CHANGE OF THE FRICTION COEFFICIENT AS A FUNCTION OF THE COMPOSITE BRAKE DISC TEMPERATURE IN THE TEST RIG TRIALS

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Abstract

The paper presents results of testing a friction pair on the KRAUSS test rig. The trials have been conducted on the composite MMC brake discs together with the commonly used OMC friction materials. Discs were made of the aluminium based composites reinforced with a silicon carbide (SiC) and fly ashes from the power station. The friction characteristics obtained presented in a form of friction coefficient graphs as a function of temperature, enable to indicate limitations in the application of these devices in comparison with the cast iron discs. The tests have been conducted on the KRAUSS test rig in the real scale using non-ventilated brake disc and „Bendix" callipers for the passenger M1 category car.

Brake discs are characterised by: high value of the friction coefficient, low wear of the friction area following tests, high thermal resistance. Brake discs tested, made of MMC: -ALFA (AK9 + 20 % vol. fly ash are characterised by: low friction coefficient $\mu < 0.3$ and high wear of the brake disc surface following tests. Characteristics show large discrepancies of the friction coefficient value between each braking cycle.

Composite Al alloys based brake discs reinforced with SiC (20 and 30 % vol.) may find application in the light sports cars and quads 3 and 4 wheeled.

Keywords: *motor vehicles, brake system, brake drums and discs, composite materials, friction coefficient*

1. Introduction

The demand for the materials of a low specific gravity in co-relation with low costs and high mechanical properties has lead to a discovery of new groups of construction materials.

Composite materials form a group of modern construction materials, which due to their attractive service properties are an object of intensive researches of many centres around the world and also domestically in Poland are regarded as preferred directions of the scientific and development tests.

The types of composite materials which are qualified to belong to the advanced high tech group of materials are as follows: polymer - OMC, metallic - MMC, ceramic - CMC, composite carbon - carbon - C-C.

1.1. Metal Matrix Composites (MMC)

The foremost area of the metal matrix composites (MMC) application in the motor vehicles is represented by components of the power transmission, engine, suspension and brake system [1].

The most often used composite material in the brake systems are aluminium alloy composites reinforced with silicon carbide (SiC) particles or fibres, aluminium oxides or ALFA- fly ashes of the particles size being between 10 μm and 50 μm.

1.2. Organic Matrix Composites (OMC)

Properties of the polymer composites (OMC) may be modified by optimising the content of the individual components. Moulding compounds for OMC composites production can be found in many varieties; dry, loose, powder moulding composites (PMC), granular moulding composites (GMC) or in the shape of composites fibrous compound. (SMC, BMC, DMC). [2].

For production of the composite friction materials, the types PMC and GMC are used. Depending on the application and required properties of the product made of a friction material, to make a brake lining it is necessary to use from 15 to 25 components.

The selection of the friction materials operating in the relation friction-wear is one of the most important matters in designing brake system.

2. Test materials

2.1. Materials for the brake discs

2.1.1. Cast iron

The most traditional types of the cast iron used is grey cast iron with lamellar graphite (Fig. 1), whose strength and hardness increase together with the increase of the perlite hardness in the matrix. The higher percentage of the graphite and thicker the lamellas the lower is the strength and ductility of the cast iron.

Fig. 1. Structure of cast iron (500 x magnification)

2.1.2. Composite materials

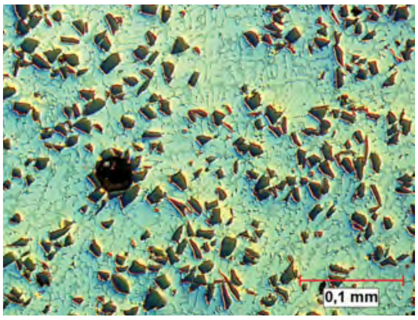
The subject of the tests was the passenger car brake discs made at Foundry Institute in Cracow of the aluminium alloys composite materials: F3S.20S, F3S.30S, ALFA. The comparison of the properties of the composite materials tested is shown in the Tab. 1 [1].

2.2. Friction materials

The brake friction materials can be divided into 3 groups: frictions materials for brake pads for the composite discs used in the passenger and sports cars - LE, frictions materials for brake pads for the sport and racing use in the 4 wheel drive sports and rally cars - EBC-2, friction materials for the lorries, buses, trailers and semi trailers, brake linings - JU-1 and brake pads – BR.

Tab. 1. Selected properties of the cast iron, AK12 alloy and composites tested

Properties Material	Tension strength [MPa]	Density [g/cm³]	Maximum operating temp. [°C]	Young Module [GPa]	Brinell hardness [HBW]
AK12	290-320	2.72	300	72	80
F3S.20S (alloy AL+20% vol. SiC)	359	2.77	350	99	105
F3S.30S (alloy AL+30% vol. SiC)	225	2.89	480	127	120
ALFA® (AK 9 + 20% vol. FA)	280-360	2.64	300	90-95	85
Grey cast iron	100-400	6.9-7.4	800	80-150	150-230



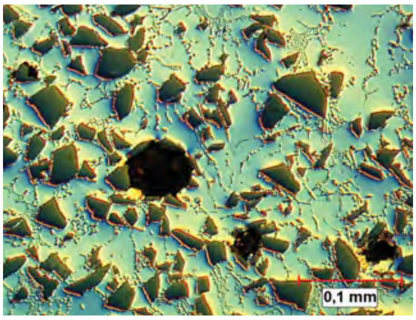


Fig. 2. Structure of F3S.20S [4] Fig. 3. Structure of F3S.30S [4] (200 x magnification)

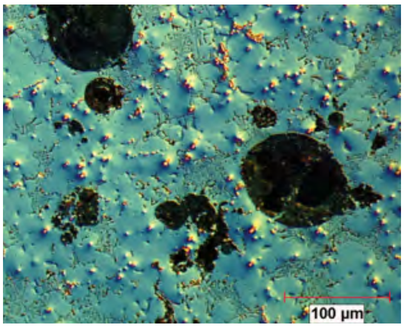


Fig. 4. Structure of ALFA® (200 x magnification) [4]

Tab. 2. Properties of the fiction materials tested

Material	Hardness HRR	Max temperature [°C]	Application
EBC-2	106	900	Racing cars - brake pads
BR	98	400	Lorries - brake pads
JU-1	93	400	Lorries - brake linings
LE	100	600	Sports cars - brake pads

3. Tests description

3.1. Friction tests on the Krauss stand

Friction properties tests have been conducted in the laboratory of the Automotive industry Institute on the Krauss stand (Fig. 5) using test program contained in the UN-ECE Regulation nr 90, concerning type approval of the replacement sets of the brake linings [3].

Fig. 5. Stand to test friction pair Krauss AB-738

Test parameters:

- rotation speed 660 ± 10 RPM,
- slipping speed 7 m/s,
- hydraulic pressure in front of the piston 15 bars, 9 bars,
- number of brakings 85 (total in the full cycle),
- air cooling expenditure 660 ± 60 m³/h.

Temperature of the brake disc at the beginning of each braking cycle was 100ºC. During each braking, registered were: brake disc temperature and friction coefficient.

The tests results presented illustrate changes of the friction coefficient as a function of temperature measured on the brake disc surface. Each graph shows five curves illustrating five cycles created after averaging each of the 10 brakings in each cycle.

4. Test results

4.1. Listing of the friction pairs

Tab. 3. List of friction pairs tested

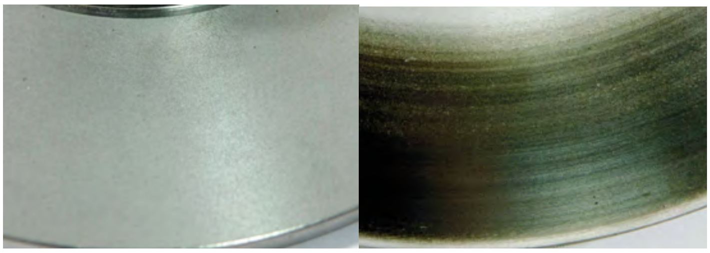
<table>
<tr><th>Fig. number</th><th>Brake pads / lining material</th><th>Brake disc material</th><th>Comment</th></tr>
<tr><td rowspan="2">7</td><td rowspan="2">Racing brake pads for the passenger car - EBC-2</td><td>F3S20S</td><td rowspan="2">15 bars</td></tr>
<tr><td>Cast Iron</td></tr>
<tr><td rowspan="2">8</td><td rowspan="2">Brake pads for the trucks - BR</td><td>F3S20S</td><td rowspan="2">15 bars</td></tr>
<tr><td>Cast Iron</td></tr>
<tr><td rowspan="2">9</td><td rowspan="2">Brake linings for the trucks - JU-1</td><td rowspan="2">F3S20S</td><td>15 bars</td></tr>
<tr><td>9 bars</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">Brake pads for the composite disc - LE</td><td rowspan="2">F3S20S</td><td>15 bars</td></tr>
<tr><td>9 bars</td></tr>
<tr><td rowspan="2">11</td><td rowspan="2">Brake linings for the truck - JU-1</td><td rowspan="2">Cast Iron</td><td>15 bars</td></tr>
<tr><td>9 bars</td></tr>
<tr><td rowspan="2">12</td><td rowspan="2">Brake linings for the truck - JU-1</td><td>F3S20S</td><td rowspan="2">9 bars</td></tr>
<tr><td>F3S30S</td></tr>
<tr><td rowspan="2">13</td><td rowspan="2">Brake linings for the truck - JU-1</td><td>F3S20S</td><td rowspan="2">9 bars</td></tr>
<tr><td>Cast Iron</td></tr>
<tr><td rowspan="2">14</td><td rowspan="2">Brake pads for the composite disc - LE</td><td>F3S20S</td><td rowspan="2">15 bars</td></tr>
<tr><td>ALFA</td></tr>
</table>

4.2. Examining friction surface of the disc

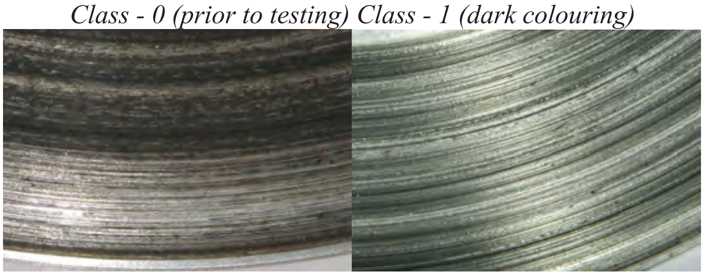
In order to evaluate the wear of the friction surface of the brake discs, the definition of a „surface wear class" has been introduced with 6 classes from - 0 to 5 (Fig. 6). The appearance of the working surfaces in each of the classes is presented on the figures below, while the description of the character of the friction wear in each of the classes linearly measured is presented in the Tab. 4.

Tab. 4. Types and extent of the brake discs working surfaces wear

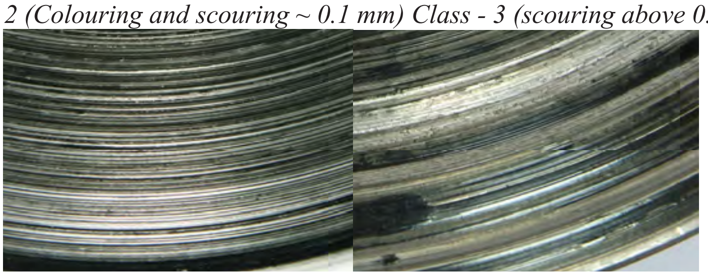
Wear class	Type of wear of the brake discs working surface	Remarks:
0	Disc surface following machining	Ra 1.6 μm
1	Dark colouring of the surface	no scouring
2	Colouring and scouring	scouring ≤ 0.1 mm
3	Colouring and scouring	scouring≥ 0.2 mm
4	Scouring and rubbing	scouring ≥ 0.3 mm
5	Deep scouring, wastage and material growths	scouring ≥ 0.4 mm



Class - 0 (prior to testing) Class - 1 (dark colouring)



Class - 2 (Colouring and scouring ~ 0.1 mm) Class - 3 (scouring above 0.2 mm)



Class - 4 (scouring above 0.3 mm) Class - 5 (wastage and material growths)

Fig. 6. Wear classes of the brake disc surface

5. Test results

Based on the tests results obtained, the friction pairs characteristics were determined, in order to observe changes in the value of the friction coefficient as a function of temperature. The characteristics of the materials tested presented below define the behaviour of the friction coefficient for the individual braking cycles. The thick continuous line represents the first braking cycle run, while the intermittent line shows the run of the last, of the five cycles. Horizontal axis represents disc temperature in the degrees centigrade, while the vertical axis represents friction coefficient. Based on the characteristics obtained, it was possible to evaluate the friction pairs tested with respect to the susceptibility to a fading phenomenon. Also state of the friction surface of the brake disc was evaluated following the trials.

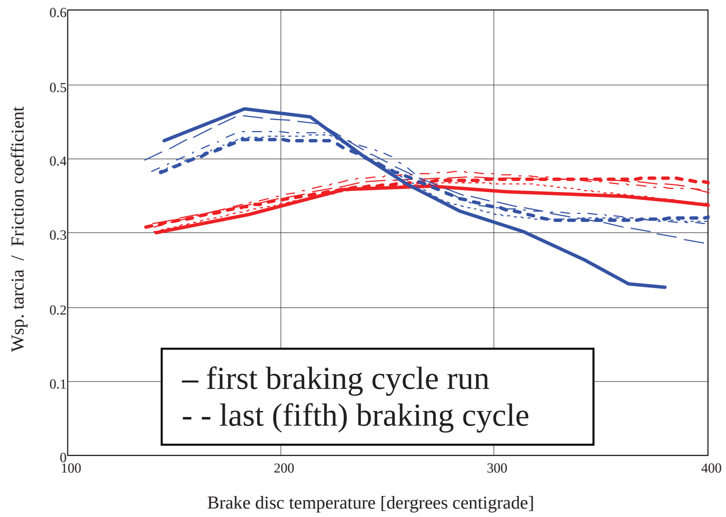


Fig. 7. Friction characteristics of the composite brake disc (20 % SiC - red line) and cast iron brake disc (blue line) with "racing" brake pads (EBC-2)

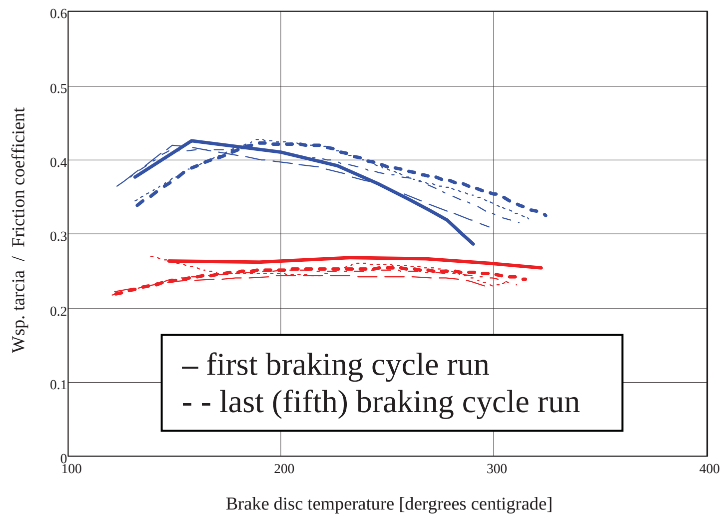


Fig. 8. Friction characteristics of the composite brake disc (20 % SiC - red line) and cast iron brake disc (blue line) with truck brake pads (BR)

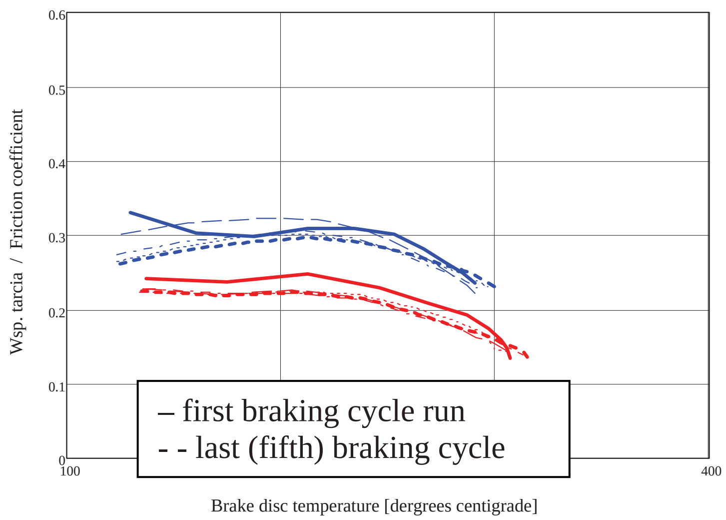


Fig. 9. Friction characteristics of the composite brake disc (20 % SiC) with truck brake shoe lining (JU-1) and different brake line pressures (15 bar - red line; 9 bar - blue line)

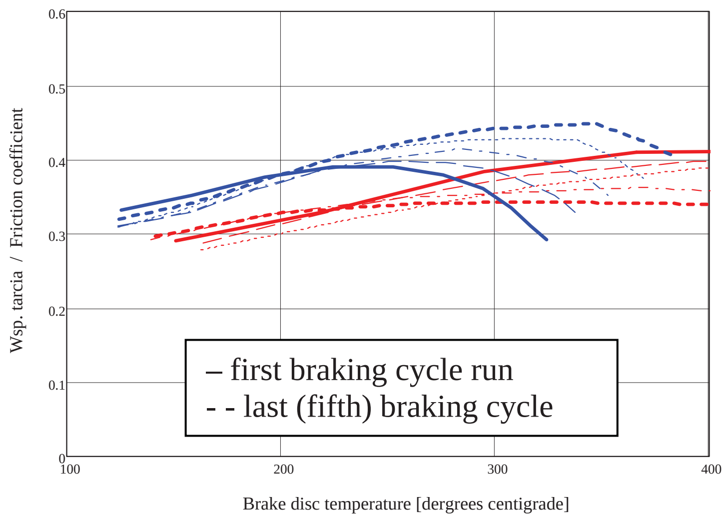


Fig. 10. Friction characteristics of the composite brake disc (20 % SiC) with brake pads for com posite brake disc (LE) and different brake line pressures (15 bar - red line; 9 bar - blue line)

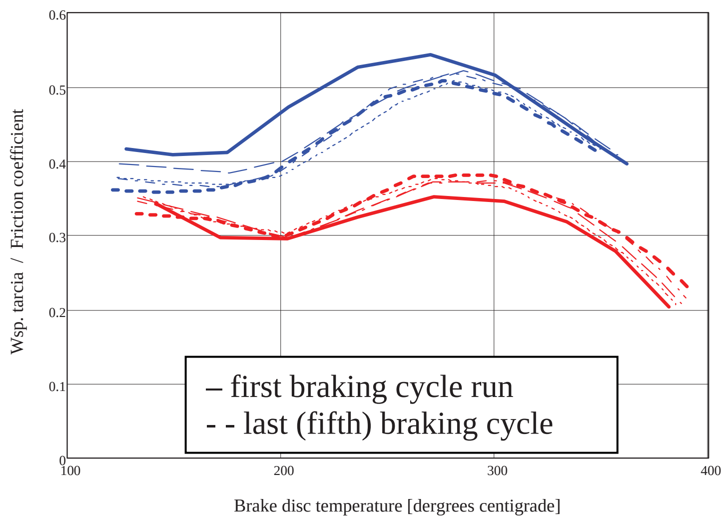


Fig. 11. Friction characteristics of the cast iron brake disc with truck brake shoe lining (JU-1) and different brake line pressures (15 bar - red line; 9 bar - blue line)

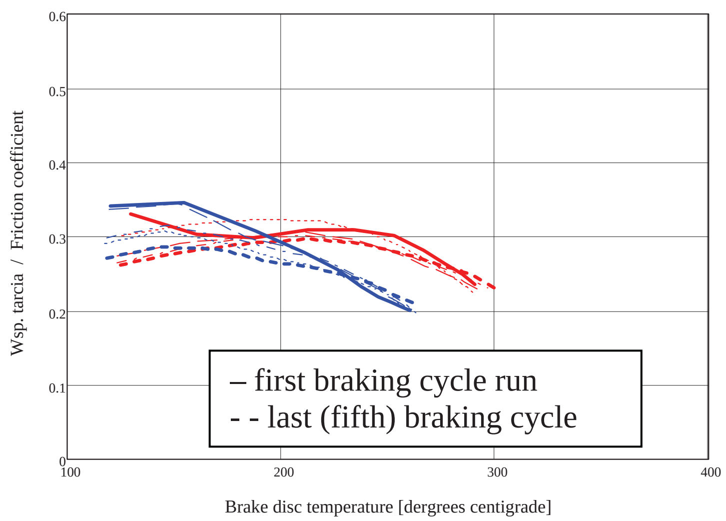


Fig. 12. Friction characteristics of the composite brake disc (20 % SiC - red line; 30 % SiC - blue line) with truck brake shoe lining (JU-1) and brake line pressure of 9 bar

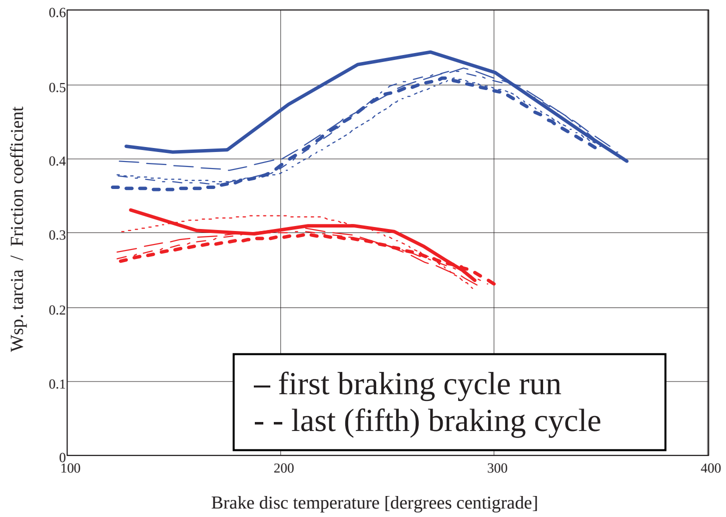


Fig. 13. Friction characteristics of th e composite brake disc (20 % SiC - red line) and cast iron (blue line) with truck brake shoe lining (JU-1) and brake line pressure of 9 bars

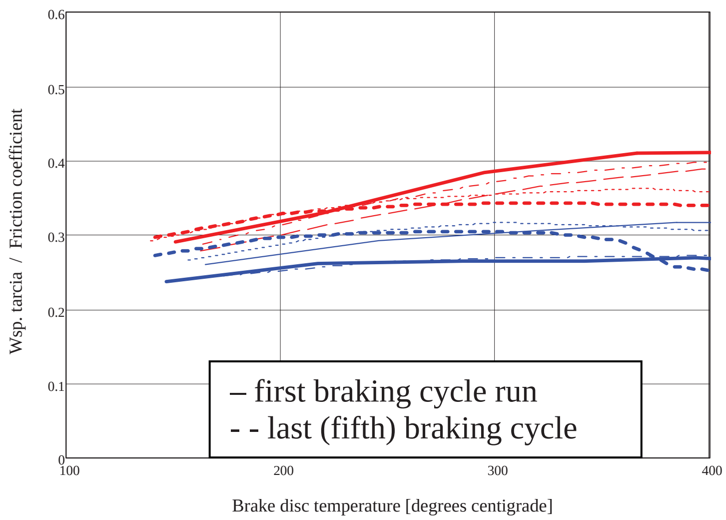


Fig. 14. Friction characteristics of the composite brake disc (20 % SiC - red line) and composite brake disc with fly ash (blue line) with brake pads for composite brake disc (LE)

6. Conclusions

Brake discs tested, made from the grey cast iron, when coupled with friction materials are characterised by:

- high value of the friction coefficient μ > 0.3 for the brake line pressure of 15 bars and μ > 0.4 for the brake line pressure of 9 bars (Fig. 7, 8, 11, 13),
- low wear of the friction area following tests (class 1),
- high thermal resistance above 400 ºC (Fig. 7).

Cast iron discs are commonly used in the motor vehicles.

Brake discs tested, made of MMC: -ALFA (AK9 + 20 % vol. fly ash) are characterised by:

- low friction coefficient μ < 0.3 (Fig. 14),
- high wear of the brake disc surface following tests (class 5),
- characteristics show large discrepancies of the friction coefficient value between each braking cycle.

Due to the reasons mentioned above, the use of ALFA composites requires further work on improving the structure, increasing the number and dispersion uniformity of the fly ash reinforcements.

Brake discs tested, made of MMC: - F3S20S and F3S30S are characterised by:

- stable friction characteristics when combined with friction materials for the brake pads of the sports cars (Lotus Elise - England - Fig. 10 and EBC-2 - England - Fig. 7),
- average value of the friction coefficient at the brake line pressure of 9 bars $\mu \geq 0.3$, and with the pressure of 15 bars $\mu < 0.3$ (Fig. 9, 12, 13),
- maximum disc temperature up to 350 ºC for the F3S20S material (Fig. 7, 8, 10), and 250ºC for the F3S30S material (Fig. 12),
- low wear of the disc surface when coupled with JU-1 linings in the class 1 (Fig. 12 and Fig. 9), and LE with the pressure of 9 bars in the class 2 (Fig. 10),
- stable friction characteristics and higher value of the friction coefficient for the composite brake disc made with the content of 20% vol. SiC than in the case of a composite with the content of 30% vol. SiC.

Composite Al alloys based brake discs reinforced with SiC (20 and 30 % vol.) may find application in the light sports cars, quads 3 and 4 wheeled on condition that:

- structure dispersion is stabilised towards increasing uniformity of the reinforcements arrangement,
- good heat dissipation is ensured by using ventilated disc,
- the construction of the brake system is ensuring low pressure per unit between the disc and friction material, by increasing the diameter of the friction are of the brake disc or by using composite disc made of SiC for the less loaded rear wheels,
- designing and testing friction material designated to be used for brake discs made of metal composite materials for the selected vehicle (ventilated),
- road tests will take place, which may unequivocally indicated higher braking effectiveness and will allow investigating the wearing down processes in the real conditions (loads, cooling, soiling, etc.).

References

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[4] Sobczak, J., Wojciechowski, A., *ATLAS of cast metal-ma trix composites structures*, Motor Transport Institute, Foundry Institute, Warsaw 2007.