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INFLUENCE OF PULSED PLASMA STREAMS PROCESSING ON WEAR BEHAVIOR OF STEELS IN DIFFERENT FRICTION CONDITIONS

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Pulsed plasma streams processing was applied for surface modification of industrial steel samples. Different types of wear tests (pin-on-disk, flat-on-flat, abrasive, cavitation) were carried out for samples irradiated by pulsed nitrogen plasma streams. There was achieved essential decrease of wear and tear of processed surfaces of all kinds of steels including previously thermally quenched ones. Obtained results are of importance for both determination of optimal regimes of plasma streams processing and the most resulting use of pulsed plasma streams for technology purposes, i.e. for identification of wear modes and optimal friction conditions for steels processed by plasma streams.

INTRODUCTION

There was shown in our previous works [1,2] that modification of steels by pulsed plasma streams should be promising way for significant improvement of materials wear resistance. Steel samples were examined with pin on disk method under the following conditions: friction was realized in air, sliding velocity 0.8 m/s, normal load 7 N and 10 N, the air temperature 293 K. The friction path varied in the range of 1 km - 20 km. The linear wear of processed steels was decreased by 7-20 times in comparison with non-treated ones.

Nevertheless, the material behavior in conditions of various wear modes realization (especially for heavy loaded tools) can be sufficiently different even for variation of velocity or load. For instance it is well known that optimal drill feed and rpm for drills with TiN coatings are differed from ones with non covered surfaces. In the case of different wear modes realization for achievement of maximum effect it can be necessary to change the regime of plasma processing, working gas, dose of treatment and so on.

This work is devoted to the investigations of wear characteristics of industrial steels, processed by plasma streams and tested by several additional methods under different friction conditions.

EXPERIMENTAL RESULTS

The experiments were carried out in a "Prosvet" device with pulsed plasma accelerator (PPA) as a plasma source [2]. The accelerator generated plasma streams with an energy of ions up to 2 keV, plasma density ~ $2x10^{14}$ cm^{-3}, average plasma power up to 10 MW/cm^2, and plasma energy density in the range of (10-30) J/cm^2.

FLAT-ON-FLAT WEAR TESTS were carried out for both previously thermally quenched and non-quenched samples of 40H steel under the following conditions: normal load 70N, speed of rotation - 650 revolutions per minute (maximum linear velocity 0.85 m/s), friction path 10 km. 40H disk was 30 mm in diameter and 3 mm thickness . At that for providing its comparison with pin-on-disk tests the quenched steel SHH15 was used as indenter (cylinder 25 mm in diameter, height 22 mm, initial microhardness 550-600 kg/mm^2). Wear of sample was determine by profilograph (accuracy of measurements 5%) [3].

Results of flat-on-flat wear tests presented in Table 1.

Table 1. Linear wear of processed samples

Sample	Linear wear of sample, µm	Wear of indenter	
		Mass wear, mg	Linear wear,µm
Non-quenched sample 40H (initial)	70	50	13,8
Processed non-quenched sample 40H	30	40	11,1
Quenched sample 40H (initial)	12	30	8,2
Processed quenched sample 40H	8	60	16,8

As follows from obtained results the linear wear of samples essentially decreased after pulsed plasma stream processing. It should be noted also that wear of samples processed by plasma streams is more homogeneous in comparison with non-treated ones. Wear resistance of non-quenched samples was improved in 2.3 times. Decreasing the friction coefficient was observed also. For previously quenched samples influence of plasma processing on wear resistance was not so strong. Significant increasing the indenter wear (in 2 times) was registered for this case. Because the contact region in flat-on-flat tests is rather large (contrary to the pin-on-disk method) particles of indenter material can not be moved away from friction zone. Presence of large size particles from indenter in friction region can be the reason of not so strong decreasing the wear of sample material.

ABRASIVE WEAR TESTS were fulfilled with vulcanite wheal of 30 mm in diameter. Normal load was 128g. Speed of rotation was varied in the range of 200-3000 rpm. Wear rate of tested samples determined as ratio of mass losses to friction path length is shown in Fig. 1.

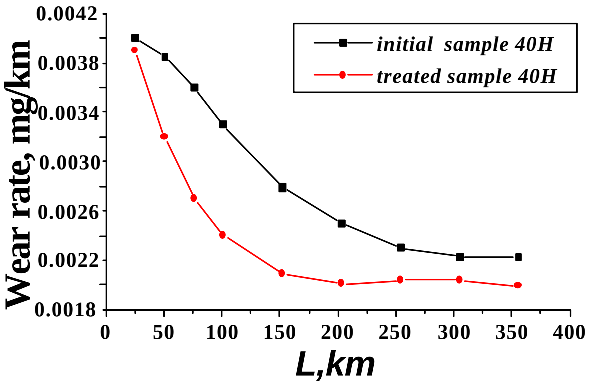

Fig. 1. Wear rate of initial and processed samples.

For all investigated samples the wear process was characterized by two strongly pronounced stages. The first one was running-in stage when the sharp jump-like changes of friction coefficient were observed. During the second stable stage the friction coefficient was decreased and its fluctuations were of low level. For non treated steel samples during the running-in period there was registered not only higher value of friction coefficient in comparison with processed samples, but higher amplitude of it fluctuations also (0.1-1.8). One can see that the wear rate for treated sample is essentially lower as compare to non-treated one. It sooner reaches plateau and remains smaller with further increasing the pass. The plateau on wear rate curve for plasma treated sample is evidence of materials lapping and stabilization of friction coefficient.

CAVITATION WEAR TESTS were carried out for investigation of micro-impact influence on material surface. Under micro-impact effect the surface of materials is exposed to specific loads, characterized by dynamic stresses. Those stresses concentrated in the regions that are comparable with the size of material structure. Micro-impact effect is realized when cavitation or high velocity flows of solid particles or liquid droplets interact with a material surface. Cavitation damage is mainly mechanical. Collapse of cavity pocket in a liquid under increased pressure is accompanied by pressure jumps with amplitude up to 10^3 megapaskals that propagated in surrounding liquid as shock waves. Moreover, the collapse of bubble close to the body surface is not spherically symmetric. Due to geometrical restrictions it spirally twisted with formation of liquid stream that impact to the surface of material. So, there are two possible mechanisms of cavitation damage: shock wave arise from collapse of bubbles and impact of streams formed as result of bubbles collapse close to the material surface. All these factors lead to the surface erosion.

The aim of cavitation wear tests was investigation of influence of pulsed plasma stream processing on resistance of steel against cavitation damages and study of structure changes under the cavitation effect.

Samples of both previously quenched and non-quenched steel 40H with size 18x10x4 mm were prepared by cutting with electrospark discharge machine. Processed by pulsed plasma streams samples were examined on cavitation resistance with using the facility with magnetostriction vibrator [4]. Ultrasonic generator USG-3-04 of Russian trade mark was used as power source. Needle concentrator of exponential profile ultrasonic oscillations manufactured from steel H18N19 had emitting surface with diameter $5 \cdot 10^{-3}$ m. Vibrator frequency was 20 kHz, amplitude of oscillations was 30 μm. Such scheme of tests is traditionally used for analysis of turbine blades of different devices permanently operated in water. The samples were tested in water under temperature 25±5 $^{\hat{\text{I}}}$Ñ. The gap between sample surface and concentrator emitting surface was 0.5 mm.

Typical image of sample surface after the cavitation tests is shown in Fig. 2. For determination of cavitation wear the mass losses of samples were measured in dependence on duration of cavi tation exposure. Results of cavitation investigations presented in Fig.3. As follow from obtained results the behavior of kinetic curves for materials is different as for processed samples and non-treated ones as for quenched and non-quenched materials.

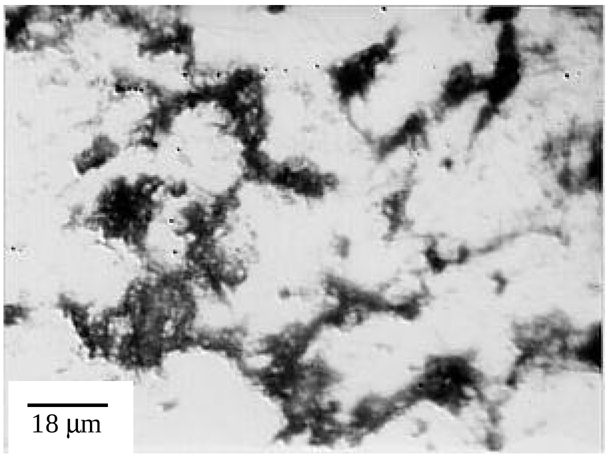

Fig.2. Sample surface after the cavitation influence.

All dependencies are characterized by two evident regions. First region corresponds an initial stage of cavitation influence. In dependence on properties of investigated material, surface quality and other factors the different in value mass losses correspond to initial stage. For plastic materials the mass losses during initial stage are rather small. Accumulation of defects in surface layer is occur during this time stage. For inductile materials the losses rate for initial stage higher in comparison with the following second stage. This can be explained by ablation of loosely coupled fragments from the surface.

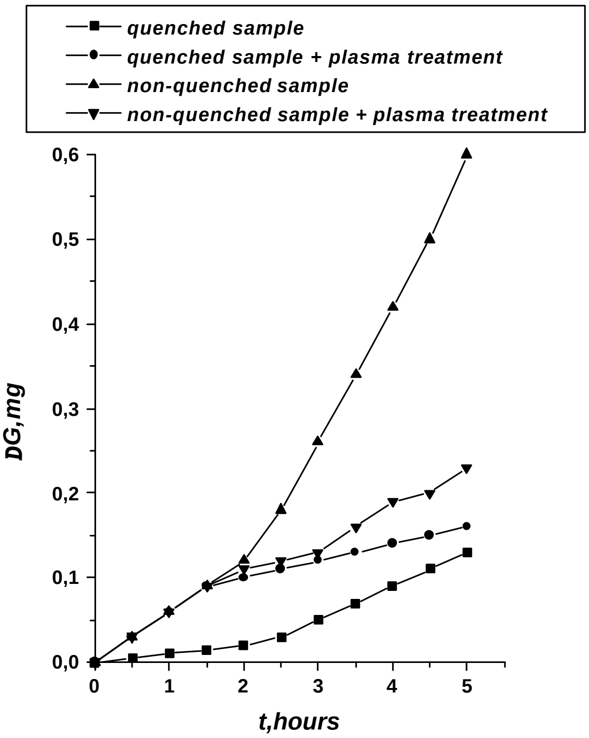

Fig. 3. Mass losses of 40H steel samples under cavitation tests.

Second region of each kinetic curve corresponds to steady-state cavitation wear, when material mass losses increase linearly and wear rate is practically constant and different for different materials. For each material the value of wear rate during this stage is not in dependence from character of first stage. Therefore for long-term cavitation influence the most objective characteristic is wear rate during the stage of steady-state cavitation wear. Cavitation wear rate of investigated samples presented in Table2.

Table 2. Cavitation wear rate of 40H samples at the steady-state stage

	Initial 40H samples		*Treated 40H samples*	
	non - quenched	quenched	non-quenched	quenched
Wear rate V,10^{-4} g/h	1.6	0.4	0.2-0.6	0.2

One can see from this table that even for previously thermally quenched steel the cavitation wear rate measured at the stage of steady-state cavitation wear (after long term cavitation influence) was decreased at least by factor of two for samples irradiated by pulsed plasma streams in comparison with non-processed ones. For non-quenched samples wear rate was decreased in 4 times.

CONCLUSIONS

Different types of wear tests (pin-on-disk, flat-on-flat, abrasive, cavitation) were carried out for samples irradiated by pulsed nitrogen plasma streams. There was achieved essential decrease of wear of processed surfaces for all kinds of steels including previously thermally quenched ones.

Comparing results of different wear tests one can conclude that optimal friction conditions for plasma processed steels realized under the medium values of friction velocity 0.4-2 m/s and load 5-10 N. For achievement of maximal effect of plasma stream processing the treatment dose do not exceed 10 pulses for non-quenched steels ands 5-7 pulses for previously thermally quenched materials.

Cavitation tests is demonstrated the positive influence of plasma streams processing on erosion decrease of materials operated in water. The experiments with real water turbine blades manufactured from steel 15H11MF is aim of our further work.

Obtained results are of importance for both determination of optimal regimes of plasma streams processing and the most resulting use of pulsed plasma streams for technology purposes, i.e. for identification of wear modes and optimal friction conditions for steels processed by plasma streams.

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