

Permeability Measurements of Sintered and Paper Based Friction Materials for Wet Clutches and Brakes

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ABSTRACT

Wet clutches are important components used in the transmission and drive trains of many modern vehicles. The clutches transfer torque via the friction between a number of friction discs and the friction characteristics is therefore of great importance for the overall behavior of the vehicles. The friction characteristics is governed by a number of parameters such as lubricant base oil and additives, type and permeability of the friction material and temperature and surface roughness of the interacting surfaces. The permeability is considered to influence time of engagement and supply the sliding interface with lubricant and additives during engagement. In this work, a permeability measurement method suitable for wet clutch friction materials is thus used to measure the permeability of friction materials of different types; sintered bronze and paper based materials. The investigated friction materials come from different vehicle applications such as Limited Slip Differentials and Automatic Transmissions. The investigation also includes measurements made with different types of lubricants such as mineral based lubricants, mineral based VHVI lubricants and ester based lubricants. As comparison similar permeability measurements are made with water since the permeability, according to Darcy's law, should not be influenced by the percolating fluid.

It is found that even though permeability is considered to be a material parameter the measured permeability for a certain material will vary depending on which fluid that is used in the measurements. Therefore, if a detailed absolute value of the permeability is of interest, i.e. for use in simulations models, the permeability should be measured with the fluid that is going to be used in the clutch or brake application in order to obtain a detailed result. However the results show

that if the permeability only is compared between different materials the test fluid is of less importance as long as the same fluid is used in all investigations.

INTRODUCTION

Wet clutches and brakes are often used in modern vehicles to distribute torque in transmissions and drive trains. The characteristics of these clutches and brakes are of great importance for the overall behavior of the vehicle. There are many properties of the clutch influencing the friction characteristics, such as materials, lubricants, surface roughness and permeability of the friction material. The permeability, i.e. the possibility for a fluid to flow inside the friction material, is considered to decrease the time of engagement and supply the sliding contact between the friction discs and separator discs with lubricant, e.g. influence the friction coefficient [1]. The time of engagement could be decreased due to decreased squeeze film effects on the contact areas between the discs.

The permeability is one of the input parameters in many simulation models developed for wet clutches [2,3,4,5,6,7]. However, the method used to obtain the permeability for the friction material is normally not thoroughly described. The value of permeability is also widely varied between roughly 10^{-15} and 10^{-11} m² in the simulation models. The effects of the permeability are often not studied but in some work, e.g. [4, 6, 8] the permeability is varied and the influence on, for example, torque transfer during clutch engagement is investigated.

For simulation models of clutches in Limited Slip Differentials, which are often working fully engaged with a limited slip under boundary lubrication conditions, it has been concluded that the permeability is often not necessary to

take into account [9]. However, when the clutch engagement is simulated the permeability is an important factor since it influences the time of the engagement.

Measurements of permeability range all way back to 1856 when Darcy did his experiments on sand [10]. During the latest decades much effort has been spent on methods to measure the permeability of materials having a sheet like form in connection to composites manufacturing [11,12,13] and making of paper [14]. For wet clutch friction materials little has been done so far. Chavdar's investigation [15] on paper based friction materials is one example of a permeability measurement made especially for wet clutch friction materials. An easy method to measure the permeability of wet clutch friction materials was developed by Marklund et.al. [16, 17]. They showed how the permeability changed due to the density of the porous friction material and the groove patterns. It was shown that a pressed groove pattern could generate completely sealed groove edges which could decrease the percolating flow inside the material in some directions to zero.

The test rig from [16, 17] is here used to further investigate the permeability of wet clutch friction materials. Different friction materials from different vehicle applications such as Limited Slip Differentials and Automatic Transmissions are investigated. These materials not only have different densities but also three different types of materials are investigated; one bronze material and two paper based materials from which one contains a very high graphite concentration. The investigation also include measurements made with different types of lubricants such as mineral based lubricants, mineral based VHVI lubricants and ester based lubricants to see if the type of lubricant that is used in the measurements will influence the measured permeability of the porous friction material. As comparison similar permeability measurements are made with water as a test fluid since the permeability, according to Darcy's law, should not be influenced by the percolating fluid and since water was used as test fluid in [16,17].

It is found that the measured permeability for a material varies depending on which test fluid that is used in the measurements. This indicates that it is important to measure the permeability of the friction material with a test fluid similar to what is to be used in the clutch or brake application in order to measure an exact absolute value. This could be of interest for use of the permeability value in i.e. a wet clutch simulation model. However, to only compare the permeability of different materials most test fluids can be used as long as the same fluid is used in all investigations.

METHOD

The flow through the material in one direction is measured by the use of an experimental method described in [11] and [16,

17]. In the wet clutch applications, where the investigated friction materials are used, the permeability is supposed to reduce the time of engagement and improve the friction characteristics. The permeability depends on the internal structure of the material as well as the porosity. Since special test specimens have to be manufactured for the tests, it is important that the friction material used in the investigation is manufactured in the same way as the original friction discs.

TEST RIG

The test rig used was originally developed for permeability investigations of textile materials such as press fabric used in paper machines and fiber mats for different composites [11]. In [16, 17] Marklund et. al. further developed the test rig to make it possible to measure the permeability of friction materials for wet clutches and brakes. A test cell where the in-plane parallel flow is measured in rectangular shaped specimens was found to be suitable for permeability measurements of wet clutch friction materials. One advantage with measuring the in-plane permeability is that the permeability is measured over a longer flow distance compared to permeability measurements in the normal direction to the surface. This gives a more accurate measurement which also is less influenced by edges of the test specimen.

The test cell, see Fig. 1, is designed as a holder for rectangular test specimens with a thickness between 1 and 5 mm and is sealed at the edges perpendicular to the flow. On top of the test specimen a closing cap is placed to prevent any flow to pass over the specimen instead of going through the permeable material. The specimen is also sealed between the cap and the test cell with rubber layers above and under the test specimen to make sure that all the measured fluid has passed through the porous material. Because of these seals, the surface roughness of the investigated friction materials is not important. The compression of the friction material is controlled with high precision spacers according to Fig. 1. The spacers enable a sufficient seal between the cap and the test specimen even for a very low compression of the friction material, since they support most of the load when the cap is loaded against the test cell and test specimen. Because of the spacers the compression of the friction material will also not be sensitive for changes in lubricant pressure.

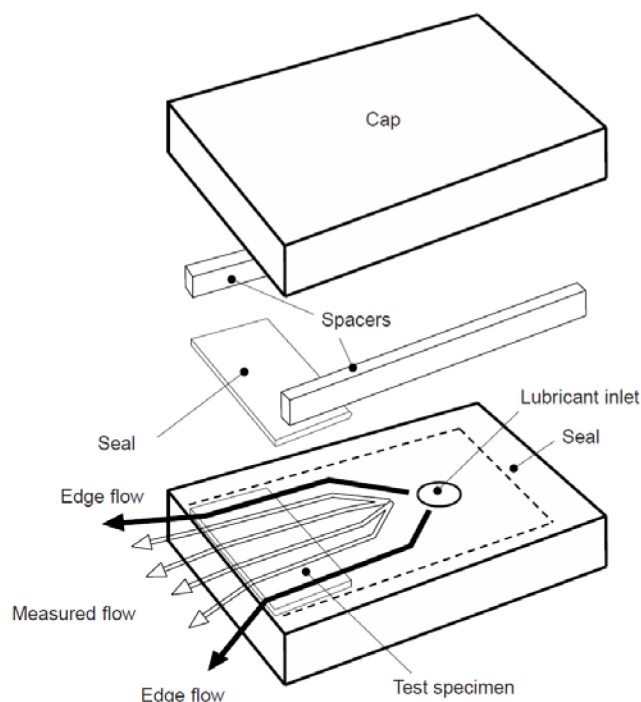


Figure 1. This Test cell for permeability measurements.

One difficulty with this method is to obtain a precise fit between the test cell and the specimen. A specimen misfit can result in leakage or suppressed flow along the sides of the sample which will influence the measured permeability. Therefore the center bulk flow is separated from the edge flow so that possible leakage can be measured separately and will not influence the bulk flow measurement. The presented flow and permeability values are the values from measurements of the center bulk flow covering the middle 60% of the specimen width.

The pressure gradient through the test specimen is considered to be linear between the measured inlet pressure, p_{inlet} , and the ambient pressure, $P_{ambient}$. The pressure transducer (WIKA type 891.13.500) is placed next to the inlet hole, see Fig. 1, while the temperature is measured at the inlet with a thermometer (GEFRAM PT100) to be able to calculate the density and the viscosity of the fluid that is flowing through the permeable material. The mass of the fluid that flows through the permeable test specimen is then measured with two separate balances (Precisa 3100D), one for the bulk flow and one for the edge flow, both with a precision of 0.1 gram.

TEST SPECIMENS

The test specimens are made of a rectangular steel backing plate which is covered with a sintered bronze or a paper based friction material layer, see Fig. 2. Four different friction materials are investigated, see Table 1. The specimens only have friction material attached on one side of

the steel backing plate in contrary to most of the friction discs used in wet clutches and brakes.

Table 1. Types and dimensions of the test specimens.

	Material	Size [mm]	Friction material thickness [mm]
Friction mtrl. 1	Sintered Bronze, normal density	15x100	0.6
Friction mtrl. 2	Paper, normal density	15x100	0.6
Friction mtrl. 3	Paper, high density	15x100	0.6
Friction mtrl. 4	Paper, high carbon content	15x100	0.5



(a). Friction material 1; Sintered bronze friction material



(b). Friction material 2 and 3; Paper based friction material



(c). Friction material 4; Paper based friction material with a high carbon content

Figure 2. Examples of test specimens used for the permeability measurements.

FRICION MATERIAL ANALYSIS

A Scanning Electron Microscope (SEM) was used to investigate the surface of the friction materials. Figure 3 shows the bronze and the carbon reinforced friction material at 100 times magnification. The pores and different structure of the different test specimens indicates a different permeability of the different materials.