MODELING OF THE ENERGY POTENTIAL SAVING IN THE PRODUCTION OF SEAMLESS PIPES

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Received 25 April 2016
Accepted 03 February 2017

ABSTRACT

The numerical simulation results of the potential of expanding the technological range of forgings manufacturing processes using forging ingots with a three-beam cross-sectional configuration due to the intensification of shear deformation in their entirety are presented. The study reveals some aspects of the impact of chemical heterogeneity and contamination of the metal ingots with non-metallic inclusions on the density of the metal and the intensity of its changes in the axial zone of the forged pipe billets in case of combined dies use.

Keywords: shear deformations, FEM modeling, forgings manufacturing, forging ingots macrostructure, hypothesis of modeling.

INTRODUCTION

Reducing the probability of formation of internal scab in the production of seamless pipes with a simultaneous increase in ratio of metal yield and, consequently, increasing the efficiency of the production methods of finished products is one of the most important components of the specific quantity of metal of the final product, the requirements to quality of which constantly grow. In relation to the process of obtaining high quality forging semi-finished products – steel billets, this problem is solved either by improving the shape of the cross section of the original ingot or applying different technological methods, which are based on the resources of such physical-mechanical impact as thermoareal-mechanical factor and effect of deformation from the dies with working surfaces, which provide intensification of shear deformation [1 - 2]. In this respect, from a perspective of increasing a workup degree of the axial zone of the ingot, namely - the conversion of coarse dendritic structure to fine-grained, one of the leading roles in the mechanism of plastic deformation and closure of deformable metal discontinuities [3 - 4] is given to shear deformations.

EXPERIMENTAL

None of production processes can be imagined without application of software engineering analysis or CAE (computer aided engineering) – software support of engineering calculations, including those based on the wide use of currently theoretical finite element method (FEM). The only criterion for the accuracy and reliability of theoretical methods is the degree of approximation of the obtained calculations results to the experimental data [5 - 6]. The potential of overcoming many difficulties in the analysis of metal forming (MF) processes, which constrains solving not only 3-dimensional problems, but also their special cases – two-dimensional in the symmetry plane and on the side, is developed by G.A. Smirnov-Alyaev and V.M. Rozenberg [7]. The implementation of the proposed in the work [7] approach of processing the experimental information not only in Eulerian or Lagrangian but also in the combined Eulerian-Lagrangian representation (CEL-method) drastically expands the capabilities of theoretical methods, including FEM.

An initial starting point for 3-D-FEM simulation of forging process was the results of processing with the CEL-method of primary data that was obtained during physical modeling using layered samples of Pb-Sb alloy in laboratory conditions [5]. The results of numerical 3-D-FEM simulation of the above-mentioned metal forming process treated by means of the software product Deform 3D with a high degree of convergence correlated to each other, on condition that isochron field is interpreted as a field of strain rates [2].

The analysis of available publications in the last decade shows that a considerable number of material was accumulated regarding the various methods and mechanisms of intensification of shear deformation in plastic forming of metal, including improving the quality of its macrostructure (the closure of discontinuities, welding of pores and cavities). 3-D-FEM-modeling using software product Deform 3D of different matching variants of the original shape of the cross section of the ingot and separate techniques of forging process allowed to identify some directions of activation of shear deformation, contributing to the seal of the axial zone of the forging shafts [2]. All of the abovementioned has provisionally enabled to point out the processes of numerical simulation of potential resources for improving

Table 1. The values of mechanical properties of pipe forgings billets, parameter C/c of permissible internal discontinuities of private desirability function di, i = 1-6 and D-criterion.

The cross section of the ingot	The diameter of the pipe billets, [mm]	Product properties / the values of the private functions of desirability d_i, i = 1–5				parameter C/c / d_5 [mm]	D-criterion
		$\sigma_{0,2}$ / d_1 [N mm^{-2}] /[mm]	δ_5 / d_2 [%]/[mm]	ψ / d_3 [%]/[mm]	score of axial looseness / d_4 [mm]		
 ingot A	410	167,4/0,71	17,1/0,66	37,2/0,70	2,0/0,60	80,5/0,63	0,66
	500	164,9/0,68	15,8/0,64	33,6/0,68	2,2/0,64	78,6/0,74	0,64
 ingot B	410	170,2/0,83	21,1/0,71	44,7/0,76	1,5/0,83	90,5/0,85	0,78
	500	168,8/0,81	20,3/0,70	42,9/0,74	1,7/0,81	88,3/0,83	0,77
 ingot C	410	172,5/0,85	23,2/0,73	45,1/0,78	1,2/0,85	93,8/0,87	0,82
	500	170,3/0,83	21,4/0,71	44,7/0,76	1,4/0,83	91,2/0,85	0,80

the production of seamless pipes by reducing a rejection of workpieces subjected to the forging due to axial porosity as a separate subsection of research.

RESULTS AND DISCUSSION

In the results of quality identification of forged pipe billets (products) the following informative parameters are set: σ_s (N mm^{-2}) – tensile strength (temporary resistance); $\sigma_{0,2}$ (N mm^{-2}) – yield strength; δ_5 (%) residual relative elongation of the sample under tension; ψ (%) relative residual narrowing of the cross-sectional area of the sample under tension; C/c – dimension parameter of permissible internal discontinuities determined during non-destructive ultrasonic testing (UT) (2 mm < d_{eqv}. < 3 mm, d_{eqv} – equivalent diameter of internal discontinuities). At that the permitted deviations of these informative parameters are regulated at the level of 5 % for $\sigma_{0,2}$, 30 % for δ_5 and 25 % for ψ.

In view of such quality identification system of forged pipe billets an estimation of their quality level was done by means of an integrated index of generalized desirability function of Harrington criterion D while production of octagonal and three-beam forging ingots with symmetric and eccentric cross-section having weight of 8 tonnes and made of steel grade – St. 20 GOST 1050-88 (Table 1). The transition from normalized to the mean values of the test results of tensile specimens and non-destructive ultrasonic testing of pipe forgings billets to private desirability function d_i, i = 1-6 was carried out on S-curve of desirability function [8].

As can be seen from Table 1, an embodiment of a three-beam forging ingots with a symmetrical cross-section (ingot B), but having different taper of their beams, allows to reduce the score dimension of internal discontinuities in forgings by average of 16.5 % and decrease the score of their axial looseness in the axial part by average of 23.7 % while improving other quality parameters. Besides, the data of Table 1 allow to make an assumption that the presence in the last ingot of distinct offset angles of the beam relatively to each other (an ingot C with eccentric cross-section) will help to reduce the dimension of internal discontinuities of forgings and reduce the score of axial looseness in their axial parts to an even greater extent.

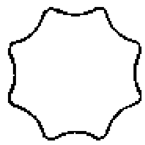
A generalized assessment of the quality level of forged pipe billets using the D-criterion of Harrington (Table 1), indicates that the use of three-beam forging ingots with a symmetrical and eccentric cross-section has the potential of releasing more competitive products of high quality level, as it is considered that the values of desirability function from 0.63 to 0.8 correspond to “good” and from 0.8 to 1 – “very good” level of properties of the products.

A special case of laboratory-industrial tests of the substitution of the forging ingots having weight of 8 tonnes and steel grade 20 GOST 1050-88 with an octagonal cross section to a three-beam forging ingots with identical mass of 8 tons and steel grade 20 GOST 1050-88, allowed us to obtain promising results of the potential of reducing the probability of internal scab formation and, as a result, ensure resources saving in the production of seamless pipes. The practical realization of such potential technological conversion of macrostructure of forging ingots weighing over 8 tons due to the intensification of shear deformation requires a detailed study by means of mathematical models.

In practice, the observed data of monitoring the quality level of forgings according to the international standards requirements without assessing the negative impact of chemical heterogeneity and contamination of the metal ingots with non-metallic inclusions on the density of the metal and the intensity of its changes in the axial zone of the forged pipe billets are not full. Using the results of even priori information about the linkage of density of the metal with the intensity of its changes in the axial zone of the forged pipe billets, including the implicit form, can significantly improve the conditioning of the mathematical problems of optimization of technological processes, increase the accuracy and reliability of obtained results of numerical simulation [6].

In view of such approach at the first stage of technological development of possible substitution of the octagonal forging ingots to three-beam forging ingots a quantitative assessment of the extreme concentrations and the relative content of chemical elements was performed (Table 2).

Table 2. Extreme concentration and relative content of chemical elements in forging ingots having weight of 8 tonnes and steel grade 20 GOST 1050-88.

chemical elements	Concentration (min, max) and relative content (Rmin and Rmax in ladle sample, Rht in melting on tapping) chemical elements							
								
	min	max	Rmin / Rht	Rmax / Rht	min	max	Rmin / Rht	Rmax / Rht
C	0,15	0,53	0,83	1,23	0,17	0,24	0,77	1,17
S	0,025	0,047	0,87	1,39	0,023	0,039	0,75	1,24
P	0,017	0,021	0,79	1,26	0,019	0,025	0,73	1,20

Based on Table 2 data it can be seen that a three-beam forging ingots detect at average less chemical heterogeneity of carbon (C) and impurities (S and P) with respect to the weighted average values Rmin/Rht: for carbon (C) 7.5 %, sulphur (S) by 14.8 %, for phosphorus (P) by 7.4 % and with respect to the weighted average values of Rmax / Rht for carbon (C) by 4,2 %, sulphur (S) by 11.2 %, for phosphorus (P) by 4.9 %.

At the second stage of the technological development of possible substitution of octagonal forging ingots the three-beam forging ingots having weight of 8 tonnes and steel grade 20 GOST 1050-88 were subjected to roughing and fullering in the combined dies with obtaining the forged pipe billets having a diameter from 280 mm to 500 mm with forging ratio FR in the magnitude range of 2.0 – 3.5. Laboratory and industrial tests of hydrostatic weighing of samples cut from their axial zone, show the following. The lowest density ρ (g cm^{-3}) according to the requirements of ASTM E 112 and NFA 04.102 (method A, ≤ A3-B3-C3-D3) is found in central layers of metal of forged pipe billets obtained from an octagonal forging ingots (Fig. 1, solid line 1), and the highest is in the three-beam forging ingots (Fig. 1, dotted line 2).

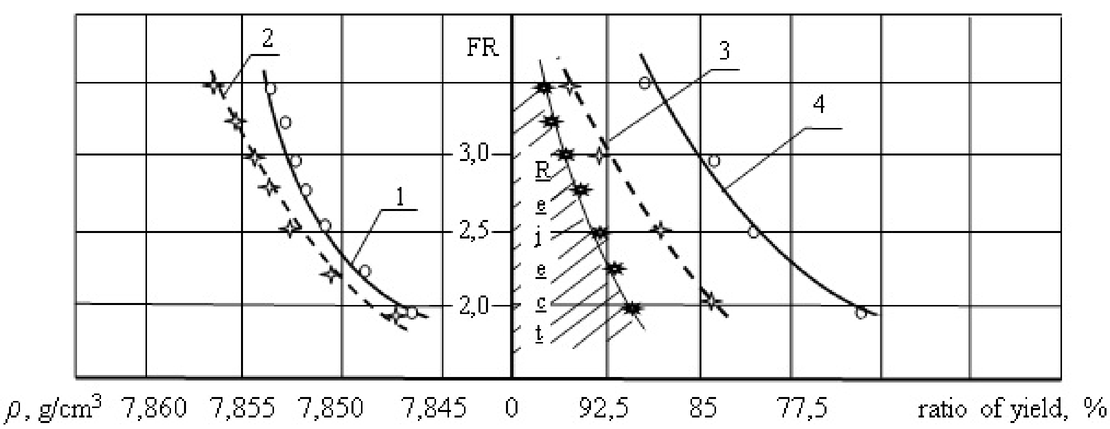


Fig. 1. The dependence of the forging ratio FR, the density ρ of the metal of forged pipe billets and the results of their UT when the value of non-metallic inclusions is less than A3-B3-C3-D3 (method ATM E 112).

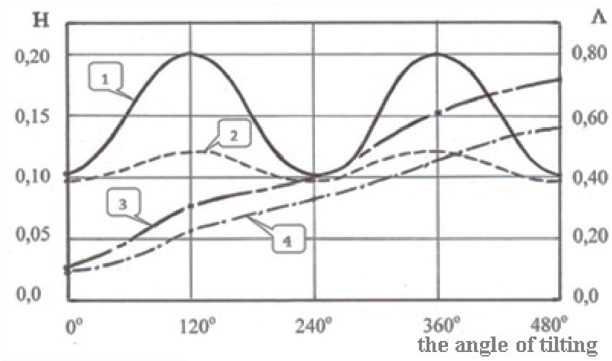


Fig. 2. Change of the variables H and Λ values of in the axial zone of the forged pipe billets: 1, 2 and 3, 4 - values of H and Λ, respectively, when forging three-beam and octagonal ingots in combined dies with an angle of cut-out is 135 o and the relative drafting ε = 10,5 %.

With increasing forging ratio FR in the forging process of pipe billets of smaller diameter, the difference in the increase of the density of metal in their axial zone grows due to the effect of "loosening" impact of non-metallic inclusions on the wrought metal. At the same time, the substitution of octagonal to three-beam ingots entails an increase at least by 13.5 % of the total ratio of metal yield of forged pipe billets, in which according to the ultrasonic test results the parameter of permissible dimension of internal discontinuities with equivalent diameter d_{eqv}. at the level of C/c corresponds to the minimum values (2 mm < d_{eqv}. < 3 mm). The decline of the share of forged pipe billets made of three-beam forging ingots that does not meet the C/c level as a results of ultrasonic test (Fig. 1, dotted line 3) in comparison with ones made of octagonal forging ingots (Fig. 1, solid line 4) is from 5.3 % at forging ratio FR ≥ 3 to 8.5 % at forging ratio FR = 2.

The results of a numerical 3-D FEM simulation of the intensity and cumulative degree (Odqvist parameter) of shear deformations ("frozen" component of the tensor of strain rates T_ξ) during plastic forming of octagonal and three-beam ingots performed using the software package Deform 3D revealed a deeper penetration in the axial zone of the forged pipe billets during plastic forming of a three-beam forging ingots. From the perspective of improving the workup of the axial zone of the forged pipe billets and, consequently, increasing its density due to the transformation of a coarse dendritic structure to fine-grained with the closure of discontinuities, welding of pores and cavities, this fact plays a particularly positive role in case of application of rational operating practices of tilting subjected to free forging of three-beam forging ingots. The values of the intensity of the instantaneous shear deformations H and Odqvist parameter $\Lambda = \int Hdt$ when using the tilting angles equal to 120° during plastic forming of three-beam forging ingots in the axial zone differ at most up to 37 % in comparison with plastic deformation of octagonal forging ingots (Fig. 2).

For a material point located at a distance of 1/3 of a beam of the three-beam forging ingot from the center of its axial zone the difference in the accumulated values of value Λ after the implementation of the fourth tilting of ingots subjected to drafting on the press die forging (at the angle 480^o with respect to its initial position) in relation to analogical conditions of plastic forming of octagonal forging ingots is a little bit more than 25 %. In the case of assumptions even with the minimal engineering accuracy (7 - 8 %) this shows the potential for improving the workup of the axial zone of the forged pipe billets and, consequently, reducing the probability of formation of internal scab in the production of seamless pipes with a simultaneous increase in metal yield ratio.

CONCLUSIONS

Numerical 3-D FEM modeling of the technological range of manufacturing processes of forged pipe billets using the forging ingots even if the final results are assumed to have minimal engineering accuracy (7 – 8 %) allows to predict at least the directions of the improvement potential of metal forming technological processes.

The use of the laboratory and industrial tests' information stipulates that the formulation of the problems of optimization of technological processes of metal forming is more correct, and their numerical simulation in the mathematical sense – more rigorous, reliable and valid.

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