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THE ANALYSIS OF THE SELECTED PROCESSES OF THERMO-CHEMICAL HEAT TREATMENT OF 20MnCr5 STEEL IN THE CONTEXT OF ABRASIVE WEAR

ANALIZA WYBRANYCH METOD ULEPSZANIA CIEPLNO--CHEMICZNEGO STALI 20MnCr5 W KONTEKŚCIE ZUŻYCIA ŚCIERNEGO

Key words:

heat treatment, steel 20MnCr5, abrasive wear

Słowa kluczowe:

obróbka cieplna, stal 20MnCr5, zużycie ścierne

Abstract

This paper presents the results of tribological tests performed on a T-11 pin-on-disc type, which made it possible to determine the intensity of abrasive wear of

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steel 20MnCr5 subjected to selected thermo-chemical heat treatments. The tested steel, after the hardening and tempering process, is characterized by high endurance parameters and is used on heavily loaded machine parts. It is frequently used for elements subjected to intense abrasion. The analysis involved the following: carburizing, boronizing, and various methods of diffusion chromizing. For large loads, it is advisable to apply boronizing or carburizing with hardening. Chrome plating entails a very thin layer of increased hardness, which is characterised by a low abrasive wear resistance at high loads.

INTRODUCTION

Resistance to abrasive wear is a crucial parameter in the process of selecting materials for machine parts. Hardness is an indicator for resistance to abrasive wear for steel. However, methods involving a plastic deformation of the surface layer do not always improve wear resistance **[L. 1, 2]**. This can occur, for instance, in the production of silicate bricks that are made in the process of densifying a calcium-sand mixture. The conditions of mixture densification (high pressure, dry friction) cause intensive wear of matrixes (or their sheeting). Due to high tensions achieved with desirable methods improving hardness, the sheetings constantly feature possibly high hardness without plastic deformation. This can be achieved by applying, e.g., heat or thermo-chemical heat treatment, welding, and alloying **[L. 3, 4, 8]**. The type of the proper treatment must correspond to a specific type of steel or the desired technological process.

RESEARCH PROCEDURE

The tested material and types of heat-chemical treatment

The research involved 20MnCr5 Chrome Manganese alloy steel intended for carburizing. In an improved state, it is characterised by a significant resistance to abrasive wear **[L. 4–6]**. It can be used for large-intersection elements, including the plates of matrixes of silicate products. Its applied parameters can also be significantly improved through thermo-chemical heat treatment.

The analysis of literature **[L. 5–12]** and the experiments performed at the Institute of Precision Mechanics in Warsaw lead to the following types of thermo-chemical heat treatment of steel 20MnCr5:

- ✓ Carburizing,
- ✓ Boronizing,
- ✓ Vacuum chromizing, and
- ✓ Powder pack chromizing.

Each sample, regardless of the type of thermo-chemical heat treatment, was subjected to normalising annealing and tempering.

Carburizing and tempering lead to the creation of a hard surface layer of high resistance to abrasive wear. The time of carburizing (6 h) was selected in such a manner so as to obtain the surface layer of high hardness over 2 mm deep. In this process, which was applied to large-dimension elements **[L. 2]**, the endurance properties of the core change to a minor or to no extent. In the case of samples for tribological studies, the process of carburizing caused carbon saturation in the total volume. High hardness and micro-hardness values shall occur throughout the total thickness of the sample.

Boronizing is another applied method of thermo-chemical heat treatment. The hardness of boride layers resulting from this process can be higher than carburized and nitrogenized layers **[L. 6, 7]**. FeB borides may reach the hardness of 1800 – 2350 µHV, and Fe2B borides – 1400 – 1800 µHV **[L. 7]**. High hardness of the resulting layers features good resistance to abrasion without lubrication **[L. 7]**.

The study also involved two methods of diffusion chromizing: vacuum and powder. They both lead to the creation of surface layers of small thickness and hardness reaching 1600 – 1800 µHV **[L. 11, 12]**.

The selected methods were conducted on steel plates 4 mm thick. **Table 1** presents the summary of parameters of the performed thermo-chemical heat treatments of steel 20MnCr5 samples.

Table 1. Parameters of the thermo-chemical heat treatment of 20MnCr5 steel
Tabela 1. Parametry obróbki cieplno-chemicznej próbek ze stali 20MnCr5

	Sample marking	Performed processes	Parameters of the sample	
			Temperature [°C]	Time [h]
20MnCr5	1	carburizing	930	6
		hardening	900	0.5
		tempering	200	2
	2	powder boronizing	950	6
		hardening	900	0.5
		tempering	200	2
	3	vacuum chromizing	1110	8
		hardening	900	0.5
		annealing	700	0.33
		tempering	200	2
	4	powder pack chromizing	950	8
		hardening	900	0.5
		tempering	200	2

Research method and conditions

The usefulness of steel 20MnCr5 upon the chosen thermo-chemical heat treatment for working at high loads was determined based on the results of friction tests. The samples used in the research had a shape of an intersection approximate to a square. The reason for applying such a shape was the technology of performing specific thermo-chemical heat treatments, where: 4-mm-thick plates at the size of 4 x 4 cm were subjected to carburizing, boronizing, and diffusion chromizing. Thus, such plates were used for extracting samples of desirable dimensions. The criterion for choosing the load was the endurance of the silicate disc. The time of the test was estimated at t = 1200 s, i.e. the time that allows for determining the intensity of the wear. The tests were conducted at unit pressures of p = 1.5 MPa. During the experiment, the value of the frictional force T was registered, which allowed the determination of the frictional coefficient μ using the following:

$$\mu = \frac{T}{P}, \tag{1.1}$$

where: T – frictional force, P – load of the steel sample perpendicular towards the surface of the silicate disc (a counter-sample shown in **Fig. 1b**).

The unit pressure p_t was calculated based on the following relation:

$$p_t = \frac{P}{ab} \left[\frac{N}{m^2} \right], \tag{1.2}$$

where: P – force loading the sample, a and b – lengths of the sides of the sample (**Fig. 1a**).

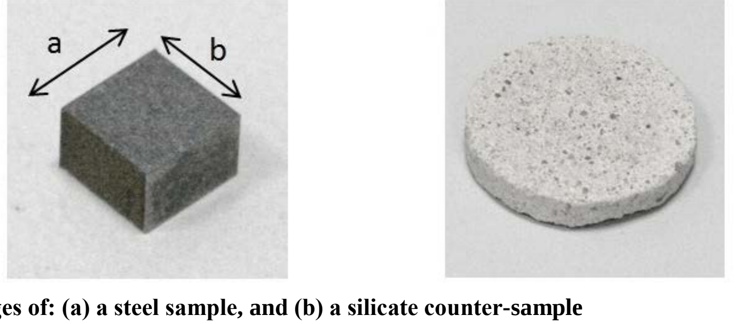

Fig. 1. Images of: (a) a steel sample, and (b) a silicate counter-sample
Rys. 1. Schemat: a) próbki, b) przeciwpróbki

Measuring the mass of the sample before and after the test made it possible to determine wear intensity based on the following relation:

$$I = \frac{M_1 - M_2}{SF} \left[\frac{mg}{m^3}\right], \qquad (1.3)$$

where: M_1 and M_2 – mass of the sample before and after the friction test [mg], S – path of friction [m], F – surface of sample intersection [m^2].

Research position – T11 pin-on-disc tester

The laboratory of the Faculty of Mechanical Engineering at Bialystok University of Technology is equipped with the adequate research facilities. Its major element is a T11 pin-on-disc tester. It allows for studying tribological properties of materials comprising friction pairs of machines and appliances. This ensures constant measurement and registration of frictional forces, and the temperature of the environment of the friction pair and linear wear **[L. 13, 14, 15]**. In the case of the conducted studies, the appliance T-11 allowed identifying the following:

- ✓ Wear intensity of the materials subjected to various thermo-chemical heat treatments,
- ✓ Average frictional force, and
- ✓ The average value of frictional coefficient.

Fig. 2 presents the position together with all components.

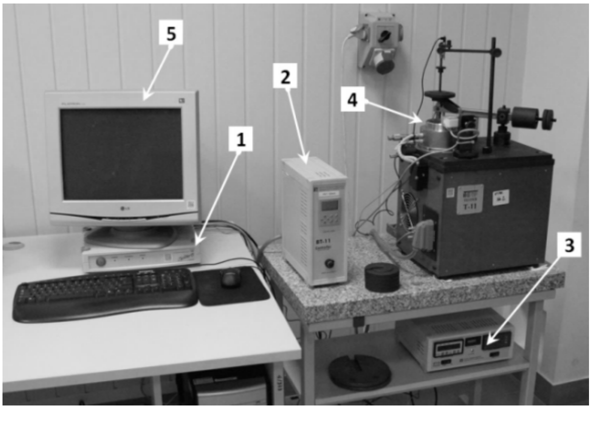

Fig. 2. A scheme of the position for the T-11 pin-on-disc-type tribological test, 1 – digital amplifier 8 Spider, 2 – controller BT-11, 3 – controller BT-03, 4 – sensors and transducers 5 – computer set

Rys. 2. Stanowisko do badań tribologicznych typu tarcza – trzpień T-11: 1 – cyfrowy wzmacniacz Spider 8, 2 – sterownik BT-11, 3 – sterownik BT-03, 4 – czujniki i przetworniki pomiarowe, 5 – zestaw komputerowy

The test stand is composed of a digital amplifier Spider 8 (1), controllers BT-11 and BT-03 (2, 3), sensors and transducers (4), and a computer (5) equipped with software registering the parameters of the experiment. The desired pressure on the sample was performed by means of applied weights. In order to determine wear intensity of the studied materials, before the test, each sample was weighed with a precision down to ten-thousandth parts of a gram with the use of laboratory scales RADWAG.

RESULTS OF THE RESEARCH

Before the friction tests, the hardness of the samples was determined (with Vicker's method) on the improved side of the surface layer of steel 20MnCr5. **Table 2** presents the obtained measurements.

Table 2. A summary of the hardness of the surface layer of steel samples 20MnCr5
Tabela 2. Zestawienie twardości ulepszonej warstwy wierzchniej próbek stali 20MnCr5

Material and the applied sample	Hardness [HV]
Carburized, hardened and tempered steel 20MnCr5	744
Boronized, hardened and tempered steel 20MnCr5	794
Vacuum chromizing, hardened and tempered steel 20MnCr5	230
Powder pack chromizing, hardened and tempered steel 20MnCr5	291

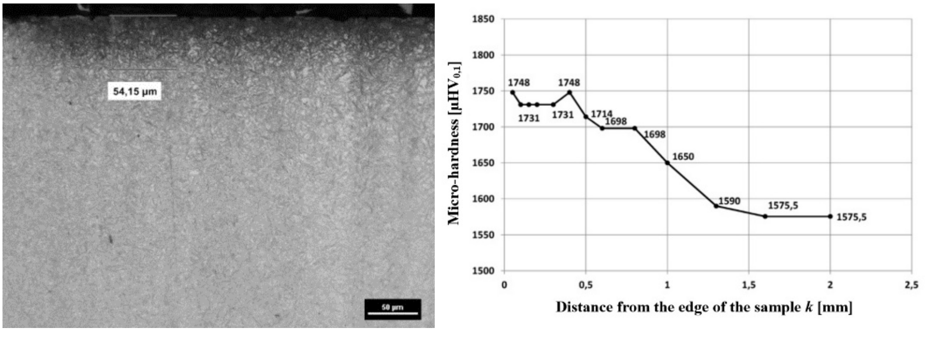

Fig. 3. The structure and distribution of micro-hardness of the surface layer of steel 20MnCr5 after carburizing (930°C, 6 h), hardening (900°C, 0.5 h) and tempering (200°C, 2 h)
Rys. 3. Struktura oraz rozkład mikrotwardości w warstwie wierzchniej stali 20MnCr5 po: nawęglaniu (930°C, 6 h), hartowaniu (900°C, 0,5 h) i odpuszczaniu (200°C, 2 h)

Subsequently, metallographic specimens were produced in order to assess the surface layer. Next, the distribution of micro-hardness was determined. **Figures 3, 4, 5**, and **6** below present the achieved structures.

At the depth of 0.5 mm, the value of micro-hardness exceeds 1700 μHV, and upon exceeding 0.5 mm, it falls systematically, reaching a value below 1600 μHV at the depth of 2 mm.

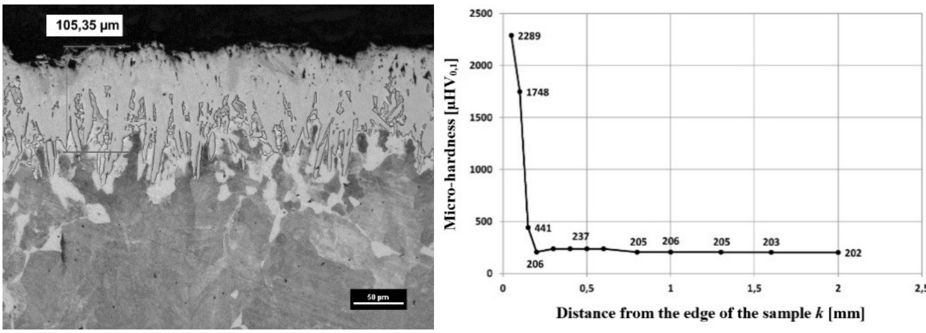

Fig. 4. The structure and distribution of micro-hardness of the surface layer of the steel 20MnCr5 after boronizing (950°C, 6 h), hardening (900°C, 0.5 h) and tempering (200°C, 2 h)

Rys. 4. Struktura oraz rozkład mikrotwardości w warstwie wierzchniej stali 20MnCr5 po borowaniu (950°C, 6 h), hartowaniu (900°C, 0,5 h) i odpuszczaniu (200°C, 2 h)

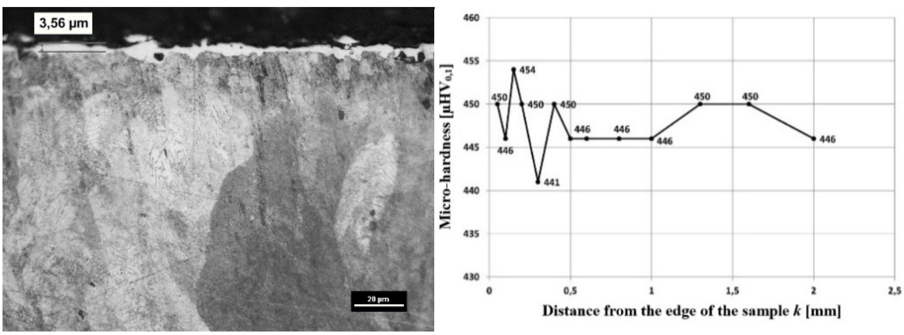

Fig. 5. The structure and distribution of micro-hardness of the surface layer of steel 20MnCr5 after vacuum chromizing (1110°C, 8 h), hardening (900°C, 0.5 h), annealing (700°C, 0.33 h) and tempering (200°C, 2 h)

Rys. 5. Struktura oraz rozkład mikrotwardości w warstwie wierzchniej stali 20MnCr5 po chromowaniu próżniowym (1110°C, 8 h), hartowaniu (900°C, 0,5 h), wyżarzaniu (700°C, 0,33 h) i odpuszczaniu (200°C, 2 h)

At the depth of 0.1 mm, the obtained micro-hardness exceeds 2000 μHV. Below this depth, hardness dramatically falls and assumes values approximate to the value of the material (steel 20MnCr5) without thermo-chemical heat treatment, i.e. down to the value of 200 μHV.

The obtained micro-hardness in the surface layer is approximately 450 μHV. In its layer carbides (Cr, Fe) are formed. The obtained hardness results from the process of hardening. Due to the temperature and the duration of chromizing process (8 hours) in the total volume of the material, there occurred changes causing the unification of micro-hardness in the surface layer.

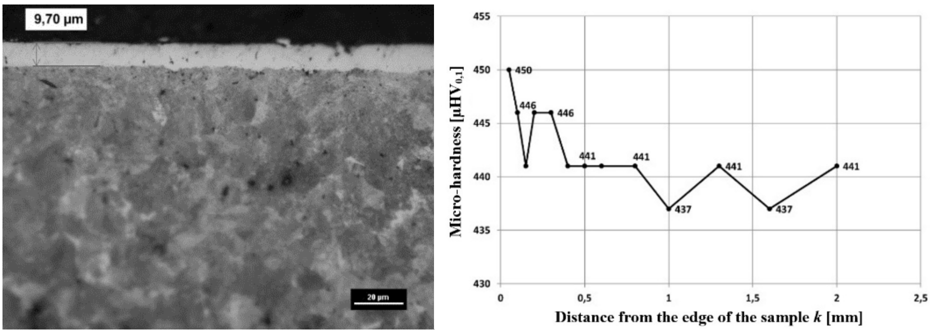

Fig. 6. The structure and distribution of micro-hardness of the surface layer of steel 20MnCr5 after powder chromizing process (950°C, 8 h), hardening (900°C, 0.5 h) and tempering (200°C, 2 h)

Rys. 6. Struktura oraz rozkład mikrotwardości w warstwie wierzchniej stali 20MnCr5 po chromowaniu metodą proszkową (950°C, 8 h), hartowaniu (900°C, 0,5 h) i odpuszczaniu (200°C, 2 h)

The obtained value of micro-hardness in the surface layer reaches 450 μHV and falls to the level of ca. 440 μHV from the depth approximately 0.2 mm. This layer is too thin to allow for determining its hardness at the load of HV 0.1. In such a case, the thickness of the layer of carbides and nitrides is too small for this layer to endure high loads during dry friction.

Results of friction tests

Three friction tests were performed for each type of a material. The obtained results were used for determining an average wear intensity I_{av}, an average frictional coefficient μ_{av} and an average frictional force T_{av}. **Table 3** presents the results of the tests at unit pressures equalling $p_t = 1.5$ MPa.

Table 3. A summary of the average frictional force, the frictional coefficient and wear intensity values for the tested samples of steel 20MnCr5 after thermo-chemical heat treatment at unit pressures p_t = 1.5 MPa

Tabela 3. Zestawienie wartości średnich: siły tarcia, współczynnika tarcia oraz intensywności zużycia próbek ze stali 20MnCr5 poddanych obróbce cieplno-chemicznej przy naciskach jednostkowych p_t = 1,5 MPa

No.	Material and the applied treatment	Average wear intensity I_{av} [mg/m^3]	Average frictional coefficient μ_{av}	Average frictional force T_{av} [N]
		p_t = 1.5 MPa	p_t = 1.5 MPa	p_t = 1.5 MPa
1.	Carburized, hardened and tempered steel 20MnCr5	1296.9	0.49	12.08
2.	Boronized, hardened and tempered steel 20MnCr5	483.3	0.43	10.01
3.	Vacuum chromizing, hardened, annealed and tempered steel 20MnCr5	15509.9	0.5	12.42
4.	Powder pack chromizing, hardened and tempered steel 20MnCr5	14255.8	0.45	10.58

CONCLUSIONS

The conducted tribological tests on wear intensity of specific materials indicate that the highest resistance to abrasive wear is characteristic of steel 20MnCr5 upon boronizing and classic carburizing with hardening. However, boronizing leads to the creation of a very hard surface layer. Its thickness reaches ca. 100 µm.

The samples subjected to vacuum and powder diffusion chromizing featured intensive wear. This corresponds to the thickness of their surface layer that did not exceed 10 µm. Hence, in the conditions of high loads, and dry friction such type of treatment is undesirable.

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Streszczenie

W pracy przedstawiono wyniki badań tribologicznych wykonanych na stanowisku typu trzpień-tarcza T-11, które pozwoliły określić intensywność zużycia ściernego stali 20MnCr5 poddanej wybranym obróbkom cieplno-chemicznym. Badana stal po procesie ulepszania cieplnego charakteryzuje się wysokimi parametrami wytrzymałościowymi i jest wykorzystywana na mocno obciążone elementy maszyn. Często wykorzystuje się ją na elementy poddawane intensywnemu zużyciu ściernemu. Analizie poddano procesy: nawęglania, borowania oraz różne metody chromowania dyfuzyjnego. W przypadku dużych obciążeń wskazane jest borowanie lub nawęglanie z hartowaniem. Chromowanie odznacza się bardzo cienką warstwą o zwiększonej twardości, dlatego charakteryzuje się małą odpornością na zużycie ścierne przy dużych obciążeniach.