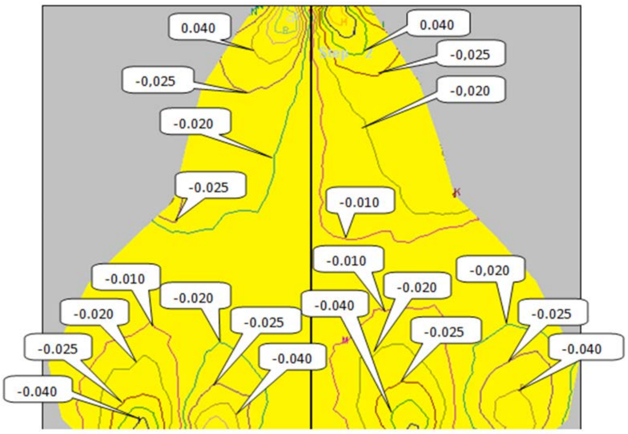


Figure 2. Isolines of shear deformations ξ_{23} in cross section models subjected to reduction ε = 3.7 %: with chemical inhomogeneity (left) and without it (right)

Taking into account that the difference, and, consequently, the square of the difference between the normal components of the strain rate tensor T_{ξ} are maximal in the axial zone where the shear deformations are developed the least,here values of the second invariant tensor T_{ξ} are expected to be relatively low, i. e. intensity of instantaneous shear deformation H, the cumulative degree of shear deformation Λ, reflecting the total effect on the working out the cast structure of forging ingot subjected to plastic deformation.

This conclusion is confirmed in further distribution of isolines values of instantaneous intensity of shear deformations H in cross section taking into account its chemical inhomogeneity. Accounting the chemical heterogeneity was carried out by varying the sizes of the elements of the finite element mesh proportional to the corresponding value of deformation stress of the workpiece deformable material.

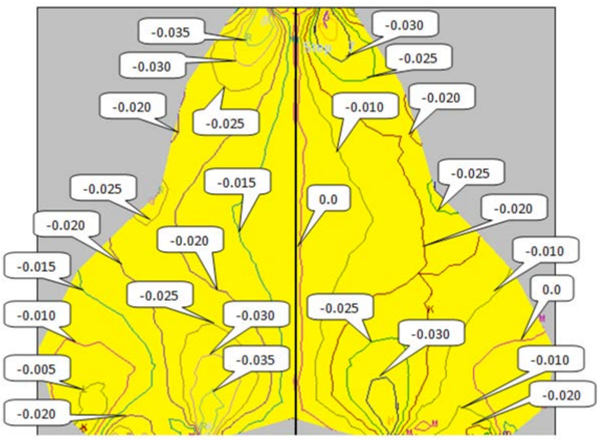


Figure 3. Isolines of tangential component T_{ξ} in cross section models subjected to reduction ε = 11 %: with chemical inhomogeneity (left) and without it (right)

Comparative analysis of intensity fields of instantaneous shear deformations H in cross section with taking into account its chemical inhomogeneity (Fig. 4, left) and without (in condition of its isotropy Fig. 4, right) reveals some illustrative differences in H valus, which is grater by 17.5% for the case of the ingot deformation based on the availability liquation in its volume.

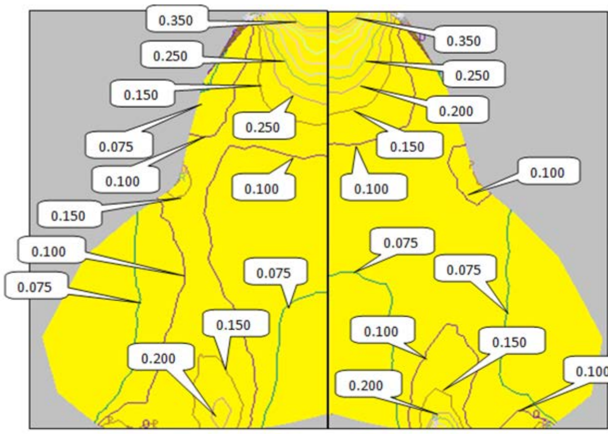


Figure 4. Intensity isolines of instantaneous shear deformations H in cross section models subjected to reduction ε = 11 %: with chemical inhomogeneity (left) and without it (right)

At the same time, the differences relate to the penetration on the greater depth in the axial zone of the deformable workpiece by the impact of deforming tool – upper flat die while expanding the occupied area of H values influence for which values liquation are specified. From the standpoint of increasing working out of axial zone this circumstance plays a positive role, especially in the case of rational technological modes of deformable workpiece turning.

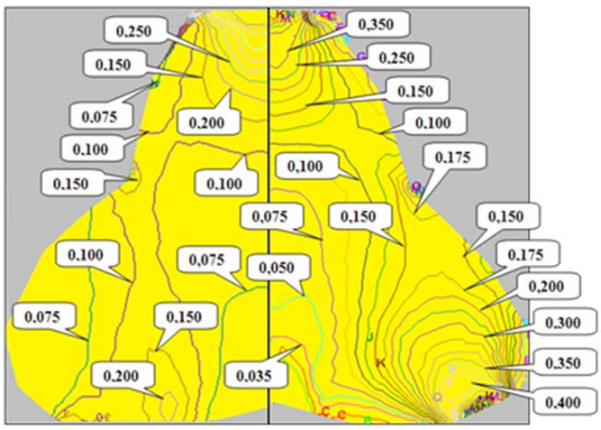


Figure 5. Intensity isolines of instantaneous shear deformations H in the cross section of models under isotropy conditions of its physical and mechanical properties, ε = 11.0 %: reduction in the flat (left) and in the combined dies (right)

Comparative analysis of isolines fields with intensity shear deformation H in cross section under condition of isotropy of its physical and mechanical properties using reduction(ε = 11%) with flat dies (Fig. 5, left) and with combined dies (upper die is flat and bottom die is rolling-impression) (Fig. 5, right) reveals some differences in the values of magnitude H mainly within the area of the bottom rolling-impression die with a cutout corner of 135° (Fig. 5, right bottom) in the direction of their increasing by at least 2 times, while in the upper flat die action area has practically similar pattern of the isolines fields with identical values of magnitude H.

Comparative analysis of the intensity fields of instantaneous shear deformations H in the cross section of the triradiate ingot by using combined dies (upper die is flat, and the bottom – rolling-impression) with taking into account chemical inhomogeneity and as a result, anisotropy of the deformation resistance in its cross section (Fig. 6, left) and without it (under condition of its isotropy, Fig. 6, right) reveals certain differences in values of the magnitude H, relating mainly axial zone and to a considerably lesser extent of areas adjacent to the zones of contact with the dies. From the standpoint of increasing the axial zone working out , i.e. the transformation of coarse dendritic structure in the fine-grained, this fact plays a positive role as a result of the significant role of shear deformation in the actual mechanism of plastic deformation and closing of discontinuities (jointing, discontinuities welding) of the deformable metal [4-5].

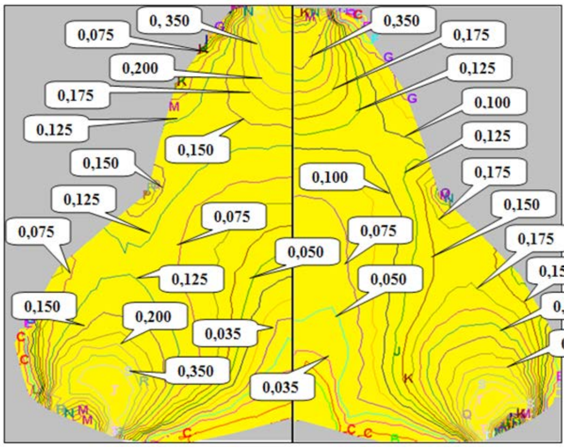


Figure 6. Intensity isolines of instantaneous shear deformations H in cross-section of models subjected to reduction ε = 11.0 % in combined dies: taking into account the chemical inhomogeneity (left) and without it (right)

The presented in Fig. 5 and Fig. 6 results allow us to expand the range of forging technological processes of difficult-to-form and low-plasticity steels and ensure minimal anisotropy of mechanical properties at low forging ratio in the case of application, in particular, rational modes of deformable workpieces turnings. This success in solving the problems of effective resource saving (energy and material capacity of forgings) is largely determined by the potential and conditions for the practical implementation of human capital of professionals of industrial production metallurgical and engineering sectors, scientists and researchers from research and development, technology and design-engineering organizations.

Conclusion

Availability of obtained in layered samples from Pb-Sb-alloy simulation conditions using the combined Euler-Lagrangian method of pilot and experimental data about the characteristics of plastic flow of the metal allowed us to develop on the basis of the finite elements method the simulation methodology of the macrostructure impact of forging ingots on the potential opportunities for obtaining the high-quality forgings by transformation of coarse dendritic structure to the fine-grained due to the intensification of shear deformations. For the first time for the free forging case of forging ingots with triradiate cross section by 3 D-FEM simulation method we obtained the fields of isoline "instantaneous" shear deformations ξ_{ij} strain rate tensor T_{ξ} ("instantaneous" tangential deformations) and the intensity of instantaneous shear deformations H for applications of flat and combined dies taking into account isotropy as well as the presence of chemical inhomogeneity of forging ingots macrostructure. The possibility of expanding the range of forging technological processes of difficult-to-form and low-plasticity steels with ensurence of minimal anisotropy of mechanical properties at low forging ratio in the case of application, in particular, rational modes of deformable workpieces turnings was predicted.

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