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WEAR RESISTANCE OF 18%Cr-9%Ni STEEL USED FOR CAST PARTS OF PUMPS OPERATING IN CORROSIVE – EROSIVE ENVIRONMENTS

ODPORNOŚĆ NA ZUŻYCIE STALIWA 18%Cr-9%Ni STOSOWANEGO NA ELEMENTY POMP PRACUJĄCYCH W WARUNKACH KOROZYJNO-EROZYJNYCH

This paper presents the results of experimental studies, the main aim of which has been to demonstrate that changes in the microstructure of austenitic 18%Cr-9%Ni cast steel provoked by the addition of 1.4% boron, and boron with titanium, give increased wear resistance. After melting the high-alloyed 18%Cr-9%Ni cast steel with an addition of boron, and boron with titanium, metallographic examinations were conducted using light microscopy and SEM. These examinations revealed in the austenitic structure of the 18%Cr-9%Ni cast steel, the presence of a eutectic rich in boron and chromium, and characterised by a microhardness of 1838-1890 μ HV_{20}. Additionally, in the cast steel inoculated with boron and titanium, the presence of titanium nitride precipitates was observed. Changes that have occurred in the microstructure as a result of introducing the additions of boron, and boron with titanium, also caused an increase of the cast steel hardness from 212 HV_{30} to 290-320 HV_{30} and 320-350 HV_{30}, respectively. To determine the abrasive wear resistance, 16-hour Miller test was performed (ASTM G 75-07), wherein the abrasive medium was a mixture of SiC and water. Obtaining the hard, rich in boron and chromium, eutectic and titanium nitride precipitates in the structure of 18%Cr-9%Ni cast steel increased the abrasive wear resistance by approximately 21%, according to the data recorded in the sixteenth hour of the test cycle. As an additional benchmark point for the results obtained served the wear resistant, structural, L35GSM steel used for castings working in difficult conditions. Comparing the values of abrasive wear resistance obtained for the 18%Cr-9%Ni cast steel and cast L35GSM steel, an increase in the wear resistance of the 18%Cr-9%Ni cast steel by about 35% has been proved.

Keywords: austenitic, cast steel, miller test, slury abrasiv resistance, microstructure

W artykule przedstawiono wyniki badań eksperymentalnych, których celem było wykazanie, że zmiany w mikrostrukturze austenitycznego staliwa 18%Cr-9%Ni na skutek wprowadzenie dodatku 1,4% boru oraz boru i tytanu skutkują zwiększeniem odporności na zużycie. Po wytopieniu wysokostopowego staliwa 18%Cr-9%Ni z borem oraz z dodatkiem boru i tytanu przeprowadzono badania metalograficzne z wykorzystaniem mikroskopu świetlnego i skaningowego. Badania te wykazały obecność w austenitycznej strukturze staliwa 18%Cr-9%Ni eutektyki bogatej w bor i chrom, o mikrotwardości 1838-1890 $\mu HV_{20.}$ W staliwie modyfikowanym borem i tytanem dodatkowo stwierdzono obecność wydzieleń azotków tytanu. Zmiany jakie zaszły w mikrostrukturze po wprowadzeniu dodatków boru oraz boru i tytanu spowodowały również wzrost twardości staliwa z 212 HV_{30} odpowiednio do 290-320 HV_{30} oraz do 320-350 HV_{30}. Do określenia odporności na zużycie ścierne wykonano 16-godzinny test Millera (ASTM G 75-07), w którym medium ścierającym była mieszanina SiC i wody. Uzyskanie twardej eutektyki bogatej w bor i chrom oraz wydzieleń azotków tytanu w strukturze staliwa 18%Cr-9%Ni doprowadziło do zwiększenia odporności na ścieranie o około 21% w 16 godzinie cyklu badań. Dodatkowym punktem odniesienia uzyskanych wyników było odporne za zużycie, konstrukcyjne staliwo L35GSM stosowane na odlewy pracujące w trudnych warunkach. Porównując otrzymane wyniki odporności na zużycie ścierne staliwa 18Cr-9%Ni oraz staliwa L35GSM wykazano, wzrost odporności na zużycie staliwa 18%Cr-9%Ni o około 35%.

1. Introduction

Conventional austenitic 18%Cr-9%Ni cast steel has good strength properties and resistance to the effect of aggressive and corrosive environments [1-3]. The well-mastered technology of melting this cast steel is the very reason why it is often used for the cast parts of pumps (blades, rotors) [1]. The use of boron in an amount of about 0.003% is well-known in metallurgy and leads to an increase in the steel hardenability. The solubility of boron in iron alloys is very low, and therefore, when present in larger quantities, this element tends to get combined with iron to form very hard and wear-resistant borides (Fe_2B, FeB). These phases may form various eutectics [4-6]. The hardness of borides is very high and reaches about 1800-2350 μHV for FeB and about 1800 μHV for Fe_2B. The hardness of borides also depends on the type of alloying elements present in steel (Mo, W, Mn, Cr – increase the hardness of FeB) [4, 7]. Additionally, as stated in

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the literature, steels subjected to boronising are characterised by very good corrosion resistance and wear resistance [8, 9]. Therefore, an attempt was made to modify the microstructure of the conventional 18%Cr-9%Ni cast steel with an addition of boron, to obtain in this microstructure a boron-containing eutectic increasing the wear resistance of the tested material. The reference material was plain 18%Cr-9%Ni cast steel and cast low-alloyed structural L35GSM steel (UTS=1100MPa, YS=850MPa, EL=8%, Ra=18%). These cast steel grades are widely used by the domestic steel foundries as a wear-resistant material for parts of caterpillar links operating in machines used by the mining industry, for teeth of excavator buckets, parts of construction machinery, and tractors.

Introducing to 18%Cr-9%Ni cast steel, boron in an amount of maximum 3% enlarges the scope of application of this material, including also the elements strongly absorbing electrons (nuclear power) [10].

2. Materials and methods

The examined 18%Cr-9%Ni cast steel with boron was melted in a vacuum induction furnace. After previous deoxidation, boron was introduced into molten metal in the form of ferro-boron. The analysis of boron content in the examined cast steel was made by the Jobin Yvon ULTIMA 2 procedure. The remaining grades of cast steel were melted under the industrial conditions. Chemical composition of the tested cast steel is given in Table 1.

TABLE 1

Chemical composition of the cast steel

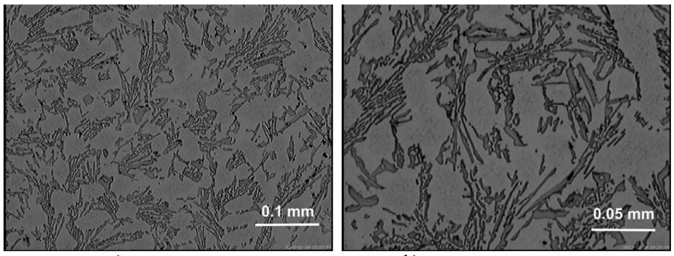
Materials	C	Mn	Si	Cr	Ni	Mo	B	Ti	Cu
	wt. %								
18%Cr-9%Ni	0.025	1.74	0.37	19.66	8.14	0.29	-	-	0.31
29/1	0.13	1,16	0.77	18.7	9.08	0.21	1.43	0.01	0.13
29/3	0.10	1.30	0.65	19.6	9.20	0.20	1.39	0.04	0.10
L35GSM	0.29	0.96	0.48	0.15	0.06	0.36	-	-	0.10

Preliminary metallographic studies were carried out under a Neophot 32 light microscope and by scanning electron microscopy (SEM). To test the wear resistance of selected cast steel grades, Miller test in a 16-hour test cycle version was applied using an SiC – water mixture in a 1:1 ratio (ASTM G 75-07). A measure of abrasion resistance was sample loss in weight recorded during the 16-hour test cycle. Hardness tests were carried out using a Vickers hardness tester. Microhardness was measured under a Neophot 32 microscope with a Hanemann attachment.

3. Discussion and results

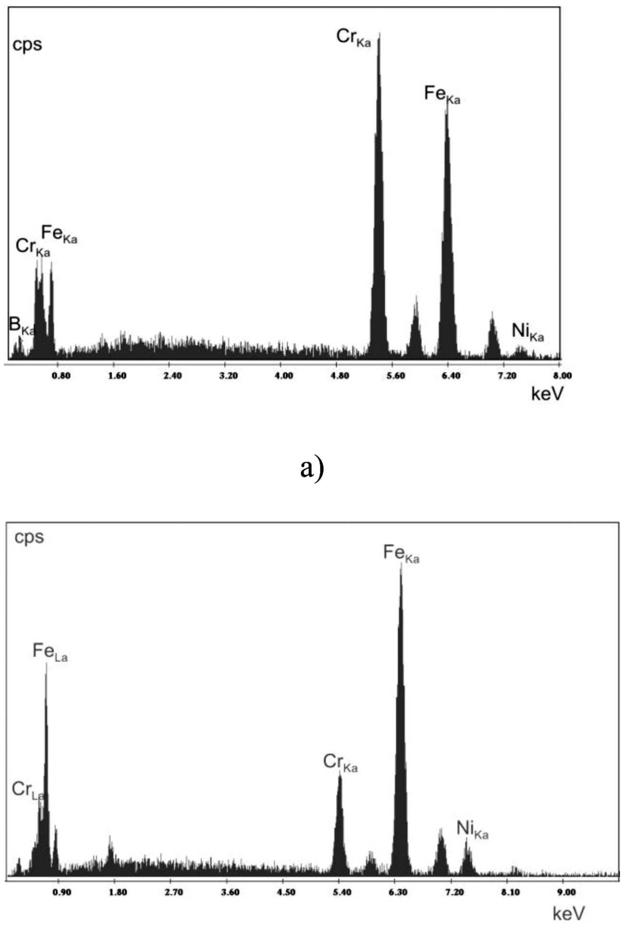
Microstructure of cast steel selected for tests

Microstructure of the heat treated 18%Cr-9%Ni cast steel (without the addition of boron). It consists of an austenitic matrix and small quantity precipitates of ferrite. The addition of 1.4% B to the 18%Cr-9%Ni cast steel has led to the formation of eutectic precipitates in an austenitic matrix (Fig. 1). The preliminary metallographic examinations have indicated that the eutectic precipitates are enriched in boron and chromium (Fig. 2, 3). Titanium, introduced to the cast steel in addition to boron, resulted in the formation of titanium nitride precipitates, occurring together with aluminium oxides (Fig. 4) [11].



a) b)

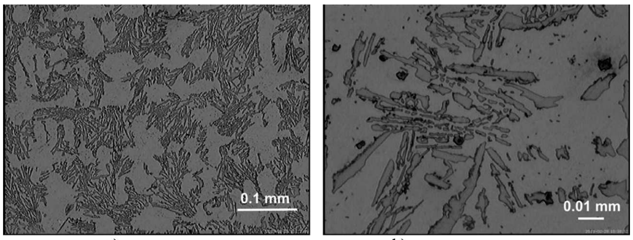
Fig. 1. Microstructure of 18%Cr-9%Ni cast steel with B, light microscope



b)

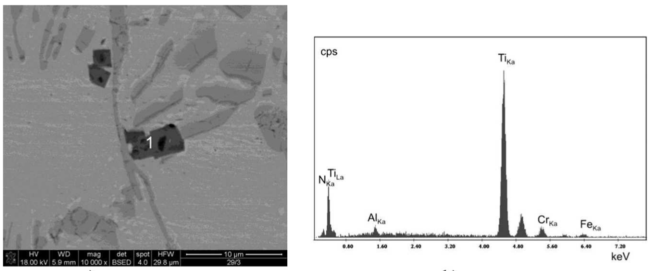
Fig. 2. X-ray spectrum with the energy dispersion (EDS) from the eutectic – a), the matrix – b)

The conducted hardness tests have showed that the addition of boron in an amount of about 1.4% introduced to the 18%Cr-9%Ni cast steel increased its hardness from 212 HV_{30} to 290-320 HV_{30}, while the addition boron of and titanium (in an amount of 0.04%Ti) raised the hardness to 320-350 HV_{30}. For the 18%Cr-9%Ni cast steel with boron, the measurements also included microhardness of the matrix and of the eutectic precipitates. The average value of the matrix microhardness was 370 μHV_{20} (and was higher by about 50 to 60 μHV_{20} than the value obtained for the plain 18%Cr-9%Ni cast steel matrix). Microhardness of the eutectic precipitates was 1838-1890 μHV_{20}. So high hardness of the precipitates may indicate that these are the Fe_2B borides.



a) b)

Fig. 3. Microstructure of 18%Cr-9%Ni cast steel with B and Ti, light microscope

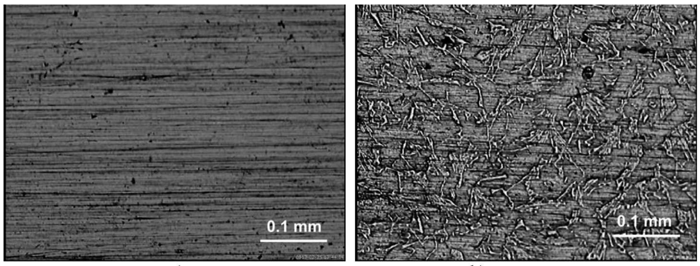


a) b)

Fig. 4. SEM image of 18%Cr-9%Ni cast steel with B and Ti – a), X-ray spectrum with energy dispersion (EDS) from the precipitate 1 – b)

Microstructure of cast steel after a 16-hour abrasion resistance test cycle

A general view of the surface of the samples of the examined cast steel subjected to abrasion tests is shown in Figure 5. The type of the surface layer degradation occurring in the examined cast steel depends on the abrasion resistance of the tested material, a sample of which has been subjected to the to-and-from movement recurring in cycles. The processes that occur in the zone of an interaction between the water mixture with SiC and surface of the samples of the examined material (friction, plastic deformation in the sample-abrasive mixture contact zone) favour the formation of scratches combined with ploughing and waviness. The examinations by light microscopy have showed that interactions taking place between the abrasive mixture and samples of the 18%Cr-9%Ni cast steel with additions of boron reveal the eutectic precipitates rich in boron and chromium (Fig. 5b). At the same time it has been noted that the typical minute cracks are passing through the austenitic alloy matrix and not through the eutectic precipitates. This confirms the high hardness of the eutectic rich in boron and chromium. On the other hand, the top layer of the 18%Cr-9%Ni cast steel shows only a network of scratches and ploughing with the visible non-metallic inclusions. A similar situation has occurred on the surface of the L35GSM cast steel samples.



a) b)

Fig. 5. Surface of the 18%Cr-9%Ni cast steel – a), and 18%Cr-9%Ni cast steel with B – b) after a 16-hour abrasion resistance test cycle, light microscope

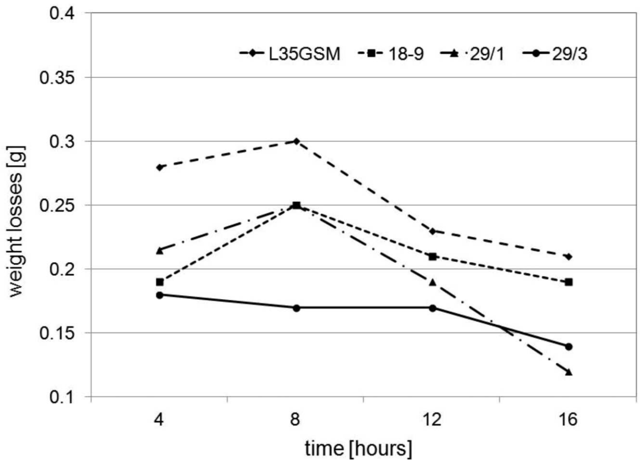


Fig. 6. Changes of weight losses of investigated cast steels during the wear test

Based on the obtained results of the wear resistance test carried out on the examined cast steel grades, it was found that the eutectic precipitates rich in boron and chromium appearing in the microstructure of the austenitic 18%Cr-9%Ni cast steel increased the abrasion resistance of this steel under an impact of the SiC + water mixture (Fig. 6, 7). At the same time, it has been proved that inoculation of the boron-containing 18%Cr-9%Ni cast steel with an addition of Ti increased the wear resistance by about 21% compared to the common grade of the 18%Cr-9%Ni cast steel, and by about 35% compared to the L35GSM cast steel after a 16-hour test cycle. Using calculated values of the total mass losses recorded after 4, 8, 12 and 16 hours of the test duration, the abrasive wear curves were plotted for each material (Fig. 7). Then the results were approximated with a power curve $W(t)= A\cdot(t)^{B}$, where W – mass loss, t – time, A, B – coefficients. The mass wear rate of the examined material was determined from the formula $V_w = A\cdot B\cdot t^{(B-1)}$, presented as a tangent of the angle of inclination of the tangent line to the wear rate curve in the fourth hour of the cycle [12]. For the boron-containing 18%Cr-9%Ni cast steel inoculated with Ti, the wear rate curve is represented by the following equation: $V_w = 0{,}1811\cdot x^{0{,}9446}$. For this cast steel, the mass wear rate is 0.17, while for the 18%Cr-9% Ni cast steel, this value is 0.21.

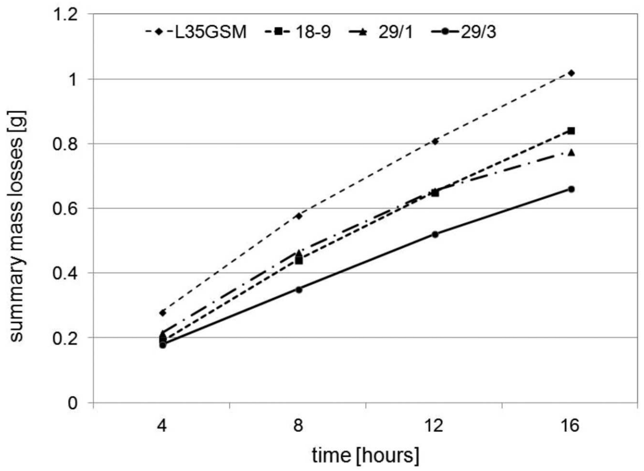


Fig. 7. Summary weight losses of investigated cast steels

4. Conclusions

- The introduction of 1.4% boron to the 18%Cr-9%Ni cast steel increases its hardness from 212 HV_{30} to 290-320 HV_{30} and after the additional introduction of titanium and boron to 320-350 HV_{30}.
- The inoculation of austenitic 18Cr-9%Ni cast steel with additions of titanium and boron hardens the matrix with eutectic precipitates rich in boron and chromium of 1838-1890 μHV_{20} microhardness and with titanium nitrides.
- The presence of boride eutectic and of the precipitates of titanium nitrides in an austenitic matrix of the 18Cr-9%Ni cast steel increases the abrasive wear resistance by about 21%.
- Comparing the abrasive wear resistance of the L35GSM cast steel and 18Cr-9%Ni cast steel inoculated with titanium and boron, an increase in the abrasion resistance by about 35% after the 16-hour test cycle was stated.

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