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Plasma hardening of corrosion-resistant steel

M V Mironova

Ural Federal University named after the First President of Russia B N Yeltsin, Nizhniy Tagil Technological Institute, 59, Krasnogvardeyskaya str., Nizhniy Tagil, 622000, Russia

E-mail: maria.mironova@urfu.ru

Abstract. The structure, phase composition and hardness of a 20X13 steel coating treated with two consecutive passes of a plasma arc are studied. It is shown that plasma treatment makes it possible to obtain martensite with a significant (30–50 %) share of permanent austenite in the structure of the local hardening zone. In this case, the hardness of the heat-strengthened blanket is 650–700 HB. The total depth of the local hardening zone with the modified structure reaches one millimeter. The study shows that a homogeneous structure with periodically changing phase composition and hardness develops in the surface layer of 20X13 steel, heat-treated plasma arc. in this case, the plasma arc must pass sequentially with a certain degree of overlap of local quenching zones. It is obvious that by adjusting the parameters of the processing conditions (the current of the plasma arc, the speed of its movement, the degree of overlap of local quenching zones), it is possible to purposefully form a certain structural-phase state of the surface layer with properties that best meet the operating conditions.

1. Introduction

Steel 20X13 is designed for manufacture of high-ductility critical parts, subjected to dynamic loads. Along with increased requirements for corrosion- and heat resistance, such parts, as a rule, shall ensure high wear resistance of the working surface in friction conditions. For the formation of the given set of properties after bulk heat treatment, subsequent local thermal strengthening of the working surface, e.g., high-frequency currents (HFC) hardening is usually provided. Given the technical and economic aspects of the rational use of high-frequency technology, surface strengthening by plasma hardening was analyzed.

The process of surface plasma tempering provides hardened cases with a depth of 0.5–2.5 mm with a fine-grained martensitic-austenitic structure, high microhardness, wear and crack resistance. Such properties are achieved by dispersion and increasing the local inhomogeneity of the structure of massive and plate martensite with different carbon content, increasing the density of dislocations, and preserving particles of carbide and retained austenite undissolved during heating in the surface layer, which helps to reduce crumbling and cracking at the breaking-in stage. The wear resistance of surfaces heat-treated with a plasma arc increases by 2–8 times; multiple layer-by-layer structural modification of the treated areas may occur; the hardening process is non-waste, environmentally friendly and can easily be integrated into flow charts for manufacturing and repairing machine parts as a finishing operation [1–6].

The use of plasma hardening for surface strengthening of parts made of steel 20X13 revealed a set of features due to a significant difference in its thermal and physical characteristics from the corresponding indices for ordinary carbon ones, and required the study of the structure, phase composition, and hardness of the heat affected zone.

2. Material and Research Methods

A 50×30×500 mm sample made of steel 20X13, containing 0.19 % carbon and 12.23 % chromium with the concentration of the remaining components according to Russian State Standard GOST 5632–72 was used for experiments. Initial heat treatment of the sample: oil quenching from 1050 °C, 770 °C tempering with air cooling. Areas of surface hardening were formed at the edges of the sample using transferred arc plasma gun [2] by two successive passes with overlapping local hardened regions to ~30 % of their width (Figure 1). Processing conditions: plasma arc current – 190–220 A, voltage – 48–50 V, plasma gun traveling speed – 2; 2.5 and 3 cm/s. The structure and hardness of the plasma hardened region was studied on sections using Olympus and Neophot-2 microscopes at magnifications of 50–1000^x. The hardness was measured with Duramin-2 instrument under a load of 4.9 N.

3. Results and Discussion

Figure 1 shows the cross section of a heat-strengthened surface layer formed by two successive passes of a plasma arc with a heat input of 0.4 MJ/m. At the same time, no surface washing is observed and the modification of the initial structure (secondary sorbite) occurs in solid.

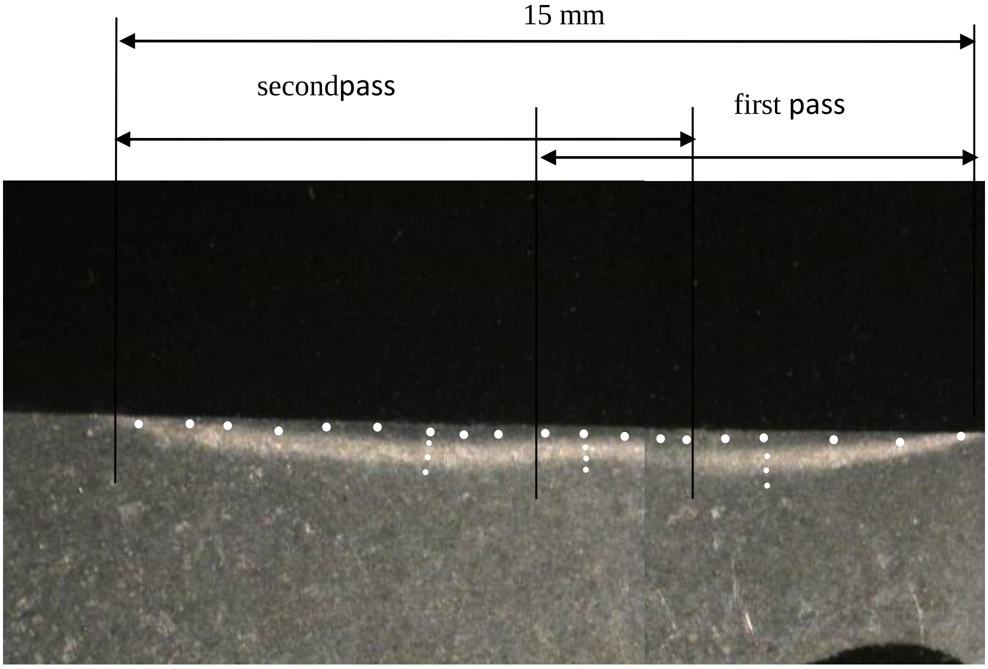
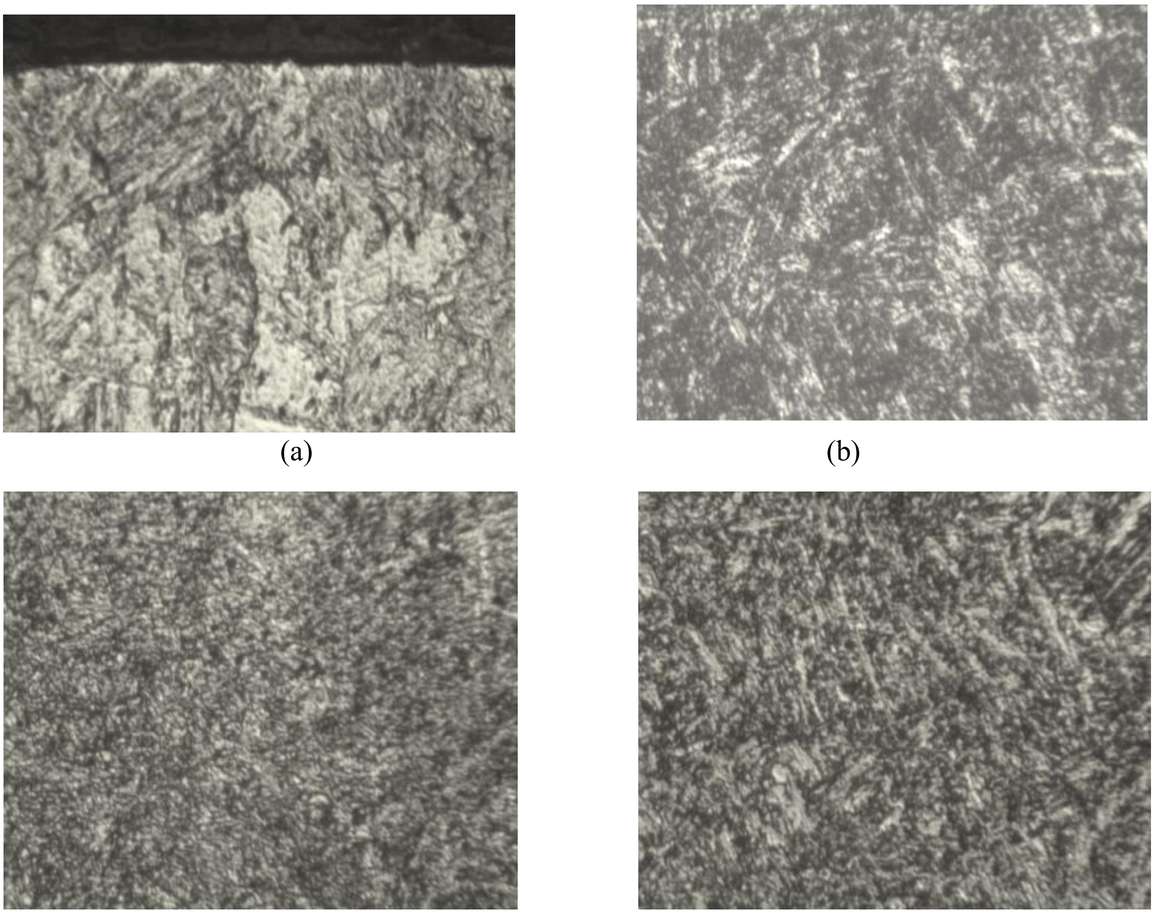


Figure 1. Cross section of a heat-strengthened surface layer formed by two successive passes of the plasma arc (dots indicate the hardness measurement diagram). ×10.

The process of plasma heat treatment is characterized by the supply of thermal energy from the surface and its distribution into the inner layers of the metal due to thermal conductivity. The microvolumes located at different distances from the surface are heated to different temperatures, and the heating and cooling rates of such microvolumes are also different. There is also no holding at a constant temperature, characteristic of volume heat treatment; phase transformations occur under conditions of flash heating and cooling and differ in various degrees of completeness; therefore, a wide range of structural conditions is observed in the heat-affected area (Figure 2).



(a) (b)

(c) (d)

Figure 2. Structure of the areas of the local zone of plasma hardening.×1000.

The temperature-time conditions for the existence of austenite under the conditions of the ongoing thermal cycle do not ensure its carbon homogenization and, upon rapid cooling, the stability of austenite in microvolumes with different carbon contents also turns out to be different. In areas with its high concentration, where the M_n point decreases, retained austenite is recorded. In areas with a low carbon content, where the M_n point is higher, martensite is formed. Since the martensite transformation progresses in fine-grain austenite, a structureless or typical massive martensite is formed, between the rods of which there are areas of retained austenite (Figure 2, a), the fraction of which near the surface can exceed 50 %. It can be noted that the nature of distribution of retained austenite in the martensitic matrix changes qualitatively in comparison with bulk hardening – the austenitic phase is evenly distributed in the form of thin interlayers between martensite crystals, which increases the plasticity of the integrated structure.

There is no doubt that the presence of metastable retained austenite in steels is desirable, since it allows the energy-absorbing process of transformation $\gamma_{ret} \rightarrow \alpha_m$ to be realized during operational loading. The martensite transformation occurring in the process of contact-impact or abrasive interaction of the working surface with a wear medium provides not only hardening, but also partial dissipation of the fracture energy in combination with stress relaxation during the formation of deformation martensite crystals. The wear resistance of the surface layer that underwent such a transformation increases many times. A similar effect also develops in the surface layer hardened by plasma quenching [3].

At a depth of more than 0.3 mm, the hardness decreases due to the formation of coarse-needled martensite with a decrease in the fraction of retained austenite (Figure 2, b); even lower, at a depth of more than 0.6 mm, an incompletely quenched area with the structure of finely divided troostite is observed (Figure 2, c), which smoothly transforms into the principal metal secondary sorbite structure (Figure 2, d).

Thus, according to experimental data, processing by a plasma arc with a heat input of 0.4 MJ/m allows to obtain martensite in the surface layer of steel 20X13 with a significant (30–50 %) fraction of retained austenite. The hardness of the surface layer in this case is 650–700 HV, the depth of the hardened area is 0.8 mm. Conditions with an increased value of the plasma arc current and a low velocity of its movement are characterized by increased energy input and, when processing hypoeutectoid carbon steels, they allow reaching maximum values of the depth and hardness of the hardened zone. In plasma hardening of the steel under consideration, the heat input of 0.4 MJ/m is apparently close to the limit one, since its increase to 0.45 MJ/m, even if providing a slight increase in the depth and hardness of the hardened zone, is accompanied by surface glazing, which is not always acceptable.

The change in hardness in the cross section of a heat-strengthened layer at a depth of ~ 0.3 mm (see Figure 1) is presented in Figure 3. The extreme points correspond to the hardness of steel not subjected to plasma treatment.

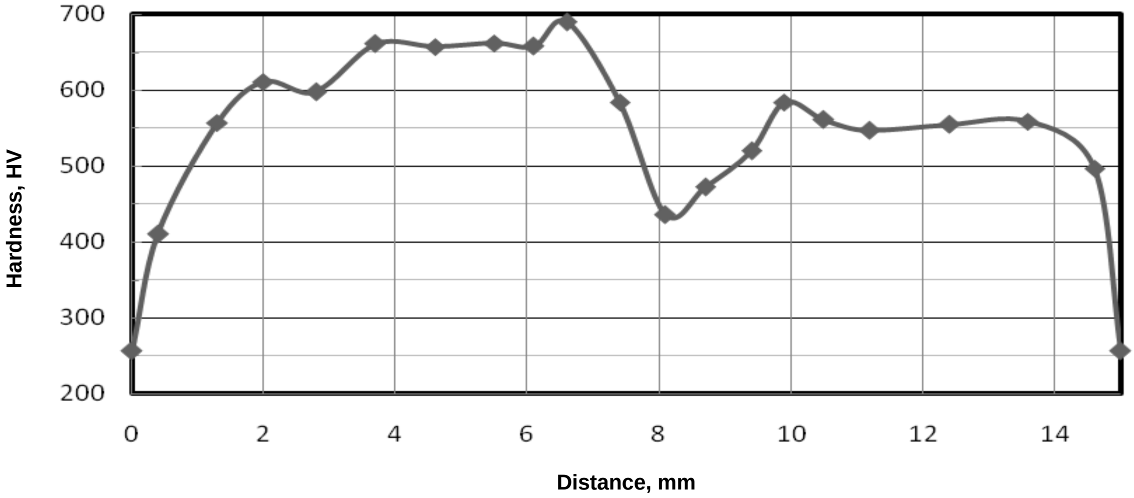


Figure 3. Change in hardness in the cross section of heat-strengthened layer at a depth of ~ 0.3 mm (see Figure 1).

The decrease in hardness in the area of overlapping of the local zones of plasma exposure is caused by tempering of steel hardened during the first pass, which occurs under conditions of reheating. When each subsequent pass forms new local quenching zone, in the area of preformed zone where the heating temperature exceeds Ac_3, rehardening occurs, as a result of which these parts do not differ in structural composition, however, according to [5], the dislocation density increases, as well as the degree of dispersion of the structure and hardness. In that part of preformed strengthening zone, where the heating temperature does not exceed Ac_1, high-speed tempering of the previously hardened structure takes place. Although the hardness in the tempering zone is lower than in the hardened zones, it significantly exceeds the level characteristic of the original structure (Figure 4).

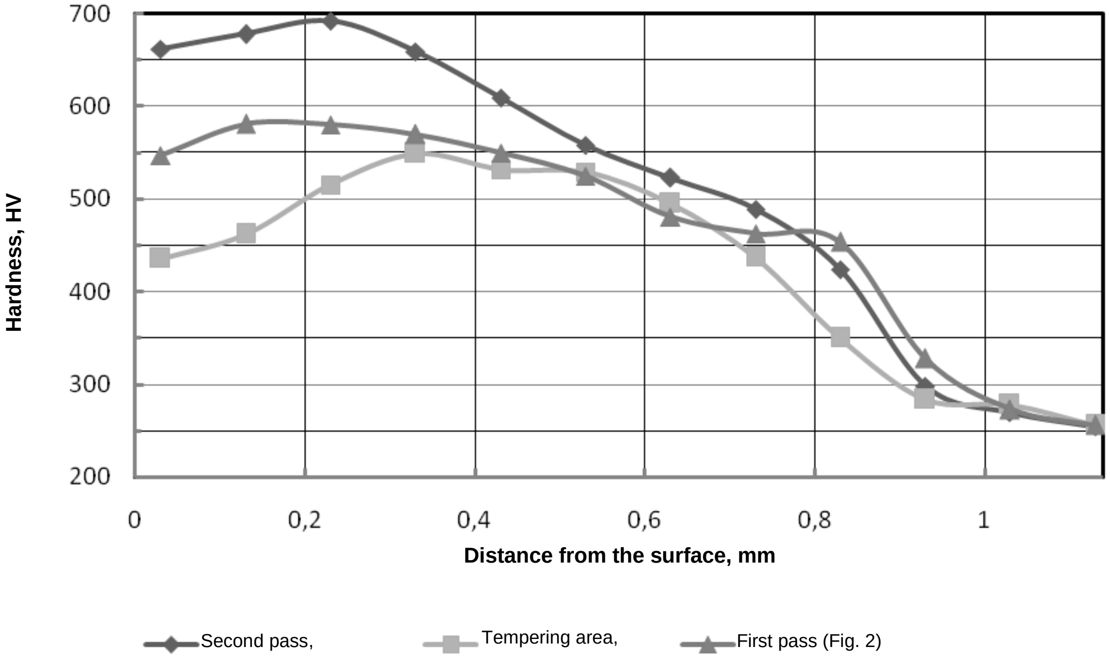


Figure 4. The change in hardness along the depth of the heat-strengthened layer.

Tempering zones with dispersed structure and reduced hardness serve as barriers to crack propagation, causing them to temporarily stop and branch out due to the higher fracture toughness of the structural components. The periodic alternation of hard and plastic layers in the structure of the working surface can effectively increase the operational life of parts operating under dynamic and thermomechanical loads [4].

Thus, a regular structure with periodically changing phase composition and hardness develops in a surface layer of steel 20X13 heat-treated with plasma arc, formed by successive passes of the plasma arc with a certain degree of overlap. Obviously, by adjusting the parameters of the processing conditions (plasma arc current, speed of its movement, degree of overlap of the local quenching zones), it is possible to purposefully form a certain structural-phase state of the surface layer with properties that most fully meet the operating conditions.

4. Conclusions

Processing by a plasma arc with a heat input of 0.4 MJ/m allows to obtain martensite in the surface layer of steel 20X13 with a significant (30–50 %) fraction of retained austenite. The hardness of the surface layer in this case is 650–700 HV, the depth of the hardened area is 0.8 mm.

A regular structure with periodically changing phase composition and hardness develops in a surface layer of steel 20X13 heat-treated with plasma arc, formed by successive passes of the plasma arc with a certain degree of overlap of local quenching zones.

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