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ROLE OF POTENTIAL COMPONENTS USED IN ORGANIC COMPOSITE MATERIALS FOR BRAKING APPLICATION: IMPACT ON FRICTION AND WEAR MECHANISMS

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Abstract: Friction materials must exhibit a good combination of several physicochemical, mechanical, thermal and tribological properties. These properties interact to respond correctly to a braking request. Understanding the role of the components and their contribution to friction and wear mechanisms is a necessity in an approach to optimize braking performance. In this paper, the contribution of some potential components to the braking behavior of friction materials is highlighted. Special attention was given to the impact of rubber and brass particles, as well as miscanthus fibers in the establishment of primary and secondary plateaus, in addition to their contribution to maintaining the friction layers necessary for stable braking. It was reported that at high braking energy, the brass particles played the role of primary plateaus. On the other hand, the miscanthus fibers promote the formation of secondary plateaus, while the majority of the rubber particles remain totally or partially uncovered. Based on these results, the possibility of green alternatives as promising components was highlighted.

Keywords: brake friction materials; components; microstructure; wear mechanisms

1. Introduction

Given their role in safety, brakes constitute one of the most sensitive parts of a vehicle. Their effectiveness and reliability directly depend on the quality of the material used for brake linings. The ideal brake lining material should have multiple qualities such as excellent thermal and mechanical properties, a stable coefficient of friction regardless of the operating conditions, low sensitivity to brake fading, a good recovery capacity, low aggressiveness to the disc, good resistance to wear, low sensitivity to vibratory excitations, ease of development at a reasonable cost, and others. [1-5]. Since the exclusion of asbestos, declared carcinogenic, new formulations for brake materials having an organic matrix, reinforced with a low amount of metal fibers, have been developed over the last two decades [6]. Their performance has improved considerably and these materials are used in most of today's vehicles. However, their development has led to complex formulations, containing up to 40 components, which is essentially based on the experience and know-how of manufacturers [7-9]. In the composition of organic composite materials there are four classes of components (binders, fibers, friction modifiers and fillers), without their action and function being clearly discernible. The combination of several components in the right proportions and acting in a coordinated manner is the key to developing a material suitable for a given application [10-12]. When braking, brake linings are subjected to several mechanical, tribological and thermal stresses. These stresses interact in synergy and lead to multi-physics phenomena such as friction-wear mechanisms, thermomechanical deformation and thermal localization, the understanding of which involves numerous disciplines, namely tribology and materials mechanics [13-15]. Indeed, braking action is occurring due to the dissipation of kinetic energy by friction between the lining (an organic matrix composite material) and the disc (generally cast iron with lamellar graphite). During operation, this friction induces very high temperatures [16, 17]. For this reason, friction materials must resist thermal degradation in order to limit the loss of efficiency of the braking system and guarantee stable friction. The complexity of the composition makes it difficult to improve the performance of brake materials, which is essential in the quest for increasingly efficient formulations and in the context of sustainable development. This question is currently approached heuristically rather than scientifically, heavily dominated by industry. Very little effort has been made towards a scientific approach to understanding not only the influence of each component, but also the interaction of the components on the performance of these materials. In fact, in the literature, there are few studies reporting on the relationships between the characteristics of the components and the global performance of friction materials. Furthermore, studies involving the link between the nature of the components, and the level of braking energy are still insufficiently explored. Therefore, understanding the sensitivity of the organic composite materials used for braking to the most impacted elements such as fibers and particles, is crucial to improve the efficiency of braking. In the current work, an effort has been made to fill this gap.

The aim of this paper is to highlight the contribution of potential components such as brass and rubber particles and miscanthus fibers in braking behavior by analyzing the established friction layer under 2 energy levels: low and high braking energy.

2. Materials and methods

In this study, we chose three types of materials acting as potential components in the composition of friction materials: brass and rubber particles, and miscanthus fiber. The size of the rubber particles is in the range of 0.5 mm in dimeter, whereas, the brass particles are the biggest; they are machining shavings up to 5 millimeters in length. For the miscanthus fiber, it was observed that the dominant length is 10 mm, and the diameter varies from 40 to 80 µm, Figure 1c.

Figure 1. *Macroscopic observations of: a) rubber particles, b) brass particles, c) miscanthus fibers*

To highlight the contribution of each component, 3 samples with a standard composition were developed with a variation in the weight percentage of the brass particles and the miscanthus fibers. For the rubber, it was introduced in the composite which contained brass shavings with the same percentage. After producing the samples, a friction test using a pin-on-disc tribometer was carried out at low and high levels of braking energy as indicated in [18]. A cast iron disc was chosen as the material for the counter-sample. The objective is to establish a uniform surface without damage of the components. After the tests, microscopic analysis was conducted using SEM and a light microscope.

3. Results

3.1 Characterization of microstructure of composite surface before friction test

Figure 2 shows the typical microstructure of the composite materials before sliding. Figure 2a presents the components with different shapes and sizes, distributed in the phenolic binder. As the contrast reflects density, the darkest zones correspond to light chemical elements whereas the lightest zones indicate the presence of heavy elements such as copper.

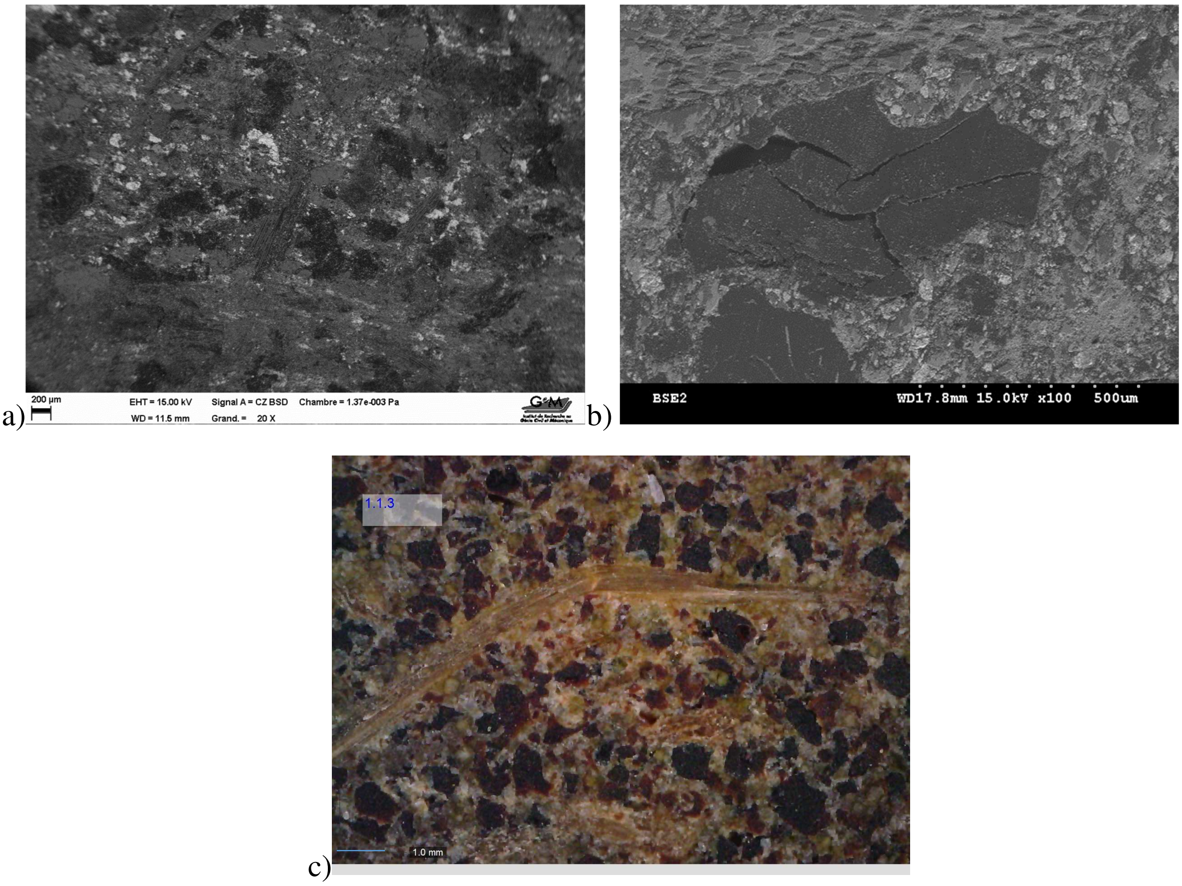

Figure 2 *a) Typical distribution of brass and rubber particles on surface of composite materials, b) shape of rubber particle, c) cluster of miscanthus fibers.*

The dark zones, with different sizes and shapes, indicate the presence of rubber particles, which cover the majority of the surface. The dominant shape is spherical, which can reach 1 mm in diameter, Figure 2b. Rough and smooth surfaces are distinguished, indicating a good distribution of the components. The brass particles, appearing as light gray, surround the large particles of rubber. They are present with various unordered morphologies and millimeters in size. Fiber bundles of miscanthus were also detected in different regions of the surface, Figure 2c. The width and length of these clusters can reach 0.5 and 2 mm, respectively. These fibers are oriented parallel to the direction of sliding, whose orientation is probably caused by compaction during the cold preforming and hot molding operations of the plate.

3.2 Analysis of rubbed surface after testing

3.2.1 At low braking energy

The SEM micrographs reveal all the components of the friction material with a large amount of carbonaceous particles dispersed on the surface. In fact, certain components, which are still distinguished by their color and morphology, are present on the rubbed surfaces. Third-body layers were detected. They are formed by the grinding and compacting of the debris during the friction process. The rubbed surfaces are covered with this dense layer, which played a role in avoiding direct contact with the friction pair surfaces. In fact, well-distinguished secondary plateaus of an average size of 500 μm in diameter were formed and distributed over the entire rubbed surface. The porosity, which characterizes friction materials, is not homogeneous in the matrix. The surface area of the pores is filled with wear debris. Some reinforcement particles are surrounded by plateaus of compacted wear debris. The wear track shows that one-directional deformation occurred in the sliding direction with the presence of wear debris, which plays the role of load-bearing particles that support the development of secondary plateaus in their surroundings. Carbonaceous particles could also still be identified in the 3rd body composition. Some rubber particles were partially or completely pulled out, forming wear debris trap imprints. They seem to be degraded under the effect of heat induced by friction. Therefore, rubber is the component the most influenced by temperature at low braking energy. The visible brass particles are flattened and remain anchored to the matrix, forming a primary support for the 3rd body. For the composite friction material with miscanthus fibers, the contact surface and porosities are rich in wear debris. Well-developed secondary plateaus in front of the miscanthus fibers were detected. On the one hand, the lying miscanthus fibers, oriented parallel to the sliding plane, become uncovered and capture the wear debris. On the other hand, the standing miscanthus fibers, oriented perpendicular to the sliding plane, form primary plateaus around which the wear debris is well compacted.

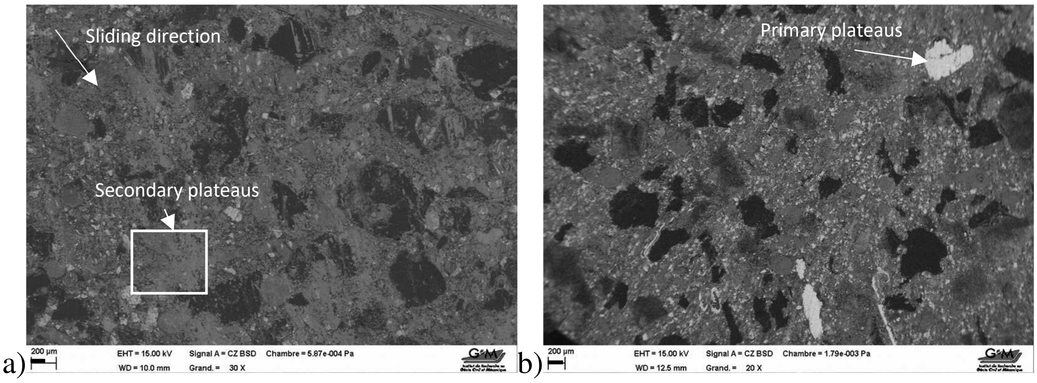

Figure 3 *a) and b) typical SEM micrographs showing general aspect of rubber and brass particles on rubbed surfaces at low braking energy*

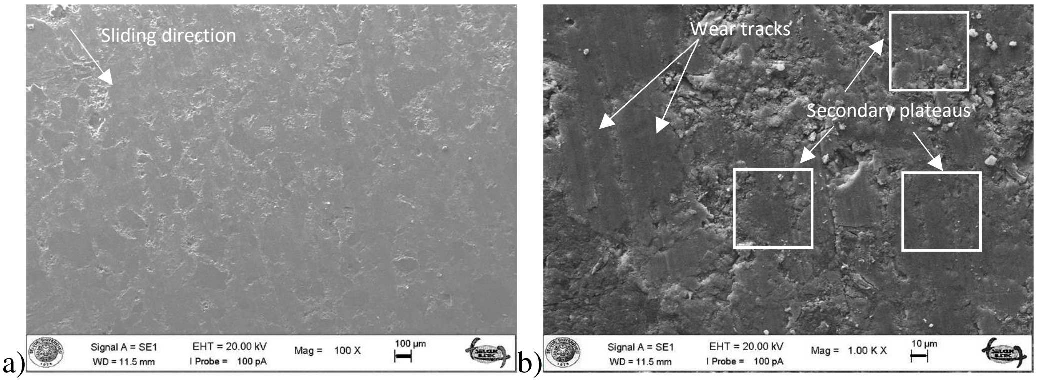

Figure 4. *Typical SEM micrographs showing general aspect of rubbed surface with presence of miscanthus fibers, b) detail of compacted friction layers at low braking energy*

3.2.2 At high braking energy

Figure 5 shows that the rubbed surfaces become a bit covered with third bodies. Evidence of pulled-out particles is also frequently observed. In fact, by increasing the level of friction, much less third body material is deposited on the rubbed surface. Even the cavities formed by the porosities do not contain wear debris. Large rubber particles were detected, but they are fragmented and pulled out. Some other rubber particles are partially pulled out of the matrix with signs of cracks (Figure 5b).

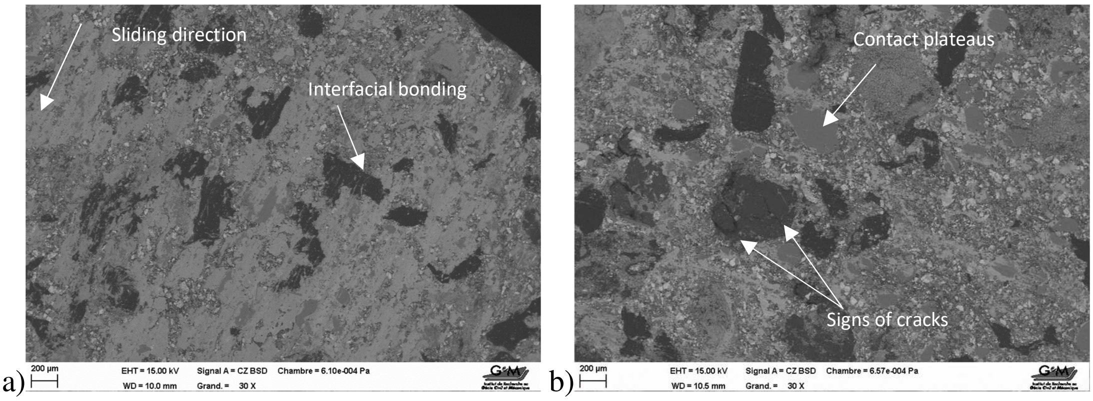

Figure 5 *a) and b) typical SEM micrographs showing general aspect of rubber and brass particles on rubbed surfaces at low and high braking energy*

For the friction composite material with miscanthus fibers, the study of the worn surfaces reveals that the formation of contact plateaus is more intensive, Figure 6; the fibers act as good support for the accumulation of particles to form a large coverage of secondary plateaus when the fibers are distributed perpendicular to the sliding direction.

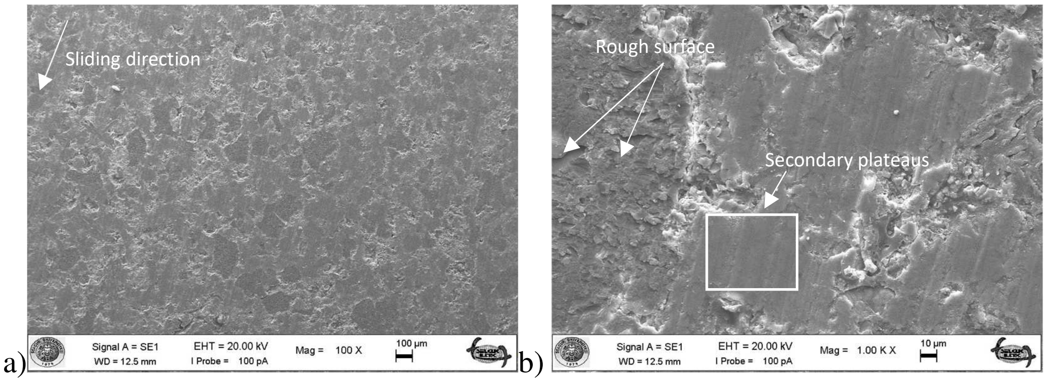

Figure 6. *Typical SEM micrographs showing general aspect of rubbed surface with presence of miscanthus fibers, b) detail of compacted friction layers at high braking energy*

4. Discussion

In braking, the pad/disc contact is the site of several thermomechanical and tribological stresses in addition to physicochemical and microstructural transformations, responsible for the degradation of friction materials. Multi-physical couplings activated in the contact must be well evaluated and studied in different braking situations in order to quantify the effectiveness of the braking system. Dealing with this problem on the brake system scale makes the study more complicated and does not enable an understanding of the phenomena involved. The study of the impact of the components and their role in braking is key in the process of improving the braking performance of friction materials. The analysis after testing is an original approach to characterize the friction and highlight the wear mechanisms, allowing understanding of the different phenomena and synergies activated in braking. For friction material sliding at low braking energy, the third body layers are more visible for the composite with the brass particles. The 3rd body layers are less well constituted than in the case of the miscanthus fibers. For both materials, the carbonaceous particles are more covered with the 3rd body, with the presence of more cracked rubber particles. When the braking energy was increased, the rubbed surfaces appeared to have less wear debris and secondary plateaus for the friction composite material with the brass particles. The surfaces have numerous fragmented and loosened rubber particles; several wear cracks were identified. On the other hand, the incorporation of miscanthus fiber induced a third powdery body trapped by the numerous clusters of fibers which emerge in the porosities of the material. This behavior could be linked to competition between the internal flow and the secondary source flow from the fragmented materials, which feeds the friction by the third bodies. Indeed, the increasing test temperature due to friction resulted in an increment in iron oxides coming from the disk. However, as the degradation of the friction composite material was so significant, recirculation flow predominated [1]. Regardless of the level of braking energy, some reinforcement particles remain anchored in the matrix and appear to be surrounded by wear debris and agglomerated particles. Akıncıoğlu et al. [8] reported that the quantity of iron decreases with the increment in the intensity of the braking energy, increasing wear and inducing the rapid renewal of secondary plateaus. This observation was already proven by previous studies showing that the concentration of a 3rd body film of metallic particles coming from the wear of the disk is high when the thermal load is low [19]. Another study showed that the friction level rises with the number of these wear particles in the established friction layers [20]. This evolution of the tribological circuit can explain the change in the surface characteristics with the increase in the braking energy. The microscopic appearance of the secondary plateaus differs according to the level of braking energy and the composition of the friction material. The hypothesis of kinetic competition for the formation of secondary plateaus, between the nature of the flow of the 3rd body and the contact time was verified. Post-testing analyses made it possible to discern the following particularities. At a low level of friction, the secondary plateaus of the composite material with brass particles appear to be well compacted and homogeneous. The components of the third body are well ground and homogeneous. By increasing the braking energy, the plateaus are speckled with wear debris. Nonetheless, the material with miscanthus fibers reveals plateaus with a homogeneous appearance in the case of low friction. In conclusion, the contact time allows the plateaus to be better expanded and compacted but also to have a more homogeneous appearance following better crushing of the wear debris. The contact plateaus established in the surfaces rich in brass particles contributed to the formation of a bearing surface.

5. Conclusions

This paper highlighted the role of some fundamental components on the friction and wear behavior of brake materials and the mechanisms activated by friction. Post-testing analysis of the worn surface of the brake materials was investigated at low and high braking energy The following conclusions were drawn:

- The initial microstructure of the friction composite material showed clusters of miscanthus fibers, mostly lying, i.e. oriented in the direction parallel to the sliding plane, following the rearrangement of these clusters during cold preforming and hot molding of the linings. The brass and rubber particles were well mixed with the matrix and dispersed along the surface of the brake material.

- At low braking energy, the brass particles were flattened under pressure. The third body was deposited on it or around. Primary plateaus were formed, supporting the development of secondary plateaus.
- At high braking energy, the majority of the rubber particles became totally or partially uncovered. They were often fragmented and detached. As a consequence, they contributed to the friction but the third body did not adhere to their surfaces. They do not form preferential supports for the development of secondary plateaus. The rubber is a component highly sensitive to high levels of friction and generally pulled out when the braking energy is increased. The brass particles played the role of primary plateaus, whereas, the miscanthus fibers contributed to the formation of large secondary contact plateaus.
- Kinetic competition for the formation of secondary contact plateaus was managed by the flow rate of the 3rd body and the friction contact duration, both at low and high levels of braking energy.

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