

Wojciech TARASIUK\*, Jerzy NAPIÓRKOWSKI\*\*, Krzysztof LIGIER\*\*, Bazyli KRUPICZ\*\*\*

## COMPARISON OF THE WEAR RESISTANCE OF HARDOX 500 STEEL AND 20MnCr5

### PORÓWNANIE ODPORNOŚCI NA ZUŻYWANIE ŚCIERNE STALI HARDOX 500 I 20MnCr5

**Key words:** Hardox 500, 20MnCr5, wear.

**Abstract** The paper presents the results of experimental studies on abrasion resistance of Hardox 500 steel and 20MnCr5 steel subjected to thermo-chemical treatment. These types of steel are often used for agricultural or construction machinery. Abrasion tests were performed on a T-11 pin using a disc tester. The test conditions correspond to the wear caused by micro-grinding and grain-cutting using particles from the product as well as a result of abrasion produced by loose abrasive material created through the chipping of silica sand grains. The obtained results can be useful in the selection of materials for machine components.

**Słowa kluczowe:** Hardox 500, 20MnCr5, zużycie.

**Streszczenie** W pracy przedstawiono wyniki badań eksperymentalnych dotyczących odporności na zużywanie ścierne stali Hardox 500 i stali 20MnCr5 poddanej obróbce cieplno-chemicznej. Stale te często stosuje się na elementy maszyn rolniczych lub budowlanych pracujących w glebie lub kontaktujących się z innymi materiałami ściernymi. Testy ścieralności wykonano na testerze typu trzpień-tarcza T-11, a parę cierną stanowił zespół stal-silikat. Warunki testu odpowiadają zużyciu na skutek mikroskrawania i bruzdowania ziarnami będącymi częścią wyrobu oraz na skutek ścierania przez luźne ścierniwo powstające w wyniku wykruszania się ziaren piasku z silikatu. Uzyskane wyniki mogą być pomocne przy doborze materiałów na elementy maszyn.

## INTRODUCTION

Abrasive wear is a common source of intensive deterioration of machine components. It is estimated that under industrial conditions, it is responsible for approximately 50% of all cases of wear [L. 1, 3] creating a need for research which can find methods of minimizing the effects of this process [L. 3]. Depending on technological requirements steels with a high resistance to abrasion or treated using hardfacing, laser cladding, and various other surface treatments (such as thermally sprayed composite coatings containing chromium, titanium or tungsten carbide) are employed [L. 2, 4, 5, 6, 7, 8, 16, 17]. The properties of the materials listed above are generally known. However, we lack sufficient knowledge and practical guidelines regarding

some peculiar or rarely occurring combinations which at times are made to work together (like steel and silicate).

Wear resistant steels are often utilized for elements of construction machinery (such as the buckets of excavators or loaders). During operation, these elements are subjected to wear through contact with abrasive materials including soil, gravel, etc. In these cases, the grains can move relatively freely [L. 1, 9, 10, 11, 12, 13]. However, during the production of construction materials (silica blocks for example), there is abrasive wear that happens as a result of micro-grinding and grain-cutting by particles that come from the product [L. 14]. This process occurs during the compaction of a lime-sand mixture and as the finished product is removed from the form. At the same time, there is also wear caused by loose abrasive material in the form of

\* Białystok University of Technology, Faculty of Mechanical Engineering, ul. Wiejska 45C, 15-351 Białystok, Poland, e-mail: w.tarasiuk@pb.edu.pl.

\*\* University of Warmia and Mazury in Olsztyn, ul. M. Oczapowskiego 11, 10-736 Olsztyn, Poland, e-mails: napij@uwm.edu.pl, klig@uwm.edu.pl.

\*\*\* Białystok University of Technology, Faculty of Management, ul. Ojca Tarasiuka 2, 16-001 Kleosin, Poland, e-mail: b.krupicz@pb.edu.pl.

the lime-sand mixture settling on the surfaces of various elements working against each other on the production line [L. 7].

Elements of agricultural or construction machines that come in contact with soil do not have to maintain fixed dimensions. If their dimensions change as a result of wear, it does not cause them to be withdrawn from use. However, when it comes to forms utilized in the production of silica brick, it is important that they retain required dimensions and shape [L. 15]. A small amount of wear can mean that they may need to be replaced or refurbished.

Hardox 500 steel exhibits good resistance to wear caused by soil abrasion in comparison with other materials intended to be used in the production of elements that come in contact with soil [L. 18]. Hardox steels are often utilized as the construction material for the beds of dump trucks and are subjected to being abraded by various materials including silicates. Currently, there is a lack of research concerning the wear caused by silicate related materials on Hardox 500 steel.

## GOAL AND SCOPE OF RESEARCH

The determination of differences in the intensity of abrasive wear of Hardox 500 steel and 20MnCr5 steel subjected to thermo-chemical treatment in a steel-against-silicate abrasion tests were undertaken. The scope of research included the following:

- Analysis of literature concerning materials being studies and processes of abrasive wear,
- A study concerning the mechanical properties of materials being considered,
- The definition of study parameters, and
- The force of friction and the coefficient of friction were established using a pin/disk wear tester.

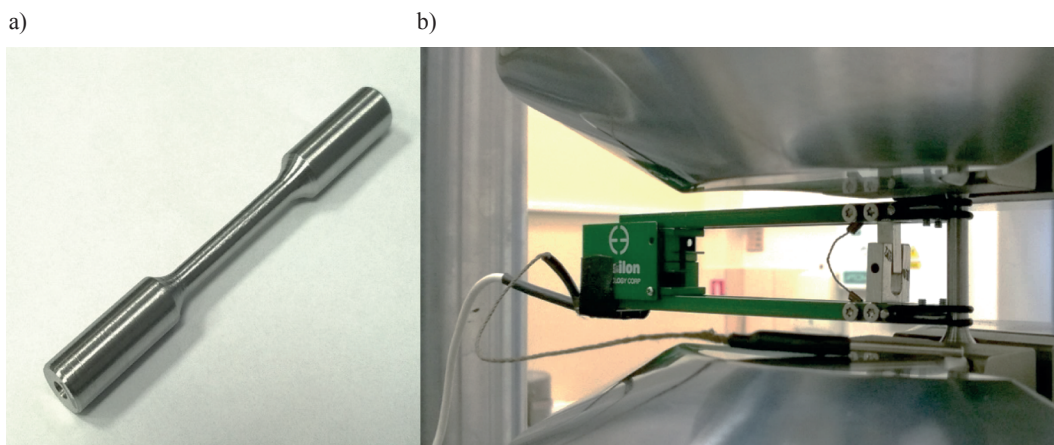
## RESEARCH METHODOLOGY

Hardox 500 steel and 20MnCr5 steel subjected to carburization (910°C), hardening (820°C), and tempering (240°C) were the materials chosen for the study. These materials are used in the production of machines used for agriculture (e.g., ploughshares), construction (e.g., excavator buckets, parts of forms for the production of bricks), and other purposes. These steels exhibit high resistance to abrasive wear [L. 1, 2, 7, 10]. Tensile tests were carried out to ascertain the exact properties of tested materials. In accordance with the EN 10002-1:2001 norm, samples of steels (**Fig. 1a**) were cylindrical with a diameter of 5 mm and a gauge length of 25 mm. Additionally, the hardness of every sample was also measured. Tensile strength tests were carried out using an MTS 322 Test Frame (**Fig. 1b**). The unit ensures the high precision of measurements and records a wide spectrum of parameters. The tensile tests were conducted on three samples of every type of steel at a temperature of 239K, and at a rate of deformation (at measurement base) of 0.02 mm·s<sup>-1</sup>.

A list of values relating to the mechanical properties of tested materials is presented in **Table 1**.

The microstructure as well as the chemical composition of tested materials was identified. Visual inspection was performed through the use of a Neophot 52 light microscope connected to a Visitron Systems digital camera. Microanalyses of the chemical composition were conducted using a JEOL JSM – 5800 LV scanning microscope. The chemical composition of the Hardox 500 steel was following: %C-0.29, %Si-0.70, %Mn-1.60%, Cr-1.00, %Ni-0.50, %Mo-0.60, and %B-0.004. The microstructure of the Hardox 500 steel has been identified as tempered martensite (**Fig. 2**).

The next step involved the establishment of the chemical composition of the 20MnCr5 steel,



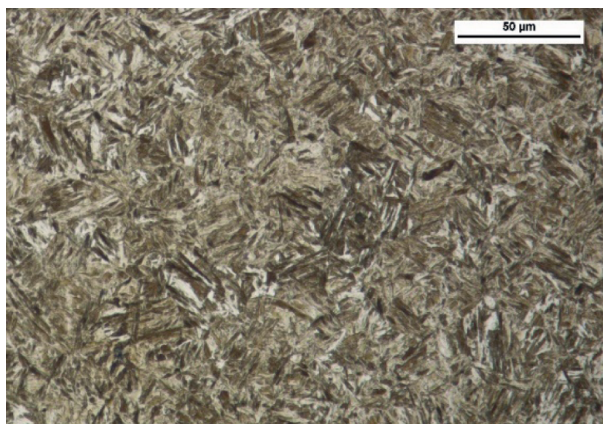
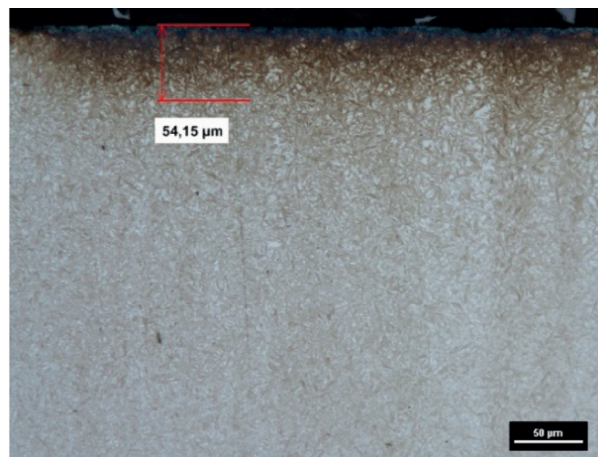
**Fig. 1. A test sample and the MTS 322 Test Frame with an extensometer**

Rys. 1. Przykładowa próbka oraz maszyna wytrzymałościowa MTS 322 Test Frame z zamocowanym ekstensometrem

**Table 1. Mechanical properties of tested materials**

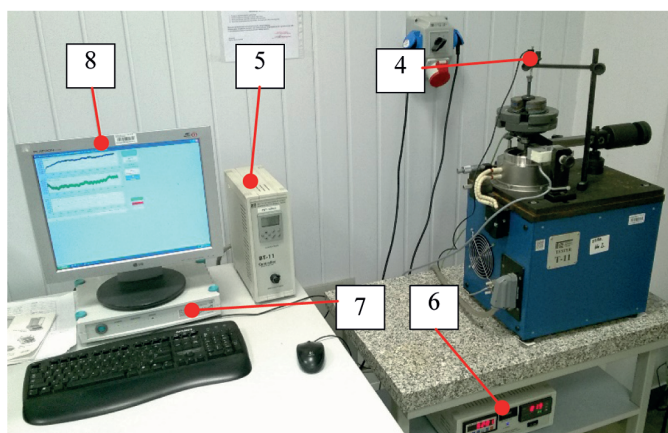
Tabela 1. Właściwości mechaniczne badanych materiałów

No.	Materials	Mechanical properties							
		$R_c$ [MPa]	standard deviation	$R_m$ [MPa]	standard deviation	E [GPa]	standard deviation	Hardness HV20	standard deviation
1.	Hardox 500	<b>1336</b>	3	<b>1623</b>	28	<b>204</b>	3	<b>511</b>	12
2.	Steel 20MnCr5 after carburizing, hardening and tempering	<b>1009</b>	6	<b>1245</b>	33	<b>198</b>	4	<b>582</b>	7

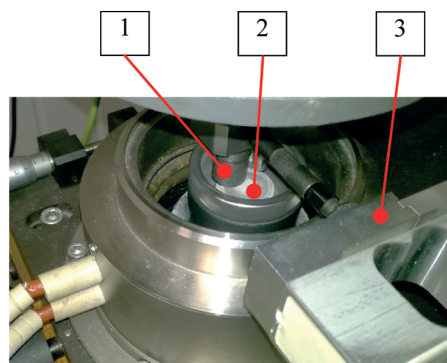
**Fig. 2. Microstructure of tempered martensite – Hardox 500 steel: Mag. 500x, etched with 3% HNO<sub>3</sub> (Mi1Fe), light microscopy**Rys. 2. Mikrostruktura martenzytu odpuszczonego – stal Hrdox 500. Pow. 500x, trawiono 3%HNO<sub>3</sub> (Mi1Fe), mikroskopia świetlna**Fig. 3. The microstructure of 20MnCr5 steel: Mag. 100x, etched with 3% HNO<sub>3</sub> (Mi1Fe), light microscopy**Rys. 3. Mikrostruktura stali 20MnCr5. Pow. 100x, trawiono 3%HNO<sub>3</sub> (Mi1Fe), mikroskopia świetlna

which was determined as %C-0.22, %Si-0.035, %Mn-1.40, %Cr-0.30, and %Ni-0.30. The microstructure of the 20MnCr5 steel which underwent thermo-chemical processing was characterized by a 55 μm outer layer having a different structure than the rest of the sample (**Fig. 3**).

Abrasion tests whose purpose was to compare the resistance to abrasive wear of both materials were conducted using a T-11 pin/disk wear tester (**Fig. 4**). The test allowed us to establish friction force, friction coefficient, and the intensity of wear [**L. 18**].

**Fig. 4. A schematic of the T-11 position for the tribological pin on disc type test: 1 – pin, 2 – disk, 3 – force sensor, 4 – displacement sensor, 5 – controller BT-11, 6 – controller BT-03, 7 – Spider 8 – digital amplifier, 8 – computer workstation**

Rys. 4. Stanowisko do badań tribologicznych typu trzpień-tarcza T-11: 1 – trzpień (próbka), 2 – tarcza (przeciwpróbka), 3 – czujnik siły, 4 – czujnik przemieszczenia, 5 – sterownik BT-11, 6 – sterownik BT-03, 7 – cyfrowy wzmacniacz Spider 8, 8 – stanowisko komputerowe



The sample was cylindrical with a diameter of 6 mm (**Fig. 5a**). The countersample was a silicate disk made from a mixture of lime and sand (**Fig. 5b**). On account of the unusual composition of the countersample, the load force was selected experimentally and the selection criterion consisted of the ability of the disk to withstand the load without braking. The duration of the test was also defined experimentally choosing it so that stable friction could be obtained. The test lasted for 40 minutes. The sliding velocity was established at  $V_p = 0.1 \text{ m}\cdot\text{s}^{-1}$ . The sample was loaded with a force of  $P = 44 \text{ N}$ . Taking into consideration established assumptions, the countersample's rotational speed was determined at  $n = 160 \text{ rpm}$ .

During the experiment, the value of friction force  $T$  was monitored, which allowed the identification of the friction coefficient  $\mu$ :

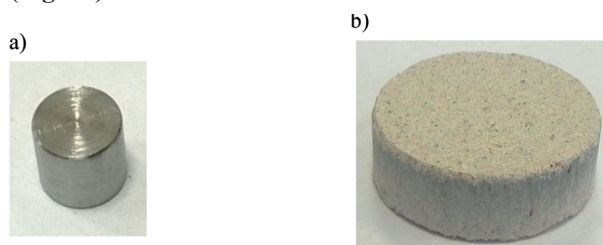
$$\mu = \frac{T}{P} \quad (1)$$

where  $T$  – friction force,  $P$  – load of steel sample perpendicular to the surface of the silicate disk (the countersample shown in **Fig. 5b**).

Pressure  $p_t = 1.5 \text{ MPa}$  was calculated on the basis of the following formula:

$$p_t = \frac{4P}{\pi d^2} \quad (2)$$

where  $P$  – load force on the sample,  $d$  – sample diameter (**Fig. 5a**).



**Fig. 5. Sample (a) and countersample (b) before the test**  
Rys. 5. Widok przed badaniem: a) próbki, b) przeciwp próbki

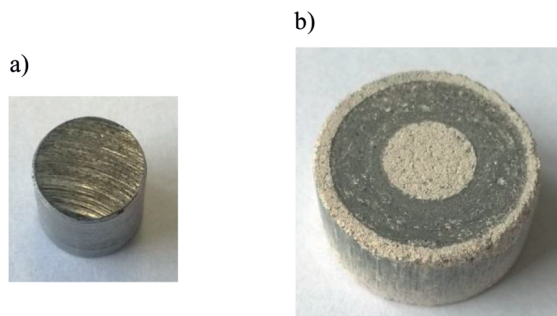
The measurement of sample mass before and after the test allowed us to define the intensity of wear using the following formula:

$$I = \frac{M_1 - M_2}{S \cdot F} \quad (3)$$

where  $M_1$  and  $M_2$  – mass of the sample before and after the wear test [mg],  $S$  – distance the sample traveled under load [m],  $F$  – area of the sample's cross-section [ $\text{m}^2$ ].

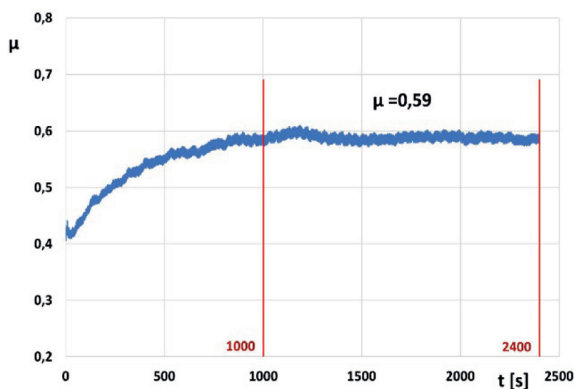
## RESEARCH RESULTS

Pictures of the sample and countersample after the tests are presented in **Fig. 6**.

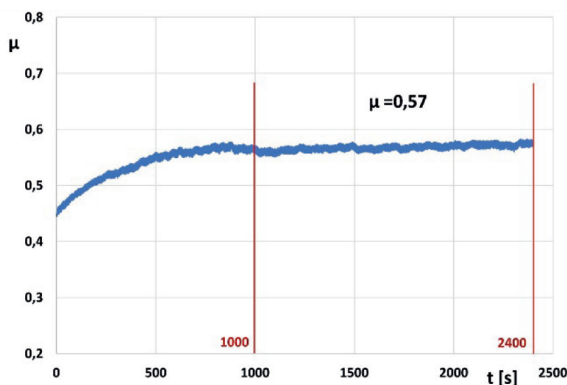


**Fig. 6. Sample (a) and countersample (b) after the test**  
Rys. 6. Widok po teście: a) próbki, b) przeciwp próbki

During the experiment, a layer of loose abrasive material was created between the sample and the countersample. Three wear tests were performed for every tested material. The results allowed the determination of friction coefficients for the materials being tested. **Figures 7 and 8** present the changes occurring in the friction coefficients over time. The calculations used values obtained after the stabilization of the process gauged to occur after 1.000 s.



**Fig. 7. Friction coefficient graph; Hardox 500**  
Rys. 7. Wykres współczynnika tarcia; Hardox 500



**Fig. 8. Friction coefficient graph; steel 20MnCr5**  
Rys. 8. Wykres współczynnika tarcia; stal 20MnCr5

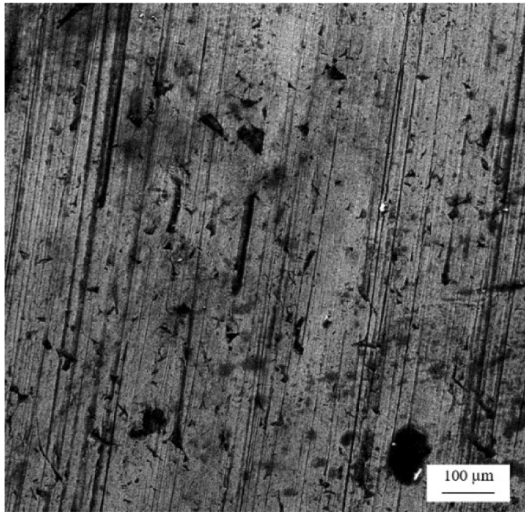
The test results were used to determine the average intensity of wear  $I_{av}$ , the average friction coefficient  $\mu_{av}$  and the average friction force  $T_{av}$ . These parameters allow the assessment of resistance to abrasive wear of

a given material. A list of obtained values of friction force, friction coefficient and the intensity of the wear of samples made of Hardox 500 and 20MnCr5 steels are presented in **Table 2**.

**Table 2. Summary of the values: friction forces, the friction coefficient and wear intensity**

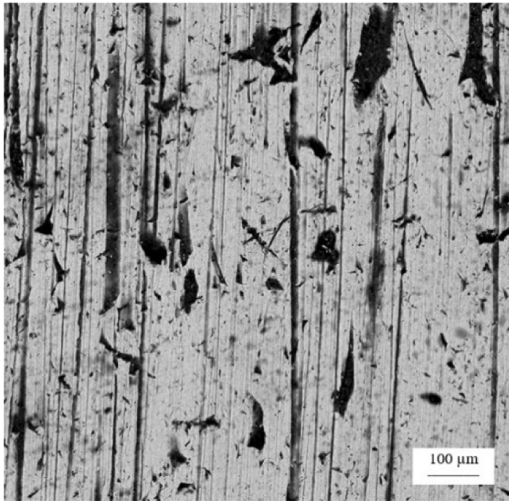
Tabela 2. Zestawienie uzyskanych wartości: siły tarcia, współczynnika tarcia oraz intensywności zużycia

No.	Material	$p_t = 1,5 \text{ MPa}$					
		Average intensity of wear $I_{av} [\text{mg}\cdot\text{m}^{-3}]$	standard deviation	Average friction coefficient $\mu_{av}$	standard deviation	Average friction force $T_{av} [\text{N}]$	standard deviation
1.	Hardox 500	<b>1252.1</b>	79.6	<b>0.58</b>	0.01	<b>25.6</b>	1.1
2.	Steel 20MnCr5 after carburizing, hardening and tempering	<b>1418.4</b>	54.3	<b>0.56</b>	0.01	<b>25.2</b>	0.9



**Fig. 9. Sample surface of Hardox 500 steel, x50**

Rys. 9. Powierzchnia próbki ze stali Hardox 500, x 50



**Fig. 10. Sample surface of 20MnCr5 steel, x50**

Rys. 10. Powierzchnia próbki ze stali 20MnCr5, x 50

Wear marks visible on the surface of samples are shown in **Figures 9 and 10**. The wear occurred mainly as a result of micro-grinding, but the surfaces also showed microscopic cracks and tears. However, in both cases, the main mechanisms responsible for wear were micro-grinding and grain cutting.

### CONCLUSIONS

The obtained results show that the material that has a greater resistance to frictional wear at a load of  $p_t = 1.5 \text{ MPa}$  when applied to a countersample made of silicate is Hardox 500 steel. This steel is characterized with greater yield strength and resistance to stretching (the difference in those values is approximately 25%). The hardness of the outer layer of 20MnCr5 steel subjected to thermochemical treatment is higher than that of Hardox 500 steel. The difference in the value of intensity of wear amounts to approximately 12%. In both cases, the main mechanisms responsible for wear were micro-grinding and grain cutting.

The obtained values of friction coefficients are very similar for both materials. This could be the result of the creation of a layer of loose abrasive material between the sample and the countersample, which had similar properties during every attempt.

*The research was conducted as part of the S/WM/4/2017 and S/WZ/1/2015 projects financed from educational funds of the Ministry of Science and Higher Education*

## REFERENCES

1. Hejwowski T., (2013) Nowoczesne powłoki nakładane cieplnie odporne na zużycie ścierne i erozyjne, Politechnika Lubelska.
2. Dobrzański L.A., (2009) Podstawy metodologii projektowania materiałowego. Gliwice, Wydawnictwo Politechniki Śląskiej.
3. Brnic J., Brcic M., (2015) Comparison of Mechanical Properties and Resistance to Creep of 20MnCr5 Steel and X10CrAlSi25 Steel, *Procedia Engineering* No 100, pp. 84–89.
4. Szymański K., Szczucka-Lasota B., (2015) Characteristics of selected tribological properties of new thermally sprayed coatings, *Solid State Phenomena*, vol. 226, pp. 1662–9779.
5. Szczucka-Lasota B., Stanik Z., Tarasiuk W., Sieteski D., (2016) A Novel Hybrid Spraying Method for Obtaining High Quality Coatings, *Engineering Transactions*, Vol. 64, nr 4, pp. 1–12.
6. Tarasiuk W., Liszewski M., Krupicz B., Kasprzycka E., (2016) The analysis of the selected processes of thermochemical heat treatment of 20MnCr5 steel in the context of abrasive wear, *Tribologia*, R. 47, nr 5 (2016), pp. 183–193.
7. Tarasiuk W., Krupicz B., (2009) Analiza właściwości materiałów stosowanych na płyty form cegły silikatowej, *Acta Mechanica & Automatica*, Vol. 3, No 1, pp. 107–110.
8. Węgrzyn T., Piwnik J., Silva A., Plata M., Hadrys D., (2013) “Micro-jet technology in welding”, *Proc of ISOPE*, Anchorage, USA, June 30–July 5, pp. 178–180.
9. Napiórkowski J., Konat Ł., Ligier K., (2016) The structural properties and resistance to abrasive wear in soil of creusabro steel, *Tribologia*, nr 5, pp. 105–119.
10. Napiórkowski J., Lemecha M., Ligier K., (2015) The analysis of tribological properties of niobium welded in the abrasive soil mass, *Tribologia* nr 3, pp. 109–120.
11. Babul T., Nakonieczny A., Senatorski J., (2006) Możliwości podwyższenia właściwości eksploatacyjnych stali narzędziowych przy wykorzystaniu procesów nawęglania. *Inżynieria Powierzchni* nr 2, pp. 3–8.
12. Kasprzycka E., Senatorski J., Bogdański B., (2013) Tribological properties of chromized tool steel in conditions of sliding friction and concentrated contact, w: *Proceedings Conference BALTTTRIB*, ss. 79–82.
13. Bogdański B., Kasprzycka E., (2008) Multifunkcjonalne warstwy węglkowe typu CrC+(ni-Mo) wytwarzane w procesie chromowania próżniowego. *Inżynieria Materiałowa*, nr 6, pp. 819–822.
14. Bressana J.D., Darosa D.P., Sokolowski A., Mesquitac R.A., Barbosa C.A., (2008) Influence of hardness on the wear resistance of 17-4 PH stainless steel evaluated by the pin-on-disc testing, *Journal of materials processing technology* 205, 353–359.
15. Kapcińska-Popowska D., (2011) Comparative research of quality and durability of welded joints of the hardox 500 and s355 steels, *Journal of Research and Applications in Agricultural Engineering* 2011, Vol. 56 (1), pp. 59–65.
16. Kostencki P., Łętkowska B., Nowowiejski R., (2013) Field tests of resistance to abrasive wear of ploughshares made of boron steel, *Tribologia*, nr 3, pp. 49–79.
17. Belahssen O., Benramache S., (2015) Improving Tribological Properties of 20MnCr5 Steel by Plasma Nitriding, *Journal of Chemistry and Materials Research* Vol. 4 (2), pp. 45–48.
18. Napiórkowski J. (red.): *Badanie i modelowanie procesów zużywania ściernego i zmęczeniowego*. Wydawnictwo UWM Olsztyn, Olsztyn 2014.
19. Instrukcja obsługi (2005) Tester typu trzpień tarcza T-11, Instytut Technologii Eksploatacji w Radomiu.
20. EN 10002-1:2001.