

Experimental Investigations of the Topography Dynamics in Brake Pads

Georg Peter Ostermeyer
Academic Research and Education

Lars Wilkening
Technische Universität Braunschweig

ABSTRACT

For more than a decade, investigations of the surface topography and chemical behavior of the boundary layer have been performed. This is of great importance for the understanding of friction, as it provides valuable insights into the dynamic processes that influence the brake pad's performance. The adaption of the boundary layer to a new load condition is of particular interest because it allows for the identification and description of mechanisms that influence macroscopically-observable effects, and quantities such as the coefficient of friction. It is possible to determine time constants that describe this process of adaption.

The investigations discussed in this paper combine tribometer tests and optical investigations at the same time. Therefore, the measured coefficient of friction can be related to the observed surface topography of the brake pad. Using a scaled laboratory-tribometer eliminates the influence of the complete brake system and allows for a highly flexible design of test procedures. This is necessary for an insightful study of the adaptation processes of the boundary layer. The generated information can be used for a macroscopic description of the friction process using dynamic friction laws with a suitable parameterization.

CITATION: Ostermeyer, G. and Wilkening, L., "Experimental Investigations of the Topography Dynamics in Brake Pads," *SAE Int. J. Passeng. Cars - Mech. Syst.* 6(3):2013, doi:10.4271/2013-01-2027.

INTRODUCTION

As a safety related component an automotive brake has to ensure a quick and reliable deceleration of the vehicle over a wide range of operating condition. Among others, one main task is to develop a brake pad which shows a high and stable coefficient of friction. In order to meet these requirements automotive brake pads undergo a lot of testing during the development process. Usually performance testing of friction materials is conducted on full scale inertia dynamometers which include the whole brake system. The test procedures for inertia dynamometer contain mostly part-stop or snub brake applications. This allows for realistic testing conditions that are similar to the conditions during vehicle operation.

Especially in the development process of new friction materials the main focus lies on the friction properties of the material itself. In this case testing on a laboratory tribometer using a scaled test specimen has some advantages. First of all the influence of the brake system on the measurement result

is eliminated. Additionally a highly flexible design of the test procedure is possible, e.g. drag braking at constant relative speeds over a wide range of normal loads.

As the friction process takes place in the boundary layer between the brake pad and the disk, the surface of the contacting bodies is of great interest. The characterization of the brake pad's surface has been the topic of several studies in the past years. On the brake pad's surface hard and flat contact areas can be found [1]. These contact patches are subjected to a dynamic process of patch generation, growth and destruction which is described in detail in [2,3]. Usually a patch originates at a hard, wear-resistant particle that comes into contact with the disk. This particle disturbs the flow of wear debris and thus wear debris accumulates in front of the particle. This leads to a local increase of temperature which enables chemical processes to form a patch out of the compacted wear debris. This patch is now capable of carrying normal and tangential load itself and thus the loads on the hard particle are decreased. On the other hand the lifetime of

a patch is also limited, e.g. a patch is destroyed when its size becomes too large. So the dynamic processes of patch growth and patch destruction form a closed loop interaction.

The total patch area is linked with the global coefficient of friction via the total patch area, because a great part of the friction power is converted on the patches. This relation can be used for the formulation of a dynamic friction law [2,3]. It allows for the description of transient friction effects by using a set of balance equations that describe the processes of patch growth and patch destruction. By considering not the friction coefficient itself but its derivative with respect to time it is possible to simulate time delayed responses of the friction coefficient to a new load condition. The general capability of these equations to simulate the results of a SAE J2522 test procedure (AK-Master-Test) [4] is shown in [5].

The challenge is to find a suitable parameterization for this dynamic friction law. In this paper an approach is presented that combines tribometer tests with the quasi in situ study of the brake pad's surface. Therefore the measured coefficient of friction can be related to the corresponding surface characteristic of the pad. Furthermore a special test procedure is needed that allows for the examination of adaption processes of the boundary layer to a new load condition. In this procedure it is essential to keep all input parameters like relative speed and normal force constant during a single brake application. This can be achieved by using the highly flexible High-Load Tribometer at IDS (Institut für Dynamik und Schwingungen) at TU Braunschweig.

EXPERIMENTAL SETUP

Measurement Equipment

The measurements are conducted on the High-Load-Tribometer (HLT) at IDS (see Figure 1).

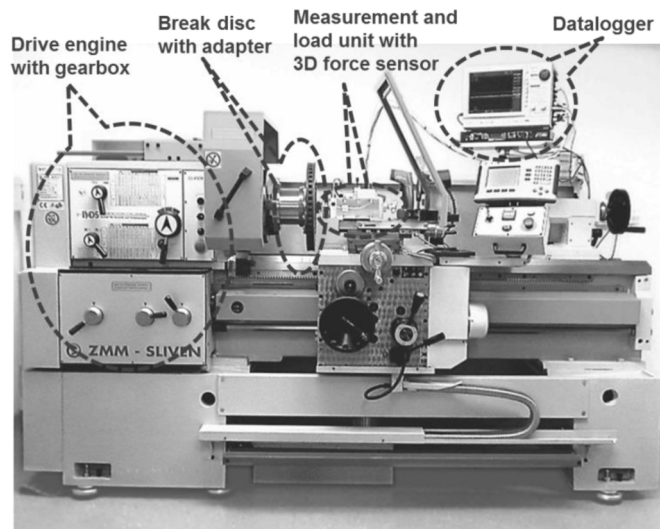


Figure 1. The IDS High-Load-Tribometer (HLT)

This tribometer uses the pin-on-disk test principle and is described in detail in [6]. It is based on a lathe which is equipped with a specially developed load and measurement unit in which the test specimen can be mounted. It contains a 3D piezo force sensor for the measurement of the normal force and the friction forces. This test setup enables the measurement of friction forces very close to the contacting bodies and thus disturbances are minimized. Also the behavior of the friction material can be examined without the influence of the brake system. The applied normal force can be varied between 0 and 1kN with rotating speeds up to 2080 rpm. Therefore by scaling the test specimen it is possible to cover a wide range of standard industry test procedures as SAE J2522. At the same time the 11 kW motor provides a very high flexibility in designing new test procedures. For example brake applications with a constant relative speed can be performed for a wide range of normal forces.

Special attention is to be paid to the resulting relative speeds in the HLT. In tests with inertia dynamometers the relative speed is usually a direct result of the friction process which leads to a deceleration of the disk and the connected flywheel mass. The angular speed of the inertia dynamometer (ID) can be calculated as follows:

$$\dot{\phi}_{ID} = \dot{\phi}_{start,ID} - \int_0^{t_{stop}} \frac{2 \cdot \mu(t) \cdot p_{brake}(t) \cdot A_{piston} \cdot r_{fr,ID}}{I} dt \quad (1)$$

In the HLT the speed can generally be chosen arbitrarily in the form of linear ramps. The problem is, that the resulting friction coefficient is not known a priori. Therefore the speed ramp has to be preset by assuming a constant, average coefficient of friction and a constant brake line pressure. This leads to the following equation for the angular speed of the inertia dynamometer:

$$\dot{\phi}_{ID} = \dot{\phi}_{start,ID} - \frac{2 \cdot \mu_{av} \cdot p_{brake,av} \cdot A_{piston} \cdot r_{fr,ID}}{I} \cdot t_{stop} \quad (2)$$

With the requirement that the relative speed in the HLT is supposed to be equal to the relative speed in the inertia dynamometer, the resulting angular speed in the HLT can be calculated as:

$$\dot{\phi}_{HLT} = \frac{\dot{\phi}_{ID} \cdot r_{fr,ID}}{r_{fr,HLT}} \quad (3)$$

Inserting (2) in (3) leads to the resulting speed in the HLT:

$$\dot{\phi}_{HLT} = \left(\dot{\phi}_{start,ID} - \frac{2 \cdot \mu_{av} \cdot p_{brake,av} \cdot A_{piston} \cdot r_{fr,ID}}{I} \cdot t_{stop} \right) \frac{r_{fr,ID}}{r_{fr,HLT}} \quad (4)$$

During friction test in the HLT the temperature is measured in the disk and the test specimen as well. In the disk a thermocouple is positioned approximately 1 mm below the disk surface in the center of the friction path. In the test specimen a thermocouple is positioned ca. 2 mm below the surface (see Figure 2).

The optical characterization of the test specimen's surface is performed with a stereo-microscope. It is equipped with a digital CCD camera with a resolution of 1.4 Mega Pixel. This enables capturing images and films of the observed surface, e.g. for the examination of patch dynamics. The test specimen can be illuminated either by coaxial ring light from the top or by a side light. The illumination with ring light allows for the identification of different structures and materials on the surface. The illumination with the side light is ideal for highlighting the topography of the surface by casting of shadows.

Friction Material

For the conducted tests a commercially available standard low-met brake pad is used. The scorched top layer (3 mm) is removed by grinding and the brake pad is cut into rectangular test specimens with a size of 10 × 20 mm. The edges of the brake pad are not used as test specimens as they might contain inhomogenities due to the manufacturing process. Afterwards the test specimen is equipped with a thermocouple and glued into a carrier (see Figure 2). The carrier can be mounted on the tribometer's measurement and load unit precisely by using two pins.

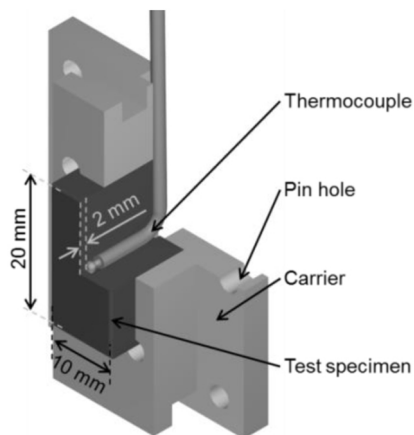


Figure 2. Test specimen with carrier

For the following tests a ventilated, cast iron brake disc with an outer diameter of 312 mm and a thickness of 25 mm is used. The brake system parameters used for the conversion of brake line pressure to surface pressure on the brake pad and vehicle speed to relative speed between disk and pad are taken from an upper class passenger car:

- friction radius: 134 mm,
- dynamic tire radius: 308 mm,

- piston area: 2552 mm²,
- pad area: 5730 mm².

Test Procedure

The friction material is tested with two different test procedures. The main difference between them is the speed during the brake application. The first procedure is run with decreasing speed while in the second procedure the speed is remained constant during the brake application.

In each procedure a combination of friction measurement and optical examination of the test specimen's surface is performed (see Figure 3). This allows for a quasi in situ observation of the test specimen's surface.

For the first procedure a section of the standard industry test procedure SAE J2522 (AK-Master-Test) has been chosen. The selected sections are 3, 4.1 - 4.3 and 5. The associated loads are summarized in Figure 4. Additionally microscope images are taken after several applications (see Figure 4). The disc temperature at the start of each brake application is approximately 25°C.

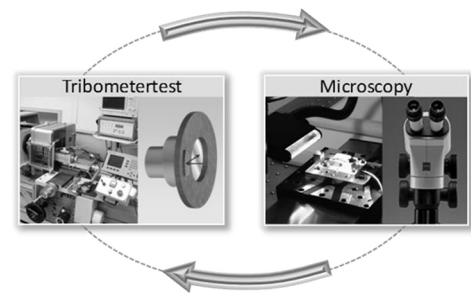


Figure 3. Quasi in situ study of the test specimen's surface

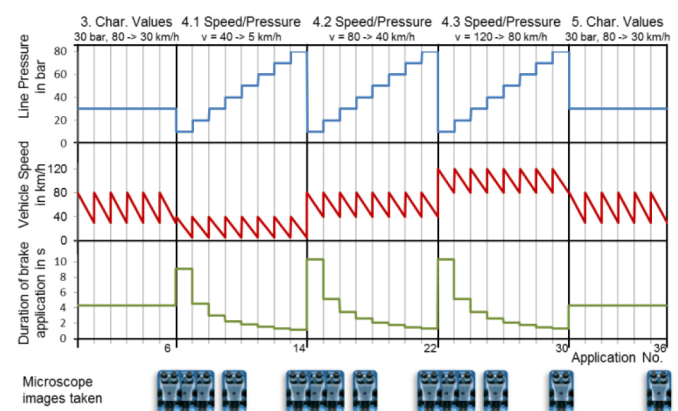


Figure 4. Test procedure with decreasing speed during brake application: Section of SAE J2522

For bedding purposes 200 brake applications with a duration of 5 s each are conducted at a constant vehicle speed of 80 km/h and a brake line pressure of 30 bar before the actual test procedure. As mentioned before the linear speed