Influence of structural state on corrosion behaviour of bearing steel 110C-18Cr-Mo

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Abstract. The paper report on the studies of the effect of severe plastic deformation on the structure and properties, including the corrosion behaviour, of 110C-18Cr-Mo bearing steel. Various structural states were formed by the methods of severe plastic deformation (SPD) and subsequent heat treatment. It is shown that SPD and subsequent heat treatment lead to the formation of a homogeneous structure with a uniform distribution of carbides. In this case, heat treatment leads to a reduction of the volume fraction of carbides and an increase in the microhardness of the samples. Steel subjected to SPD demonstrates a decrease in the corrosion rate in one-molar solutions of salt and sodium hydroxide. Subsequent heat treatment leads to an additional decrease in the corrosion rate.

1. Introduction

Bearing steels are similar to instrumental ones by the composition and properties, and their final properties are achieved by heat treatment, namely, by quenching followed by tempering. This treatment provides a high level of strength and hardness required for operation of the bearings. However, the performance properties are determined not only, and in some cases even not so much by the level of hardness, but by the uniformity of hardness distribution in the bulk of the material. In its turn, the homogeneity of properties is determined by the homogeneity of the microstructure, as applied to bearing steels, primarily by the uniformity of the distribution of the carbide phase [1]. In addition, corrosion resistance is also a structurally sensitive property. In the case of bearing steels, the main problem is a significant heterogeneity of carbide, which leads to a decrease in wear resistance and premature failure. To solve this problem, severe plastic deformation (SPD) by equal channel angular pressing (ECAP) was used. In the last decade, it has been shown that this method can be successfully used not only for the refinement of the grain structure of the matrix phase, but also for the redistribution of particles of the second phases [2]. Hiash et al. [3] showed that the microstructure of steel could strongly influence its behavior during electrochemical dissolution. The dissolution of different phases (ferrite and cementite) occurs in different ways, because different phases have different electrode potentials, which leads to the formation of galvanic pairs [4, 5]. Qu et al. [6] showed that ferrite and bainite formed a galvanic pair in a solution of NaCl ferrite – bainite dual-phase steel, and corrosion proceeded mainly along the boundary of these phases and depended on the volume fraction of each phase. A number of studies of the corrosion behavior of ferrite-pearlite and ferrite-bainitic steels have been carried out [3-7]. On the other hand, not only different phases, but also SPD and size refinement of structural elements can affect the corrosion behavior. In work [8], the effect of SPD on austenitic or low- carbon steels considered. There is practically no information on studies of hard-to-deform high-carbon steels.
2. Materials and methods

Structural bearing steel 110X18M of standard chemical composition (table 1) was chosen as the material for the study.

| Steel     | C    | Cr     | Mo     | Si     | Mn     |
|-----------|------|--------|--------|--------|--------|
| 110C-18Cr-M | 1.10±1.20 | 16.5±18.0 | 0.50±0.80 | 0.53±0.93 | 0.50±1.00 |

SPD was carried out by the ECAP method. The workpieces were in the shape of cylinders 10 mm in diameter and 60 mm in length. The deformation was carried out at a temperature of 600°C, the angle between the channels was 120°, the number of passes n = 5. Standard heat treatment (HT) was used prior to SPD: quenching in water from a temperature of 1050°C, holding for 1 hour and subsequent low tempering at 170°C (1 hour). Microstructure analysis was carried out by scanning electron microscopy on a JSM-6490LV microscope. The structure was revealed by etching in a solution of 3% nitric acid and 97% ethyl alcohol. Microhardness was measured using a Duramin device at a load of 100 g for 10 seconds. Corrosion behavior was investigated by potentiodynamic method in 3% sodium chloride and sodium hydroxide 1M, which are the most common media for this steel.

Polarization curves were recorded on a PG12-100 programmable potentiostat-galvanostat up to an anode potential of + 0.5V. Based on the obtained polarization curves, the corrosion currents were calculated by the three-point method and by constructing the Evans curves.

3. Results and discussion

The microstructure in the initial state is a granular pearlite with an average carbide size of 2.9 ± 0.3 μm and 15.6 ± 0.8 μm, the volume fraction of carbide particles is 51 ± 2% (figure 1a). It should be noted that the structure is characterized by a heterogeneity of the sizes of the carbide phase. Very large carbides up to several tens of micrometers in size are observed, and the distribution is bimodal. Such heterogeneity of the carbide structure leads to a decrease in contact fatigue [1]. After SPD, the average size of carbides was 5.1 ± 0.5 μm, with a volume fraction of 25 ± 1% (figure 1b). Compared to the initial state, the carbides are refined, the size heterogeneity remains, but the distribution of carbides over the ferrite matrix becomes more uniform.

The structure of the bearing steel after quenching and tempering is highly dispersed. Heat treatment of steel is carried out to eliminate carbide inhomogeneity, tempering martensite, retained austenite and undissolved cementite are present in the structure, the amount of large carbides is noticeably reduced (figure 1c, d). The average size of carbides is 2.5 ± 1.5 μm and the volume fraction is 19 ± 1% for the initial state and 4.3 ± 3.0 μm, the volume fraction of carbides is 16 ± 1% for the state after SPD and HT.
The microhardness of the initial state is 287 ± 6 HV, after ECAP the microhardness increased to 420 ± 10 HV, in the sample after heat treatment, the microhardness increased by 2.5 times compared to the initial state and amounted 709 ± 23 HV, the highest microhardness is observed in the sample subjected to ECAP and subsequent heat treatment - 829 ± 35 HV. The distribution of microhardness over the diameter of the samples is uniform.

Studies of corrosion behavior have shown that dissolution for samples after heat treatment begins at higher positive potentials, i.e. dissolution is influenced to a greater extent by heat treatment, after which the volume fraction of carbides in the structure decreases (figure 2). The original sample is more corrosive, which is explained by a heterogeneity of the sizes of the carbide phase and their greater number and size.

Steel after SPD is more corrosion-resistant in sodium hydroxide compared to coarse-grained state, the components of steel dissolve in sodium hydroxide, chromium can dissolve, molybdenum also reacts with hydroxide, and since the structure after ECAP is more homogeneous, dissolution occurs at lower rates compared to with a coarse-grained state.

Heat treatment promotes a decrease in corrosion rates both for specimens obtained by SPD by the ECAP method and for the initial coarse-grained specimen. However, the effect is more pronounced for the samples obtained by ECAP.

4. Conclusions
Thus, the use of SPD by the ECAP processing of bearing steel 110C-18Cr-Mo followed by heat
treatment leads to a decrease in the volume fraction of carbides, the amount of large carbides, which, firstly, were refined during deformation, and, secondly, partially dissolved as a result of heat treatment, significantly decreases.

The study of corrosion resistance by the potentiodynamic method showed that samples with a more homogeneous structure, obtained as a result of a combined processing of ECAP with subsequent heat treatment, exhibited the highest corrosion resistance.

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