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AN ASSESSMENT OF THE APPLICABILITY OF AUSTEMPERED DUCTILE IRON CONTAINING Mo AND Ni FOR MINING MACHINES PARTS

OCENA PRZYDATNOŚCI ŻELIWA SFEROIDALNEGO AUSFERRYTYCZNEGO ZAWIERAJĄCEGO Mo I Ni NA CZĘŚCI MASZYN GÓRNICZYCH

The research described in this article is a fragment in the series of published works trying to determine the applicability of new materials for parts of the mining machinery. Tests were carried out on the – very popular in mining applications – 36HMN steel and three types of the austempered ductile iron, using special stand for the controlled abrasion testing of samples subjected to the effect of loose abrasive. Tests carried out with the use of corundum showed the competitive properties of cast iron as compared with the examined steel. Microscopic evaluation, hardness measurements and magnetic tests showed that the surface layer of austempered ductile iron undergoes a strong work hardening, resulting in abrasion wear indices superior to those of the steel for heavy-duty use.
Keywords: austempered ductile iron, wear resistance, microstructural transformactions

Badania przestawione w artykule wpisują się w cykl publikacji określających przydatność nowych materiałów na części maszyn górniczych. Testy przeprowadzono dla popularnej w zastosowaniach górniczych – stali 36HMN i trzech rodzajów żeliwa sferoidalnego ausferrytycznego, na specjalnym stanowisku do kontrolowanego ścierania próbek suchym ścierniwem. Badania zrealizowane z użyciem korundu wykazały konkurencyjne właściwości żeliwa w stosunku do badanej stali. Ocena mikroskopowa oraz pomiary twardości i magnetyczne wykazały, że w warstwie wierzchniej żeliwa sferoidalnego ausferrytycznego zachodzi silne umocnienie spowodowane zgniotem, co skutkuje lepszymi niż dla stali wskaźnikami zużycia dla dużych obciążeń.

1. Introduction

Polish mining industry uses for special applications the well-proven materials, showing satisfactory resistance to the conditions generally prevailing in mining operations. This attitude is also justified by the need to ensure the highest possible reliability of constructions usually operating under extreme conditions. However, it is the development of this industry that forces continuous progress, and hence the search for new materials that can meet higher quality standards and offer competitive prices. One of such new materials, undergoing rapid development all over the world, is without any doubt the austempered ductile iron [1-7]. It has a number of properties that make it suitable also for mining applications, to mention only an ease of shaping the cast product geometry, high levels of strength, high wear resistance, vibration damping capacity, density by about 10% lower than that of steel or cast steel, etc. Therefore, recently, studies have been conducted to find out what are the chances to use this cast iron in some special applications, such as e.g. parts of longwall scraper conveyors [3].

Austempered ductile iron is produced by casting and heat treatment of common cast iron. Its microstructure is formed during casting, when special methods of metallurgical inoculation of molten metal ensure the formation of graphite in the form of nodules with a diameter of tens of micrometers, while the subsequent heat treatment shapes the matrix and changes it into a mixture of lamellar ferrite and austenite. The properties that such a microstructure provides are classified according to the European Standard [8], giving the four typical grades of austempered ductile iron. The properties of the austempered ductile iron strongly depend on the parameters of heat treatment, which consists of the operations of austenitising and austempering. Therefore, searching for specific applications is usually limited to the selection of heat treatment parameters in combination with the properly chosen cast iron chemical composition. Yet, due to the large number of variables, this engineering task is not an easy one.

In this article, the authors tried to compare the three types of austempered ductile iron with forged 36HMN steel, popular in mining applications. The ductile iron containing 1.5% Ni and 0.47% Mo was after casting subjected to the three different variants of heat treatment. The resultant material was then evaluated for its abrasion wear resistance using special test-stand (see Fig. 1), and numerous tests were performed

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to establish which phenomena can influence the quality of potential applications.

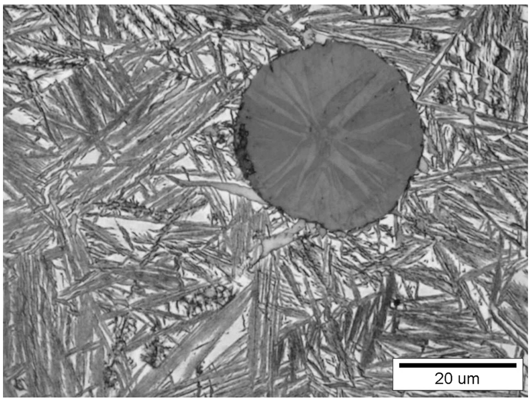

Fig. 1. Microstructure of typical austempered ductile iron

2. Methodology

The ductile iron containing 1.5% Ni and 0.47% Mo was cast into three rods with the dimensions of Ø60×450mm. Samples cut in shape of Ø60×20mm were austenitized in a Nabertherm furnace, while austempering was carried out in a salt bath at a temperature of 370, 320 and 270°C (Table 1). From castings, specimens were cut out to test the abrasion wear behaviour (Fig. 2), to measure hardness and to carry out the metallographic studies. The results of hardness measurements taken on the steel and heat-treated cast iron are compared in Table 1.

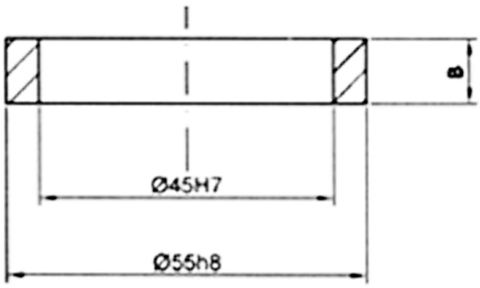

Fig. 2. The design of sample used for the measurement of weight loss during tests carried out on an apparatus available at the Institute of Mining Mechanisation: B – the sample width: upper B = 10 mm, bottom B = 6 mm

TABLE 1

Heat treatment and initial hardness of the tested materials

Specimen designation	Heat treatment				Hardness
	Austenitising		Austempering		
	[°C]	[min .]	[°C]	[min .]	HRC
ADI NiMo 370_150	900	120	370	150	32
ADI NiMo 320_150			320		35
ADI NiMo 270_150			270		43
Specimen designation	**Austenitising (quenching – oil)**		**Tempering**		**Hardness**
	[°C]	**[min .]**	**[°C]**	**[min .]**	**HRC**
36 HMN	860	150	180	60	50

3. Stand for the abrasion wear test

The abrasion wear test stand has been designed and constructed at the Institute of Mining Mechanisation. It's complex with engine, frequency converter, clutch, shaft, samples fixing system, and cover. Detailed description is given in the literature [9]. In the apparatus for abrasion testing using loose abrasive, the samples had the form of rings with outer diameter Ø55mm and inner Ø45 and width of upper part 10 mm and bottom 6 mm, with the face surfaces exposed to wear. Tests were performed using corundum of the 0.05-0.2 mm grain size as an abrasive. Measurements were carried out for the three different variants of compressive stress formed between the samples, i.e. 0.063 MPa, 0.094 MPa and 0.125 MPa.

All samples subjected to abrasion wear test were next cut into two parts, and on the resulting cross-sections, tests and examinations were made, including hardness measurements, macro- and microscopic examinations and magnetic measurements. Vickers hardness under a load of 100 g was measured as a distribution of values in the direction from the face of the tested sample towards its interior, i.e. the core. Macroscopic examinations were carried out using a stereoscopic microscope and examining the degree of abrasion wear and damage mode on the sample face. Microscopic observations were conducted on metallographic specimens unetched and etched with 3% Nital, at a magnification of ×200 and ×1000, identifying the edge exposed to abrasion wear conditions. Magnetic measurements were based on the use of a ferrite content measuring device which, applying the method of eddy current, allowed the assessment of ferromagnetic phase content (ferrite and / or martensite) in each sample.

4. Results and discussion

The results of the abrasion test in a corundum abrasive environment show high resistance of the tested materials, comparable with materials used up to date in the mining industry [9]. Clearly visible are the differences in the behaviour of cast iron heat treated under different conditions (Fig. 3a, b, c). The best abrasion wear resistance is offered by the ductile iron austempered at 370°C, which is the most ductile material being tested. This is a very interesting phenomenon, because it indicates that abrasion wear resistance may be affected by parameters other than hardness. Looking carefully at the results of the abrasion testing of cast iron and steel, it can be concluded that as the load increases, the cast iron starts behaving in a mode superior to the steel tested. It is characteristic that under the load of 0.094 and 0.125 MPa both types of cast iron with the lowest initial hardness behave in a similar manner and show similar degree of the wear resistance. The hardest grade has the resistance similar to that of 36HMN steel.

The abrasion test results can be easily correlated with the results of hardness distribution on the specimen cross-section, starting from the edges of the specimen most exposed to the wear effect (Fig. 4a, b, c, d). On the distribution diagram it is easy to note the surface hardening effect in each of the materials tested for abrasion wear, resulting in much higher hardness values measured in the top layer, just below the surface subjected to abrasive impact. The highest degree of hardening was recorded in the specimens of the highest ductility, austempered at 320 and 370°C – more than 100units of hardness in the surface layer vs. the core. The increase of hardness was similar in the 36HMN steel and the hardest NiMo 270_150 ADI grade.

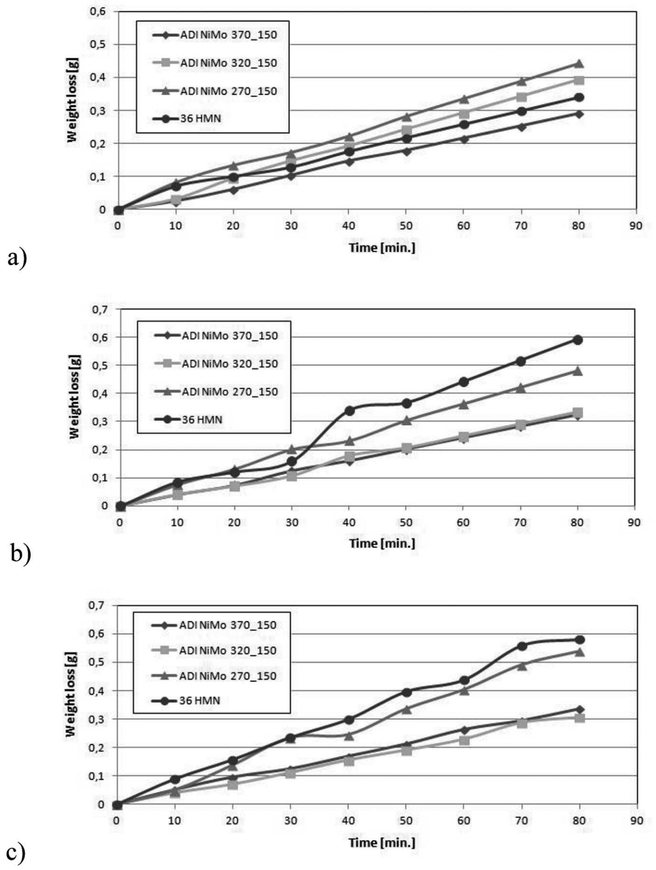

Fig. 3. The results of abrasion test carried in the environment of dry corundum abrasive. Compressive stress: a) 0,063MPa, b) 0,094MPa, c) 0,125MPa

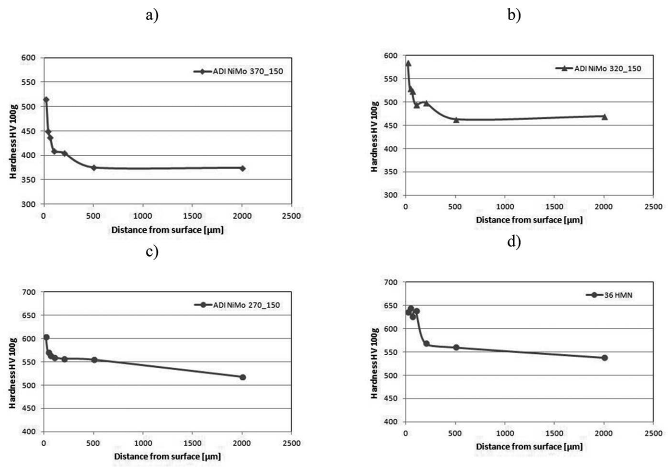

Fig. 4. The results of hardness measurements plotted as a distribution of hardness values in the specimens of cast iron and steel

The worn out surfaces were subjected to thorough stereoscopic examinations, which revealed different forms of the surface wear. Figures 5a and 5b shows the surface of one of the specimens before and after the impact of the abrasive material. The milled surface clearly changes its character and becomes the surface cut with gaps of uneven plastic deformation and microcutting losses. The surface exposed to abrasion also shows a heterogeneity in the process of wear – some parts of this surface are more exposed to the effect of abrasion than the others.

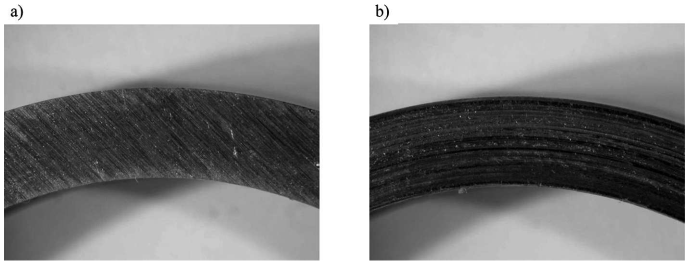

Fig. 5. View of the NiMo 270_150 ADI sample surfaces after milling before the abrasion test (a) and with traces of wear after the test (b)

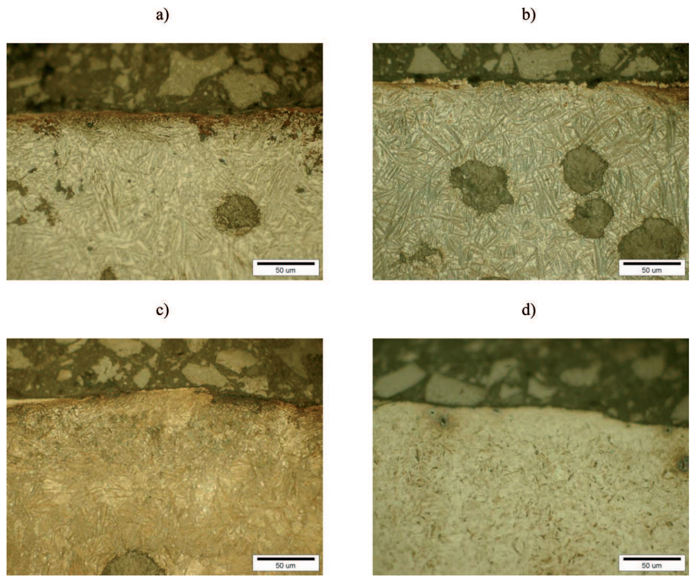

Fig. 6. Surface layer microstructure after the abrasion test. Samples: a) ADI NiMo 370_150, b) ADI NiMo 370_150, c) ADI NiMo 270_150, d) 36 HMN

The surfaces of the examined specimens can also be assessed in combination with the microstructure observed on the cross-section (Fig. 6a,b,c,d). According to this assessment, the most uniform run of the abrasion wear shows the sample of ADI NiMo 370_150 with the lowest hardness, austempered at 370°C. Other specimens show clear signs of microcutting, except that for the hard variants these signs of microcutting are of less plastic nature than they are in the specimens with a lower hardness.

Micrographs showing edges of the specimens, particularly the unetched ones, indicate subtle differences in the effect that the abrasive exerts on the specimen material. In specimens of high ductility, the grains of the abrasive deform the specimen material rather than cut it in microregions, as is the case of a hard material (Fig. 7b). In cast iron, this mode of the abrasive effect changes the shape of graphite nodules in a deformed microstructure (Fig. 7). Microcutting is rather characterised by the presence of jagged and irregular edges, as shown in Figure 7b.

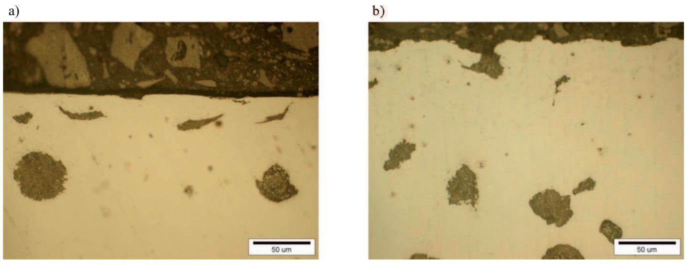

Fig. 7. Edges of specimens after the abrasion test carried out on austempered ductile iron: a) austempered at 370°C, b) austempered at 320°C

The measurements of ferromagnetic phases in cast iron and steel showed slight differences in the magnetic nature of the microstructure. All cast iron samples showed a similar level of magnetic properties, i.e. about 40%, while the content of ferromagnetic phases in the steel sample was estimated at 68%. For steel, this result indicates the presence of large amounts of the ferromagnetic martensite and paramagnetic phases like the retained austenite and carbide phases formed during tempering. The remaining samples are much more difficult to analyse. A similar level of the content of ferromagnetic phases in cast iron (i.e. of ferrite and martensite) gives a similar volume content of the remaining phases, i.e. of austenite and graphite. The results of hardness measurements (Fig. 4) and different level of the surface layer hardening indicate, however, that despite the same content of phases, their properties differ significantly. Analysis of the microstructure shown in Figures 6 enables recognising different morphology of the phases which, however, could not contribute in a way so significant to the increase of hardness. The only possible explanation seems to be the transformation of metastable austenite to martensite under the effect of the, previously documented, deformation in the surface layer of the specimens subjected to abrasion. This phenomenon is known from earlier studies of the austempered ductile iron [10-12]. Analysis of the increase in hardness suggests that the transformation must have occurred most intensely in the ductile iron austempered at 370°C.

5. Summary

The article compares the 36HMN steel and three types of austempered ductile iron with different hardness levels. It was found that during the abrasion test using carborundum, steel behaved in a mode similar to cast iron with a hardness of 43HRC. The best results of this test were, however, obtained on the cast iron with lower hardness, which was observed to undergo a very strong surface hardening under the effect of cold work, thus reducing the abrasion wear. The surface hardening effect was probably due to the presence in microstructure of the metastable austenite, which underwent the transformation to martensite during abrasion.

The research also clearly shows that the tested types of austempered ductile iron are competitive with the 36HMN steel, especially as regards the abrasion wear resistance. The encouraging test results indicate a high research potential for this kind of cast iron and considerable application opportunities.

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REFERENCES

[1] www.zanardi.com
[2] www.ductile.org
[3] A. Wieczorek, D. Myszka, Scientific Conference „Temag", Wisła (2011).
[4] J.R. Keough, K.L. Hayrynen, 8th Int. Symposium SPCI, Beijing, China, (2006).
[5] J. Arnazabal, I. Gutierrez, J.M. Rodriguez-Ibabe, J.J. Urcola, Materials Science and Technology **8**, 263-273 (1992).
[6] J. Yang, S.K. Putatunda, Materials Science and Engineering **A382**, 265279 (2004).
[7] K. Katuku, A. Koursaris, I. Sigala, J. of Materials Processing Technology **209**, 2412-2420 (2009).
[8] European Standard PN-EN 1564 (1997).
[9] A. Dolipski, A. Wieczorek, Scientific Conference „Górnictwo Zrównoważonego Rozwoju 2010", Gliwice (2010).
[10] U. Seker, H. Hasirci, Journal of Materials Processing Technology **173**, 260-268 (2006).
[11] J.L. Garin, R.L. Mannheim, Journal of Materials Processing Technology **143-144**, 347-351 (2003).
[12] D. Myszka, Archives of Metallurgy and Materials **52**, 1-6 (2007).

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