

## Plasma-arc surface modification of metals in a liquid medium

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**Abstract.** The method of saturation of the steel surface with carbon under the action of a plasma electric arc in a liquid is considered. The microstructure and microhardness of the hardened layer after treatment using this method were studied. It is established that during the time of plasma action of 0.1-1c the surface layer is saturated with carbon and nitrogen to the level of concentration of high-carbon steel. Microstructures and characteristics of the metal surface after plasma modification in a liquid medium were studied. The main parameters of the modified layer were determined: depth of the layer is 15-1200  $\mu\text{m}$ , microhardness reaches 7.000-14.000 MPa.

### 1. Introduction

The process of operation of machines and equipment is always accompanied by wear, which gradually leads to a decrease in the service life of machines. Therefore, increasing the wear resistance of wearing parts for various purposes is the most important task of modern mechanical engineering and other branches of engineering [1-10].

In this paper, we present the results of an experimental investigation of the surface layer structures formed in the process of plasma heating in liquid media. To saturate the surface layer with carbon or nitrogen, the workpiece is immersed in a liquid which contains carbon (toluene, mineral oil, etc.) or nitrogen (an aqueous solution of ammonium chloride, etc.).

### 2. Materials and methods of research

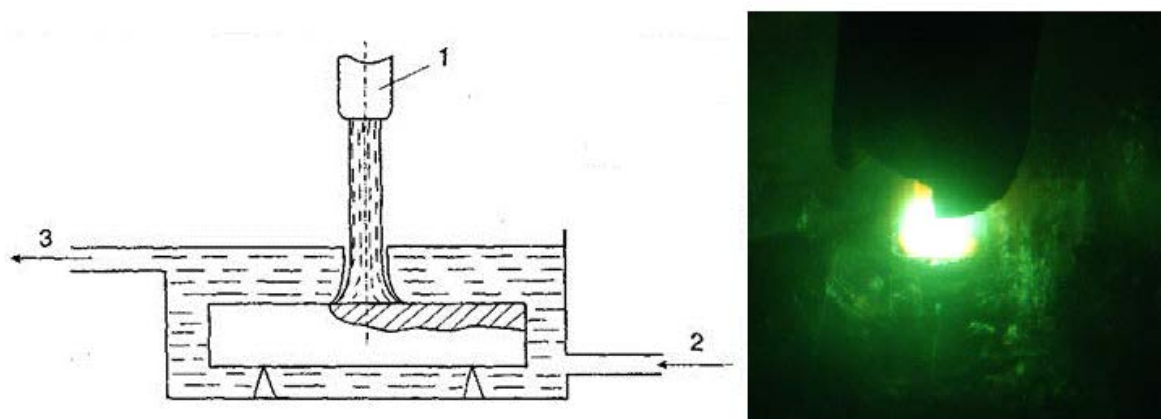
Plasma surface modification in liquid media was carried out on steels 1018 and 1020 according to the ASTM standard. Chemical composition of the material in percent according to ASTM A29 standard is shown in the table. To test the regimes of plasma modification, samples of 80x20x10 mm were used.

**Table 1.** Chemical composition of the material.

	1018	1020
Iron, Fe	98.81-99.26%	99.08-99.53
Carbon, C	0.18%	0.20%
Manganese, Mn	0.6-0.9%	0.30-0.60%
Phosphorus, P (max)	0.04%	0.04%
Sulfur, S (max)	0.05%	0.05%



Figure 1 shows the scheme of the process of plasma arc modification in liquid media. The workpiece is immersed in a layer of a flowing liquid (position 2, 3). Plasma arc is created by a plasmatron (position 1). Under the action of the gas-dynamic pressure of the plasma arc, a funnel is created in the liquid and a chemical-thermal influence on the surface layer of the metal occurs. Processing takes place in a semi-enclosed volume of fluid that is limited from all sides. When the plasma jet moves relatively to the surface of samples, heated to the temperatures of structural transformations, surface is immediately closed by a liquid, cooling them.



**Figure 1.** Scheme of the process of plasma-arc surface modification of a metal in liquid media.

The microstructure was examined on OLYMPUS GX51 microscopes with magnification of 100 and 500 times. Electron microscopic studies of the surface of metal samples were carried out using a scanning electron microscope JIB-4501. Microhardness was measured on a microhardness tester HMV-2T (Shimadzu) at a load of 0.01-120 g. Distance from the surface of the sample to the point with the maximum hardness values in comparison with the hardness of the base metal was considered as the depth of the modified layer.

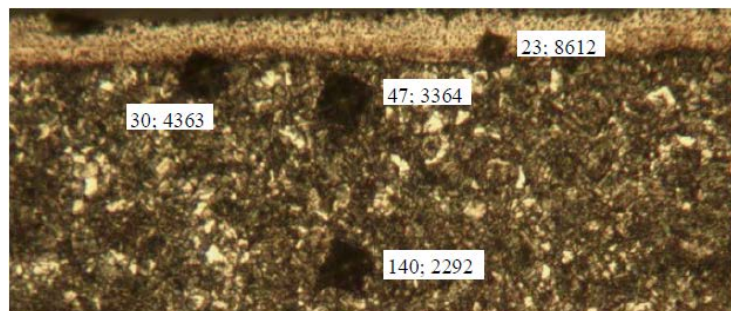
### 3. Investigation of the structure

The conducted studies on plasma-arc modification in a liquid medium showed changes in the microrelief on the metal surface. After etching the sections (Figure 2), a white layer with a high microhardness of 4000-12000 MPa (under a load of 2H) is observed under the microscope in the cross section. Figure 2 shows the microhardness measurements for the depth of the modified layer (first digit is the depth of measurement in  $\mu\text{m}$ , second is the microhardness value). Depending on the carbonitride and nitride zones. The transition regimes of plasma-arc modification, it is possible to obtain layers with different structures in the surface layer.

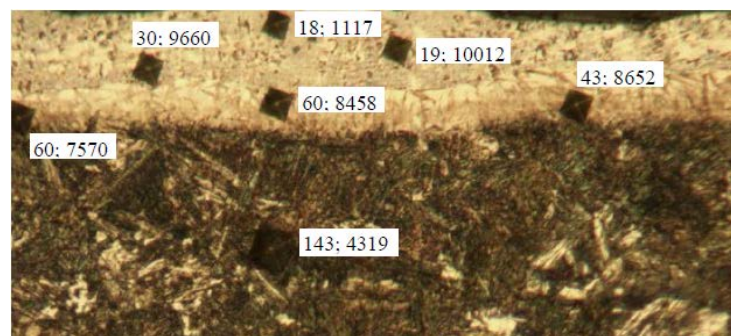
Directly on the surface, a non-etching  $\epsilon$ -phase saturated with nitrogen is formed, followed by a supercooled  $\gamma$ -phase, under which nitrogenous martensite is. The photographs show an ultrafine-grained structure of iron from the nitrated layer to the underlying layers is smooth, which is one of the basic requirements for the microstructure of nitrated steel. The thickness of the diffusion zone varies from 50 to 200  $\mu\text{m}$ . Structure of the quenched zone is martensite, residual austenite and carbides.

### 4. Nitriding

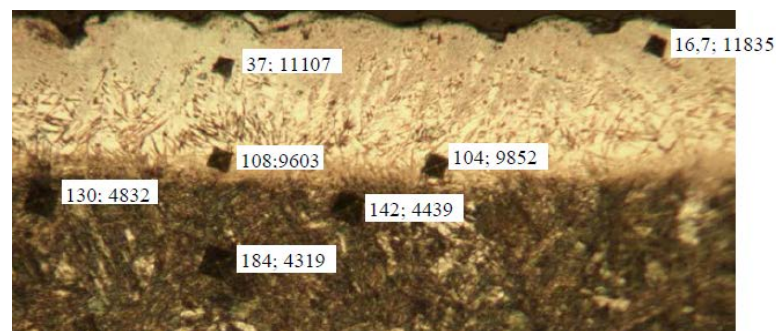
As a liquid medium, an aqueous solution of an ammonium salt of different concentrations was used.



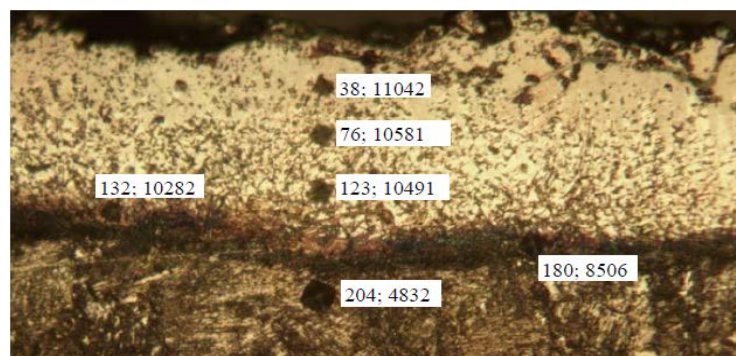
(a)



(b)



(c)



(d)

**Figure 2.** Microstructure of the modifying layer in various regimes of plasma-arc modification in liquid media.

Chemical-thermal treatment consists of three processes: dissociation - production of a saturating element in the active atomic state:  $2\text{NH}_3 \leftrightarrow 2\text{N} + 3\text{H}_2$ ,  $\text{CH}_4 \leftrightarrow \text{C} + 2\text{H}_2$ , etc.; absorption - absorption of active atoms of the saturating element by the metal surface; diffusion - movement of atoms of the saturating element from the surface into the interior of the metal. The conducted studies have shown that an increase in the concentration of nitrogen in the treatment zone leads to an increase in the nitrogen content in the surface layers, which results in an increase in the depth of the layer and microhardness. Microstructure of the layer after the modification in liquid media is the same as after simple nitriding from the gas and solid phases [5], but there are some differences.

A nitrogen-modified reinforced layer which consists of two zones: bond zones (a white layer consisting of submicroscopic nitrides indistinguishable during the metallographic analysis) and a diffusion zone. After modification at a minimum processing speed (1-3 mm/s), white layer is absent, and the diffusion zone is characterized by greater homogeneity. According to X-ray diffraction analysis, a  $\gamma'$ -phase of the (Fe, Me) 4N type is present on the surface nitrided at a minimum speed of processing of 1020 steel, and at a processing speed of 10 mm/s, in addition to the  $\gamma'$ -phase, an  $\varepsilon$ -phase of the (Fe, Me) 2-3N is presented too. In the first case, the intensity of the x-ray lines which correspond to the  $\alpha$ -solid solution is several times higher than in the second one, and exceeds the intensity of the lines which correspond to the  $\gamma'$ -phase. Consequently, due to the change in technological saturation factors, it is possible to regulate the resulting layers in terms of structure and phase composition and optimize the properties of the nitride workpieces and tools.

## 5. Nitrocarburizing

A unique feature of nitrocarburizing during plasma-arc modification in a liquid is an increased concentration of nitrogen and carbon. The depth of the diffusion layer on 1020 steel was 0.6-1.1 mm, microhardness was 11000-12500 MPa. Microhardness increases with increase of heating rate. Heating at a lower rate increases the time, during which the nitrogen-carbon-containing liquid evaporates intensively, which increases the concentration of active carbon and nitrogen atoms at the boundary line between the saturated medium and the metal surface. However, an increase in the concentration of nitrogen and carbon in the region of the anode spot of the plasma arc [6] leads to an increase in the residual austenite (from 2.5 to 40% on 1020 steel), which reduces the microhardness. The depth of the diffusion layer on 1018 steel was 0.05-0.1 mm, and the microhardness was 10200-11100 MPa. The depth of the diffusion layer on 1020 steel was 0.06-0.12 mm, and the microhardness was 11200-13000 MPa.

The presented results show the possibility of surface plasma-arc modification in liquid carbon and nitrogen containing media. Processing this way causes appearance of a boundary condition of the workpieces surface, where thin surface layers can have traces of micro-melting without forming a pool of liquid metal in the form of a thin film. In this state, process of diffusion of carbon and nitrogen into the metal is greatly accelerated. Important parameters are the composition of the liquid medium, heating and cooling rate of the surface layer of the metal.

## 6. Conclusion

The conducted studies on the estimation of plasma-arc modification of the surface of metals in liquid media have shown the promising outlook of this method for the production of complicated in terms of microstructure of modified layers. Modified by carbon and nitrogen layers of thickness up to 200-250  $\mu\text{m}$  with a microhardness of 8000-12400 MPa were obtained. By regulating the ratios of the components, which are part of the liquid medium, it is possible to obtain different surface layers of the metal with respect to structure and properties.

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