Comparison of wear resistance of induction-hardened and gas-nitrided samples in the abrasive mass motion

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COMPARISON OF WEAR RESISTANCE OF INDUCTION-HARDENED AND GAS-NITRIDED SAMPLES IN THE ABRASIVE MASS MOTION

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Preliminary Note – Prethodno priopćenje

The experiment was focused on comparison of mass loss exhibited by induction-hardened and gas-nitrided samples made of 42CrMo4 steel. The mass loss was caused by abrasive wear, i.e. by motion of the abrasive particles. Wear testing was performed with different input parameters (sample velocity and impact angle of abrasive particles and the tested surface). This experiment proceeded with metallographic analysis performed by an optical microscope and by imaging of wear path done by scanning electron microscopy (SEM), to conclude with the statistical analysis of obtained data. The conducted experiment determined that the gas-nitrided samples lost less mass at all levels of input parameters than the induction-hardened samples.

Keywords: 42CrMo4 steel, induction hardening, gas nitriding, wear, testing factors

INTRODUCTION

Wear of materials is considered an important issue in many segments of industry, and it is especially emphasized in exploitation of various mechanical systems with movable elements [1]. Wear of materials in abrasive mass occurs on mechanical parts of agricultural machinery, on vehicles for soil excavation and transport, on mining and construction machinery, on equipment used in brick and cement manufacturing, etc. [2]. Quartz is perceived as the major abrasive element.

In order to protect working parts of machinery and equipment against wear, there are measures undertaken to change the structure of material or to change the type of surface material exposed to wear [1].

Thermal process of induction hardening [3, 4] and thermochemical gas nitriding process [5, 6, 7] are usually applied to change the materials' structure. Induction hardening is applied to many mechanical parts in order to improve their mechanical properties, as well as friction and wear properties [3]. This process results in a hard surface layer and a tough core, since the heating affects the thin surface layer while leaving the core unaffected [3, 8]. According to [8], nitriding is a process of surface heat treatment that assures wear resistance of the treated structures. As a typical thermochemical treatment, gas nitriding improves the surface properties of materials because it increases the nitrogen concentration in the surface layer [5]. It was also confirmed that nitriding improves tribological and anti-corrosive properties of steel [6].

The research objective was to examine wear resistance of induction-hardened samples and gas-nitrided samples at their motion in an abrasive mass depending on sample velocity and on the impact angle of abrasives with the worn surface.

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EXPERIMENTAL PROCEDURE

Wear test samples

The experiment was performed on samples made of 42CrMo4 low-alloy structural steel, with maximum surface hardness of 35 HRC. Declared chemical composition of the sample steel was: C = 0,41 %, Mn = 0,76 %, Si = 0,24 %, P = 0,009 %, S = 0,021 %, Cr = 1,08 %, Ni = 0,09 %, Cu = 0,21 %, Mo = 0,15 %, Al = 0,021 % [9].

Samples were cut to dimensions of 40 x 25 x 15 mm. Microstructural analysis was performed with an Olympus BX51 optical metallurgical microscope. The surface hardness of the samples was measured on a Gnehm - Horgen GM150 hardness tester, while the microhardness HV0,1 of the sample cross section was measured by Shimadzu Vickers Microhardness Tester – Type M.

Induction-hardened samples

Induction hardening of samples was performed on a HGL-400 device manufactured by Fritz Düsseldorf GmbH, with a shift of 3 m/min and direct water-jet cooling to a room temperature. The Figure 1 presents the microstructure of induction-hardened sample.

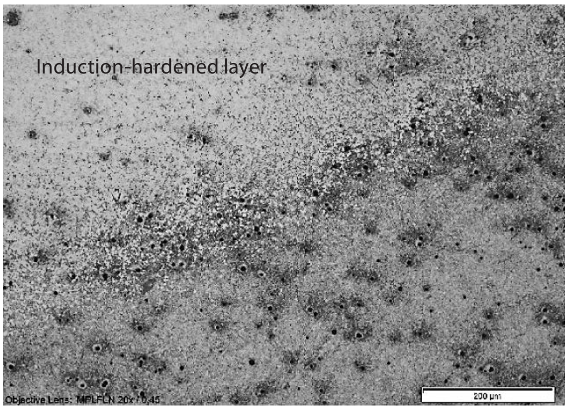

Figure 1 Microstructure of induction-hardened sample

The sample surface hardness was 60 HRC, while the average microhardness at cross section was 678 HV0,1 measured to a depth of 0,6 mm, which is the effective thickness of the hardened layer.

Gas-nitrided samples

The process was carried out in a gas nitriding furnace in an atmosphere rich in ammonia (NH_3), at a temperature of 510 °C for 20 hours. Surface hardness of the gas-nitrided samples was 58 HRC. The average microhardness at the sample cross section was 631 HV0,1, measured to a depth of 0,3 mm, which is the effective thickness of the hardened layer. Microstructure of the gas-nitrided sample is shown in Figure 2.

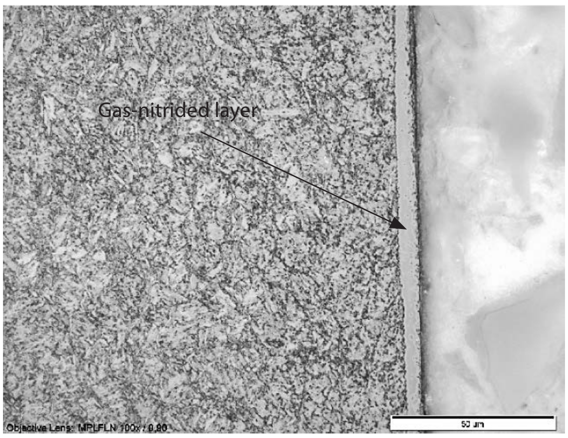

Figure 2 Microstructure of gas-nitrided sample

Abrasive used in wear testing

Wear testing was performed by using commercially available quartz sand FB150S, of 0,5 - 1,5 mm granulation and of hardness 7, as of the Mohs hardness scale. The sand was washed to remove dirt and dust and then dried at high temperature. Declared chemical composition of the sand used in this experiment was: SiO_2 > 99 %, Fe_2O_3 = 0,297 %, Al_2O_3 = 0,658 %, CaO = 0,041 %, MgO = 0,027 %, P_2O_5 = 0,009 %, K_2O = 0,104.

Wear testing device

The wear test was performed on an abrasive mass wear device in which samples were immersed in the abrasive mass and rotated at a constant velocity of n = 58 min^{-1}. Motion speed of samples was 1,0, 1,75 and 2,5 m/s, and impact angles of abrasive mass and worn surface were 30° and 60° (α – the angle show in figure 3). Stated parameters were selected because of their similarity with common agrotechnical methods of tillage. The Figure 3 presents kinematic quantities in the wear experiment, by showing that the samples were placed on a precisely determined diameter of inscribed circle (*D*), which they move along, and that the sample velocity (*v*) was calculated according to the expression for peripheral velocity.

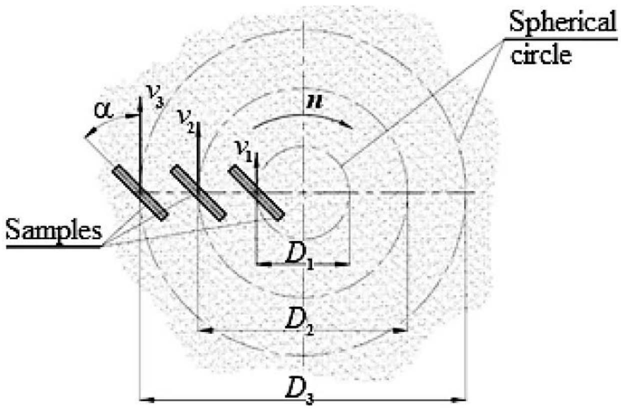

Figure 3 Schematic presentation of kinematic quantities in the experiment

Based on previous research [10] and following the assumption about abrasiveness of quartz sand, the total wear path for all samples was 20 000 meters.

Mass loss of samples was determined as of the difference in masses of samples measured before and after wear testing. Mass of samples was measured by an Adam PW 124 analytical balance of 10^{-4} gram precision.

RESULTS AND DISCUSSION

Wear testing was performed in three repetitions for all levels of input parameters.

The Table 1 overviews the data referring to mass losses of tested samples.

Obtained results of mass losses were statistically processed in the SAS Enterprise Guide 7.1 software.

The distribution of data referring to mass losses depending on levels of input parameters (sample velocity and impact angle) and referring to material condition is shown in Figures 4, 5 and 6. It is noticed that the distribution of mass loss was the highest when depending on the impact angle and material condition. As seen in the Figure 4, the increase in sample velocity caused the increase in mass loss. Such result is a consequence of increased impact energy between the abrasive particles and the worn surface, which leads to increased mass loss.

Table 1 **Mass losses of tested samples**

Velocity / m/s	Mass loss at Impact angle of 30° / g		
	Δm_1	Δm_2	Δm_3
Induction-hardened samples			
1,0	0,0248	0,0225	0,0264
1,75	0,0352	0,0296	0,0320
2,5	0,0842	0,0804	0,0755
Gas-nitrided samples			
1,0	0,0232	0,0218	0,0249
1,75	0,0271	0,0266	0,0227
2,5	0,0721	0,0671	0,0682
Velocity / m/s	Mass loss at Impact angle of 60° / g		
	Δm_1	Δm_2	Δm_3
Induction-hardened samples			
1,0	0,0081	0,0078	0,0073
1,75	0,0244	0,0230	0,0265
2,5	0,0650	0,0588	0,0718
Gas-nitrided samples			
1,0	0,0048	0,0068	0,0085
1,75	0,2020	0,0219	0,0197
2,5	0,0620	0,0635	0,0602

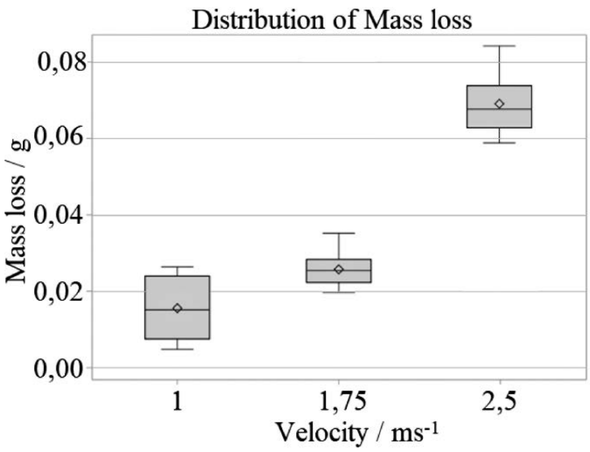

Figure 4 Distribution of mass loss depending on sample velocity

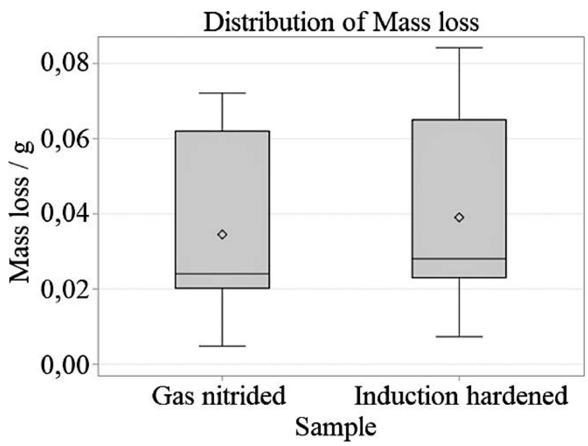

Figure 5 Distribution of mass loss depending on impact angle

As of the Figure 5, it is clear that the increase of impact angle reduces the mass loss, which is a consequence of shorter contact between the abrasive particles and the worn surface at a higher impact angle.

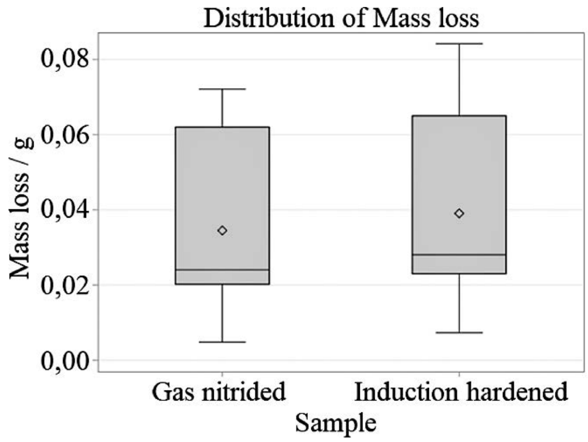

Figure 6 Distribution of mass loss depending on material condition

The Figure 6 shows that induction-hardened samples exhibited a slightly higher mass loss than gas-nitrided samples. Due to lower surface hardness, gas-nitrided samples were better at absorption of the impact energy between the abrasive particles and the worn surface, which led to lesser mass loss of these samples.

Significance of input parameters and their interactions was determined by the analysis of variance (ANOVA), as presented in the Table 2, which shows the significant influence of all three input parameters, with the sample velocity having the highest significance.

Table 2 **ANOVA for testing factors**

Source	DF	Type I SS	Mean Square
Angle	1	0,001156	0,001156
Velocity	2	0.019367	0,009684
Sample	1	0,000187	0,000187
Ang.*Vel.	2	0,000165	0,000082
Ang.*Sam.	1	0,000028	0,000028
Vel.*Sam.	2	0,000056	0,000028
Ang.*Vel. *Sam.	2	0,00021	0,000011
Source	F value		Pr > F
Angle	140,24		< ,0001
Velocity	1174,79		< ,0001
Sample	22,66		< ,0001
Ang.*Vel.	9,99		0,0007
Ang.*Sam.	3,41		0,0773
Vel.*Sam.	3,42		0,0492
Ang.*Vel. *Sam.	1,27		0,2978

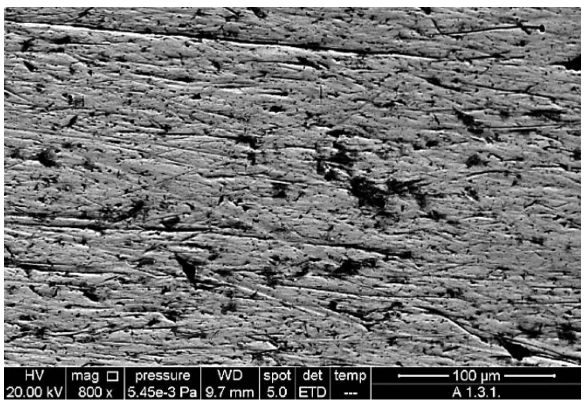

Figure 7 SEM wear of induction-hardened samples

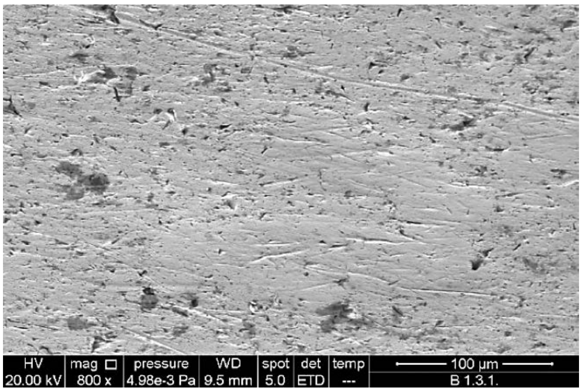

Figure 8 SEM wear of gas-nitrided samples

The Figures 7 and 8 show scanning electron microscopy (SEM) recording of the wear paths, proving that induction-hardened samples had higher mass loss than gas-nitrided samples, as well as higher mass loss at the highest sample velocity (2,5 m/s) and at lower impact angle. As presented in the Figure 7, clear evidence of abrasive wear was present in form of tiny rills and holes.

CONCLUSION

The conducted research resulted in the following conclusions:

- Wear in the abrasive mass at increased velocity caused an increased mass loss in all samples, which happened because of higher impact energy between the abrasive particles and the worn surface.
- At increased impact angle, the mass loss of all samples was lower. Such result is a consequence of the shorter contact between the worn surface and the abrasive at higher impact angle.
- Gas-nitrided samples had slightly less mass loss than induction-hardened samples at all sample velocities and at both impact angles. This result is connected with lower surface hardness and with higher toughness of gas-nitrided samples, due to which they were better at absorption of abrasive impact energy.

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Note: Responsible translator: Martina Šuto, Master of Arts in English and German language, University of Osijek.