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EXPERIMENTAL STUDY ON RUBBER-GRANITE FRICTION IN DRY AND CONTAMINATED CONTACT

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Abstract: *In this study, the rubber-granite contact for a dry surface and two types of contamination, were analyzed by performing a series of experiments under controlled conditions, in the laboratory, using specialized equipment. These experiments were carried out under conditions close to those in reality, respectively for three cases, as follows: clean rubber-granite contact, contact in the presence of a runway deicer fluid and contact in the presence of aircraft deicing fluid. The paper presents a comparative analysis for the measured values of the friction coefficients in the rubber-granite contact, for sliding friction in the presented three situations, at different normal forces. To obtain the values of the friction coefficients an MFT2000 tribometer was used. Measurements were performed for three different values of the normal force, dry contact and the two types of contamination, at ten values of the measurement speed on each set. To characterize the microtopography of the test surface was used a MarSurf CM - 3D Optical Microscopy equipment. Conclusions resulting from the study are: in sliding motion, in the case of friction on a dry surface, the values of the friction coefficient are mainly influenced by adhesion and the microtopography of the contact surface, while in the case of contamination with runway deicer and aircraft deicing fluid, adhesion decreases; for the analyzed contact, the contaminant with lower viscosity affects the values of the friction coefficient in contact less than the contaminant with higher viscosity, which significantly decreases the values of the friction coefficient.*

Keywords: *friction coefficient, sliding, adhesion, rubber, granite*

1. INTRODUCTION

Granite is a rock commonly found as aggregate in asphalt or concrete mixtures used in the construction of automobile roads, highways or airport runways. In order to study the effect of this component on the friction between tyre and runway, a series of friction experiments were conducted between granite slabs and a semi-spherical shape pin made by rubber from an airplane tire. Within the procedures of landing/taking off of aircraft on an airport runway, the condition and friction characteristics of the runway surface plays an essential role in ensuring flight safety.

Measuring and monitoring the friction characteristics on the runway are mandatory actions at each airport.

The values of the friction coefficients on the runway depend largely on the contact kinematics, the friction characteristics on the surface and the contamination of the surface (dry, contaminated - snow deposits, ice, deicing fluid, etc.).

The tyre-runway contact in the sliding movement has a direct impact on the safety of landing and take-off operations. In the tyre-runway contact, the macro approach treats and measures the values of the friction coefficient on the surface using dedicated equipment, which vary in measurement mode, type of wheel used for measurement, measurement principle and algorithms for calculating the friction coefficient values, [1].

For a better understanding of tyre-runway interaction and contact mechanics, conditions close to reality were simulated in the laboratory, with dry and contaminated contact, and a comparative analysis of the influence of the type of surface contamination on the friction coefficient values was performed.

In the specialized literature, experimental studies are found that treat the rubber-granite contact, in dry and contaminated contact. In [2], considerations are presented regarding the evolution of the friction coefficient values at low values of the measurement speed, and in [3] the evolution for dry and wet contact is analyzed.

For rubber-granite contact, in the presence of contamination, according to [4], [5], some considerations are presented regarding the influence of viscosity characteristics on the friction coefficient values. A correlation between the hardness of the rubber used and the friction coefficient values, rubber-granite contact, on a less rough surface is presented in [6].

2. THEORETICAL CONSIDERATIONS

The theory of rubber friction, developed by Kummer and Mayer [7] and Geyer [8], considers that the value of the total friction force, F_T, is:

$$F_T = F_A + F_H + F_V + F_C \qquad (1)$$

where F_A – adhesion force; F_H – histeresis force; F_V – shear forces of a viscous liquid layer between the elastomer and the surface ;F_C - intramolecular cohesion forces.

Due to large difference between the elastic and viscous characteristics of the two materials used: rubber and granite, friction in this situation presents distinct particularities because the stiffness of the two materials are very different and thus granite can be considered absolutely rigid compared to rubber.

In the presence of a normal load, in our case being the Fn values, the granite microasperities penetrate the surface layer of the rubber, micro-areas of contact appear and the load is transmitted between the elements in the coupling. When a tangential force occurs, generated by the movement of the granite plate, the pressure distribution in the microcontact becomes asymmetric, opposing the relative displacement. The pressure distribution during the relative displacement in the tangential direction remains asymmetric, the rubber returning to the gap between the granite microasperities being less and dependent on the time (given by the ratio between the microasperities pitch and the relative displacement speed), [9]. The tangential force that occurs is called hysteretic and is mainly due to elastic hysteresis.

In contact, due to the differences and incompatibility at the molecular level between granite and rubber, the cohesion is not significant. On microcontacts an adhesive contact will appear, which in the presence of movement will generate tangential adhesion forces. Thus, having reference equation (1), for the analysis, in the case of contact on a dry surface it is observed that the value of the total friction force in the coupling becomes :

$$F_T = F_A + F_H \qquad (2)$$

In reality, the hysteresis phenomenon (correlated with the elastic deformations of the rubber) and the adhesion phenomenon (correlated with the contact area) overlap, the variations of the friction coefficient in the coupling being a superposition of the two variations.

In the case of fluid friction, depending on the thickness and viscosity of the lubricant film, the load is transmitted between the bodies (rubber and granite) partly through microasperities and partly through the lubricant film. Thus, for the two surface contaminations, equation (1) will become:

$$F_T = F_A + F_H + F_V \tag{3}$$

In the movement or in incipient sliding motion between real bodies, a tangential force, in this case the friction force, appears, which acts on the surfaces in the opposite direction of the movement.

Generally, the circular contact area is divided into two zones: an inner ring (the stick region), where the tangential stresses are lower than the maximum friction force, and an outer ring (the slip region), where the tangential stresses exceed the maximum friction force and the surfaces begin to slide. At the boundary of the contact there may be a region where the tangential stresses are zero or negligible (traction free annulus), [10].

When a tangential force is applied, with a constant normal load, the stresses first increase in the stick zone and as the tangential force increases, the adhesion zone decreases and the slip zone expands.

With increasing normal force, at a constant traction force, the stick adhesion zone increases and a traction free annulus zone appears at the contact tip.

3. EXPERIMENTAL METHODOLOGY

To obtain friction coefficients values, the MFT-2000 tribometer was used, which allows multiple configurations. The test programs are fully automated and the advanced controllers allow highly repeatable and accurate measurements.

The measurements were performed for three values of the normal force: 1N, 3N and 5N and pin-disk configuration . The tests were carried out at ten distinct values of the measurement relative speed, respectively: 1.04E-06, 1.04E-05, 1.05E-04, 1.05E-03, 1.05E-02, 5.24E-02, 7.85E-02, 1.05E-01, 1.57E-01 and 2.09E-01 meter per second, for three different situations: dry contact and contaminated contact with two specific airport substances. The purpose of these experiments was to evaluate the behavior of the granite-rubber contact in order to extrapolate to the aircraft tire-runway contact in the three situations.

The tests were carried out progressively from lower to higher speeds and were stopped due to the occurence of vibrations caused by the stick-slip phenomenon.

Two aspects were taken into account in this study: the first aspect is related to the types of contamination of the granite surface (runway and aircraft deicing liquids); the second aspect is related to reproductibility, the same measurement speeds were used for each of the three values of the normal force and for each of the three types of surface.

The type of material used for the tests is white granite. To characterize the microtopography of the test surface a MarSurf CM equipment was used - 3D optical microscopy. The MarSurf CWM 100 is a high-precision 3D optical measurement system manufactured by Mahr Gmbh, Göttingen Germany. It combines a confocal microscope with a white light interferometer, allowing detailed analysis of the surface structures of various materials. The system offers a high resolution and is suitable for measuring various surface textures.

The MarSurf CWM 100 is equipped with a CNC controlled object stage with a travel range of 100 mm on the X and Y axes, and a CNC controlled Z axis with a travel range of 100 mm. The system uses a 505 nm LED light source and offers the option of using various lenses. A 10X lens was used for the tests. The Mahrsurf MfM software allows analysis and processing of the obtained data. Users can perform precise measurements of roughness, surface profiles and other surface parameters.

The 3D topography of an analyzed granite surface is shown in figure 1. The axes indicate the spatial dimensions in millimeters (X and Y) and the surface height (Z) in micrometers. The color gradient suggests variations in surface roughness, where different shades represent differences in height.

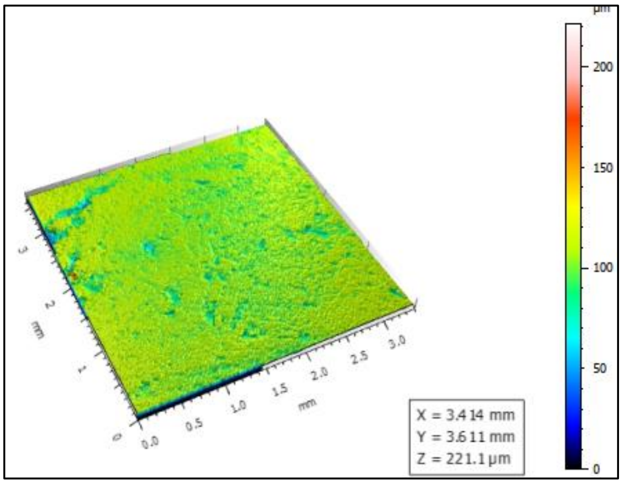

Figure 1. 3D surface topography

Following an analysis of the surface roughness parameters according to the ISO 25178 standard, used for the characterization of 3D surfaces, the values obtained for the parameter Sa - the arithmetic mean deviation of the surface irregularities (4.882 µm) indicate a relatively rough surface. The values of the parameter Ssk - the degree of bias of the roughness shape (-1.386 µm) indicate that the surface presents more pits than peaks, which can be explained by natural microcracks and pores. The Smr (peak material portion) value is relatively low (5.239es-005%) is also specific to surfaces with valleys and suggests that only a small part of the surface effectively contributes to the contact.

Figure 2 shows a profile extracted from the analyzed surface.

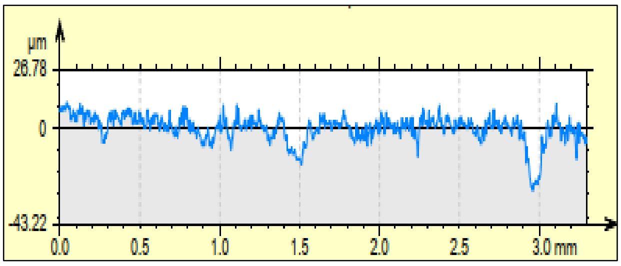

Figure 2. Profile curve

The three measurement situations were for the following cases: dry surface, surface contaminated with Nordway-KF runway deicing fluid (viscosity ⩽3 mPas at 20^0 C) and surface with Cryotech Polar Guard II aircraft deicing fluid (viscosity 80 mPas at 20^0 C).

The rubber used for testing is a part of a Goodyear-Flight Special II, 6.00-6 aircraft tyre and it was shaped into a spherical surface with a diameter of approximate 8.1 mm. The rubber in the tyre is mainly RSS1(Ribbed Smoked Sheets) type, a natural rubber with high purity, superior elasticity and durability. The measured hardness of the rubber is 60 ShoreA.

Before taking measurements, the contact surfaces, granite and rubber, were cleaned to remove any impurities on the materials that could influence the results.

To visualize the contact area at the three values of normal force used in the study, a Fujifilm prescale with a sensitivity of 0.05-0.2 MPa was interposed between the spherical rubber pin and granit rigid surface. The loading was performed using the MFT 2000 tribometer imposing only normal approch between the bodies, without relative movement in contact , figure 3. Analyzing the images from figure 3 it can be remarked that the contact is on microasperities. On low loading values of normal force a reduced number of asperities are in contact with the spherical rubber pin. As the load grows the contact area increases and the contact boundary became more legible. Also, the density of microaperities, which are in contact with the pin, increase.

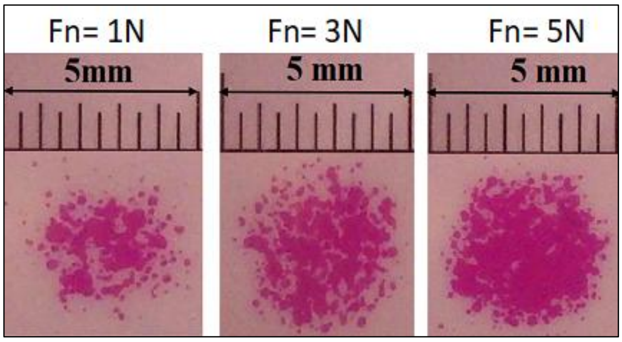

Figure 3. Static contact rubber area

4. RESULTS AND MEASURED DATA INTERPRETATION

4.1 General considerations

The variations in the friction coefficient are determined by: the relative kinematics in contact - sliding motion, the microtopography of the surface, the elastic deformation of the rubber, the different types of contamination (dry, with runway deicing fluid and aircraft deicing fluid), the characteristics of the contact film at the contact interface.

For the interpretation of the data and in order to create readable graphs, a number of measurement was associated with each measurement speed. Thus, for a speed of 1.05E-06 m/s -the test number is 1, for a speed of 1.05E-05 m/s – the test number is 2, for a speed of 1.05E-04 m/s – the test number is 3, for a speed of 1.05E-03 m/s – the test number is 4, for a speed of 1.05E-02 m/s – the test number is 5, for a speed of 5.24E-02 m/s – the test number is 6, for a speed of 7.85E-02 m/s – the test number is 7, for a speed of 1.05E-01 m/s – the test number is 8, for a speed of 1.57E-01 m/s – the test number is 9 and for a speed of 2.09E-01 m/s – the test number is 10.

Different markers were used on the graphs and the relationship was made with the values in the legend of the graphs. It was abbreviated as COF - coefficient of friction.

4.2 Data interpretation

The study treats a rubber-granite contact, with sliding friction, for dry and two contaminations and ten different values of the test speeds.

In dry contact between rubber and granite, with a constant normal force and a variation in the tangential force, the friction coefficient between rubber and granite increases because: a) RSS1 type rubber is a hiperelastic material, which deforms to adapt at the micro-asperities of the granite surface; b) at low speeds, the rubber has time to deform and penetrate deeper into the asperities of the granite, which increases the actual contact surface and, implicitly, the friction; c) at low speeds, the contact time between rubber and granite is sufficient to allow the formation of stronger adhesive bonds between the contact bodyes.

The values of the friction coefficient between rubber and granite, dry contact, corresponding to the 10 different values of the measuring speed for each of the three values of the normal force (Fn=1, Fn=3 and Fn=5) are presented in Figure 4.

It is observed that in dry contact, as the normal force increases, the friction coefficient also increases. This is due to the characteristics of the rubber used, the relative speed and the microtopography of the surface.

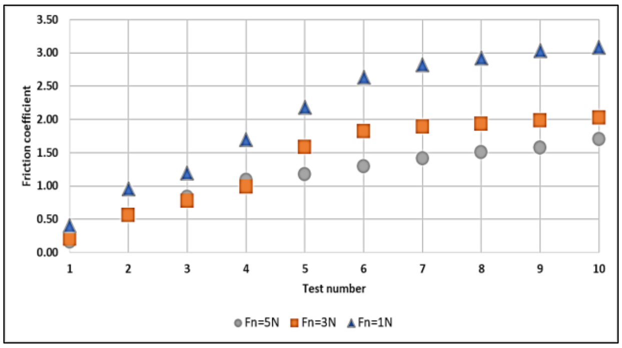

Figure 4. Dry contact COF values

In figure 5 the values of the friction coefficients are presented depending on: contamination (dry surface, surface with runway deicing liquid and aircraft deicing liquid) and the Fn values (1N, 3N and 5N), which correspond to each test.

It is observed that with increasing speed, the influence of the viscosity of the interface liquid becomes greater. It is identified that, depending on the values and the shape of the three representations, the liquid with the highest viscosity generates the greatest decreases in the values of the friction coefficient.

The COF values obtained in test no. 1, as shown in figure 5, are in the range 0.08-0.41. With increasing measurement speed, for example test no. 5, as shown in figure 5, the COF values are in the range 0.22-2.19 and for test no. 10

the values are between 0.32-3.09. This aspect demonstrates that the spread of COF values becomes greater with increasing speed and Fn value.

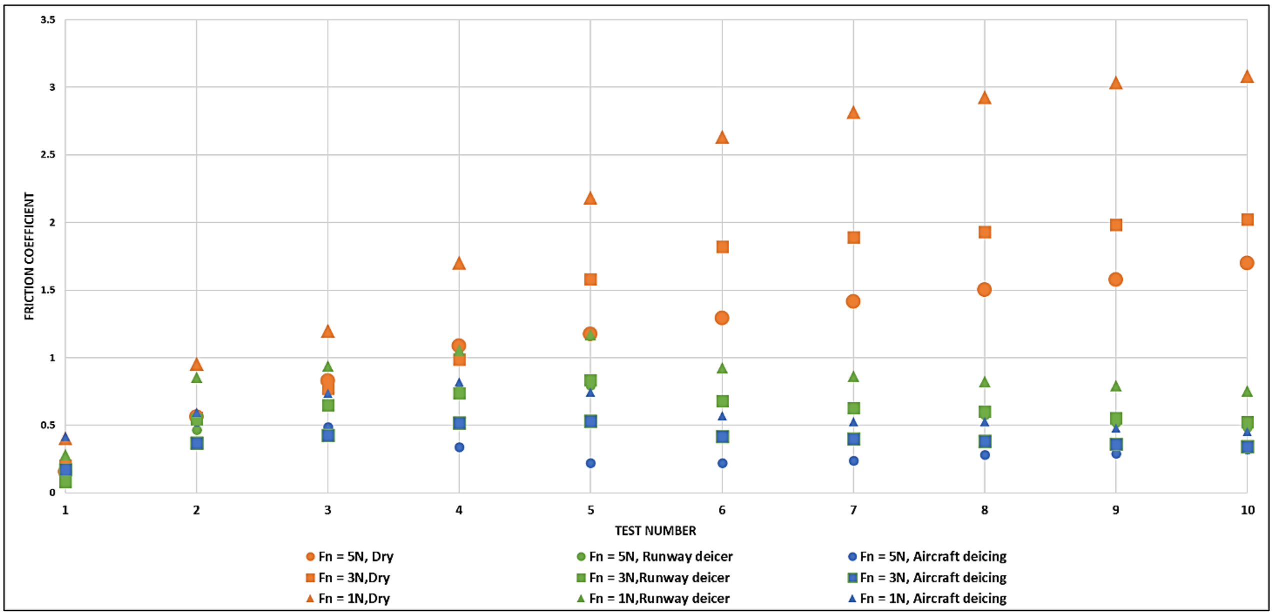

Figure 5. Measured COF values

An example is shown in figure 6, for a constant value of the normal force during the tests, in this case Fn=5 N. This value was chosen because it is the maximum value allowed by the experimental setup and for a more suggestive representation of the evolution of the COF values. It is observed that the spread of the COF values becomes greater with increasing speed for dry contact and for contaminated contacts, have a initial ascending evolution corresponding to low velocity followed by a decrease.

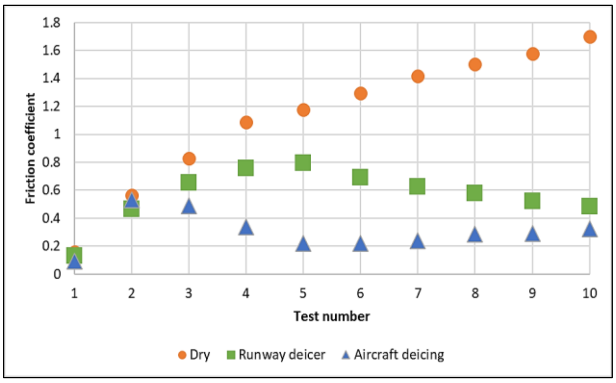

Figure 6. COF contamination values, Fn=5N

Next, an analysis of the average values of the friction coefficients is performed, calculated as the arithmetic mean of the 10 values of μ corresponding to the 10 test speeds. For example, in figure 7, a comparison is made between the average values of the friction coefficient for the three types of surfaces: dry (μ=1.13), contaminated with runway deicing fluid (μ=0.57) and contaminated with aircraft deicing fluid (μ=0.30), for a normal load of 5N.

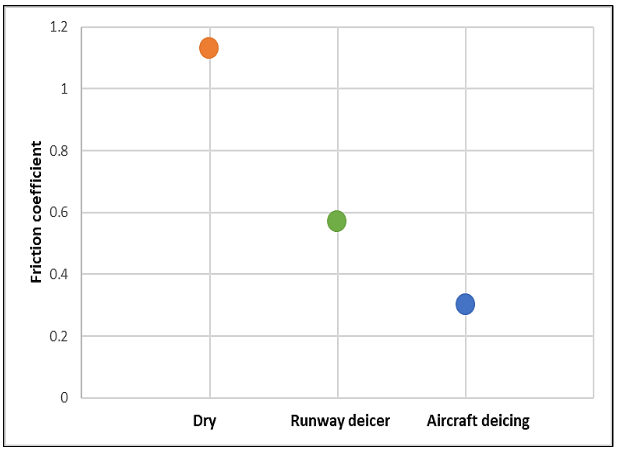

Figure 7. Average COF values, Fn=5N

It is observed that contamination with a highly viscous fluid (aircraft deicing fluid) reduces the friction coefficient values more than in the case of a low viscous fluid (runway deicing fluid). Figure 8 shows the average of the COF values for dry and contaminated contact. It is observed that the average values, in dry contact μ= 1.13, 1.38, and 2.10, corresponding to Fn=1N,3N and 5N, are the highest. In the case of runway deicing fluid the COF values are: 0.57, 0.58 and 0.84 and for aircraft deicing fluid COF are : 0.30, 0.39, 0.59.

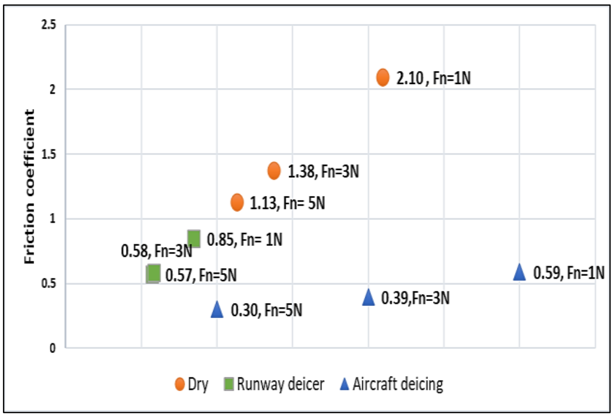

Figure 8. Average COF values for dry and contaminated contact

Thus, it is observed that the average values of the friction coefficient decrease from dry contact to contact with runway deicing fluid, having the lowest values for aircraft deicing fluid.

5. CONCLUSIONS AND DISCUSSIONS

The friction coefficient measurements for rubber-granite contact, with and without contamination, presented in this experimental study, lead to the following conclusions:

- in sliding motion, in the case of friction on a dry surface, the values of the friction coefficient are mainly influenced by adhesion and the microtopography of the contact surface;
- in the case of contamination with runway deicer and aircraft deicing fluid, adhesion decreases;
- for the analyzed contact, the contaminant with lower viscosity affects the values of the friction coefficient in contact less than the contaminant with higher viscosity, which significantly decreases the values of the friction coefficient due probably to the generation of a fluid film;
- the friction coefficient increases with the normal contact loading force, which constitutes an argument for the occurrence of adhesion;
- the friction coefficient increases with speed with a tendency to attenuate at higher speeds;
- the presence of deicing liquids in contact significantly affects the value of the friction coefficient, in the range of forces and speeds used in the experiment.

Considering the novel elements introduced by the study, through the substances used on surface as contaminants, it proved difficult to attempt to achieve a correlation with similar situations found in literature. However, some correlations with close situations were found, which are considered suggestive, presented below.

In the rubber-granite contact, in the presence of contamination, a good correlation is observed between the results obtained and [6], [7], the viscosity characteristics of the interface liquid significantly influence the values of the friction coefficient, leading to a decrease evolution of this parameter.

For a dry contact in [8], a similar pattern of the values of the friction coefficient at low speeds is observed, as in our case, the friction coefficient increases with increasing speed. Regarding the evolution of the friction coefficient in dry contact at low speeds, in [9] a maximum value μ_{max}= 1.15 is obtained, for NBR type rubber. In the tests carried out, we obtained a maximum value of μ_{max}= 1.13 for a RSS1 type rubber.

In [10] at speed values of 0.05m/s and 0.3 m/s, it is observed that the values of the friction coefficient are 1.82 and 1.92, in dry contact, and in our case at speeds at 0.52 m/s and 0.21 m/s the values of the friction coefficient are 1.82 and 2.02.

This work is a preliminary study regarding the friction and wear at small scale , in future to be used in a more extensive analisys in a tyre-runway contact. This is a micro approach to be extrapolated to a macro approch in a contact aircaft tyre- runway.

Subsequently, the rolling motion will be simulated to perform an analysis of the values for the friction coefficients and how they are affected by surface contamination, for dry and contaminated contact with the two fluids.

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