RESEARCH OF INFLUENCE EQUAL CHANNEL ANGULAR PRESSING COMBINED WITH A HEAT TREATMENT ON THE MICROSTRUCTURE OF THE STEEL 45

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Abstract

The effect of preliminary heat treatment and equal channel angular pressing in step die on the microstructure and properties of steel grade 45 are analyzed. There is revealed that the grain size after equal channel angular pressing depends little on the preliminary heat treatment, however, annealing reduces the hardness of steel, which helps to reduce the effort of pressing on the first passes. Ultra-fine grained structure in steel of grade 45 is retained at heating up to 400 °C, and only at heating up to 500 °C, the recrystallized grains appear, substantially free of dislocations, with balanced triple grain junctions.

Keywords: Equal channel angular pressing, heat treatment, microstructure, steel grade 45

1. INTRODUCTION

One of the priorities of modern materials science in the last decade is the creation of materials with high strength, wear and corrosion resistance. The problem is that it is often high strength accompanied by increasing the brittleness material and during operation brittle fracture occurs. It is known that formation of nano-and sub ultra fine-grained structure results in a significant change in the materials properties. This problem can be solved by deformation processing. There are various methods of deformation processing, the existing methods are improved and new processing techniques based on physical methods are developed. The easiest and most effective way to structure refinement is severe plastic deformation (SPD) [1].

The most successful method of intensive plastic deformation is by far the equal channel angular pressing (ECAP) method [2]. This process has a great potential to obtain ultra fine-grained structure with a uniform equiaxed structure with grain boundaries, in which high-angle misorientation is dominated. In this method, workpiece retains the original sizes suitable for tensile testing. When implementing the ECAP uniform compression scheme is provided, excludes the formation of micro-and macro material discontinuities in the deformation that will provide obtaining the high-quality workpieces.

This paper is devoted the influence of severe plastic deformation is implemented by the pressing of steel workpieces of grade 45 in a equal channel step die (**Fig. 1**) [3], as well as the study of the influence of preliminary and subsequent thermal treatment on microstructure evolution of steel. Choice of this direction research is stems from the fact that just equal channel angular pressing is not always fully provides the metal with an ultra fine-grained structure for a small number of cycles and for this it is advisable to use a preliminary and final heat treatment.

Initial state of the material has a great influence on the process of creating the dislocation structure, its thermomechanical stabilization and after the subsequent treatment on the properties of the material. The role of pre-treatment, preceding SPD is to obtain the equilibrium structure, changes in hardness, strength, toughness, ductility, machinability, grain shape and size, alignment, chemical composition, removal of internal stresses.

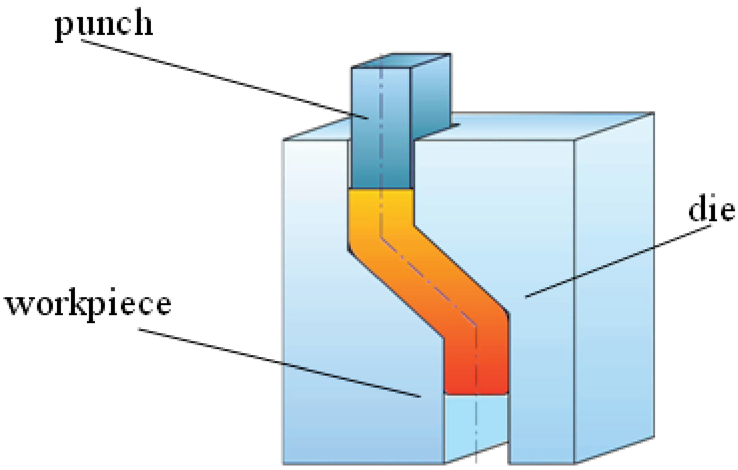


Fig. 1 Equal channel step die for pressing

By increasing the number of passes of pressing intensity dispergation the structure increases, but at the same and the work hardening increases, which in turn leads to destruction of the sample after 5-6 cycles ECAP. To reduce redundant density of dislocations, samples must be subjected to heat. During heating (annealing) the deformed metal recrystallizes, resulting in a qualitatively new structure with specific mechanical properties is created, for this final heat treatment requires.

2. MATERIAL AND EXPERIMENTAL TECHNIQUE

Research material is quality structural carbon steel grade 45 with ferrite-pearlite structure. Until ECAP in step die samples were subjected to preliminary heat treatment: annealing, quenching and normalizing by the standard mode. Samples of square section 15×15×70 mm were subjected to ECAP in equal channel step die with an angle of junction channels 125° on the route Bc with tilting the workpiece by 90° around the longitudinal axis [2]. The friction between the tool and the workpiece is decreased using palm oil as a lubricant.

When the ECAP temperature increases process of strain-stimulated grain growth may develop during deformation. In order to eliminate the effect of strain-stimulated growth of the grains, it is necessary to carry out the deformation at temperatures lower than the temperature of the onset of recrystallization of the material $(0.5 \div 0.6)T_{melt}$. [4]. Therefore the choice of temperature mode based on the fact that, during the hot deformation primary recrystallization took place completely, but collective was suppressed. One of the features of nano- and microcrystalline materials obtained by severe plastic deformation is significant instability of their structure when heated. In particular, the recrystallization temperature in the nano-and microcrystalline materials is substantially lower than the usual recrystallization temperature of pure metal, and is $T_1=0.275 \div 0.35T_{melt}$ [2]. Based on the studied data, it was proposed the deformation of samples at temperatures for steel 45 $(0.55 \cdot (1530+273))-273=718$ °C

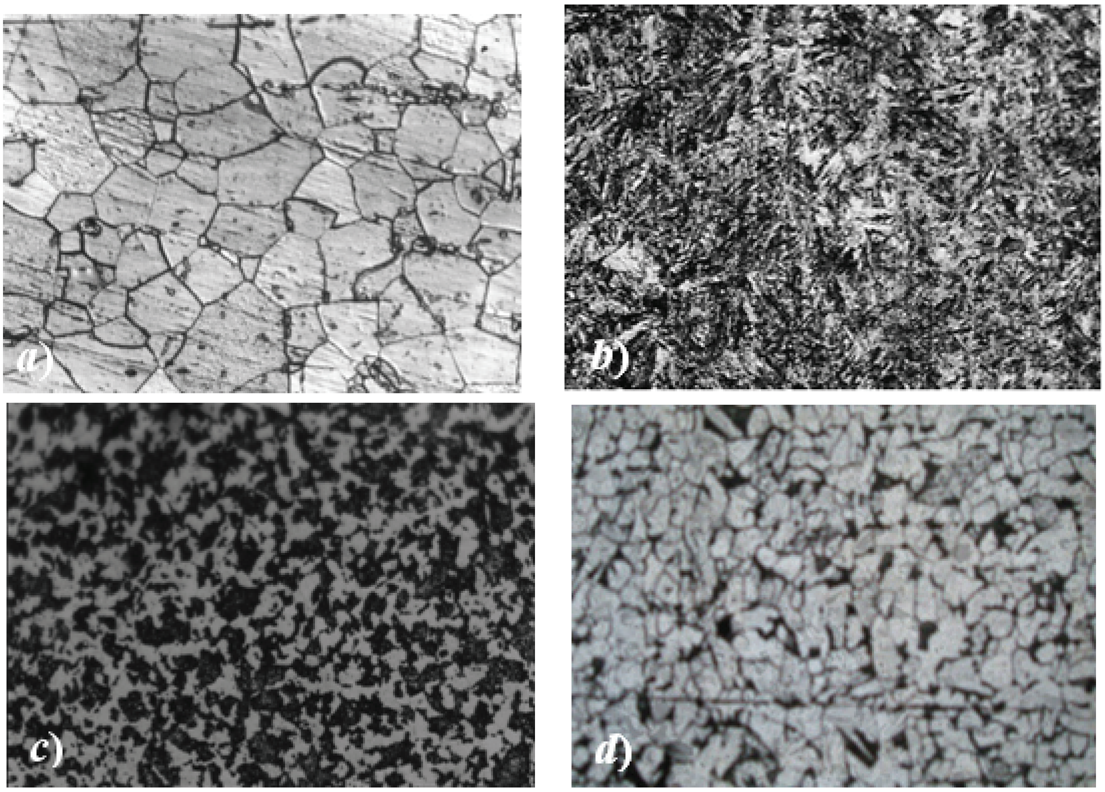
With an increasing number passes at the ECAP plasticity resource is lost and further deformation and the use in industry of such metal is impossible because of its destruction. To increase the ductility resource such metal must be subjected to heat treatment. It is known that heating above the recrystallization onset temperature leads to a strong grain growth, and a sharp decrease in strength, so it is necessary to determine the temperature of the onset of recrystallization. Have calculated the approximate temperature of the onset of recrystallization on accepted formulas [2] a laboratory experiment was carried out. Samples after ECAP were cut into thin plates of 5 mm thickness and were heated at temperatures in the range 400 - 550 °C with exposure time of 1 hour. Cooling of samples is carried out in water.

The treated samples were studied using an optical microscope and a transmission electron microscope. Pressed samples were also tested for torsionally tensile testing machine in the tension test and compression. The resulting samples were considered in two sections: transverse and longitudinal.

Preparation of thin sections for metallographic investigations carried out by the standard method for the study an optical microscope Leica, equipped micro durometer was used. Electron microscopic studies were performed on the raster scanning microscope JSM 5910 at an accelerating voltage of 25 kV in the mode of secondary and elastically scattered electrons.

3. RESULTS AND DISCUSSION

On the **Fig. 2** the optical microstructure photos of steel 45 after preliminary heat treatment are shown: annealing, quenching, quenching+tempering and normalizing.



a - annealing, b - quenching, c - quenching+high tempering, d - normalization

Fig. 2 Optical photos of microstructure steel grade 45 after preliminary heat treatment, x200

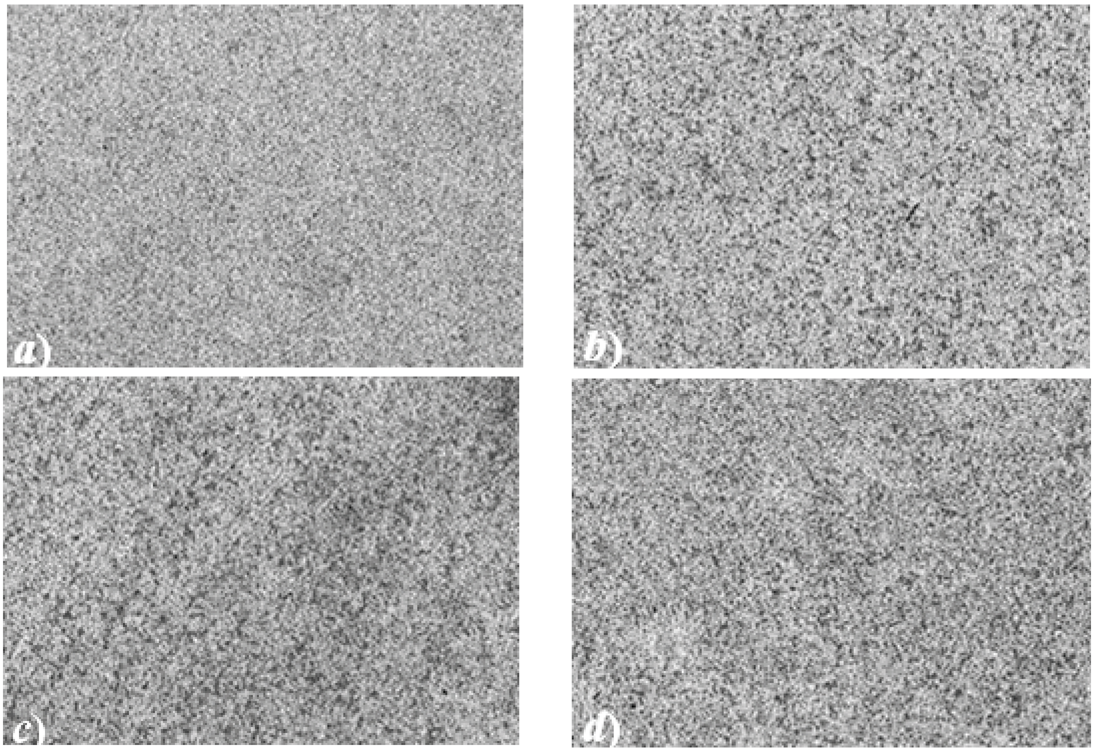
After annealing hypoeutectoid steel 45 acquires ferrite + pearlite structure, which is shown in **Fig. 2a** and corresponds to grain size № 7 (31 microns). On the photo light grains - ferrite, dark - pearlite. Grains are appeared homogeneous.

After quenching the steel structure grade 45 consists of martensite needles. Dimensions of needles depend on the carbon content in steel and the original austenite grain size, from which martensite is formed. As already noted, quenched on martensite steel has increased fragility. This is due to the fact that having never succeeded stand out during the rapid cooling carbon is forcibly detained in formed from austenite a bcc-lattice and deforms it, creating enormous internal stresses.

Therefore, quenching usually is used in combination with tempering. Tempering is designed to reduce the brittleness and improve toughness and ductility after quenching. At high temperature tempering further disintegration of martensite with the isolation and coagulation of particles of cementite and form ferrite-cementite mixtures occurs. With increasing tempering temperature dispersion of ferrite-cementite mixtures decreases, sorbite structure of tempering is formed (**Fig. 2c**). This structure for the phase composition is similar to homonymous quenching structure, but differs from the latter in that cementite particles have granular but not lamellar form. The structure of sorbite over the section of workpiece is more uniform, compared with the initial state. In accordance with GOST 5639-88 grain size corresponds to № 8-9 (17.5 micron on average).

For hypoeutectoid steel normalization mode differs from the mode of annealing only higher cooling rate, which is provided in the conditions of cooling in the air. As a result of normalization ferrite + pearlite structure obtains similar to the structure of annealed steel, but with even more dispersed structure of pearlite (**Fig. 2d**).

To evaluate the effectiveness ECAP steel microstructure necessary to compare before and after deformation. Photos of the microstructure obtained in the study steel 45 after pressing are shown in **Fig. 3**.



a - annealing, b - quenching, c - quenching+high tempering, d - normalization

Fig. 3 Optical photos of microstructure steel 45 after 6 cycles of ECAP in step die, x500

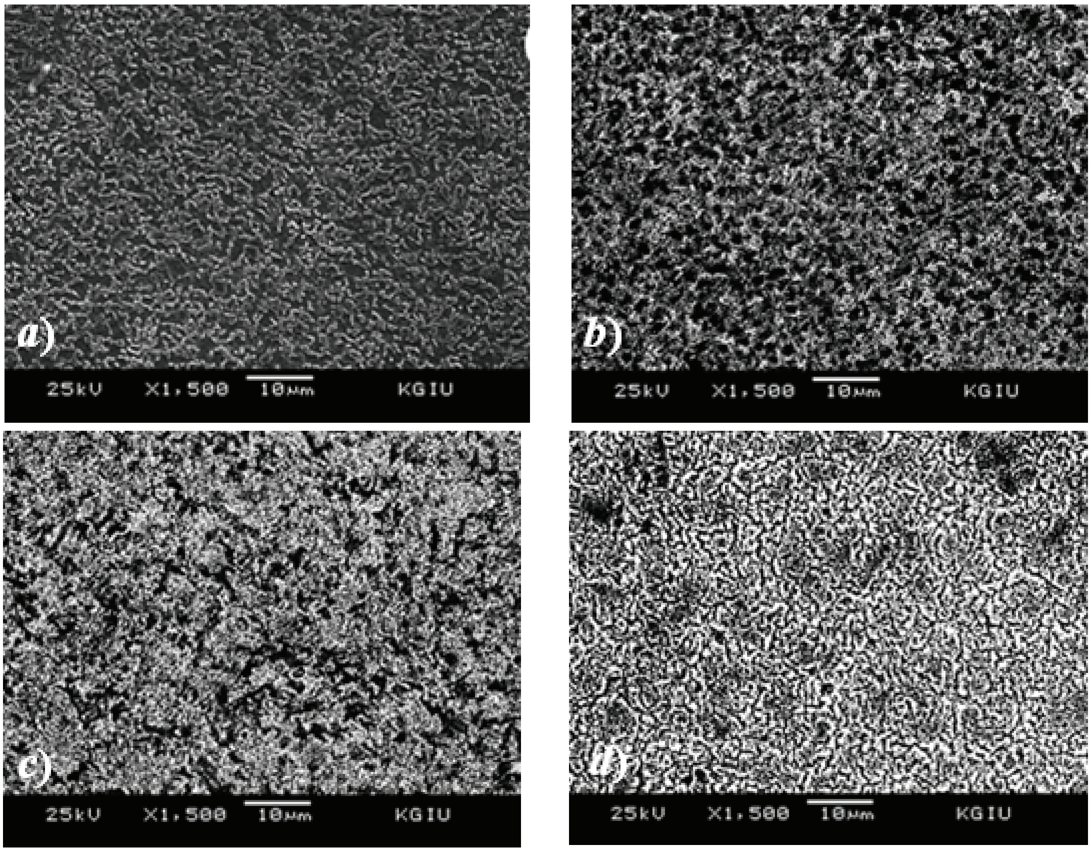
Metallographic analysis of the steel after ECAP showed that at the initial stage of pressing the initial grains are oriented at an angle to the axis of the sample, but the initial grain substructure is not etched. After the third cycle structure is a partial cellular, partly polygonized structure. Light microscopy was unable to identify an ultra fine-grain structure therefore electron-microscopic studies were performed on the raster scanning microscope JSM 5910.

By electron-microscopic method the formation of substructure at ECAP was revealed.

During research of the microstructure of steel samples it was revealed that after each cycle of deformation grain significantly crushed. The resulting structure is much smaller than the initial, and is almost identical with the microstructure obtained at different preliminary heat treatments. Intensive milling of the structural components occurs until the 6th cycle of deformation in which succeeded in obtaining a relatively uniform grains and subgrain structure with a size 0.26-3.5 um. Cementite particles sizes from 3500 to 200 nm have a nonspherical shape. After eight cycles of deformation the grain size is the same as after the six cycles.

As a result of ECAP in steel of grade 45 grinding structural components the initial ferrite-pearlite structure occurs due to crushing of perlite and "smearing" in the deforming ferrite matrix in the form of small isolated grains size of 1 ... 3 microns.

The minimum grain size obtained during the pressing of steel in equal channel step die is within 0.5-0.26 um and attained after 6 cycles of deformation and preliminary heat operation - annealing.



a - annealing, b - quenching, c - quenching+high tempering d - normalization
Fig. 4 Microstructure of steel 45 after 6 cycles of ECAP in step die, obtained by a scanning electron microscope

A significant disadvantage of most severely deformed metals and alloys is an almost complete lack of ductility. Observed at this significant fragility prevents further plastic metal processing. To make the plastic properties of the metal is necessary, as saying reduce stress, which is achieved by annealing, aging and tempering the metal. In order to select the required final heat treatment is necessary to know the temperature of the onset of recrystallization.

Structure, formed during ECAP and the preliminary annealing obtained most fine-grained, so for determining temperature of the onset of recrystallization samples after annealing + pressing 6 cycles are using.

Microstructure after heating of samples from ultra fine-grained steel grade 45, received as a result of the joint operation of preliminary heat treatment - annealing and ECAP is shown in **Fig. 5**. Microanalysis showed that the structure over the section of samples in all cases has a grainy character, is sufficiently uniform and rather disperse. Reveal features of structural changes using light microscopy method was not possible, so investigations were carried out only on the scanning electron microscope.

For research the thermal stability the analysis of changes metallographic parameters is carried out (dimensions of ferrite-pearlite areas).

By scanning microscopy, it was found that the ultra fine-grained structure steel of grade 45 is maintained even at heating to 400 °C, and only at heating to 500 °C, the recrystallized grains occur, substantially free of dislocations, with the equilibrium triple grain junctions (**Fig. 5c**).

Analysis of the microstructure of steel of grade 45 after heating showed that heating up the temperature 400 ^{0}C accounts for temperature range of return, which is characterized by a gradual decrease in the dislocation density and decrease concentration of excess defects, the redistribution of dislocations leading to a decrease in the level of microdistortions.

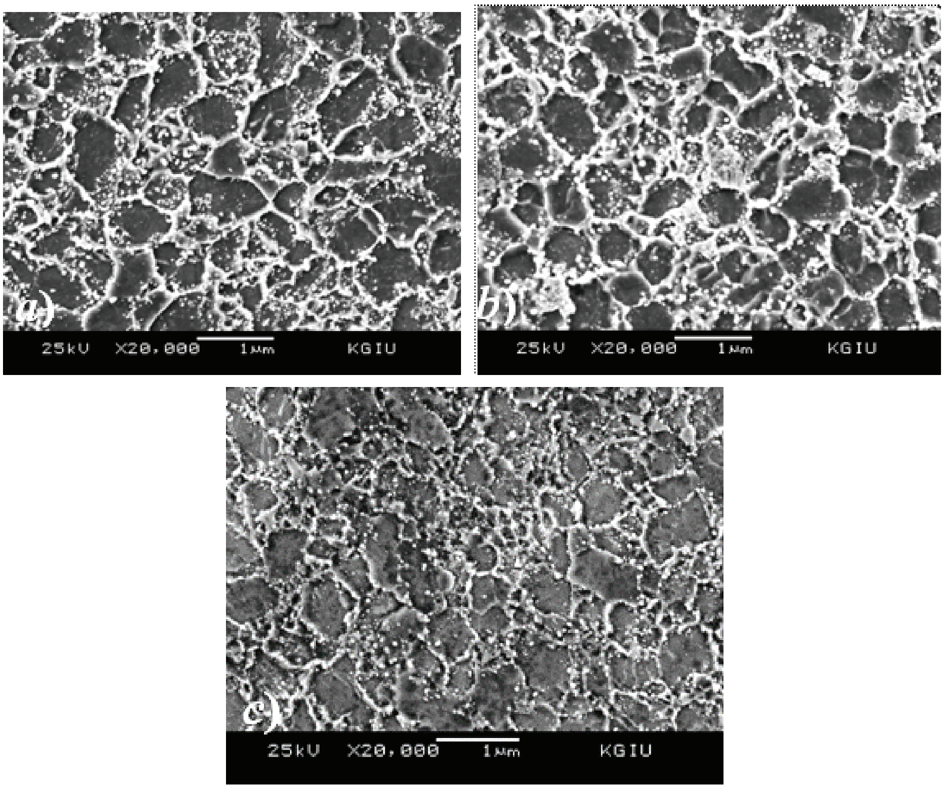


Fig. 5 The microstructure of the steel of grade 45 after heating at 300 °C (a) 400 °C (b), 500 °C (c), obtained on a scanning electron microscope

With further increase in the annealing temperature to 560 °C in the samples after ECAP collective recrystallization occurs rapidly, which coincides with the observations of S.S. Gorelik [4] for small grains (d ≤ um) magnitude of the driving force of collective recrystallization has the same order as the magnitude of the driving force of the primary recrystallization.

4. CONCLUSIONS

The main conclusions as a result of the research:

1) As a result of ECAP in step die there is a noticeable decrease in the grain size after each cycle of deformation, such as for steel grade 45 after preliminary annealing from 31 microns to 0.26 microns for 6 cycles of deformation on the route Bc.
2) There is revealed that the grain size after ECAP depends little on the preliminary heat treatment, however, annealing reduces the hardness, which helps reduce the effort of pressing on the first passes and resulting in obtain more fine-grained structure.

3) It has been established that the ultra fine-grained structure of steel of grade 45 is maintained even at heating up to 400 °C, and only at heating up to 500 °C, the recrystallized grains occur, substantially free of dislocations, with the equilibrium triple grain junctions.

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