

Wear and Friction Behavior of Friction Pairs Tested with Different Types of Grey Cast Iron and Low Met Friction Material

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ABSTRACT

Wear and friction behavior of disc brakes are important properties of disc brake systems and are mainly addressed by appropriate selection and tuning of friction material. Disc material composition is often considered as "given". The most common material used for brake discs is grey cast iron which can have carbon content between 2.5 to 4.2 percent. It is difficult to find in literature investigations related to the influence of cast iron material in combination with modern low-met friction material on wear and friction performance of disc brakes. In this work, the author will try to analyze impact of brake disc material properties on wear and friction performance.

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INTRODUCTION

Gray cast iron is a material used for production of vehicle brake components since the beginning of production of passenger cars. Gray cast iron, having mostly graphite flakes of type A disposed in a perlite matrix, is the basic material used for production of brake discs and drums. The generic chemical composition of gray cast iron can be described as: %C 2.5-4.2; %Si 1.0-3.0; %Mn 0.15-1.0; %S 0.02-0.25; %P 0.02-1.0. There are also alloying elements like Cr, Ni, Mo, Si, Al and Cu. The microstructure of gray cast iron depends not only on chemical composition, but significant contribution comes from manufacturing processes [1,2].

Advantages of gray cast iron as the material used for production of brake discs are as follows: good casting properties, good machinability, damping properties, low thermal expansion, good thermal capacity and conductivity and low cost. The disadvantages can be defined as low corrosion resistance, low mechanical properties of unalloyed materials and low plasticity [3].

For production passenger car brake discs there are two main families of cast irons in use: high carbon cast iron (C%>3.5%) and low carbon cast iron (C%<3.5%). High carbon material is usually applied on front discs which experience higher thermal and mechanical loads during braking applications [4].

Increase of carbon content in GCI increases thermal conductivity. Depending on carbon content, the thermal conductivity value can be between 42 and 66 W/m*K in room temperature [5,6,7].

Morphology of the microstructure should also be considered when comparing cast irons of similar chemical composition. Hecht [6] investigated dependencies between cast iron microstructure and physical properties responsible for heat transportation like thermal diffusivity and conductivity. It was noticed that the diffusivity rises together with increase of carbon equivalent and graphite flake length. Similar relations were found by Jimbo et al. [8]. Additionally, Jimbo has observed that cast irons with graphite flakes type D have lower diffusivity than irons with the same chemical composition and graphite flakes of type A.

Carbon content and related thermal properties are important properties of cast iron which influence temperatures generated during braking. Using method of finished elements Belhocine et al. [9] simulated temperatures in brake discs composed of cast irons of different types and demonstrated differences in temperature up to 40°C when simulated with the same loads and boundary conditions.

Increased thermal conductivity decreases the temperature gradient between the friction surface and inside of the disc, therefore thermal deformation and tendency for heat cracking of the friction ring is reduced. However the presence of a high amount of graphite flakes has a negative impact on mechanical properties of cast iron.

Increased thermal conductivity of cast iron allows better transportation of thermal energy to other areas or components using them for heat storage or heat dissipation (hat section of

brake disc, hub or wheel). In this manner, average brake temperatures can be reduced which can have a positive effect on wear resistance of brake pad and disc.

On the other hand, connected graphite flakes are preferred places for propagation of cracks under mechanical load and could accelerate the wear process on the friction surface by faster removal of the perlite matrix.

All the above mentioned factors play a significant role in the end results obtained during development of brake systems. A common approach used for development of a new brake system is to use carry over brake discs or at least cast iron type, however friction materials due to continuous changes introduced by law makers (asbestos ban in 80's and copper limitation from 2017) and constant increase of NVH expectations, are subjected to many modifications.

It is difficult to find in literature information about the impact of different cast iron compositions on brake behavior when tested with the same friction material. It is of great interest to investigate the impact of cast iron material properties on the most important brake properties. In this paper the author will look at the relation between material properties (chemical composition and hardness) on wear and friction coefficient

SAMPLE AND TEST PROCEDURE DESCRIPTION

It was decided to use B-platform sized front vented disc brakes with a performance friction material. Friction material used during all tests was from the same batch. [Table 1](#) shows chemical composition (carbon, silicon and chrome content) together with carbon equivalent of tested rotors. Carbon equivalent was calculated according to [equation 1](#).

$$\text{Carbon equivalent (CE)} = \%C + 1/3\%Si - 1/3(\%Cr - 0.1)$$

(1)

[Table 1. Chemical composition of brake rotors used for investigations.](#)

No.	C %	Si %	Cr %	CE:
1	3.23	2.544	0.1506	4.086
2	3.44	2.075	0.2234	4.135
3	3.67	1.235	0.0945	4.087
4	3.55	1.705	0.316	4.127
5	3.24	1.961	0.1692	3.901
6	3.4	1.908	0.2448	4.040
7	3.31	1.888	0.1772	3.950
8	3.28	2.005	0.1984	3.957
9	3.26	2.559	0.1586	4.121
10	3.65	1.889	0.1642	4.285
11	3.63	1.858	0.1945	4.260
12	3.63	1.839	0.2365	4.251

The microstructure of tested materials was evaluated according to ASTM A247 [10]. The results are shown in [Table 2](#).

[Table 2. Microstructure of brake rotors used for investigations.](#)

No.	Graphite type A [%]	Graphite type B [%]	Graphite type D / E [%]	Flake size [%]		Ferrite	Cementite / free carbides
				3 - 5	6		
1	95	4	<1	90.00	10	<1 %	<1 %
2	95	4	<1	85.00	15	<1 %	<1 %
3	90	9	<1	85.00	15	<2 %	<1 %
4	95	5	0	85.00	15	<1 %	<1 %
5	90	8	<2	90.00	10	<1 %	<1 %
6	90	9	<1	85.00	15	<1 %	<1 %
7	90	9	<1	90.00	10	<1 %	<1 %
8	95	3	2	90.00	10	<1 %	<1 %
9	95	4	<1	90.00	10	<1 %	<1 %
10	95	4	<1	85.00	15	<3 %	<1 %
11	90	9	<1	90.00	10	<1 %	<1 %
12	95	5	0	85.00	15	<1 %	<1 %

Graphite type A dominates the microstructure of the analyzed materials. Graphite A has a shape of flakes equally spaced within the perlite matrix. Some amounts of graphite type B are also present. This kind of graphite is characterized by nest-like formations of graphite flakes. Comparing with type A, the dispersion of graphite in the perlite matrix is less equal. Graphite flakes type D and E, which have dendritic shape, are present less than 2 percent.

The first four parts were prepared according to a specification with higher content of carbon and mechanical properties similar to low carbon material. Parts marked with numbers from 5 to 8 were requested to be casted according to low carbon cast iron material specification, parts from 9 to 12 according to high carbon one.

The materials were analyzed for hardness on friction surfaces. On each brake disc, 8 Brinell indents (HB 10/3000) have been placed on the inner and outer braking surface each at 0, 90, 180 and 270 degrees. [Table 3](#) shows average hardness measurements.

It was decided not to make tensile strength measurements because of the nature of the tested rotor. Each braking plate had a nominal thickness of 7.5 mm. Probes cut out of such plates would have an insufficient diameter to guarantee reliable

results. The relation of graphite flake dimension to probe diameter would be too high and would influence the measurement. European Norm 1561 [11] allows a wedge penetration test as an alternative method for evaluation of tensile strength of grey cast irons. However regression coefficients need to be established in order to calculate tensile strength. In the case of this project, a limited number of parts were casted which did not allow these coefficients to be generated.

Dynamometer Performance Test For Development and Quality Control of Disc Brake Friction Materials [12], was used for evaluation of friction coefficient behavior. Wear properties of brake rotors and pads were evaluated with Dynamometer Mojacar Cross Country Route Simulation [13]. The tests were run on LINK Model 3900 NVH Dynamometer. There was an exemption related to the cooling air used during the tests. These test procedures require cooling air controlled for temperature and humidity. The brake dyno used in this project took the cooling air from inside the laboratory, so there was no possibility to set up the air temperature and humidity. However, these values were monitored, and remained stable during the whole testing activity. Therefore the results can be used for comparison. Absolute values should be treated carefully.

Table 3. Friction surface hardness values of tested rotors.

No.	Hardness HB
1	195
2	182
3	178
4	179
5	201
6	186
7	206
8	197
9	188
10	126
11	181
12	169

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The Dynamometer Performance Test for Development and Quality Control of Disc Brake Friction Materials is composed of 25 sections. For purposes of this document only the sections where the greatest differences between the materials were noticed, will be analyzed:

- Average (by time) friction coefficient of sixth stop from section 4.3 (4.3 Stop #6 avg. by time).

- Average maximum friction coefficient from all stops in sections from 4.1 to 4.4 (4.1 - 4.4 max. stop avg. all stops).
- Average (by time) friction coefficient of first stop from section 7 (7.0 Stop 1 avg. by time)

Table 4 presents braking data from sections taken into consideration.

Table 4. Description of test sections considered for analysis [12].

Sect. No.	Section Description	Control Attribute	Speed (kph)	IBT (°C)	No. of Stops
4.1	Speed/Pressure Sensitivity	P = 5,10,15,20, ... 80	40 → 0	100	16
4.2	Speed/Pressure Sensitivity	P = 10,20, ... 80	80 → 40	100	8
4.3	Inop power stops	P=25	100 → 0	85	6
4.4	Speed/Pressure Sensitivity	P = 10,20, ... 80	120 → 80	100	8
7	Motorway Braking Check	T, 0.6 G	100 → 5 0.9 → 0.5 V _{max}	80	2

Figure 1 shows measured friction coefficient values on the Y axis and on the X axis cast iron type number from Table 1.

One can see significant differences in terms of observed friction coefficient between different rotor materials in all analysed sections. For example, average maximum friction coefficient from all stops in sections from 4.1 to 4.4 varies between 0.39 to 0.47. This is a 20% difference.

Relations between material properties should be analysed at this stage. It was seen that carbon and carbon equivalent are very important elements responsible for important cast iron properties. Figures 2, 3, 4, 5, 6, 7, 8, 9, 10 present friction coefficients from previously described sections in relation of carbon, silicon and carbon equivalent of tested rotors.

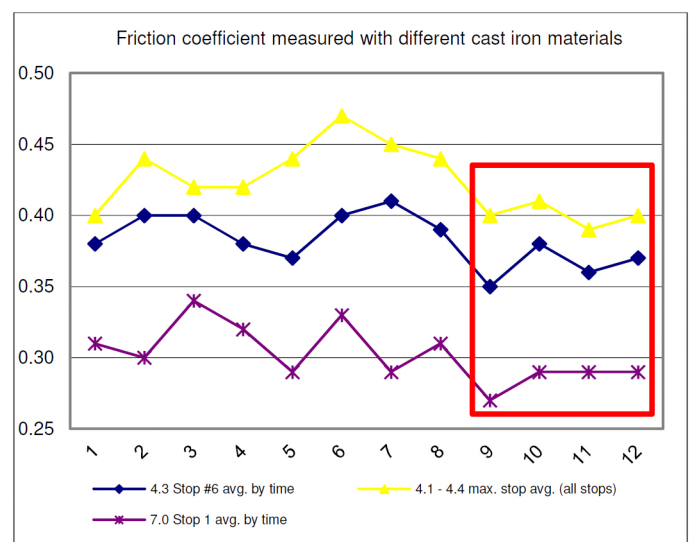


Figure 1. Friction coefficient values from section 4.3 as a function of cast iron type.