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COMPOSITE MATERIAL WITH CAST IRON MATRIX DESIGNED FOR BRAKE SYSTEMS OF TECHNICAL MEANS OF TRANSPORT

MATERIAŁ KOMPOZYTOWY Z OSNOWĄ Z ŻELIWA PRZEZNACZONY NA UKŁADY HAMULCOWE ŚRODKÓW TRANSPORTU

Key words:

means of transport, brake disc, composite, cast iron, SiC foam.

Abstract:

The paper presents the basics of manufacturing and the tribological properties of the developed cast iron-ceramic composite designed for brake discs or drums. The matrix of the composite consists of GJL-150 grey cast iron used for the production of brake discs. The reinforcing phase is a SiC foam with an activated surface. The use of ceramic foam simplifies the production process because it does not require expensive mixing of the matrix and the reinforcing phase to ensure the homogeneity of the composite. An addition of 10% SiC ($\lambda_{\text{SiC}} = 100\text{--}350 \text{ Wm}^{-1}\text{K}^{-1}$) improves the thermal conductivity of cast iron ($\lambda_{\text{CI}} = 50\text{--}60 \text{ Wm}^{-1}\text{K}^{-1}$). The presence of foam elements homogeneously distributed throughout the whole matrix volume reduces the wear of both the composite and the counter-sample. The results of comparative studies of contacts between the cast iron and the composite brake disc showed almost a threefold lower wear of the pad and disc and about a 10°C lower temperature in the pad near the friction zone under the pressure of 1 MPa and at a sliding velocity of 0.5 m/s. The significantly lower wear of the friction elements of the brake system will contribute to a reduction in environmental pollution by wear debris, which is required by European Union directives.

Słowa kluczowe:

środki transportu, tarcza hamulcowa, kompozyt, żeliwo, pianka SiC.

Streszczenie:

W artykule opisano podstawy wytwarzania i właściwości tribologiczne opracowanego kompozytu żeliwno-ceramicznego przeznaczonego na tarcze lub bębny hamulcowe. Osnowę kompozytu stanowi stosowane do wytwarzania tarcz hamulcowych żeliwo szare GJL-150, a umocnieniem jest pianka z SiC z aktywowaną powierzchnią. Użycie pianki ceramicznej upraszcza proces wytwarzania, ponieważ nie wymaga kosztownego mieszania osnowy i fazy zbrojącej dla zapewnienia homogeniczności kompozytu. Dodanie 10% pianki SiC ($\lambda_{\text{SiC}} = 100\text{--}350 \text{ Wm}^{-1}\text{K}^{-1}$) poprawia przewodność cieplną żeliwa ($\lambda_{\text{CI}} = 50\text{--}60 \text{ Wm}^{-1}\text{K}^{-1}$). Obecność równomiernie rozłożonych w całej objętości osnowy elementów pianki zmniejsza zużycie zarówno kompozytu, jak i współpracującego z nim materiału ciernego. Wyniki badań porównawczych skojarzeń z tarczą żeliwną i kompozytową wykazały mniejsze prawie trzykrotnie zużycie klocka i tarczy oraz niższą o 10°C temperaturę w klocku w pobliżu strefy tarcia przy nacisku 1 MPa i prędkości 0,5 m/s. Znacząco zmniejszone zużycie elementów ciernych układu hamulcowego przyczyni się do zmniejszenia zapylenia środowiska produktami zużycia, co jest wymagane w dyrektywach Unii Europejskiej.

INTRODUCTION

Technical means of transport during the execution of transport tasks move at variable speeds, starting from zero at the moment of starting up until the maximal permissible speed. For the regulation

of speed, power transmission systems are used. Acceleration necessitates an increase in the power of the propulsion unit, and deceleration can be achieved by driving in neutral or using braking systems. In a braking system, the kinetic energy of a moving car vehicle is dissipated in two ways,

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i.e., by friction and by the wear of the materials of the rubbing machine parts. Braking processes are exothermic; therefore, the materials used for brakes will necessitate a stable coefficient of friction under variable braking conditions, low wear ensuring high reliability and lower environmental pollution, as well as high thermal conductivity facilitating the dissipation of heat generated by friction [L. 1–7].

Heat not dissipated can cause the brake fluid to boil, reducing braking efficiency. An important material property of braking elements in technical means of transport is their density. A brake disc with similar dimensions (diameter 350 mm) made of GJL-200 grey cast iron weighs 5800g, whereas one made of an AIMC composite (AC-AlSi12Ni1,8CuMg+40% SiC) weighs 1860 g [L. 8] (Fig. 1)

Materials which fulfil the abovementioned requirements are composites. The use of composites with a silumin matrix (with an addition of 40–60% SiC) and a carbon matrix with an addition of carbon fibres for the production of brake drums and discs are widely known. A disadvantage of composite

brake discs is that they are more expensive than cast iron ones. The more stringent requirements of the European Union with regard to environmental pollution oblige producers to increase the wear resistance of brake materials with the least possible change in price [L. 9]. Therefore, less costly materials with enhanced wear resistance are sought.

New composite material for brake discs with a grey cast iron matrix reinforced with activated ceramic SiC foam with a porosity of up to 90% has been developed in cooperation with the Faculty of Materials Engineering and the Faculty of Transport and Aviation Engineering of the Silesian University of Technology. Such a combination of a matrix and reinforcing phase allows the price to be kept at a level similar to that of cast iron, with enhanced wear resistance and better heat dissipation (thermal conductivity of cast iron $\lambda = 60 \text{ W/(mK)}$, whereas SiC about 100–360 W/(mK)). This paper concerns comparing the selected tribological properties of the developed composite with the properties of the cast iron used to date for the production of brake discs and drums.



Fig. 1. Brake disc made of AIMC (a) and CF-C (b) after tribological tests

Rys. 1. Trzcza hamulcowa z kompozytu AIMC (a) i CF-C (b) po badaniach tribologicznych

FABRICATION OF COMPOSITE WITH CAST IRON MATRIX

The matrix of the developed composite was GJL-150 cast iron with lamellar graphite, which is used for brake disc production to date. As the reinforcing phase, a porous preform made of silicon carbide was used. The foam has an open porosity of 10 ppi (pores per inch). The SiC content was selected based on industrial practice (Mahle pistons contain 10% Al₂O₃ fibres [L. 10]) and the authors' own previous research [L. 11, 12]. A higher than 10% content of the reinforcing phase results in slight changes in the tribological properties.

The preform was made by depositing a suspension SiC of particles in a water glass on the surface of polymer precursor foam. Then the preform was dried and held at a temperature of about 800°C, which resulted in obtaining a tight coating on the precursor. The prefabricated preform was subjected to additional surface activating treatment in order to increase adhesion at the interface. The activated preform was placed in a cylindrical casting mould and was infiltrated with cast iron at the temperature of 1250°C. After cooling down, the cylindrical cast piece was machined to form discs with a diameter of 45 mm and thickness of 5 mm, which were counter-samples for the

tribological tests. A detailed description of the composite production process can be found in patent application P.438234 [L. 13].

CONDITIONS AND COURSE OF TESTS

In order to determine the effect of the SiC foam addition on the tribological properties of the cast iron matrix, comparative tests of the two following contacts were carried out:

- frictional material P50 094/ GJL-150 (reference cast iron – the matrix of the composite),
- frictional material P50 094/ GJL-150+10% SiC (developed composite).

The tests were conducted on a T-01M tribological tester under the following conditions:

- pin with a diameter of 5 mm made of frictional material placed in the holder,
- discs with a diameter of 45 mm and thickness of 5 mm made of GJL-150 and GJL-150+10% SiC
- sliding radius 14 mm,
- sliding distance $s = 5000$ m (equivalent to 100 braking cycles of a vehicle with a mass of 2000 kg in urban traffic),
- unit pressures $p_1 = 1$ MPa, $p_2 = 1.5$ MPa and $p_3 = 2$ MPa.
- sliding velocity $v = 0.5$ m/s under friction in wear conditions (equivalent to vehicle braking

at the lowest allowed speed in a city centre of 30 km/h).

The sliding contact of the T-01M tester is presented in **Figure 2**. Commercial frictional material P50 094 (Brembo) used for manufacturing brake pads was given by the producer of brake discs in order to compare the tribological properties of the developed composite with the GJL-150 matrix and brake discs produced from this cast iron.

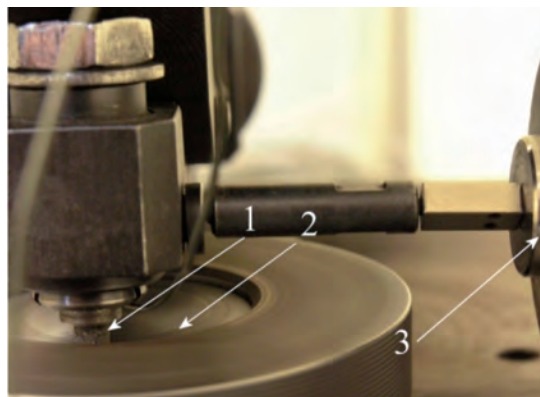


Fig. 2. View of sliding contact of T-01M stand: 1 – sample of frictional material, 2 – cast iron/composite counter – sample, 3 – strain gauge for measuring friction force

Rys. 2. Widok węzła tarcia stanowiska T-01M do badań tribologicznych: 1 – próbka z materiału ciernego, 2 – przeciwpróbka z żelaza/kompozytu, 3 – tensometryczny przetwornik do pomiaru siły tarcia

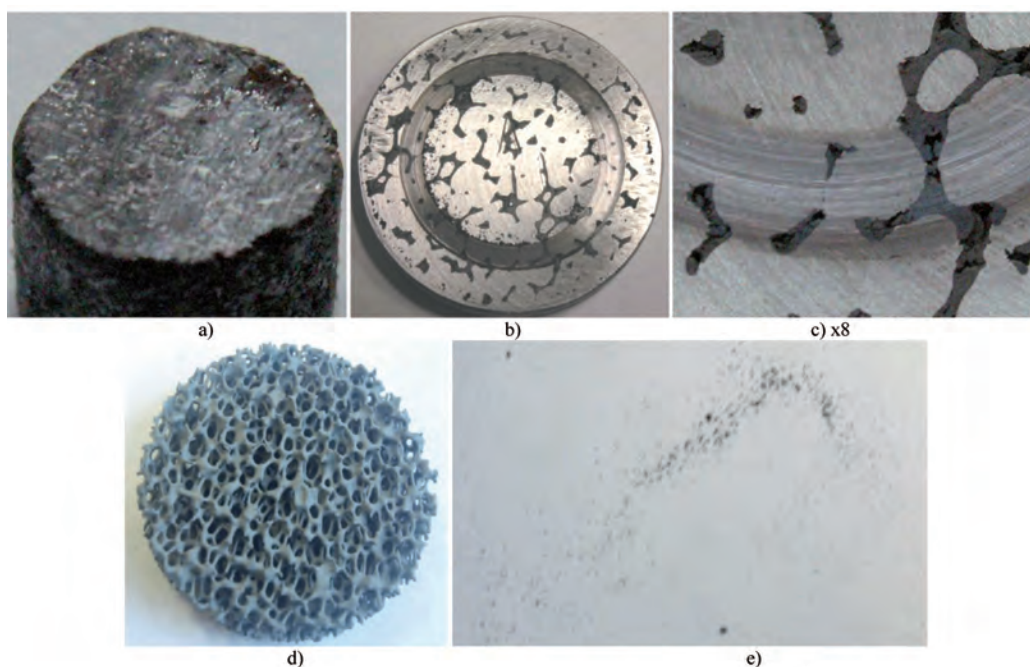


Fig. 3. Sample of P50 094 friction material (a), counter-sample made of GJL-150+10% SiC (b) sliding trace (c) SiC foam (d) wear debris (e) after tribological tests

Rys. 3. Próbkę z materiału ciernego P50 094 (a), przeciwpróbka z GJL-150+10% SiC (b) i ślad współpracy (c) oraz pianka SiC (d) i produkty zużycia (e) po badaniach tribologicznych

RESULTS AND DISCUSSION

During the tests, the friction forces were recorded using a strain force gauge and a software recorder for calculating the friction coefficient at a given load and the sliding radius during the investigation. The friction force measuring distance inaccuracy was 3% of the measured value. The friction wear (weight loss of the sample and counter-sample) was measured using HM-300 laboratory scales with an inaccuracy of 0.2 mg. The results are presented in

Tables 1 and 2. The surfaces of the samples and counter-samples were subjected to macroscopic and microscopic (SEM) examinations and chemical composition analysis at chosen points. The results are presented in **Figs. 4 and 6.** The temperature was periodically measured on the side surface of the pin at a distance of 1 mm from the rubbing surface using a thermocouple with an inaccuracy of 3%. The results are presented in **Figs. 7 and 8.**

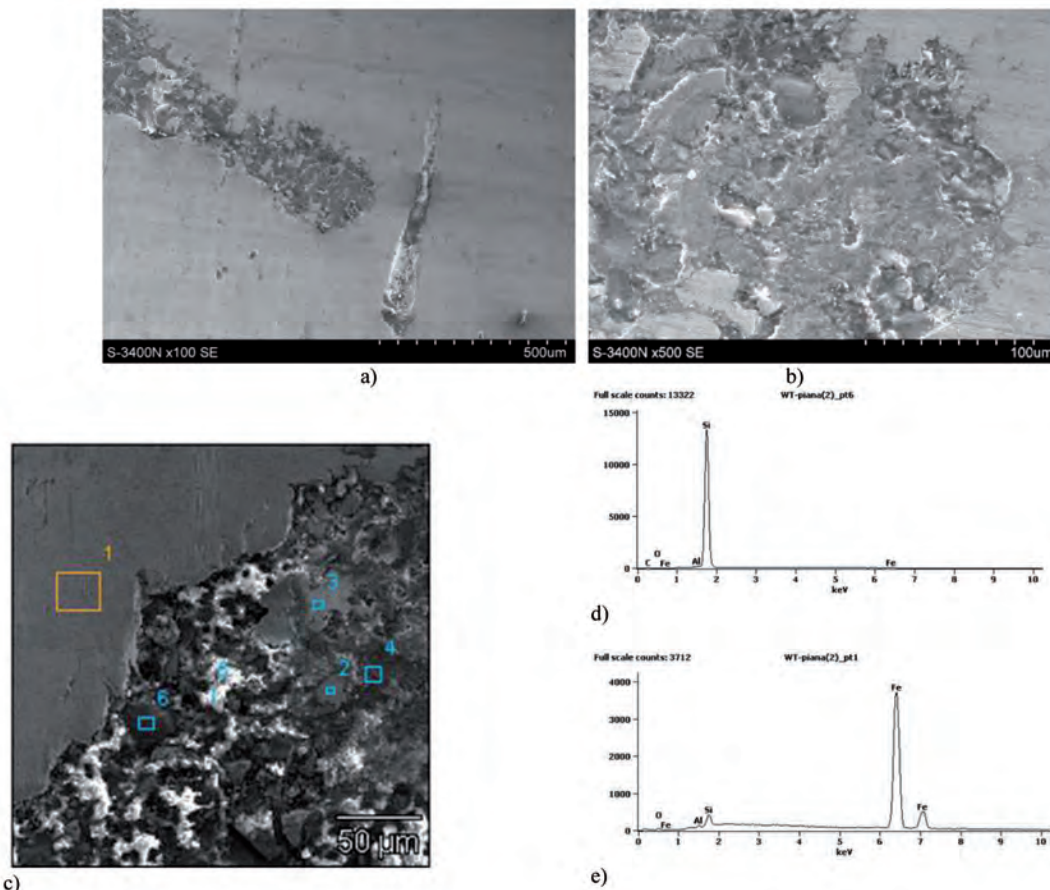


Fig. 4. View of the composite surface after sliding (a) and magnified part of SiC foam (b) with deposited wear debris (SEM) results of chemical composition analysis of SiC foam (point 2 in Fig. c) (d) and matrix material at point 1 (e)

Rys. 4. Widok z powierzchni tarcia kompozytu (a) i powiększony fragment pianki SiC (b) z naniesionymi produktami zużycia (SEM) oraz wyniki analizy składu chemicznego kompozytu (d) w punkcie 2 z rys. c i materiału osnowy w punkcie 1 (e)

Table 1. Wear of elements of P50 094/GJL-150 contact

Tabela 1. Zużycie elementów skojarzenia P50 094/GJL-150

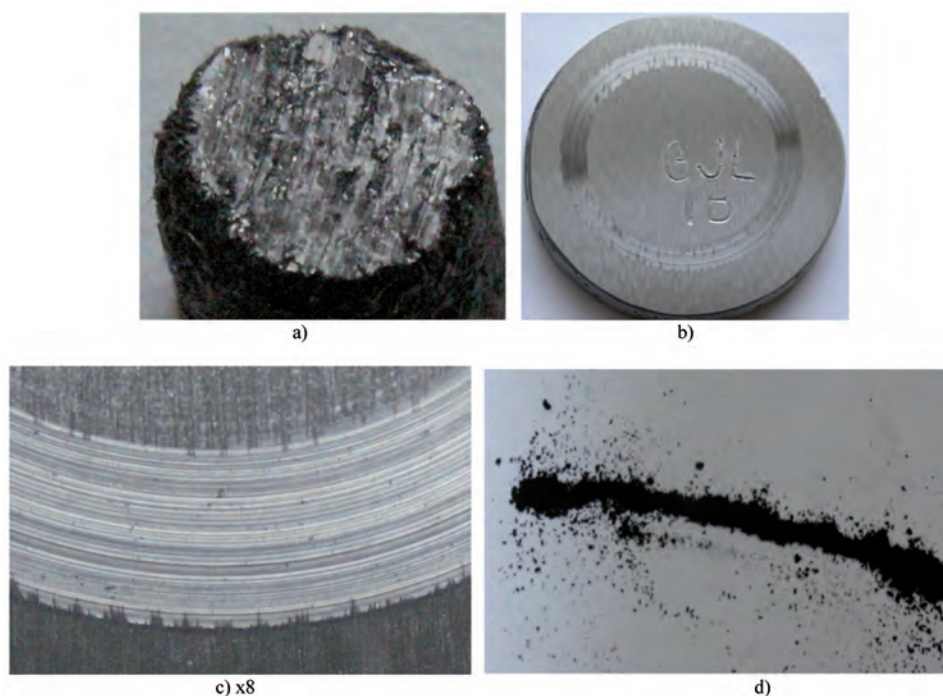
Δm , mg	Pressure	p = 1 MPa	p = 1.5 MPa	p = 2 MPa
Pin		6.0; 4.0; 3.3 $\Delta m_{aver.} = 4.43$	5.7; 8.4; 2.4 $\Delta m_{aver.} = 5.5$	6.0; 10.4; 11.4 $\Delta m_{aver.} = 9.26$
Disc		17.3; 11.2; 9.1 $\Delta m_{aver.} = 12.53$	10.5; 22; 3.4 $\Delta m_{aver.} = 11.96$	16.3; 22.6; 30 $\Delta m_{aver.} = 22.96$
μ		0.1–0.40 ¹⁾	0.26–0.32	0.18–0.44

¹⁾ minimal and maximal values from 3 measurements.

Table 2. Wear of elements of P50 094/GJL-150+10% SiC contact

Tabela 2. Zużycie elementów skojarzenia P50 094/GJL+10% SiC

Δm , mg	Pressure	p = 1 MPa	p = 1.5 MPa	p = 2 MPa
Pin		1.4; 1.0; 2.5 $\Delta m_{aver.} = 1.63$	0.4; 1.4; 2.1 $\Delta m_{aver.} = 1.3$	2.5; 1.0; 2.7 $\Delta m_{aver.} = 2.1$
Disc		5.2; 2.2; 1.2 $\Delta m_{aver.} = 2.86$	2.6; 2.1 4.3 $\Delta m_{aver.} = 3$	2.5; 2.1; 4.0 $\Delta m_{aver.} = 2.86$
μ		0.32–0.42	0.35–0.42	0.35–0.40

**Fig. 5. Sample made of friction material P50 094 (a) counter-sample made of GJL-150 (b) sliding trace (c) wear debris (d) after tribological tests**

Rys. 5. Próbkę z materiału ciernego P50 094 (a) i przeciwpróbkę z GJL-150 (b) oraz ślad współpracy (c) i produkty zużycia (d) po badaniach tribologicznych

Based on the obtained macroscopic (**Figs. 3b and 3c**) and microscopic (**Fig. 4**) investigations, it can be stated that the developed GJL-150+10% SiC composite has a homogeneous structure with evenly distributed spatial elements of SiC foam and good bonding of the matrix to the SiC foam. Areas of local exposure of the SiC foam show small discontinuities on the phase boundaries, which is an effect of the carborundum foam production technology. The SiC foam was fabricated from a suspension of SiC particles with an average diameter of 10–30 μm dispersed in the water glass, deposited on a polymer foam substrate and hardened at a temperature much lower than the sintering temperature of SiC particles, which is about 1400°C. Consequently, during hardening at

1000 °C, complete melting and bonding between the individual sinter grains do not occur. As a result, the SiC preform may have increased porosity compared to a material produced at a higher temperature. The porosity is further increased by the evaporation of the water glass solvents. Liquid cast iron can infiltrate pores and discontinuities formed both in the sintering process and water glass evaporation. EDS chemical composition studies verified this. The chemical compositions from selected matrix areas and the silicon carbide foam are presented in **Figures 4d and 4e**. The conducted analysis shows the presence of the same elements of the composite matrix on the worn surface (**Fig. 4** point 1) and in the SiC foam (points 2 and 3).

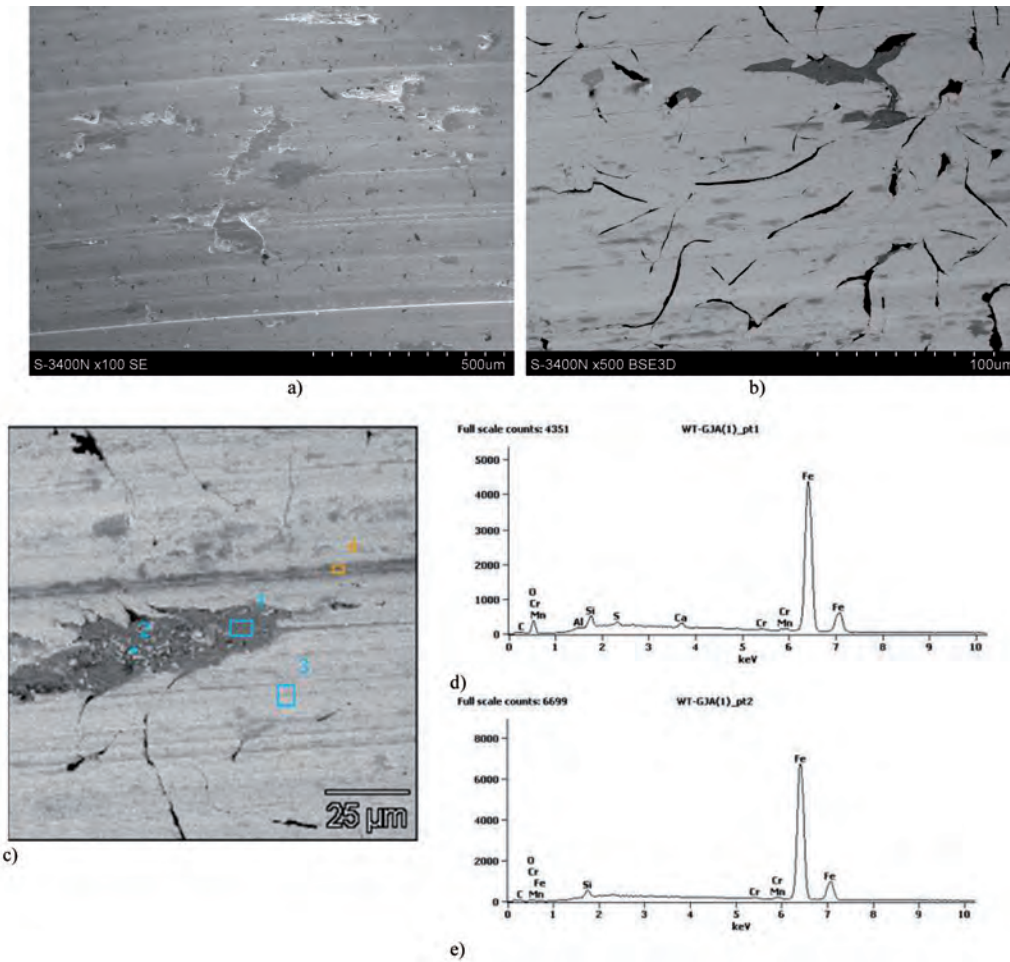


Fig. 6. View of GJL-150 cast iron surface after sliding (a) magnified part with exposed graphite (b) (SEM) results of chemical composition analysis (c, d, e)

Rys. 6. Widok z powierzchni żeliwa GJL-150 po tarcu (a) i powiększony fragment z odsłoniętym grafitem (b) (SEM) oraz wyniki analizy składu chemicznego (c, d, e)

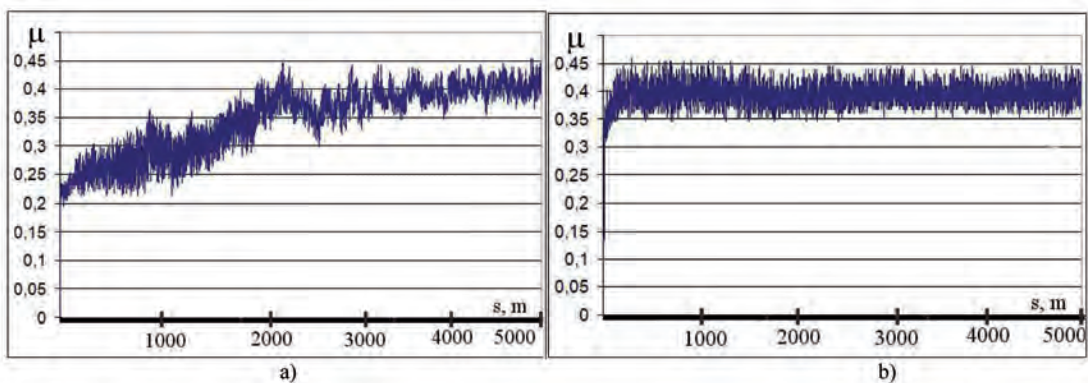


Fig. 7. Coefficient of friction in contact with GJL-150 (a) GJL-150+10% SiC (b) at $p = 1 \text{ MPa}$, $v = 0.5 \text{ m/s}$

Rys. 7. Współczynnik tarcia w skojarzeniu z GJL (a) i GJL+10% SiC (b) przy $p = 1 \text{ MPa}$, $v = 0,5 \text{ m/s}$

Based on the analysis of the reference cast iron surface (Fig. 5b and 5c) and from the composite (Fig. 3b and 3c) after rubbing against the brake pad (Figs. 3a and 5a), it can be said that both in contact

with the reference cast iron as well as in contact with the composite, abrasive wear (scratches along the sliding direction are visible – Figs. 3c and 5c) is a dominant mechanism. This is a typical mechanism

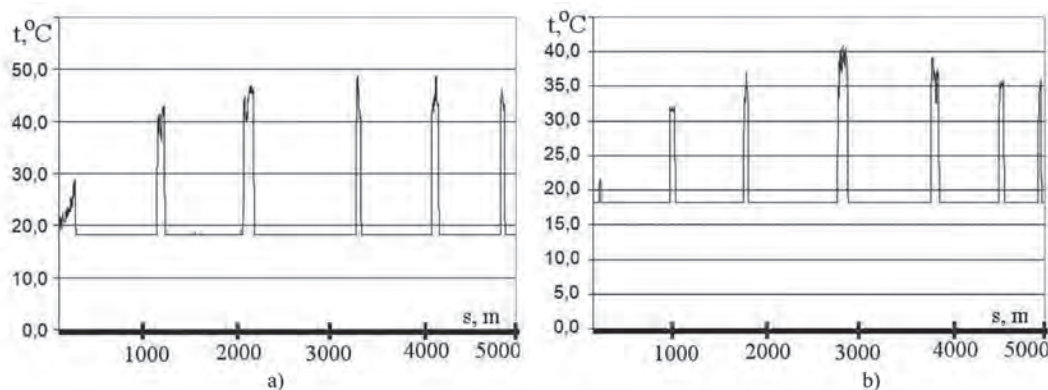


Fig. 8. Pin temperature during sliding against GJL-150 (a) GJL-150+10% SiC (b) by $p=1$ MPa and $v=0.5$ m/s

Rys. 8. Temperatura w trzpieniu podczas tarcia w skojarzeniu z GJL-150 (a) i GJL-150+10%SiC (b) przy $p=1$ MPa i $v=0.5$ m/s

of brake system wear. In comparing the wear traces on the matrix material and the composite material, it can be seen that the scratches and grooves resulting from micro-cutting are visible only in the SiC area. Wear traces are difficult to see on the cast iron matrix surface (**Fig. 4a**). This is because the surface of the reinforcing phase protrudes over the matrix surface. During sliding, the SiC foam and frictional brake pad material are the only parts in contact. The markedly higher hardness of SiC than the matrix material (ferritic cast iron) causes a substantial difference between examined contacts, which can be seen in the wear of the brake pad and the disc (**Tables 1 and 2**). The wear of the frictional parts in contact with the composite is near threefold lower than in contact with the reference cast iron (**Figs. 3a and 5d**). In contact with the cast iron, the wear increases with rising unit pressure up to 2 MPa, and the changes in wear in contact with the composite are insignificant. From **Fig. 8**, it can be seen that a SiC addition of 10% to GJL-150 cast iron increases the heat dissipation from the brake disc friction zone, which results in about a 10°C lower brake pad temperature. Such a decrease can reduce the thermoelastic deformation of the brake disc, which will improve driving comfort and reduce noise emissions from the brake system.

The contact with a cast iron brake disc requires heating of the brake system in order to obtain higher values of the coefficient of friction (required for vehicles with $\mu = 0.3$ or 0.4 on the drive axle). After sliding at a distance of about 1000 m, the coefficient of friction reaches a value of 0.4. In contact with the composite brake disc, it would be achieved after about 100 m. This is important for the vehicle's safety when braking with unheated

brakes (so-called cold brakes), which extend the braking distance.

In the conducted laboratory investigations, samples were made with foam uniformly distributed in the whole volume of the metallic matrix. In the production of brake discs or drums, it is sufficient to use SiC brake inserts only in the areas where friction occurs, reducing production costs.

CONCLUSIONS

The results of the conducted research allow the formulation of the following conclusions:

1. An addition of 10% SiC used in the production of brake systems made of GJL-150 cast iron reduces the wear of frictional parts threefold. It stabilises the required value of the coefficient of friction on a shorter sliding distance than 100 m, which can improve the braking performance of so-called "cold brakes".
2. The use of foam as the reinforcing phase simplifies the brake disc manufacturing process, ensuring homogeneous distribution of the reinforcement without additional mixing, which reduces production costs and stabilises the tribological properties.
3. The composite reinforced with silicon carbide foam contributes to a reduction in the operating temperature of the brake contacts, which allows one to suppose that it will improve the thermal stability and thermo-elasticity and possibly increase the permissible loads of brake systems.

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