ACCURACY OF PLASMA SURFACE HARDENING OF WHEELSETS IN DEPOT CONDITIONS

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ABSTRACT

The technology of plasma surface hardening is characterized by new capabilities in terms of increasing contact-fatigue strength of metal and, therefore, extending the life and improving the reliability of wheelsets of rolling and traction stock. The main outcome of the more than 5-year operation of locomotives and train cars with plasma hardened flanges of the wheelsets is as follows: plasma hardening is a high-productivity and efficient method, which provides the 2 to 3 times extension of life of the wheelsets and which can be applied under the typical depot conditions. The accepted technology, providing that it is fulfilled properly, increases the safety factor for reliability of the wheelsets (naturally, in the absence of melting and preliminary treatment defects). The guaranteed reproducibility of the best values of operational reliability and wear resistance is ensured only at strict adherence to the preset parameters of hardening of each wheel. Under conditions of achieving an assigned surface hardness of 380-430 HB the spread of values of the increased wear resistance in operation of the hardened wheelsets is caused only by the spread of parameters of the hardened layer on different wheels. The spread of parameters of the layer, characterized by distribution of microhardness through its thickness and across the width, as well as its location on the flange, is determined only by the accuracy and consistency of the process parameters.

Keywords: plasma, surface hardening, wheelset.

1. INTRODUCTION

An increase in service characteristics of the hardened parts can be achieved by ensuring the optimal thermal cycle (heating-cooling) on the basis of principles of structural, phase and polymorphic transformations of the component material.

The technology for plasma hardening of surfaces of wheelsets developed by authors. [1] is based on properties of the plasma. Heating for hardening is performed by the high-enthalpy plasma jet of the products of combustion of a hydrocarbon gas with air [2]. The jet creeps over the surface being heated with an opposing relative displacement speed. The heated zone is cooled immediately after it goes out from the plasma, primarily because of removal of heat into the body of a massive steel part, as well as conductive and radiation removal of heat from the surface into the atmosphere. Heating of each region of the surface occurs with an increasing density of the heat flow, in accordance with variations in the thermal-physical parameters of the plasma with an approach to the jet mouth. In turn, these parameters can be regulated over wide ranges [3]. The flow diagram of the process of plasma surface heating for hardening is characterized by high efficiency, equal to 60-80 %, and the match between the rates of growth of the heat flow from the heating medium and the thermal-physical properties of steel.

The purpose of plasma surface hardening of the wheelsets is to increase their life and improve reliability in operation without any sacrifice of performance of rails. To achieve this purpose, it is necessary to solve three inter-related and conflicting problems [4].

- The first of them consists in providing local hardening of the working surface of a flange to achieve the preset value of hardness and finely dispersed structure of metal of the hardened layer. It is these factors that ensure a decrease in the rates of wear of flanges and the coefficient of friction between the flange and side surface of the rail head, which has a favourable effect on rails, especially in curves, through delaying their wear.
- The second problem is associated with the formation of fields of internal stresses acting both in the bulk of metal and between grains. Rapid heating and cooling of a local region of the massive wheel lead to structural transformations, which involve changes in the specific volume, and to plastic deformations, i.e. compression and tension. The most serious problems arise in hardening of tyres. Material of the wheel tyre is in a complex heterogeneous stressed state.
- The third problem is associated with a change in a fine structure of metal caused by plasma surface heating [5]. Depending upon the plasma hardening conditions the results obtained may be quite opposite. In a case of the proper technology, the resulting metal structure will be mostly of the troostite-sorbite and fine-laminated type mixed with structureless martensite. This structure has a somewhat increased microhardness and is characterized by the absence of nonmetallic inclusions, of the sulphide type in particular. The resulting fine structure contains dispersed sub-structural elements (sub-grains, blocks, cells) and features a uniform distribution of dislocations without dislocation density gradients. In this case the initial metal structure and all mechanical properties are improved. In a case of violation of the technology the structure is coarse-laminated (ferritic-pearlitic), containing ferritic fringes and nonmetallic inclusions of the sulphide type, and the coarser sub-structure with a non-uniform distribution of dislocations and dramatic dislocation density gradients formed as a rule in a region of contact of rigid and soft structural constituents (cement laminae with ferritic interlayers in pearlite or at the pearlite grain boundaries with ferritic fringes, etc.). In this case there is a risk of cracking

2. PECULIARITIES OF PLASMA SURFACE HARDENING OF WHEELSET RIDGES

Local plasma treatment is justifiable technically and economically. In this case hardening is done only to the most loaded working surface of a part, whereas the central part remains untreated. The plasma method is the most cost effective and productive among other methods of heat treatment involving the concentrated heat sources. This method is characterized by reduced costs, higher affordability of the process equipment and larger sizes of the hardened zone.

All three above mentioned problems are determined by the thermal cycle of heating and cooling a steel part (time dependence of temperature) in a cross section along the plasma jet axis at a differing depth. The thermal cycle at a differing depth of 0-1-2-3-4-5 mm is shown in Figure 1. The average mass temperature of the plasma jet is 6000 K. The relative displacement speed is 1.5 cm s^{-1}, the plasma gas is a mixture of air with 10 vol. % methane. Figure 2 shows temperature fields in a steel part at the moment of outlet from the zone affected by the plasma jet, following the thermal cycle shown in Figure 1.

Analysis of these dependencies shows that the rates of heating and cooling the surface layer of metal depend primarily upon some localization of heat input into a workpiece.

The important factor at each stage of heating is the ratio of the fuel gas to air in the plasma mixture. A small addition of fuel gas to the plasma air provides a substantial intensification of heating by increasing transmission of heat from the plasma to the surface being heated.

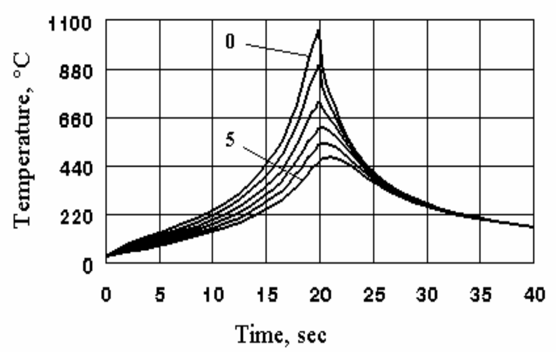

Fig.1. Thermal cycles for microvolumes at the depth

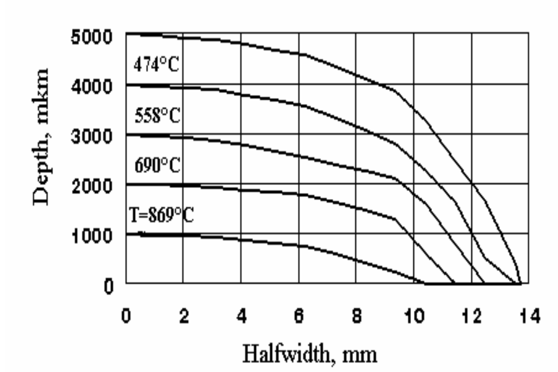

Fig.2. Temperature fields

The depth and width of the HAZ depend upon conditions of plasma treatment. They decrease with an increase in the relative displacement speed. Variation of the depth with the speed is almost linear. By increasing the speed, it is possible to maintain the surface temperature by increasing the plasmatron power by raising the arc current or the coefficient of heat transmission from the plasma to the heated surface through changing its composition. However, in this case the temperature gradient through the thickness increases. The most important feature of structures formed during plasma hardening, in the case of other methods of treatment using highly concentrated heat sources, is a high degree of dispersion of a material in the hardened zone, which determines the combination of its service properties.

Distribution of microhardness through the thickness along the axis of the hardened path corresponding to this microstructure is shown in Figure 3.

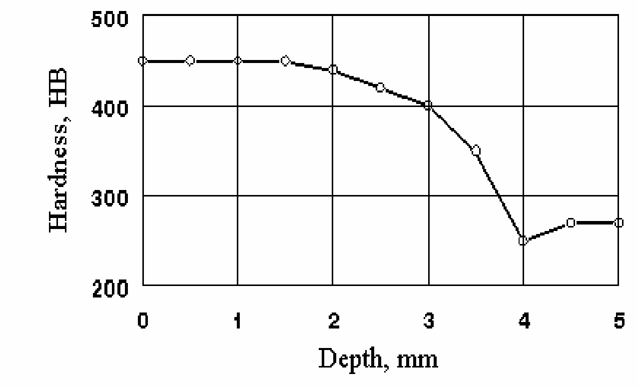

Fig.3. Distribution of hardness through the thickness.

Measurements of microhardness in dynamics through the entire thickness, i.e. from the surface to the base metal, show the following. Between the zone of complete recrystallization and that of ICR there occurs a dramatic decrease of down to 35 N/mm^2 in microhardness. Starting approximately from the centre of ICR and up to the heat-affected zone, microhardness increases by 30 N/mm^2 on the average. In the heat-affected zone there is a gradual decrease in microhardness until the base metal is reached, where it becomes stabilized. There is a microhardness dip, which can be shifted to a certain degree and is located between the heat-affected zone and the base metal.

Different researchers observed the microhardness dip in the transition layer between the martensite structure and the basic structure in the centre, which is formed during the process of heat hardening by the method of interrupted quenching. Increased tensile stresses are formed in this location. In our case such stresses can be formed also during phase recrystallization.

3. INDUSTRIAL TESTS

First locomotives with the wheels plasma hardened by the ours technology were put into experimental operation at the Lviv-Zapad shed early in March 1996 and the cars - at the Kiev-Passenger shed in summer that same year. Comparison of the plasma hardened wheel ridges of electric locomotives with the traditional ones under the same service conditions of the Lviv railway proved already by the end of April 1996 the expected two-fold decrease in the rate of their wear. After that a decision was made to expand the scopes of application of plasma hardening of the wheelset ridges. It was for that purpose that the new specialized two-module high-speed plasma hardening machine UVPZ-2M was developed [4]. Its application initiated the arrangement of workshops for plasma hardening of wheelsets without wheeling out from under a locomotive, which was completed in 1997. This was done using the KZh-20 machine tool at the Znamenka shed. Similar workshops for plasma hardening with wheeling out were arranged in Osnova, Kharkiv. Workshops for plasma hardening of the wheelset ridges without wheeling out, based on the KZh-20 machine tool, were built at the Kazatin shed, those based on the K-40 machine tool were built at the Lviv-Zapad, Osnova (Kharkiv), Kotovsk, Nizhnedneprovsky junction, etc. The car wheels are hardened using the specialized production line with wheeling out [6] at Kiev, Kherson, Dneprodzerzhinsk and other car sheds. More than 20 workshops for plasma hardening of surfaces of wheelsets using specialized machine UVPZ-2M have been put into operation.

Industrial tests were conducted on wheelsets with plasma hardened necks and mass-produced wheelsets (for comparison). Results of testing the locomotive wheels with the plasma hardened necks under conditions of the Carpathian Mountains are shown in Figure 4. In all the cases the intensity of wear of the plasma hardened wheel necks was much lower (2.5-3 times), as compared with the untreated wheels.

Observations showed a change in the character of wear of the plasma hardened necks. They had no spalling in the microvolumes of metal within the zones of contact with the side surface of a rail, and roughness of the surface was much lower. This circumstance suggests more favorable conditions of contact of the plasma hardened wheel with the rail.

The final outcome of more than 5 years operation of locomotives and cars with the plasma hardened wheelset ridges is as follows: 1. Plasma hardening is a highly productive efficient method for 2- or 3-fold extension of service life of the wheelsets, which can be applied under conditions of a typical car shed. The accepted technology provides a very high safety factor for operational reliability of the wheelsets. 2. The guaranteed reproducibility of the best indicators of operational reliability and wear resistance is ensured by keeping precisely to the prescribed hardening parameters for every wheel.

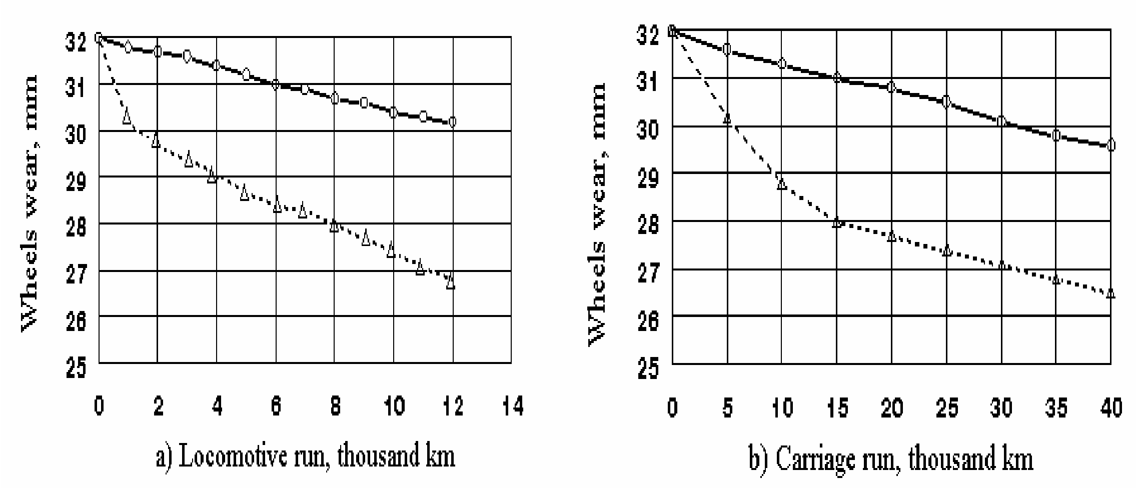

Fig.4. Wear of wheelsets:
--Δ----Δ-- -mass-produced; —o——o— - plasma hardened

4. ENSURING ACCURACY OF PLASMA HARDENING

Our investigations and experience of operation of the plasma hardening machines prove that this process can be automated. All the above three problems are reduced to ensuring repeatability of the optimal thermal cycle for each wheel. For this we created the off-line optimization system, the idea of which is shown in Fig. 5.

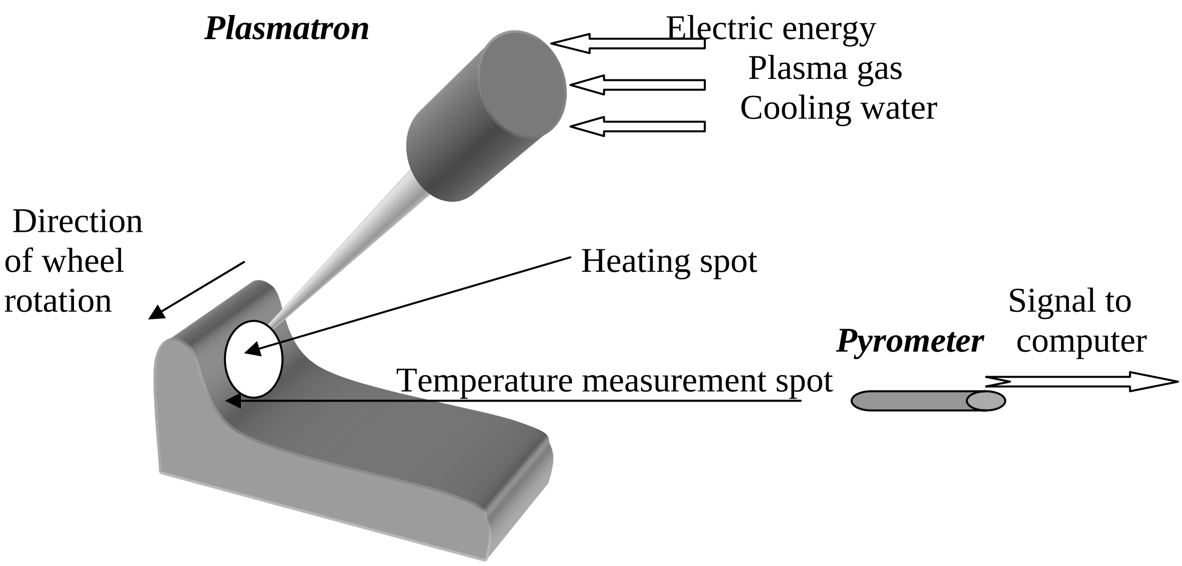

Fig. 5. Schematic of monitoring and control of the process of plasma hardening

Proceeding from a requirement of the guaranteed accuracy and repeatability of the hardening process, developed the computerized off-line optimization system for the UVPZ-2M machines. The off-line optimization system provides:

- in-process programming of working conditions and parameters;
- real-time display of the state of the process parametersbeing monitored;
- recording and permanent memory storing of parameters of the technological process of plasma surface hardening of wheelsets;
- output of the stored information to PC;
- processing of analogue signals from the "Smotrich" pyrometer, power supplies of the "Plasma-2" plasmatrons and pressure transducers, as well as of input discrete signals from the final control mechanisms,
- formation of output control instructions following the preset program.

5. CONCLUSIONS

1. The readily available high-enthalpy reactive air-gas plasma is widely applied as the plasma-forming environment for technology purposes. Theoretical principles of development of the high-efficiency equipment and technological processes that use it are described.
2. The new approach to making the plasma surface hardening machines is presented. The new types of the plasma hardware were developed and the new technological processes of high-speed plasma surface hardening were devised.

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