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MICROABRASION TESTING OF PULSE PLASMA NITRIDED 42CrMo4 STEEL

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Abstract

Experiments in microabrasion testing of pulse plasma nitrided 42CrMo4 (AISI 4140) construction steel samples were performed at laboratory of Faculty of Electrical Engineering in Belgrade. The behaviour of nitrided steel in real conditions was tested by accomplishing the experiments with dry and lubricated sliding of the abrasion sphere. Experimental results showed distinctly increased (20÷30)% abrasive wear resistance of nitrided samples in the case of lubricated sliding, compared to the same not nitrided material. Even greater increase (about 100% on Vickers scale) of surface hardness was noticed on nitrided samples. Hardness depth profile measurements indicated the presence of diffusion zone with increased hardness over 200 μm deep. Pulse plasma nitriding can be used as technological treatment for machine parts exposed to large contact stress with restricted sliding possibility (cog wheels, ball bearings, etc.). In applications where friction can not be avoided lubrication of nitrided komponents is obligatory in order to extend its service life and at the same time to reduce energy consumption.

***Keywords**: Pulse plasma nitriding, abrasive wear, wear resistance*

1. INTRODUCTION

As a thermochemical process for the improvement of surface properties of steel tools and machine parts nitriding has an important role in modern industry. This treatment, with it's long tradition is based on nitrogen introduction in the steel surface layer, thus forming dispersion of hard nitrides which significantly improves the mechanical properties including wear, fatigue and corrosion resistance up to depth of a few hundred of μm. This way the bulk material remains ductile and is not disposed to cracking which remains the most common risk of heat treatment by oil- or water- case hardening.

During the last few decades a new nitriding technique – plasma nitriding – substituted the classical procedures of salt bath and gas nitriding. Oving to many changeable process parameters this treatment has significant advantages including a better control of surface structures, their chemical composition and functional characteristics, and unlike the older procedures it is environment-friendly. The latest process modification – pulse plasma nitriding ofers even more process parameters (process temperature and duration, gas pressure and composition, electric voltage and current, pulses frequency and pulse to pause ratio) and more sophisticate control of obtained surface layers [1].

Our microabrasion tests were performed on samples of several steel grades nitrided in pulse plasma. Construction steels were represented by DIN 42CrMo4. This steel grade, aloyed with about 0.45% C, 0.7% Mn, 1% Cr, 0.2% Mo, of great guaranteed tensile strength Rm = (900÷1050) MPa and yield strength R_e = 650 Mpa, is meant for the manufacture of highly loaded engine parts.

Its superficial hardness after heat treatment is about (300÷400) $HV_{0.05}$, and (700÷800) $HV_{0.05}$ after nitriding.

2. EXPERIMENTAL SAMPLES

Experimental samples were cylinder shaped, 18 mm high with 14 mm in diameter. Cylinder basis meant to be nitrided has been previously grinded up to the surface roughness (N4÷N5) with uneven spots of average highness R_z = (1÷2) μm or $R_a = R_z /4$ = (0.25÷0.5) μm.

Nitriding was performed in pulse plasma under following process conditions: sample temperature T = 500 ^{0}C, process amosphere pressure p = (10÷50) Pa, process amosphere composition 25% N_2 + 75% H_2, nitriding time t = 4 h, pulses frequency f = 1 kHz, active/total pulse time ratio d.c. = 95%.

After nitriding procedure nitrided basis was polished to the surface roughness (N3÷N4) t.j. R_z = (0.4÷0.8) μm, or $R_a = R_z/4$ = (0.1÷0.2) μm. Surface rougness was determined using optical microscope with 100x magnification and engraved scale of 2 μm resolution. Using this method after additional polishing the roughness of nitrided sample was determined to be about 1 μm. On this base the mentioned value of R_z was adopted for uneven spots highness. The sliding friction coefficient μ in different conditions was determined by the two inclined planes method [2]. Obtained values are given in Table 1.

Table 1. Sliding friction coefficient in different surface conditions

	Not nitrided	Nitrided
Dry	μ = 0.18	μ_N = 0.22
Lubricated	μ_L = 0.12	μ_{NL} = 0.12

Hardness depth profile of nitrided sample (Fig. 1) indicated diffusion zone depth of over 200 μm. Inside the 100 μm deep superficial zone the hardness is increased for over 50%. Microhardness of the core (not nitrided) material was 370 $HV_{0.05}$ while nitrided zone was about 750 $HV_{0.05}$ hard in the depth of upper 50 μm.

3. CALOWEAR TESTING

Following trends in development and localized application of modified surface layers in the last decade, a new method in microabrasive wear testing took place. Beside the well known pin-on-disc [3] this method, named Calowear test, was proved to be a simple, relatively quick and reliable form of abrasive wear examination. The small area of sample required for testing, together with a small penetration depth make such a test ideally suited for studies of small samples and surface ingeneered components.

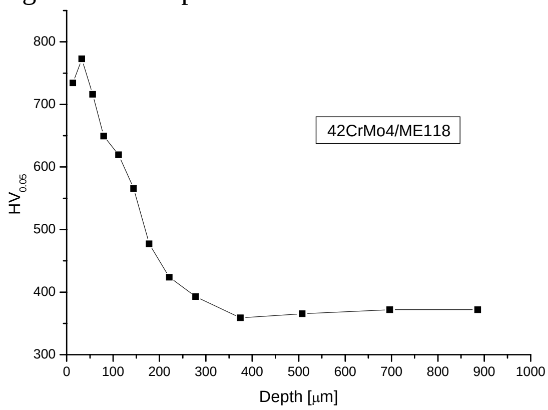

Fig.1: *Hardness depth profile of nitrided sample*

The principle of Calowear tester operation is shown in Fig.2. Abrasion sphere is reposed on three points. Through couple of them the rotation of profiled, motor driven shaft is transferred to the sphere. The third point is reposed on the sample surface ,which is also the place of abrasive wear. The test result is a worn out circular crater whose diameter can be easily measured by the suitable microscope. Real device configuration with the sample in experimental position is shown in Fig.3. The shaft rotation speed and time, as well as the inclination of the worn surface can be controlled.

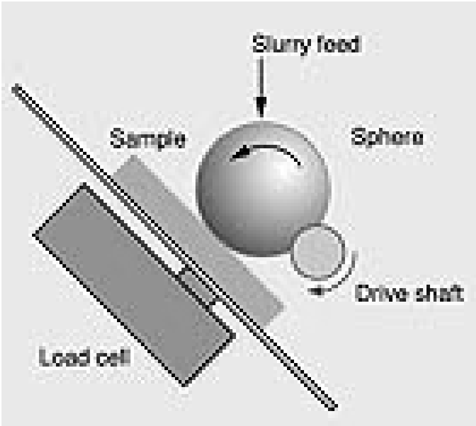

Fig. 2: *Calowear device principle [4]*

The wear coefficient (abrasion index) is one of the important tribological quantities for costruction steel grade, which can be easily calculated from the Calowear test results. For the abrasive wear it is:

$$k = \frac{V}{F \cdot S}$$

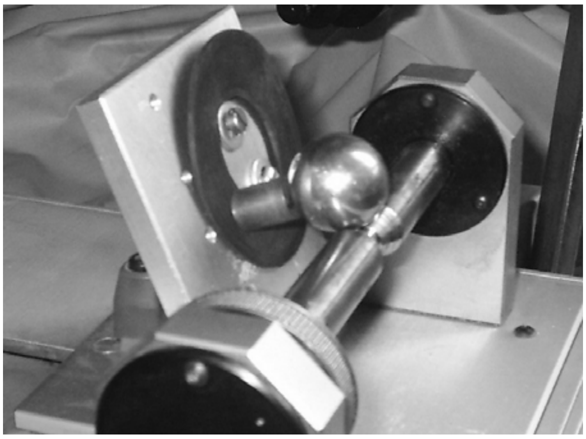

Fig. 3: *Experimental setup*

where the worn out volume V is defined by the diameter a of circular crater arised, after a sliding way S of the rotating sphere. F is the normal component of contact force acting to the worn surface. In our experiment diameter a was measured using the microscope mentioned beforehand. Sliding way was determined by the sphere revolutions counting. For the contact force determination a special method is developed which is the object of the other report.

In our examinations the rotating sphere diameter was $2R$ = 25 mm and the sample surface inclination was $\varphi = 65^0$. All the experiments were performed at the same drive shaft rotation speed.

Before tests starded the values range of normal contact force has been established. The contact force in static mode (ω_S = 0 – without rotation) was determined as F_S = 0.36 N. In this mode the sliding friction coefficient is $\mu = 0$. After the motor was swiched on the value of dynamic contact force was measured as F = 0.29 N. In this case the sliding friction coefficient was previously determined at $\mu = 0.4$. This way the boundaries of dynamic force range have been established in the diagram of contact force versus sliding friction coefficient (Fig. 4).

After the actual values of sliding friction coefficient (from Table 1) had been considered, the mean value of 0.33 N for dynamic contact force F was taken from the diagram in Fig.4.

In order to explore advantages and drawbacks of nitrided surfaces in abrasion conditions the tests have been performed with and without lubrication. The oil for fine mechanisms lubrication was used.

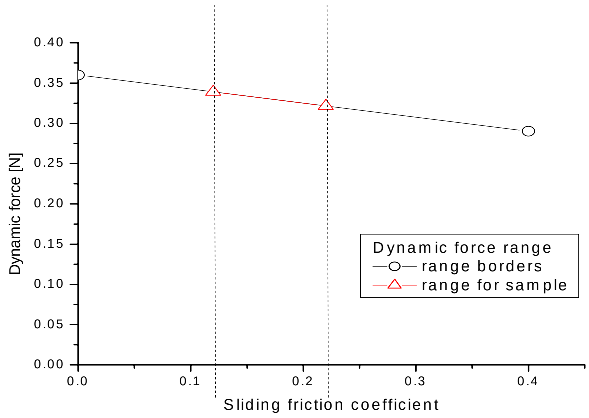

Fig. 4: *Contact force dependence on sliding friction coefficient*

During dry sliding tests the mean value of angular velocity of abrasion sphere was ω = 120 rev/min = 2 rev/s. In the lubricated abrasion condition the mean angular velocity was ω_L = 90 rev/min = 1.5 rev/s. The comparative test with diamond paste used as abrasive medium was also performed. Testing results are given in Table 2.
Last column gives the values for abrasion coefficient (abrasion index) calculated after [2] for

the longest abrasion time t = 300 s. The abrasion index k has been calculated from:

$$k = \frac{V}{F \cdot S} = \frac{\pi\, a^4}{64 R \cdot F \cdot R\, \omega\, t}$$

4. DISCUSION

The influence of surface treatment of steel grade 42CrMo4 by pulse plasma nitriding on the abrasion resistance has been calculated using experimental results from Table 2.

a) Dry abrasion

$$\frac{k}{k_N} = \frac{V}{F \cdot \mathrm{S}} \cdot \frac{\mathrm{F_N} \cdot S_N}{V_N} = \frac{a^4}{a_N^4} \cdot \frac{\mathrm{F_N}}{\mathrm{F}} \approx \frac{a^4}{a_N^4} = \left(\frac{0.87}{0.77}\right)^4 = 1.63$$

The abrasion rate of not nitrided surface is 63% more intense compared to the nitrided sample surface.

b) Lubricated abrasion

$$\frac{k_L}{k_{NL}} = \frac{V_L}{V_{NL}} = \frac{a_L^4}{a_{NL}^4} = \left(\frac{0.65}{0.54}\right)^4 = 2.1$$

Table 2 Experimental results and calculated abrasion index k for different abrasion conditions

t [s]	60	120	180	240	300	10^{14} k [m^2/N]
a [mm]	0.58	0.69	0.77	0.82	0.87	14.5
a_L [mm]	0.44	0.52	0.57	0.62	0.65	5.8
a_N [mm]	0.52	0.61	0.68	0.73	0.77	8.9
a_{NL} [mm]	0.36	0.43	0.47	0.51	0.54	2.78
a_{ND} [mm]	0.83	0.99	1.10	1.17	1.25	67.0

Notation for diameters of worn out crater: a – dry sliding on not nitrided surface; a_L - lubricated sliding on not nitrided surface; a_N – dry sliding on nitrided surface; a_{NL} – lubricated sliding on nitrided surface; a_{ND} – sliding on nitrided surface with diamond paste

During the lubricated abrasion the abrasion rate value of nitrided sample is one half of the corresponding value of the not nitrided sample.

c) Comparing dry abrasion of not nitrided sample to the lubricated wear of nitrided sample we obtained for the abrasion rates ratio:

$$\frac{k}{k_{NL}} = \frac{V}{F \cdot \mathrm{S}} \cdot \frac{\mathrm{F_{NL}} \cdot \mathrm{S_{NL}}}{\mathrm{V_{NL}}} = \frac{a^4}{a_{NL}^4} \cdot \frac{\mathrm{F_{NL}}}{\mathrm{F}} \cdot \frac{\mathrm{S_{NL}}}{\mathrm{S}} = \left(\frac{0.87}{0.54}\right)^4 \cdot 1.1 \cdot 0.75 = 5.6$$

The values from last row in Table 2 reflect the great increase of abrasive wear during sliding when abrasive particles are present. When nitrided layer is worn the hard nitrides particles arise in the contact area greatly accelerating the abrasion process. It is of essential importance to remove these particles with good lubrication during the wearing of nitrided surfaces.

5. CONCLUSION

By the pulse plasma nitriding of 42CrMo4 construction steel the following improvements has been achieved:

1. Surface microhardness has been changed from initial 370 $HV_{0.05}$ to about 750 $HV_{0.05}$ (100% increase)
2. Hardness dept profile indicates that the hardness is preserved at over 600 $HV_{0.05}$ up to the 100 μm depth
3. Abrasion testing results in the case of dry sliding have shown improved abrasion resistance after pulse plasma nitriding for over 60% compared to the not nitrided sample (Table 2).

4. Concerning abrasion resistance, the best result has been obtained in experiment with the lubricated wearing of nitrided steel. In that case the abrasion resistance was over five times larger compared to the basic case of dry abrasion on not nitrided sample.

It has be stressed that by abrasion wearing of nitrided 42CrMo4 steel, oving to formation of hard abrasive particles, the good lubrication is of essential importance.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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