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Research Article

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Correlation between the Developed Tribofilm in Dry Automotive Clutch Field Applications with those Reproduced at Laboratory by Using a Pin-on-Disc Tribometer for Three Different Severity Conditions

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Abstract

In this work the tribofilm development mechanisms in three severity levels on the field application were correlated with those simulated in a pin-on-disc tribometer. It was found that the tribofilm characteristics depend on the severity of application. In addition, the pin-on-disc tribometer can reproduce the same mechanisms that were identified on the field, due to the parity between the tribosystem characteristics of test model and field condition.

Keywords: Dry automotive clutch; Multiphase friction material; Field application; Pin-on-disc test; Tribofilm

Abbreviations: SEM: Scanning Electron Microscopy; GFR: Glass Fiber Roving; CF: Copper Fiber; PM: Polymeric Matrix

Introduction

Torque from an internal combustion-engine to a gear box, either in automobiles or trucks, is transmitted by a clutch system. In order to transmit torque from one side to the other, sliding contact between a multiphase friction material and a gray iron rotor is necessary. Torque transmission depends on the friction level among the tribological couples, and it have to be relatively high and most importantly stable to allow an efficient and regular performance.

During the sliding between the coupling surfaces, material is transferred from one surface to the other causing microstructure and chemical changes. As consequence, a new surface, also known as tribofilm, is developed. This surface governs the clutch system performance and understanding its characteristics is very important to improve the development of efficient clutch systems. For this, a large number of tests are necessary to understand the tribological behavior of the raw materials. Such investigation is highly empirical and in order to have a consistent data it's necessary to carry out several friction tests repetitions. Alternatively, to save time and money, and have better control over the test variables, the real tribological interactions can be simulated in laboratory by using simple equipment, pin-on-disc tribometer. The simplicity of this device allows evaluating a larger number of alternative materials.

This work aims to correlate the tribofilm development mechanisms in three severity levels on the field application (those tests are more time-consuming, complex and expensive, because it is necessary to produce the entire prototype) with those simulated in a pin-on-disc tribometer (faster and simpler test).

Experimental Procedure

As it was presented in [1,2] the clutch friction material is a semi-metallic, resin-bonded composite intended for heavy-duty commercial vehicles. It contains the most important constituents normally used in conventional automobile clutch systems, such as phenolic resins, organic, inorganic and metallic fibers, abrasives, lubricants and other ingredients. A commercial grey cast iron rotor was used as the counter body. The cast iron had a perlitic matrix with less than 5% of free ferrite and the graphite flakes were homogeneously distributed and oriented in the matrix.

Three clutch assemblies intended for truck applications were tested in the field and some of the representative samples were characterized to identify the tribofilm development mechanisms. The field applications were classified as sub-mild, mild and severe. More details can be finding in [2].

The tribological tests were carried out in laboratory on a pin-on-disc tribometer using the methodology developed by Fernandes, et al. [3,4]. Round specimens measuring 13 mm in diameter and 4 mm in height were cut from an unworn clutch friction material disc intended for a commercial truck. The cast iron disc was 74 mm in diameter and 5 mm in thickness and the contact radius of the wear track was 26 mm. The disc was rotated in a horizontal plane. The tribological tests were performed by changing the PV level at 3.08, 7.88 and 10.09 MPa ms^{-1} [2].

The worn surfaces were investigated by SEM at sliding surface and through cross-section.

Results and Discussion

Figure 1 correlates the surface characteristics and the tribofilm development mechanisms which were identified in the sample tested in field at low severity regime with those reproduced at laboratory in a pin-on-disc tribometer by adopting a PV of 3.08 MPa ms^{-1}.

In overview observations (Figures 1a and 1b) the surfaces presented quite similar aspects. There were enough similarities between the

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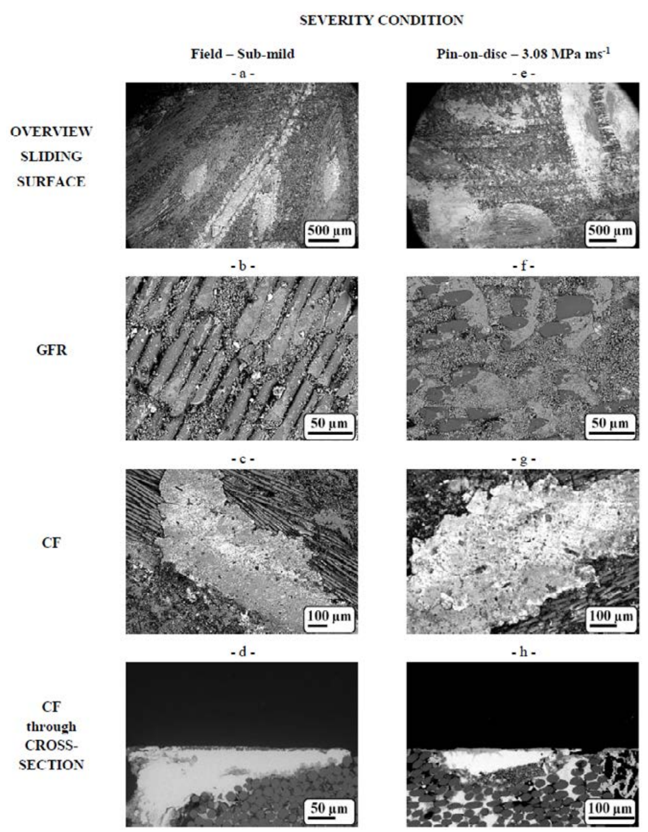

Figure 1: Correlation between the tribofilm development mechanisms identified in the sample tested in the field at sub-mild wear regime with those reproduced in the laboratory in pin-disc tribometer in the PV of 3.08 MPa ms^{-1}.

tribofilm developments mechanisms reproduced at laboratory when compared to the field conditions. These figures revealed the glass fiber rovings and copper fibers exposed to the contact surface and an undeveloped tribofilm.

At higher magnification the similarities between the mechanisms from field and those reproduced in laboratory were even more evident. In glass fiber roving structure (Figures 1b and 1f) the tops of the filaments were worn and acted as a primary plateau favoring the tribofilm development. The copper fibers (Figures 1c and 1g) were observed quite similar and in both surfaces the tribofilm were partial developed. Their plastic deformation indicated the sliding direction and also spread over the roving structure (Figures 1d and 1h).

Figure 2 presents the tribofilm characteristics identified in the sample which was tested in the field at mild wear condition with the one tested in laboratory at 7.88 MPa ms^{-1}. The overview observations (Figures 2a and 2e) showed an equivalent tribofilm development, and they appeared much more developed when compared to those observed in sub-mild application. At higher magnification (Figures 2b and 2f), in both samples, clusters formed by resins due to the microstructure heterogeneity acted as primary plateaus and around them tribofilms developed.

In both circumstances, the glass fibers rovings (Figures 2c and 2g) the whole structure were fully covered by the tribofilm. Figures 2d-2h presents one more time the equivalence between copper fibers deformations, pointing the sliding direction and their spreading over the glass fiber structure. Besides, these copper fibers seemed more deformed when compared to those observed in sub-mild application.

Figure 3 presents the tribofilm development mechanisms observed in the sample tested in the field at severe wear condition with those reproduced in the laboratory applying PV of 10.09 ms^{-1} MPa.

Overview observations revealed certain differences between the surfaces. In the field sample, the tribofilm appeared much more developed when compared to the one simulated in laboratory as show Figures 3a and 3e.

Wear marks generated by the action of abrasive particles were observed on the surface of the polymeric matrix of the field sample. On the surface of the laboratory sample also presented wear marks, though much higher intensity. Moreover, the polymeric matrix of the laboratory sample degraded thermally (Figures 3b and 3f).

In the glass fiber roving structure certain similarities were observed as present Figures 3c and 3g. In the field sample the tribofilm developed over the roving, but due to the severity it broke and exposed again the glass fibers to the surface. Mechanism similar was observed on the roving structure of the laboratory sample. It means, the tribofilm developed and subsequently it was broken and the glass fibers were also exposed.

In the surface of copper fiber a quite different of tribofilm development mechanisms were found. In the field sample, the tribofilm was formed by compressed wear debris while in laboratory sample

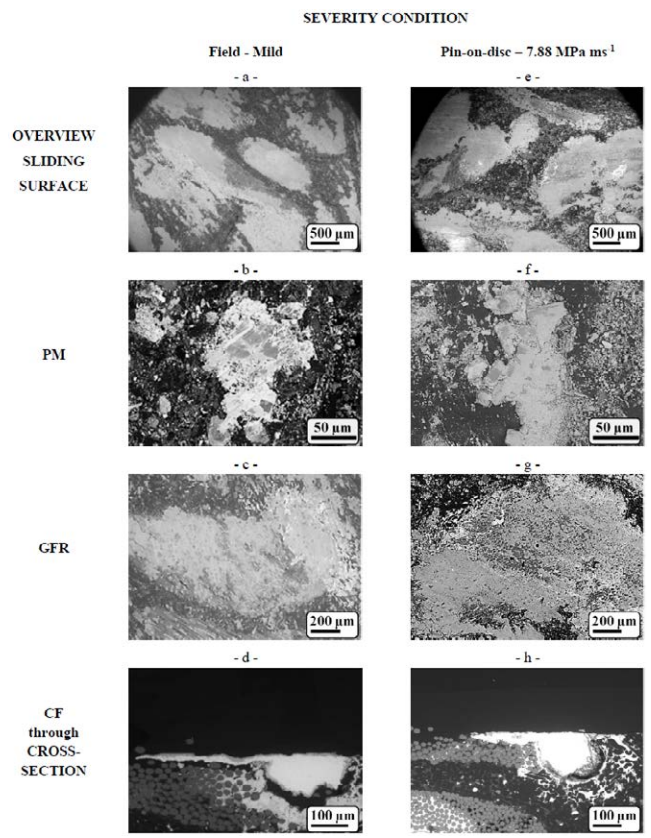

Figure 2: Correlation between the tribofilm development mechanisms identified in the sample tested in the field at mild wear regime with those reproduced in the laboratory in pin-disc tribometer in the PV of 7.88 MPa ms^{-1}.

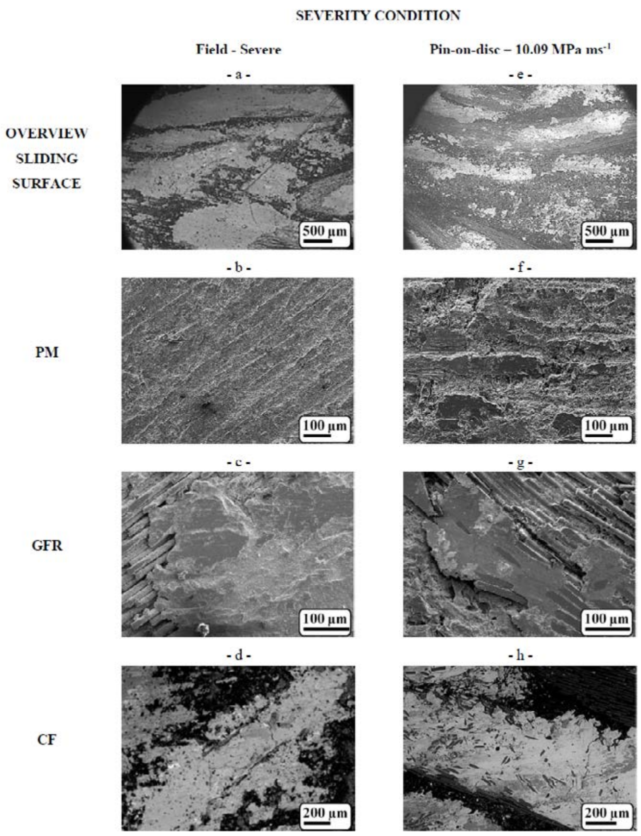

Figure 3: Correlation between the tribofilm development mechanisms identified in the sample tested in the field at severe wear regime with those reproduced in the laboratory in pin-disc tribometer in the PV of 10.09 MPa ms^{-1}.

fragments of glass fibers were embedded to the surface (see figures 3d and 3h).

Conclusions

This paper presented a correlation between the tribofilm development mechanisms identified in field samples tested at three different conditions with those simulated in a pin-on-disc tribometer, and the most important conclusions are:

1. Pin-on-disc tribometer tests proved to be able to simulate in a small-scale, simplified and accelerated way, either the different operating or severity conditions which clutches are submitted in the field.
2. Tribometer tests reproduced the different tribofilm development mechanisms on several structural elements of the friction material (polymeric matrix; glass fiber roving and copper fiber) equivalently.
3. Pin-on-disc test applying a PV of 3.08 MPa ms^{-1} simulates a sub-mild field condition while the PV of 7.88 MPa ms^{-1} corresponds to the mild field application.
4. Although certain differences were found between the mechanisms identified in the field at severe condition with those reproduced at laboratory with PV of 10.09 MPa ms^{-1}, it can be concluded that the laboratory procedure is able to simulate the functional clutch performance at extreme severity condition. Perhaps the collected clutch assembly was not the most representative to the severity reproduced at laboratory.
5. Pin-on-disc tribometer has been proved to be an alternative and useful tool for the study and development of new materials for automotive clutches (faster, simpler and cheaper test), due to the parity between the tribosystem characteristics of test model and field condition.

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