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THE ANALYSIS OF THE TRIBOLOGICAL PROPERTIES OF THE ARMOURED FACE CONVEYOR CHAIN RACE

BADANIA WŁASNOŚCI TRIBOLOGICZNYCH PŁYTY ŚLIZGOWEJ PRZENOŚNIKA ZGRZEBŁOWEGO

Generally, the power and capacity of the armoured face conveyor (AFC) are determined by the motor size, pan width and chain size. It is well known that the dynamic behaviour of an AFC drive has a significant influence on tension in the AFC chain, and is therefore critical in determining the reliability of the chain and the entire AFC system. However, the chain long service life is also affected by tribological contact with the chain race plate of the AFC and with the coal.

The main objective of this work was to determine the tribological properties of AFC twin chain race (top plate). Characterization of the twin chain race, made of the Hardox 450 abrasion resistant steel, included microstructural examination by light microscopy, hardness test, X-ray diffraction and examination of tribological properties.

The studies were carried out on samples cut from top plate of the whitdrawn face conveyor twin chain race. It was found, that the Hardox450 steel has quite good wear resistance for such purpose as AFC twin chain race. It is possible to use more wear resistant material than Hardox 450 steel but it would cause premature wear of the AFC chain.

Keywords: armoured face conveyor, tribological properties, Hardox 450 abrasion resistant steel, hardness

Parametry użytkowe górniczego ścianowego przenośnika zgrzebłowego są określane m.in. przez moc silnika, szerokość przenośnika oraz rozmiar łańcucha. Dynamiczne warunki pracy przenośnika zgrzebłowego mają istotny wpływ na wielkość naprężeń w łańcuchu i determinują niezawodność łańcucha i całego przenośnika zgrzebłowego. Na czas bezawaryjnej pracy łańcucha ma również wpływ szereg innych czynników, w tym zużycie tribologiczne ogniw łańcucha wskutek kontaktu ciernego z dnem rynny przenośnika oraz transportowanym urobkiem. Głównym celem pracy było określenie własności tribologicznych rynny przenośnika zgrzebłowego wykonanej z odpornej na ścieranie stali Hardox 450. Wykonano badania metalograficzne, pomiary twardości, badania rentgenowskie oraz próby tribologiczne. Stwierdzono, że zastosowany materiał wykazuje optymalne własności tribologiczne a ewentualne

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zwiększenie jego odporności na zużycie mogłoby skutkować przedwczesnym zużyciem i w konsekwencji uszkodzeniem łańcucha przenośnika.

Słowa kluczowe: przenośnik zgrzebłowy, własności tribologiczne, stal odporna na ścieranie Hardox 450, twardość

1. Introduction

Each of the armoured face conveyor (AFC) components, including line pans, has to be engineered to perfection, but also has to work together optimally with the other parts of the system (*High-capacity AFC...*, 2011). It is well known that that the dynamic behaviour of an AFC drive has a significant influence on the tension in the AFC chain, and is therefore critical in determining the reliability of the chain and the entire AFC system (Wauge, 2002). The main factor that influences the power requirements of any AFC installation is the cumulative friction force on the conveyor. One of the dominant factors that determine this friction force is steel-on-steel friction of the AFC chains on the AFC pans (chain race plate) (Broadfoot & Betz, 2000). The friction phenomena can also affect the conveyor chains service life. Thus, the line pans material has to be made of good wear resistance steel but so high resistance could cause the premature wear of the AFC chain.

Optimum wear resistant profiles for chain and chain race plate should give significantly increased operational life of chain. In mining practice, chains work, as other parts made of steel, in an aggressive environment undergo fatigue, abrasive, adhesive, corrosion and tribochemical wear processes (Dolipski et al., 2011; Pawłowski & Bała, 2012). According to (Antoniak, 2002a, 2002b), there are no perfect chains meeting the all requirements for mining chains. However, using the computer method of chain selection elaborated on Silesian Technical University, it is possible to select chains best suited for desired conditions (Antoniak, 2002a, 2002b).

Chain race plates are made from very hard and wear-resistant materials, such as Hardox steels. Hardox is a trade name of SSAB – Svenskt Stål AB (equivalents are available from other manufacturers). Hardox steels, according to the manufacturer, are referred as "high quality abrasion resistant steels" (*Hardox...*, 2002). They are characterized by high resistance to abrasive wear, the possibility of specialized machining tools, good weldability, high strength and resistance to shock loads.

2. Material and experimental procedure

The samples for this study were cut from top chain race plate of withdrawn AFC line pan from central area of high wear loss (marked as A in Fig. 1) and from side area without significant signs of friction (marked as B in Figure 1). The chemical composition of the samples was examined by mass spectrometer Foundry Master WAS. Hardness measurements, by Vickers method according to ASTM E92 standard, were made using the load of 294 N. Characterization of microstructures was performed by an Zeiss Axiovert 200MAT optical microscope. The tribological examinations were carried out using T05 tester with the load of 50, 100, 150 and 200 N at room temperature and 2000 sec test duration. The abrasive pair was represented by the tested samples and the roll 35 mm in diameter, made of 100Cr6 bearing steel with the hardness of about 57 HRC. During the tests, the friction coefficient was recorded on a PC. X-ray diffraction (XRD) studies were performed using a Siemens D500 diffractometer with Bragg-Brentano geometry.

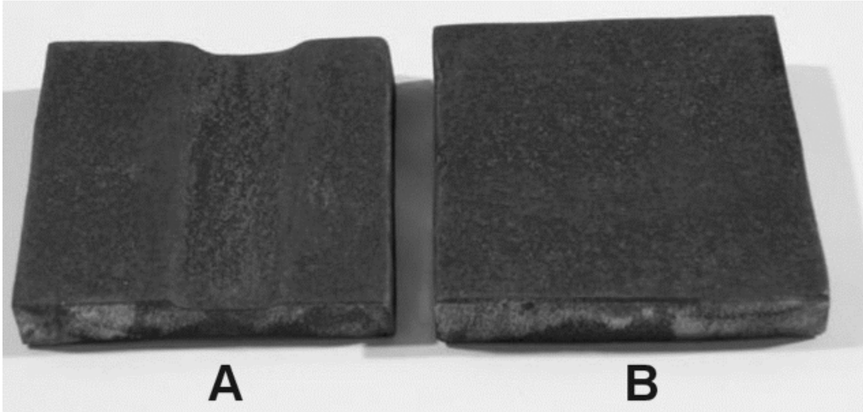


Fig. 1. The specimens with high (A) and slight (B) wear loss

3. Results and discussion

The chemical compositions of the tested samples are presented in Table 1. As it is shown, chemical compositions meet the requirements of SSAB for Hardox 450 steel. For both samples (A and B, see Fig. 1), the metallographical observations were carried out in the middle section of specimens, perpendicular to the direction of coal movement.

TABLE 1

Chemical composition of the investigated samples (in wt. %)

Sample	C	Mn	Si	P	S	Cr	Ni	Mo	B
A	0.23	1.12	0.33	0.012	0.004	0.74	0.10	0.22	0.002
B	0.23	1.14	0.34	0.012	0.004	0.76	0.10	0.24	0.002
SSAB data sheet, ver.2012.04.02 for plate width 20-40 mm	max. 0.23	max. 1.60	max. 0.70	max. 0.025	max. 0.010	max. 1.00	max. 0.25	max. 0.25	max. 0.004

The microstructures showed in Figure 2 and Figure 3 are typical for rolled sheet with the preserved remains of band structure deformation. The use of varying etching intensity leads to the conclusion that the plates were heat treated by quenching and tempering. Microstructure should be considered as optimal and appropriate for use on an element that has been made of the material analyzed.

Mechanical properties (Vickers hardness) of the sample B was measured in the area of its cross-section. The change in hardness is shown in Figure 4. As it is shown, there is a continuous change in hardness from one to the other surface of the plate, in the range 387÷540 HV. The highest hardness observed at upper surface region (working surface) is probably due to the plastic deformation caused by moving coal. Cross-section change in hardness may be due to the sheet production technology, in particular as regards the heat treatment. This may result from uneven cooling intensity on both surfaces or uneven heating sheet (location in the oven) during the annealing (heating with different intensity). Since the plateau occurs in the distribution of hardness

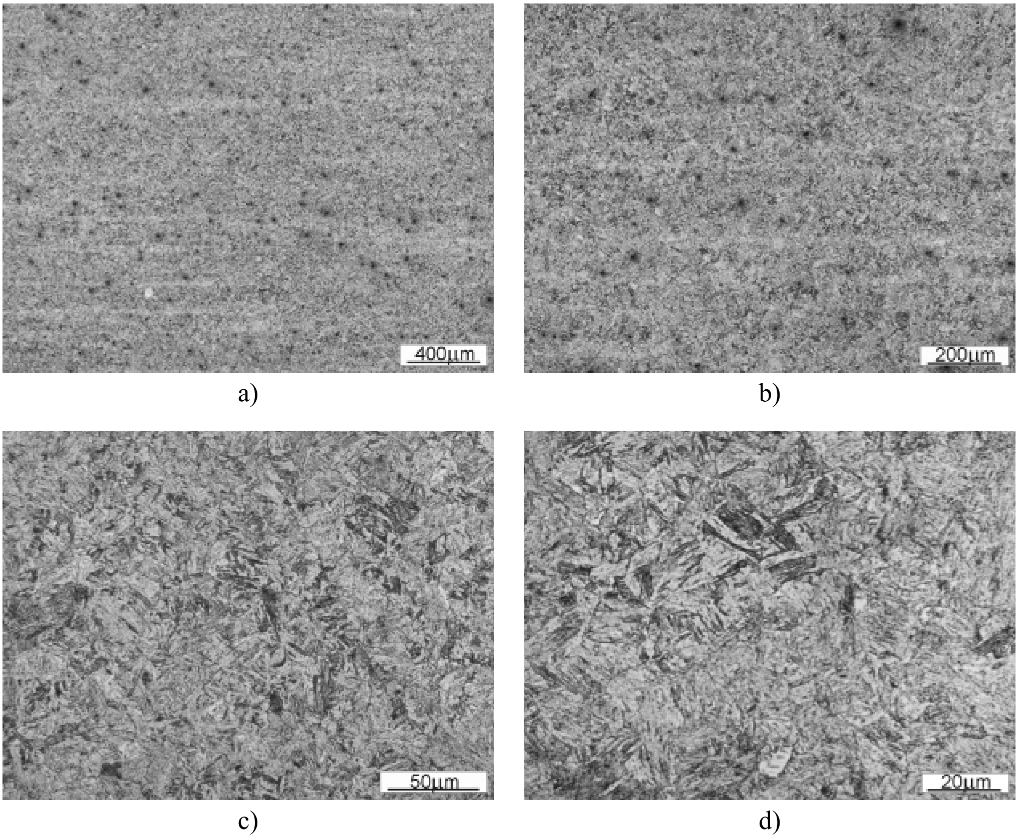


Fig. 2. Microstructure of the sample A. Etched with 2% Nital

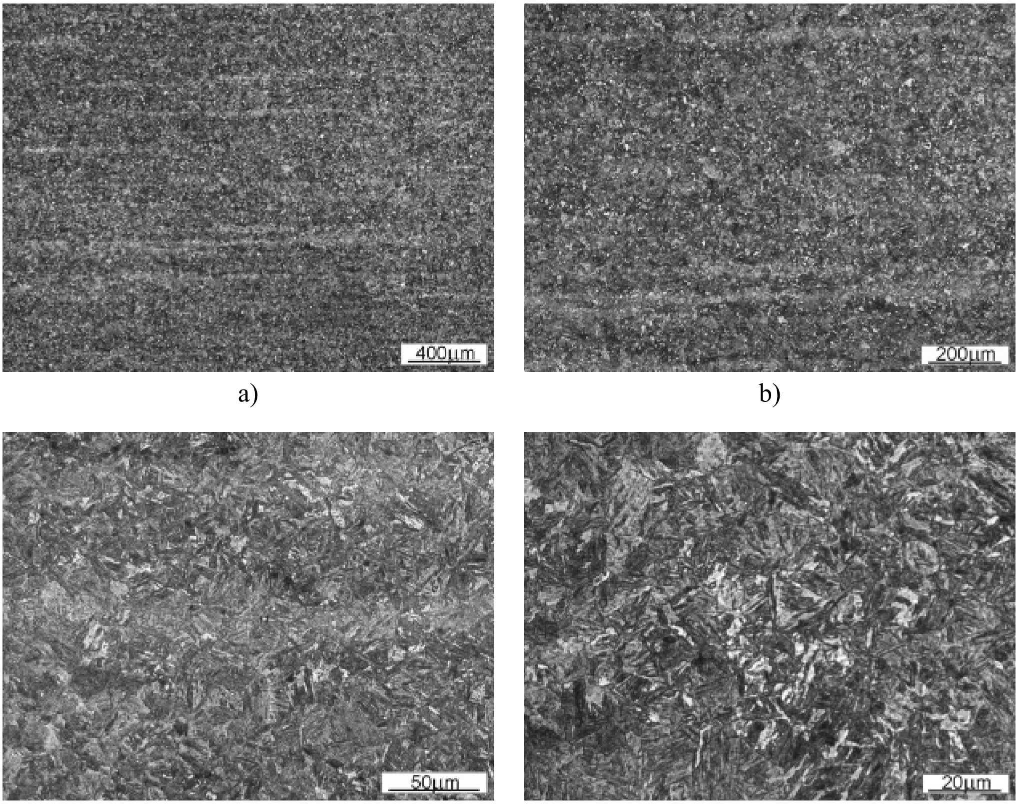
values for 450 HV, hardness should this be taken as par for the test material. For this reason, as well as analyzing the chemical composition (Table 1), it should be considered that investigated top race plate is made of the steel trade name Hardox 450.

In the chain conveyor movement central area of the sample A there is a region of the high wear loss, which can be determined by observing the cross-section (Fig. 5).

There is more wear on the upper surface of the plate, which is a result of the frictional interaction of transported coal and plate surface. Also, the same chain scraper can affect the surface of a plate, as evidenced at the lower surface of the plate.

In order to determine the coal-mine environment influence on the AFC plate the X-ray analysis of the corroded surface of the sample A was made. As a result of the above analysis, it was found corrosion products in the form of iron oxide Fe_3O_4, manganese oxide Mn_2O_3. Due to the coal-mine water presence and salinity evidence of corrosion products in the form of $Fe_{21}HO_{32}$ and hydrated iron oxide as well as $Fe_2(SO_4)_3$. Above analysis indicates a very difficult working conditions for conveyor elements.

Results of metallographic examinations of the surface layer of the sample B (cross-section parallel to the direction of chain movement) are presented in Figure 6. It can be seen that the



a) b) c) d)

Fig. 3. Microstructure of the sample B. Etched with 2% Nital

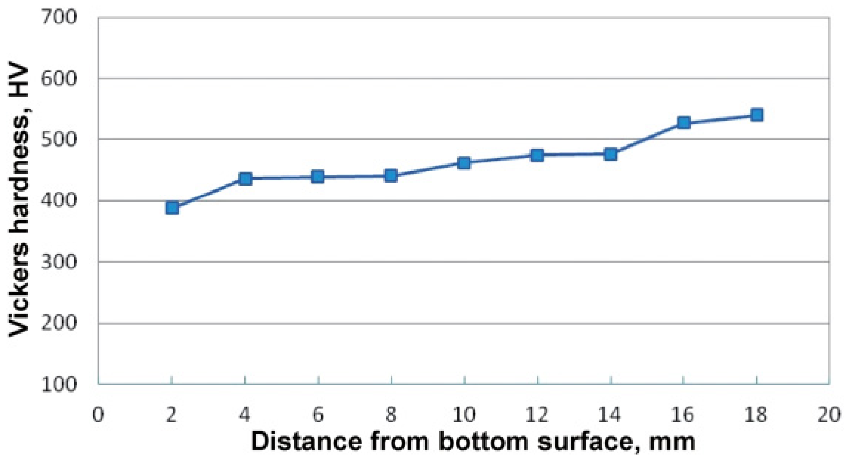


Fig. 4. Changes in hardness on the cross section of the sample B

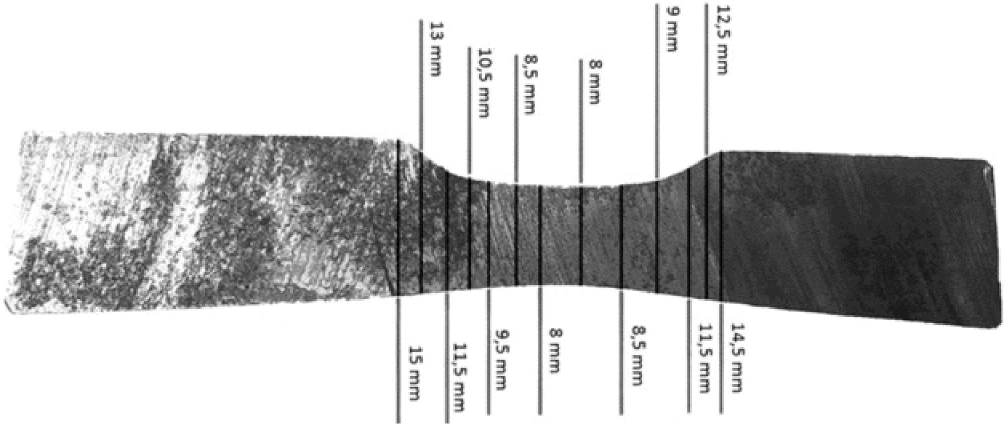


Fig. 5. Cross-sectional profile at the plate chain conveyor movement area of the sample A

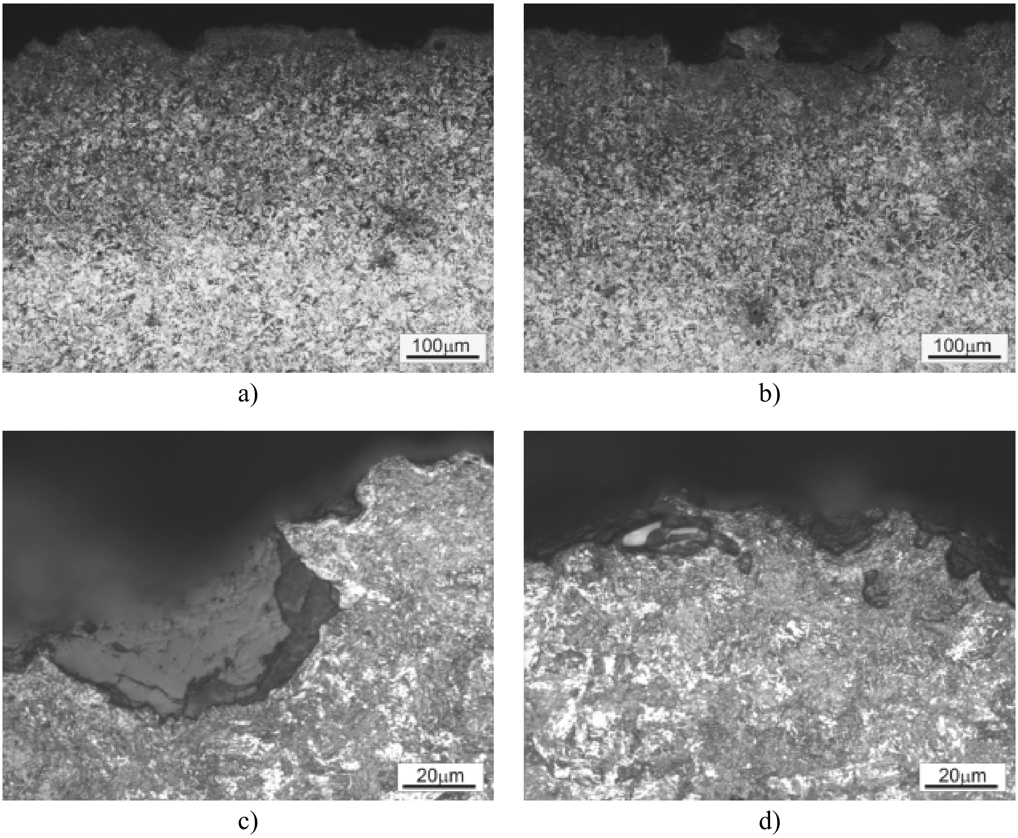
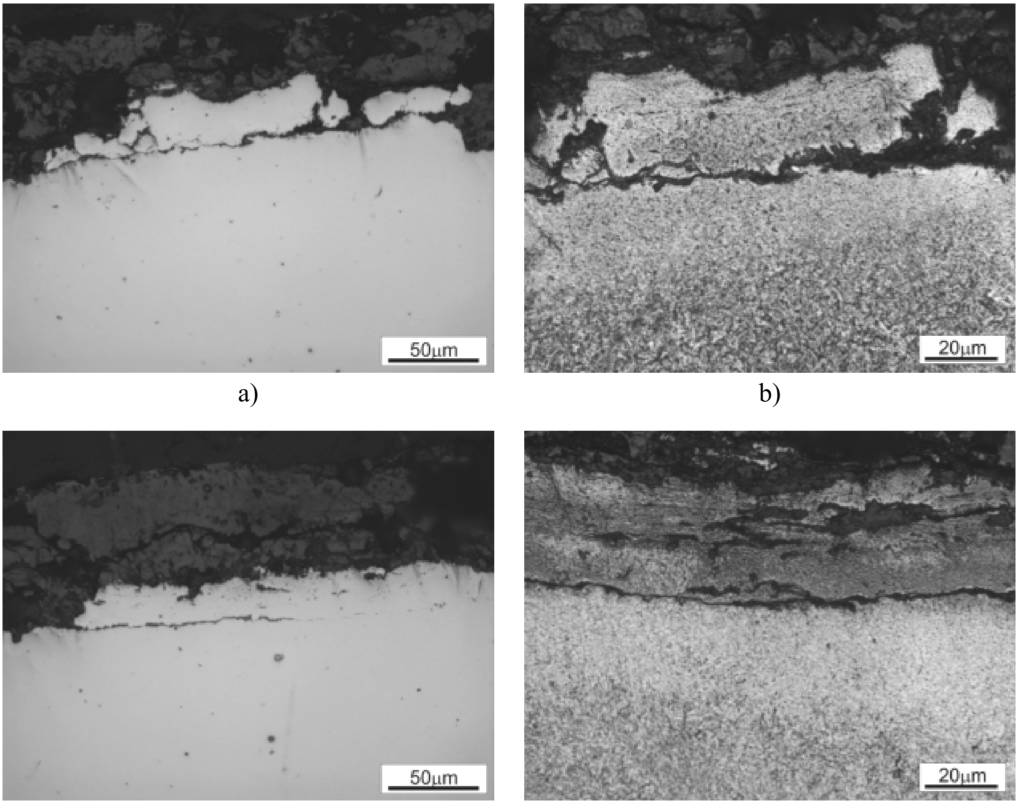


Fig. 6. Surface layer of the sample B, cross-section parallel to the direction of chain movement, etched with 2% Nital

surface layer as a result of interaction of coal and rock has been plastically deformed, resulting in the strengthening (Fig. 6a). Strengthened surface layer, however, has a lower ductility, which contributes to a result of the impact of hard particles of excavated material, pulling out from the surface of the fragments (Fig. 6b). Region of pitting corrosion and oxidation, seen in Fig. 6b, observed at higher magnification leads to the conclusion that the grain boundaries and martensite plate boundaries, the surfaces on which the result of tempering nucleation of the carbides occurs, act as the places of intensive oxidation (Fig. 6c). Erosion mechanism of the wear degradation of the upper surface of the plate caused by the hard rock particles is shown in Figure 6d. The microstructures of the surface layer of the central area of sample A (chain movement area, cross-section parallel to the direction of chain movement) are shown in Figure 7. Observations made in this area points to chipping and moving parts of a disc (Fig. 7a). Etching indicates that in these areas there is often a so-called white layer (Krawczyk & Pacyna, 2006), as shown in Figure 7b. Formation of a white layer (ultra fine grain or nanocrystalline martensite which is hard and brittle) requires such intense tribological impact that the thin austenitic film has formed by local heating to a temperature above Ac_1, plastic deformation and then rapid cooling. Crumbled white layer



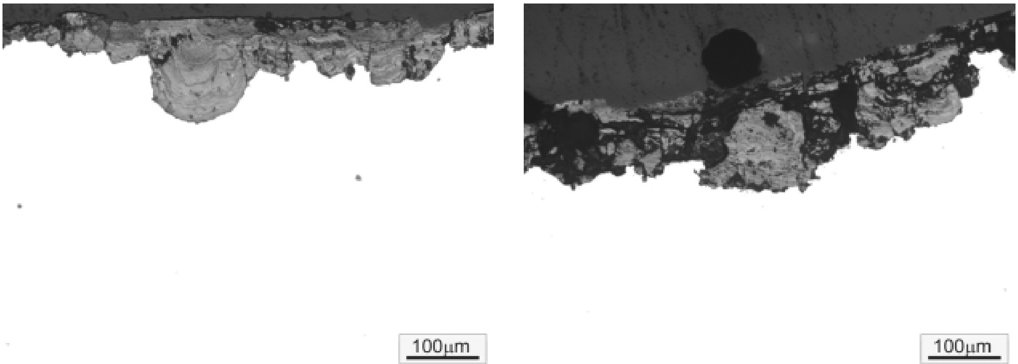
a) b) c) d)

Fig. 7. Surface layer of the sample A, cross-section parallel to the direction of chain movement, etched with 2% Nital

fragments, due to its high hardness can also abrasive affect the plate surface further intensyfing its wear. The same role coud play the particles of the transported material (coal and rock).

Directly in the axis of the chain conveyor movement the process of corrosion, surface oxidation, occurs much more intense than in the previously discussed location outside the conveyor chain impact and a continuous, thick oxide layer can be seen in Figure 8a, b. The fragments of chain material were identified in such region, as it is shown in Figure 9. Within the bulk of the plate material the intense intergranular corrosion was also observed (Fig. 10).

So, it may be concluded that in this region particularly hard corrosive and tribological conditions occur.



a) b)

Fig. 8. Surface oxidation layer of the sample A, cross-section parallel to the direction of chain movement, non-etched specimen

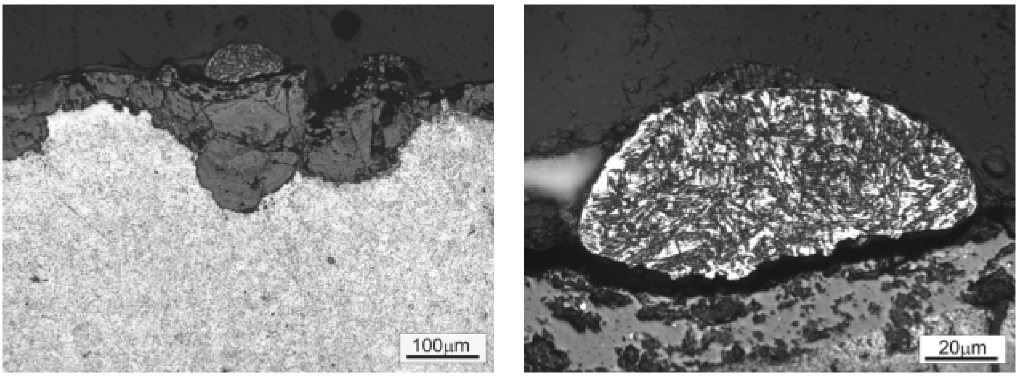


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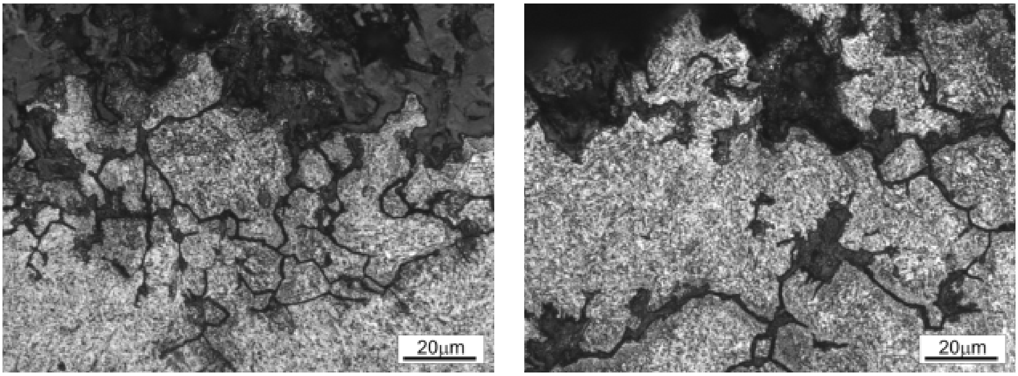
Fig. 9. The fragments of chain material identified in surface oxidation layer of the sample A, cross-section parallel to the direction of chain movement, etched with 2% Nital



a) b)

Fig. 10. The intense intergranular corrosion of plate material of the sample A, cross-section parallel to the direction of chain movement, etched with 2% Nital

Laboratory wear test of Hardox 450 steel showed a typical abrasive wear mechanism, examples of wear scars are presented in Figure 11 and 12. The tests were conducted under a load of 50, 100, 150 and 200 N. The results indicate that increasing load increases chipping wear process of plastically deformed steel surface and strongly affect the weight wear as it is shown in Figure 13.

4. Conclusions

From the results presented in this paper it is evident that in place of Hardox 450 steel could be proposed higher wear resistant steel, i.e. Hadfield steel. However, taking into account the conveyor working conditions, especially because of the impact of fine particle erosion of excavated material, and due to fabrication technology associated with the need to weld plate with side profiles, Hadfield steel is unlikely to be of optimal performance. Considering manufacturing technology (including weldability), the wear and corrosion resistance, chain service life and economic aspect, Hardox 450 steel must be regarded as a optimum material for the above application.

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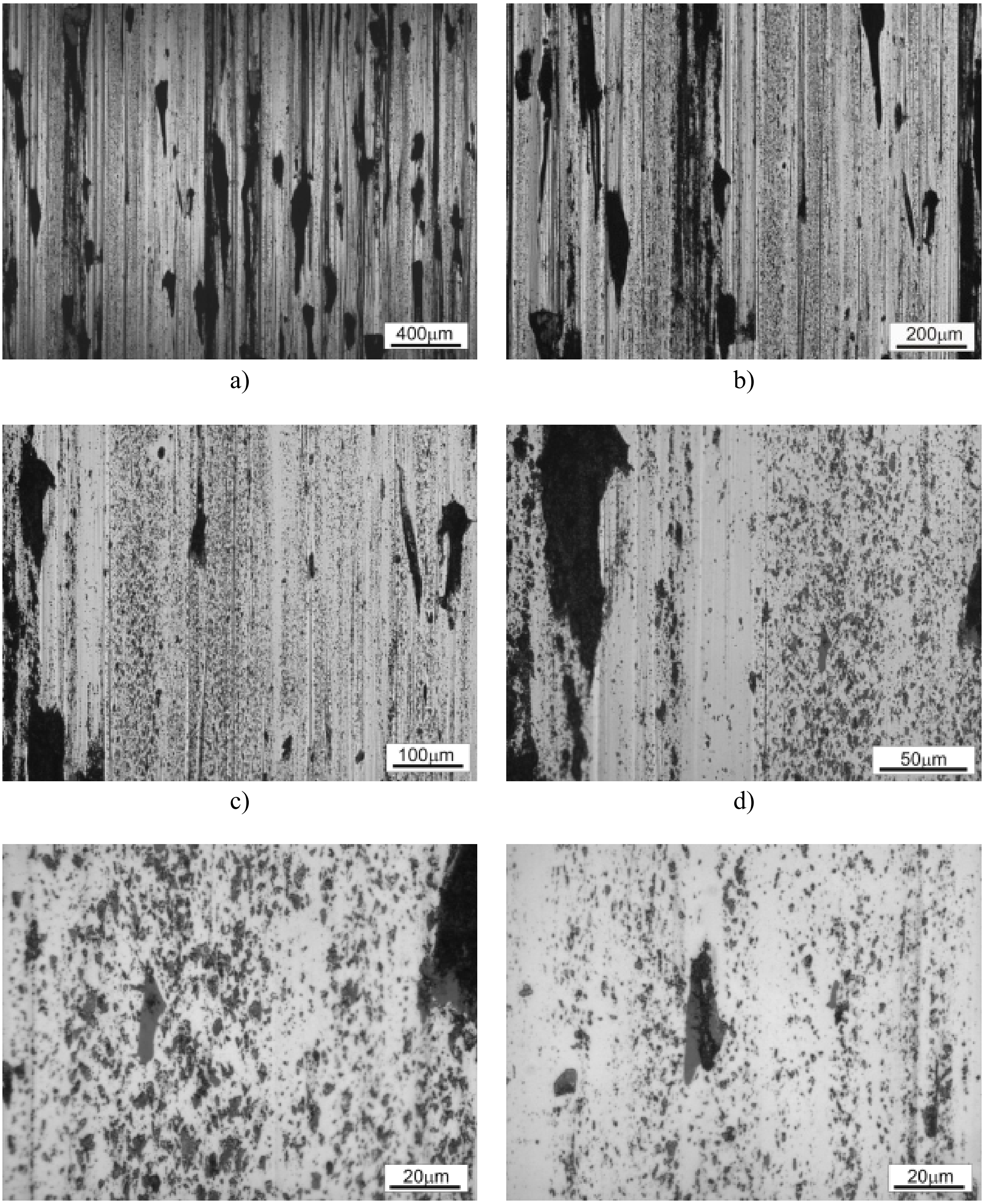

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Fig. 11. Wear scars for Hardox 450 steel after the wear test (load 50 N, test time 2 000 sec.)

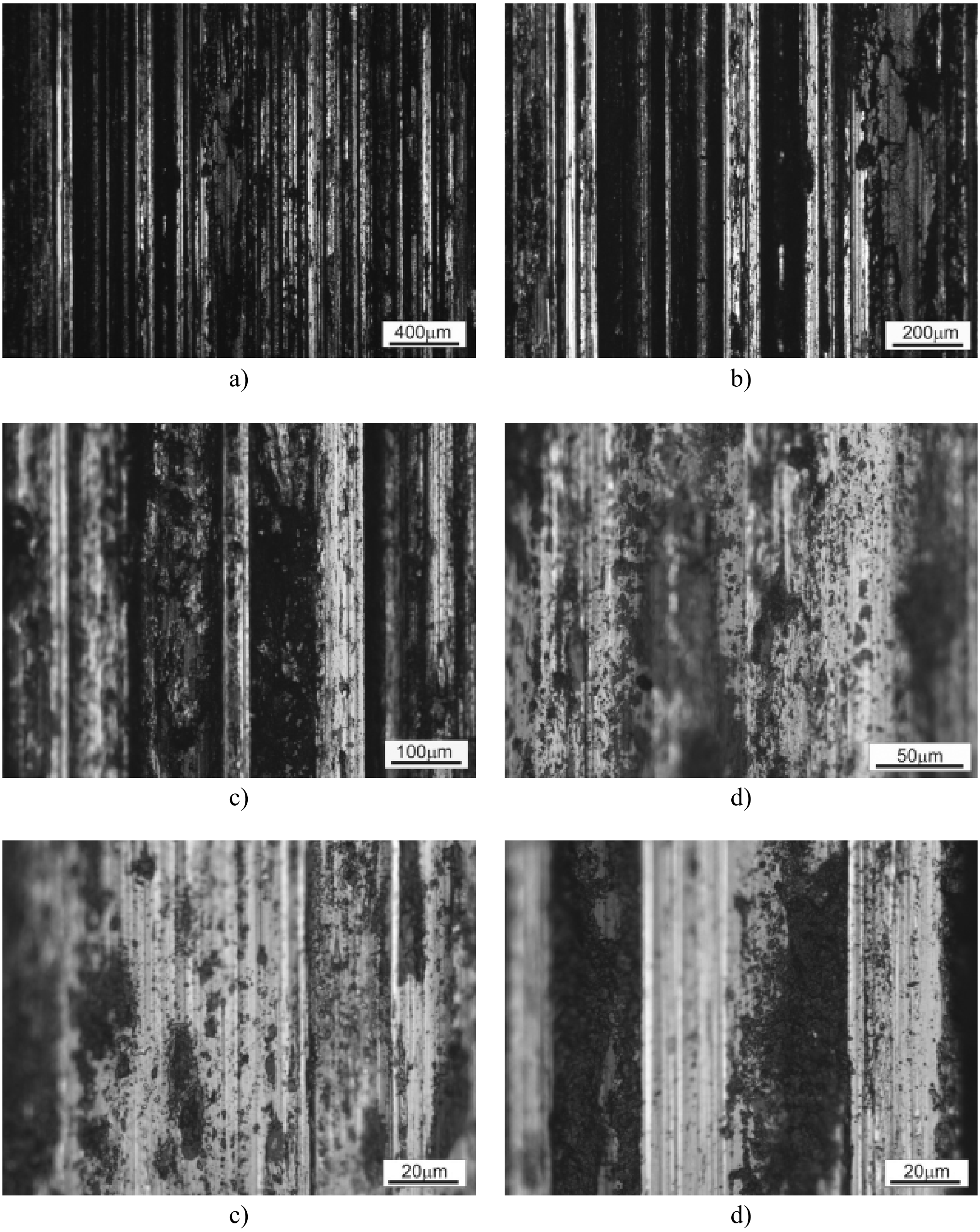

Fig. 12. Wear scars for Hardox 450 steel after the wear test (load 200 N, test time 2 000 sec.)

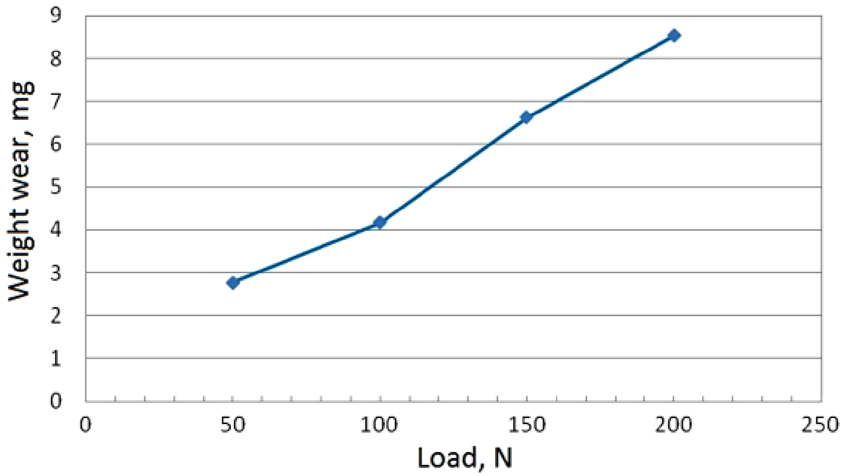

Fig. 13. Weight wear for different test load

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