Investigations on sintered materials for automotive component manufacturing

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Abstract: The present paper presents a study on sintered materials with lower wear rate, constant friction coefficient and high durability and thermal stability connected to a good self-brazing capacity. Copper and Iron based friction materials were sintered and the influence of the composition on the friction and wear properties were studied. Employing a Copper based material with a moderate graphite and ceramic content the desired properties are reached.

1 Introduction

Generally, the friction materials have a complex composition containing both metallic and non-metallic elements. Each constituent has a significant utility during the braking route and the right selection of the elements constitutes a critical phase in the growth of any commercial product. The most important components for brake pads typically contain:

- the frictional additives, which govern the frictional properties of the brake pads including a combination of abrasives and lubricants;
- fillers, which increase the production of the brake pads;
- binders, to keep the components made up the brake pad together;
- reinforcing fibres, guaranteeing the right mechanical strength to the whole piece.

The types of the different elements in a brake friction material are determined considering the friction force, noise affinity, aggressiveness against gray cast iron rotors, wear, brake induced vibration. During the time, many studies have been carried out to investigate different features related to the improvement of the brake performance [1-4].

Ceramic fibres are the most suitable to be used as reinforcing material and glass fibres have also been proposed to be used in reinforcing materials, due to their appropriate thermal resilience, with high melting point and low conductivity, compared to asbestos [5-7]. The concept of use of TiC to reach higher hardness, higher melting point and higher abrasion resistance, as well as the possibility of the self-lubricating effect of graphite in case of lead free copper contact materials reducing the strength of the composites have been extensively studied during the years. Metallic chips or granules are commonly used as reinforcing fibres, like steel, brass and copper. The weakness of using steel is related to their corrosion, when used close to the seaside surroundings. The most important advantage of employing metal fibres is due to their high thermal conductivity. The utility of the binder is to maintain stable the structural integrity of the brake pads under mechanical or thermal stresses. It must show high heat resistance, since if it does not remain structurally continuous at all times during braking, the other constituents will disintegrate. The presence of fillers is necessary in order to increase the manufacturability and to moderate the overall cost of the brake pad and they play an important role in changing some characteristics of the brake friction material. Generally, the choice of the filler material depends on the particularity and type of the components. Generally, the frictional additive modifies the friction coefficient and the wear rates and can be classified in two groups:

1. lubricants, stabilizing the developed friction coefficient during braking, particularly at high temperature; generally graphite and metal sulphides are used for such purposes;

2. abrasives, increasing the friction coefficient and the wear rate; they remove iron oxides and other undesirable surface films developed during braking from the counter friction material; hard particles of metal oxides and silicates are the mostly used abrasives [8-12].

In the present paper, Cu and Fe-based friction materials will be investigated and the optimization of their composition will be performed to achieve higher tribological properties, compared to those produced using polymer matrix materials. Information about the exact composition of the optimized friction material studied will not be make known in the paper.

2 Experimental procedure

Sintering has been performed using different powder mixture made of: iron, copper, bronze, graphite, SiC, Al_2O_3, kindly offered by Höganäs, Sweden and Makin Metal Powders, UK and their size has been selected in line with the industrial application request. The mixed powders have been pressed and then have been positioned on a C72 high carbon steel discs and simultaneously have been bonded to a steel backing during sintering. The samples have been prepared by traditional powder metallurgy method. The cold-compacted samples have been sintered using a tubular furnace (with a heating rate of 10°C/min, T= 900°C-1000°C and a holding time 15 min-45 min and a protective N_2 atmosphere). Cooling to room temperature has been reached naturally. Optical (OM, MeF4 Reichart-Jung) and Scanning Electron Microscopy (SEM, Leo 1450VP) observations, compositional analysis (EDS, Oxford microprobe) and tribological tests have been performed imitating the “repeated single braking” conditions used industrially. The contact pressure varies from 4 MPa to 8 MPa, while the sliding velocity varies between 1÷10 mm/s. After 50 cycles, the reduction of the depth has been measured in 3 points and the wear has been calculated using a semi empirical formula, reported in Equations 1 and 2.

$$\mu = (265/p*r_m*L)/(0.206/p*r_m) \quad (1)$$

where: μ: friction coeffcient, p: mass applied on the samples (kg), r_m: average radius of the wear track (cm), L: length of braking (mm);

$$u = 10^3 *(A*h)/(E*N) \quad (2)$$

where: u: specific wear ($cm^3/10^{-6}$ kg*m), A: contact area (cm^2), E: kinetic energy of the apparatus (J), h: reduction of the depth of the sample tested (mm), N: number of braking.

3 Results and Discuss

Sintered-metal friction materials have been prepared with a variable compositions reported in Table 1, and their properties have been compared to those manufactured with polymer matrix materials.

Table 1. Composition of the friction materials investigated.

Samples	Composition (wt%)
A	55% Fe + 33% Cu + 7% bronze + 5% graphite
B	52% Fe + 31% Cu + 7% bronze + 5% graphite + 5% SiC
C	57% Cu + 35% Fe + 7% bronze + 1% graphite
D	56% Cu + 34% Fe ++ 7% bronze 3% graphite
E	55% Fe + 30% bronze + 5% graphite + 1% Al_2O_3 + 9% $ZrSiO_4$
F	30% Fe + 55% bronze + 5% graphite + 1% Al_2O_3 + 9% $ZrSiO_4$
G	33% Cu + 45% bronze + 2% graphite + 20% $ZrSiO_4$

During sintering, the compacted samples are simultaneously bonded to a steel backing. The first step of the research is dedicated to optimize the consolidation method and the sintering, using the mixtures A-D reported in Table 1. The second step makes use the mixtures E-G reported in Table 1.

High amount of bronze (due to its good joint potentiality and good tribological behavior) and ceramic material has been used. As well, in this condition the possibility to exploit the self-brazing capacity of bronze with no any use of liquid binding agent is possible. Different kinds and quantity

(< 25wt%) of abrasives (SiC, $Al2O_3$, $ZrSiO_4$) have been used and the comparison on their effect on the performance of the friction material has been completed. Microstructural characterization and performance tests, including the determination of the friction coefficient and wear rate have been carried out.

Because of the different nature of the parteicles, the pressure acts and deforms in a different way the grains according to their hardness. The use of different mixtures and the experimentally evaluation of their performances have been carried out with the purpose to reproduce as much as possible the industrially employed conditions. Generally, as Fe content increases the density of the green increases as well: this is because of their larger size and for the fact that porous nature has higher tendency for compression. Cu reduces the amount of fade due to its thermal diffusivity by preventing hot spots in the friction interface. Use of SiC involves lower density, but because of its hardness, it can confer higher fragility to the material and generally lower compaction rate. The optimal pressure which produces a high density compacts has been fixed to 800 MPa. The optimal sintering temperature (975°C) has been selected according to the Sn-Cu and Cu-Zn phase diagrams. At this temperature 55 wt.% of the metal is liquefied. In all cases about 10% of small porosity persists, which guarantees a good workability of the piece.

The sintering of the Fe-based materials has been realized and a non-uniform compositional distribution of the different phases (Fig.1.1) has been obtained showing a high content of Fe (grey area Fig.1.2) immersed in an ample content of Cu and bronze, with quite the same appearance and colour on the SEM microstructure (Fig.1.2). Porosities have been closed by the liquefied bronze. Soldering of the sintered material to the steel is not strong enough and a fracture occurs, as reveals the micrograph in Fig.1.3. The evolution of the microstructure is obtained by adding SiC particles to the mixture and reducing the metal content, maintaining the same metals ratio.. An efficient soldering between the two parts (Fig.1.4) and the presence of a high residual porosity (Fig.1.5) has been obtained. A non-homogeneous composition and in the metal matrix high presence of Fe has been detected. SiC particles have been integrated within the metal matrix (Fig.1.6).

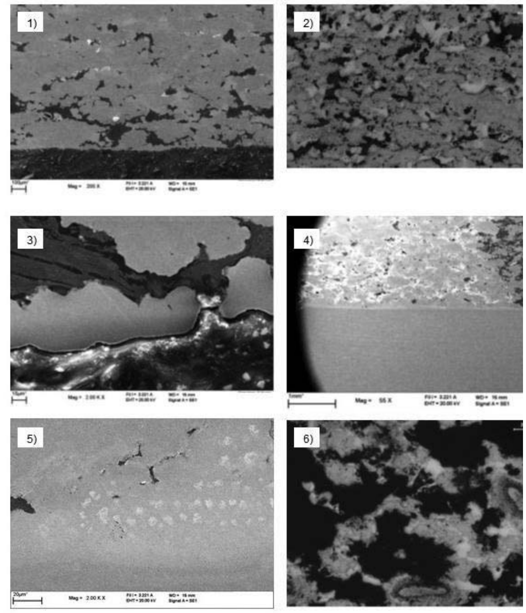

Figure 1. Microstructure of the sintered material: Sample 1 (1, 2) and details of the joining zone between the steel and sintered material (3) and Sample 2 (4, 5) and details of the joining zone between the steel and sintered material (6)

The Cu-based sintered materials are regular with a low porosity, nevertheless an insufficient joining of the parts has been realized (Fig.2.1) with an evident presence of voids and some cracks. In this case, synthetic glue has been used to facilitate the joining during sintering. As expected a high Cu and bronze presence and a reduced Fe and graphite content (Fig.2.2) favor a uniform development of the microstructure (Fig.2.3).

Improving the graphite amount to 3% compared to the previously shown samples no significant variation has been detected as the homogeneity of the samples regards and an improvement of the joining between the sintered part and steel occurs (Figs.2.4 and 2.6). A partial soldering takes place (Fig.2.5) which can be solved by increasing the holding at the maximum temperature. During tribological characterization, failure of samples takes place. The samples with a higher content of bronze and ceramic material (Samples E-G, Table 1) have been prepared.

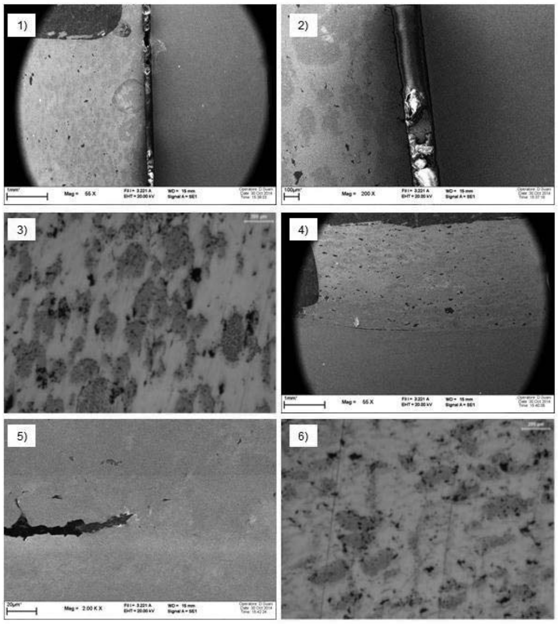

Figure 2. Microstructure of the sintered material: Sample 3 (1, 3) and details of the joining zone between the steel and sintered material (2) and Sample 4 (4, 5) and details of the joining zone between the steel and sintered material (6).

Uniform distribution of the ceramic particles inside the metal matrix is favored in case of low Fe and high bronze content (comparison of Figs.3.1 and 3.2), even if the porosity results superior in this case on the whole surface.

No discontinuity or crack development has been observed at the interface between the sintered material and the steel support demonstrating a good self-brazing capacity of the mixture.

In the case of the sample containing Cu with high bronze and ceramic particles (Sample 7) a uniform diffusion of the ceramic particles within the metallic matrix and a continuous interface with development some large porosity (Fig.3.3) can be detected. The thickness of the joining material is uniform and as expected, it is totally made of bronze.

Gradual heating of the samples has been produced at various loads and speeds during two series of braking: at the end of the braking test, the reduction of the depth has been measured in 3 points and the wear has been calculated using a semi empirical formula, reported in the Equations 1 and 2.

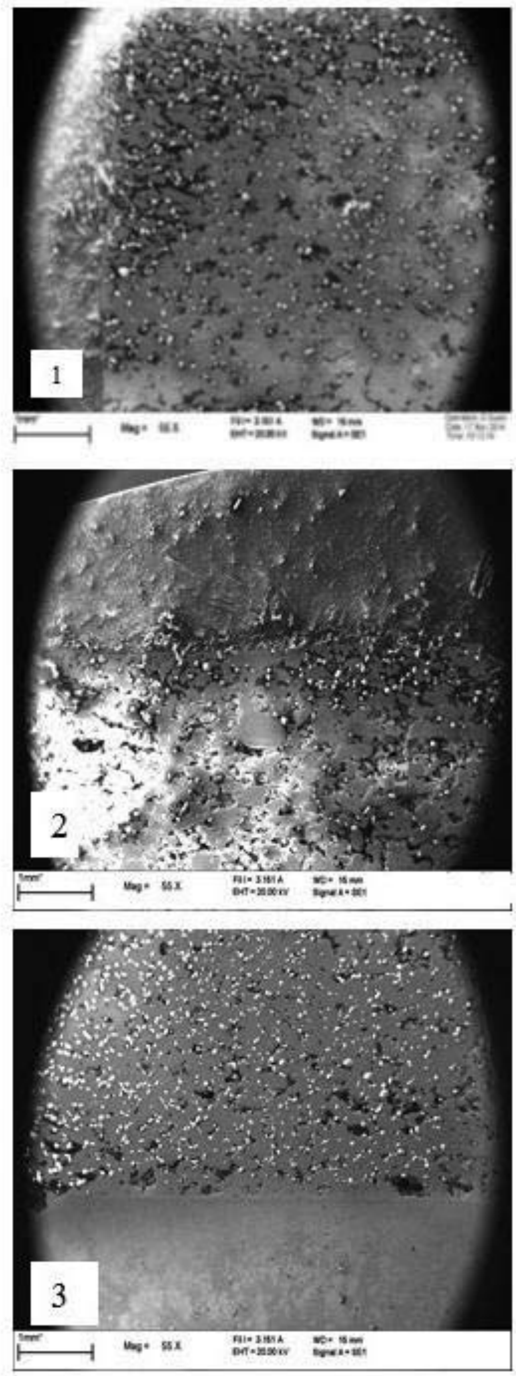

Figure 3. Microstructure of the Samples 5 (1), 6 (2) and 7 (3)

Oscillation on the friction coefficient has been observed. The results are reported in Figure 4. The low graphite content, the metal matrix made of Cu and bronze or Fe and bronze are significant for lowering the friction coefficient in the range of 0.4÷05. As wear rate regards, a comparison between the studied sintered materials and the commercially employed materials has been realized.

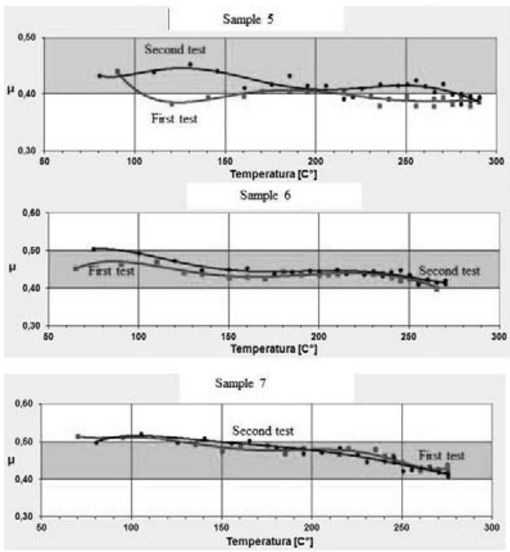

Figure 4. Friction coefficient vs. temperature for the Samples 5÷7

All samples show a lower wear rate compared to the organic material and the average values are below the limit established (1 $cm^3/10^6$ kg against 2,77 $cm^3/10^6$ kg for the organic material).

4 Conclusions

Development of sintered friction material was performed, as an alternative solution for the actually used polymer matrix materials. The samples were obtained with a high and constant friction coefficient, a high durability and thermal stability connected to a lower wear rate. Additionally, lack of noise during braking and a good self-brazing capacity were realized. Cu and Fe-based friction materials were sintered and for the optimized compositions, oscillation on the friction coefficient was observed. The friction coefficient of the produced materials fulfills the industrial need: the optimized sintered materials have a lower wear rate compared to those of the actually employed organic material.

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