Wear 376-377 (2017) 1437–1449

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Case Study

Effect of dry deposited particles on the tire/road friction

Y. Hichri *, V. Cerezo, M.T. Do

IFSTTAR, AME-EASE, 44344 Bouguenais, France

ARTICLE INFO

Article history:
Received 2 September 2016
Received in revised form
9 January 2017
Accepted 10 January 2017

Keywords:
Friction
particles
dry lubrication
mass of particles
index of starvation

ABSTRACT

Road accidents increase during the first rain after a long dry period. It is widely accepted that the tire traction loss is due to fine particles accumulated on the road surface. Yet, the involved mechanisms at the tire/road interface are not clearly understood.

This paper deals with the particle-induced lubrication on dry road. Tests are performed in laboratory. Sediments are extracted from a catchment area which collects runoff water. The process of extracting particles from sediments in laboratory by drying and sieving is described. Particles are separated into fractions characterized by their chemical composition and size distribution. Protocol to simulate the process of particles' build-up on the road surface is described. The effect of the particle's size and concentration is studied. Surfaces representative of real road surface textures are tested. Friction tests are conducted using the Skid Resistance Tester, which is widely used to assess friction characteristics of road surfaces. Samples are weighed before and after each friction run. On a surface initially covered by a compacted particle layer, successive friction runs are performed, without resupplying particles, to follow the evolution of the friction coefficient with the particle depletion.

Friction drops significantly when a surface is covered by particles. Successive runs induce an increase of the friction coefficient until reaching a stable value which is still lower than that of a clean surface. Particles are considered as third bodies introduced artificially in the interface between the friction slider and the test sample. Analysis of particles' flows (particles trapped and ejected), through particles' mass extracted from weighing, helps to explain the friction variation.

Assuming that friction is governed by the surface fraction (X) covered by particles, a model was developed. The calculated friction coefficient is a weighted sum of friction coefficients when the surface is respectively clean (X=0) and fully covered by particles (X=1). It was found that the surface fraction can be expressed as a function of the ratio of available particles' mass to initial particles' mass. Comparisons between model and experiment are satisfactory. Discussions are made in terms of interactions between surface textures and particles' size and concentration.

1. Introduction

Road accidents increase during the first rain after a long dry period [1]. Eisenberg [1] analyzed the relationship between precipitation and traffic crashes over 25 years in the US and found a significantly increasing crash risk with the number of dry days since the last rain. This excess risk is generally attributed to the accumulation of fine particles on the road surface. The origin of these particles is diverse (dust, debris from tires, road surface and equipment, etc.). Authors in [2,3] developed models to predict the particle's accumulation, also known as particle's build-up, as a function of the number of dry days and other weather conditions such as wind characteristics, traffic, etc. The same authors looked also at the particle size distribution depending on the land use (industrial, residential, commercial, etc.). For example, Egodawatta [3] observed the distribution of the particles' size in three urban areas and found that 50% (resp. 70%) of the particles are less than 100 μm (resp. 200 μm) in size. On highways surfaces, Shakely et al. [4] collected particles by vacuum cleaner and found mainly particles bigger than 50 μm followed by the fractions 7–50 μm and 3.3–7 μm.

Shakely et al. [4] found on the other hand that friction coefficient, measured by a locked wheel (full sliding) equipped with rubber tire, decreases with increasing dust concentration. Wilson [5] showed a graph illustrating how friction varies over a dry-wet-dry period. The friction coefficient is considered as constant during the dry period; at the first rain drops, friction coefficient decreases significantly; as the rain continues to fall, the surface is washed

* Correspondence to: IFSTTAR, Route de Bouaye, CS4, 44344 Bouguenais Cedex, France.

E-mail address: yosra.hichri@ifsttar.fr (Y. Hichri).

http://dx.doi.org/10.1016/j.wear.2017.01.037

and friction coefficient increases until reaching a stable value; as the rain stops and the surface dries, it increases to a level similar to that prior to the rain. Do et al. [6] developed in laboratory an experimental protocol which reproduces qualitatively the loss of skid resistance with time during a rain preceded by a long dry period. These authors investigated the effect of particles' concentration and found that higher concentrations induce lower friction coefficients and delay the washing process. Visual observations of the road samples showed that residual contaminants can still be observed even after the wash-off period.

It can be said that the risk induced by fine particles on road safety is well perceived. However, the way these particles act on the tire/road friction is still questionable. In the road field, dry friction is most of the time considered as satisfactory and water is usually designated as the main element which is harmful for drivers. Actually, when the road surface is wet, there is a sharp reduction in the friction coefficient due to the presence of a water film acting as a lubricant between the tire and the road surface. Kulakowski and Harwood [7] reported that even a water depth as thin as 0.025 mm on the road can reduce the tire/road friction by as much as 75% compared with a dry surface. Do et al. [8] found on the other hand that, depending on the surface microtexture (asperities provided by road aggregates), wet friction coefficient can be maintained at a value near to the dry friction coefficient until a critical water depth is reached. Relationship was found between the critical water depth and the asperities' height [8]. Sabey [9] conducted friction tests with spherical and conical single sliders and proved that there is a link between the calculated average pressure exerted by the sliders (on an elastic plane) and the measured wet friction coefficient (between the sliders and a rubber plane). Savkoor [10] explained Sabey's findings by the fact that the water depth at the asperities' summits can be as low as 10 μm and only a high pressure exerted by sharp asperities can break the water film and reestablish direct contact between the tire and the road.

The presence of particles on the road is considered as an additional element which degrades the wet friction. Lambourn and Viner [11] tested various contaminants (clay, sand, etc.) on road surfaces and found a substantial decrease of the friction coefficient (divided by 2) when the surface is contaminated compared with the dry friction coefficient. Persson [12] said that the mix of particles with water is highly viscous and then lubricates more the tire/road interface. The lubricating action of particles mixed with lubricants has been observed in other tribosystems like piston ring-cylinder liner pairs in internal combustion engines [13–15]. These authors have shown that adding additives like molybdenum disulfide [13,14] or graphite [15] in oils helps to reduce friction and wear. Xu and coauthors in [15] attributed this performance to the higher viscosity of oil with additives (an esterified bio-oil has been used) compared with pure oil. This observation corroborates that made by Persson in [12].

However, other authors found that the particles alone can induce lubrication actions. Li et al. [16] studied the friction between footwear and floor covered with particles and found that particles can reduce the friction coefficient even under dry conditions. According to these authors, the dry friction coefficient decreases when the particles' size increases. Mills et al. [17], who also studied friction on dry floors covered by particulate contaminants, stated that there is a critical size of the particles (around 50–60 μm) above which particles roll one on the other, when a rubber pad slides on the floor, and below which they tend to stick together due to cohesive forces and promote a sliding mechanism at the rubber slider/floor interface. On the other hand, the roughness of the floor's surface can trap a proportion of particles and, by preventing particles passing over the surface asperities, contributes to the shearing of the particle layer [17]. Heshmat [18] has demonstrated that solid particles can form load-carrying lubricant films which exhibit a behavior resembling that of fluid films. This author looked at full particles' film whereas other authors, like Higgs et al. [19], studied the case of partially covered surfaces. Regardless of the lubrication regime, authors agree that tribo-particulates – to reuse a definition provided by Blau in [20] – have an effect on friction between two contacting bodies. So logically particles deposited on road surfaces should have an effect on the tire/road friction under dry condition as well.

To fully understand the effect of deposited particles on tire/road friction, there is then a need to investigate the dry road condition. This paper presents a laboratory study aiming at contributing to this objective. Friction tests are performed to assess the effect of particles' size and concentrations which are known as factors affecting the particle's build-up during a dry period [3]. Analyses are performed to represent friction variation and explain it by the particles' flows. A model is proposed to represent experimental data and helps to get some insights into the involved mechanisms.

2. Research methodology

Friction analysis provides valuable information about the effect of particles on road skid resistance. However, understanding the lubrication mechanisms needs another approach much more directly linked to the particle itself. We have thought that using the third body concept, as developed originally by Godet [21], could be a relevant way to reach this aim. Godet considered that two-body contacts merely exist only during the very first moment of rubbing and third bodies are generated practically immediately; the consequence is that a two-body contact is most of the time a mixed contact. Third-bodies can be lubricants, such as oils or powder, or debris detached – due to wear – from the first bodies. They can have a lubrication action or a load-carrying role. Godet stated that to fully predict load and friction in contacts with a third body at the interface, at least three conditions are required: the knowledge of the rheological behavior of the third-body material, information about boundary conditions (for example, how particles adhere or roll on the face of the first bodies), and the existence of a general theory of thin film mechanics. As the nature of third bodies is very diverse, as well as the way they circulate inside the contact, prediction tools must be adapted to specific materials and operating conditions.

In the present study, the third body – particles – is artificially introduced into the tire/road contact, even if some natural third bodies can exist too. A weighing procedure is developed to extract the mass of particles before and after friction measurements. Friction and particles' mass are analyzed separately then combined to see how particles govern friction. The analysis presented in the following paragraphs has been inspired from works of Fillot et al. [22]. These authors studied wear-induced particles. Using a mass equilibrium equation and expressing separately the particle detachment (source) flow and the particle ejection (wear) flow, they developed an analytical model based on particles' masses to explain wear as a competition between the source and wear flows. Even if Fillot and coauthors focused their analysis on wear, many similarities exist between the wear particles' flows and the flows of particles investigated in the present paper. We have thought that analyzing particles' flows inside the contact using particles' masses would be promising to understand how the particles behave at the rubber slider/test sample interface (formation of interfacial layer, ejection, etc.).

In the modeling phase, we had looked for a model expressing the fact that the rubber slider (which represents a tire tread element) is supported partly by the particles' layer and partly by