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THE STRUCTURAL PROPERTIES AND RESISTANCE TO ABRASIVE WEAR IN SOIL OF CREUSABRO STEEL

WŁAŚCIWOŚCI STRUKTURALNE I ODPORNOŚĆ NA ZUŻYWANIE W WARUNKACH GLEBOWEJ MASY ŚCIERNEJ STALI CREUSABRO

Key words:

steel resistant to abrasive wear, structural and mechanical properties, Creusabro steel, abrasive soil mass

Słowa kluczowe:

stale odporne na zużywanie ściernie, własności strukturalne i mechaniczne, stal Creusabro, glebowa masa ścierna

Abstract

The paper presents the results of abrasive wear resistance tests on Creusabro 4800 and Creusabro 8000 steel. The results obtained for laboratory samples were referred to the structure of the examined types of steel and to the basic indicators characterising their mechanical properties. As a result of the conducted tests, which used the methods of light and scanning microscopy, it

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has been concluded that, in its delivered condition Creusabro, steel exhibits a complex type of structure, characteristic for steel with the "TRIP effect." The identified type of structure indicates a precisely adjusted chemical composition and the use of specialised heat treatment and forming processes in the production process of those materials. The abrasive wear resistance tests conducted by means of the "spinning bowl" method in real soil masses, i.e. light soil (loamy sand), medium soil (light till) and heavy soil (normal till), as well as the conducted measurements of hardness, have proven the strict dependence of the obtained indicators of abrasive wear resistance on the phase structure and on the status of the heat treatment of the tested steel. The results of abrasive wear resistance tests for Creusabro steel were referred to 38GSA steel in a normalised condition for comparison.

INTRODUCTION

The impact of soil mass, in relation to the cutting elements of tools and agricultural or mining machines, generates considerable losses associated mainly with a loss in the mass of these elements. This implies considerable financial expenses resulting from the necessity to use high quality construction materials or very complex heat treatment and forming processes in their production.

The wear process of soil cutting elements is a complex one. In the case of abrasive mass, the impact of particles is considered to be fixed grains favours the increased abrasive wear of materials due to furrowing, scratching, and microcutting (the processes accompanying abrasive wear). Paper **[L. 1]** presents the relation between the physical and chemical properties of soil characterised by grain sizes, cohesiveness, humidity, as well as acidity, and the course of the wear process for construction materials. In actual operating conditions, the material properties of working elements are the primary factors that decide the durability of the used elements **[L. 2, 3]**.

Based on long-standing research conducted at the Wrocław University of Technology in cooperation with the Department of the Construction and Operation of Vehicles and Machines of the University of Warmia and Mazury involving construction materials used in the mining industry of mineral resources, it can be concluded that the intense processes of abrasive wear and dynamic load are the main factors limiting the usage of these materials in the construction elements of working machinery subject to heavy load. In relation to materials, the above factors may be formulated based on paper **[L. 4]** as the following requirements:

– High resistance to abrasive wear
– The ability to bear heavy loads of a random nature;
– The homogeneity of properties over the whole cross-section of an element;
– The possibility to be joined by means of welding techniques; and,

– Resistance to degradation processes, involving, among other things, corrosive changes or ageing processes occurring in steel.

In recent years, due to its advantageous performance qualities, the popularity of high-strength, low-alloy types of steel, described as materials resistant to abrasive wear, has been increasing. Their properties are possible to achieve by obtaining a homogenous structure of those types of steel over the whole cross-sections of the construction elements made from it. The possibility of obtaining homogeneous structures over large cross-sections results, on the other hand, from a very precise adjustment of the chemical composition as a function of the thickness of sheet metal, the presence of a boron micro-additive, the lowered amount of harmful additives, and from the specialist procedures of heat treatment or heat and forming processes. Nonetheless, an unambiguous assessment of the usefulness of the described group of materials for the selected area of application is very difficult, and it requires a complex and comprehensive approach towards this issue. According to the authors of the present paper, structural tests are a point of reference for this type of assessment. The currently conducted research involves the use of the selected materials for elements subject to intense abrasive wear, including soil-cutting tools **[L. 5–10]**.

THE MATERIAL AND METHODOLOGY OF THE RESEARCH

Two types of steel resistant to abrasive wear were used to test resistance to abrasive wear by means of the "spinning bowl" method: Creusabro 4800 and Creusabro 8000. According to the producer's information **[L. 11]**, these types of steel are described as materials featuring high resistance to abrasion under conditions of sufficient impact or pressure. This results from the conceptual design of these types of steel results in the use of the phenomenon of the deformational transformation of residual austenite into martensite (the TRIP effect). In the case of Creusabro steel, this should result in its resistance to wear processes increased by 40–45% compared to steel after conventional heat treatment with a hardness of 400 HB (in relation to Creusabro 4800) and 500 HB (in relation to Creusabro 8000). The conceptual design of these types of steel is based mainly on a precisely adjusted chemical composition and structure, whose resistance to wear processes is achieved due to the presence of the hard carbide phases inside it: chrome (1500 HV), molybdenum (1800 HV) and titanium (3000 HV).

Creusabro 4800 steel is delivered as sheet metal 3–150 mm in thickness in the following heat treatment conditions: after thermomechanical rolling (for thickness ≤ 20 mm), after oil hardening (for thickness 20–50 mm), and after water hardening (for thickness > 50 mm). In the initial state, its hardness amounts to 340–400 HB. In addition, it may be subjected to removal machining and cold forming processes, as well as welding processes.

Creusabro 8000 steel is delivered as sheet metal 5–60 mm in thickness after oil hardening only. In the initial state, its hardness amounts to 430–500 HB. This steel may be additionally subjected to removal machining by specialist tools and forming processes, even at a temperature of 450–500°C without losing its mechanical properties.

38GSA steel in a normalised condition was used as a reference material for Creusabro steel. The results of research involving abrasive wear processes in abrasive soil mass are frequently referred to this type of steel. The sheet metal used to construct the analysed machine parts was made using hot rolling technology and subjected to annealing for normalisation. Due to the very numerous applications of this steel in its normalised condition, all test results presented in the present paper refer to this delivered condition of 38GSA steel.

The tested steel samples were collected as cuboids with dimensions of 30x25x10 mm, using methods that ensured the stability of their structure. A cutting method using a high-energy jet of water with abrasive grains was used to cut the samples. The finishing machining of samples meant to reach the required surface roughness was handled by means of grinding and polishing.

The analyses of the chemical composition were performed by means of the spectral method using a GDS500A emission analyser with glow discharge from the Leco company, using the following parameters: U = 1250 V, I = 45 mA, and argon. The obtained results constituted an arithmetic mean of five measurements.

A Nikon Eclipse MA200 light microscope (LM) was used for the observations of the microstructure. The observations were conducted with magnifications ranging between 100 and 1000 times. Microstructural images were recorded by means of a Nikon DS-Fi2 digital camera using NIS Elements software. The observations of the microstructure at greater magnifications, as well as the microanalyses of the chemical composition and the morphology and type of phases, were conducted using a JEOL JSM-5800LV scanning electron microscope (SEM) coupled with an Oxford LINK ISIS-300 X-ray micro-analyser. Accelerating voltages of 20 and 25 kV were used during the tests. The observations of the microstructure were conducted in a material contrast using SE and BSE detectors. Prior to microscopic observations, the samples were sprayed with amorphous carbon.

The hardness of the tested samples was measured by means of the Brinell method in accordance with the quality standard PN-EN ISO 6506-1:2008P. A ZWICK ZHU 187.5 hardness tester with a 2.5 mm sintered carbide ball was used, with a load of 1875 kgf applied for a duration of 15 s. The measurements were conducted for samples previously subjected to an assessment of their microstructure in their core areas. The values of hardness were obtained from at least five measurements.

The tests of the resistance to abrasive wear of the analysed types of steel were conducted by means of the "spinning bowl" method using an MZWM–1 device **[L. 12]**. **Figure 1** presents the general layout of the construction and the principle of operation of the used device.

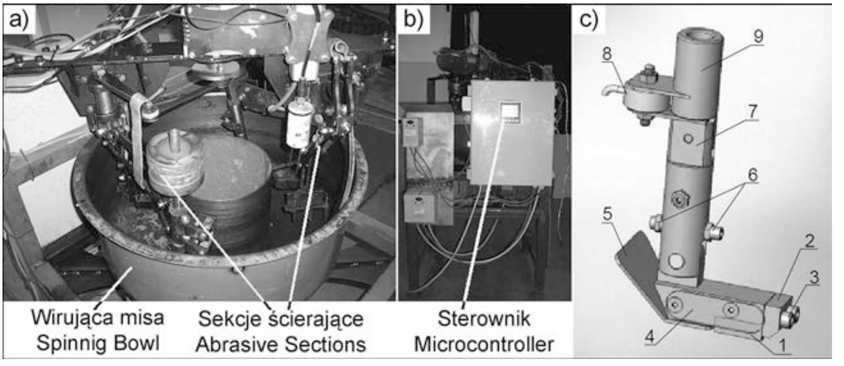

Fig. 1. The spinning bowl method: a, b) A general view of the test stand; c) A layout of the shoe with the friction force measurement mechanism: 1 – the tested sample, 2 – a jaw (fixing the sample), 3 – fixing screws 4 – side housing of the sample, 5 – a front skid, and 6 – screws adjusting the angle of attack and departure of the shoe

Rys. 1. Metoda wirującej misy: a, b) ogólny widok stanowiska badawczego; c) schemat stopy z mechanizmem pomiaru siły tarcia: 1 – próbka badana, 2 – szczęka (docisk próbki), 3 – śruby dociskowe, 4 – osłona boczna próbki, 5 – płoza przednia, 6 – śruby regulujące kąt natarcia i zejścia stopy

In the tests of abrasive wear, cuboidal steel samples with dimensions of 30x25x10 mm – 12 samples for each type of tested material were used. During the tests, two samples were simultaneously placed in the machine – one for each type of steel. Each sample travelled a total friction distance of 20000 m, with a velocity of approximately 1.7 m/s. The mass of a sample was measured every 2000 m on a laboratory weighing scale with an accuracy of 0.0001 g, upon its previous cleaning in an ultrasonic cleaner. During this time of the tests, the soil mass was replaced with a new one, and output parameters were determined for the mass of the samples. The samples travelled along the friction distance with an oscillating motion. The characteristics of the abrasive soil mass are presented in **Table 1**. The evaluation of the grain sizes was performed by means of a Mastersizer 2000+Hydro laser particle size meter, while the soil humidity was calculated by means of the measurement of the mass of the solid phase dried at a temperature of 105°C. The tests were conducted for a humid abrasive mass.

Table 1. Characteristics of the abrasive soil mass

Tabela 1. Charakterystyka glebowej masy ściernej

Soil mass type	**Grain size group**	**Grain size content [%]**			**Density moisture [%]**
		Sand 2.00–0.05 mm	Silt 0.050–0.002 mm	Clay < 0.002 mm	
LIGHT	Loamy sand	82.7	8.4	8.9	10–12
MEDIUM	Light till	58.3	22.5	19.2	11–13
HEAVY	Normal till	38.0	35.7	26.3	12–15

TESTS RESULTS

Table 2 presents the results of the conducted spectral analyses of the chemical composition of the tested types of steel for 15 mm-thick sheet metal, as well as the selected mechanical properties based on the authors' own research and information from the producers.

Table 2. The chemical compositions and selected mechanical properties of the tested types of steel based on the authors' own research and the producer's data [L. 12, 13]
Tabela 2. Składy chemiczne i wybrane właściwości mechaniczne badanych stali na podstawie badań własnych oraz danych producenta **[L. 11, 13]**

Element [wt%]	**38GSA**		**CREUSABRO 4800**		**CREUSABRO 8000**	
	BW – based on the authors' own research; DP – producer's data					
	BW[1]	DP[2]	BW[3]	DP[3]	BW[3]	DP[3]
C	0.38	0.34–0.42	0.20	≤ 0.20	0.27	≤ 0.28
Mn	0.97	0.70–1.10	1.49	≤ 1.60	1.28	≤ 1.60
Si	0.90	0.80–1.10	0.35	-	0.70	-
P	0.011	≤ 0.035	0.012	≤ 0.018	0.012	≤ 0.015
S	0.007	≤ 0.040	0.004	≤ 0.005	0.002	≤ 0.005
Cr	0.05	≤ 0.30	1.45	≤ 1.90	0.68	≤ 1.60
Ni	0.08	≤ 0.30	0.30	~ 0.20	0.29	~ 0.40
Mo	0.02	-	0.16	≤ 0.40	0.23	≥ 0.20
Cu	0.25	≤ 0.30	0.23	-	0.20	-
Al	0.02	0.02–0.06*	0.03	-	0.03	-
Ti	0.002	0.03–0.06*	0.05	0.20	0.02	-
Co	0.01	-	0.02	-	0.01	-
B	-	-	0.0004	-	0.0024	-
HBW	272 ±7	440	373 ±4	340–400	463 ±9	430–500
R_e [MPa]	-	1200	-	900	-	1250
R_m [MPa]	-	1500	-	1200	-	1630
A_5 [%]	-	8	-	12	-	12
KCV_{-20} [J/cm^2]	-	30**	-	45	-	≥ 40
[1] condition after normalisation; [2] condition after hardening (870–900°C/water) and tempering (200–250°C in air or oil); [3] in the delivered condition; *if combined, then Al+Ti ≥ 0.03 wt%; **KCU_{+20}						

The performed analyses of the chemical composition of the tested types of steel have proven that the factual amounts of alloying additives are lower than what is stated by their producers. Additionally, the presence of elements not included in technical specifications provided by the producers of these types of steel was recorded in their chemical compositions in all cases. Among these elements were copper, aluminium, titanium and cobalt, as well as silicon and boron, whose contents of both types of Creusabro steel additionally considerably exceed the values that are considered to be standard for alloys.

Not considering the 38GSA steel, whose properties were already a subject of discussion for the authors of the present paper, the general carbon content of the Creusabro steel ranges between 0.20 and 0.27%. From the point of view of the possible heat treatment processes, these values make it impossible to obtain the declared hardenability. To this end, alloying additives are introduced into those types of steel, including manganese, chromium, nickel, molybdenum, titanium, and especially boron (Creusabro 8000). Nickel is added to the tested steel in order to lower the temperature of austenitization and lower the temperature of the material's transition into a brittle state, while the carbide-generating elements, Cr, Mo and Ti, increase the hardenability, delaying diffusional transformations. In order to additionally intensify this effect, chromium and molybdenum are often used together, since chromium (as well as nickel and manganese in its presence) increases the vulnerability of steel to brittleness during the processes of tempering. Moreover, the addition of aluminium and titanium in the tested steel bind the nitrogen and prevent the expansion of austenite grains during heat treatment processes. A characteristic feature of the tested types of steel is also the lowered amount of harmful additives in the form of sulphur and phosphor.

As a result of the conducted studies of the microstructure, it can be concluded that 38GSA steel is characterised by a structure of non-equilibrium grains of ferrite with a quasi-eutectoid of fine platy structure. Pearlite colonies with finely dispersed morphology were also identified.

The structure of Creusabro 4800 steel in the delivered condition (**Figs. 2a–4a**) consists of hardening sorbite with areas of martensite with distinct banding features (**Fig. 2a**). In the matrix of this steel, one can also observe, apart from partially coagulated cementite, the insets of carbide phases uniformly distributed within the area of the microstructure. Although Creusabro 4800 steel is categorised as steel with a complex structure characteristic for TRIP steel, no presence of residual austenite can be recorded in it based on the conducted structural tests. This may indicate that its amount does not exceed 10%.

Creusabro 8000 steel in its delivered condition is characterised by a structure of finely slatted hardening martensite with some areas of tempered martensite (**Figs. 2b–4b**). The presence of the insets of upper bainite may be observed locally in the structure of the analysed steel (**Fig. 3b**). Numerous insets of fine carbides were observed inside the slats of martensite. Similar to Creusabro 4800 steel, no presence of residual austenite was observed in type 8000 of this steel.

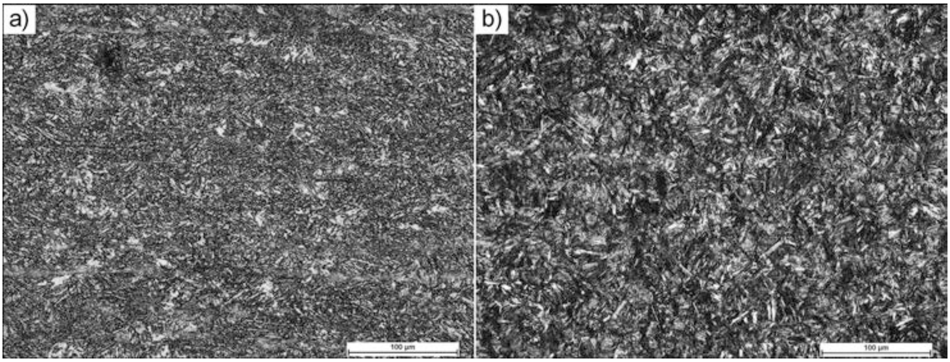

Fig. 2. The microstructure of Creusabro steel in the delivered condition: a) Creusabro 4800 steel – fine-grained structure of hardening with the banded distribution of the areas of martensite; b) Creusabro 8000 steel – fine-grained structure of hardening without visible banding features. Etched with 2% HNO_3; LM, and Magnification ~200x

Rys. 2. Mikrostruktura stali Creusabro w stanie dostarczenia: a) stal Creusabro 4800 – drobnoziarnista struktura hartowania z pasmowo ułożonymi obszarami martenzytu; b) stal Creusabro 8000 – drobnoziarnista struktura hartowania bez wyraźnych cech pasmowości. Traw. 2%HNO_3; LM; Pow. ~200x

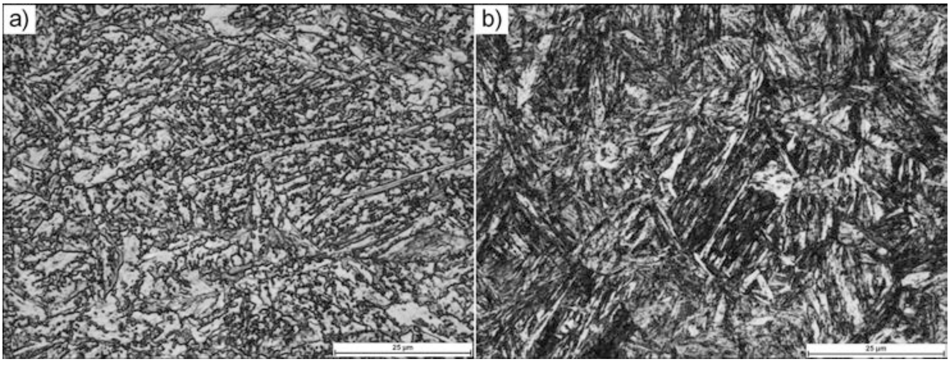

Fig. 3. A magnified image of the microstructure of Creusabro steel shown in Fig. 1. a) Creusabro 4800 steel – the structure of hardening sorbite with diverse morphology; b) Creusabro 8000 steel – the structure of slatted hardening martensite with insets of bainitic structure. Etched with 2% HNO_3, and LM, and Magnification ~1000x

Rys. 3. Powiększony obraz mikrostruktury stali Creusabro pokazanej na **Rys. 1**: a) stal Creusabro 4800 – struktura sorbitu hartowania o zróżnicowanej morfologii; b) stal Creusabro 8000 – struktura listwowego martenzytu hartowania z wydzieleniami struktury bainitycznej. Traw. 2%HNO_3; LM; Pow. ~1000x

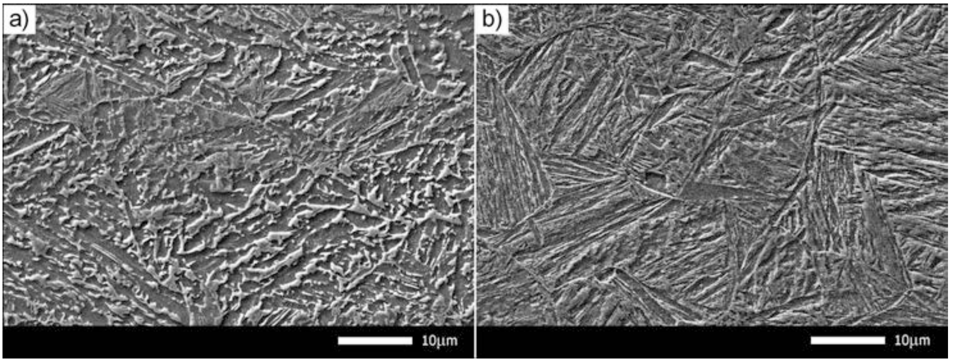

Fig. 4. A magnified image of the microstructure of Creusabro steel shown in Fig. 2. a) Creusabro 4800 steel – the structure of hardening sorbite with areas of slatted martensite; b) Creusabro 8000 steel – the structure of slatted martensite with visible edges of the grains of former austenite. Etched with 2% HNO_3, SEM, and Magnification ~ 2000 x

Rys. 4. Powiększony obraz mikrostruktury stali Creusabro pokazanej na **Rys. 2**: a) stal Creusabro 4800 – struktura sorbitu hartowania z obszarami listwowego martenzytu; b) stal Creusabro 8000 – struktura listwowego martenzytu z uwidocznionymi granicami ziaren byłego austenitu. Traw. 2%HNO_3; SEM; Pow. ~2000x

The results of the abrasive wear resistance tests are presented in **Table 3** and in **Figs. 5–10**.

Table 3. The mass wear of 38GSA and Creusabro steel samples over a friction distance of 20000 m in various kinds of abrasive soil masses

Tabela 3. Zestawienie zużycia masowego próbek stali 38GSA oraz Creusabro na drodze tarcia 20000 m w różnych rodzajach glebowych mas ściernych

Soil mass type	**38GSA**		**CREUSABRO 4800**		**CREUSABRO 8000**	
	loss in mass: AVG – average value [g]; UN – unit value [g/km/cm^2]					
	AVG	UN	AVG	UN	AVG	UN
LIGHT	2.4049 ±0.3260	0.0160	2.7148 ±0.8464	0.0181	1.0870 ±0.4349	0.0072
MEDIUM	2.2084 ±0.2112	0.0147	2.2023 ±0.0665	0.0147	1.0300 ±0.3084	0.0069
HEAVY	3.7087 ±0.4008	0.0247	0.8366 ±0.3126	0.0056	No data	No data

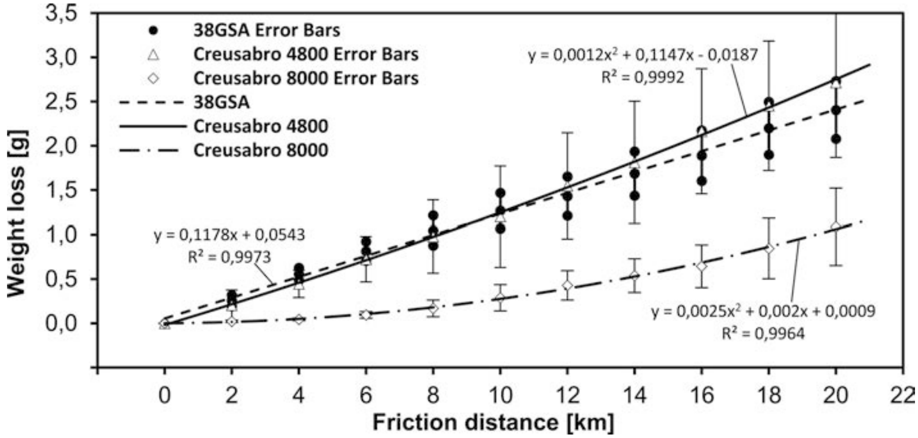

Fig. 5. The loss in the mass of the tested types of steel as a function of the friction distance. Tests conducted in a light soil mass

Rys. 5. Ubytek masy badanych stali w funkcji drogi tarcia. Próby zrealizowane w masie glebowej lekkiej

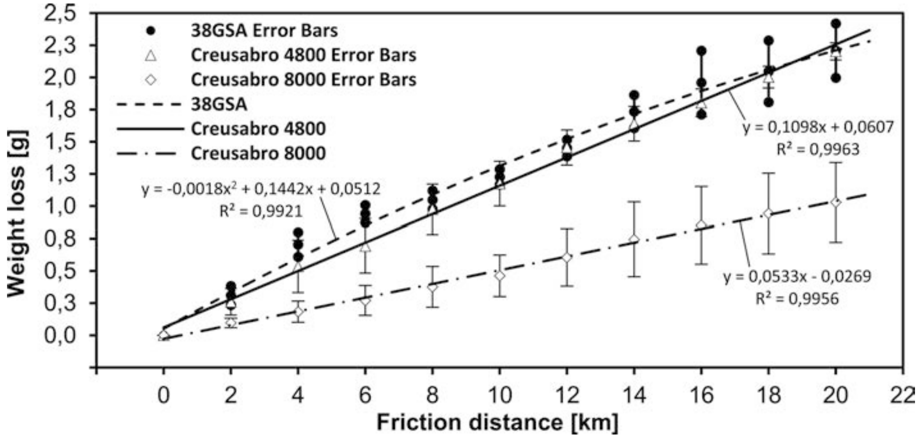

Fig. 6. The loss in the mass of the tested types of steel as a function of the friction distance. Tests conducted in a medium soil mass

Rys. 6. Ubytek masy badanych stali w funkcji drogi tarcia. Próby zrealizowane w masie glebowej średniej

Based on the results of the conducted tests, it can be concluded that Creusabro 8000 steel was characterised by the lowest loss in mass among the examined materials, both in light and medium soil. For light soil, the difference in the loss in mass between 38GSA steel in a normalised condition and Creusabro 4800 was minor, and after a friction distance of 20000 m, it amounted to approx. 0.3 g. In medium soil, the loss in mass for those two materials was almost identical, amounting to approx. 2.2 g. Creusabro 8000 steel stood out in these settings; its respective losses in mass amounting to 1.087 g for light soil and 1.03 g for medium soil, which in both cases, resulted in its abrasive wear being over two times lower compared to the remaining materials. In heavy soil, on the other hand, a difference in mass wear was observed between 38GSA and Creusabro 4800 steel. The respective losses in mass after a friction distance of 20000 m amounted to 3.7087 g for 38GSA steel and 0.8366 g for Creusabro 4800 steel.

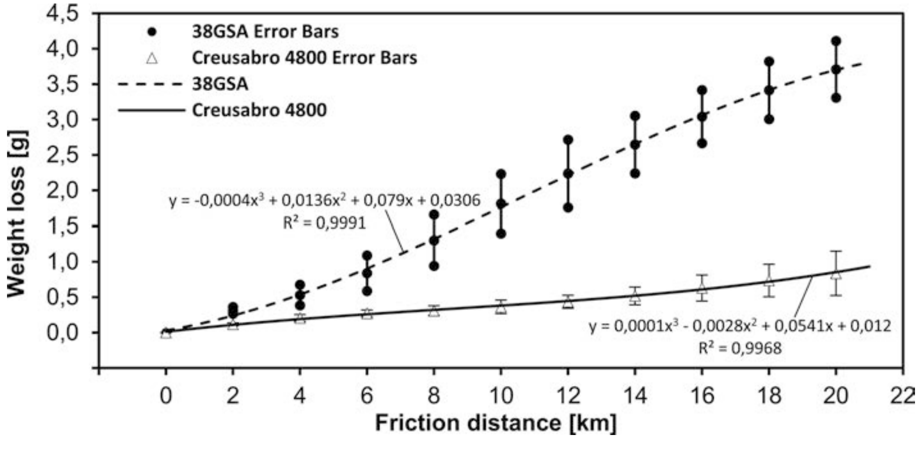

Fig. 7. The loss in the mass of the tested types of steel as a function of the friction distance. Tests conducted in a heavy soil mass

Rys. 7. Ubytek masy badanych stali w funkcji drogi tarcia. Próby zrealizowane w masie glebowej ciężkiej

The process of abrasive wear caused by loose grains takes place in light soils due to the abrasive particles rolling and hitting against the surface of the abraded material. Apart from the traces of furrowing, there are impact marks of loose particles visible on the surface of the samples (**Figs. 8a–10a**). Apart from hardness, the strength of the material seems to be an important feature in terms of wear. A combination of great hardness and strength in Creusabro 8000 steel under these conditions resulted in the highest resistance to abrasive wear.

In medium soil, the traces of furrowing and a decrease in the number of impact marks of loose abrasive particles were primarily observed on the worn surface of the tested steel (**Figs. 8b–10b**). Medium soil affects the material mainly by furrowing and microcutting.

Heavy soil contains large amounts of clay-sized grains, which, apart from abrasive impact, also act as cement for larger soil grains. The higher cohesiveness of soil mass results in the fact that the process of abrasive wear may be considered as abrasion by strengthened abrasive grains. In this case, the main actions involve scratching and microcutting of the surface. The scratch marks created as a result of this process are shallower and smaller compared to medium and light soils, but their number is significantly higher (**Figs. 8c–10c**). Under such conditions, the abrasive wear resistance index is more affected by the hardness of material, which was greater for Creusabro 4800 steel compared to 38GSA steel in a normalised condition.

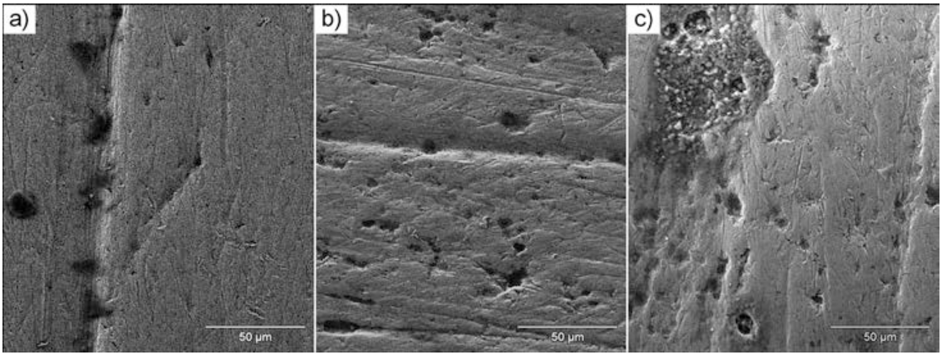

Fig. 8. A microscopic image of the surface of 38GSA steel in a normalised condition after the tests of abrasive wear resistance in various soil masses: a) light; b) medium; c) heavy. Not etched; SEM

Rys. 8. Mikroskopowy obraz powierzchni stali 38GSA w stanie normalizowanym po badaniach odporności na zużywanie ścierne w masie glebowej: a) lekkiej; b) średniej; c) ciężkiej. Stan nietrawiony; SEM

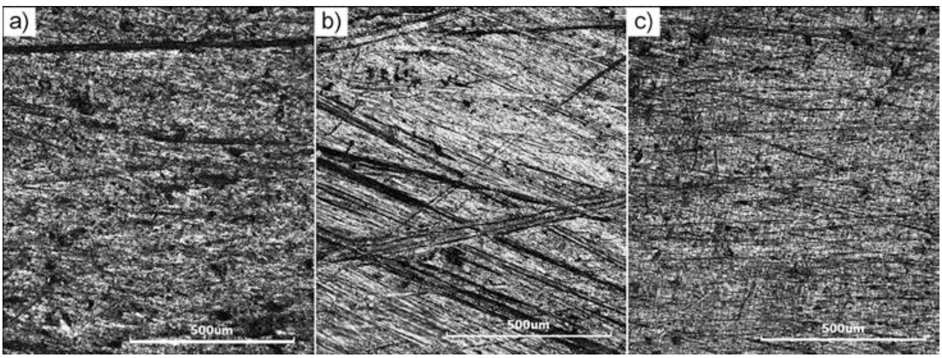

Fig. 9. A macroscopic image of the surface of Creusabro 4800 steel in the delivered condition after the tests of abrasive wear resistance in various soil masses: a) light; b) medium; c) heavy. Not etched; LM

Rys. 9. Makroskopowy obraz powierzchni stali Creusabro 4800 w stanie dostarczenia po badaniach odporności na zużywanie ścierne w masie glebowej: a) lekkiej; b) średniej; c) ciężkiej. Stan nietrawiony; LM

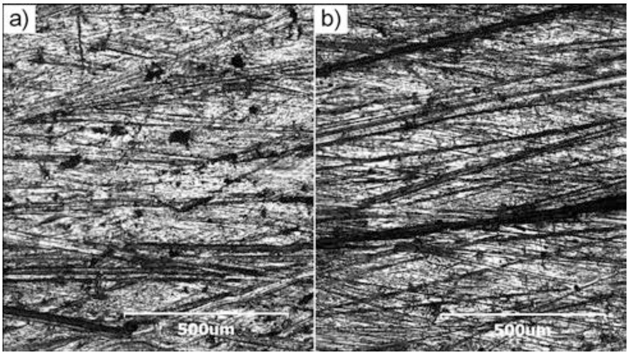

Fig. 10. A macroscopic image of the surface of Creusabro 8000 steel in the delivered condition after the tests of abrasive wear resistance in various soil masses: a) light; b) medium; c) heavy. Not etched; LM

Rys. 10. Makroskopowy obraz powierzchni stali Creusabro 8000 w stanie dostarczenia po badaniach odporności na zużywanie ścierne w masie glebowej: a) lekkiej; b) średniej; c) ciężkiej. Stan nietrawiony; LM

SUMMARY AND CONCLUSIONS

In the course of the performed spectral analyses of the chemical composition of the tested steel types, it has been proved that the amounts of selected alloying elements are slightly lower than are those stated in the data sheets of the examined types of steel. The presence of elements not listed by their producers in the information materials was also recorded. A common characteristic feature of all the tested types of steel was the lowered amount of harmful additives in the form of sulphur and phosphor.

In terms of its structure, 38GSA type steel in the examined condition of heat treatment was characterised by the structure of non-equivalent grains of ferrite with the insets of a quasi-eutectoid and with the colonies of finely dispersed pearlite. The structure of Creusabro 4800 steel consisted of hardening sorbite and martensite with distinct banding features. The insets of carbide phases uniformly distributed within the matrix were also observed in the microstructure of this steel. In the case of Creusabro 8000 steel, it was proven to be characterised by a structure of finely slatted hardening martensite with areas of tempered martensite, as well as the insets of upper bainite. The insets of carbide phases were observed inside the slats of martensite.

In terms of the resistance to abrasive wear, it can be concluded that Creusabro 8000 steel was characterised by the lowest loss in mass among the tested materials, both in light and medium soils. In both examined cases, the mass wear of this steel was over two times lower when compared to the remaining materials. In heavy soil, on the other hand, a considerable difference in mass wear was observed between 38GSA and Creusabro 4800 steel. The respective losses in mass after the friction distance adopted for the tests amounted to 3.7087 g and 0.8366 g, which unambiguously indicates the advantage of Creusabro 4800 steel in heavy soils.

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Streszczenie

W pracy przedstawiono wyniki badań odporności na zużywanie ścierne stali Creusabro 4800 i Creusabro 8000. Uzyskane wyniki prób laboratoryjnych odniesiono do budowy strukturalnej badanych stali oraz do podstawowych wskaźników charakteryzujących ich własności mechaniczne.

W wyniku przeprowadzonych badań z wykorzystaniem metod mikroskopii świetlnej i skaningowej stwierdzono, iż w stanie dostarczenia stale Creusabro posiadają złożony typ budowy strukturalnej charakterystyczny dla stali z tzw. efektem TRIP. Zidentyfikowany rodzaj budowy wskazuje na precyzyjnie dobrany skład chemiczny oraz zastosowanie w procesie wytwarzania tych materiałów specjalistycznych zabiegów obróbki cieplno-plastycznej. Zrealizowane próby odporności na zużywanie ścierne metodą „wirującej misy" w rzeczywistych masach glebowych, tj. gleba lekka (piasek gliniasty), gleba średnia (glina lekka) oraz gleba ciężka (glina zwykła), a także przeprowadzone pomiary twardości wykazały ścisłą zależność uzyskanych wskaźników odporności na zużywanie ścierne od budowy fazowej oraz od stanu obróbki cieplnej badanych stali. Wyniki badań odporności na zużywanie ścierne stali Creusabro zostały odniesione porównawczo do stali 38GSA w stanie normalizowanym.