Journal of Physics: Conference Series

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To cite this article: E N Safonov and M V Mironova 2019 *J. Phys.: Conf. Ser.* **1353** 012065

HIRM-2019 IOP Publishing
Journal of Physics: Conference Series **1353** (2019) 012065 doi:10.1088/1742-6596/1353/1/012065

Plasma hardening of medium carbon steels

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Abstract. The structure, size and hardness of the zone of hardening of pre-annealed steels (30ХНМА, 34ХН1М, 35ХН2Ф, 38ХГН, 40ХНМА, 40ХН2МА, 45) was studied after treatment with a plasma arc of direct polarity. It was shown that plasma hardening forms a thin layer of martensitic-austenitic structure with variable composition and hardness on the treated steel surface. The zone subjected to hardening was represented by marten site of different dispersion and ferrite veins. Between the quenching zone and the base metal there was a transition zone with a gradient structure of plate perlite and elements of perlite-ferrite base, the share of which was gradually increasing. The structural-phase structure of this zone provided a smooth transition of mechanical properties from the hardened layer to the base metal. Dependences for management of a structural condition, hardness and depth of a zone of hardening were determined.

1. Introduction

Medium-carbon low-alloy steels are typically used in a thermally hardened state to provide the required strength. This does not allow realizing the maximum hardness of the working surface of the parts, which is accompanied by a corresponding decrease in their life, especially in friction conditions. A rational solution to this problem is the use of hardening of working surfaces, for example, plasma hardening [1-8]. At the same time, the physical and chemical state and structure of steel in the inner layers of the product do not change. Surface hardening allows increasing the wear resistance and service life of parts due to a favorable combination of high hardness of the surface working layer with a sufficiently strong and plastic core, the structure and properties of which are formed at the previous stages of production.

The purpose of the work is to determine the rational parameters of the surface plasma hardening mode of medium-carbon structural steels based on the study of the structure, depth and hardness of the local hardening zone.

2. Materials and methods

The structure, size and hardness of the zone of hardening of pre-annealed steels (30ХНМА, 34ХН1М, 35ХН2Ф, 38ХГН, 40ХНМА, 40ХН2МА, 45) after treatment of their surface by a plasma arc of direct polarity were studied. Argon was used as a plasma-forming and protective gas. The range of variation of parameters of the process mode: arc current 120...300 A, the speed of movement of the plasma torch 1...5 cm/s. The linear energy of the arc was changed in the range 1320...3400 J/cm preventing macro-melting of the treated surface.

The structure and dimensions of the heat-treated zone were investigated on transverse micro-grinding with AXIOVERT 40 microscope at magnifications of ×50 and ×1000. Assessment of dispersion of structural components was carried out according to State Standard 8233-56 "Steel. The standards of the microstructure". Hardness was measured by the device ERGOTEST COMP 25. Tests were carried out with a Vickers pyramid under load 98.07 H. Phase composition of the surface layer of steels 34XH1M, 35KHN2F, 38KHSN, 45 studied using x-ray diffractometer DRON-1 in the iron Kα radiation. The volume fraction of phases was determined with respect to the integral intensities of austenite lines (311) and martensite lines (112-211) – (121). To estimate the carbon content in the phase components, the parameters of their lattices were determined.

3. Results and discussion

As a result of the studies it was found that with the increase in the linear energy of the plasma arc, the depth and hardness of the local hardening zone increase. The increase in the arc speed at a fixed current value is accompanied by a decrease in these indicators. This is due to the decrease in the linear energy of the heat input process. Figure 1 shows the dependence of the hardness change in the depth of the thermal influence zone for a number of steels under different values of linear energy.

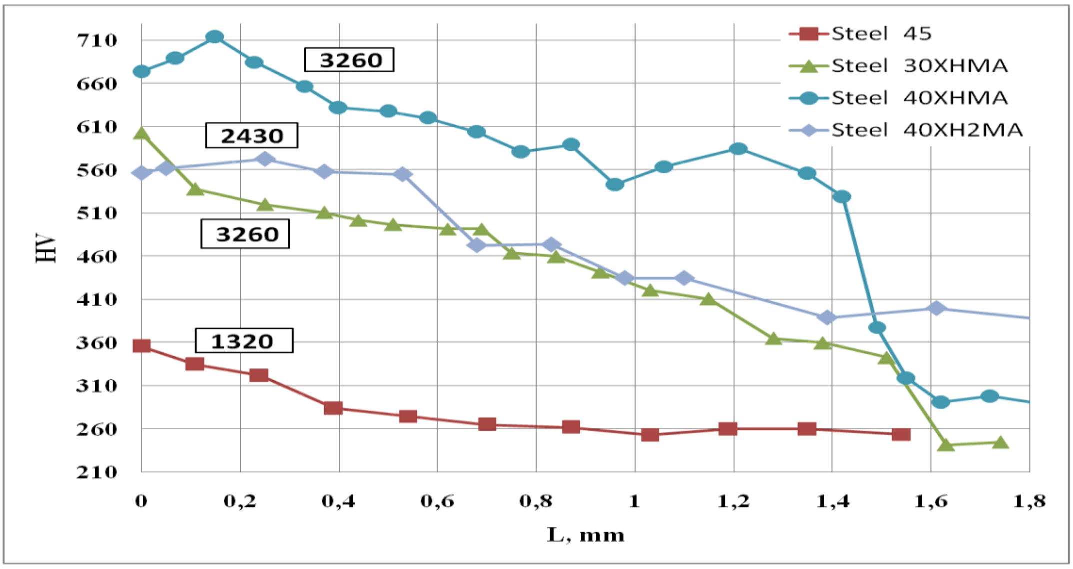

Figure 1. Change of hardness (HV 10) in depth (L) of the local zone of plasma hardening of steels at different values of linear energy (J/cm)

Comparing the data obtained, it can be concluded that the depth and hardness of the plasma-quenching zone increase with the increase in the arc energy. Steels with higher carbon content have a greater depth and hardness of the hardened zone. However, it should be noted that the surface hardness of the heat-treated zone for steel 40XHMA and 40XH2MA slightly below the maximum values observed in its depth.

X-ray analysis shows the presence of a thin (~ 0.01...0.03 mm) surface layer of samples treated with plasma arc, residual austenite. Its volume fraction varies depending on the composition of the steel and the linear energy of the arc (Tables 1, 2).

Evaluating the results of steel 45 processing, it can be noted that the value of the linear arc energy of 1320 J/cm is insufficient for its full hardening (Figure 1).

The initial structure of steels is represented by ferrite and perlite (30...50 %). The typical structural state of the plasma quenching zone observed at an increase of ×50 for the studied steels is shown in figure 2. It is seen that the structure naturally changes in depth. In the process of plasma heating in the areas of perlite, carbon austenite is formed, the composition of which is close to eutectoid. In the surface layer, where the heating temperature and its duration are maximum, the diffusion equalization of the carbon concentration occurs. As a result of the development of this process, a thin layer of martensitic-austenitic structure is fixed on the treated surface after cooling, with a variable content of residual austenite depending on the treatment mode and steel composition.

Table 1. Dependence of the local depth of the hardening zone, the volume fraction residual austenite (γ_r, %) in the surface layer and its hardness from linear arc energy at plasma hardening of steel 45

Linear arc energy, J/cm	Depth of zone, mm	γ_r, %	HV 10
1320	0.40	40	360
1710	0.75	29	545
1800	0.95	28	665
2100	1.10	28	730
2400	1.30	17	757
2700	1.50	< 5	780

Table 2. Dependence of the lattice parameter of martensite (a (211)) and the volume fraction of residual austenite (γ_r, %) in the surface layer, as well as its hardness from linear arc energy at plasma hardening of steels

Linear arc energy, J/cm	34XH1M			35XH2Ф			38XГH		
	a(211), Å	γ_r, %	HV 10	a(211), Å	γ_r, %	HV 10	a(211), Å	γ_r, %	HV 10
1320	2.8737	37	470	2.8742	45	560	2.8740	39	545
1500	2.8729	< 5	675	2.8740	25	674	2.8695	< 5	600
1650	—	< 5	634	2.8730	< 5	695	2.8720	< 5	653
1800	—	—	—	2.8736	< 5	660	2.8716	< 5	633

It can be noted that the main structure of the quenching zone is needle martensite. The length of its needles gradually decreases from 16 μm (8 score) at the sample surface to 2 μm (2 score) at a depth of up to 1.5 mm from the surface. In the transition zone from the hardened metal to the main one, which has not experienced phase transitions during processing, martensite is gradually replaced by perlite with an interplate distance of 0.2...0.3 mm (sorbit). This increases the proportion of structurally free ferrite, which together with perlite is the initial structure of the investigated steels.

According to the experimental data, the regimes with minimal heat input allow obtaining martensite with a significant (30...40 %) fraction of residual austenite in the surface layer of the studied steels. The surface hardness is 360...670 HV 10, the depth of the hardened zone – 0.4...0.8 mm. Processing modes with high values of linear arc energy are characterized by increased heat input. In the studied range, they form on the surface mainly a martensitic structure with a maximum hardness (690...780 HV 10) and a depth of the quenching zone (1.3...1.5 mm).

Several hypotheses of the austenitization mechanism are known, but an austenite is formed that is inhomogeneous in carbon for all mechanisms [9]. The reason for the stabilization of austenite in the surface layer of ferrite-pearlite steels is the hereditary preservation of sites with a high concentration of carbon in austenite. Austenite is formed from perlite by high-speed short-term heating of the surface by a moving heat source. At the same time, the process of diffusion equalization of the carbon concentration in the volume of the formed austenitic grain does not have time to develop. The increased carbon content provides a corresponding decrease in the Mн point near the interface and the subsequent fixation of austenite during cooling.

In the process of plasma heating there are various stages of formation of austenite in the depth of the zone of thermal influence. This is due to the heat flow spreading from the metal surface. In the upper layers, is heated to a high temperature, is the transformation of excess ferrite in the austenite and ferrite saturation of the former sites of carbon. However for all investigated steels there are signs of incompleteness of this process, especially after processing with minimal heat investment (Tables 1, 2).

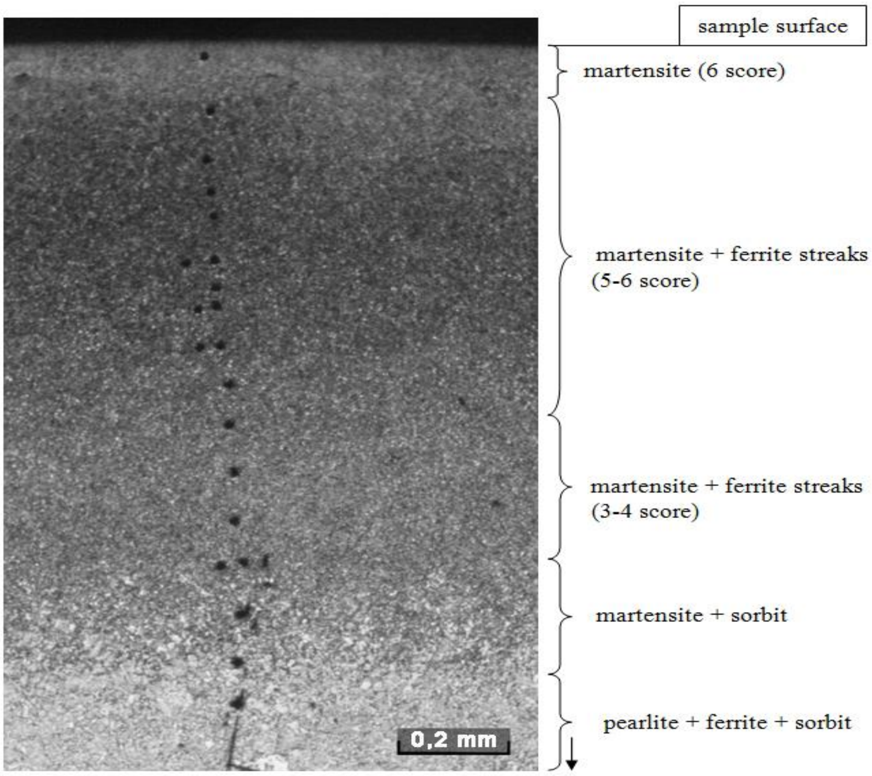

Figure 2. Structural state of the plasma hardening zone of steel 30XHMA

The X-ray analysis records the presence of austenite and martensite with different carbon content in the surface layer. It can be explained by the fact that in the process of high-speed heating, the pearlite colony passes into an austenitic state with a carbon concentration close to eutectoid. Further, carbon diffuses within the grain of structurally free ferrite. This is a condition for its complete transformation into austenite. The degree of completion of the carbon redistribution process is determined by the parameters of the thermal heating cycle, the composition and the initial structure of the steel, in particular, the grain size. As a rule, in the conditions of continuous heating-cooling, characteristic of the considered technology, due to the short-term stay at a high temperature, the alignment of the austenite composition with carbon is not achieved. After cooling, in areas with a high concentration of carbon, residual austenite and high-carbon martensite are formed, between the cementite plates, where the solid solution is less saturated with carbon, low-carbon martensite occurs.

It was previously shown [8] that in hypereutectoid steels containing excess cementite, austenite is most saturated with carbon, formed after plasma treatment in the range of increased values of linear energy. The obtained experimental data allow concluding that the influence of the regime parameters on the concentration of residual austenite in the surface layer of pre-eutectoid and hypereutectoid steels differs. With increasing arc energy in the surface layer of the zone of thermal influence of hypereutectoid steels, the degree of dissolution of excess cementite increases, austenite is saturated with carbon, which leads to the formation of a significant proportion of residual austenite together with carbon tetragonal martensite of increased hardness during cooling.

In steels with pre-eutectoid ferrite, the increase in heat deposition is accompanied by a decrease in the carbon concentration in the resulting austenite. This is due to its diffusion into the ferrite with a corresponding decrease in the stability of austenite. Martensite is formed in the process of cooling carbon inhomogeneous austenite. It inherits this microchemical heterogeneity. The proportion of low-carbon martensite increases, and the residual austenite decreases. Consequently, in pre-eutectoid steels, the largest proportion of residual austenite in the surface layer is fixed after treatment with the minimum for each grade values of the linear energy of the plasma arc. This ensures the formation of austenite during heating and martensite during cooling. Moreover, for each steel grade, depending on the concentration of carbon and alloying elements affecting the temperature of MN, these values differ and should be determined experimentally. Often, these values of the arc energy are insufficient to obtain a hardened zone of the required depth and hardness (Figure 1, Steel 45). Therefore, for plasma hardening of medium-carbon (pre-eutectoid) steels it is possible to recommend regimes with a maximum value of the arc running energy, taking into account the degree of melting of the surface.

4. Conclusion

1. Plasma hardening of the investigated steels with linear arc energy within 1320...3260 J/cm forms on the treated surface a thin (~ 0.01...0.03 mm) layer of martensitic-austenitic structure with a hardness of 360...730 HV 10 with a volume fraction of the phases varying depending on the treatment mode and composition of the steel.

2. The hardened zone is represented by a martensite whose needle length gradually decreases from 16 μm (8 score) at the sample surface to 2 μm (2 score) at a depth of up to 1.5 mm from the surface, and by ferrite veins.

3. Between the quenching zone and the base metal there is a transition zone with a gradient structure of plate pearlite with a hardness of 520...260 HV 10 and elements of the pearlitic-ferritic basis, the proportion of which gradually increases. The structural-phase state of this zone provides a smooth transition of mechanical properties from the hardened layer to the base metal.

4. With an increase in the running energy of the arc, as well as the carbon concentration in the steels studied, the depth and hardness of the plasma quenching zone increase.

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