27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 12-16 June 2000 ECA Vol. **24B** (2000) 1272 -1275

Structure and Tribological Characteristics of Modified Surface Layers of Steel Samples Processed by Pulsed Plasma Streams

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Introduction

Plasma processing of different materials is widely used now in technology of heating, etching, evaporation, sputtering and so on. The energy of plasma particles or ion beams can be varied in the range of several eV up to several hundreds keV. Plasma streams with low particle energies are mainly used in plasma deposition methods. The beams with high energy of particles are valid for ion implantation into materials [1]. Recently the plasma streams with medium particle energy (of an order several keV) but with high enough plasma energy density are successfully utilized for surface modification of different materials with the result of sufficient improvement of their physical properties [2, 3].

In our previous investigations there was analyzed phase structure of surface layers of different industrial steels being irradiated by pulsed nitrogen plasma streams [3]. Formation of austenite, carbides and nitrides in modified fine-grained surface layer with a depth up to 30 μm were observed as result of plasma processing. Such modified surfaces have sufficiently increased microhardness and wear resistance. Investigations carried out had shown that modified layer represents tense structure characterized by increased strength.

The pulsed plasma treatment led to melting of a surface layer, simultaneous introduction of nitrogen into liquid surface layer and subsequent fast solidification. Those processes are rather complicate and require precise analysis of surface layer structure. This paper presents the results of further investigations of influence of plasma stream treatment on modified layer mass composition and some its tribology characteristics.

Experimental device

The experiments were carried out in Prosvet device with pulsed plasma accelerator (PPA) as a plasma source [4]. The experimental device consists of a coaxial plasma accelerator (the anode diameter is 14 cm, the diameter of a cathode is 5 cm) and the vacuum chamber of 120 cm in length and 100 cm in diameter. The power supply system of the accelerator is a capacitor bank with stored energy W = 68 kJ at the charge voltage 35 kV. The samples of various steels were irradiated by nitrogen plasma streams with pulse length of an order (2-3) μs. Plasma density was (1-3) x 10^{14} cm^{-3}. Energy density of plasma streams was varied in the range of (10-25) J/cm^2. The energy of accelerated ions achieved 2 keV.

Experiments were carried out both with quenched samples and with non-quenched ones. The variation of specific power, transmitted to the material surface, was reached either by changing the voltage of capacitor bank, supplying the discharge between accelerator electrodes, or by sample placing at the various distances from plasma accelerator output. This provided the specific plasma energy changing with constant ion energy or with plasma density.

Cross-sectional metallography, mass spectrometry, X-ray analysis, measurements of microhardness and wear tests of processed samples were applied for investigations of structure and tribological properties of the modified surface layer.

Experimental results

Analysis of steel 40H samples with using scanning electron microscope JEOL with X-ray analyser LINK has shown that content of Fe, Cr, Si in modified layer was not practically differed from their content in the bulk of sample material (Fig. 1). The presence of manganese in modified layer was sufficiently decreased (as much as 40%) as compare to non treated sample. The latter result is possibly explained by more sufficient evaporation (sublimation) of manganese in comparison with other elements belonging to the material of sample.

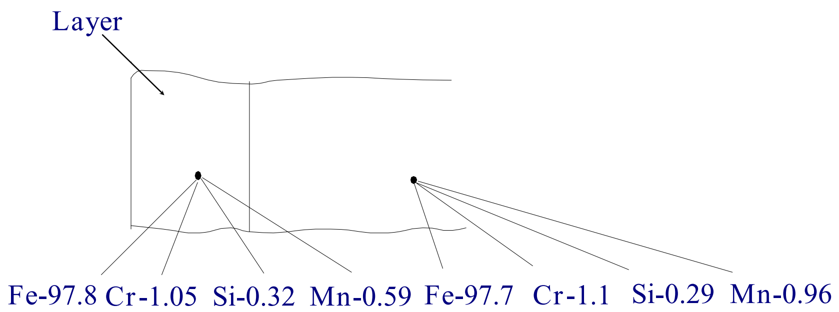

Fig. 1. Content of some elements in 40H sample after plasma processing.

Content of light elements (first of all nitrogen) in sample material was determined with using the mass analyzer with laser ion source EMAL-2. There was found that content of nitrogen in modified layer was increased as much as 25 times and achieved (0.12 - 0.15) %. Therefore one possible to conclude that effective increasing the content of nitrogen in modified layer has took place as result of pulsed plasma stream processing. The possible reason for intensive penetration of nitrogen into modified layer structure is sufficient gas diffusion in liquid stage of material due to significant gradient of temperature under high speed heating and impurity concentration gradient. There was observed also (40-60)% increasing the carbon content in the modified surface layer. For explanation of such increase of a carbon content in the sample surface under the plasma treatment the additional investigations of carbon segregation mechanisms are needed.

The scanning electron microscope (SEM) photo of a cross-section of the steel 40H sample irradiated by plasma stream is shown in Fig. 2. It follows from this picture that impact of a plasma stream to the sample surface leads to the formation of a modified layer with a thickness of an order (11-12) μm. This layer has a fine structure. As to the structure of a bulk of a sample material, it is a typical microstructure of a carbon steel and consists of two phases ferrite and pearlite. Under the high level of magnification of the sample surface image one possible to see that pearlite has lamellar eutectoid structure.

The wear dynamics tests were performed with using the pin-on-disc method described in [4]. The wear dynamics of the surface layer of the steel 45 processed by nitrogen plasma streams is illustrated in Fig. 3. The linear wear of the surface layer slowly increased from 0.75

μm till 1.5 μm with increasing the friction path from 1 km to 10 km. It should be noted, that wear depth for initial sample of steel 45 (before plasma treatment) achieved 7 μm for friction path value 1 km. So, increasing the wear resistance was observed as a result of plasma processing.

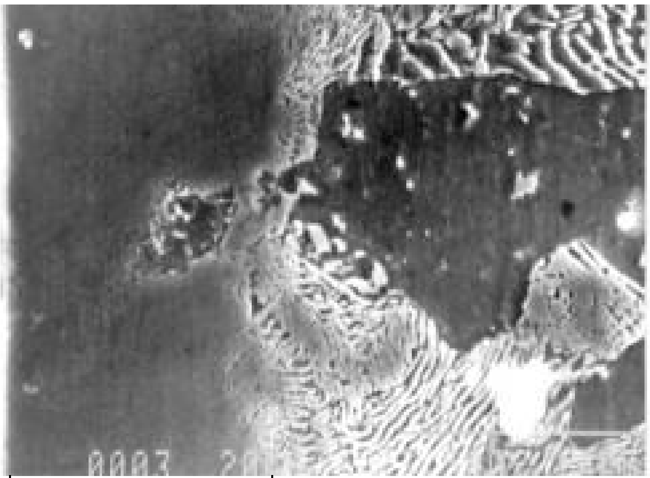

Fig. 2. Cross-section of treated 40H sample

The wear rate defined as a ratio of linear wear and friction path was sufficiently decreased from 7.5×10^{-4} μm/m down to 1.5×10^{-4} μm/m with friction path increasing. Further increase of the friction path doesn t change sufficiently the wear rate value. The depth of worn layer does not exceed 5 μm for the path length at least up to 25 km. Investigations of wear resistance for steels 40H, 12HN3A, SHH15 and others have shown the similar dependence of linear wear on the friction path. The wear rate for all tested steels processed by pulsed plasma streams does not exceed 3×10^{-4} μm/m (or 3×10^{-10} in dimensionless units) for value of friction path in the range of (10-20) km.

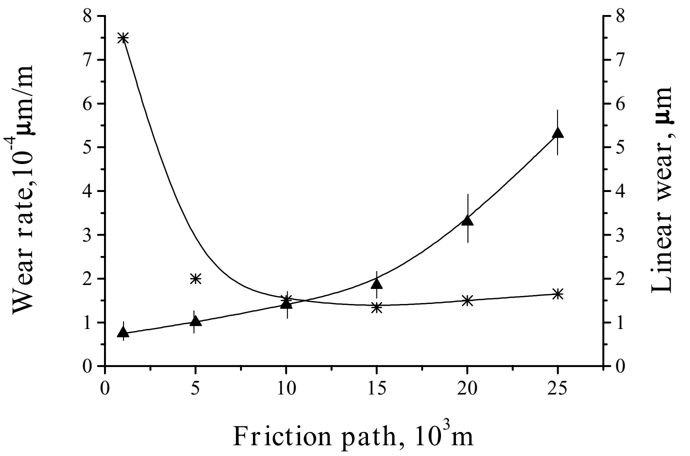

Fig. 3. Wear dynamics of the modified surface layer.
** - wear rate, ▲ - linear wear depth*

The typical values of surface roughness parameters for all tested steels being treated by plasma streams with energy load below 20 J/cm^2 were as follows: R_a= (0.6-0.8) μm, R_z= (1.4-2) μm. The height of the largest asperity of a profile varied in the range of R_p= (1.4-2.6) μm. The mean distance between asperities was S_m = (250-300) μm. Those values are comparable with initial surface roughness parameters of steel samples. Moreover, pulsed plasma stream processing of samples with initial roughness R_a> 1 μm led to decreasing the surface roughness parameters.

Conclusions

The analysis of the pulsed plasma stream influence on the material surfaces had shown that the material surfaces were sufficiently modified due to both thermal effects and nitration process. Under the irradiation of the steel 40H sample by nitrogen plasma (5 pulses) the content of nitrogen in the modified layer with the depth of an order 12 μm was increased as much as 25 times (in comparison with non treated sample) and achieved 0.12%. The profile of nitrogen in the material depth and dependence of nitrogen concentration on the dose of irradiation are the subjects of our further investigations.

The modified layer has a fine grain structure and has an increased resistance with respect to the etching. Therefore, one possible to expect the increased corrosion resistance of plasma treated surfaces also.

The wear dynamics of treated samples was investigated. The possibility of sufficient decreasing the wear rate of treated samples was demonstrated.

This work was supported by Science and Technology Center in Ukraine (STCU) in the frame of Project #881.

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