ISSN 0208-7774 TRIBOLOGIA 3/2020 p. 39–42
DOI: 110.5604/01.3001.0014.4763

Jan SENATORSKI[*], **Paweł MĄCZYŃSKI**[**]

THE TRIBOLOGICAL ASPECT OF THE COOPERATION OF VARIOUS SURFACE-STRENGTHENED STEELS WITH HEAT-TREATED STEEL

TRIBOLOGICZNY ASPEKT WSPÓŁPRACY RÓŻNYCH STALI UMACNIANYCH POWIERZCHNIOWO ZE STALĄ OBROBIONĄ CIEPLNIE

Key words: structural and tool steels, nitriding, heat treatment, shot peening, friction cooperation.

Abstract: The presented work was mainly aimed at assessing the tribological properties of gas nitrided samples subsequently subjected to shot peening. This assessment was carried out using the standard "three rollers – cone" method. In these tests, different materials of roller samples were used, i.e. both structural and tool steels. In addition, the selected material of conical counter-samples, i.e. heat-treated medium carbon steel, was used. The obtained test results allowed us to assess the influence of the use of dissimilar material of nitrided (under different conditions) roller samples, as well as their surface plastic processing, i.e. shot peening.

Słowa kluczowe: stale konstrukcyjne i narzędziowe, azotowanie, obróbka cieplna, kulowanie, współpraca tarciowa.

Streszczenie: Prezentowana praca miała głównie na celu ocenę właściwości tribologicznych próbek azotowanych gazowo i następnie kulowanych. Ocenę tę przeprowadzono znormalizowaną metodą „trzy wałeczki – stożek". W próbach tych użyto zróżnicowane materiały próbek wałeczkowych, tzn. zarówno stale konstrukcyjne, jak i narzędziowe. Ponadto zastosowano wybrany materiał przeciwpróbek stożkowych, tj. ulepszaną cieplnie stal średniowęglową. Uzyskane wyniki badań pozwoliły ocenić wpływ stosowania zróżnicowanego materiału azotowanych (w różnych warunkach) próbek wałeczkowych, a także ich powierzchniowej obróbki plastycznej, tzn. kulowania.

INTRODUCTION

This article is an essential continuation of previously completed works, including among others **[L. 1]**. In these works, data from tests of various thermo-chemically treated and surface treated materials were collected and interpreted. As follows from the information about these works, the basic thermo-chemical treatment, for which tribological characteristics were developed, was nitriding. This process is still of interest to tribologists **[L. 2]** or specialists dealing with fatigue strength **[L. 3]** or corrosion **[L. 4]**.

Among many studies related to the description of tribological properties of materials subjected to gas nitriding, including our own studies **[L. 5]**, a few words should be devoted to the work by K. Eliasen, T. Christiansen and M. Somers **[L. 2]**. In their study, they tried to assess the possibility of using low-temperature nitriding of nickel-based super-alloys (type: Nichrome or Nimonic) to obtain "expanded austenite," causing the stabilization of their tribological properties, as it happens in the case of stainless steels. They also indicated a significant effect of the chemical composition of the tested superalloys on the assessed

[*] ORCID: 0000-0001-7799-4419. Łukasiewicz Research Network – The Institute of Precision Mechanics, Duchnicka 3 Street, 01-796 Warsaw, Poland.
[**] ORCID: 0000-0002-9655-9401. Łukasiewicz Research Network – The Institute of Precision Mechanics, Duchnicka 3 Street, 01-796 Warsaw, Poland.

physical and mechanical properties (including structure and hardness).

The equally substantial information like this related to the tribological properties of nitrided materials, also concerns the fatigue strength of elements after such thermo-chemical treatments **[L. 6]**. Among this information, it is worth quoting the one related to the assessment of the effect of nitriding on the durability of rolling bearings **[L. 3]**. In this study, its author, O. Beer, subjects the ball bearings made of nitrided, non-aluminium steel grade 15CrMoV5-9 to multiple tests. As a result, very favourable test results are obtained, both of durability assessed by the Weibull distribution, as well as of hardness and measurements of internal stress to such an extent that they can be compared to the properties of high-speed steel.

It is also possible to find in the literature a number of publications on the beneficial effect of nitriding on the corrosion resistance properties of materials **[L. 7]**. One of these numerous publications is worth discussing **[L. 4]**. In her study, its author, B. Haase, uses various methods to assess the corrosion resistance properties of various materials (C15, X5Ni1810, 42CrMo4 steels) after the nitriding or carbonitriding processes. She states that, among the various research methods of this assessment, the impedance measurement method should be highlighted as being clearer in explaining the corrosion mechanism of the tested materials and thermal-chemical treatments.

IMPLEMENTATION OF THE UNDERTAKEN RESEARCH WORK

The research assumption of this work was to extend (among others, by the technology of shot peening **[L. 8]**) the effects of testing the tribological properties of gas nitrided materials. For this purpose, appropriate materials were prepared and their thermo-chemical treatment (i.e. gas nitriding) and shot peening (after nitriding) were carried out.

Preparation of materials for tribological tests

The tests of tribological properties of nitrided material samples were decided to be carried out using the standardized "3 rollers – cone" method **[L. 9]**. Preparation of materials for testing by this method required the preparation of both test elements, i.e. rollers, and counter-samples, i.e. cones **[L. 9]**. The selected materials of roller samples and technological variants of their surface treatment are summarized in **Table 1**. As the table shows, the subjects of testing were nitrided structural and tool steels, which were subsequently subjected to shot peening. A Nitrex furnace type Nx609 was used in the nitriding processes. The exact conditions of the carried out processes are summarized in **Table 2**. A more precise description of structures of the investigated nitride layers was given in our earlier publication **[L. 11]**.

The shot peening process was carried out by the pneumatic method at the PEEN – IMP stand using the following parameters:

- Shot: tungsten carbide with a diameter of ø 0.9 mm,
- Air pressure during shot peening: p = 4 bars,
- The shot peening intensity was determined on the Almena control plate of the AI type, and it was f_A = 0.25 mm,
- 98% surface coverage.

Table 1 summarizes the surface hardness and roughness of the prepared roller samples.

Table 1. Tested materials of roller samples and conditions of their surface treatment
Tabela 1. Badane materiały próbek wałeczkowych oraz warunki ich obróbki powierzchniowej

No.	Steel grade	Type of thermo-chemical treatment	Nitriding process parameters		Nitrogen process designation acc. to Table 2	Surface hardness HV0,5	Type of surface treatment	Surface roughness			
			Temperature T [°C]	Time t [min]				Before shot peening		After shot peening	
								R_a [µm]	R_z [µm]	R_a [µm]	R_z [µm]
1	38HMJ	Nitriding	540	1140	1209	1127.7	Shot peening	0.78	5.55	0.54	3.69
2	40HM (42CrMo4)		600	960	1208	487.7		0.52	4.01	1.50	7.74
3			570	300	1213	915.7		0.35	2.70	1.30	6.39
4	45 (C45)		540	1140	1209	400.7		0.22	1.66	1.79	8.68
5	80WCrV8 (NZ3)		600	960	1211	780		0.50	3.54	0.55	3.62
6	120CrWV6-6 (NWV1)		540	1140	1209	647		0.41	2.78	1.34	6.21

Table 2. Nitriding conditions for tested steels
Tabela 2. Warunki azotowania badanych stali

Process designation	Steel type	Steel grade	Nitriding parameters			
			Temp. T [°C]	Time t [min]	Atmosphere NH_3 (%)	Flow max [/min]
Nx 1208	structural	40HM (42CrMo4)	600	960	72	10
Nx 1213			570	300	100	5
Nx 1209		38HMJ	540	1140	100	7
	tool	120CrWV6-6 (NWV1)	540	1140	100	7
Nx 1211		80WCrV8 (NZ3)	600	960	83	10

As mentioned above, the elements cooperating with the described rollers were the cones made of 45 (C45) steel improved to a hardness of 31HRC. The conditions for conducting tribological tests were as follows:

– Unit pressures during the test: 50, 100, and 400 MPa,
– Testing time: 100 min. with wear measurements every 10 minutes,
– Rotation speed of the conical counter-sample: 576 rpm,
– Lubrication: Lux-10 oil.

Implementation of tests and their results

The drawn-out tribological characteristics of linear wear as a function of friction time were prepared for the selected materials and their nitriding processes (**Tables 1** and **2**). These characteristics were prepared for the nitriding process of 38HMJ structural steel marked with number 1209 and the nitriding process of 80WCrV8 tool steel marked with number 1211. These processes differed not only in the type of thermo-chemically treated and surface treated (shot peening) material, but also in the parameters of the carried out nitriding process.

The selected tribological characteristics obtained in the tests are shown in **Figures 1** and **2**. They provide full information about the tribological properties of the tested material associations.

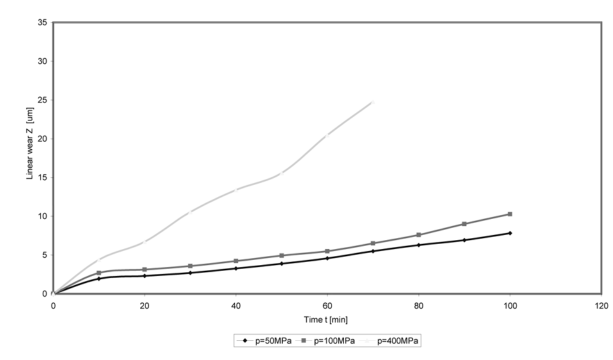

Fig. 1. Tribological characteristics of the samples made of nitrided and subjected to shot peening 38HMJ steel (process 1209) cooperating with improved C45 steel
Rys. 1. Charakterystyka tribologiczna próbek z azotowanej i kulowanej stali 38HMJ (proces 1209) współpracującej z ulepszaną stalą C45

Moreover, it should be mentioned that supplementary tests, such as chemical composition analysis, hardness and roughness measurements were carried out using the methods and procedures employed in the accredited laboratory of the Łukasiewicz – IMP Research Network **[L. 10]**. The results of these tests are also included in **Table 1**.

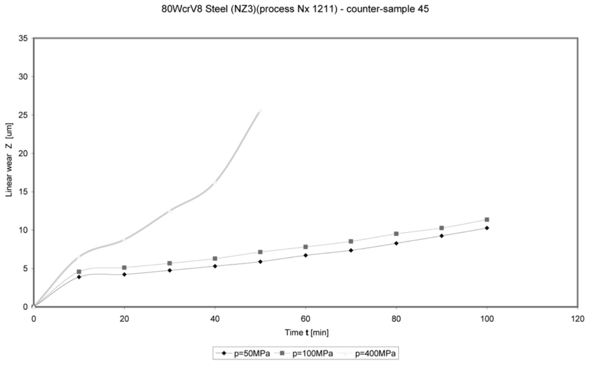

Fig. 2. Tribological characteristics of the samples made of nitrided and subjected to shot peening 80WCrV8 steel (process 1211) cooperating with improved C45 steel
Rys. 2. Charakterystyka tribologiczna próbek z azotowanej i kulowanej stali 80WCrV8 (proces 1211) współpracującej z ulepszaną stalą C45

DISCUSSION OF THE TEST RESULTS

Discussion of the test results, or rather their analysis, is facilitated by both the compilation of the basic information contained in **Table 1**, as well as by the prepared tribological characteristics (diagrams) presented in **Figures 1** and **2**). These characteristics were prepared for the selected materials (i.e. both structural and tool steels) as well as for their nitriding and shot peening processes, and they also contained the values of linear wear as a function of friction time. The processes selected for testing differed not only in the material of the nitrided and subjected to shot peening samples, but also in the temperature and the time of the process.

Thus, the tribological characteristics included in **Figures 1** and **2** give complete information about the tribological properties of the tested material associations and about the used variants of the gas nitriding process.

Comparison of wear resistance of structural steel (especially 38HMJ) which is only gas-nitrided (see **[L. 1]**), with the same nitrided and subjected to shot peening steel, is favourable for the applied shot peening process after thermo-chemical treatment, especially in cooperation with the heat-treated counter-sample, i.e. improved C45 steel.

SUMMARY AND CONCLUSIONS

The described work, the purpose of which was the presentation of data based on tribological characteristics of the selected materials and technologies for their thermo-chemical treatment (nitriding) and subsequent shot peening, was completed with a positive result and the assumed goal was achieved. The results of our tests contributed to this goal. In the case of tests of tribological properties, frictional cooperation concerned the samples made of nitrided structural and tool steels, after their subsequent shot peening, with the counter-sample made of improved C45 steel. All tribological tests were carried out using the "3 rollers – cone" method, which had shown its beneficial features during the implementation of previously conducted works **[L. 1]**. The only drawback of this method used in the Łukasiewicz – IMP Research Network is the inability to measure the coefficient of friction.

The overall assessment of the tribological properties of nitrided and subsequently subjected to shot peening structural and tool steels cooperating with the selected conical counter-sample material makes it possible to make conclusions concerning the beneficial effect of cooperation with improved C45 steel, which was also affected by a small change in roughness after shot peening (mainly of structural steels). A general assessment of the influence of shot peening on the tribological properties of nitrided samples indicates the beneficial effect of this surface treatment technology, especially with regard to structural steels at high unit pressures, i.e. above 400 MPa.

REFERENCES

1. Senatorski J., Tacikowski J., Mączyński P., Wach P.: Tribologiczne aspekty badań węzła tarciowego: azotowane stale konstrukcyjne vs. stale obrobione cieplnie. Inżynieria Powierzchni, nr 3, 2019, pp. 17–21.
2. Eliasen K., Christiansen T., Somers M.: Low temperature gaseous nitriding of Ni based superalloys. Surface Engineering, Vol. 26, No. 4, 2010, pp. 248–255.
3. Beer O.: Nitriding of Rolling Contact Races. HTM – Journal of Heat Treatment and Materials. No. 5, 2019, pp. 317–330.
4. Haase B.: Elektrochemische Korosionsprüfung verschleiβbeständiger Schichten. HTM J. Heat Treamtm. Mat. 68, 2013, 1 pp. 49–55.
5. Senatorski J., Tacikowski J., Roliński E.: Evaluation of wear behaviour of nitrided and nitrocarburized steels. Surface Engineering, No. 3, 2018, pp. 11–25.
6. Neves Penka R., Murilla I.C., Vataruck J., Canale L.C.F.: Nitriding effect on fatigue resistance of grey and nodular cast irons. Internal Heat Treatment and Surface Engineering No. 1, Vol. 6, 2012, pp. 33–37.
7. Dalke A., Gleiβner J., Spies H.J., Zehner R., Franke A.: Einfluss der Behandlungsbedigungen beim Nitrocarburiren auf Härte, Verschlei und Korosionswiderstand der Randschicht nichtrosender Stähle. HTM 69, 2014, pp. 201–208.
8. Nakonieczny A.: Dynamiczna powierzchniowa obróbka plastyczna – kulowanie, shot peening. Wydawnictwo Instytutu Mechaniki Precyzyjnej. 2002.
9. PN-H-04302:1983: Badania wytrzymałościowe stali – Próba tarcia w układzie: 3 wałeczki – stożek.
10. Procedury badawcze akredytowanego Laboratorium Sieć Badawcza Łukasiewicz – IMP, LB-4 Laboratorium Badań Materiałów, Części Maszyn i Konstrukcji.
11. Senatorski J., Tacikowski J., Mączyński P., Wach P.: Tribologiczne aspekty badań węzła tarciowego azotowane stale konstrukcyjne vs. stale obrobione cieplnie. Inżynieria Powierzchni, nr 3/2019, pp. 17–21.