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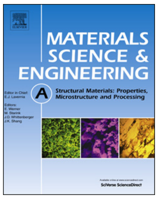

Effect of nanostructuring frictional treatment on the properties of high-carbon pearlitic steel. Part I: microstructure and surface properties

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ABSTRACT

In this first part of the work, the microstructure, surface roughness, residual stresses, microhardness and micromechanical properties of the high-carbon (1.03 wt% C) steel with a fine-lamellar pearlitic structure have been studied before and after frictional treatment with a sliding indenter. It has been found that the frictional treatment is a nanostructuring treatment, which forms a high-quality surface with low roughness (*Ra* = 0.065 μm), leads to a significant surface hardening (microhardness increases from 450 to 1040 HV0.05) and forms favorable residual stresses in the hardened surface layer. The instrumented microindentation data also testify to substantial hardening of the steel after the frictional treatment and increased resistance of the steel to intensive mechanical contact. Tensile properties and the experimental verification of the ability of the high-carbon steel with different structural states of its surface to withstand contact loads will be presented in the second part of this work.

1. Introduction

Increasing the strength of steels is one of the most urgent problems of modern materials science. Although numerous new materials have been recently developed, steels maintain their leadership in the global production, up to 90% of them being carbon steels [1]. The use of high-strength steels in engineering products and structures decreases metal intensity, which, in its turn, reduces operation costs due to lower fuel and power consumption. However, in many cases, increased strength alone may fail to ensure the serviceability of a product or structure under specified operational conditions. A whole complex of properties is required, which is defined by specific service conditions and may include such characteristics as fracture toughness, fatigue strength, and so on [2,3].

According to the modern ideas, a complex of mechanical properties of metal materials can be improved considerably through creating ultrafine structures by severe plastic deformation (SPD) [4,5]. Besides bulk treatments, surface ones are also widely used. These treatments increase mechanical and tribological properties through the formation of the submicro- and nanocrystalline structure in the surface layers of metal materials by various SPD methods. These can be, for example, ultrasonic impact [6,7] and shock laser [8,9] treatments, surface mechanical attrition treatment (SMAT) [10–21], shot peening [22,23] and frictional treatment [24–29]. Lately, studies have appeared where combinations of bulk and surface treatments by SPD methods [30] or deformation and heat treatments [31,32] are used to increase mechanical properties. The aim of this first part of the work is to study the microstructure, surface roughness, residual stresses, microhardness and micromechanical properties of the high-carbon (1.03 wt% C) steel with a fine-lamellar pearlitic structure before and after frictional treatment with a sliding indenter.

2. Experimental procedure

Commercial high-carbon steel GOST U10 (in wt%: 1.03 C, 0.072 Cr, 0.056 Ni, 0.27 Mn, 0.059 Si, 0.072 Cu, 0.023 P, 0.016 S, Fe for balance) was studied. The steel as received was in the form of a 12 mm in diameter rolled round bar. In order to form the structure of fine-lamellar pearlite, specimens to be tested were heat treated by austenization at 1050 °C for 15 min, isothermal holding in a salt bath at 500 °C for 5 min followed by water cooling. The heat-treated specimens were mechanically ground and then electrolytically polished in a 90%CH_3COOH–10%$HClO_4$ solution. The frictional treatment of the gauge length portion (25 × 6.3 mm) of 2.2 mm thick flat specimens was performed in circulating air by means of reciprocating sliding with a cylindrical dense boron nitride indenter having a cylinder diameter of

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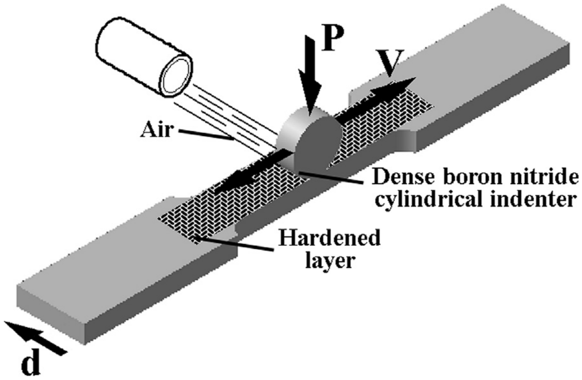

Fig. 1. Scheme of frictional treatment of the flat specimens for mechanical tests.

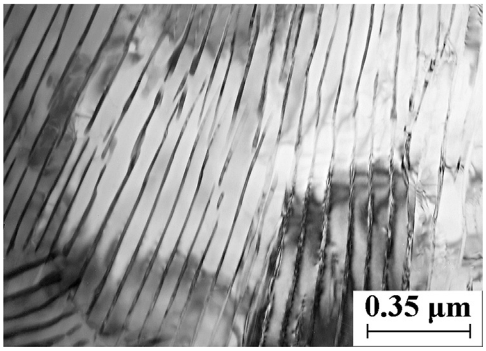

Fig. 2. Microstructure of the high-carbon steel subjected to heat treatment.

9.5 mm and a cylinder height of 4.6 mm, at the load on the indenter P = 880 N, the average sliding velocity V = 0.03 m/s and the transverse displacement d = 0.1 mm after each reciprocal sliding cycle of the indenter until the whole surface was treated (Fig. 1). The dense boron nitride indenter, unlike the hard-alloy one [24], is not transferred to the steel surface. However, it must be cooled during frictional treatment. The flat specimens were subjected to frictional treatment on two sides.

Microstructure and surfaces of the specimens were examined with the use of Tescan VEGA II XMU scanning electron microscope (SEM). The surface roughness of specimens was studied by a Wyko NT-1100 optical profilometer. Investigation of fine structure was performed via transmission electron microscopy (TEM) method on a JEOL JEM-200CX microscope. The images of fine structure were obtained by the thin foil method. The foils were made by consecutive mechanical and electrochemical thinning of the specimens. In order to study the microstructure in the thin surface layer, not thicker than 5 μm, the specimens were subjected to one-sided electrolytic thinning in a chlorine-acetic electrolyte jet on the side of the unhardened metal. The microstructure at a depth of 25 μm was studied after uniform two-sided electrolytic thinning, both on the side of the unhardened metal and on the side of the hardened surface layer. Dark field images of the structure were used for the calculation of the average grain size. The calculation was carried out by the linear intercept method [33], up to 300 grains being calculated for each depth. The integral breadth of the (110)α line $B_{(110)\alpha}$ and residual stresses in the α-phase from pearlite σ_α were determined on a Shimadzu XRD-7000 diffractometer with CrK_α radiation. To calculate the residual stresses, the $\sin^2\psi$ method [34] was used.

Microhardness was determined by the recovered indentation method on Leica VMHT AUTO microhardness tester using a Vickers indenter at the loads of 0.25 and 0.49 N, the loading rate of 40 μm/s,

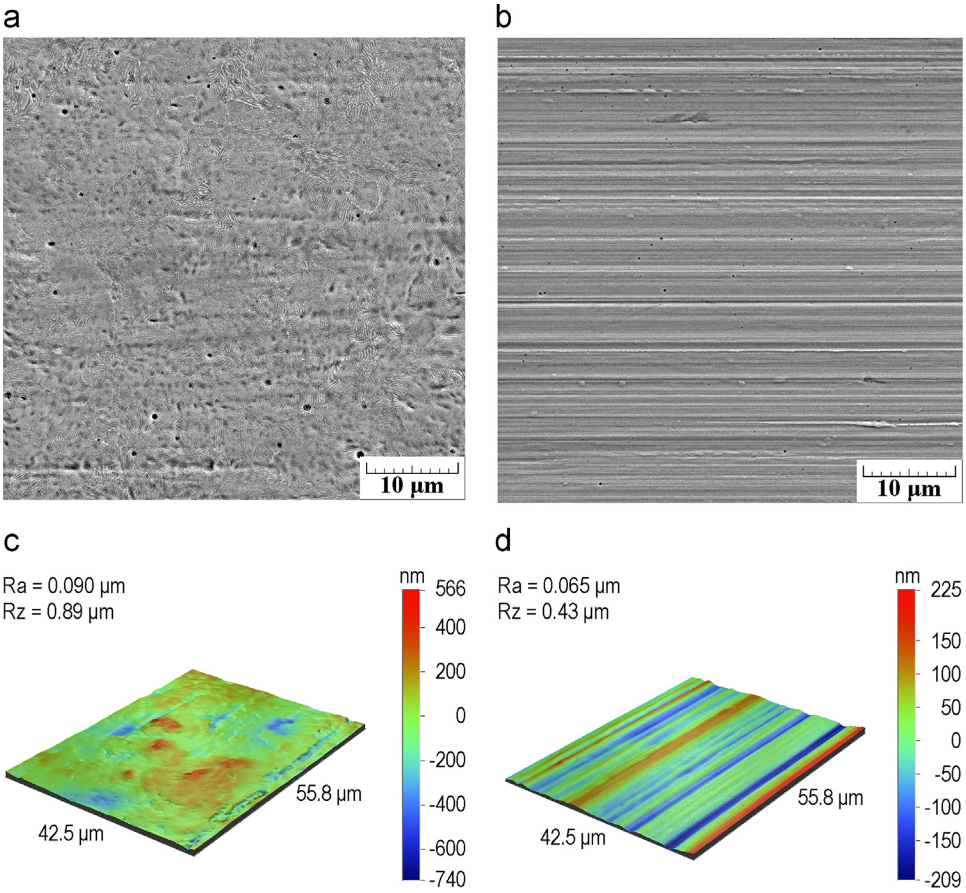

Fig. 3. SEM (a and b) and optical profilometry (c and d) images of the surface of the high-carbon steel with a fine-lamellar pearlitic structure before (a and c) and after (b and d) frictional treatment.