

Promaxon® D in NAO Non Steel Disc Pad Formulations: the Importance in the Third Body Layer and its Effect on Brake Noise

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ABSTRACT

Friction performance is the result of the interaction between rotor and friction material surfaces. Kinetic energy has to be transformed into heat, plastic deformations, chemical reactions and wear debris. The later generates the formation of the so-called third body layer and its initiation, growth and degradation will generate the actual friction coefficient and vibrations behavior.

Some raw materials seem to promote third body layer formation more than others. The composition of plateaus usually contains iron oxide, copper, carbon, silicon and calcium. Since copper free materials are under development, the importance of understanding the third body layer formation has become bigger.

Promaxon® D is widely used in NAO non steel formulations. It is a calcium silicate with a special morphology that influences friction material at two levels: the macro -bulk- scale and the micro -surface- scale.

Bulk effect is related to the volume and porosity degree of the friction material. This affects the elastic modulus and vibration adsorption.

The micrometric effect is related to the third body layer. When Promaxon® D is combined properly with an anchoring material (i.e. a fibre) it can promote the initiation and stabilization of the third body layer. As a result friction coefficient stabilization and wear will be improved. Wear is also directly related to noise as proposed by Lee et al [15].

This paper deals with the understanding of the importance of calcium silicate morphology for the bulk properties and in the third body layer formation. It demonstrates how the raw materials morphology, regardless of its chemical composition, plays an important role at macro and micro level in NAO non steel materials.

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INTRODUCTION

Friction performance and the mechanisms taking place at the contact area between brake pad and rotor surface are a combination of physical, thermomechanical and chemical phenomena. Kinetic energy has to be converted into heat, plastic deformations, chemical reactions and wear debris [1].

Due to its complexity, the tribology of brake pads can be analyzed from two points of view. The first one is the macrometric scale of friction material analysis, the bulk properties of the brake pad, rotor

and caliper and their influence on friction performance. The second point of view is the micrometric scale in which the sliding contact between friction material and rotor surfaces is analyzed: [Figure 1 \[10\]](#).

The braking system, environmental and testing conditions, and the volumetric properties of the pad (such as porosity, density, impact strength, compressibility and elastic modulus) determine the macrometric scale. Some influences are caused by the braking system and others by the friction material bulk properties.

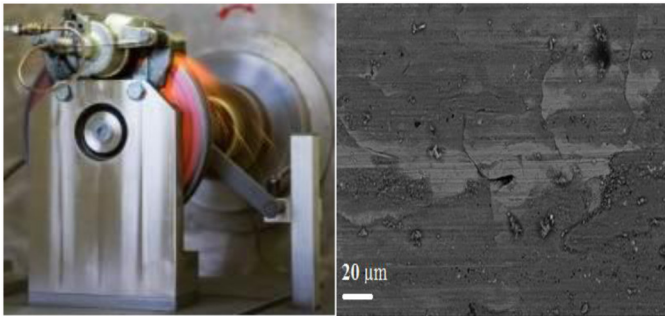


Figure 1. Braking: A multiscale phenomena. a) Macroscopic b) microscopic.

The second -microscopic- point of view is related to the pure interaction between rotor and friction material surface.

Achieved temperature in the contact area, specific generated vibrations and frequencies, amount of produced dust and involved chemical interactions will directly depend on the coupling dynamics of the two surfaces. The design of the braking system plays an important role.

Figure 2 shows some of the elements involved in the friction dynamics for friction performance, wear and squeal generation. Brake pads will change the friction performance depending upon the design of the pad, rotor, caliper and in general of the braking system.

At the same time friction material behavior shows a dependency on testing conditions such as applied speed and pressure, environmental moisture and temperature, water presence and other factors. A lot of research has been done on this subject [3, 4, 5, 6].

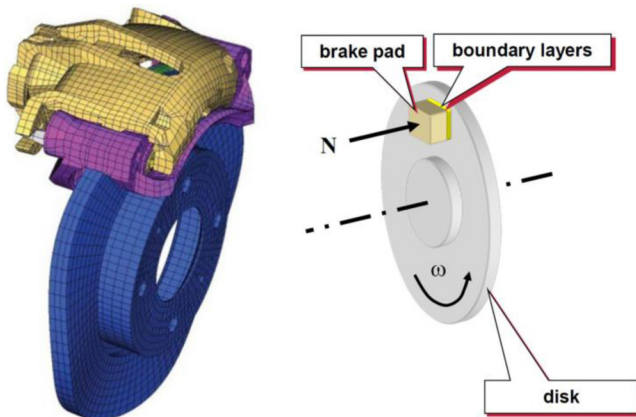


Figure 2. Left: a finite element model used to investigate squealing involving rotor, caliper and friction material; right: elements involved in the surfaces coupling between rotor and disc [2]

Thus, friction phenomena is a complex interaction between rotor and brake pad surfaces and many factors can play a decisive role in the friction, wear and noise behavior. Friction material surface and rotor surface coupling have also been widely studied [7, 8, 9].

At the micrometric scale, sliding friction generates the formation of the so-called third body layer and its initiation, growth and degradation will generate the actual friction coefficient and wear [11]. The third body layer consists of a semi continuous layer formed by primary and secondary plateaus [12]. Its chemical composition depends upon the combination of compounds present in the friction material formulation, rotor chemical composition and quality, environmental conditions and testing procedures [11] (involved energy can vary at different speeds or decelerations, as a consequence achieved temperature on the surface is not always the same resulting in different chemical reactions).

Some raw materials seem to promote third body layer formation more than others. Many observations show that the main chemical composition of third body layer is iron oxide -probably coming from the rotor- copper, carbon, silicon and calcium [13]. Most of the research is based on characterizations done on the third body layer after it has been created under certain conditions. Studying its formation and at the same time perform realistic testing procedures is very complex.

Nevertheless, the importance of understanding the third body layer formation is fundamental for formulators, especially when dealing with groundbreaking developments as the copper free materials. It is crucial to understand, by adjusting all system conditions, how production processes, formulations (thus raw materials) and environmental conditions might affect transfer layer formations.

In order to make this study as thorough, comprehensible and adaptable as possible, both macrometric and micrometric scale will be analyzed. Dynamic testing procedures have been carried out and static surface characterizations have been used to support the paper.

RESEARCH SETUP

This study deals with the concept of the importance of calcium silicate morphology in bulk properties and in the third body layer formation in a copper free NAO non steel formulation. It demonstrates how raw material morphology, next to chemical composition, have combined effects at microscopic and macroscopic level in NAO non steel materials. These effects play an important role on brake pad performances.

In order to investigate the impact of Promaxon® D morphology in passenger car disc pads with NAO non-steel formulations, a reference sample without calcium silicate and two samples with different morphologies of calcium silicate have been evaluated. The two of them were introduced in the same friction material formulation at the same volumetric rate.

A more precise description of the NAO non steel formulation is shown in [table 1](#).

Table 1. Copper free NAO non steel disc pad formulation.

	Volume [%]
Novolac resin	16
Aramid fibres	6
Solid lubricants	12
Friction dust/rubber crumb	10
Potassium titanates	17.5
Abrasives	14
RB205-Roxul®1000 fibre	8
PROMAXON® D (Calcium Silicate)	6.5
Fillers	10
Total	100

A basic characterization on calcium silicate samples has been carried out and morphological differences have been studied at different steps of the processing. Macroscopic properties of the produced friction materials have been measured and finally friction performances have been evaluated (Efficiency and NVH tests). Microscopic analysis after testing has been done in order to understand the influence of morphologic properties of calcium silicate at the surface level.

Mixing was done in two stages using a multiple blade, high-speed, vertical MTI laboratory mixer (speed 2000 RPM). In the first stage, the aramid fibres and mineral fibres were dispersed by mixing the fibres with graphite and fillers for two minutes. In the second stage, the remaining raw materials -including calcium silicates- were added to the mixture for an additional two minutes.

Pads were processed in a positive mold for 5 minutes under a pressure of 300 kg/cm² and cured for two hours at a constant temperature of 220°C with a heating and cooling ramp of two hours each (for a total of 6 hours).

Instruments and testing procedures

Microscopic pictures have been made using a scanning electronic microscope (SEM) FEI Inspect S and elemental analysis has been obtained with an Energy Dispersive X-Ray analyzer (EDX) using the EDAX Genesis XM system.

Thermogravimetric analysis has been done in a Mettler TGA/SDTA 851 instrument between 40 and 900 °C at a heating rate of 10 °C/min in air.

For the micro tomography measurements the SkyScan 1172 was used. This is a high resolution desktop X-ray micro-CT system with a closed X-ray micro-focus source. The detection system consists of a gadolinium (Gd₂O₂S) scintillator with a 2:1 fibre optic coupling to a 4000 2096 large format 12-bit cooled CCD camera.

Efficiency performance has been evaluated in a Horiba dynamometer according to SAE J2522 and noise performance was evaluated according to SAE J2521. The pads were not scorched and did not contain an anti-noise shim, slot or chamfer. The brake system used for dynamometer testing was the front brake of a VW Golf (WVA21974) using a ventilated disc and inertia of 65 kgm².

Materials

Calcium silicate with spherical shape is widely used in NAO non steel formulations. It is a synthetic hydrated calcium silicate with a specific density of 2.6 g/cm³. By using a special crystallization process and controlled crystal growth, white particles have been formed with a spherical and porous morphology. Figure 3 shows its chemical composition making use of EDX.

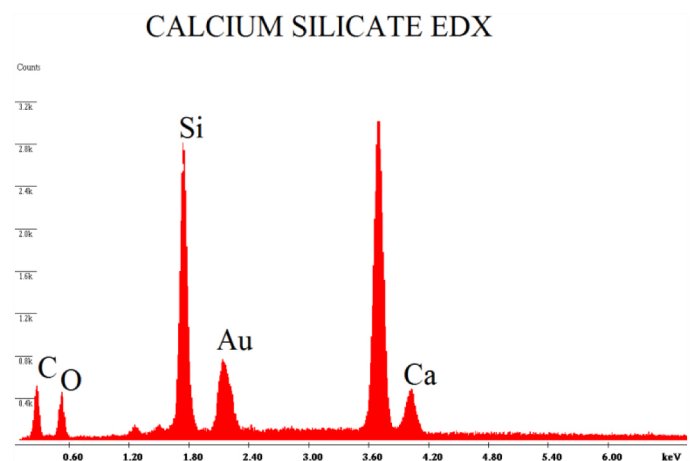


Figure 3. Promaxon® D elemental analysis at the EDX, typical average.

The process results in particles with an open inner structure consisting of needles surrounded by an outer shell of closely knitted crystals with an average particle size of about 60 microns as shown in figure 4.

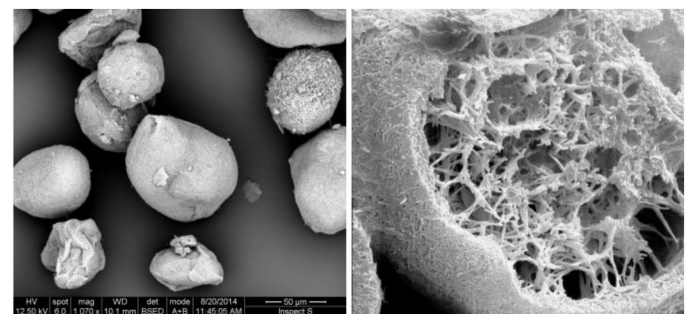


Figure 4. Promaxon® D morphology and internal needle structure.

Because of its unique structure and chemical composition Promaxon® D has remarkable properties, including a melting point of >1500°C (2732°F) and a very high porosity (>90%), resulting in a bulk density of approximately 0.1 g/cm³. Figure 5 shows a thermogravimetric analysis of Promaxon® D.

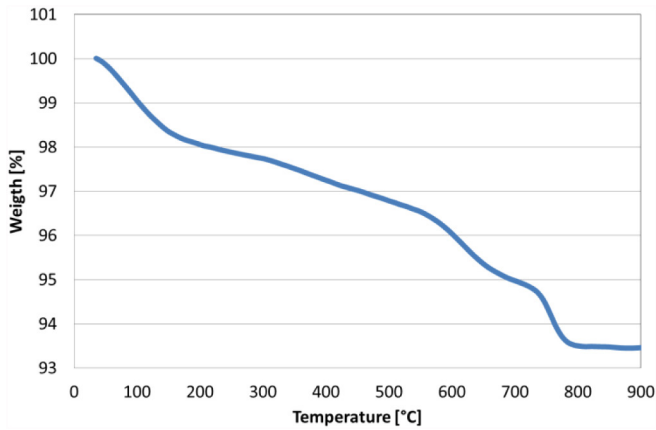


Figure 5. Promaxon® D elemental analysis at the EDX, typical average.

Amorphous morphology of calcium silicate has been produced by milling the spherical shape of calcium silicate. Chemical composition and thermal resistance were kept intact. Only particle size and morphology have been modified, particles are shown in [figure 6](#).

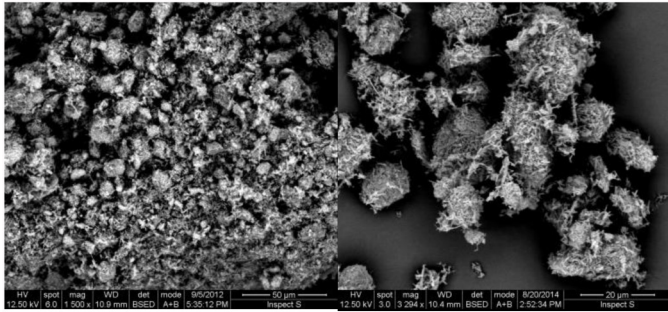


Figure 6. ACS sample, amorphous morphology.

Three different samples of friction material have been produced with the formulation shown in [table 1](#), a copper free NAO-non steel formulation. A reference sample without calcium silicate, a second one with the use of spherical calcium silicate and a third one with the milled down calcium silicate. [Table 2](#) shows a summary of produced samples.

Table 2. Samples produced for NVH tests.

Sample name	Promaxon type	Calcium Silicate morphology
REF	No Calcium Silicate	NA
ACS	Milled Promaxon® D	Amorphous powder
SCS	Promaxon® D	Spherical shape

Morphology Verification

Pictures 4 and 6 show the morphology of spherical and amorphous calcium silicates, respectively. In order to prove the real influence of these morphologies in the friction material properties, a similar verification has been done after each step of the pads production process.

[Figure 7](#) shows spherical calcium silicate integrity after mixing.

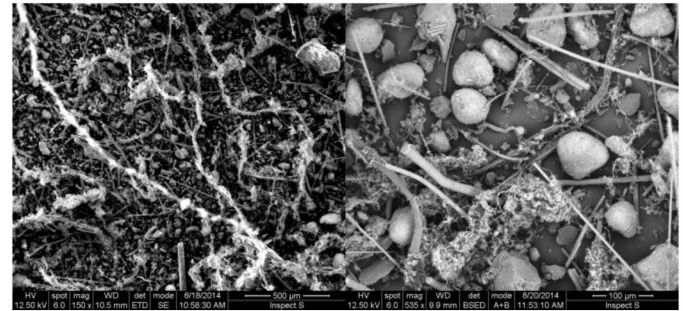


Figure 7. Spherical morphology of calcium silicate after mixing step and its distribution in friction material mix.

Distribution of sample SCS silicate seems to be homogeneous and its spherical morphology is kept intact after mixing. The energy involved in the mixing process (up to 2000 rpm) is not enough to destroy calcium silicate particles.

[Figure 8](#) shows dispersion behavior and amorphous morphology of sample ACS.

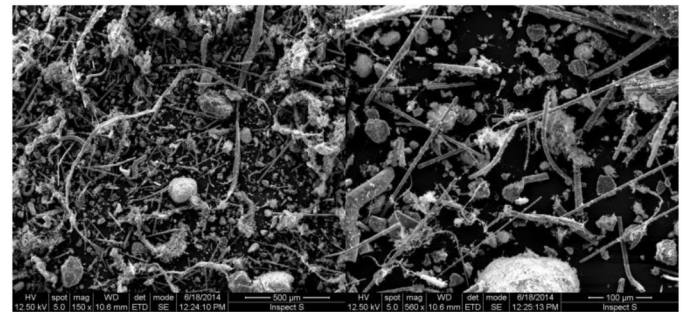


Figure 8. Amorphous morphology of calcium silicate after mixing step and its distribution in friction material mix.

Samples ACS and SCS show different distributions after mixing in the friction material formulation. Amorphous material seems to prevent homogenous mixing and to generate agglomerations of calcium silicate. In order to be sure that agglomerations are formed by particles of sample ACS, a higher magnification and chemical verification are needed. [Figure 9](#) shows amorphous calcium silicate agglomerations and their chemical composition.

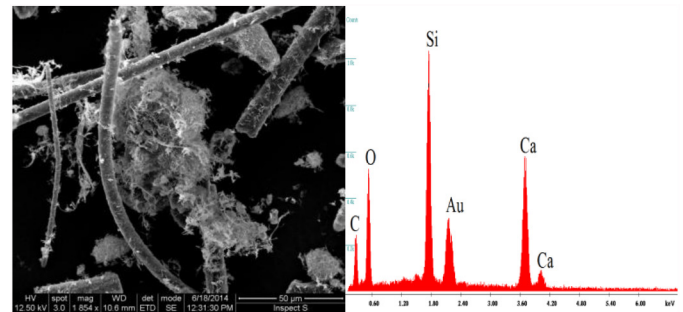


Figure 9. Amorphous morphology of calcium silicate after mixing step and its distribution in friction material mix.

Samples SCS and ACS behave differently in their distribution during the mixing of friction materials. Due to their morphology and particle size, they seem to contribute in a different way to the homogeneity of