

Effect of Directional Surface Finish of Brake Discs on Friction Behavior During Running-in

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ABSTRACT

This paper focuses on the interaction in friction behavior between the surface texture of brake discs, rotational directions in braking operations and metal-cutting process, and friction materials with different degrees of aggressiveness. A factorial experiment for front brake discs was conducted by combining eight discs with directional surface finishes, two rotational directions, and two NAO friction materials on a brake dynamometer. The author analyzed several test results, such as the friction coefficients, disc wear, roughness, and the correlation between them. An assumed mechanism describing the friction behavior is discussed using the experimental results and by introducing the contribution of the aggressiveness and adhesiveness to the friction and confirmed by the test results.

INTRODUCTION

A brake system performs the most significant function from among those of automobiles; driving, steering, and stopping. Modern automobiles use friction brakes as their service brake. A disc brake system, which is a typical friction brake, converts the kinetic energy of a running vehicle into heat and decelerates the vehicle by using the friction created between a disc and the pads. Brake pads and linings are generally designated as friction materials, but a disc and pads pair is necessary to produce friction. Accordingly, a brake disc is also a friction material.

The surface texture of a brake disc may significantly affect the braking effectiveness of a vehicle in the early stages of use, which is called running-in. There are various processes for finishing the friction surfaces of a brake disc, such as grinding, turning, milling, and roller-burnishing [1]. In the roller-burnish process, a roller or a pair of rollers provides

plastic deformation to the asperities of the turning-finished surfaces and smoothens their roughness.

Brake discs usually turn in one rotational direction in their finishing process, and have a directional tool mark in a centripetal spiral. They, however, are used in two rotational directions even if a vehicle moves forward, since they are mounted to both the left-hand (LH) and right-hand (RH) wheels on a vehicle. This may affect the friction behavior during running-in. In the first case, the rotational direction of a disc against the brake pads on a vehicle is the same as that against the cutting tool in the turning process. On the other hand, the rotational direction against the brake pads is opposite that against the cutting tool. Roller-burnishing as well as turning are directional finishes. The directional surface textures of brake discs finished by turning or additional roller-burnishing may cause this directional interaction to become more severe than those by grinding, and in some cases may cause a brake pull issue or poor braking effectiveness [2].

The author et al. presented a paper at the SAE 2004 Brake Colloquium discussing the effect of the surface texture of brake discs on the friction behavior during running-in [3]. Various friction pairs were tested combining the brake discs finished by roller-burnishing and grinding and five friction materials including non-asbestos organic (NAO) and low-steel materials. Some NAO materials largely affected the difference in friction behavior between the surface textures of the disc and the rotational directions, while low-steel material had less effect.

The effects of the surface texture of brake discs on the friction behavior have recently become more significant. One reason is that large diameter discs have become popular for vehicles pursuing better braking performance. They are

designed to maintain a consistent braking performance under severe conditions, such as braking from extremely high speeds, and accordingly the braking loads in daily use are relatively small compared to them. Another reason is that the sales volume of hybrid and pure electric vehicles continues to increase. They are equipped with regenerative braking and their friction brakes work less than vehicles driven by conventional internal-combustion engines. As a result, the running-in periods for these vehicles, such as the high performance, hybrid, and pure electric vehicles, have been extended and it takes longer for the contact surfaces of a brake disc and the pads to suitably wear down, match each other, and, produce stable friction. It is important for foundation brakes to have a consistent braking performance, even though sophisticated electronically controlled brake systems can compensate for the effects of the surface texture of the brake discs on braking effectiveness.

The effects of the surface texture on the friction behavior during running-in were studied again when taking the background described above into consideration. The paper focused on the interaction in friction behavior between the surface finish and rotational directions. A factorial experiment for a front brake disc was conducted on a brake dynamometer and the test results were then analyzed. An assumed mechanism describing the friction behavior was discussed based on the experimental results and by introducing the contribution of the aggressiveness and adhesiveness to the friction and confirmed by the test results.

DESIGN OF EXPERIMENT (DOE)

SPECIFICATION OF DISC AND PAD

A factorial experiment for a front brake disc was designed by combining eight discs with the directional surface textures, two NAO friction materials (with different degrees of aggressiveness), and two rotational directions (LH and RH for a vehicle) on a brake dynamometer. The brake disc was 320 mm in diameter and 28 mm thick. [Table 1](#) lists the finishing conditions of the eight samples with different surface textures. The turning-finished discs were finished under the four conditions described in [Table 1](#), which were a combination of insert nose radius and feed rate. Roller-burnished discs were additionally burnished by the rollers after turning under the same conditions for the four turning-finished discs. [Table 1](#) also enumerates the arithmetical mean roughness (Ra) of the eight surface textures, which is an average of the inboard and outboard values at the effective radius.

Table 1. Specifications of brake disc samples

Turning Condition		Turning Finish		Roller Burnish	
Insert Nose Radius (mm)	Feed (mm/r)	Disc No.	Ra (μm)	Disc No.	Ra (μm)
1.6	0.16	T1	1.29	R1	0.95
1.6	0.30	T2	2.78	R2	1.36
0.8	0.16	T3	1.82	R3	0.94
0.8	0.30	T4	3.21	R4	2.07

[Figure 1](#) illustrates the material ratio (Abbott-Firestone or bearing area) curves of the roughness profile for two discs finished by turning (T2) and roller-burnishing (R2). This figure clearly indicates that the roller-burnishing gave plastic deformation to the asperities of a turning-finished surface and smoothed its roughness.

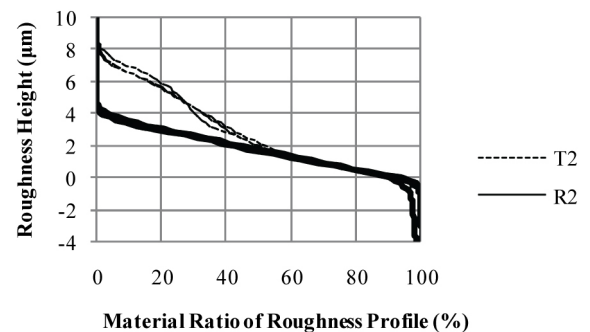


Figure 1. Material ratio curve for typical discs finished by turning (T2) and roller-burnishing (R2)

Two NAO friction materials, A1 and A2, were picked from five available materials including NAO and low steel tested in the former study by the author et al [3]. Friction material A1 caused a large difference in friction behavior between the discs with different surface textures and rotational directions; while material A2 caused only a slight difference since it is more aggressive and caused more disc wear than A1. Accordingly, the friction pairs with the eight discs and friction material A1 were tested in two rotational directions, LH and RH for a vehicle, for examining the effects of the rotational direction on the friction behavior. The friction pairs with the A2 material, on the other hand, were tested in only one direction for LH.

BRAKING SCHEDULE

JASO C 406 [4] designates a dynamometer test procedure for the braking devices of passenger cars. However, only the burnish braking listed in [Table 2](#) was repeated, since this experiment was designed for studying the effects of the disc surface texture on the friction behavior during running-in corresponding with accumulated brake applications under constant conditions. The brake accumulation was set at 100

brake applications, which was assumed to be long enough to study the friction behavior at the early stages of running-in.

Table 2. Braking conditions

	Specifications
Vehicle Speed	60 km/h to 0
Deceleration	2.94 m/s ²
Braking Interval	IBT Control
Initial Braking Temperature (IBT)	130°C

A regenerative brake reduces the loading energy of friction brakes. Accordingly, the dynamometer inertia needs to be reduced when simulating the usage of friction brakes in hybrid or pure electric vehicles. The inertia for this study, however, was kept at the same values as that for a conventional vehicle in order to avoid an extremely long test period, which was necessary to conduct 24 test runs in total.

PARAMETERS OF CONCERN

Analyzing the friction behavior requires various parameters on a wide range of scales. Table 3 lists the parameters concerned in this study. The parameters, excluding those with asterisks (*), were measured and analyzed for the scales listed in Table 3. The mean friction coefficients were calculated as an average based on time. The in-stop friction coefficients were recorded at the prescribed intervals but not analyzed for the current paper. The parameters for the surface texture, such as the material ratio curve and reduced peak height (Rpk), are defined in the industrial standards such as JIS [5] and ISO.

Table 3. Scale of space and time parameters

	Space and Mass	Time
Macro	Disc diameter* Disc thickness* Pad wiping width* Disc wear	Vehicle life* Running-in period Mean friction coefficient
Micro	Arithmetical mean roughness Material ratio curve Reduced peak height Two-dimensional wear Plastic metal flow Metal pick-up content	In-stop friction coefficient

TEST RESULTS

MEAN FRICTION COEFFICIENTS

Figures 2,3,4,5 illustrate the behaviors of mean friction coefficients over the accumulated brake applications for friction material A1. All the figures exhibit a friction coefficient peak to some extent at around 50 to 100 brake applications. The turning-finished discs in Figs. 2 and 3

exhibit a large variance in the number of brake applications for producing the friction coefficient peaks, while the roller-burnished discs in Figs. 4 and 5 exhibit a small variance in the timing for the friction peaks but a large variance in the friction coefficients in the final stage.

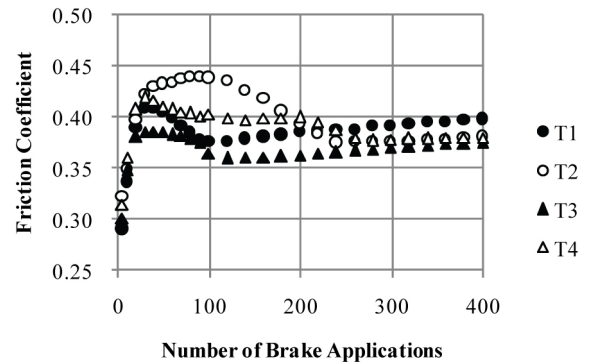


Figure 2. Friction coefficient of turning-finished discs and friction material A1 for LH

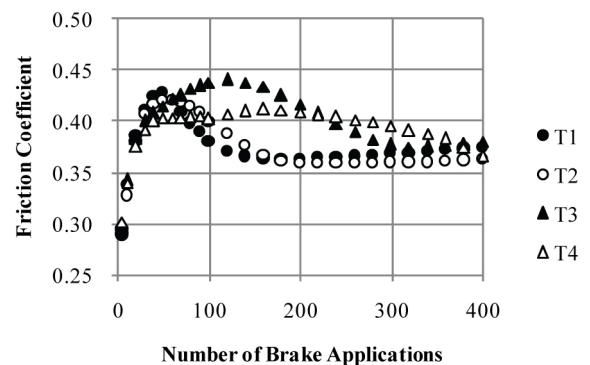


Figure 3. Friction coefficient of turning-finished discs and friction material A1 for RH

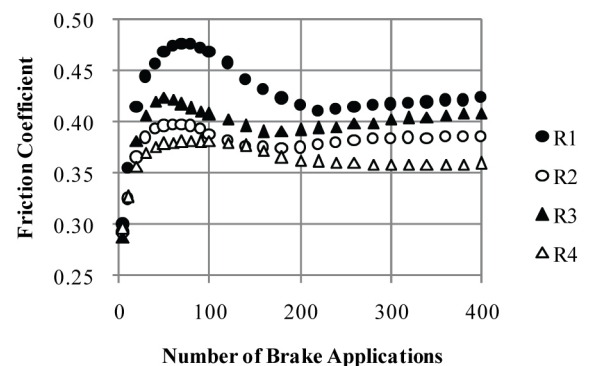


Figure 4. Friction coefficient of roller-burnished discs and friction material A1 for LH