Zenon PIROWSKI*, Marek GOŚCIAŃSKI, Bartłomiej DUDZIAK****
*Instytut Odlewnictwa; ul. Zakopiańska 73, 30-418 Kraków, Poland
**Przemysłowy Instytut Maszyn Rolniczych; ul. Starołęcka 31, 60-963 Poznań, Poland
e-mail: office@pimr.poznan.pl

WEAR OF FOUNDRY CARBON-IRON ALLOYS IN THE CONDITION OF EROSIVE DESTRUCTION. PART II

Summary

A comparative laboratory research on a special testing stand of casting materials erosive wear have been conducted in terms of assessing their tribological properties. Different types of carbon iron alloys have been used, as well as modified alloys (metallurgically) in order to increase their resistance to this type of wear. Results have been presented in the form of tables and graphs.

***Key words**: wear, erosion, cast iron alloys, agricultural tools, machine elements, parts, castings*

ZUŻYCIE ODLEWNICZYCH STOPÓW ŻELAZA Z WĘGLEM W WARUNKACH NISZCZENIA EROZYJNEGO. CZ. II

Streszczenie

Przeprowadzono laboratoryjne porównawcze badania materiałów odlewniczych w warunkach zużycia erozyjnego w aspekcie oceny ich właściwości tribologicznych z użyciem specjalistycznego stanowiska badawczego. Wykorzystano różne stopy żelaza z węglem; do badań tych użyto także stopy modyfikowane metalurgicznie i cieplnie w celu zwiększenia ich odporności na ten rodzaj zużycia. Wyniki badań zaprezentowano w postaci wykresów i tabel.

***Słowa kluczowe**: zużycie, erozja, stopy żelaza z węglem, elementy maszyn rolniczych, odlewy*

1. Introduction

Many tools, machine parts and agricultural equipment operate under abrasive wear. These conditions have a significant impact on the tool's durability. Next to conventional abrasive wear of the components in dry friction conditions a significant meaning has also a wear in complex erosion conditions, especially when we deal with a wet abrasive medium, which particles impinge on the surfaces of the device at different velocities.

Undoubtedly, this is a stochastic process resulting from the random interaction of particles on the element surface in the real in.e. soil conditions. Individual particles impacts of soil medium cause momentary stresses which are not fully relax resultiong in the gradual accumulation of residual stresses [1]. At the same time, it can cause on the surface of the material: hardening in the microregions, microcracks and damage to the structure of the continuous material. Alloy resistance to erosive wear is largely dependent on its ability to strengthen as a result of the stress caused by external forces.

In the first part of the article the wear resistance of cast iron alloys (ADI) in the dry friction wear condition have been described [2]. Second part discusses the results of tests carried out in the erosion conditions in the water suspension of abrasive medium (quartz sand). In these studies different types of carbon iron alloys have been used, as well as modified alloys (metallurgically and heat treatment).

2. Research material

The research material consists of carbon-iron alloys samples (two types of ductile cast iron: low-alloy and plain; two types of alloy cast steel: chromium-manganese and chromium-nickel in different microstructural variants).

Some of these alloys have been metallurgically modified by nitrogenation (fallowing markings have been used: N - after nitrogenation P - without nitrogenation) and subjected to heat treatment. In the case of low-alloy ductile cast iron a hardening with isothermal transformation (austenitization: 900°C/1.5h; hardening in salt: 280^{o}C/2h) have been done. In the case of chromium-manganese cast steel and chrome-nickel cast steel annealing respectively at 900°C, and 1100°C have been done.

3. Carbon-iron alloys erosive wear research and results

Methods of research and different testing stands for erosive wear tests have been described extensively in many publications in e.g. [3, 7]. In this paper an attempt to assess the behavior of selected carbon - iron alloys have been studied in laboratory tests under such an abrasive wear condition, on the testing stand located in the Foundry Research Institute in Cracow. Basic idea of operation and structure scheme of the testing stand is shown in Figure 1.

This testing stand operates on the similar principle of operation as the centrifugal pump. At the bottom of the container (8) with an abrasive medium water solution (9) special vertical baffles (7) are located with proper flow through channels. Rotor (3) rotates with samples (1), places on the circumference between two plates (2,4) and sets in motion water solution of quartz sand. Centrifugal force causes the ejection of sand in the direction of of the outer wall of the container. The sand on its movement way hits the test samples, and then sinks to the bottom of the container and is again drawn in the central areas. Therefore, the erosive medium flows in a closed cycle.

At the applied rotation speed 450 rpm sample is moving at the speed of 3.7 m/s relative to the container with the erosive medium. Special baffle system with the flow through channels directs the movement of sand on the test samples, intensifying the process of wear. As a result of the friction the temperature of the liquid rises to about 70°C. Impeller design allows the simultaneous examination of 30 samples with following measurements: square side 8 mm and lenght 50 mm. As a destructive medium a water suspension of quartz sand with a grain size of the main fraction 0.20 / 0.32 / 0.40 and uniformity of 84% have been used. The container holds a volume 2.5 dm^3 of sand and 4 dm^3 of water. Tests of erosive wear have been conducted during cycle of 40 hours time. All alloy samples have been tested simultaneously, which provided the same experimental conditions for all samples and provided the possibility of a comparative evaluation between the various carbon iron alloys. As a measure of wear resistance of various carbon iron alloys have been taken the intensity of erosive wear **Z** mg/h, determining the weight loss in time. The test results heve been summarized in the Table 1.

Graphic presenting the results of erosive wear resistance measurements of test carbon iron alloys, reflecting the influence of the applied nitrogenation and heat treatment, are shown in the Figure 2.

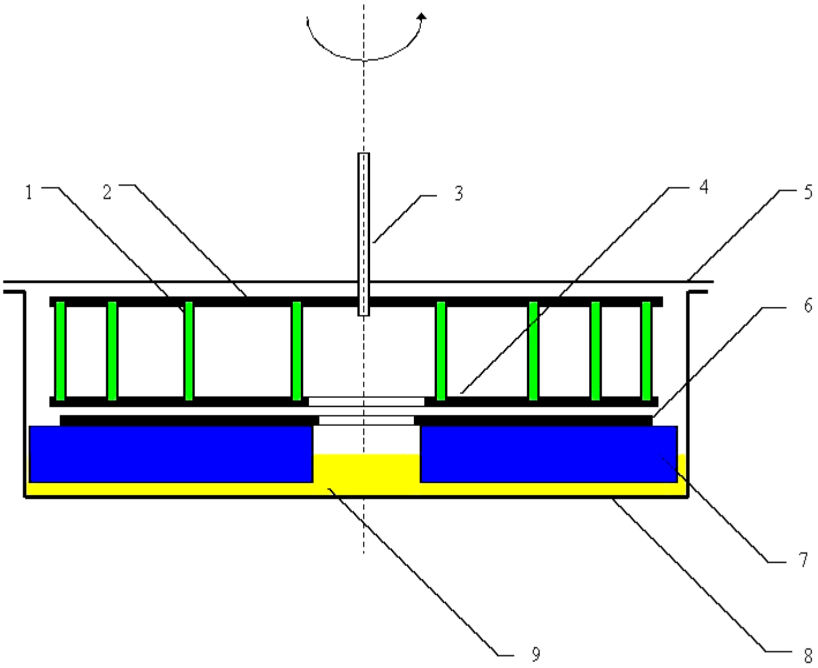


Fig. 1. Scheme of the test stand for erosion testing of metal alloys: 1 - alloy sample, 2 - drive plate, 3 - rotor drive axis, 4 - plate for fastening the alloy samples, 5 - top cover, 6 - horizontal baffle, 7 - vertical baffle, 8 - container, 9 - abrasive medium (quartz sand)

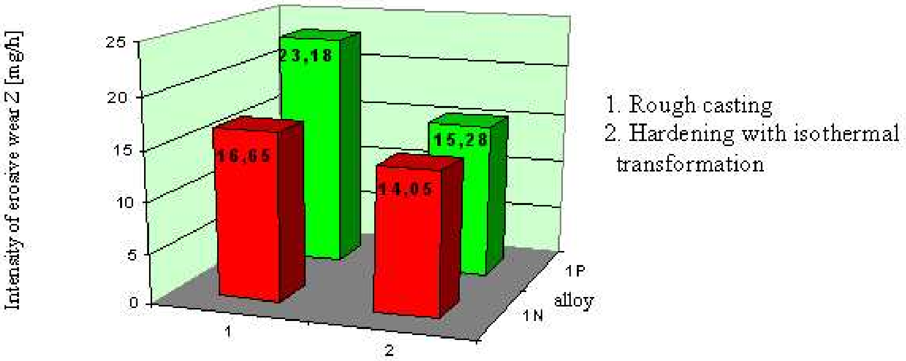
Rys. 1. Schemat stanowiska do badań erozyjnych próbek ze stopów metali: 1 - próbka, 2 - tarcza napędowa, 3 - oś napędowa wirnika, 4 - tarcza mocująca próbki, 5 - pokrywa, 6 - przegroda pozioma, 7 - przegrody pionowe, 8 - zbiornik, 9 - medium ścierne (piasek kwarcowy)

Table 1. Test results of erosive wear intensity of selected carbon iron alloys

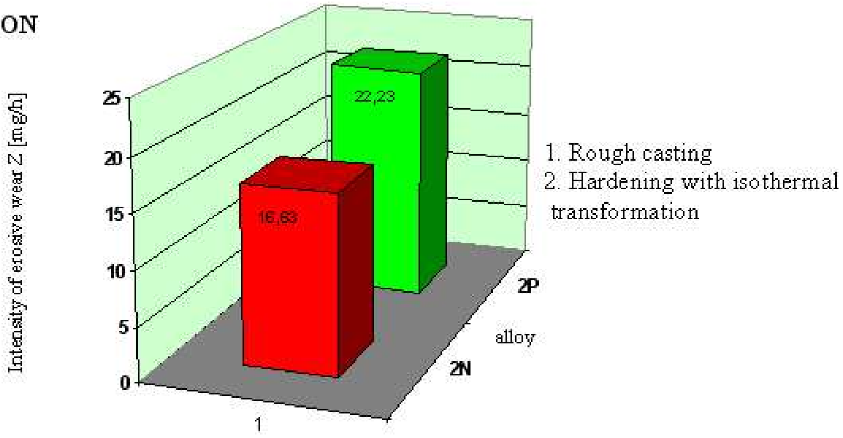
Tab. 1. Wyniki pomiarów intensywności zużycia erozyjnego badanych stopów

No.	Carbon iron alloy type	Applied heat treatment	Metallurgical modification (nitrogenation)	Sample marking	Intensity of erosive wear Z [mg/h]
1.	low-alloy ductile cast iron	without, rough casting	NO	1P	23,175
2.			YES	1N	16,650
3.		hardening with isothermal transformation	NO	1P-hi	15,275
4.			YES	1N-hi	14,050
5.	plain ductile cast iron	without, rough casting	NO	2P	22,225
6.			YES	2N	16,625
7.	chromium-manganese cast steel	without, rough casting	NO	3P	12,350
8.			YES	3N	12,200
9.		annealing at 900°C	NO	3P-900	13,150
10.			YES	3N-900	11,425
11.		annealing at 1100^{o}C	NO	3P -1100	12,175
12.			YES	3N -1100	11,875
13.	chromium-nickel cast steel	without, rough casting	NO	4P	13,025
14.			YES	4N	10,750
15.		annealing at 900°C	NO	4P -900	11,625
16.			YES	4N -900	11,375
17.		annealing at 1100^{o}C	NO	4P -1100	12,350
18.			YES	4N -1100	13,100

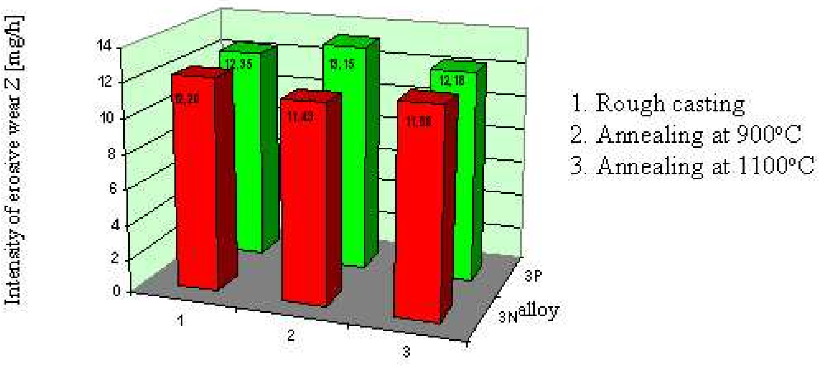
LOW-ALLOY DUCTILE CAST



PLAIN DUCTILE CAST IRON



CHROMIUM-MANGANESE CAST



CHROMIUM-NICKEL CAST STEEL

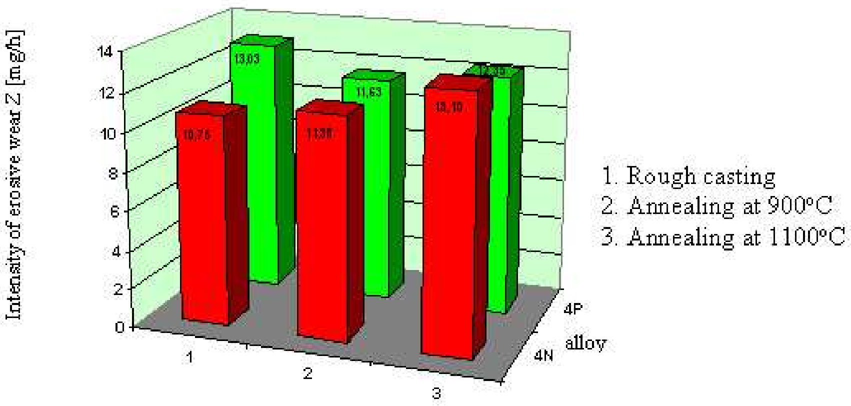


Fig. 2. Intensity of erosive wear of selected carbon iron alloys depending on the type of heat treatment, marked as: 1-4N means alloys after nitrogenation, 1-4P alloys without metallurgical modification

Rys. 2. Intensywność zużycia erozyjnego badanych stopów żelaza w zależności od rodzaju zastosowanej obróbki cieplnej, gdzie: 1-4N oznacza stopy modyfikowane metalurgicznie azotem, 1-4P stopy niemodyfikowane

4. Analysis of the test results

Conducted comperative experiments of carbon iron alloys erosive wear resistance have shown beneficial effects of nitrogen presence on the increase their immunity to this type of wear. Well-visualizated it's been done in the case of ductile cast iron, both types: plain and low-alloy. The slight increase in the content of this additive in the ductile cast iron from level of 0.008% by weight to the level of 0.025% by weight had a significant influence on the intensity of erosive wear during test. In the case of iron plain ductile cast iron, the decrease of wear intensity was more than 25%, and in the case of low-alloy ductile cast iron, the decrease of weat intensity was more than 28%. This phenomenon arises from the strengthening of the individual phases by dissolution of nitrogen, and from the fact that ductile cast iron with nitrogen does not have around the graphite particles ferrite fractions (little resistance to erosive wear). After the nitrogenation graphite is much more fragmented, and in some places has the form of vermicular fractions and even nodular [4].

The tested low- alloy ductile cast iron had a chemical composition typical for ADI cast iron. Hardening with isothermal transformation of ADI cast iron caused a decrease of the erosive wear intensity by more than 30%. The combination of heat treatment with the nitrogenation into the alloy resulted in further decrease of the erosion wear of almost 40%.

A significant increase in erosive wear resistance as a result of nitrogenation have been observed for the chromium-nickel cast steel as well. Wear intensity of this alloy decreased by over 17% after the nitrogenation. Higher wear resistance of the cast steel due to the introduction of nitrogen is determined by the microstructural changes in the alloy under the influence of this element. Tested chromium-nickel cast steel without nitrogen is a typical two-phase alloy, with a small amount of regions of lamellar structure (austenite + carbonitrides) expanding around the austenite grains. Introduction of nitrogen element into the alloy matrix resulted in obtaining a austenitic matrix with inter-dendritic areas of lamellar microstructure. Loss of ferrite (susceptible to erosive wear) increases the resistance of alloy to this type of wear.

Chrome-manganese cast steel in the nature is an austenitic alloy and introduction of nitrogen element did not affect the change in the amount of ferrite in the alloy microstructure. It was found out that the intensity of erosive wear of this cast steel did not change significantly after the metalurgicall modification. Both of the tested alloy samples have been subjected to heat treatment (annealing at 900°C and 1100°C). In the case of chrome-nickel cast steel some increase in the erosive wear resistance have been obtained after the annealing at 900^{o}C. Annealing at 1100°C did not give such a good results. This is due to the microstructural changes that occur as a result of heat treatment. Effect of the heat treatment on the microstructure of such an alloys have been shown in work [5].

Comparing the structural phases of alloys with their erosive wear intensity it was found out that the most resistant phase for this type of wear is austenite, and slightly less - lamellar microstructure (austenite and carbonitrides). Much lower resistance for this type of wear had ferrite. Therefore is why treatments that restrict the amount of this phase in cast steel (introduction of nitrogen element into the alloy and annealing at 900°C) had helped to reduce the erosive wear of tested alloys. However, annealing at 1100°C of chromium-nickel cast steel with nitrogenation had lead to the formation of more ferrite phases with interdendritic areas distribution, which increases the intensity of erosive wear.

5. Conclusion

Summarizing the results of erosive wear, it was found out that the use of appropriate heat treatment (hardening with the isothermal transformation) for ductile cast iron and nitrogenation as a metallurgicall modification, can greatly increase the resistance to erosion. Obtained in this method alloy properties and erosive wear resistance will be comparable to expensive high-alloyed cast steel (without the addition of nitrogen). Among the studied foundry materials most resistant to wear by erosion was chrome-nickel cast stell in a state of a rouch casting. This material had more than 23% lower wear intensity than the best low - alloy ductile cast iron with the addition of nitrogen and hardfaced with isothermal transformation. However, the barrier for its common use is very high cost of production, particularly the cost of batch materials (nickel, chromium, molybdenum, etc.) and alloy properties (strength, ductility, impact resistance, fatigue, mechanical, thermal strenght etc.) which have to be individually adjusted to the specific operating conditions for the element.

It must be remarked that these results refer to erosive wear carried out for alloys tested at about 70°C temperature, in a particular abrasive medium (quartz sand). Changing these conditions, for example the significant increase in the temperature at which the wear process takes place, changes strongly the results of erosive wear intensity, especially for ductile iron with heat treatment (isothermal transformation) when the temperature rises above 350°C [6].

6. References

[1] Jura S., Suchoń J.: Zużycie erozyjne stopów żelaza jedno i wielofazowych. Krzepnięcie Metali i Stopów, Nr 34/1997 PAN - Oddział Katowice.

[2] Gościański M., Pirowski Z., Dudziak B.: Porównawcze badania właściwości tribologicznych żeliw ADI w warunkach tarcia suchego. Część I. Journal of Research and Applications in Agricultural Engineering, 2012, Vol. 57(1), s. 51-54.

[3] Pirowski Z., Gwiżdż A., Uhl W., Wodnicki J.: Fonderie Fondeur d'aujourd'hui. 2003, N^{o} 225, 20-27.

[4] Pirowski Z., Olszyński J., Radzikowska J.: Innowacje w odlewnictwie - część II; rozdział IV.2: Metalurgia pod ciśnieniem. Instytut Odlewnictwa, Kraków; 2008, s. 381-389.

[5] Pirowski Z., Gwiżdż A., Gazda A.: Innowacje w odlewnictwie - część III; rozdział IV.2: Metalurgia pod ciśnieniem; Instytut Odlewnictwa; Kraków; 2009, s. 277-287.

[6] Gazda A.: Analysis of decomposition processes of ausferrite in copper-nickel austempered ductile iron. Journal of Thermal Analysis and Calorimetry; 2010; 102(3); s. 923-930.

[7] Nosal S.: Tribologia, Wprowadzenie do zagadnień tarcia, zużywania i smarowania. Wydawnictwo Politechniki Poznańskiej, 2012.

The work was partly done within the framework of the EUREKA project E! 4102 MEDHIAL - Decision No. 46/2009 Director of the National Centre for Research and Development from the 2009-12-31.