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Investigation of Wear Properties on Duplex Surface-treated 42CrMo4 Steel

Krisztián KORSÓS,[1] Dorina KOVÁCS[2]

[1] *Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Department of Materials Science and Technology, Budapest, Hungary, krisztian.korsos@edu.bme.hu*

[2] *Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Department of Materials Science and Technology, Budapest, Hungary, kovacs.dorina@gpk.bme.hu*

Abstract

During the research, 42CrMo4 steel specimens were compared based on surface properties; after three types of duplex surface treatment, and in the untreated state. The treatments included combinations of surface polishing, chemical passivation, and direct current plasma nitriding. The coefficient of friction, wear resistance, and surface hardness properties were determined during the analysis. Scanning electron microscope and stereomicroscope were used to evaluate the results further. Based on the results, it has been proven that all samples with duplex surface treatment in a different way have unique, significantly different surface properties from the other samples, which raises the possibility of widely modifying the surface properties of materials used in industry through the targeted application of duplex surface treatments.

Keywords: *duplex surface treatment, 42CrMo4, direct current plasma nitriding.*

1. Introduction

The continuous development of the technical industry and growth of competitive market demands encourage industrial research specialists to constantly develop existing technologies and develop new technologies, which aim to produce better and higher performance industrial parts and machine components.

If the part in question is exposed to surface stresses, be it mechanical or corrosion, the obvious performance-enhancing technical solution is the targeted modification of the surface of the structure, especially in areas of application where the surface and volume of the part are subject to different stresses.

1.1. Literature review

Plasma nitriding is used in many places to improve the wear resistance of steels due to the compound layer containing iron nitride on the surface and the diffusion zone below it [1, 2].]. The passivation of the surface [3, 4] is already a well-established method among stainless steels, by which stains and incipient pitting on the surface caused by environmental corrosion is prevented, but it is also used for other types of steel, as we will cover in the following research.

Molinari et al. [5] investigated the wear properties of 42CrAlMo7 steel specimens treated with gas and plasma nitriding, with particular attention to the different wear behaviour of the diffusion and compound layers. In their research, they found that in the case of a diffusion layer, the microstructural homogeneity of the layer has a greater influence on the friction properties than its hardness. Concerning the compound layer, it was established that thin, non-porous, two-phase surface layers have significantly better friction properties than porous, single-phase compound layers.

Landek et al. [4] performed an examination of the friction and corrosion properties of nitrided, nitrided and phosphated specimens with a composition of 42CrMo4. During their research, they determined, among other things, that a significant improvement in wear resistance can be observed on the test specimen that has undergone plasma nitriding, while the test specimens that have undergone plasma nitriding and phosphating have a lower wear resistance and coefficient of friction compared to the nitrided one.

Flis [6] attempted passivation of AISI 321 and 431 plasma nitrided steels. As a result of his research, it can be shown that he successfully created, on nitrided test specimens, phosphate and oxide layers that improve both the corrosion properties and, presumably, the wear properties.

Kapuścińska [7] investigated the surface morphology and corrosion properties of nitrided and then phosphated steel with a composition of 42CrMo4. In his research, he found a correlation between the thickness of the formed compound layer and the morphology of the surface phosphate crystals formed during phosphating and established the significant effect of increasing the corrosion resistance of the phosphate layer created on the nitrided layer.

2. Experimental methodology

In the next chapter, we describe the material used in the research, the applied surface treatments and the experimental methods.

2.1. Material

The material chosen for the research is noted as 1.7225 or 42CrMo4. This material is widely used in the automotive industry, with high toughness and an affordable price. Automotive parts, shaft joints, drive shafts, gears and racks are typically made from this type of steel, which is frequently exposed to fatigue, surface wear and friction. Common to all applications is that a targeted modification of the surface properties can greatly increase the service life.

The chemical composition of the steel used in the research, based on the EN 10083 standard, contains the following components: 0.38–0.45 % C, <0.4 % Si, 0.6–0.9 % Mn, <0.025 % P, <0.035 % S, 0.9–1.2 % Cr and 0.15–0.3 % Mn. The raw material was used in the form of ø20 mm round steel, in QT heat treated state and was cut with a water-cooled cutting machine; four test specimens with a thickness of 10 mm were produced.

2.2. The applied surface treatments

Three significantly different surface modification treatments were performed during production of the test specimens. Two of the three available specimens were polished with a 1 μm grain size polishing paste, two were nitrided for 40 hours at 525 °C in a 1:3 nitrogen-hydrogen atmosphere, and two specimens were cleaned and treated with 10 % HCl solution, after which pickling in a phosphoric acid medium at 75 °C for 30 minutes was performed. The test specimens are each subjected to two different surface treatments from the three available treatments in such a way that all possible combinations are realized. The specimens that did not undergo polishing, including the reference specimen, were prepared by sanding to a P4000 grain size with gradually decreasing grain size sandpaper before the treatments. The samples produced for the research are listed in **Table 1.**

Table 1. *The samples produced for the research*

Notation	1. treatment	2. treatment
R	-	-
PF	Polishing	Phosphating
PN	Polishing	Nitriding
NF	Nitriding	Phosphating

2.3. Test methods

After the production of the test specimens, the samples were worn under a load of 5 N, on a 25 m wear path, with a 2 mm diameter carbide ball, without the use of lubricant and with an Anton Paar TRB 3 brand, pin-on-disc type tribometer. During the entire duration of the abrasion, the values of the surface friction coefficient characteristic of the test specimens were registered and then evaluated. After the wear test, the wear track was evaluated with an Olympus SZX16 stereo microscope. The hardness of the samples was determined with a Lynx type Rockwell hardness tester. After the surface tests, the chemical composition of the surface and the wear track, as well as the cross-section images, were examined with a Zeiss EVO MA 10 type scanning electron microscope.

3. Test results

The compound layer formed during nitriding appears as a clearly visible, continuous white layer on the surface (**Figure 1**). Our present research did not examine the thickness, composition, or structure of the layers produced by nitriding or phosphating technology, only the variation in the wear properties caused by the treatment combinations.

3.1. Hardness measurement

We found that a large increase in hardness compared to the reference sample can be observed on the test specimen marked PN. After phosphating in phosphoric acid, a decrease in hardness can be observed on both the PF and NF samples compared to the R and PN samples. These hardness measurement results are illustrated in **Figure 2.**

The decrease in hardness after phosphating is primarily due to the porous surface formed after the treatment (**Figure 3**), while the increase in hardness experienced in the case of nitriding is due to the formed compound and diffusion layer.

3.2. Tribological examination

The results of the tribological tests are illustrated in **Figure 4.**

After plotting the friction coefficient values registered during wear as a function of the sliding distance, the tribological behaviour of the different friction systems can be established in addition to the measurement range and measurement parameters.

The reference sample marked R is characterized by the highest coefficient of static friction, the value of which is 0.56. The gradual reduction of the friction coefficient is the initial run-in period of the friction system, during which the surface roughness is smoothed, and the contact surfaces are formed. After a friction path of 5 meters, the coefficient seems to stabilize at a value of 0.54.

The sample marked PF, which has undergone polishing and phosphating, has the lowest static friction coefficient of 0.29. During the wear test, a gradual increase in the friction coefficient of the PF sample can be observed, and then, similarly to the R sample, it stabilizes at a value of 0.47 after covering a 5-meter sliding distance.

The sample subjected to polishing and plasma nitriding, marked PN, shows a static friction coefficient of 0.20, but at the same time, a significant increase in its value can be observed within a friction distance of approximately 0 and 5 meters. A gradual decrease in the friction coefficient of the sample can be observed between 5 and 22 meters. The initial sudden value increase and decrease together characterize the run-in period of the sample, during which the gradual decrease from 5 to 22 meters indicates the smoothing and wear of the hard surface roughness peaks on the nitrided surface. At 22 meters, the sample reaches its constant wear coefficient of 0.59.

The sample, noted as NF, shows an initial static friction coefficient value of 0.38. The friction coef-

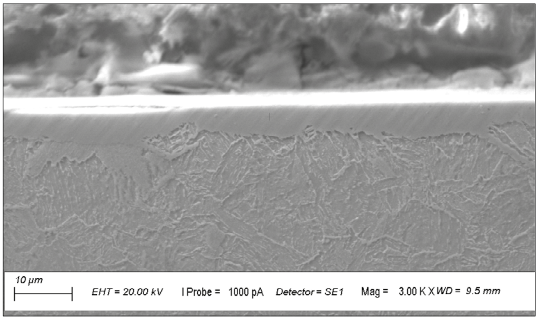

Fig. 1. *Compound layer present on the sample marked PN.*

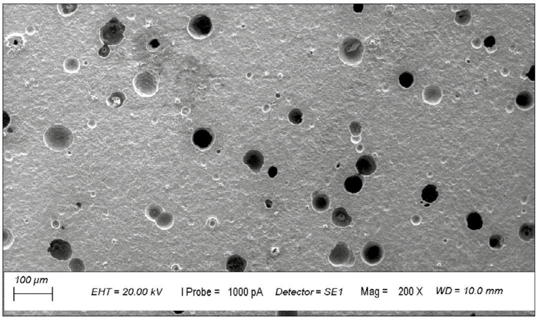

Fig. 3. *Surface pores formed on sample PF.*

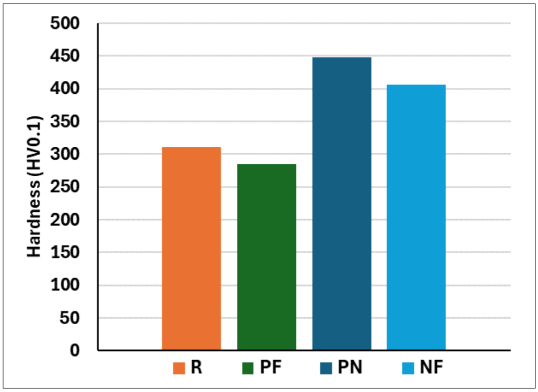

Fig. 2. *Hardness values of the samples.*

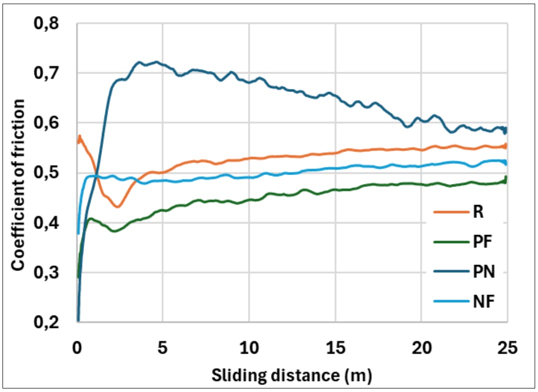

Fig. 4. *The results of the tribological tests.*

ficient of the sample stabilizes at an average value of 0.50 after only 1 meter.

It can be noted that plasma nitriding greatly increases the surface friction coefficient during the run-in period and causes a notable increase in the steady-state coefficient compared to the reference sample. Phosphating basically reduces both the static and steady-state friction coefficients compared to the reference sample. The combined application of nitriding and phosphating results in a reduced run-in and steady-state friction coefficient compared to the reference and plasma nitrided sample. On sample NF, wear debris clogged pores can be observed, which further decreased the friction coefficient of the sample **Figure 5.**

3.4. Abrasion resistance tests

The wear volumes were determined by knowing the width and length of the wear tracks and the diameter of the wear ball. The measurement results are illustrated in **Figure 6**.

Regarding the results, it can be concluded that the wear resistance shows a correlation with the surface hardness values. The sample marked PN has the smallest wear volume, while a proportional increase in hardness can be observed in the case of the NF sample. A slight increase can also be observed in the phosphatized sample compared to the reference sample.

5. Conclusions

During the measurement results, it can be established that phosphating as a secondary surface treatment can reduce the friction coefficient of the base surface, but at the same time, it reduces its wear resistance. It can be observed that after the passivation of the nitrided samples, the improvement in the value of the coefficient of friction is significantly greater than the visible decrease in the hardness value. The surface layers created by phosphating showed an outstanding coefficient of friction in both cases.

At the same time, deterioration is observed after phosphating in terms of hardness and wear resistance properties. As a result of the research, it can be concluded that the duplex layer produced by plasma nitriding and surface treatment in a phosphoric acid medium shows a significant improvement in both friction coefficients compared to the reference and plasma nitrided samples, while at the same time, an improvement can be observed in the wear resistance of the duplex surface treatment sample compared to the reference and phosphated samples.

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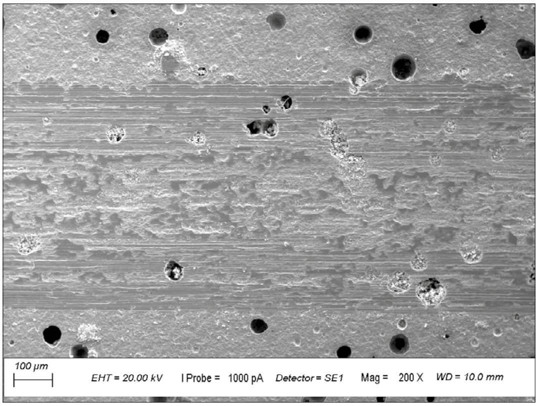

Fig. 5. *Pores filled with wear debris found in the wear track of sample PF.*

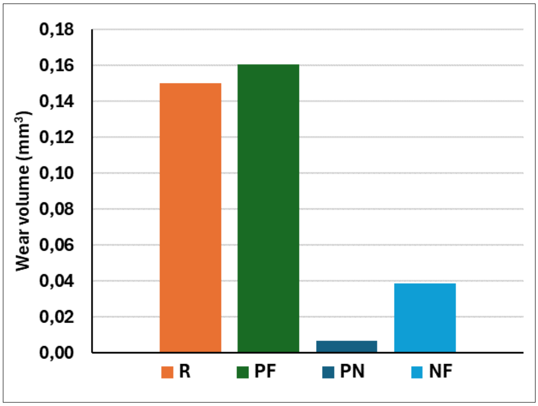

Fig. 6. *The results of the wear resistance test.*

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