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On Short-time Measurements of Friction and Wear with a Self-adjusting Pin-On-Disc Tester

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ABSTRACT: The Automated Universal Tribotester (AUT) represents a fully automated reduced scale brake dynamometer. The setup is based on the pin-on-disc principle and the specifically designed load unit was recently enhanced with an adaptive anti-tilting system. With the conventional load unit, long bedding processes are applied after a change in load to enable a full surface contact. For short-term variations in loads, the specimens angle has to be closely controlled to generate valid results for wear and emission measurements. For this purpose, an adaptive control system was designed and implemented in the AUT, which is published elsewhere. This paper compares measurements of a pin-on-disc tester equipped with an adaptive system to control the specimens contact angle (adaptive pin-on-disc) to a test setup with disabled adaptive control (conventional pin-on-disc). During friction measurements, the specimen angle and the emissions around the friction contact are recorded to get a detailed insight into wear and emission dynamics. Furthermore, the coefficient of friction is correlated to the occurring specimen angles.

KEYWORDS: Pin on disc, self-adjusting, friction, tilting, short-time, wear, emission, misalignment

1. Introduction

Wear and emissions are sensitive to a fully aligned contact. Usually, this is achieved by long bedding procedures and sufficient wear of the implicated surfaces to adapt to each other. In short-term wear and emission measurements, such bedding procedures are too short or not present at all. Emissions are in the focus of research activities around the world [1], and in this paper, a step towards fundamental prerequisites for correct measurements with a pin-on-disc tester is made.

The Automated Universal Tribotester (AUT) is a technologically advanced and fully automated tribometer with a pin-on-disc setup. It is capable of handling various test materials, e.g. full-size brake discs and sample cutouts from commercial brake pads. The central part of this tribometer ist the load unit (Figure 1), which combines the tasks of applying the normal load, guiding the pin in the contact and withstanding the occurring friction loads. This includes besides the friction force also thermal loads and wear particles polluting the test stand. Speeds and forces can be dynamically varied to simulate various friction scenarios and topography measurements can be conducted intermittently [2, 3, 4].

Test procedures are designed to map the full characteristic of a friction pair. This means fast and sudden changes of parameters for efficient utilisation of the tribometer and reduction of test time. In contrast to long-term measurements of wear and emissions, short term characteristics are in the focus of current research activities [5].

Fast-changing load parameters induce deformations in the test stand and hinder the friction surfaces to adapt properly. This problem was first addressed by geometrical changes of the load unit, which is published in [6].

Due to the variation of loads, a static and passive solution is only valid for a specific load case. To compensate all occurring deformations, an adaptive angular compensation was developed and implemented in the AUT.

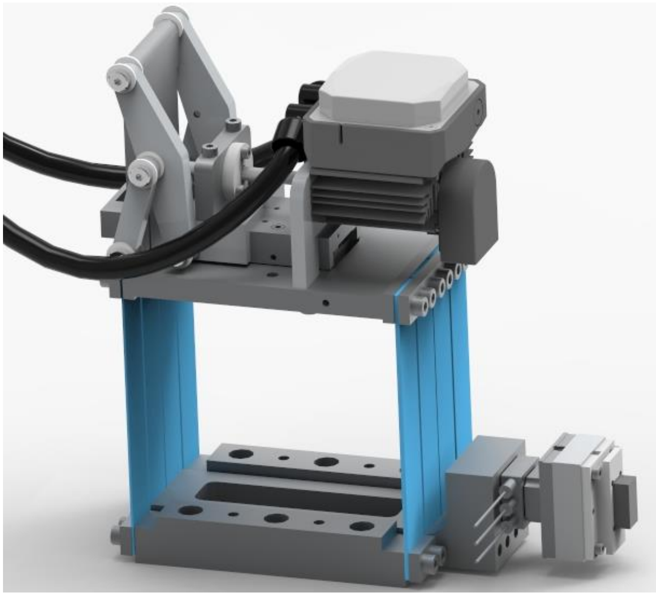

Figure 1: Load unit of the AUT with adaptive actuator on top. The hoses belong to the water cooling system of the motor to avoid interference with emission measurements

The initial prototype [7] was functional, but since then it was improved in terms of angular range, adjustment speed and applied load. Also, an observer model was implemented to determine the actual angle of the specimen's surface based on the measured forces. The device can compensate the occurring angles during friction measurements in 20 ms, the whole setup including functionality and performance is presented in [8].

second measurement (red values), the angular compensation was turned on and was operating throughout the whole procedure.

The coefficient of friction drops within the first applications after the force drops but starts to recover to the initial level. This

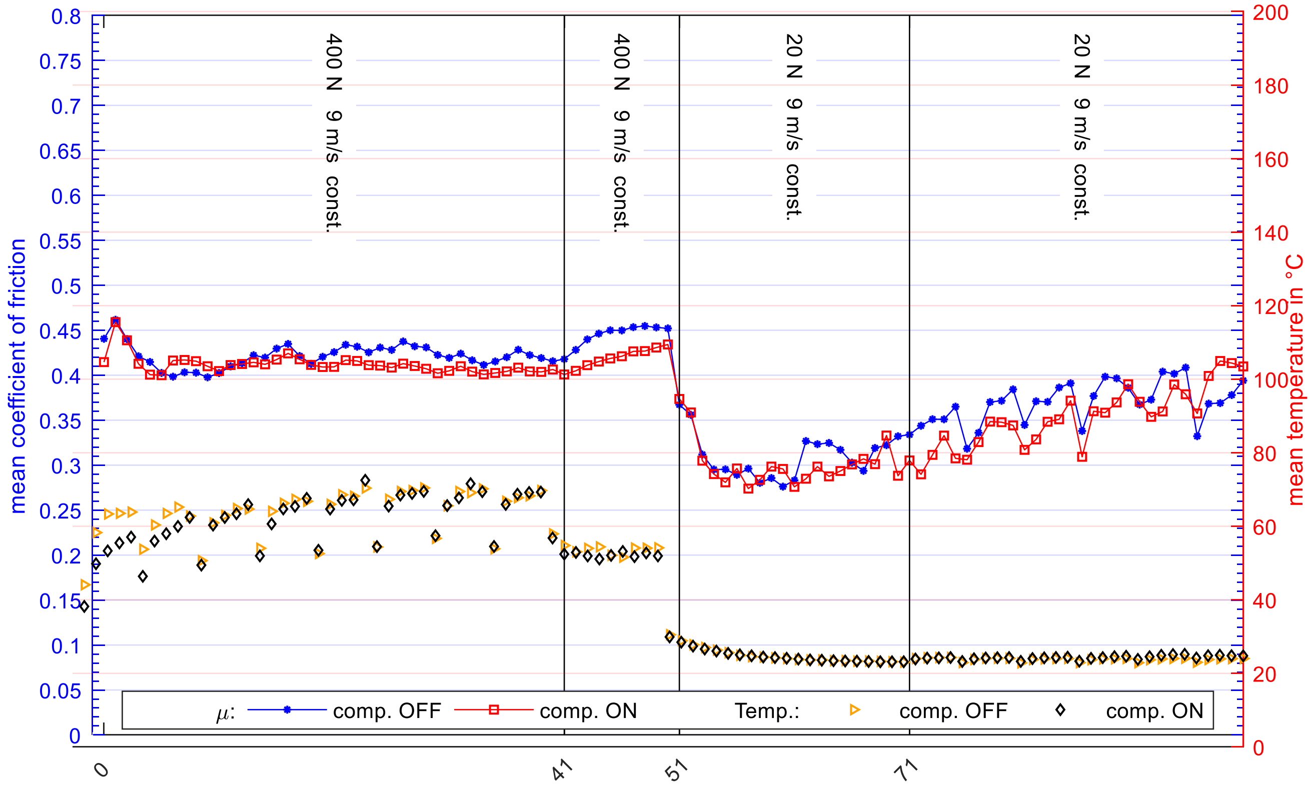

Figure 2: Comparison of the coefficient of friction for measurements with and without angular compensation

behaviour is present independently of the application of the angular compensation and supports the initial statement that the coefficient of friction is less sensitive to misalignment.

2. Influence on the coefficient of friction

The coefficient of friction is less sensitive to the dynamic tilting of the test specimen compared to wear and emission measurements since it is not sensitive to the friction area. To evaluate the influence of tilted devices, a special measurement was carried out (compare Figure 2). To provoke tilting and misalignment of the test specimen, an instant change in normal load is necessary. This is similar to typical measurements and occurs frequently throughout measurement projects.

For fast bedding, the friction surfaces are adapted to each other under a relatively high load of 400 N on a 10 x 20 mm² specimen (2 MPa normal stress). The coefficient of friction settles before the normal force drops by 95 % to 20 N (0.1 MPa) at application no. 51.

The fluctuating temperatures of the specimen in the first (bedding) part of the procedure arises from the breaks in between to take pictures, which will be presented in the following section. The temperature settles when the pictures are taken every application (applications 41 to 71) and when the friction power is reduced (starting at application 51).

This measurement was carried out two times. The first time, the angular compensation was turned off (blue values). During the

Corresponding measurements of the number of particles show that there is a significant change in the emission output. When the force is reduced to 20 N, the emission amount drops from over 300 particles per cm³ to around 100 particles per cm³ and below. The

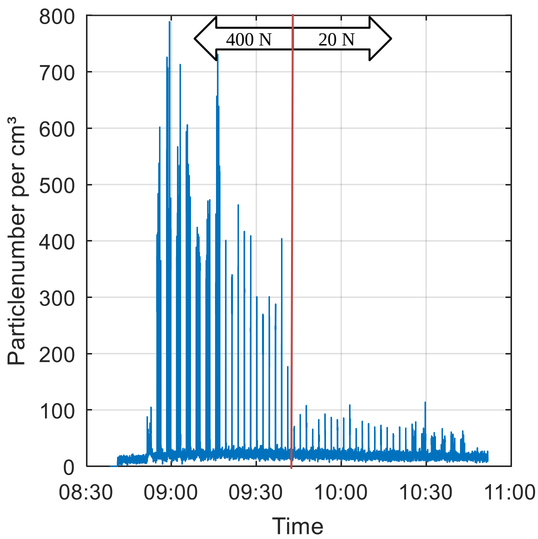

Figure 3: Particle emission measurement with operating angular compensation

measurement is shown in Figure 3, the angular compensation was operating here. In the future, more detailed and accurate measurements will be carried out.

3. Influence on surface characteristics

The wear processes in the friction interface are more sensitive to the tilting of the specimen and its misaligned contact. The reduced contact surface in addition to the maintained overall normal force leads to significantly higher normal stress, which in turn alters the interface temperatures.

During the measurements of Figure 2, pictures where taken. This happens automatically and without dismounting the test specimen, which means that the friction measurement is not affected. Nevertheless, taking pictures lets the specimen cool down, which can be seen in the temperature plot.

Again, two measurements are evaluated, including a conventional pin on disc measurement without any angular control, and measurement with controlled angle compensation. The results are given in Figure 4.

Both measurements are similar until application 50, which is necessary because this represents full contact after a sufficient bedding procedure. The force was then dropped from 400 N to 20 N after application 50, with 51 being the first at 20 N.

On the left-hand side of the diagram, the conventional pin on disc measurement is shown. When the force drops and thus the deflection of the specimen is reduced although it was in full contact, the pictures reveal a contact area that is located at the top of the specimen. Wear debris is collected further down, and the top of the specimen is comparatively clean from wear debris. In comparison, when the angular compensation is working, the effect of a force drop is not visible and wear debris is distributed evenly over the whole friction surface. This indicates that under the condition of a controlled contact, the contact situation within the friction contact stays the same, and frequent changes in loads are legit.

4. Manually tilted test specimen

To get a better understanding of the impact of tilted surfaces on the wear debris, the device used for tilting compensation can also be used to set the desired angle. Utilizing the surface investigation possibilities of the AUT, a detailed view of the wear debris transport can be obtained.

For this purpose, two separate measurements were performed, which are summarized in Figure 5. The first 20 applications and 100 applications beforehand (not shown) are necessary to achieve a fully bedded contact and the same initial condition for the following test. After application 20, the specimen is tilted by 0.14 degrees in the negative and positive direction, respectively. This results in a partial contact, which is in the upper or lower part of the interface surface.

Although the induced angle is artificial here, this measurement resembles contact situations that occur during real measurements. Coming from a high load and dropping to lower normal forces, as presented in the previous section, invokes a contact area in the upper specimen area (negative manual tilting). If the normal force

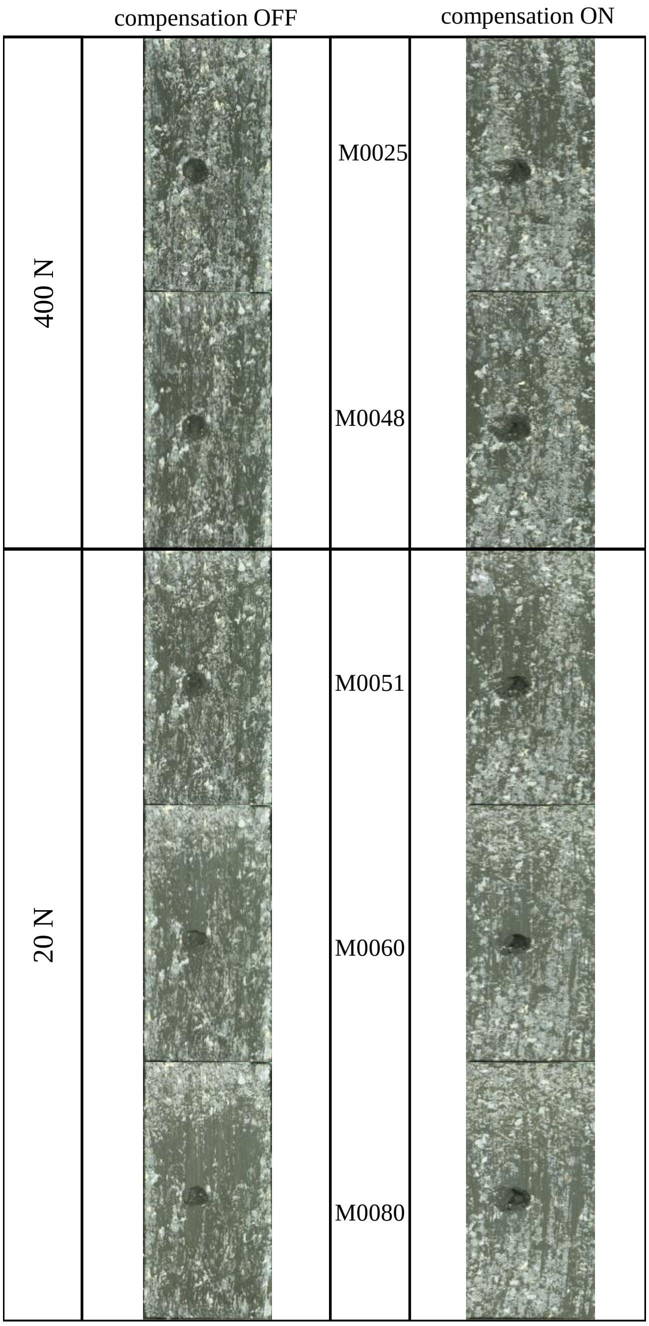

Figure 4: Surface pictures of measurements with a sudden change in normal force, with and without angular compensation

is rapidly changed to higher loads, a contact situation similar to positive tilting occurs.

Negative tilting: The specimen is mainly in contact with the top of the area. This results in wear debris that is collected in the lower area because the wear debris is transported by the rotating disc out of the contact and again into the friction interface after a full revolution. As the wear goes on, the misalignment of the specimen

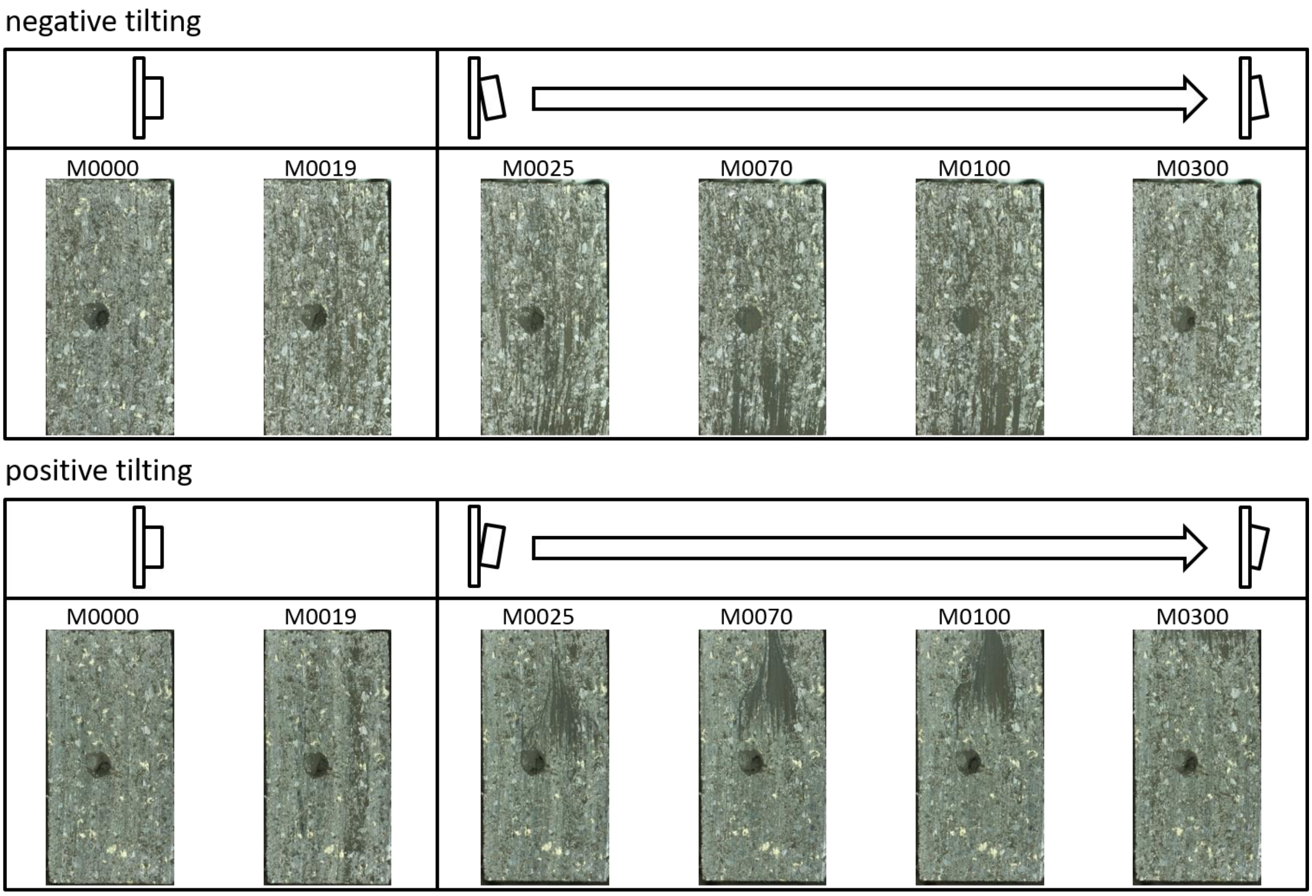

Figure 5: Manual tilted specimen and corresponding surface pictures, 100 N normal load

is reduced, resulting in a full surface contact at the end of the measurement. This surface situation is comparable to the initial state.

Positive tilting: The measurement starts with the same bedded surfaces. When the specimen is tilted positively, it is mainly in contact at the lower part in the friction interface. This area increases while the material wears, and comes to a full contact again at the end of the measurement (also comparable to the initial surface). Wear debris is carried out of the contact on top of the specimen.

Both measurements result in full surface contact, but differ in the way wear debris is carried through the interface on a large time scale.

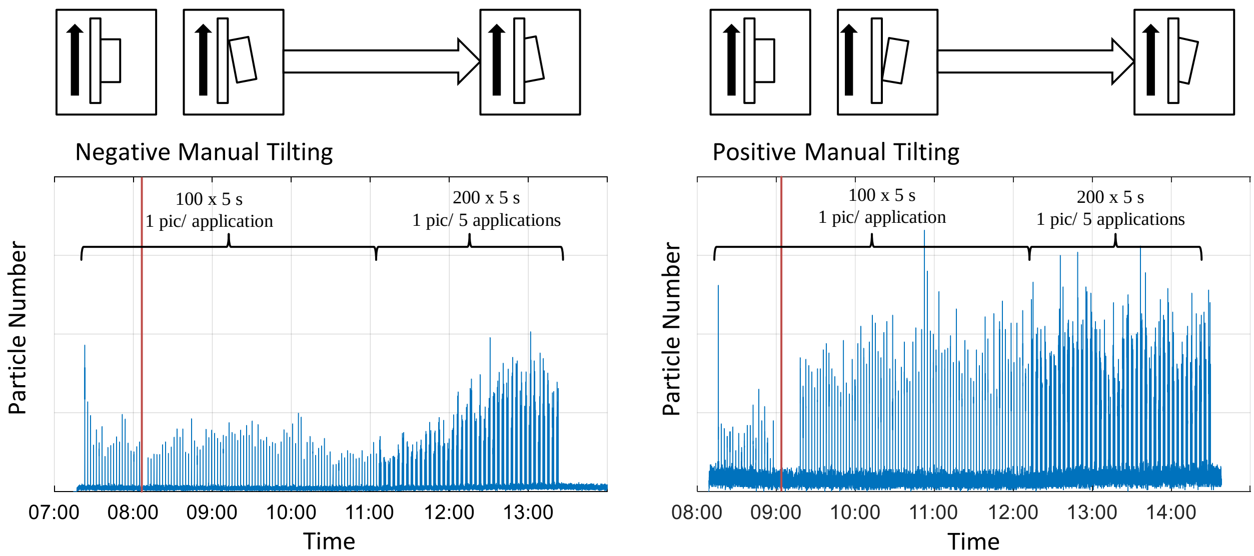

Figure 6: Emission measurements for positive and negative tilted specimen

5. Emissions

The above-mentioned measurements are accompanied by emission measurements using a PALAS Promo 1000 aerosol spectrometer. This device measures the range 200 nm to 10 µm with a time resolution of 1 Hz [9]. The emissions were measured continuously throughout the friction measurements, and are not interrupted by the application pause. The specimen is tilted at the time which is marked with the red vertical line (Figure 6).

In the diagram, the qualitative particle concentration is displayed over the measurement time. The intervals for taking surface pictures where chosen asymmetric to ensure a compromise between a detailed insight and adequate measurement time. It starts with one picture per friction application at the beginning and throughout the initial tilting phase, and is then extended to one picture per five applications (clusters of five applications in the diagram). This shortens the measurement time, but it is worth noting that it distorts the actual contact time, which is 100 x 5 s for the first part and 200 x 5 s for the subsequent part.

The qualitative emissions differ significantly. With negative manual tilting, the particle number stays the same after the adjustment, increasing only with the last 200 applications when the surface of the pad wears and the contact area increases to the initial size. With positive manual tilting, the increase in particle number is instantly linked to the adjustment and stays in a steady state throughout the rest of the procedure. Both tilting mechanisms result in completely different qualitative emission behaviour.

Keeping in mind the measurement limits of the aerosol spectrometer, it may be that not all effects are seen in this diagram. Particles below 200 nm are not measured, so ultrafine particles may not be seen. The available time resolution results in an integral particle value over one second, and the underlying time scales are not yet known. In the future, more research work will be done to shift the measurement limits and to get a close insight into quantity and size distribution of brake emission particles.

6. Conclusion

In this paper, first measurements concerning friction and wear were made using the new self-adjusting enhancement for a fully automated pin-on-disc tester.

The coefficient of friction is rather robust to the tilting induced by a sudden change in normal load since it is not sensitive to the pad area. This means that measurements of the coefficient of friction are valid even with high dynamic load changes.

However, rapid changes in load result in a different wear behaviour and wear debris distribution in the contact area. If the contact angle is not controlled, uneven wear occurs. With the help of the adaptive angle compensation, this problem is no longer present.

To get an insight into the wear debris transport throughout the specimen and the effects of tilting, artificial angles were induced and surface pictures were taken. This reveals different transport mechanisms for the scenarios of step-up or step-down of the normal load.

Processes in the boundary layer seem to happen on different time scales. On the long-term scale, we see the wear of the tilted object and the different ways of wear debris transport from the reservoirs through the specimen and out of the contact. On the short-term scale, the emission characteristic has to be determined since here different force variations and processes in the boundary layer occur. The particle production and the particle transport in both time scales may be very different.

In the future, more precise and time-resolved measurements will be done. In addition to this, a particle sensor cluster of more than eight sensors is used by coworkers [9] to gain insight into the particle dynamics around the friction contact, which will then be correlated to the different contact situations.

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