The Importance of Static Friction Characteristics of Brake Friction Couple, and Methods of Testing

S.F. Ścieszka and A. Jankowski
Technical University of Silesia, Gliwice, Poland

Abstract

Detailed knowledge about static friction materials is required for the accurate calculation of the braking torque needed to hold a load at rest. This is particularly important for brakes in cranes, elevators, hoists and mining winding machines, which must meet specifications such as the definite value of the static safe braking factor. The study of static friction is also a useful supplement to the dynamic testing of brake friction materials. In such a study, precise control of the temperature on the surfaces is possible, as well as surface roughness, and existence of the third-body can be accurately identified. It is an important fact that the coefficient of static friction, μ_s, is not an invariant, and it cannot be adequately represented in many engineering applications as a single number. The study of static friction dependence upon factors such as stationary contact time, rate of tangential loading, and surface temperature, contributes to a better understanding of friction phenomena.

In this paper, a test apparatus is presented, and a series of experiments is described. The experiments reveal the static friction characteristics of some brake friction materials.

Keywords

static friction, brake, testing, materials, properties, time-dependence, creep

INTRODUCTION

Two basic functions are essential for any friction brake in mechanical systems: the first is to provide controlled deceleration; the second, equally important, function is to keep the mechanical system in the rest position as long as required. The latter function is particularly important in installations such as cranes, elevators and mining winding machines, since rapid changes of torque take place as a result of the unloading and loading actions during the rest period.

The values of static friction forces are crucial in maintaining the rest position of the mechanical systems. The static friction forces, on the other hand, are determined by the coefficient of static friction and the clamp forces on the brake shoes.

Figure 1 Overall view of the experimental set-up

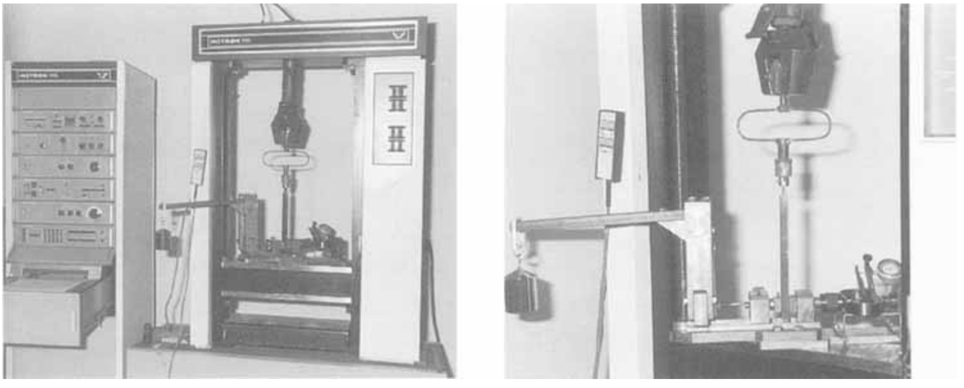
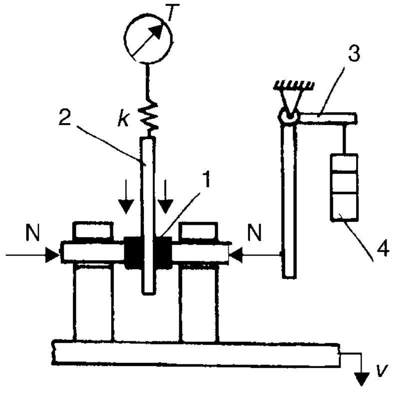


Figure 2 The test apparatus
1 – sample. 2 – counterspecimen. 3 – knee lever. 4 – load



Accurate estimation of the static friction coefficient for brake friction materials is an important part of the procedure for brake calculation and design. In the brake calculation, the notion of the static friction coefficient is not always distinguished from the coefficient of kinetic friction. This is a result of the lack of sufficient reported work on the differences between static and kinetic friction. The coefficient of static friction is rarely presented as a function of service parameters of the defined friction brake arrangement. There have been a number of reports on tribological problems during dynamic friction processes in brakes,[1] but only a few concern static friction in brakes.[2]

Contrary to early claims by Amontons and others, the static friction characteristic is a multi-parametric function:

$$\mu_s = f(p_1, p_2, \ldots p_n)$$

where p_1, $p_2, \ldots p_n$ are parameters influencing the coefficient of static friction.

The most often studied and described relations have been the empirical functions between the coefficient of static friction and the stationary contact time, and between the coefficient of static friction and the rate of tangential loading. Over the last forty years, a number of studies of stick-slip sliding have produced a variety of data on static friction. Several equations have been proposed by Brockley, Rabinowicz, Derjagin, Kato, and others expressing the functional relationship.[3,4]

In this paper, emphasis is put on the importance and measurement of static friction in the brake composite material–steel friction couple.

EXPERIMENTAL

The dependence of static friction on a number of material combinations was investigated in experiments conducted under conditions of controlled stick-slip vibration. The apparatus employed for the work consisted of two main parts: a caliper-type friction sample holder with knee lever to provide normal load, and a counterspecimen in the form of a carbon steel strip, both mounted on a tensile testing machine. An overall view of the set-up is shown together with the tensile testing machine in **Figure 1**, and a drawing of the apparatus is given in **Figure 2**.

The samples were made from four brake friction composite materials currently used in hoisting machines, or anticipated for future use. The samples' chemical composition and other properties are described fully in **Tables 1** and **2** (overleaf).[5] The counterspecimens were made from carbon steel, the same material used for brake discs in hoisting machines, and counterspecimens with different surface roughnesses were used. The height of the profile asperities at 10 points, R_z, was introduced for the surface roughness description. To investigate the influence of temperature on the coefficient of static friction a heating element was fitted inside the counterspecimen.

Table 1 Chemical composition of friction materials

		Friction materials			
Components	*Unit*	*FM1*	*FM2*	*FM3*	*FM4*
Phenolic resin	wt.%	30	15	25	-
Synthetic rubber	wt.%	-	20	-	27
Creosote asbestos	wt.%	-	45	25	10
Glass fibre	wt.%	10	-	-	20
Steel fibre	wt.%	15	-	-	-
Barite	wt.%	10	-	20	5
Cashew dust	wt.%	-	10	-	15
Copper powder	wt.%	15	10	20	15
Remainder	wt.%	20	-	10	8

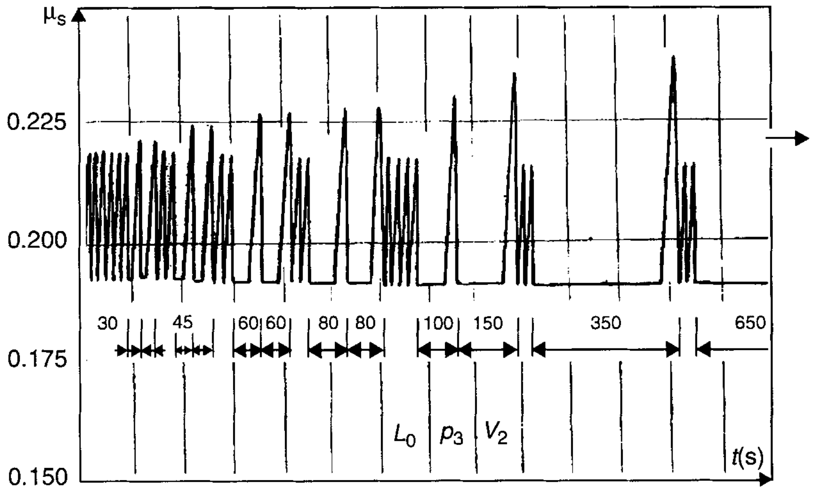
Table 2 Properties of composite friction materials

		Friction materials			
Property	*Unit*	*FM1*	*FM2*	*FM3*	*FM4*
Density	kgm^{-3}	2140	2470	2240	2220
Water imbibition	%	0.50	0.51	0.10	0.40
Impulse strength	kJm^{-2}	32	42	93	9.3
Compressive strength	MPa	12	31	26	12
Bending strength	MPa	10	15	16	8
Tensile strength	MPa	3.8	13	12	3.5
Hardness, HB	MPa	108	30	194	104

The experiments were carried out under the following conditions:

stationary contact time $t = 3 \div 1250$ s
rate of tangential loading $Q = 0.062 \div 12.4$ N/s
height of asperities $R_z = 0.9 \div 36.4$ µm
surface temperature $T = 20 \div 300$°C
pressure $p = 0.5 \div 2.0$ MPa.

Figure 3 The recording of stick-slip movement showing the dwell time influence on static friction for the following conditions:
steel – FM4 friction pair, Q = 0.248 N/s, R_z = 0.9 μm, T = 20°C, p = 1.0 MPa



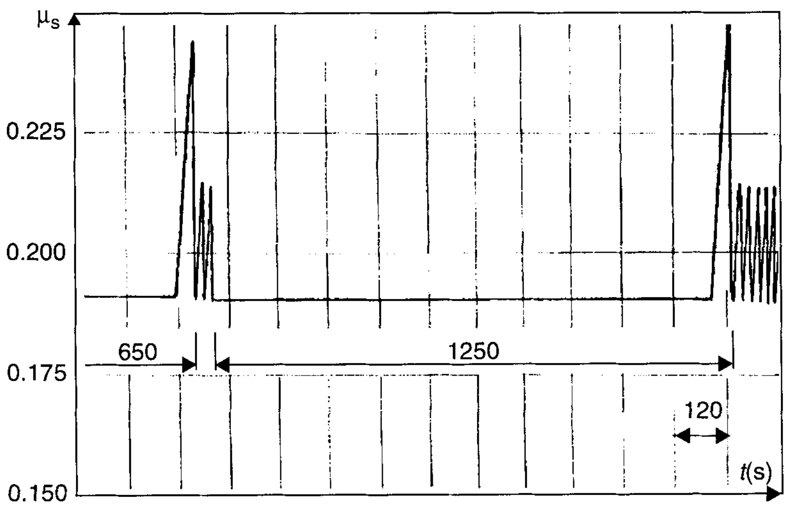
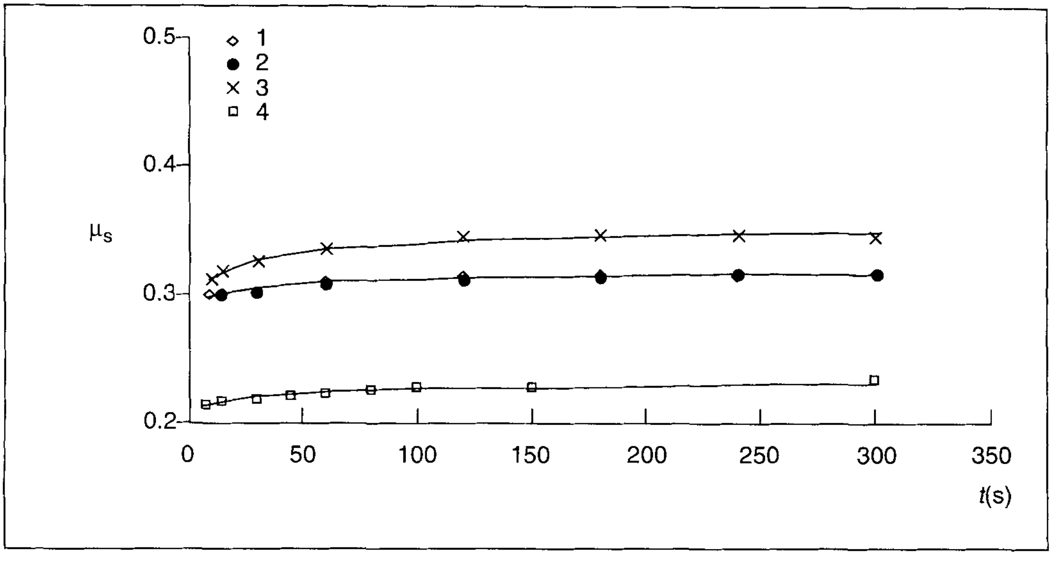


Figure 4 Coefficient of static friction vs contact time:
***Q* = 0.248 N/s, R_z = 0.9 μm, *T* = 20°C, *p* = 1.0 MPa, 1 = FM1, 2 = FM2, 3 = FM3, 4 = FM4**



The influence of each variable on static friction was studied in separate series of tests with the other variables and operational conditions constant.

RESULTS AND DISCUSSION

From the test results, the coefficient of static friction versus contact time, the rate of tangential loading, surface roughness, surface temperature, and pressure is given in **Figures 3** to **10**.

The investigations confirmed that the coefficient of static friction is a multiparametric function. In all tests an increase in static friction with the increase of stationary contact time was recorded (**Figure 4**). The increase in μ_s was between 7 and 15% in relation to the initial values, and was best represented by Derjagin's proposition:[5]

$$\mu_s = \mu_0 + c_1 \frac{t}{t + c_2}$$

where c_1 and c_2 are constants, presented in **Table 3** (see p.147).

The time-dependence of static friction can be explained by the fact that the real contact area is a function of time. The pressure on the real contact gives rise to plastic deformation and causes the material to creep. As a result, the characteristics of the contact change, as the load application time increases. the relation

Figure 5 Stick-slip movements showing the tangential loading rate influence on static friction for the following conditions:
steel – FM4 friction pair, R_z = 0.9 μm, T = 20°C, t = 30 s, p = 1.0 MPa
(a) Q = 0.124 N/s, (b) Q = 0.248 N/s, (c) Q = 0.620 N/s, (d) Q = 1.240 N/s

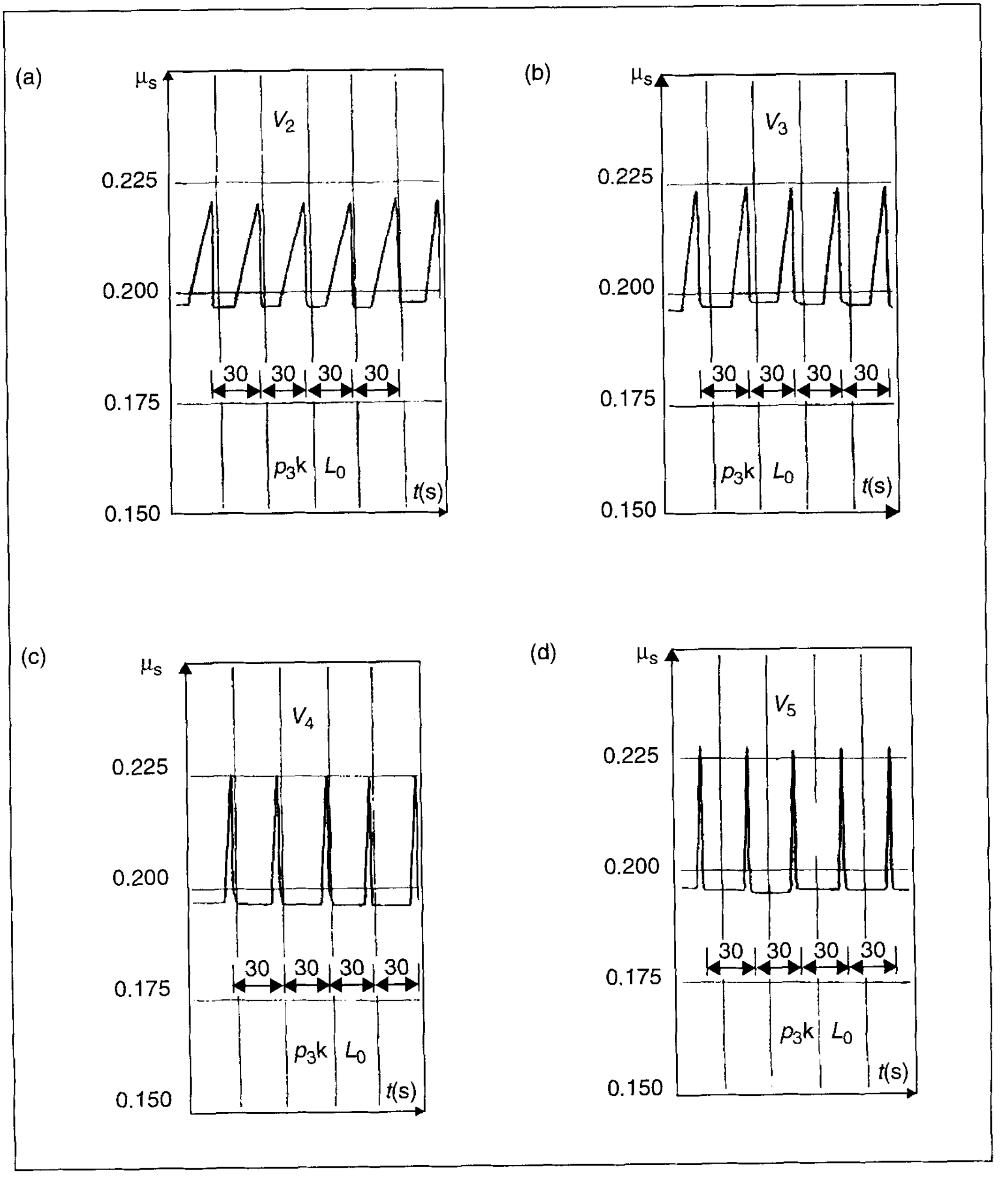


Figure 6 Coefficient of static friction vs rate of tangential loading:
t = 30 s, R_z = 0.9 μm, T = 20°C, p = 1.0 MPa, 1 = FM1, 2 = FM2, 3 = FM3, 4 = FM4

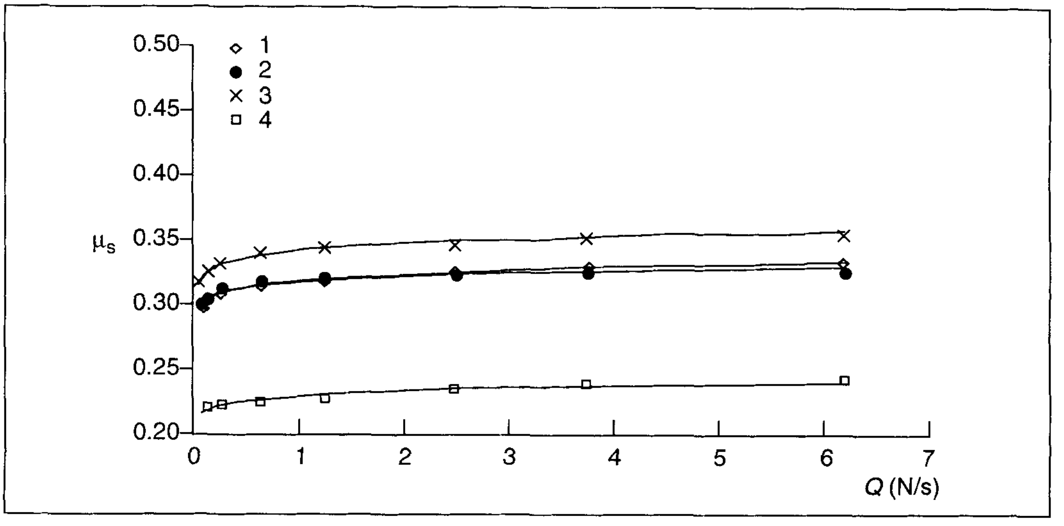
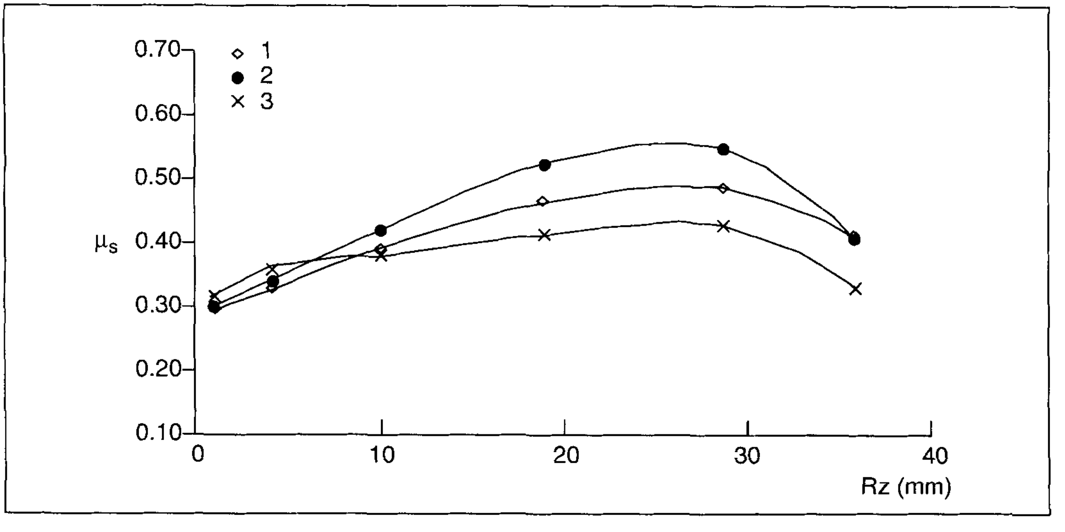


Figure 7 Coefficient of static friction vs counterspecimen roughness:
t = 120 s, Q = 0.248 N/s, T = 20°C, p = 1.0 MPa, 1 = FM1, 2 = FM2, 3 = FM3



between deformation of the contact and time is determined by the rheological properties of the materials in contact, surface roughness, surface temperature, and applied load.

In contrast to early reports,[6,7] the increase in the static friction coefficient was measured with the increase of the rate of

Figure 8 The recording of stick-slip movement showing the surface temperature influence on static friction for the following conditions: steel – FM3 friction pair, t = 120 s, Q = 0.248 N/s, R_z = 0.9 μm, T = 30-240°C.

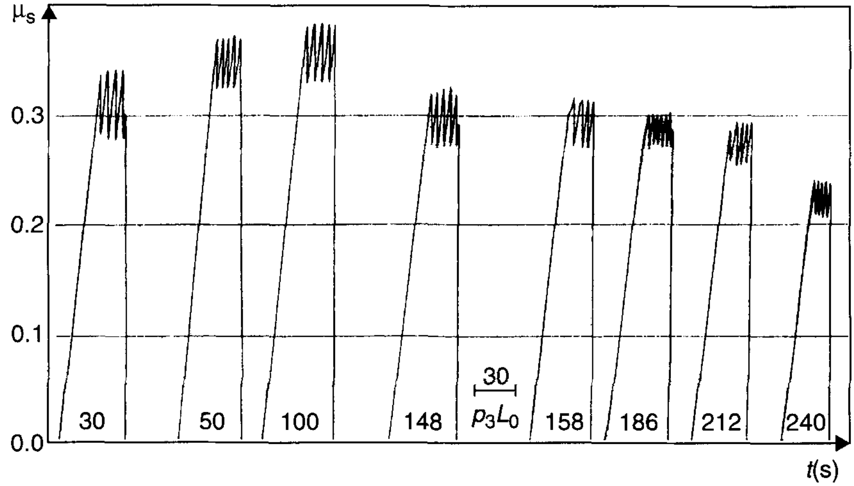
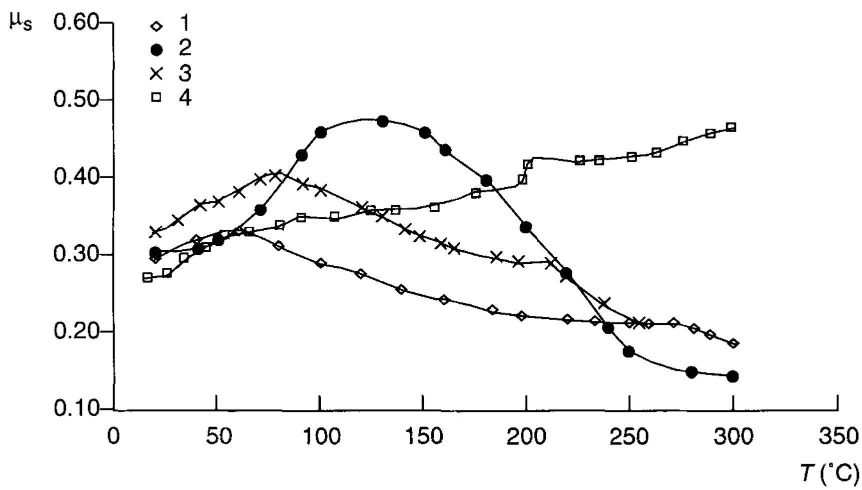
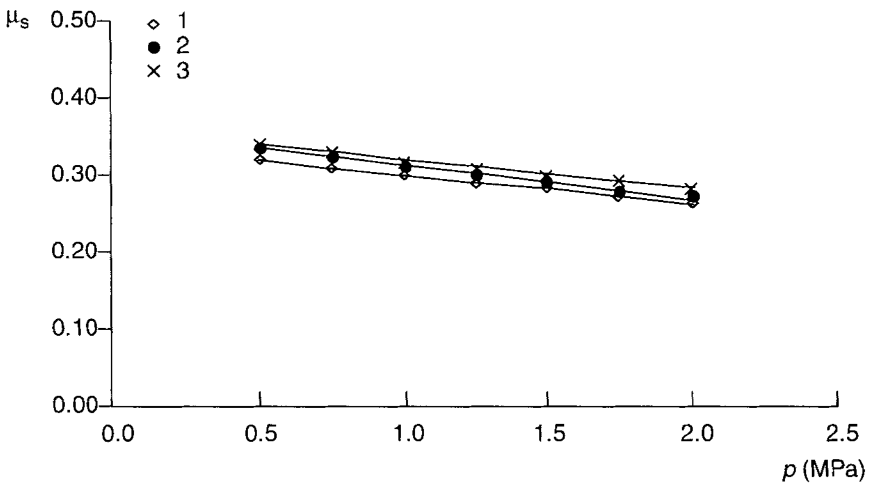


Figure 9 Coefficient of static friction vs surface temperature: t = 120 s, Q = 0.248 N/s, R_z = 0.9 μm, p = 1.0 MPa, 1 = FM1, 2 = FM2, 3 = FM3, 4 = copper



tangential loading (**Figures 5** and **6**). The rate of tangential loading Q has an effect on μ_s similar to that of the contact time t.

Figure 10 Coefficient of static friction vs pressure:
t = 120 s, Q = 0.248 N/s, R_z = 0.9 μm, T = 20°C, 1 = FM1, 2 = FM2, 3 = FM3



An equation similar to Derjagin's was applied in order to present analytically the function between the coefficient of static friction and the rate of tangential loading:

$$\mu_s = \mu_0 + c_1 \frac{Q}{Q + c_2}$$

where c_1 and c_2 are constants (presented in **Table 4**).

During the course of the investigation, the surface roughness showed a significant influence on the static friction coefficient (**Figure 7**). For industrial practice, this means that the running-in and surface layer formation processes influence static friction. Incorporation of these processes along with the third-body formation process, into the modelling procedure of static friction in brakes, is currently in progress.

The surface temperature effect on the coefficient of static friction was found to be different for each material tested (**Figures 8** and **9**). The changes of static friction with temperature were controlled by the mechanical properties of the friction materials, such as hardness and plasticity, and by chemical degradation of the materials at temperatures above the critical temperature. In this relatively simple experiment, it is possible to establish the critical temperature for any friction material in which the coefficient of

Table 3 Constants for Derjagin's equation

	Constants		
Materials	μ_0	c_1	c_2
FM1	0.2922	0.03389	39.31
FM2	0.2980	0.0345	114.10
FM3	0.3020	0.0561	33.86
FM4	0.2162	0.0366	161.97

Table 4 Constants for μ_s vs. Q function

	Constants		
Materials	μ_0	c_1	c_2
FM1	0.2964	0.0416	1.0743
FM2	0.2906	0.0322	0.1790
FM3	0.3118	0.0429	0.3482
FM4	0.2201	0.0318	3.5627

static friction μ_s drops below the acceptable level for a certain application.

In order to show that organic binders (synthetic rubber and phenolic resin) are the main sources for such significant static friction fluctuation as a function of surface temperature, additional tests were carried out with a copper slider under identical conditions as previously (**Figure 9**). Each material behaves differently, because their binders, chemical composition, and proportions in wt.% are different (**Table 1**). In the first phase, starting from an ambient temperature of 20°C, the three friction materials increased their static friction (**Figure 9**): FM1 by 20% to a temperature of 60°C, FM2 by 55% to a temperature of 130°C, and FM3 by 23% to a temperature of 80°C. This phase might be explained by a softening of the material's binders and increase of the real area of contact, hence stronger adhesion interaction between the surfaces, and perhaps also by more mechanical interlocking between the asperities as a result of the materials' creep. Each material has its own optimum temperature corresponding with the highest combined deformation and adhesion components of static friction.

CONCLUSIONS

At temperatures above the optimum, friction materials undergo mechanical and thermal transformation and destruction, including evaporation, melting, pyrolysis, cracking, and oxidation.

Testing the static friction characteristics for brake friction couples is a useful supplement to dynamic friction testing, and should be a normal part of the evaluation process of complex friction materials.

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