

DESIGN IMPROVEMENT OF THE STEP-WEDGE DIES AND EXPERIMENTAL STUDY OF THE FORGING PROCESS OF 45 STEEL BILLETS

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ABSTRACT

In this paper, a forging tool of a new design is proposed, which allows to implement shear and alternating strain in the entire volume of the deformed billet with a smaller change in its initial dimensions. To confirm the effectiveness of the proposed new forging tool in obtaining billets and forgings of the plates and slabs type of the required quality, a laboratory experiment was conducted. During the laboratory experiment, the forging of billets made of the steel 45 was carried out in such forging tools as step-wedge dies of two different variants (proposed and previously known) and in step dies. Analysis of the shape change of billets and the evolution of the microstructure of steel after two deformation cycles showed that the use of the step-wedge dies with a wedge protrusion on the upper die and a wedge cavity on the lower die is more promising for forging billets and forgings of the plates and slabs type with a given level of mechanical properties, since it allows to obtain a fine-grained structure with a smaller change in the initial dimensions of the billet.

Keywords: shear strain, forging, step-wedge dies, step dies, microstructure, mechanical properties.

INTRODUCTION

When choosing a forging tool for carrying out the deforming operation of billets, it is advisable to use dies with such design that will allow for a sufficiently good refinement of the cast metal structure with reduced energy consumption or fewer deformation cycles. This will significantly increase the service life of the tool, reduce the consumption of the energy, which will eventually give a tangible economic effect. Classical flat dies, despite still being widely used in many

metallurgical enterprises, have long lost their relevance, since deformation in such dies is extremely energy-consuming, since in this case in the deformable metal mainly develop normal stresses and there is practically no shear strain. Therefore, the development of new forging technologies, and drawing, which would allow to increase the ratio of shear strains, is an urgent direction for the development of forging production.

Now, there are many tools for forging that allow both shear and alternating strains to be realized during the deformation process [1 - 14]. They have both their

advantages and disadvantages. But now there is still no perfect or at least universal tool for forging that implements shear and/or alternating strains during deformation.

Thus, for example, a tool for production of forgings is known, which consists of dies with step and inclined sections, made with an angle of inclination to the horizontal plane of the section between the steps of no more than 45° and a width of a step of greater length of at least 1.5 of the total length of a smaller step and an inclined section [15]. But the disadvantage of this well-known tool is that when drawing billets in the step dies, to obtain a fine-grained structure of forgings that provides the necessary level of mechanical properties in these forgings, it is necessary to carry out several drawing passes, which reduces the productivity of this process.

A tool for making forgings is also known, containing dies with step and inclined sections, made with an angle of inclination to the horizontal plane of the section between the steps of no more than 45° and the width of the step of a greater length of at least 1.5 of the total length of the smaller step and the inclined section, while the inclined section and the smaller step in cross-section are made in the form of a wedge [16]. But this tool also has a disadvantage, which is that when drawing billets in this tool, a fine-grained structure, and the necessary level of mechanical properties of forgings are obtained in fewer passes, but with a greater change in the initial dimensions of the billet compared to step dies.

In this work, the task was to improve the quality of the metal of the billet with fewer passes and a smaller change in the initial dimensions of the billet by implementing intense plastic strains in the entire volume of the deformable body.

This problem can be solved by implementing intense plastic strain in the billet material according to the simple shear scheme simultaneously in the longitudinal and transverse directions. This is achieved by the fact that the tool for producing forgings contains dies with step and inclined sections, made with an angle of inclination to the horizontal plane of the section between the steps of no more than 45° and the width of the step of a greater length of at least 1.5 of the total length of the smaller step and the inclined section, while the inclined section and the smaller step of the top die in cross-section are made in the form of a wedge, and on the bottom die in the form of a similar wedge cavities (Fig. 1) [17].

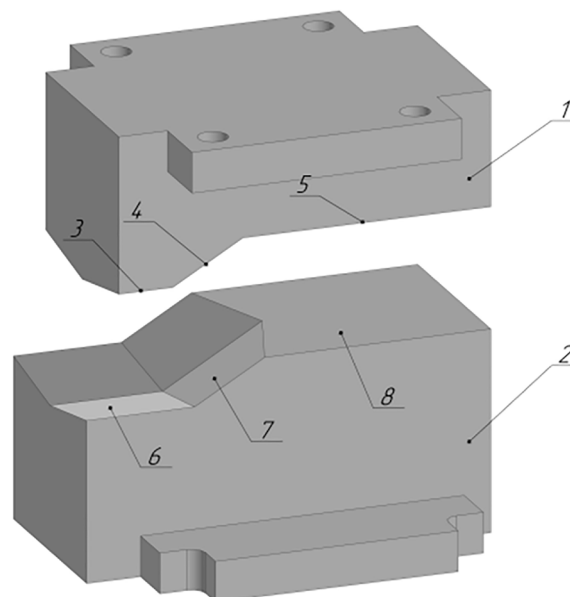


Fig. 1. Step-wedge dies of a new design: 1 - top die; 2 - bottom die; 3 - a smaller step with a wedge of the top die; 4 - an inclined section with a wedge of the top die; 5 - a large flat step of the top die; 6 - a smaller step with a wedge cavity of the bottom die; 7 - an inclined section with a wedge cavity of the bottom die; 8 - a large flat step of the bottom die.

EXPERIMENTAL

To conduct a laboratory experiment to study the effect of the new technology of forging billets in step wedge dies of a new design on the evolution of microstructure and changes in mechanical properties, 45 carbon steel billets with dimensions $h \times b \times l = 30 \times 40 \times 200$ mm were prepared. To restore the initial structure of the billets made of the steel 45, they were subjected to incomplete annealing at a temperature of 820°C with an exposure of 2 h in a tubular resistance furnace before deformation [18].

For the experiment, step wedge dies of a new design were prepared with an angle of inclination of 30° and with the angle of the wedge of the top die and the wedge cavity of the bottom die equal to 160° , step wedge dies of the old design also with an angle of inclination of 30° and with the angle of the wedge of the top and bottom dies equal to 160° and step dies with the angle of inclination of 30° .

The billets were deformed under laboratory conditions using a PGM - 1500MG4 hydraulic press.

The deformation of the billets was carried out as follows. The billets were heated to the forging start temperature of 1200°C, and then they were fed into step wedge dies of a new design [17] to the first step with a wedge on the top die and a wedge cavity on the bottom die. After compression of the billet at the first step, the billet was fed to the inclined section and compression was also performed. After that, the billet was fed to the second flat step, on which the billet was straightened. Thus, the billet was subjected to compression along the entire length.

The dimensions of the deformed billets after their drawing along the entire length were 24.9 x 42.4 x 227.3 mm, while the forging reduction is equal to 1.14.

The second batch of billets was subjected to two deformation passes without tilting according to the deformation scheme presented above. Forging reduction after 2 passes was - 1.22.

Billets of the same size were deformed in step wedge dies of the old design and in step dies with the same number of passes as in step wedge dies of the new design.

At the same time, the dimensions of the deformed billets after their drawing along the entire length in the step wedge dies of the old design were 24.1 x 42.7 x 233.2 mm, forging reduction is equal to 1.17. Forging reduction after 2 passes was - 1.28.

The dimensions of the deformed billets after their drawing along the entire length in the step dies were 25.2 x 42.2 x 225.7 mm, forging reduction is equal to 1.13. Forging reduction after 2 passes was - 1.2.

To eliminate accidental errors, all experiments were duplicated 3 times.

Templets in the transverse and longitudinal directions were cut out of all the deformed billets and

standard samples were made according to GOST 1497-84 for tensile testing, to determine the mechanical properties of the steel 45 after deformation. Templets and samples for tensile test were also cut out and made from the original billets. The study of the microstructure was carried out on specially prepared microslices. Preparation of microslices was carried out according to the standard method: cutting of the template using a BRILLANT 230 cutting machine; obtaining a flat surface of the sample; grinding and polishing with the SAPHIR 520 ATM grinding and polishing machine; etching (4 % solution of nitric acid in alcohol) [19]. The microstructure was studied using a Leica optical metallographic microscope.

Tensile testing of samples was carried out on a universal electromechanical testing machine Shimadzu AG 100 kN in the conditions of the national scientific laboratory for collective use with the priority “Technologies for the hydrocarbon and mining metallurgical sectors and related service industries” at JSC “Institute of Metallurgy and Enrichment”, according to the methodology specified in [20].

RESULTS AND DISCUSSION

The data obtained during the study of the microstructure of steel 45 are shown in Table 1 and Fig. 2.

In the initial state, pre-eutectoid steel before deformation has a ferrite-pearlite structure consisting of relatively large, for steel, grains in size of 55.2 μm (Fig. 2a).

Analysis of the microstructure of the deformed samples showed that forging in step wedge dies of old design leads to significant grain refinement, the structure

Table 1. Results of determining the average grain diameter of 45 steel.

Tool	Study direction	Initial (average) grain size, μm	Average grain size after deformation, μm	
			after the 1st pass	after 2 passes
Step wedge dies of old design	transverse	55.2	35.1	17.3
	longitudinal		35.3	17.6
Step wedge dies of new design	transverse	55.2	34.2	18.1
	longitudinal		34.5	18.3
Step dies	transverse	55.2	39.8	27.9
	longitudinal		39.2	27.2

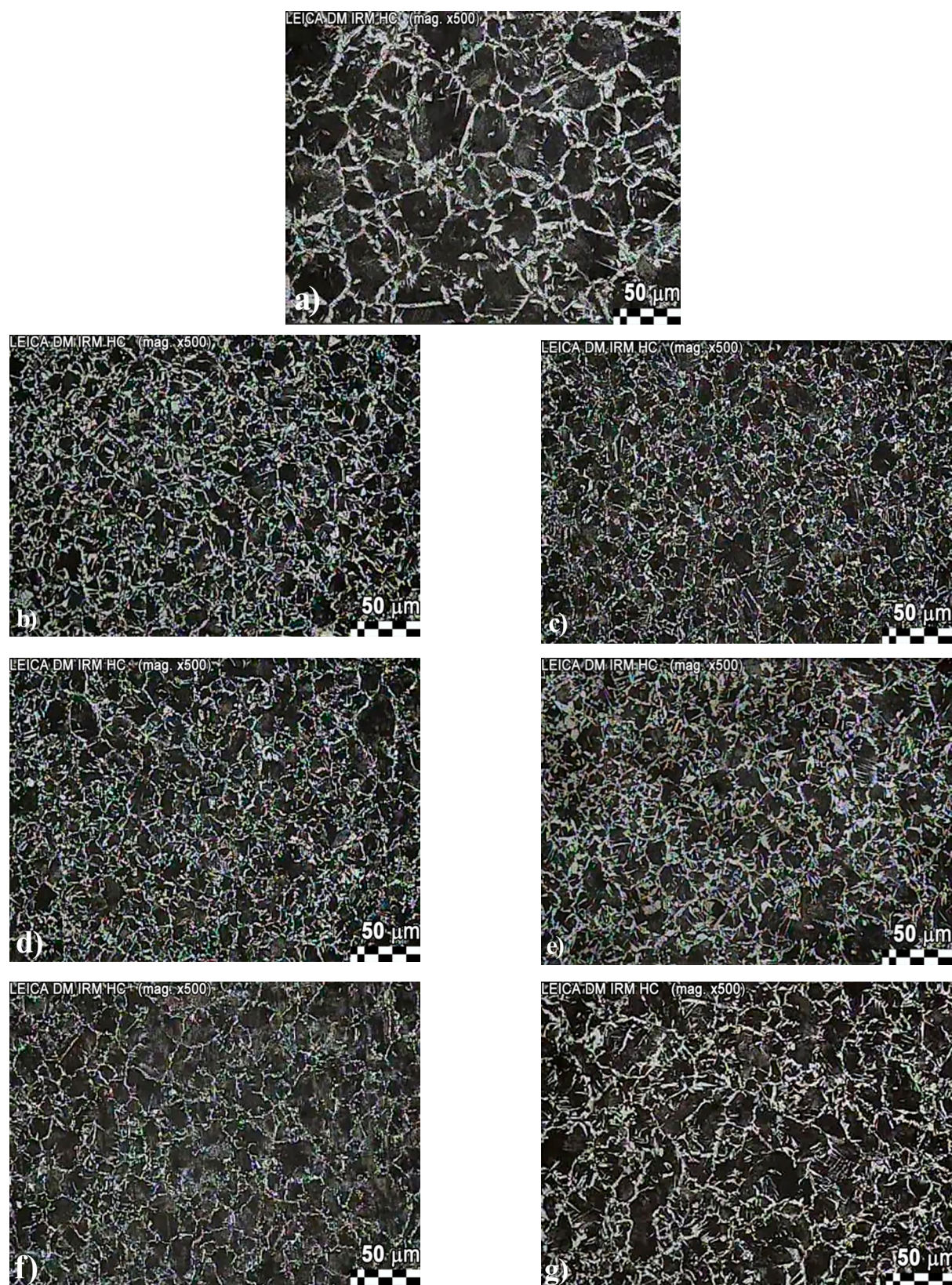


Fig. 2. Microstructure of the 45 steel: a - the original structure; b, c - after deformation in the step wedge dies of new design; d, e - after deformation in the step wedge dies of old design; f, g - after deformation in the step dies; (b, d, f - in the longitudinal direction; c, e, g - in the transverse direction).

Table 2. Mechanical properties of billets made of 45 steel.

Tool	Property	Average properties values		
		Initial	After deformation	
			after the 1st pass	after 2 passes
Step wedge dies of old design	yield strength, MPa	312	345	364
	tensile strength, MPa	534	582	605
	relative elongation, %	14.2	18.4	20.3
	relative reduction, %	39.2	44.2	47.9
Step wedge dies of new design	yield strength, MPa	312	340	361
	tensile strength, MPa	534	579	601
	relative elongation, %	14.2	17.8	20.0
	relative reduction, %	39.2	43.6	47.3
Step dies	yield strength, MPa	312	334	352
	tensile strength, MPa	534	562	586
	relative elongation, %	14.2	15.8	18.3
	relative reduction, %	39.2	42.1	44.5

is uniform, both in longitudinal and cross sections, the average grain size after two passes is 17.3 - 17.6 μm (Fig. 2d, e). The microstructure is characterized by the presence of both recrystallized and deformed grains. After forging in step wedge dies of new design, the resulting structure is also fine-grained and homogeneous, both in longitudinal and cross sections. The average grain size after two passes is 18.1 - 18.3 μm (Fig. 2b, c). When deformed in step dies, the weakest refinement of the structure is observed, the microstructure consists of many recrystallized grains with an average size lying in the range of 27.2 - 27.9 μm (i.e., there is a greater spread of the average grain value). After deformation in the dies of all three modifications, a ferrite-pearlite structure was obtained, almost all ferrite grains are fragmented, which distinguishes them from ferrite in the steel structure in the initial state.

The results of the study of the mechanical properties of billets made of the steel 45 before and after deformation in dies of various designs are shown in Table 2.

The results of mechanical tests show that both the strength and plastic properties of 45 steel formed in all three structures have increased compared to the initial values (after incomplete annealing). At the same time, the yield strength and tensile strength of 45 steel formed

in step wedge dies, of both old and new designs, are 2.5 - 3.5 % higher than the same indicators for the billet deformed in step dies. The plastic characteristics of steel 45, after deformation in step wedge dies (2 different designs), are on average 5 - 7 % higher than the plastic characteristics of this steel after deformation in step dies.

CONCLUSIONS

In this work, a new forging technology and a tool for its implementation were developed step wedge dies of new design having a wedge on an inclined section and a smaller step of the top die, and a similar wedge cavity on the bottom die. From the comparative analysis of the results of the study of the microstructure during deformation of billets in step and step wedge dies (new and old designs), it can be concluded that when using all three designs of dies, a uniform refinement of the initial metal structure is observed throughout the volume of the deformed billet. At the same time, the use of step wedge dies for forging billets and forgings such as plates and slabs in both cases still provides a more intensive refinement of the initial structure of the metal in one cycle. And because when using step wedge dies with a wedge on the top die and a wedge cavity on the bottom

die, there is a smaller change in the initial dimensions of the billet compared to using step wedge dies with a wedge on the top and bottom dies and almost equal to the change in the initial dimensions when forging in step dies. The use of step wedge dies of new design is more promising for obtaining the necessary quality of forgings with a given level of mechanical properties with less forging reduction.

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