Janusz KRAWCZYK[*], **Łukasz FROCISZ**[*], **Adam KOKOSZA**[*], **Edyta ROŻNIATA**[*], **Rafał DZIURKA**[*], **Marcin MADEJ**[*]

THE IMPORTANCE OF PRIMARY CARBIDES FOR THE TRIBOLOGICAL PROPERTIES OF FERROUS ALLOYS

ZNACZENIE WĘGLIKÓW PIERWSZORZĘDOWYCH WE WŁASNOŚCIACH TRIBOLOGICZNYCH STOPÓW ŻELAZA

Słowa kluczowe:

stal, staliwo, węgliki pierwotne, tribologia, mikrostruktura, walce hutnicze

Key words:

Steel, cast steel, primary carbides, tribology, microstructure, mill rolls

Abstract

Among the materials used for the mill rolls, one of the main groups are materials with eutectoid primary carbides in their microstructure. The volume fraction and morphology of these carbides influent in a significant way on the tribological properties of tool materials. In the paper, the role of the primary

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[*] AGH Academy of Science and Technology, Faculty of Metals Engineering and Industrial Computer Science, Al. Mickiewicza 30, 30-059 Kraków, Poland, tel. 12 617-26-19, e-mails: jkrawcz@agh.edu.pl, lfrocisz@agh.edu.pl, akokosza@metal.agh.edu.pl, rozniata@agh.edu.pl, dziurka@agh.edu.pl, mmadej@agh.edu.pl.

carbides morphology on the fatigue wear of mill rolls after exploitation was presented. The role of the primary carbides morphology in the sliding wear of tool materials was also investigated. The evaluation of the sliding wear mechanism and its degree was performed by the investigation of the mill rolls surface roughness after exploitation. Whereas, the role of ledeburite cementite morphology in wear mechanism changes ware investigated by the laboratory tests. Tests were performed with the use of different loads, time, and temperature during the trials. The microcutting of counter sample material by the primary carbides from the tested samples was observed.

INTRODUCTION

The changes in the microstructure of iron alloys have a significant influence on the material's wear resistance. It was shown that the lowest wear resistance was observed for the materials with the spheroidal precipitations of carbides in the soft ferritic matrix, while the highest wear resistance was observed in the materials with the plate morphology of the carbides **[L. 1, 2]**. With the decrease of the plate dimensions, the wear resistance increased **[L. 3, 4].** It should be noted that, for the materials used to production of mill rolls, only a small group of steels is characterized by the non-carbide microstructure, despite the high wear resistance requirements for this tools. **[L. 5–9]**. Among the steels used for the cold working mill rolls, the main group of materials are the hypereutectoid or hypoeutectic materials with the secondary and primary carbides in their microstructure **[L. 10, 11]**. Among the materials used for the mill rolls production, two main groups are distinguished: hot working and cold working materials. In the case of the cold working materials, one of the most characteristic is X153CrMo12 steel. In the case of the hot working materials, the main types are the cast steel alloys and cast iron alloys. The morphology of primary carbides in the cast steel alloys are modified by plastic deformation; whereas, in the case of cast iron alloys, the morphology of the carbides is changed only by heat treatment **[L. 8, 9, 12–18]**.

The aim of this paper is the definition of primary carbides role in the wear of materials used for the mill roll production and the estimation of the mill rolls' wear after the exploitation.

MATERIAL FOR THE INVESTIGATIONS AND METHODOLOGY

Research ware performed for twenty iron alloys used for the mill rolls. **Table 1** presents the chemical compositions of investigated materials. Materials were sorted with the increase of carbon content for each of the groups. For the laboratory tests, the samples were prepared from each material. Additionally, tests were performed on the mill rolls after the exploitation.

Table 1. Chemical composition (weight %) of investigated materials (Fe bal.), samples taken from experimental cast – s, mill rolls – r, samples taken from the mill rolls – s, r

Tabela 1. Skład chemiczny (% masowy) badanych materiałów (reszta Fe), próbki pobrane z wytopów próbnych – s, walce hutnicze – r, próbki pobrane z walców hutniczych – s, r

No.	material	C	Mn	Si	Cr	Ni	Mo
steel							
1	70MnCrMo8-2 (s)	0.70	2.15	0.30	0.51	0.13	0.44
2	70MnCrMo8-2 (r)	0.83	1.90	0.38	0.42	0.30	0.41
3	X153CrMo12 (r)	1.53	0.37	0.22	11.20	-	0.73
4	X153CrMo12 (s)	1.56	0.34	0.28	11.20	-	0.70
cast steel							
5	120CrNiMo4-3-3(s,r)	1.22	0.73	0.51	0.99	0.47	0.42
6	150SiCrNi4-4-3 (s,r)	1.34	0.65	1.12	0.83	0.60	0.19
7	200CrNiMo4-3-3 (s,r)	1.83	0.64	0.56	1.30	0.47	0.33
8	200CrNiMo4-3-3 (s)A	1.90	0.58	0.65	1.08	0.52	0.23
9	200CrNiMo4-3-3 (s)B	1.97	0.60	0.65	1.01	0.75	0.28
10	200NiSiCr8-4-4 (s,r)	1.99	0.80	1.30	1.24	1.81	0.35
11	200SiCrNi4-4 (s,r)	2.00	0.70	1.12	0.84	0.51	0.33
12	200CrSiMn4-4 (s,r)	2.00	1.10	1.20	1.20	0.30	0.10
13	200CrNi4-4 (s,r)	2.10	0.50	0.70	1.20	1.20	0.20
cast iron							
14	GJSL–300SiNiCr8-6-2 (s,r)	3.04	0.72	2.19	0.48	1.32	0.31
15	GJSL–320NiSiCrMo14-8-3 (s,r)	3.22	0.51	2.16	0.71	3.45	0.62
16	GJSL–330NiMoCr8-5 (s,r)	3.32	0.72	1.40	0.28	2.06	0.52
17	GJLL–350NiCrMo13-4 (s,r)	3.45	0.53	0.65	1.03	3.23	0.44
18	GJSL–350NiMoCr12-8-3 (s,r)	3.45	0.65	1.40	0.70	3.07	0.86
19	GJSL–350NiCr6-2 (s,r)	3.46	0.41	1.35	0.39	1.46	0.17
20	GJLL–350CrNiMo6-5-3 (s,r)	3.50	0.74	1.22	1.37	1.23	0.32

Tribological tests at room temperature were performed by the use of a block-on-ring friction couple, tribotester used for these investigations was T-05. For the investigation, 50 N, 100 N, and 150 N loads were used, tests were performed without lubrication. Time for each test was 2000 s. Test at a temperature 750°C were performed under the load 10 N with a time of 5000 s. For these tests, pin-on-disc friction couple was used **(Fig. 1)**. As a counter sample for all tests, 100Cr6 steel was used. Counter samples were quenched, hardness of the counter samples was 57±2 HRC.

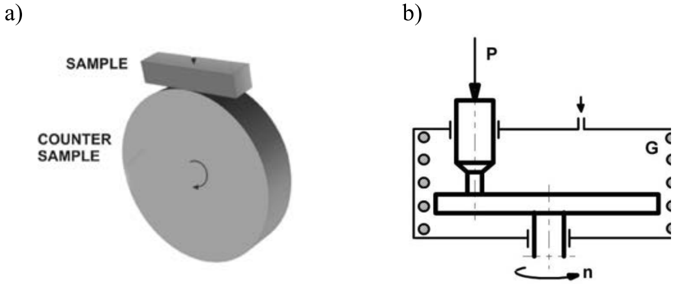


Fig. 1. Tribological systems used in laboratory tests: a) block/ring - RT, b) pin on disc (750°C)

Rys. 1. Zastosowane układy tribologiczne w badaniach laboratoryjnych: a) klocek/pierścień-temperatura pokojowa, b) trzpień/tarcza (750°C)

THE IMPACT OF PRIMARY CARBIDES ON MATERIALS DURING FRICTION TESTS

The large precipitations of primary carbides on the mill rolls' surfaces after the exploitation could be easily observed. Its existence on the material surface is related to the wear of the matrix around the hard precipitation of carbide **(Fig. 2a)**. It is related to significant differences between the mechanical properties of carbide and the matrix, and the retention properties of the carbide **(Fig. 2b)**. Similar results were obtain during the tribological tests **(Fig. 3)**. Increase of matrix hardness attenuate this effect **(Fig. 3d)**. Primary carbides at the material surface could act as the cutting edges which degrade surface of the counter sample **(Fig. 4)**. However, during the friction, primary carbides could crack and spall from the surface, possibility of such behaviour increases with the decrease of the carbide width **(Fig. 5)**.

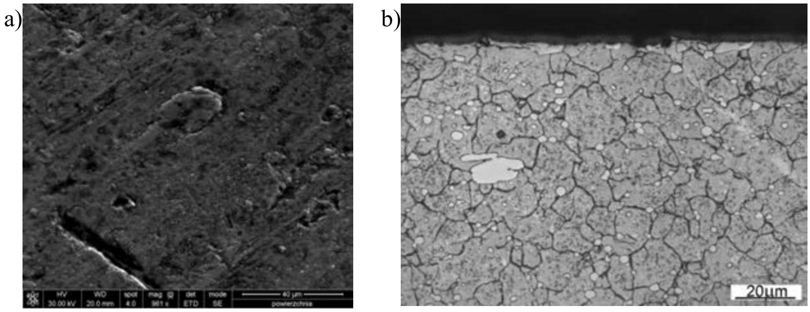


Fig. 2. Workspace of cold work mill roll made of X153CrMo12 steel (the standard heat treatment): a) working surface (SEM), b) cross-section through the working surface (light microscope – etched with 2% nital)

Rys. 2. Obszar roboczy walca hutniczego ze stali X153CrMo12 (po klasycznej obróbce cieplnej) do pracy na zimno: a) powierzchnia robocza (SEM), b) przekrój przez powierzchnię roboczą (mikroskop świetlny – traw. 2% nital)

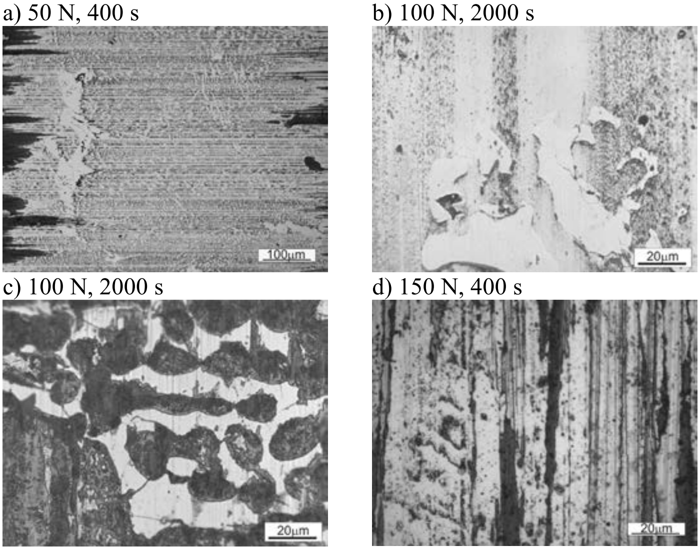

a) 50 N, 400 s
b) 100 N, 2000 s
c) 100 N, 2000 s
d) 150 N, 400 s

Fig. 3. The material surface after tribological tests: a) cast steel 200CrNiMo4-3-3 A (Sam. 8), b) cast iron GJSL–300SiNiCr8-6-2 (Sam. 14), c) cast iron GJSL – 320NiSiCrMo14-8-3 (Sam. 14), d) cast steel 200CrNiMo4-3-3 A (Sam. 8) – quenched matrix

Rys. 3. Powierzchnia po testach tribologicznych: a) staliwo 200CrNiMo4-3-3 A (pr. 8), b) żeliwo GJSL–300SiNiCr8-6-2 (pr. 14), c) żeliwo GJSL–320NiSiCrMo14-8-3 (pr. 14), d) staliwo 200CrNiMo4-3-3 A (pr. 8) – hartowana osnowa

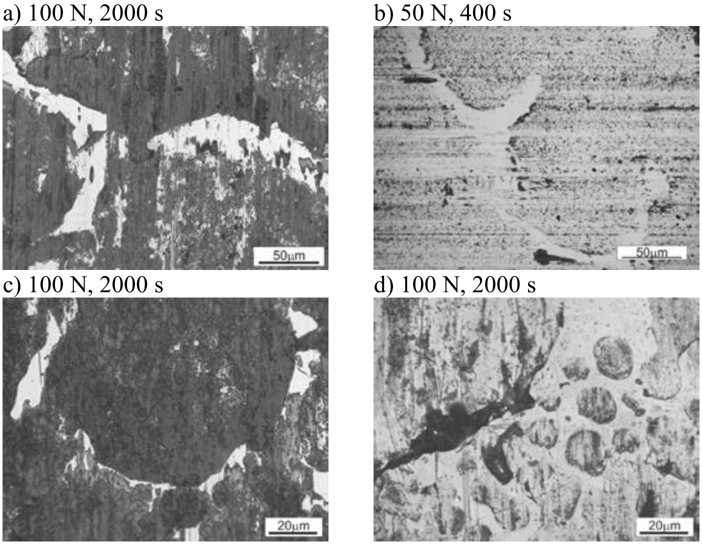
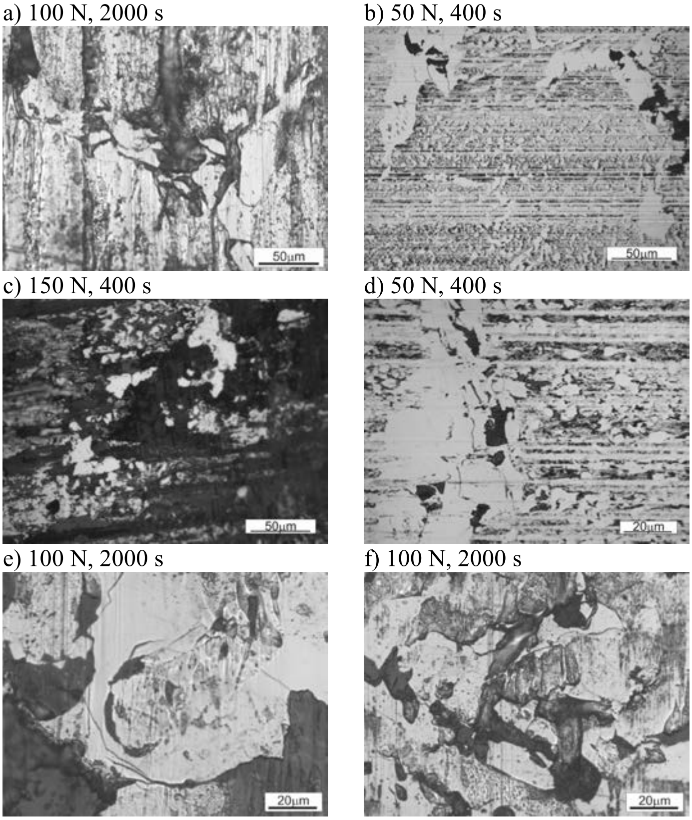

a) 100 N, 2000 s
b) 50 N, 400 s
c) 100 N, 2000 s
d) 100 N, 2000 s

Fig. 4. The material surface after tribological tests: a) cast steel 200NiSiCr8-4-4 (Sam. 10), b) cast steel 200CrNiMo4-3-3 A (Sam. 8) – quenched, c) cast iron GJSL–330NiMoCr8-5 (Sam. 16), d) cast iron GJLL–350CrNiMo6-5-3 (Sam. 20)

Rys. 4. Powierzchnia po testach tribologicznych: a) staliwo 200NiSiCr8-4-4 (pr. 10), b) staliwo 200CrNiMo4-3-3 A (pr. 8) – hartowana osnowa, c) żeliwo GJSL–330NiMoCr8-5 (pr. 16), d) żeliwo GJLL–350CrNiMo6-5-3 (pr. 20)



a) 100 N, 2000 s
b) 50 N, 400 s
c) 150 N, 400 s
d) 50 N, 400 s
e) 100 N, 2000 s
f) 100 N, 2000 s

Fig. 5. The material surface after tribological tests: a) cast steel 200NiSiCr8-4-4 (Sam. 10), b-d) cast steel 200CrNiMo4-3-3 A (Sam. 8), e) cast iron GJLL – 350NiCrMo13-4 (Sam. 17), f) cast iron GJLL–350CrNiMo6-5-3 (Sam. 20)

Rys. 5. Powierzchnia po testach tribologicznych: a) staliwo 200NiSiCr8-4-4 (pr. 10), b-d) staliwo 200CrNiMo4-3-3 A (pr. 8), e) żeliwo GJLL – 350NiCrMo13-4 (pr. 17), f) żeliwo GJLL–350CrNiMo6-5-3 (pr. 20)

THE INFLUENCE OF PRIMARY CARBIDES ON WEAR MECHANISMS

Analysis of tribological tests results performed on the cast steel mill rolls allow us to observe influence of primary carbides (ledeburitic cementite) on the sliding wear **(Fig. 6)**. However, it should be noted that such influence is observed only in the case of high loads and longer times of the trials. In the case when the trials are quicker and with lower loads, primary carbides did not reduce the sliding wear **(Fig. 7)**. Tests performed in such conditions are characterized by the increase in sample mass. It is probably related to the microcutting of the counter sample by the primary carbides and deposition of the counter sample material on the tested materials. Additionally, in the case of the study presented in **Figure 7**, the primary carbide volume fractions decrease, which is related to the higher volume fraction of secondary carbides. Secondary carbides in such materials nucleate heterogeneously at primary carbide–material matrix interphase boundaries. In-situ precipitations of secondary carbides occurred during the cooling from the austenite temperature. Smaller secondary carbides during the tribological test did not spall from the surface of the material and "cutting" counter sample. Similar results are observed during tests at elevated temperatures **(Fig. 8)**. In this case, microcutting of the counter sample material by the primary carbides increases the sliding wear.

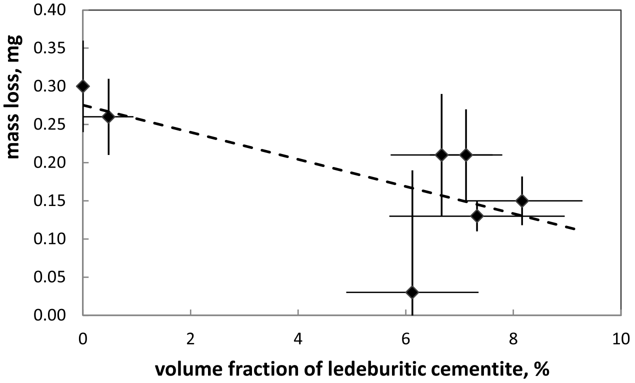


Fig. 6. Effect of the primary carbides on the wear of the cast steels No. 5-7 and 10-13 under the load of 100 N, at time = 2000 s

Rys. 6. Wpływ udziału węglików pierwotnych na zużycie staliw nr 5-7 i 10-13 w warunkach obciążenia 100 N w czasie 2000 s

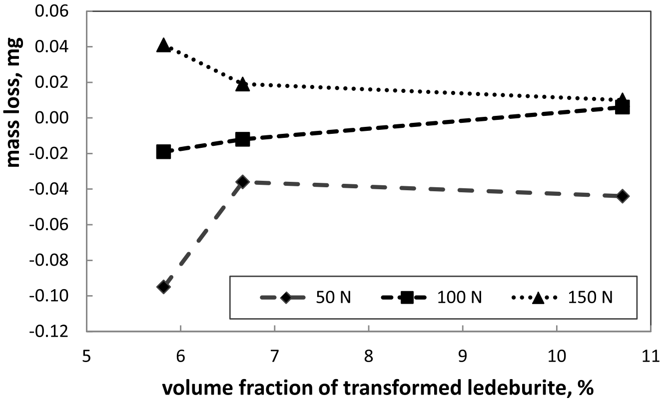


Fig. 7. The effect of the primary carbides on the wear of the cast steel 200CrNiMo4-3-3 (No. 8) after the different heat treatments at time = 400 s

Rys. 7. Wpływ udziału węglików pierwotnych na zużycie staliwa 200CrNiMo4-3-3 (nr 8) po różnej obróbce cieplnej, w czasie 400 s

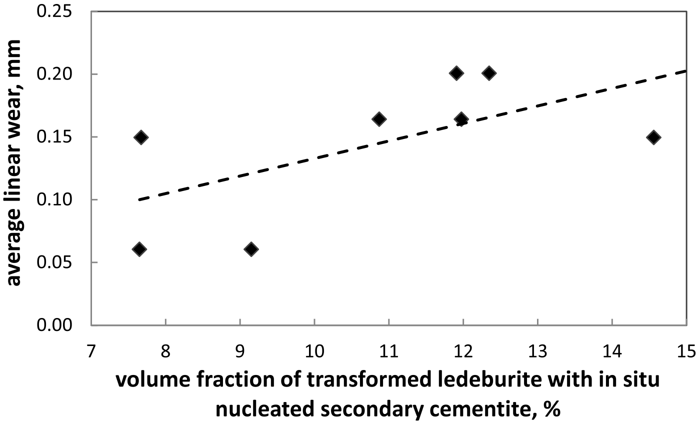


Fig. 8. The effect of the primary carbides on the wear of the cast steel 200CrNiMo4-3-3 (No. 8 and No. 9) after the different heat treatments at a temperature of 750°C, with load of 10 N, at time = 5000 s

Rys. 8. Wpływ udziału węglików pierwotnych na zużycie liniowe staliwa 200CrNiMo4-3-3 (nr 8 i 9) po różnej obróbce cieplnej, w temperaturze 750°C, przy obciążeniu 10 N w czasie 5000 s

Primary carbides could influence on wear in a numerous ways, according to mechanical properties of material matrix. Changes in matrix properties obtained by heat treatment could reduce the wear of the sample **(Fig. 9)**. The influence of the matrix properties on sample mass loss was presented bycomparing materials with the primary carbides precipitations (X153CrMo12) and material without such carbides in the microstructure (70MnCrMo8-2).

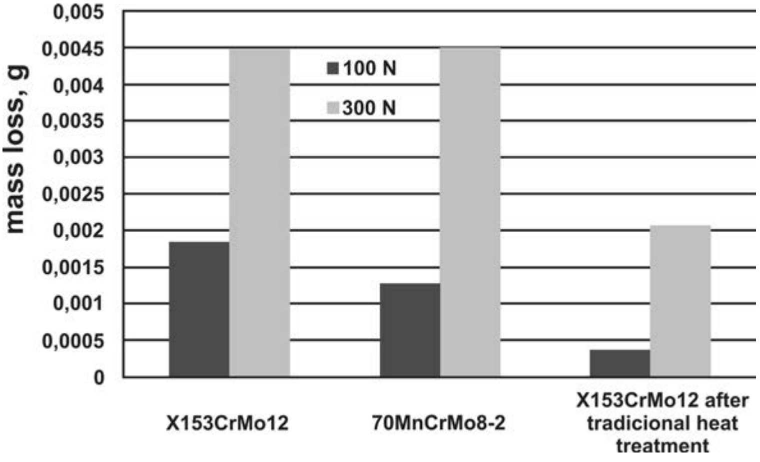


Fig. 9. Mass loss of steel No. 1 and No. 4 after 2000 s of tribological test

Rys. 9. Zużycie stali nr 1 i 4 po czasie 2000 s trwania testu tribologicznego

By using heat treatment, the wear resistance of X153CrMo12 steel increased. Heat treatment of such materials reduces the mass loss of the sample compared to the previous two variants. It is related to the more difficult spalling of the carbides located in the hard matrix and, of course, the increase of matrix hardness **(Figs. 9** and **10)**. Additionally, the same results could be observed based by the analysis of changes in mill roll surface roughness changes. For materials with the primary carbides in the microstructure, a lower degradation of the surface is observed, compared to the material without such carbides **(Fig. 11)**.

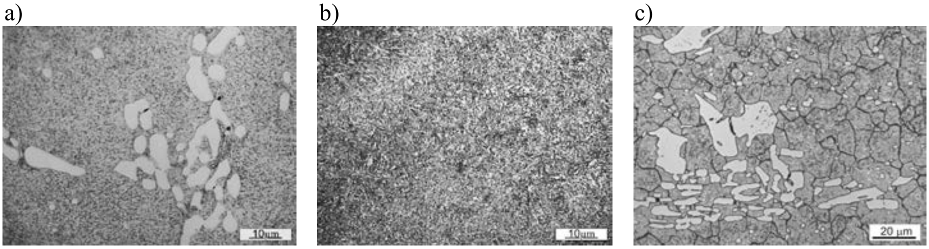


Fig. 10. Microstructure: a) X153CrMo12 steel (low tempering), b) 70MnMoCr8-2 steel, b) steel X153CrMo12 (standard heat treatment)

Rys. 10. Mikrostruktura: a) stal X153CrMo12 (niskie odpuszczanie), b) stal 70MnCrMo8-2. b) stal X153CrMo12 po klasycznej obróbce cieplnej

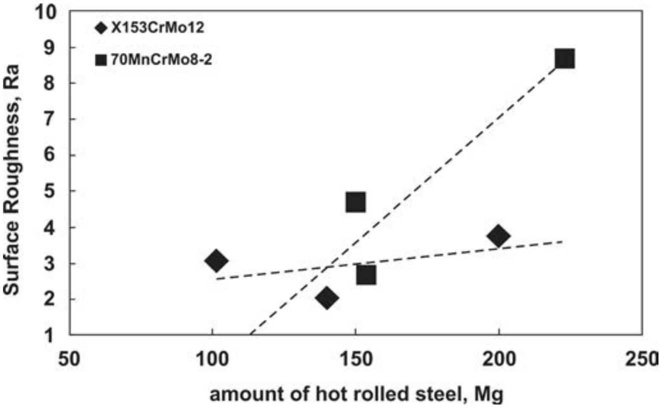


Fig. 11. The effect of the volume of the roll steel on surface roughness of mill rolls made of steel No. 2 and No. 3

Rys. 11. Wpływ ilości walcowanej stali na chropowatość powierzchni walców ze stali nr 2 i 3

THE INFLUENCE OF PRIMARY CARBIDES ON THE FRICTION COEFFICIENTS

Large precipitations of primary carbides influent on the friction coefficient. Analysis of friction coefficient during tests of cast iron alloys allow us to observe the changes in friction coefficient related to the volume fraction of primary carbides. Precipitation of secondary carbides was avoided by the graphitization heat treatment. An increase of ledeburitic primary carbide volume fractions caused the increase in the friction coefficient. The friction coefficient increase stops the microcutting behaviour of primary carbide until volume fraction of carbides reach the critical value **(Fig. 12)**. Such behaviour of primary carbides was observed when the the volume fraction of carbides was above 30%. In the case of lower loads and lower volume fraction of carbides, an increase of friction coefficient is observed **(Fig. 13)**.

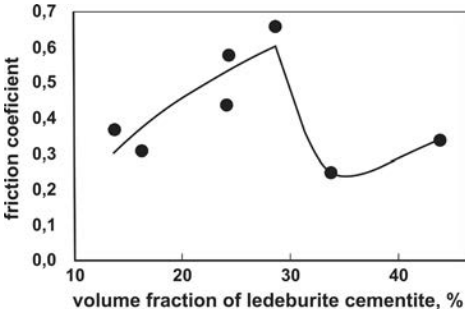


Fig. 12. The effect of primary carbides on the friction coefficient of the cast irons No. 14-20 under the load of 100 N, at time = 2000 s

Rys. 12. Wpływ udziału węglików pierwotnych na współczynnik tarcia żeliw nr 14-20 w warunkach obciążenia 100 N, w czasie 2000 s

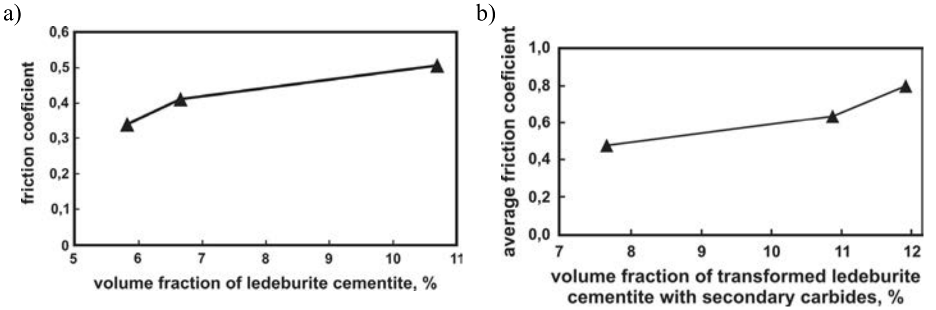


Fig. 13. The effect of the primary carbides on the friction coefficient of the cast steel 200CrNiMo4-3-3 under the load of 50 N, at time = 2000 s: a) sample of cast steel No. 9, b) sample of cast steel No. 8

Rys. 13. Wpływ udziału węglików pierwotnych na współczynnik tarcia staliwa 200CrNiMo4-3-3 w warunkach obciążenia 50 N, w czasie 2000 s: a) próbka ze staliwa nr 9, b) próbka ze staliwa nr 9

Friction coefficient decrease caused by the primary carbides is a result of the Bielajew point position stabilization (maximal shear stress point). The stable position of Bielajew point in combine with the easily propagation of cracks along the carbides precipitation bands could result in catastrophic damage of the mill rolls. **(Fig. 14)**.

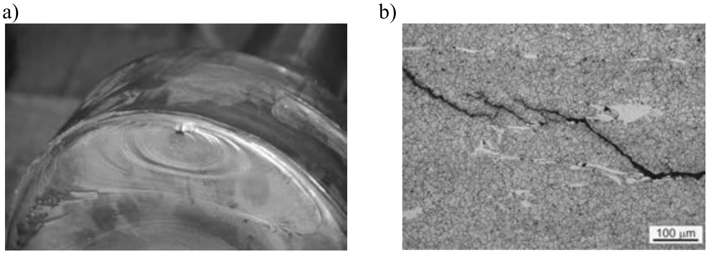


Fig. 14. Fatigue cracking of mill roll of X153CrMo12 steel after the classical heat treatment: a) the places of mill roll damage, b) the participation of primary carbides in the cracks propagation

Rys. 14. Pękanie zmęczeniowe walca hutniczego ze stali X153CrMo12 po klasycznej obróbce cieplnej: a) miejsca uszkodzenia walca, b) udział węglików pierwotnych w rozwoju pęknięcia

SUMMARY

- They act as a cutting edges which degrade the counter sample surface. Cracking and spalling of the carbides during the tests reduce this effect but increase the wear.
- The cutting behaviour of primary carbides could resulted in transfer of the counter sample material on the tested surface.
- During the tests in elevated temperature the primary carbides increases the average linear wear of the material.
- The increase of matrix mechanical properties could reduce the spalling of the carbides from the sample surface. It resulted in the tested material mass loss decrease.
- The increase of volume fraction of primary carbides resulted in increase of friction coefficient. But above the 30% of primary carbides volume fraction in microstructure the decrease of the friction coefficient was observed. Above this critical value the cutting behaviour of primary carbides is reduced and the high hardness of the carbides reduce the wear.

Acknowledgements

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Streszczenie

Wśród materiałów stosowanych na walce hutnicze są takie, które w swojej mikrostrukturze zawierają również węgliki powstające w wyniku przemiany eutektycznej. Ponieważ powstają one z cieczy, nazywane są węglikami pierwszorzędowymi. Ilość oraz kształt tych węglików może istotnie wpływać na własności tribologiczne takich narzędzi.

W pracy przedstawiono rolę morfologii węglików pierwotnych w zużyciu zmęczeniowym na przykładach walców hutniczych po eksploatacji. Przedstawiono również rolę węglików pierwotnych w zużyciu ściernym. Ocenę zużycia ściernego wykonano na podstawie wpływu czasu eksploatacji na chropowatość powierzchni walców pracujących w walcowni zimnej płaskowników. Natomiast rolę morfologii cementytu ledeburytycznego w zużyciu ściernym badano w warunkach testów laboratoryjnych przy stosowaniu zmiennych obciążeń pary trącej oraz temperatury pracy. Wykazano mechanizm mikroskrawania przez odsłonięte węgliki pierwszorzędowe (jako „mikroostrza”) materiału przeciwpróbki.