EFFECT OF PRE-HEAT-TREATMENT ON THE STRUCTURE AND PROPERTIES OF STEEL BEFORE EQUAL-CHANNEL ANGULAR PRESSING

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Abstract

In this work is described the effect of pre-heat-treatment on the microstructure and mechanical properties of different grades of steel before equal-channel angular pressing. Nomograms with mechanical properties of different grades of steel till and after annealing were obtained. It was found that the annealing of the second kind is an appropriate operation began before pressing.

Keywords: Heat-treatment, equal-channel angular pressing, microstructure, severe plastic deformation

1. INTRODUCTION

Development of methods of preparation, study of structure and properties of ultrafine-grained (UFG) metals are the actual area of solid-state physics and physical science. This is because this type of material has a unique set of physical and mechanical properties. In particular, UFG metals have changed, compared to coarse-crystalline, higher utility properties, improved machinability, as well as fundamental, usually structure-insensitive properties, among which are elastic modules, saturation magnetization and others. As a result, these metals become very attractive for wide use in industry. The development and use of UFG materials having high mechanical properties, is of great importance for the rapid development of metallurgical, machinery and other industries.

Promising methods of forming in metal UFG structures are methods of severe plastic deformation (SPD). The main advantages of the latter include the possibility of obtaining massive UFG samples of various metals and alloys, full absence of porosity.

One of the most effective methods SPD is equal-channel angular pressing (ECAP), the principle of which is the repeated punching of the workpiece in a special snap-through two channels with the same cross sections, intersecting generally at an angle of 90° [1-4].

However, when studying the effect of this method SPD on the structure and properties of samples of the steels was found that after conducting this process can obtain only partially microcrystalline structure with grain size of ~300 nm depending on the initial state. Along with grain there is sub-grain, oriented structure.

Getting products not only high precision but also with excellent mechanical properties is achieved through a combination of processes of deformation with heat treatment, as the use of pressing separately without heat treatment leads to embrittlement of the material and obtaining a heterogeneous, partially UFG structures. Ensuring the formation of a uniform UFG structure-tour across the workpiece by the pressing method requires a large number of passes (usually eight or more) [5]. To avoid this, the pressing is used in conjunction with heat treatment, which will prepare the original structure stood before this process, much will solicit grain, so will help to avoid brittle fracture of the product during extrusion due to give it greater toughness and plasticity, will relieve the internal stress and thereby facilitate subsequent deformation. The combined use of heat treatment with pressing will allow you to obtain a homogeneous ultrafine-grained steel structure with high complex mechanical properties.

2. MATERIALS AND METHODS

As the material for the study samples were made from carbon and low-alloyed constructional steel. Billets 15x15 mm were subjected to preliminary heat treatment.

For the formation of fine grain steel requires complete phase recrystallization. Therefore, as a preliminary heat treatment is advisable to use full steel (steel 60) and isothermal (steel 55H, 35HM) annealing, which consists of heating the steel at 30-50 °C above the line AC_3, extract and subsequent slow cooling with the oven.

The main objectives of the selected annealing were as follows:

1) eliminate defects of the patterns that emerged in the previous processing (metal casting, hot forming, welding, heat treatment);
2) obtaining a homogeneous fine-grained structure;
3) exemption from the internal stresses;
4) reducing hardness, improving the ductility, softness and viscosity, that is, the softening of steel before subsequent pressing operation.

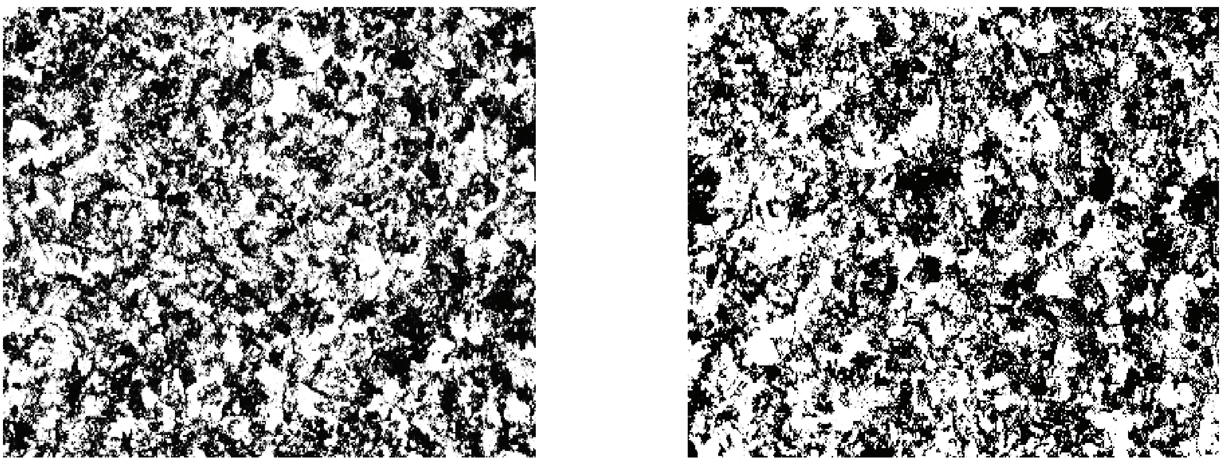
The experiment consisted of determining the structure and mechanical properties of the steel before and after heat treatment.

The initial mechanical properties of the investigated steel grades have been determined on a universal tensile testing machine MI-40KU and listed in **Table 1**.

Table 1 The initial mechanical properties of the investigated steel grades

Steel grade	Yield strength, MPa	Tensile strength, MPa	Contraction, %	Elongation, %
60	866.1	1082.7	9.3	2.2
55H	649.6	824	30.6	4.4
35HM	687.7	982.4	21	4.4

The microstructure of each sample was studied in several fields under the microscope, and then visually compared with the scale for the determination of grain size according to GOST 5639-88. It was determined score grains of each sample. The microstructure of the Central part of the investigated steels, the original hot-deformed condition, are presented in **Figs. 1 - 3** (a - in longitudinal direction; b - in transverse direction).



a) b)

Ferrite and pearlite. Score grain 7-8 (31-22 μm), ×100

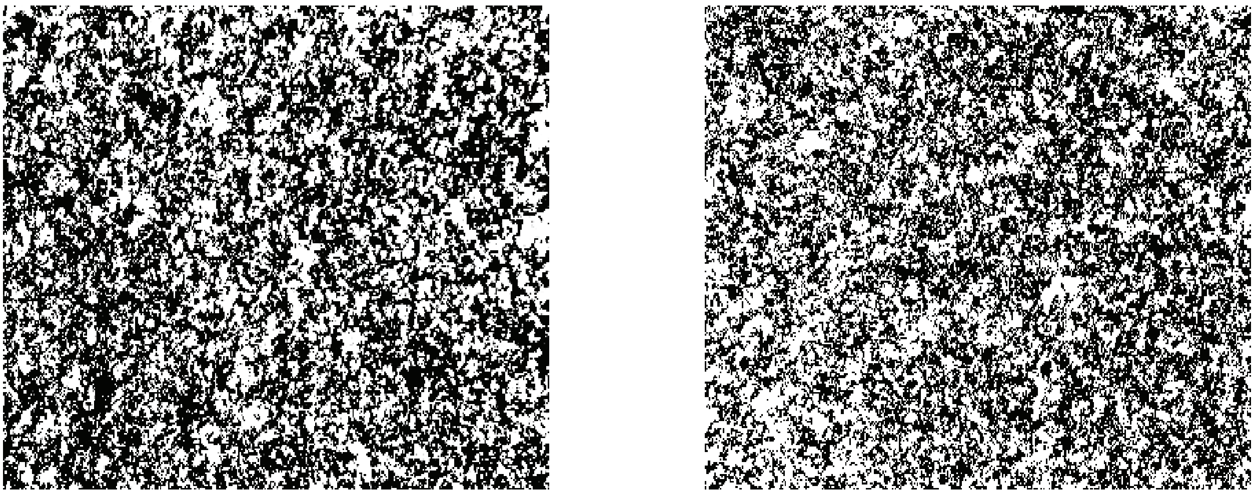
Fig. 1 The initial microstructure of the steel grade 60

3. RESULTS AND DISCUSSION

The preliminary heat treatment was carried out according to the standard for the investigated steel grades modes (**Table 2**). Heating of the samples was conducted in an electric furnace NABERTHERM with automatic temperature control, located in university laboratories.

Table 2 Modes of preliminary heat treatment of steels

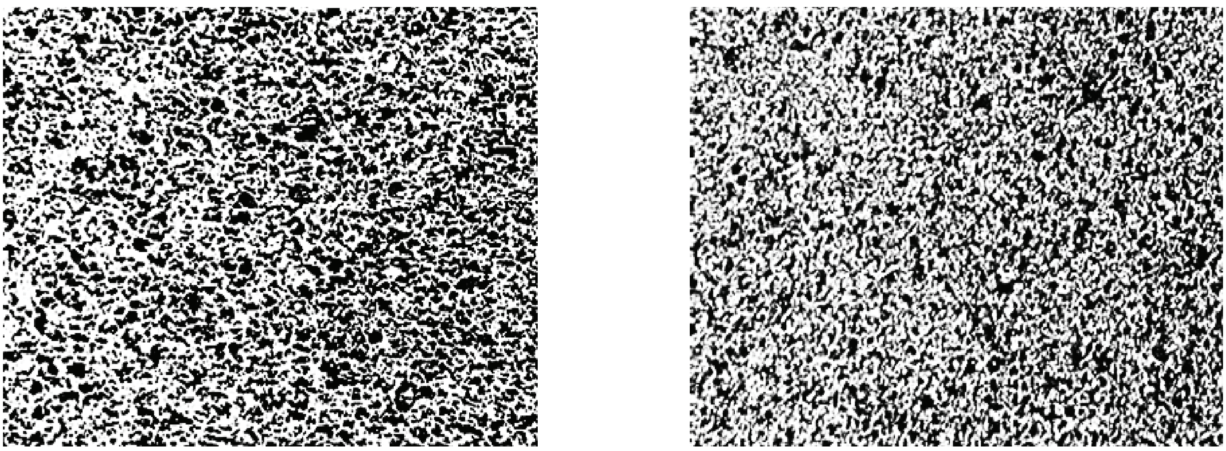
Steel grade	Operation	Heating temperature, °C	Time, min	Cooling
60	Full annealing	790	15	With furnace
55H	Isothermal annealing	1st stage		
		850	20	With open furnace till 650 °C
		2nd stage		
		650	25	With open furnace
35HM	Isothermal annealing	1st stage		
		860	20	With open furnace till 650 °C
		2nd stage		
		650	25	With open furnace



a) b)

Ferrite and pearlite. Score grain 8-7 (22-31 μm), ×100

Fig. 2 The initial microstructure of the steel grade 55H



a) b)

Ferrite and pearlite. Score grain 8 (22 μm), ×100

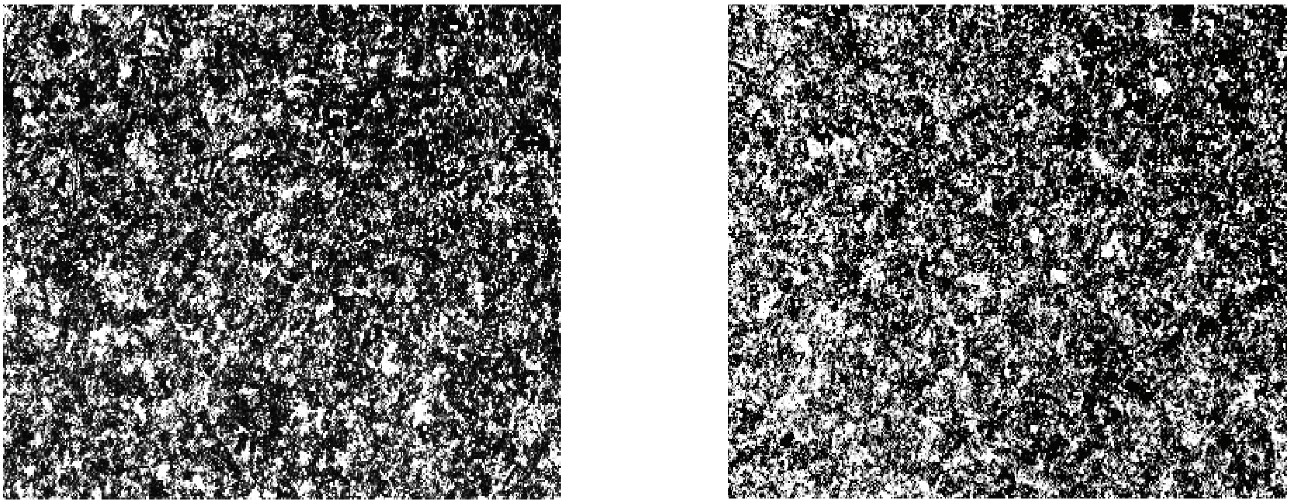
Fig. 3 The initial microstructure of the steel grade 35HM

The mechanical properties of the samples obtained after annealing listed in **Table 3.**

Table 3 The mechanical properties of the samples obtained after annealing

Steel grade	Yield strength, MPa	Tensile strength, MPa	Contraction, %	Elongation, %
60	554.7	951.8	60.9	7.6
55H	433.8	713.4	37.7	5.4
35HM	409	680.4	54.4	12.3

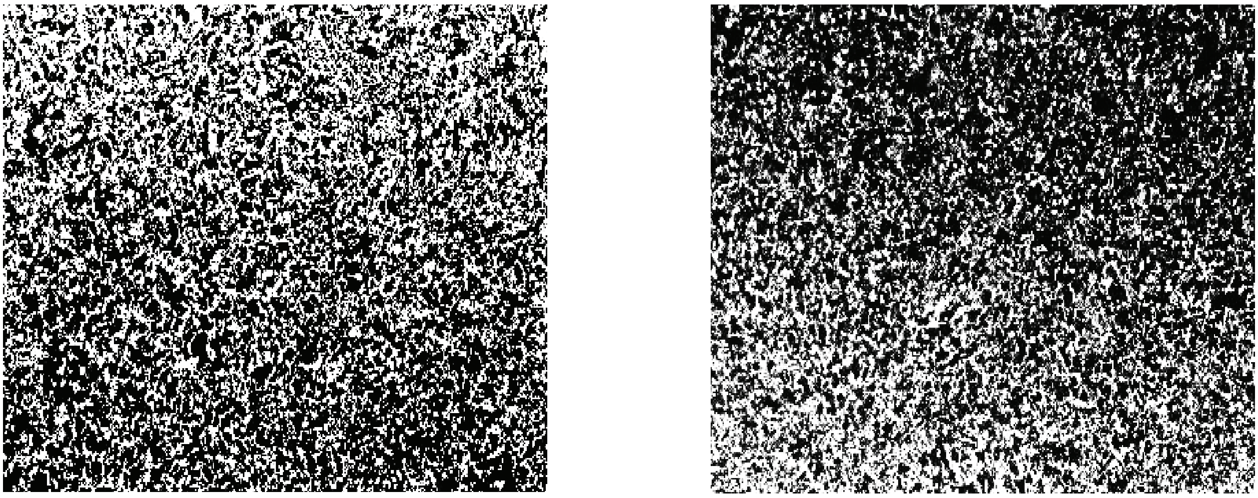
After carrying out annealing was carried out the manufacturing process of metallographic sections for holding microstructural analysis. The microstructure of samples after conducting heat treatment are presented in **Figs. 4 - 6** (a - in longitudinal direction; b - in transverse direction).



a) b)

Ferrite and pearlite. Score grain 9-8 (15-22 μm), ×100

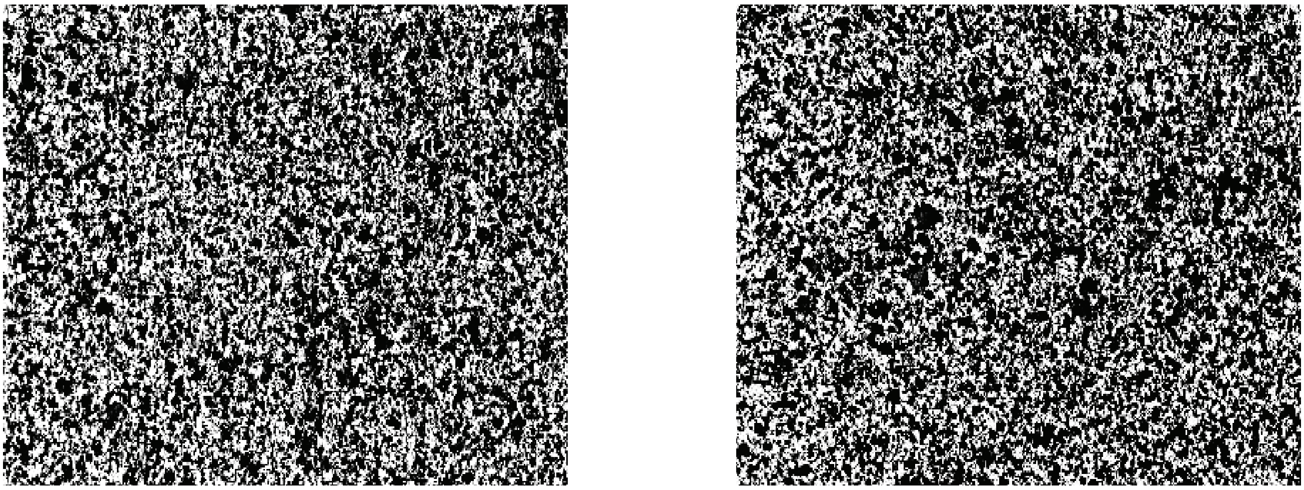
Fig. 4 Microstructure of the steel grade 60 after annealing



a) b)

Ferrite and pearlite. Score grain 9 (15 μm), ×100

Fig. 5 Microstructure of the steel grade 55H after annealing



a) b)

Ferrite and pearlite. Score grain 9 (15 μm), ×100

Fig. 6 Microstructure of the steel grade 35HM after annealing

As a result, after carrying out the above operations in the steel clearly observed fine structure. The size of the resulting grains after annealing is less in contrast to the original structure and is located within the № 8 and № 9 on a scale to determine the magnitude of the grain according to GOST 5639-88. It should be noted that after annealing the steel microstructure became more homogeneous in comparison with the initial state.

Steel with a grain size № 6-14 according to GOST 5639-88 are fine. This suggests that these samples have an inherent fine grain, which is determined by different melting of steel containing different amounts of tiny impurities, carbides, oxides, sulfides and nitrides, stable at high temperatures, evenly distributed, and providing, when passing through the critical point, during the heating of steel, formation of a uniform small grains of austenite, as well as preventing the amalgamation of neighbouring grains. Therefore, the tendency of steel to the grain growth when heated depends not only on its composition on the core components, but also from the metallurgical quality of the production technology.

While cooling, the austenite transforms into other phases, the size of the grain is an important characteristic of steel. This is due to the fact that all structural components with slow and rapid cooling of the steel are formed within each austenite grain. The smaller austenite grains, the smaller the grid excessive ferrite in their borders, less than the size of the pearlite colonies [6].

The main transformation that occur during cooling after the annealing of steel is the eutectoid decomposition of austenite to a mixture of ferrite and pearlite. Thus, the final structure of steel after carrying out annealing is ferrite and pearlite.

To compare the mechanical characteristics of the steel in the initial state and after heat treatment were constructed nomograms (**Fig. 7**).

Built nomograms can be judged from the decrease of the strength performance after carrying out annealing. Annealing of the 2nd kind increases the plasticity of the material due to the decrease of tensile strength and yield strength of steel, thereby to facilitate the further deformation of the material. In addition, the annealing of steel significantly grinds grain that will further contribute to obtain a homogeneous sub-ultrafine-grained structure with a minimum number of ECAP passages, therefore, will reduce energy costs to the pressing force.

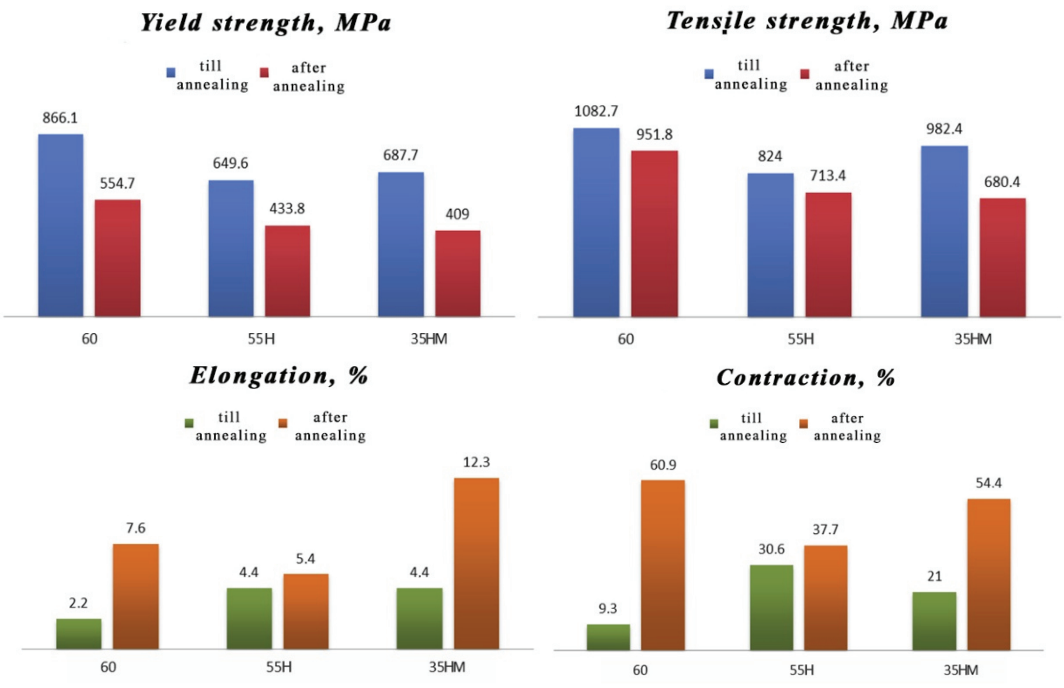


Fig. 7 Nomograms of strength and plastic parameters of steel in the initial state and after annealing

CONCLUSIONS

In the course of the research found that the annealing of the 2nd kind is an appropriate operation began before pressing. When considering the microstructure of the steel samples after the preliminary heat treatment revealed that achieves the required task is getting fine-grained structure. The resulting structure has a score of grain equal to 8-9 by GOST 5639-88, which speaks to its hereditary fineness. As a result of annealing the second kind of steel is released from the evils of the structure obtained in the previous stages of processing. Obtaining fine patterns is a very important task, because the steel has high strength, which makes it impossible for further machining. Further milled grain will help to obtain a homogeneous sub-ultrafine-grained structure with a minimum number of ECAP passages, therefore, will reduce energy costs to the pressing force. By selecting and holding the correct pre-heat treatment is a significant increase of the resistance of the steel brittle fracture, due to the increase of plasticity that is required for suitability of the material for further cold plastic deformation, that is, equal-channel angular pressing, and as a consequence, a significant increase in product quality.

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