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Squealing characteristics of worn brake pads due to silica sand embedment into their friction layers

A.R. Mat Lazim [a], M. Kchaou [b,*], M.K. Abdul Hamid [a], A.R. Abu Bakar [a]

[a] Department of Ocean, Aeronautics and Automotive Engineering, Faculty of Mechanical Engineering,
Universiti Teknologi Malaysia UTM, 81310 Skudai, Malaysia
[b] University of Sfax, ENIS, LASEM, Route Soukra km, 4-3038 Sfax, Tunisia

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ABSTRACT

Disc brake squeal is a very annoying sound and a source of considerable discomfort that leads to customer dissatisfaction. There are various possible mechanisms that could trigger brake squeal generation either from a structural dynamics and/or tribological point of view. This research investigates a characterization of worn surface of friction material squealing with external silica sand particles (SSP). The objective is to study the embedment mechanisms of these particles with different size in the case of a brake pad/disc system in order to correlate their effect to the friction and dynamic behaviour. In the first stage, the squealing characteristics, the friction coefficient, and the wear of brake pads is examined without silica sand. Then, three different sizes of silica sand particles are introduced into the brake pad/disc interface. Surface topography and friction layers of the squealing brake pad with and without the presence of silica sand particle are examined. A correlation between SSP size, squeal and friction behaviours and embedment mechanism is established to highlight the impact of the introducing particle on the friction layer.

1. Introduction

Brake noise and vibration induced by friction is a complex subject, partly because of its strong dependence on various intrinsic and extrinsic properties of the brake system, and partly because of the coupling between phenomena that interacts on synergy, including thermo-mechanical, chemical, tribological and dynamic aspects [1]. In particular, brake squeal noise generally occurred in the frequency range between 1 and 20 kHz and it was believed that squeal noise generated due to dynamic instability in the brake system and also influenced by the brake pad compositions [2]. In fact, brake pads are composed of different elements such as fibres, fillers, and polymer binders. Non-asbestos organic friction materials (NAO) are commonly composed of abrasives and lubricant fillers, mineral and organic fibres which are acrylic fibre, glass fibre aramid pulp, carbon fibre, slag fibre, oxidized polyacrylonitrile fibre and cellulose fibre. Phenolic resin and cashew-modified phenolic are the most used binders in the NAO formulation. Kim et al. [3] reported that NAO friction materials are characterized by a stick–slip behaviour during slow speed braking tests, which was more significant when silicon carbide is used as abrasive. Eriksson and Jacobson [4] noticed that steel fibre improves the dynamical performance of the friction material, due to their good malleability and plasticity. Kchaou et al. [5] recently studied the effect of 1.5 wt% of brass filler on the squeal behaviour of NAO materials under different sliding conditions. They concluded that the presence or absence of brass filler affected the squeal occurrences. Previous researchers [6] noticed a high squeal noise propensity attributed to the high abrasive action (hardness) which increased the coefficient of friction. As the brake squeal behaviour involves the dynamics of the brake system as much as the local dynamics of the pad-disc contact surface, many approaches were developed to acquire a comprehensive understanding on the correlation between squeal behaviour and contact surface evolution. Earlier, Eriksson et al. [7] studied the surface evolution of brake pad, running under squealing and silent conditions. They highlighted that squeal brake was excited by local flat areas, raising a few micrometres over the rough surroundings. They concluded that the size of these areas called small contact plateaus affects the generation of brake squeal when they observed that pads with many small plateaus generated more squeal than pads with few large plateaus. Exploiting contact surface properties from pads at different states of wear, many researchers were trying to investigate the sensitivity of squeal brake to surface evolution by statistical and numerical approaches based on simplified structural model [8–10]. However, most of them neglected surface

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* Corresponding author. Tel.: +216 55 95 43 98.
E-mail address: kchaou.mohamed@yahoo.fr (M. Kchaou).

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Nomenclature

WPS2 pad without external particle effect

XiS2 with X {silica sand particle "SS"} and i {100–150 μm "100", 150–200 μm "200", 300–400 μm "400" μm}

topography evolution induced by foreign external particles to the initial composition of the pad-disc system. In fact, despite the strong influence of the initial friction material formulation and the surface roughness of pad/disc on the occurrence of self-excited vibrations, the brake system is additionally exposed to the effect of external particles, which can be introduced into the pad/disc contact surfaces, like road grit particles [11], or an established water spray onto the interface [12]. Coupled with the initial composition and the friction layer evolution, these environmental sources act in synergy and affect the brake performance, particularity squeal noise occurrences. In spite of the sensitivity of the brake pad to his environment such external particles, there exist only a limited number of research articles considered with this issue. A few researchers closely examined the effect of external particles on brake squeal noise since it played a crucial role in the formation of friction film, which can attenuate or promote friction noise excitation depending on particle properties and consequently the contact surface evolution [13,14]. In fact, Nasaruddin et al. [15] studied the road particle size effect on the brake squeal occurrences of NAO materials. They reported that the friction material associated with a hard and large size particle generates a low squeal level at a low vehicle speed compared to friction materials exposed to small external particles. Studying the effect of silica sand particles with a size range between 200 and 400 µm, Mat Lazim et al. [16] reported that small particles introduced to the initial contact has reduced the squeal level from 70–92 dBA to 70–85 dBA. However, small difference in terms of frequency level is noticed: the addition of particles induced 4583–4650 Hz compared to 4492–4550 Hz of squeal without silica sand particles [17,18].

Though friction material engineers and manufacturers often suggest solutions based on empirical and/or trial and error approaches or through vast experiences to formulate high braking performance and non-squealing brake, there is a lack of scientific research concerning the influence of environmental factors like external road particles on dynamic behaviour and friction layers evolution of brake pad. In this work, focus has been made on the effect of external particles with different sizes, coming from Malaysian environment, on squeal and contact surface evolution of brake pads. One type of external particle was used, i.e. silica sand particle, in three different sizes ranges (100–150, 150–200 and 300–400 μm). A comparative study of these particle size effects on the friction layer establishment and contact surface evolution is discussed.

2. Materials

2.1. Brake pad

Commercial automobile brake pads are studied in this paper (Fig. 1). These brake pads were a proprietary commercial product (automotive brake pads, MINTY manufacturer, Terengganu-Malaysia); however, their composition and microstructure were characterized using a scanning electron microscope equipped with energy dispersive X-ray spectroscopy (EDX) analysis is used to characterize the pad surface heterogeneity and the compound size and morphology. Typical SEM observations of the new pad show a multitude of ingredients in the pad surface having different sizes and shapes distributed in the phenolic binder (Fig. 2). A clear grey and black contrast is noticed. Individual grey fibres are observed, which cover the majority of the surface. The length and the width of the biggest one can reach 1.5 and 0.1 mm respectively as shown in Fig. 2a. Some dark particles with different size and shape are observed. The dominant form is spherical that can achieve 150 μm in diameter can be seen in Fig. 2b. It is noticed that the grey shades from the darkest to the lightest correspond respectively from the lightest to the heaviest elements. To identify the chemical composition and the nature of different elements, EDX analysis is conducted as shown in Fig. 2c. Spectra results are shown in Fig. 3. The large peaks of iron indicate that the biggest elements are steel fibres (Fig. 3a and b). These fibres with a millimetre dimension are preferentially oriented lengthwise. The dark particles correspond to carbon particles like rubber and graphite compounds (Fig. 3c and d). The dominant size of these particles is micrometric; the biggest rubber can exceed 800 μm diameters. The analysis of small fibres shows the presence of combined peak of silica and alumina associated with less important peaks of Si, Ca, O and Mg elements (Fig. 3e), corresponding to rock fibre composition. A small amount of silicon oxide particle (SiO) is identified. Silica is thus present in the form of spherical particles whose diameters do not exceed 30 μm. Small grey particles (whose size is nearly 10 μm) which are constituted of Ba, S and O elements correspond to barite ($BaSO_4$), which is an inorganic compound (Fig. 3f). The identification of multitude constituents having different sizes and shapes (large particles such as carbonaceous particles, agglomerates of mineral particles like barite) and the constituent distribution (parallel steel fibres, bundles of shots derived from mineral fibres) reveals a higher heterogeneous microstructure of the brake pad. Mechanical (shear stress, Young's modulus) and physical (density) properties of the NAO material are summarized in Table 1. The average surface hardness values of the pad are 85HRs.

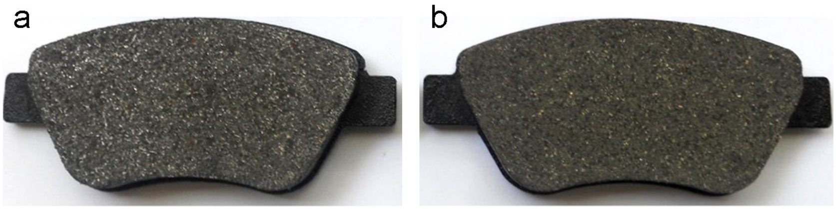

Fig. 1. Brake friction material, (a) Piston pad (b) Finger pad.