IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Plasma hardening hypereutectoid steel

To cite this article: E N Safonov and M V Mironova 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **411** 012069

IOP Conf. Series: Materials Science and Engineering **411** (2018) 012069 doi:10.1088/1757-899X/411/1/012069

Plasma hardening hypereutectoid steel

E N Safonov and M V Mironova

Nizhny Tagil Technological Institute (branch) of Ural Federal University,
59 Krasnogvardeyskaya street, Nizhny Tagil, 622031, Russia

E-mail: e.n.safonov@urfu.ru

Abstract. There has been studied the effect of heat input plasma hardening steels process 0.9 C-Cr-Si, 1 C and 1.7 C-Cr-Ni-Mo on the structure, the depth of hardening and the hardness of the local area. It is shown that a graded structure is formed along the depth of the zone with regularly changing dispersion and microhardness. There have been specified the dependences, allowing to operate the structural state and performance properties of the hardening zone, ensuring their optimum ratios for different wear conditions.

1. Introduction

Hypereutectoid steels potentially have increased hardness and wear resistance under contact loading. They are usually applied in a thermally strengthened state (hardening with tempering) to provide the necessary strength. Such heat treatment does not allow the maximum hardness of the working surface of the parts to be realized. It is accompanied by a corresponding decrease in their service life. The solution of this problem is actual for massive products such as rolling rolls. It is associated with the use of thermal hardening of working surfaces, e.g., plasma hardening [1]. At the same time, the physico-chemical state and the properties of the material in the inner layers of the product do not change. They provide the predetermined structural strength. Surface hardening of such products increases their wear resistance and service life due to a favourable combination of high hardness of the surface working layer with a sufficiently strong core.

When the surface of a part is heated by a plasma arc of direct action, the main characteristics of the thermal cycle are the maximum temperature, the residence time of this point above the temperature of the point Ac1. The interdependent heating and cooling rates are determined by a combination of processing mode parameters. For example, with other things being equal, the maximum cycle temperature and residence time of the heated volume in the austenite region decrease with increasing arc travel speed. The cooling rate increases.

On the contrary, an increase in the maximum temperature, the depth of heating, the residence time of the heated volume in the temperature range of the existence of austenite increase the arc power. An increase in the grain size of the austenite and a corresponding increase in the M_n point accompany a possible decrease in the cooling rate.

The analysis of the results of experimental researches will reveal the patterns of size formation, structural-phase composition and properties of a layer heat-treated by a plasma arc. In the course of experiments, it is possible to determine the influence of technological process regimes on these indicators.

The target of the research is to determine the rational parameters of the surface plasma quenching of steels 9ХС (0.88 % C), У10 (1.03 % C) and 170ХНМ (1.65 % C). The research is based on the study of the structure and properties of the local hardening zone.

2. Methods of research

The steels are preliminarily annealed. Such samples have perlite-cementite structure. Further, such samples are processed with an arc of direct polarity in argon.

Range of mode parameters change: arc current 130…300 A, speed of its movement 1…5 cm/s. The voltage on the arc was 21...23 V. The combinations of the mode parameters take into account the maximum process performance. The depth and width of the hardening zone are important in the absence of macro-melting of the surface.

Geometrical dimensions (depth and width), structure and microhardness of the local hardening zone were studied on cross-section microsections. Optical microscopes were used. These were Neophot-2, Zeiss Observer D1m with an increase 50-1000×. The software Thixomet PRO was used. Measurement of the microhardness of the Vickers pyramid under a load of 1.962 N (200 g) was carried out on a Future-Tech 300 and PMT-3 hardener under a load of 0.784 N (80 g). The microhardness was measured in sections with the maximum depth of the hardening zone. Phase analysis of the surface layer was carried out using X-ray diffractometers DRON-1, DRON-3 in Fe and Co Kα-radiations.

3. Results

As a result of the investigations carried out, it has been established that the depth, width and hardness of the local hardening zone increase with increasing current of the plasma arc.

An increase in the speed of arc displacement with a fixed value of the current is accompanied by a decrease in these parameters. This is explained by a decrease in the running energy of the heat input process. Running energy is the value of the specific heat flux through the surface. Running energy can be represented as the ratio of the effective thermal power of the arc to the speed of its translational motion. Thus, the running energy determines the geometrical dimensions of the local zone of plasma quenching, the characteristics of the temperature field and the thermal cycle of the heat treatment process. Dependence of the depth of the local zone of plasma quenching is presented in figure 1.

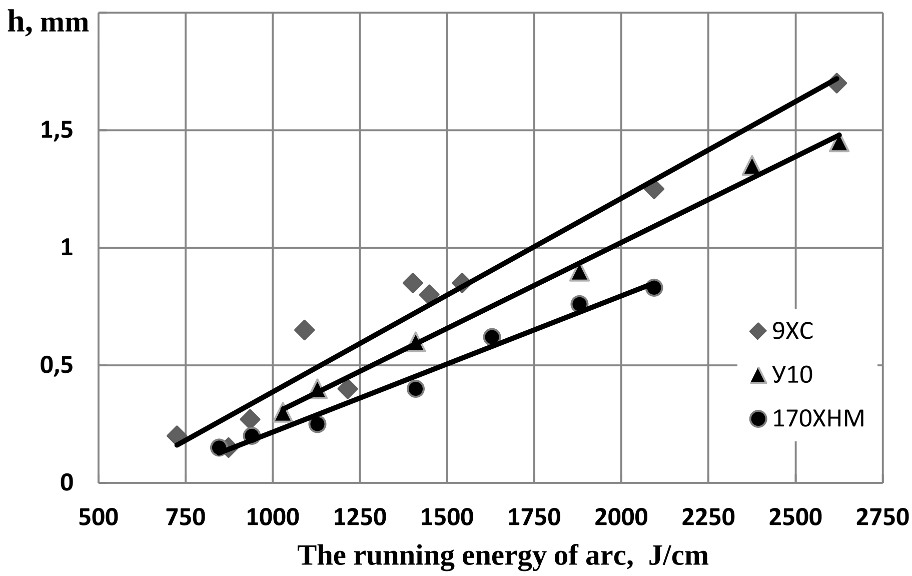
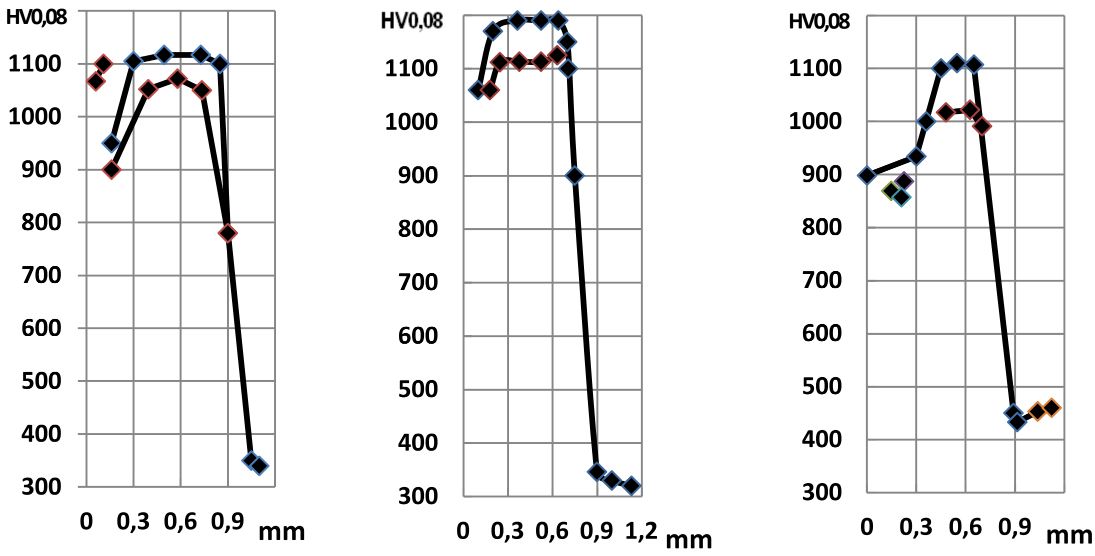


Figure 1. Influence of the running energy of arc on the depth (h) of the zone of plasma quenching of hypereutectoid steels.

In figure 2 shows the dependence of the change in microhardness on the depth of the quenched zone of the steels studied at different values of the running energy. It can be noted that the phase transformations occurring in the surface layer during plasma treatment make it possible to effectively increase the microhardness of all the investigated steels in the thermal-effect zone.



(2094) (a) (2375) (b) (2094) (c)

Figure 2. A change in the microhardness (HV 0.08) over the depth of the plasma quenching zone of steels: 9XC (a), У10 (b), 170XHM (c) for different values of running energy of arc (J/cm).

For example, for an arc quenched arc with a running energy of 2618 J/cm, the surface layer of 9XC steel is characterized by the presence of residual austenite (up to 43 %), needle martensite of lamellar morphology (up to 51 %) with a dispersion of 5…15 μm and up to 6 % of the carbide phase. Starting from a depth of ~ 0.5 mm (for the central section), the residual austenite content is reduced. The carbide phase increases. Martensite and troostite appear in the structure with an interplanar distance of 0.1...0.15 μm. The microhardness of this zone decreases in accordance with the volume ratio of the phases present. At a depth of 1.3...1.5 mm troostite is gradually replaced by sorbitol with an interplanar distance of 0.3...0.5 μm and plate-like perlite. At a depth of 1.7 mm and further the effect of surface heating is not traced. The structure is perlite and secondary cementite with a characteristic microhardness (figure 3).

For other processing regimes, the general laws governing the formation of the structural-phase state of the hardening zone are preserved with a decrease in the length of sections of a homogeneous structure and a change in the ratio of structural components.

Figure 4 illustrates the effect of the running energy of the plasma arc on the ratio of the structural components in the surface layer of the local hardening zone of У10 steel. Phase analysis of the surface layer showed that asymmetry is observed on the γ-phase lines from the side of large reflection angles. This indicates the incompleteness of the processes of homogenization of austenite upon heating.

The value of the true austenite lattice parameter for all regimes was determined by extrapolation. This value was for all regimes higher than that corresponding to the total carbon content in the steel (~ 1 %). The amount of carbon in austenite, calculated by these parameters, depends on the running energy of heat treatment and varies within the range 1.3...1.6 %. This indicates that complete homogenization of austenite over carbon even in the surface layer, which is most heated by the arc, does not occur in the range of the investigated parameters of the regime.

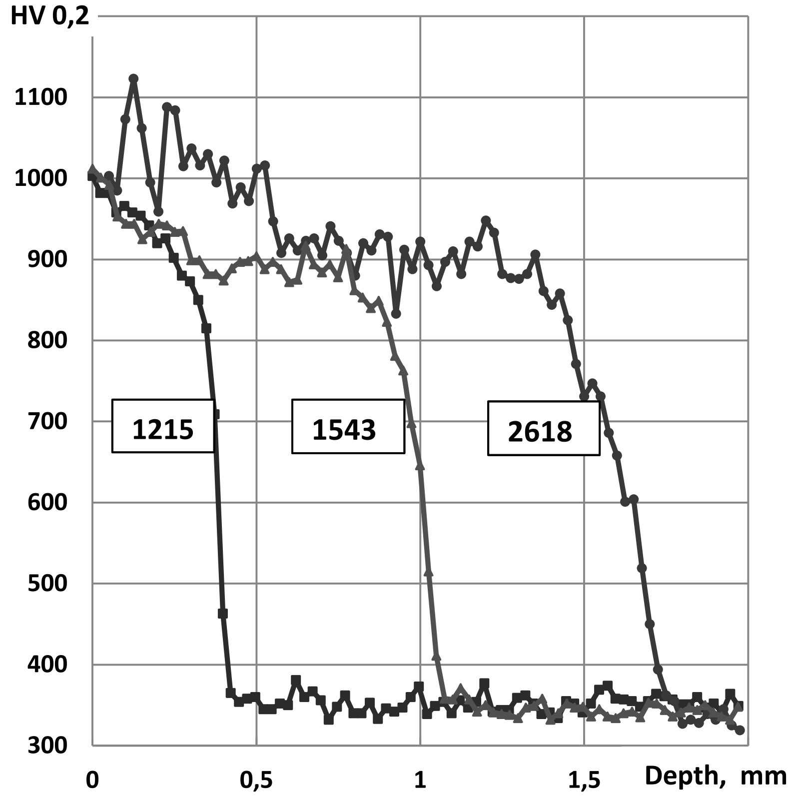


Figure 3. A change in the microhardness along the depth of the local zone of plasma quenching of 9XC steel at different running energy of arc values (J/cm).

Reflections from cementite on diffractograms have not been observed. It is logical to assume that local enrichment of austenite with carbon occurs due to its dissolution. The temperature-time diffusion conditions are not sufficient to completely equalize the carbon concentration. Carbon-enriched austenite has an improved resistance against decomposition upon cooling. Therefore, a high (up to 78 %) concentration of residual austenite is fixed in the surface layer of the samples. In the range of small values of running energy of arc, the residual austenite content does not exceed 30 %.

In the course of the X-ray structural analysis of У10 steel, the shift of the diffraction lines of the α-phase toward the smaller angles of reflection. This indicates the presence of an α-solid solution enriched in carbon. It has been experimentally established that the plasma treatment of У10 steel at elevated running energy of arc values allows to fix martensite with a carbon content of more than 1 %. The maximum amount of high-carbon martensite calculated at the graphical separation of the martensitic multiplet was 85 % of the total α-phase. At the initial values of the investigated range of running energy, the carbon concentration in the martensite does not exceed 0.6...0.7 %. The amount of high-carbon martensite in the α-phase decreases to ~ 40 % (figure 4). Thus, with an increase in the running energy of plasma quenching in hypereutectoid steels, the degree of dissolution of excess cementite. Austenite is saturated with carbon. This leads to the formation of a significant fraction of the residual austenite together with the carbon tetragonal martensite of increased hardness upon cooling.

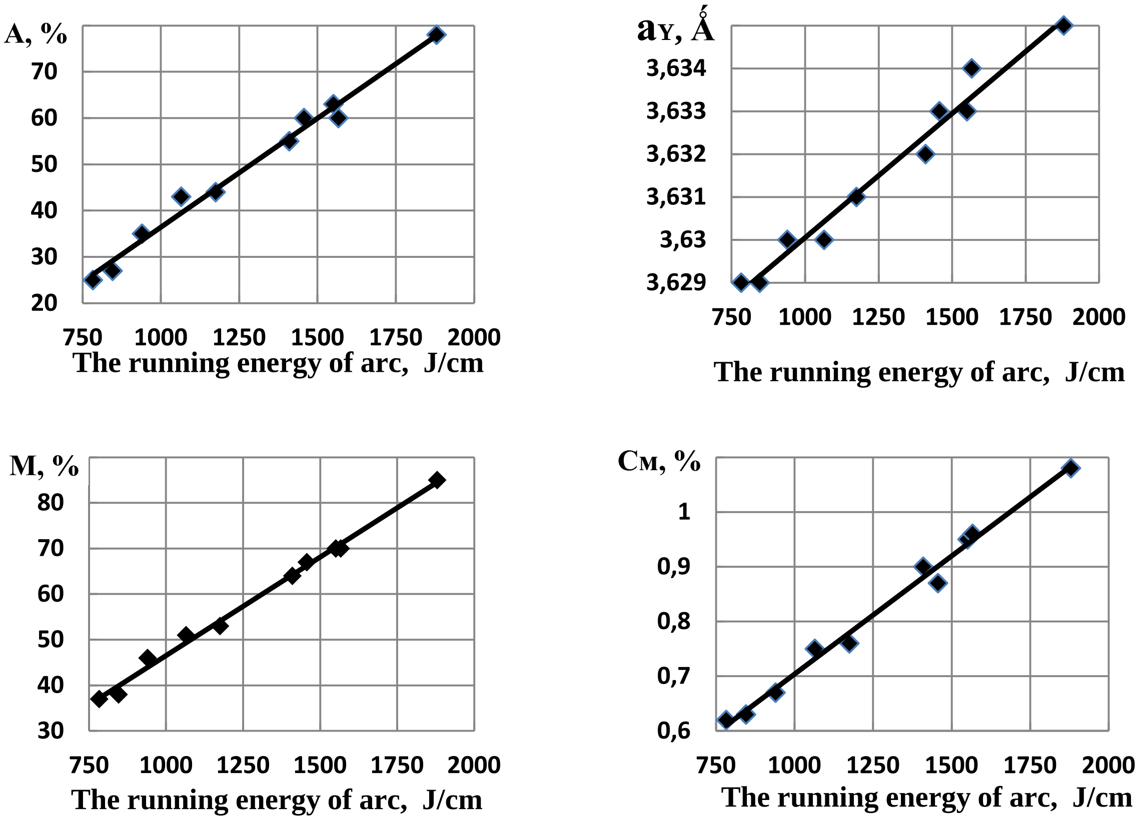


Figure 4. The effect of the running energy of arc in the plasma hardening of steel У10 on the volume fraction of the residual austenite in the surface layer (**A**, %), the austenite lattice parameter (**a**γ, Å), the volume fraction of the martensite of quenching in the composition of the α phase (**M**, %), the carbon concentration in martensite quenching (**Cм**, %).

4. Discussion of the results

The increase in heat input with increasing running energy during plasma hardening promotes the achievement of higher surface heating temperatures and an increase in the residence time in the temperature region above Ac_1. At the same time, the softer effect of treatment parameters on the increase in carbon concentration in hypereutectoid steels is explained by the presence of structurally-free cementite (for example, the amount of carbide phase in steel 170XHM reaches 15...20 %). Carbides have a lower thermal conductivity than steel. Energy costs to form a heat-treated layer of a certain depth increase with increasing content of the carbide phase.

Let us consider the influence of the running energy of the arc on the structural-phase composition and hardness of the hardening zone. When the hypereutectoid steels are heated above the phase transition temperature, the average carbon concentration in austenite increases from 0.8 % by dissolving the carbide phases. The stability of austenite increases.

It should be noted that the mechanism and kinetics of austenitic transformation during rapid heating, characteristic for plasma hardening, have not been studied in detail until now. Several hypotheses of the austenitization mechanism, analyzed in [2], are known, but for any mechanism an austenite is formed that is inhomogeneous in carbon [3, 4]. This heterogeneity in the case of rapid cooling is inherited by the products of its transformation. As a result, the high-carbon austenitic-martensitic structure is fixed after cooling in a thin surface layer (up to ~ 0.3 mm). Its microhardness varies with the ratio of the phases present and the martensite morphology (figure 2). In both cases, the degree of completeness of carbon redistribution is controlled by the temperature-time parameters of the thermal processing cycle. It depends on the initial structure of the steel. It can be different. This, in turn, determines a significant variety of structural states of the heat affected zone after treatment. For example, it is known that the hardness of martensite effectively increases as the carbon concentration in it increases to 0.6 %. Further, the increase in hardness slows down. Therefore, the treatment regime of hypereutectoid steel should provide a degree of dissolution of carbides sufficient to produce martensite with this concentration. Further growth of heat input and dissolution of the carbide phase increase the proportion of residual austenite.

Therefore, for hypereutectoid steels, when processing for the maximum hardness of the surface, heat regimes are preferred, which will provide the necessary degree of austenite saturation with carbon from the dissolving carbide phase.

A predominantly martensitic structure in the surface layer of hypereutectoid steels is formed in regimes with minimal heat input. It contains up to 30 % residual austenite. The carbon concentration in the martensite is ~ 0.65 %. The share of high-carbon martensite in the α-phase does not exceed 30 %. The hardness of the surface with such a structure reaches ~ 1000 HV 0.2 and gradually decreases in depth. The increase in heat input is accompanied by the formation in the surface layer of the investigated steels of a high (up to 78 %) fraction of high-carbon (~ 1.5 % C) residual austenite. In addition, we can observe an increase in the carbon concentration in martensite (over 1 %) and an increase in the volume fraction of high-carbon martensite in the α-phase composition.

Such a structure is a composition of solid constituents-martensite and carbides in less solid residual austenite. It is characterized by a considerable spread of microhardness (see figure 3). It is potentially unstable after cooling and has an increased margin of durability.

The martensitic transformation of the residual austenite proceeds in the course of contact-shock or abrasive interaction with the wear medium. It provides an increase in hardness and partial dissipation of fracture energy in combination with stress relaxation during the formation of martensite crystals of deformation. The wear resistance of the working surfaces of parts in the process of such a transformation of the structure is repeatedly increased.

Thus, the surface layer can be formed by varying the arc energy with the parameters of the plasma hardening mode of hypereutectoid steel. It will possess a dispersed martensitic-austenitic-carbide structure with a variable content of the constituent phases. With an increased content of carbon martensite and carbides, the hardness of such a layer will be the maximum for a given steel composition. The surface has increased wear resistance under conditions of contact friction of rolling and sliding. When the predominant phase in the composition of this layer is a high-carbon residual austenite, the hardness of the surface will be lower. But under appropriate operating conditions, it is possible to realize the mechanism of transformation of austenite into martensite deformation with increasing wear resistance.

5. Conclusion

The influence of the running energy of the plasma hardening process of hypereutectoid steels on the structure and properties (depth and hardness) of the local hardening zone was investigated. It is shown that a gradient structure is formed along the depth of the zone. It regularly changes the dispersity and microhardness of the components. The structural-phase state of this zone provides a smooth transition of mechanical properties from the quenched layer to the base metal.

It is shown that a dispersed martensitic-austenite-carbide structure is formed in the surface layer of the hardening zone. It has a variable content of components depending on the processing mode. The concentration of residual austenite and martensite decreases with depth. In the structure appears troostite, which is gradually replaced by sorbitol. The perlite-cementite structure of steels is located deeper. It has not undergone phase transformations as a result of thermal effects.

Based on the results of the research, regularities have been established that make it possible to purposefully manage the structural state and technological properties of the hardening zone of the investigated steels. You can achieve their optimal ratio for different wear conditions.

References

[1] Balanovsky A E 2015 *Strengthening Technologies and Coatings* **12** 18–30
[2] Dyachenko S S 1982 *The Formation of Austenite in Iron-carbon Alloys* (Moscow: Metallurgy) p 128
[3] Christian J W 2002 *The Theory of Transformations in Metals and Alloys* (Oxford: Pergamon Press) p 617
[4] Shtansky D V, Naka K and Onomori Y 1999 *Acta Mater*. vol 47 **9** 2619–32