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INITIAL ASSESSMENT OF ABRASIVE WEAR RESISTANCE OF AUSTEMPERED CAST IRON WITH VERMICULAR GRAPHITE

WSTĘPNA OCENA ODPORNOŚCI NA ŚCIERANIE ŻELIWA Z GRAFITEM WERMIKULARNYM HARTOWANEGO IZOTERMICZNIE

The work compares the abrasive wear resistance of cast iron containing vermicular graphite, measured in the as-cast state and after austempering carried out at 290°C, 340°C, or 390°C. The examinations were performed by means of the T-01M tribological tester using the pin-on-disc configuration. Specimens used for examinations were taken from the end tabs of the tensile specimens, these being cut out of the test walls of the double-leg keel block test castings. Examinations proved that the austempering process increases the abrasive wear resistance of vermicular cast iron by several times as compared with the as-cast material. A tendency for a slight decrease in abrasive wear with an increase in austempering temperature can be stated. The coefficient of friction took a little higher values for cast iron after thermal treatment than for the as-cast material. The work was completed with roughness examination by means of electron scanning microscopy.

Keywords: cast iron, vermicular graphite, austempering, abrasive wear resistance

W pracy porównano odporność na ścieranie żeliwa z grafitem wermikularnym w stanie lanym oraz po hartowaniu izotermicznym przeprowadzonym w temperaturach 290°C, 340°C i 390°C. Badania odporności na ścieranie przeprowadzono przy użyciu zestawu trybologicznego T-01M typu trzpień-tarcza. Próbki do badań pochodziły z próbek wytrzymałościowych wyciętych ze ścianek badawczych wlewków próbnych w kształcie odwróconej litery „U". Badania wykazały, że poddanie żeliwa wermikularnego hartowaniu izotermicznemu prowadzi do kilkukrotnego wzrostu odporności tworzywa na ścieranie w porównaniu z żeliwem w stanie lanym. Zaobserwowano niewielki spadek zużycia wraz ze wzrostem temperatury hartowania. Współczynnik tarcia dla żeliwa po obróbce cieplej przybrał nieco większe wartości aniżeli w przypadku żeliwa w stanie lanym. W ramach pracy wykonano także badania chropowatości z wykorzystaniem mikroskopii skaningowej.

1. Introduction

Many machine elements, from which the high abrasion resistance is required, are made of cast iron. They include e.g. grinding balls and liner plates for various types of mills, vehicle tracks, or disc and drum brakes. The abrasion-resistant castings are made of either white or grey cast iron [1, 2], depending on specific requirements and working conditions. They can also be made of cast steel, and in this case their technological properties can be improved by creating the alloyed layer at their working surfaces [3].

According to C. Podrzucki [1], cast iron is a material which fully meets most of the requirements put forth to the castings working in such conditions as vehicle discs or drum brakes. The basic material for castings of this type is the non-alloyed gray cast iron with flake graphite uniformly distributed within the pearlite matrix. Opinions vary in the matter of suitability of nodular cast iron for brake drums, however [1]. Its application is favourable due to its good mechanical and plastic properties, and its remarkable resistance to thermal fatigue, higher than in the case of grey cast iron. But the nodular cast iron castings exhibit a tendency to buckle under the influence of temperature changes, which – on the other hand – restricts application of the considered alloy to a large degree.

The cast iron with vermicular graphite precipitates exhibits higher mechanical properties than the one containing flake graphite, and manifests greater thermal conductivity and vibration damping capacity than nodular cast iron. This type of cast iron becomes more and more popular as a material for many types of castings, including brake drums or discs. It was already found over thirty years ago [2] that the durability of brake discs made of vermicular cast iron with pearlitic matrix is distinctly greater than the durability of such elements made of cast iron with flake graphite and a matrix of the same type. The shape and the size of graphite precipitates influence also the abrasive wear resistance of graphitized steel [4].

The microstructure of cast iron and the properties of its components influence significantly the abrasive wear resistance of the material. Therefore it is reasonable to search for the possibilities of enhancing the abrasive wear resistance of vermicular cast iron by achieving the austenitic-ferritic matrix, as it is done for austempered ductile iron (ADI), which ex-

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hibits remarkably high mechanical properties and an excellent abrasive wear resistance [5].

2. The purpose, the scope, and the results of investigations

The purpose of investigations was an initial assessment of the possible degree of increasing the abrasive wear resistance of vermicular cast iron by transforming the alloy matrix from the ferritic-pearlitic one to the ausferritic one by means of heat treatment. Experiments were carried out for vermicular cast iron produced under industrial conditions of chemical composition shown in Table 1.

TABLE 1
Chemical composition of the examined vermicular cast iron

Content of elements, %						
C	Si	Mn	Cu	P	S	Mg
3.27	2.80	0.20	0.98	0.051	0.0127	0.0166

The presence of copper in the amount of about 1% should be noticed. Such a composition was aimed to obtain the as-cast alloy matrix containing as much as possible of pearlite, advantageous for the effectiveness of the intended heat treatment. The detailed data concerning this type of vermicular cast iron can be found in Reference [6]. The test castings were double-leg keel blocks with wall thickness of 25 mm (type IIb according to the Standard [7], see Fig. 1).

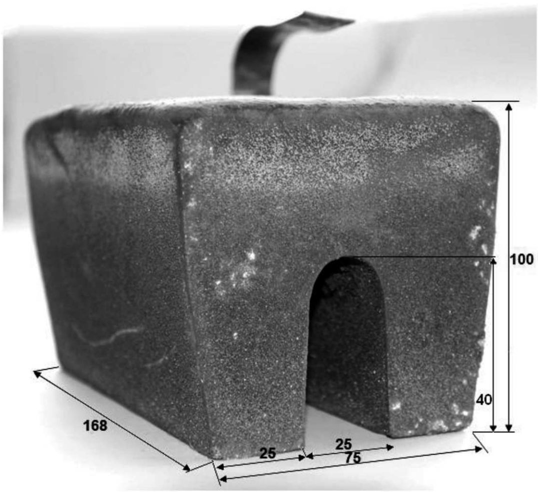

Fig. 1. Test keel block of IIb type, according to the Standard [7], cast of the examined vermicular cast iron

Figure 2 presents the shape and the size of graphite precipitates in the examined as-cast vermicular iron, as well as the microstructure of the material.

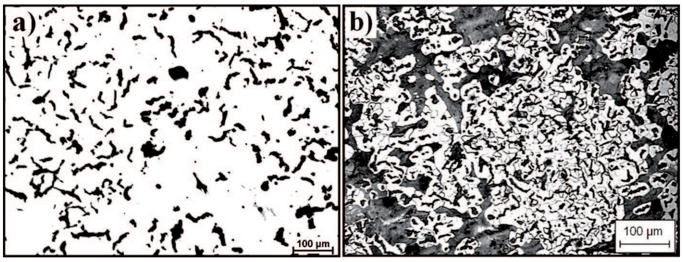

Fig. 2. The as-cast vermicular iron: (a) the shape and the size of graphite precipitates, (b) the microstructure of the alloy, etched with Nital

The tensile strength R_m of the investigated cast iron fell within 360 MPa – 400 MPa range, the yield strength $R_{p0.2}$ was from 300 MPa to 320 MPa, the unit elongation A_5 – within the range of 3.0-3.3%, and the hardness reached 166-169 HB [6]. Investigations presented in References [8] and [9] confirm that these mechanical properties can be significantly changed by austempering. The appropriate selection of austempering temperature makes possible to rise the tensile strength even by about 150% (retaining the unit elongation of the cast iron within 0.5-0.7%), or – in another case – to achieve a smaller degree of increase in R_m value while providing elongation within the range of 1.5-1.8%.

The present work deals with further experiments concerning the possible enhancement of tribological properties of the examined material.

The material for examination was taken from tensile specimens used for examination of mechanical properties, i.e. either from those simply cut out of the as-cast material or from the ones which underwent thermal treatment according to the data presented in Table 2.

TABLE 2
Parameters of thermal treatment of the examined vermicular cast iron

Thermal treatment option	Austenitization		Austempering	
	Temperature [°C]	Time [min]	Temperature [°C]	Time [min]
A	960	90	390	90
B	925	120	340	120
C	960	90	290	150
D	960	150	290	150

Specimens intended either for metallographic examination or for abrasive wear tests were cut out of the end tabs of tensile specimens. The latter specimens were cylinders of 4 mm diameter and 35 mm length. The sliding area of a cylinder was 12.56 mm^2, and the pressure exerted by a specimen was equal to 1.56 MPa.

Figure 3 shows microstructures of vermicular cast iron after the thermal treatment and Figure 4 presents a tribological tester working in a pin-on-disc configuration used for the abrasive wear resistance tests carried out for the material under consideration.

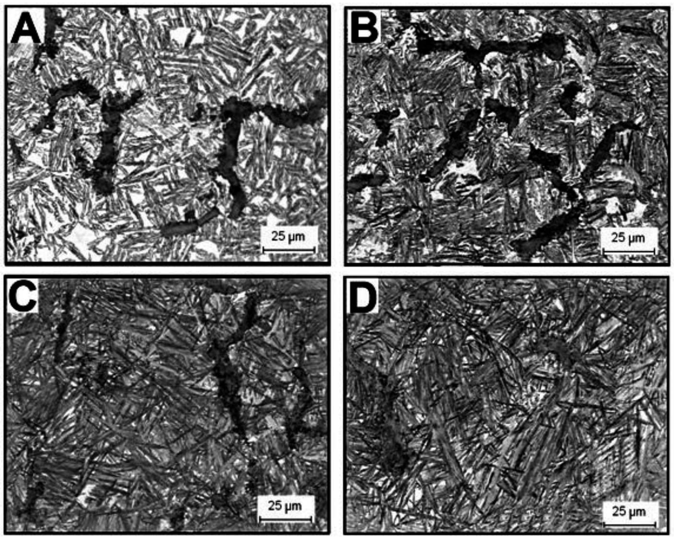

Fig. 3. Microstructures of vermicular cast iron after thermal treatment according to the option A, B, C, or D (Table 2); etched with Nital

Fig. 4. Tribological tester working in a pin-on-disc configuration: 1 – specimen (pin); 2 – counter surface (disc); 3 – weights; 4 – tensometric force sensor; 5 – records of friction force

During the experiment the vertically mounted, immobile cast iron specimen was pressed with the 19,62 N force to the counter surface, constituted by the heat-treated NC10 steel disc. The sliding speed was equal to 0.55 m/s. Examinations were carried on under the dry friction conditions. Each specimen was abraded along the total sliding distance equal to 2000 m. The mass loss of each specimen was determined by weighing it every 500 m.

The tester was equipped also with a contact thermocouple, so that the specimen temperature can be measured during the abrasion test. This temperature was measured at the end of the examination by touching the specimen surface with the thermocouple.

The average intensity of abrasive wear I_{sw} was determined from the mass loss measurements according to the formula [10]:

$$I_{sw} = \frac{Z_{sw}}{s} \ [g/m], \tag{1}$$

where Z_{sw} is the mass loss [g] of a specimen after a fixed sliding distance; s – the fixed sliding distance [m].

The tester makes possible continuous measurement of the friction force and recording of results by means of a tensometric sensor system. The coefficient of friction was calculated from the formula [10]:

$$\mu = \frac{T}{N} \tag{2}$$

where: T denotes the friction force, while N stands for the pressing force.

The obtained results allowed for determining the kinetics of abrasion of the examined cast iron. Figure 5 presents the tribological wear versus the sliding distance, while Fig. 6 compares the average intensities of wear for the examined types of cast iron determined after abrading them along the distance of 2000 m.

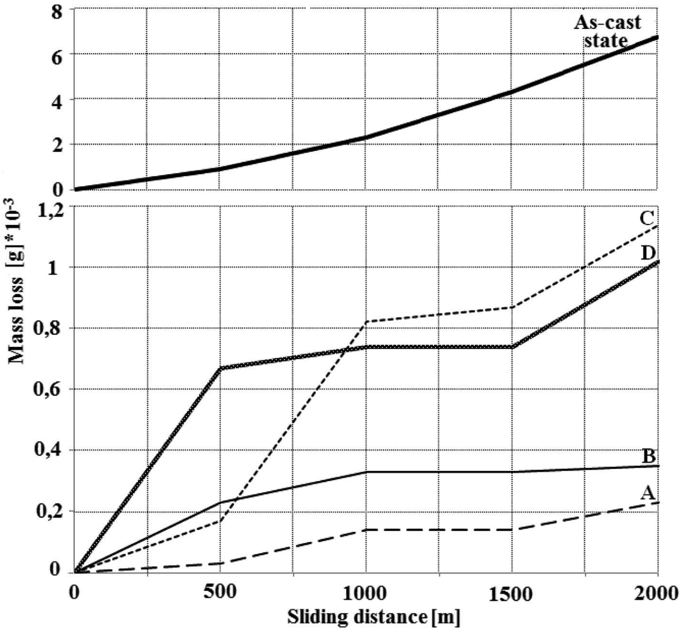

Fig. 5. The mass loss of cast iron specimens along the sliding distance of 2000 m; A, B, C, D – types of thermal treatment according to Table 2

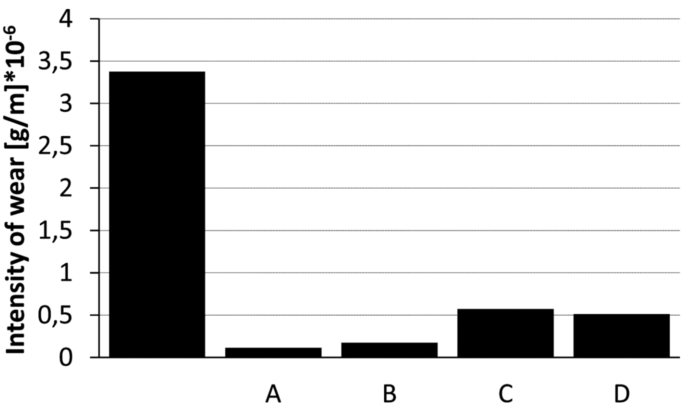

Fig. 6. Comparison of the average intensities of wear along the sliding distance of 2000 m; A, B, C, D – types of thermal treatment according to Table 2

After completion of the abrasion test, the measurements concerning geometry of the examined specimens were taken by means of a scanning microscope of Phenom-World BV production. The results of surface texture observations, as well as the course of lines along which the surface roughness was examined are exemplified in Fig. 7.

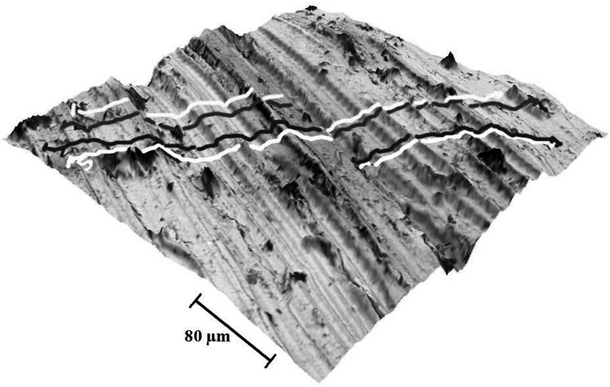

Fig. 7. The after-abrasion surface topography of a specimen heat treated according to the option D with marked lines along which roughness was measured

The results of roughness measurements, values of the coefficient of friction, and maximum temperature of specimens during the test are gathered in Table 3.

TABLE 3

The cast iron specimen surface roughness after abrasion test, the coefficient of friction, and the maximum temperature of specimen during the test

Type of cast iron specimen	Roughness parameters [μm]		Coefficient of friction μ	Maximum specimen temperature [°C]
	R_z**	R_a***		
As-cast state	17.5	6.1	0.57	40
A*	8.3	3.2	0.72	41
B*	9.2	3.5	0.71	39
C*	18.6	6	0.66	41
D*	25.5	7.5	0.70	37

* A, B, C, D – types of thermal treatment according to Table 2;
**R_z – ten-point mean roughness height;
***R_a – arithmetic average roughness height.

3. Conclusion

The performed thermal treatment of vermicular cast iron led to the formation of ausferritic matrix, being a mixture of acicular ferrite and austenite supersaturated with carbon (see Fig. 3). It results from a comparison of the microstructures presented in this Figure and of the data given in Table 2 that the fraction of residual austenite increases with an increase in austempering temperature, as it was expected. The change in cast iron matrix due to the performed thermal treatment distinctly influence the intensity of its abrasive wear (see data in Fig. 6). The largest wear after abrading specimens along the sliding distance of 2000 m was found for the as-cast vermicular cast iron, while the smallest mass loss occurred in cast iron austempered at the temperature of 390°C. As the austempering temperature is lowered (and the fraction of residual austenite in cast iron matrix is reduced), one can observe a decreasing tendency in the abrasive wear resistance of cast iron.

Data presented in Fig. 5 lead to the conclusion that, after abrading cast iron specimens along the sliding distance of 1000-1500 m, the wear process begins to stabilize at a certain level for specimens austempered at the temperature of either 390°C or 340°C. This cannot be said, however, either of the specimens austempered at 290°C or of the as-cast ones, both still being intensively worn.

Cast iron specimens exhibiting the highest abrasive wear resistance (i.e. those austempered at 390°C) were characterised by the lowest roughness (see data in Table 3 and Figures 5 and 6). The roughness of vermicular cast iron specimens austempered at 340°C was somewhat larger, and their abrasive wear resistance was a little less than of the specimens made of cast iron austempered at 390°C. The distinctly greater surface roughness was found for specimens austempered at the temperature of 290°C, as well as for the as-cast ones.

The coefficient of friction, which took the value of 0.57 for the as-cast iron, increased considerably after subjecting the alloy to austempering treatment. The highest value of this coefficient (0.72) occurred for the cast iron austempered at the temperature of 390°C. The temperature of specimens at the end of the test ranged from 37°C to 41°C.

To finish this conclusion, it should be stressed that the austempering treatment applied for vermicular cast iron leads to the increase in the abrasive wear resistance of the material by several times. It can be supposed that such noticeable abrasive wear resistance of the austempered vermicular cast iron is related to the stress-induced transformation of the high-carbon residual austenite. It takes place when a casting is subjected to deformation and leads to the significant increase in its surface hardness [5]. Such strengthening generated due to deformation makes possible to preserve the high surface hardness permanently.

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