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The Influence of the Shape of Graphite Precipitates on the Cast Iron Abrasion Resistance

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Abstract

The paper presents the initial results of investigation concerning the abrasion resistance of cast iron with nodular, vermicular, or flake graphite. The nodular and vermicular cast iron specimens were cut out of test coupons of the IIb type with the wall thickness equal to 25 mm, while the specimens made of grey cast iron containing flake graphite were cut out either of special casts with 20 mm thick walls or of the original brake disk. The abrasion tests were carried out by means of the T-01M tribological unit working in the pin-on-disk configuration. The counterface specimens (i.e. the disks) were made of the JT6500 brand name friction material. Each specimen was abraded over a distance of 4000 m. The mass losses, both of the specimens and of the counterface disks, were determined by weighting. It was found that the least wear among the examined materials was exhibited by the nodular cast iron. In turn, the smallest abrasion resistance was found in vermicular cast iron and in cast iron containing flake graphite coming from the brake disk. However, while the three types of specimens (those taken from the nodular cast iron and from grey cast iron coming either from the special casts or from the brake disk) have almost purely pearlitic matrix (P95/Fe05), the vermicular cast iron matrix was composed of pearlite and ferrite occurring in the amounts of about 50% each (P50/Fe50). Additionally, it was found that the highest temperature at the cast iron/counterface disk contact point was reached during the tests held for the nodular cast iron, while the lowest one occurred for the case of specially cast grey iron.

Keywords: Nodular cast iron, Vermicular cast iron, Grey cast iron, Abrasion resistance

1. Introduction

Many elements, from which the high abrasion resistance is demanded, are produced of cast iron. These include e.g. mill balls and mill liners, as well as brake drums and brake disks for various types of vehicles. The abrasion resistant casts are made either of white iron or of grey iron, depending on the expected working conditions and operational requirements [1, 2]. They can be also made of cast steel; in such a case their tribological properties can be significantly improved by generation of the alloyed layer at their surfaces [3].

In a number of cases grey cast iron containing flake graphite is replaced by nodular or vermicular cast iron, despite its excellent technological properties and relatively low costs of its production. This results from the fact that these two high-grade cast iron types, exhibiting considerably higher mechanical properties, reveal also high abrasion resistance and heat resistance. Application of nodular or vermicular cast iron as a structural material allows to improve the reliability and the performance of the final products operating under highly abrasive conditions [4, 5].

The assessment of suitability of various cast iron types for casts intended to work under the specified conditions in many cases require the determination of the tribological properties of the materials under friction, usually the dry friction. The possibility of comparison of these properties measured for various specimens during abrasion tests held under the same conditions is particularly valuable.

2. Authors' investigations

The purpose of investigations was to determine the tribological properties of nodular cast iron, vermicular cast iron, and grey cast iron containing flake graphite under dry friction. Both the specimens made of the examined cast iron types and the counterface disks were examined with respect to their wear losses along the sliding distance of 4000 m, and the temperature generated at the contact point of each frictional pair at the final stage of experiment was measured.

Specimens cut out either of the specially produced casts or of the original brake disk were examined. The nodular and vermicular cast iron specimens came from test coupons of the IIb type [6] with the wall thickness equal to 25mm, while the specially produced grey iron casting had 20 mm thick walls. Chemical composition and hardness of the examined cast iron types is presented in Table 1. The hardness was measured by means of Brinell hardness tester (the ball of 2.5 mm diameter, the load equal to 1839 N).

Table 1.
Chemical composition and hardness of nodular, vermicular, and grey cast iron with flake graphite and of the cast iron from the brake disk

		Nodular cast iron	Vermicular cast iron	Cast iron with flake graphite	Brake disk
Content, %	*C*	3.57	3.22	3.75	3.05
	Si	2.33	2.38	1.32	1.78
	Mn	0.38	0.19	0.60	0.75
	Cu	0.55	1.02	0.55	0.07
	P	0.061	0.054	0.026	0.042
	S	0.008	0.022	0.094	0.099
	Mg	0.062	0.027	-	-
	Cr	-	-	0.21	0.13
	*Sc**	0.85	0.90	0.99	0.83
Hardness HBW		255	183	222	213

* the eutectic saturation degree Sc

Figures from 1 to 4 show graphite precipitates occurring in the considered cast iron types and the microstructures of these alloys.

Metallographic examination included the classification of graphite precipitates in cast iron types under investigation, according to the Standard [7], and the assessment of the alloy microstructure based on the Standard [8]. The results are gathered in Table 2.

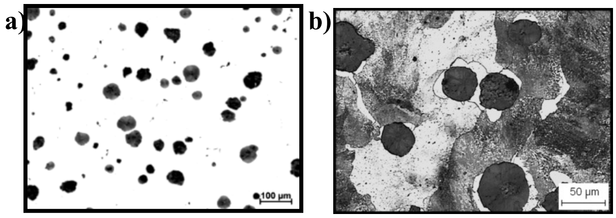

Fig. 1. Nodular cast iron in the as-cast state; (a) size and shape of graphite precipitates – non-etched microsection; (b) microstructure of the alloy – microsection etched with Nital

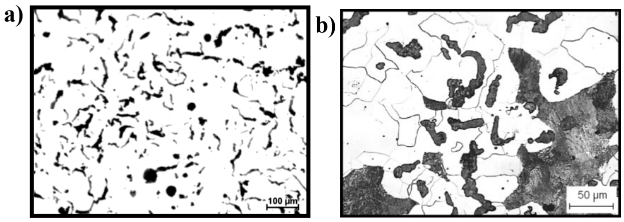

Fig. 2. Vermicular cast iron in the as-cast state; (a) size and shape of graphite precipitates – non-etched microsection; (b) microstructure of the alloy – microsection etched with Nital

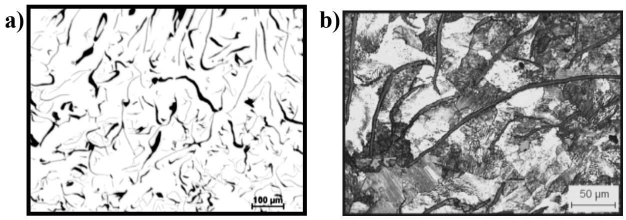

Fig. 3. Grey cast iron – material cut out of a special casting; (a) size and shape of graphite precipitates – non-etched microsection; (b) microstructure of the alloy – microsection etched with Nital

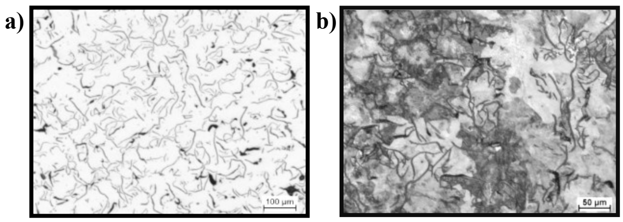

Fig. 4. Grey cast iron – material from the original brake disk; (a) size and shape of graphite precipitates – non-etched microsection; (b) microstructure of the alloy – microsection etched with Nital

Table 2.
Characteristics of graphite precipitates occurring in the examined cast iron and the pearlite and ferrite content in the respective alloys

Cast iron type	Assessment of graphite precipitates according to the Standard [7]	Microsection area occupied by pearlite and ferrite assessed in accordance with the Standard [8]
Nodular	95% VI 4/5 + 5% V 4/5	P95 Fe05
Vermicular	95% III 4/5 + 5% VI 5/6	P50 Fe50
Grey with flake graphite	90% I C 2/3 + 10% I D 5/6	P95 Fe05
Grey with flake graphite – material from the brake disk	80% I E 4/5 + 20% I C 4/5	P95 Fe05

The abrasion resistance was measured by means of a T-01M tribological tester working in a pin-on-disk configuration [9]. The specimens made of the examined cast iron types were of cylindrical shape, 4 mm in diameter and about 35 mm in length. Three measurements were taken for each type of tested cast iron.

The counterface specimens of disk shape were made of the friction material JT6500, from which also the brake pads for various car vehicles, motorcycles, construction and agricultural machines are produced. The material was produced by "MAKLAND" company, one of the leading manufacturers of friction materials in Poland [10]. The material used for counterface disks is an azbestos-free one, based on synthetic resins and synthetic rubber binders, with steel powder fillers, steel and mineral fibre fillers, and the additions of correcting agents and stabilizers of the coefficient of friction. The counterface disk of 45 mm diameter and 5 mm thickness, with the visible inclusions of steel and copper wool, is shown in Fig. 5. The density of the friction material determined according to the Standard [11] was equal to 2.7 g/cm^3, and its hardness determined in accordance to the Standard [12] was 78 MPa.

Each of cast iron specimens was abraded along the sliding distance of 4000 m. Mass losses for both the specimen and the counterface disk were measured by weighting them after every 500 m distance by means of the WA35 analog scales of the PRL TA14 type. The vertically placed cast iron specimen was pressed against the counterface by the force equal to 29.43 N. The abraded area of a specimen was 12.56 mm^2, and the unit pressure accounted for 2.34 MPa. The abrasion speed was 0.55 m/s. The tribological unit was equipped with a contact thermocouple which allowed for measuring the temperature during the abrasion by touching the specimen surface with the thermocouple. The tribological unit made also possible the continuous measuring and recording of the friction force.

Fig. 5. Counterface disk made of friction material JT6500 (photo by the authors)

Figure 6 presents the average results of examination concerning the tribological wear of specimens made of nodular and vermicular cast iron, as well as of the grey cast iron with flake graphite and grey cast iron being the material from a brake disk. Figure 7 shows the wear of counterfaces cooperating with the examined types of cast iron.

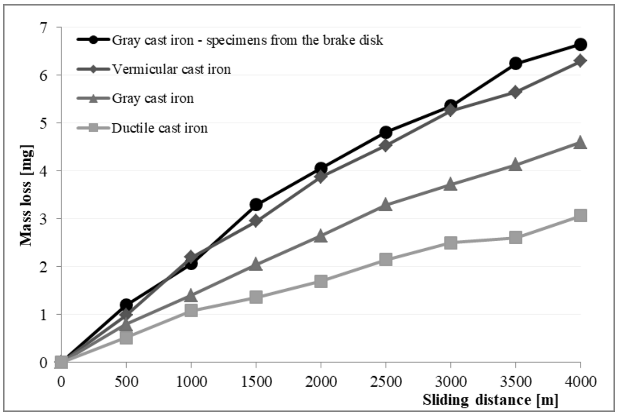

Fig. 6. Average mass losses of cast iron specimens along the sliding distance up to 4000 m

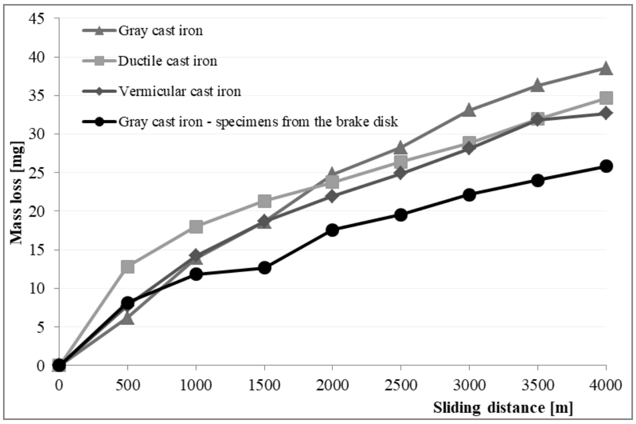

Fig. 7. Average mass losses of counterface disks made of JT6500 friction material – cooperating with the examined cast iron types

The average results with respect to the coefficient of friction for the examined types of cast iron are presented in Table 3. This table contains also the detailed data concerning the performed temperature measurements.

Table 3.
The values of the coefficients of friction determined during abrasion tests of the examined cast iron types sliding against the JT6500 friction material used for counterfaces and the temperature values recorded during the experiment

Average coefficient of friction	Maximum temperature at the specimen/ counterface contact point [°C]	Average ambient temperature [°C]	Difference between the temp. at the specimen contact point and the ambient temp. [°C]
Nodular cast iron			
0.36	64.1	24.2	39.9
Vermicular cast iron			
0.35	58.0	29.4	28.6
Grey cast iron with flake graphite			
0.34	42.8	25.3	17.5
Grey cast iron with flake graphite – specimen from brake disk			
0.35	48.7	22.6	26.1

3. Conclusion

Four groups of specimens were subjected to abrasion tests during the experiment: specimens cut out of the nodular cast iron, the vermicular cast iron, and it two cases the specimens from cast iron with flake graphite (one group taken from the specially produced casting, the other from the original brake disk). The alloy matrix was almost purely pearlitic in three cases: nodular cast iron and grey cast iron with flake graphite, both the one from a special casting and the one from brake disk (see data in Table 2, comp. Figures 1, 3, and 4). The pearlitic-ferritic matrix, containing 50% of each of these structural components, occurred only in the case of vermicular cast iron (see data in Table 2 and Fig. 2). It is worth noticing that even the over one-percent content of copper in this alloy did not ensure the pearlitic matrix occurrence. It is related to the course of crystallization of graphite precipitates in such material and to the cast iron tendency to form the ferritic matrix.

A comparison of the average mass losses of the abraded specimens (see data in Fig. 6) reveals that the highest abrasion resistance among the materials with almost purely pearlitic matrix was exhibited by the nodular cast iron, the somewhat lower abrasion resistance was found for grey cast iron from the special casting, the worst one occurred for the cast iron from the brake disk. The reason of such a low result in the last case can be the disadvantageous arrangement of graphite precipitates (E and C types) – see the data in Table 2 and Fig. 4.

The relatively low abrasion wear resistance of vermicular cast iron (lower even than the respective value found for cast iron with flake graphite) should be attributed to the matrix character. The distinctly lower content of pearlite, as compared with other cast iron types, which negatively influenced the examined material properties, outweighed the advantageous – with respect to the abrasion wear resistance – effect of the shape of graphite precipitates.

The greatest total mass loss of counterface specimen was observed in the case of its cooperation with grey cast iron (material from the special casting), the smallest one in the case of grey iron from brake disk.

During the abrasion test, the highest temperature increase was recorded for the nodular cast iron (by about 40°C), the smallest one for grey cast iron from the special casting (by about 18°C). This is related to the thermal conductivity of cast iron, which is significantly lower for the nodular cast iron than for grey cast iron. It is characteristic that the cast iron from brake disk (with its highly disadvantageous arrangement of graphite precipitates) heated up to the greater degree than the grey cast iron from the special casting (see data in Table 3).

The further examination of the cast iron abrasion resistance seems to be justified, e.g. the examination under greater unit force, and primarily over the significantly greater sliding distance.

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