Development of the Braking Performance Evaluation Technology for High-speed Brake Dynamometer

Min-Soo Kim

***Abstract*—** Brake system of railway vehicles has a crucial role for the safety as well as riding quality of passengers. And the technology of braking performance evaluation has been generally developed with technology of speed improvement of railroad vehicle. Brake dynamometer is designed to simulate the brake characteristic of the high speed train, and has a function of record the data which can be reproduced and help to analyze and compare the experimental object, and also is used to develop and test the brake systems. In this paper, we tried to test braking friction materials (disc brake and block brake) for the high speed rotation which is in a current use commercially, and its results will be introduced by means of arranging of a braking performance test evaluation technology on braking friction materials of railway vehicle using the high speed dynamometer (400 [km/h]-grade).

***Keywords*—**Brake Dynamometer, Railway Vehicle, Friction Coefficients, Disc Brake, Block Brake.

I. Introduction

THE technology of braking performance evaluation has been generally developed with technology of speed improvement of railroad vehicle. Nowadays, test procedure and evaluation standard from technology of test evaluation on single braking parts to controlling of the braking system, running testing of integration performance and its evaluation technology are systematically established[1]~[3].

The test evaluation technology has also been developed with study for localization development of braking parts in the domestic market. The test evaluation techniques has accumulated with full scaled dynamometer that its level is below 200 [km/h] in the performance testing fields of friction materials, KRS(Korean Railway Standards) presents about coefficient of friction, abrasion and so on as a test evaluation standard.

Dynamometer is a device for measuring the torque, force, or power available from a rotating shaft. The shaft speed is measured with a tachometer, while the turning force or torque of the shaft is measured with a scale or by another method. The first dynamometer was designed to measure the brake horsepower of a motor. This invention was the work of an engineer, Gaspard. He invented the Prony Brake Dynamometer in 1821 in Paris. Variations of this dynamometer are still in use today [4][5].

Brake dynamometer is designed to simulate the brake characteristic of the high speed train, and has a function of record the data which can be reproduced and help to analyze and compare the experimental object, and also is used to develop and test the brake system.

Fig.1 the 400 [km/h] grade high-speed brake performance tester (brake dynamometer)

Recently, high-speed braking performance tester, which is top speed 400 [km/h]-grade is introduced. And then it became able to perform the test of developed braking parts in KRRI (Korea Railroad Research Institute). Therefore we tried to test braking friction materials (disc brake and block brake) for the high speed rotation which is in a current use commercially, and its results will be introduced by means of arranging of a braking performance test evaluation technology on braking friction materials of railway vehicle using the high speed dynamometer (400 [km/h]-grade).

This paper is organized as follows. Section 2 overviews a brake dynamometer. Section 3 describes the experiment environment for the tread brake and the disc brake. Section 4 shows the experiment results in various initial braking speed condition when the block brake and disc brake are applied. The main conclusions are then summarized in section 5.

Manuscript received September 2, 2011: Revised version received December 5, 2011.

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II. Overviews of the Brake Performance Tester

A dynamometer consists of the following main elements.

-The drive-train consists of the following elements: motor, interchangeable flywheels and brake disc. The flywheels and brake disc is matched to the part number to be tested.

-The test bed consist of the following elements: caliper & adapter, power transfer axle, load bearing arm and load cell to calculate the braking force.

In general, dynamometers are widely used to simulate the brake performance of the railway vehicle. Brake dynamometer is designed to simulate the brake characteristic of the high speed train, and has a function of record the data which can be reproduced and help to analyze and compare the experimental object, and also is used to develop and test the brake system.

The expected effect and practical scheme of the brake dynamometer are followings:

-Development of the brake, disc-pad, wheel and brake system of the high-speed & conventional train

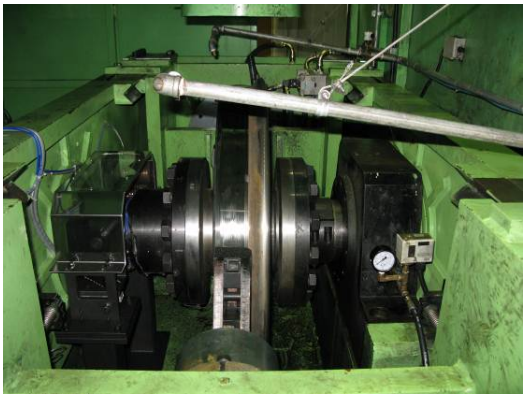
-Test and performance evaluation of the brake system of the high-speed & conventional train with the international standard

-Performance and certification test of the brake system of the manufactured high speed train

Table 1 shows the main features of the brake dynamometer.

Table 1 main performance of the brake dynamometer

Max. drive power	397[kW](540[HP])
Max. drive torque	2,527[Nm]
Max. brake torque	25,000[Nm]
Pressure Brake	6,000 [N] x 2
Flywheel Inertia	Max./Min. 1900[kg•㎡]/400[kg•㎡]
Diameter of the test wheel	Φ700~1120[mm]
Acceleration time	(0~1500[rpm]) 2 min. 30 sec
Max. drive speed	2,500[rpm](400[km/h])



(a) the parts of block brake

(b) the parts of disc brake

Fig.2 brake performance dynamometer for high speed train

III. Performance Test of Block Brake

A. The Test Outline and Material

This test refers to friction material test about braking shoe (wheel-thread brake block) which is being applied in domestic KTX, it is an important procedure of braking shoe performance and safety evaluation. Braking tests were conducted on the basis of UIC Code (UIC541-4“Brakes-Brakes with composition brake blocks") and shape of braking shoe was shown in the Fig.3 [17].

The material of braking shoe used in this test is composed of organic composition and major properties include 2.6 [g/cm3] in density 0.92 [kJ/kgK] in specific heat capacity.

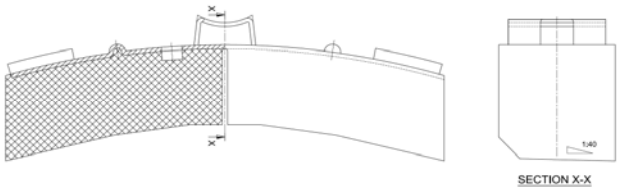


Fig.3 the shape of the brake shoe for the block brake

B. Test Method

The test for measuring the friction coefficient was carried out with reference to UIC 541-4 provisions, tests were conducted after obtaining more than 80% friction surface of braking shoe through adequate pre-test (bedding) prior to the test.

We executed the test in accordance with various initial speed of braking respectively in order to grasp the characteristics of high-speed braking system. The test executed in order of 80, 120, 160, 200 [km/h] under air pressure force 16.6 [kN]. And in condition of air pressure force 5.9 [kN], the test also executed in turns of 80, 120, 160, 200, 250, 300 [km/h].

The actual braking tests as shown in Fig.4. Thermal band on the wheel thread is formed like this figure.

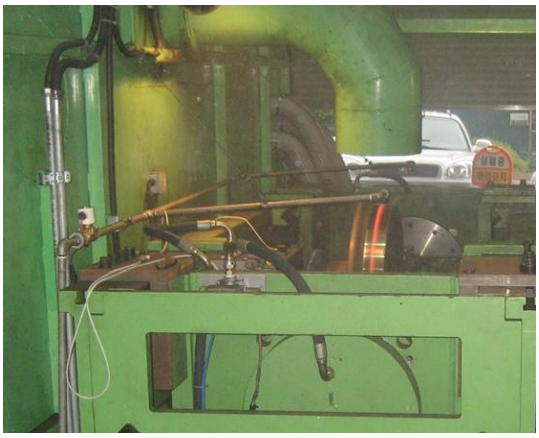


Fig.4 the shape of braking test and thermal band observed on the wheel when it is on braking

Table 2 dynamometer test program (block brake)

Air pressure force	Initial velocity	The number of tests
[kN]	[km/h]	Dry
16.6	80 120 160 200	01 02 03 04
5.9	80 120 160 200 250 300	05 06 07 08 09 10

IV. Performance Test of Disc Brake

A. The Test Outline and Material

This test is as a test for the brake disc pads, refers to a test to assess the safety by verifying the performance of the brake pad tests were conducted with reference to UIC specification (UIC541-3"Brakes-Disc brakes and their application-General conditions for the approval of brake pads"), braking pad is applied to the current KTX as the pad and the shape of the pad is shown in the Fig. 5 [16].

Material is composed of sintered metal, heat capacity and thermal conductivity is respectively 600 [J kg ℃], 25 [W m ℃].

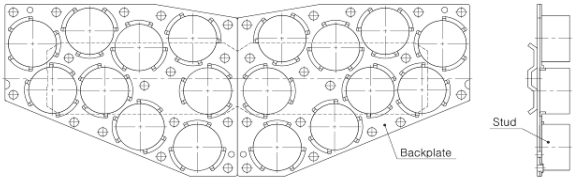


Fig.5 the shape of the brake pad for the disc brake

B. Test Method

The test for measuring the friction coefficient was carried out with reference to UIC 541-3 provisions, tests were conducted after obtaining more than 80% friction surface of braking pad through adequate pre-test (bedding) prior to the main test. The test was performed in braking initial temperature as 60 ° C.

We executed the test in accordance with various initial speed of braking respectively in order to comprehend the characteristics of high-speed braking system. In two kinds of conditions of air pressure force (two conditions: 15 and 22.5 [kN]), the braking test executed in the order of 120,160,200,300 km/h.

The actual braking tests look like this Fig.6, thermal band in the disc surface is formed like this figure and the surface morphology of speculated as the formation of hot spots was observed after braking stopping.

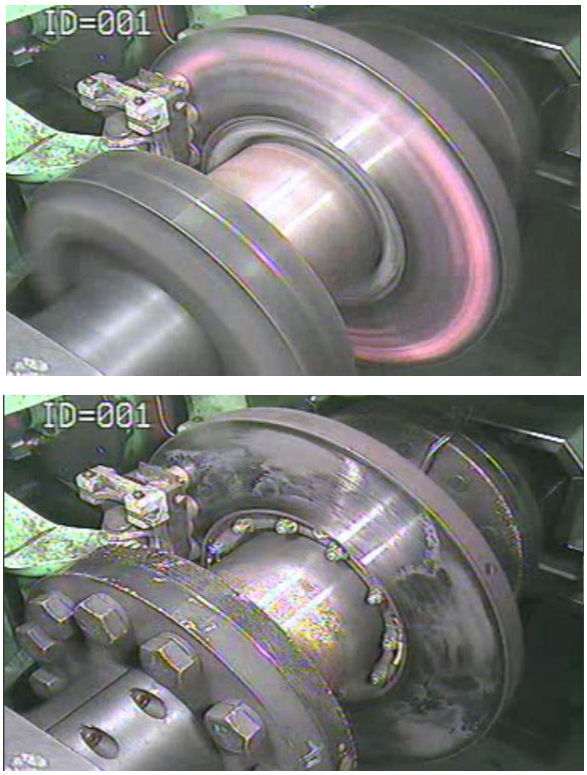


Fig.6 the shape of hot spot is observed when stopping, thermal band is observed when testing of braking disc

Table 3 dynamometer test program (disc brake)

Air pressure force	Initial velocity	The number of tests
[kN]	[km/h]	Dry
15	120 160 200 300	01 02 03 04

22.5	120 160 200 300	05 06 07 08

V. Test Results

A. Average Coefficient of Friction of Block Brake

The average coefficient of friction each initial speed of braking is shown in the table 4. The average coefficient of friction means the average value of the friction coefficient during braking; we found that higher initial braking velocity gets lower average coefficient of friction.

Table 4 results of the average coefficient of friction of brake shoe

No.	Speed (km/h)	Test Result (μ)	Max Temp (℃)	Remarks
1	80	0.311	60.3	
2	120	0.323	98.1	
3	160	0.299	123.8	
4	200	0.261	232.6	
5	80	0.307	74.7	
6	120	0.337	90.6	
7	160	0.384	221.5	
8	200	0.351	281.0	
9	250	0.308	210.5	
10	300	0.293	977.0	

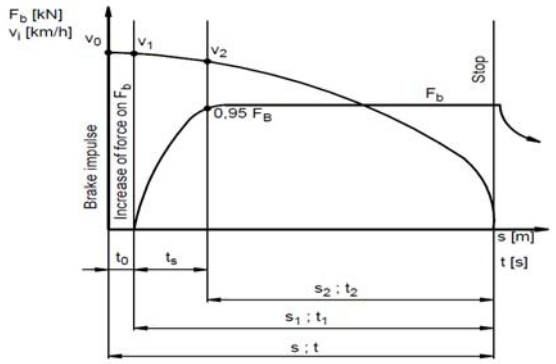


Fig.7 calculation of the instantaneous coefficient of friction and the average coefficient of friction

Fig. 7 shows the calculation method of the instantaneous coefficient of friction and the average coefficient of friction during braking time. v_1 means the speed at the beginning of the increase in force of F_b and v_2 denotes the speed at the time at which $F_b = 0.95 \cdot F_B$, where F_B represents the total nominal contact force per disc or per wheel.

The instantaneous coefficient of friction, which μ_a is determined in any instant of the braking by the ratio of total braking force F_t to total contact force F_b, is calculated as

$$\mu_a = \frac{F_t}{F_b} \tag{1}$$

And the average coefficient of friction μ_m, which is determined by integrating the instantaneous coefficient of friction from reaching 95% of the nominal contact force F_b of the friction coefficient over the braking distance S_2 as Eq. (2).

$$\mu_m = \frac{1}{S_2}\int_0^{S_2} \mu_a ds \tag{2}$$

B. The Instantaneous Coefficient of Friction of Block Brake

In general, friction coefficients were obtained ranging from 0.261 to 0.323 in 80-200 [km/h] speed in the condition of air pressure force 16.6 [kN].

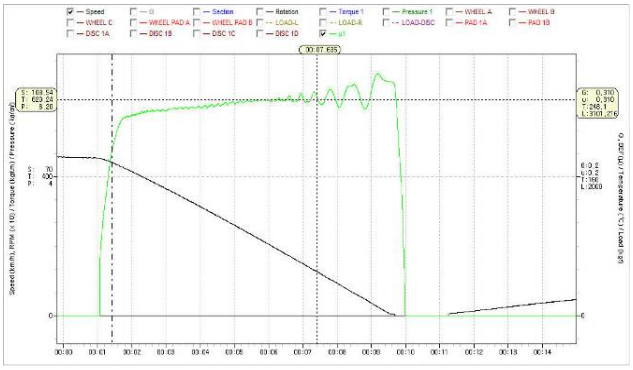


Fig.8 the change on instantaneous coefficient of friction in braking initial speed 80 [km/h] (at wheel contact force 16.6 [kN])

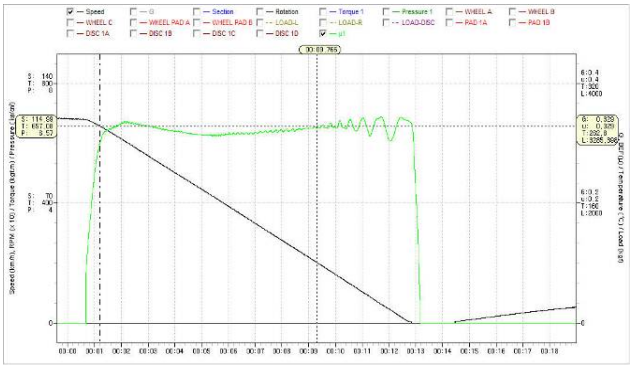


Fig.9 the change on instantaneous coefficient of friction in braking initial speed 120 [km/h] (at wheel contact force 16.6 [kN])

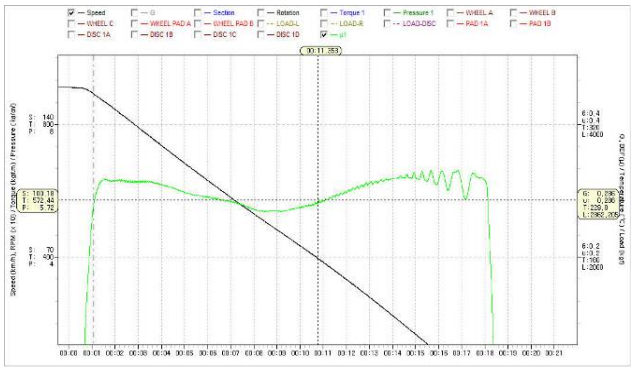


Fig.10 the change on instantaneous coefficient of friction in braking initial speed 160 [km/h] (at wheel contact force 16.6 [kN])

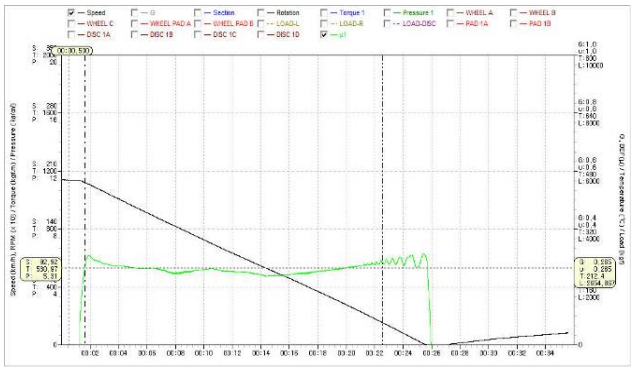


Fig.11 the change on instantaneous coefficient of friction in braking initial speed 200 [km/h] (at wheel contact force 16.6 [kN])

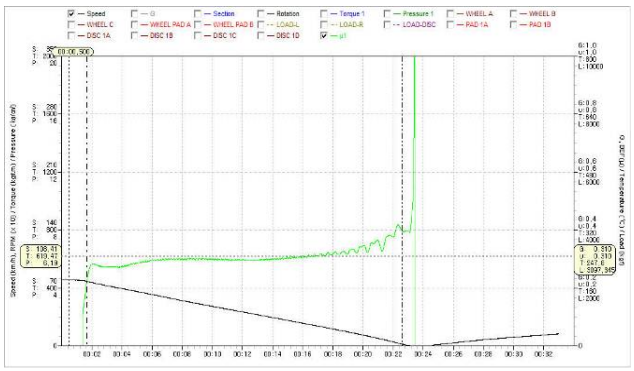


Fig.12 the change on instantaneous coefficient of friction in braking initial speed 80 [km/h] (at wheel contact force 5.9 [kN])

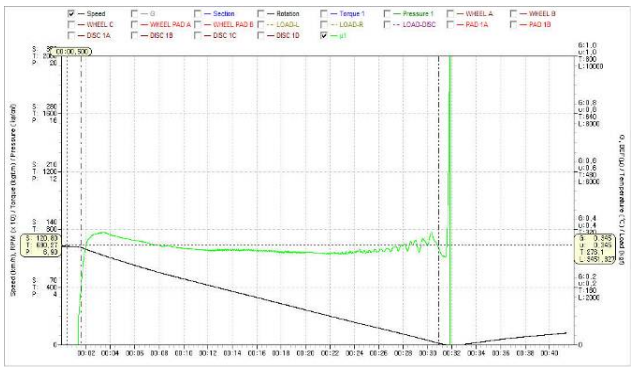


Fig.13 the change on instantaneous coefficient of friction in braking initial speed 120 [km/h] (at wheel contact force 5.9 [kN])

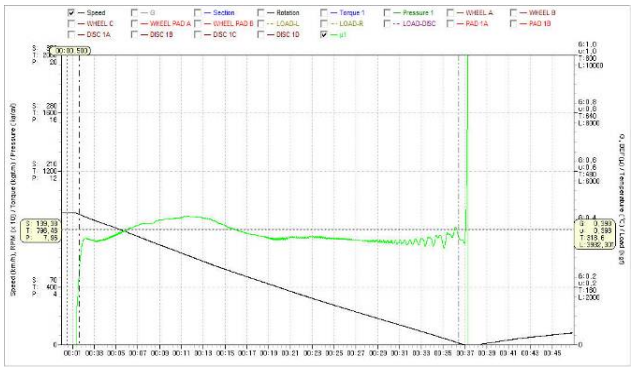


Fig.14 the change on instantaneous coefficient of friction in braking initial speed 160 [km/h] (at wheel contact force 5.9 [kN])

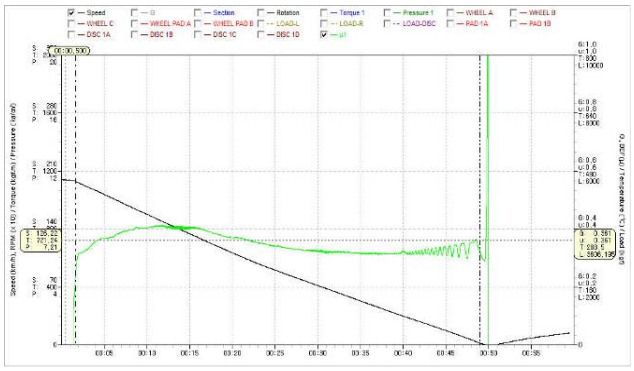


Fig.15 the change on instantaneous coefficient of friction in braking initial speed 200 [km/h] (at wheel contact force 5.9 [kN])

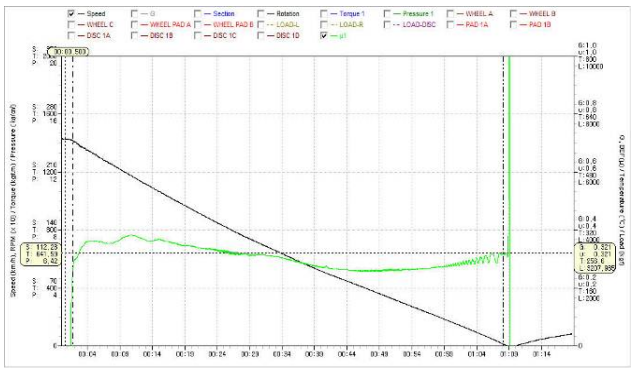


Fig.16 the change on instantaneous coefficient of friction in braking initial speed 250 [km/h] (at wheel contact force 5.9 [kN])

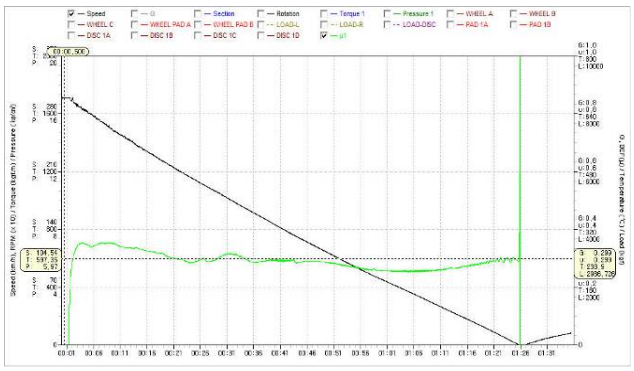


Fig.17 the change on instantaneous coefficient of friction in braking initial speed 300 [km/h] (at wheel contact force 5.9 [kN])

Friction coefficients were obtained ranging from 0.293 to 0.384 in the condition of air pressure force 5.9 [kN] (the air pressure force is lower than above condition), we can get the result that high friction coefficient was obtained in the condition of low air pressure force.

C. Average Coefficient of Friction of Disc Brake

The average coefficient of friction each initial speed of braking is shown in the table 5. The average coefficient of friction means the average value of the friction coefficient during braking, we found that the higher initial braking velocity gets, the lower average coefficient of friction gets typically in less than 200 [km/h]. Similar trend were presented in condition of disc contact force 15 [kN] and 22.5 [kN],

Average coefficient of friction like 0.344 to 0.412 are shown in braking initial speed less than 200 [km/h].

The average coefficient of friction each braking initial velocity was obtained from data analysis of braking characteristics, detailed results of the instantaneous coefficient of friction of disc brake were shown in the following figures.

Table 5 results of the average coefficient of friction of brake shoe

No.	Speed (km/h)	Test Result (μ)	Max Temp (℃)	Remarks
1	120	0.381	110.7	
2	160	0.451	135.3	
3	200	0.462	191.4	
4	300	0.360	249.3	
5	120	0.344	107.4	
6	160	0.380	157.0	
7	200	0.412	200.0	
8	300	0.330	257.4	

D. The Instantaneous Coefficient of Friction of Disc Brake

In general, friction coefficients were obtained ranging from 0.330 to 0.412 in 120~300 [km/h] speed in the condition of air pressure force 22.5 [kN].

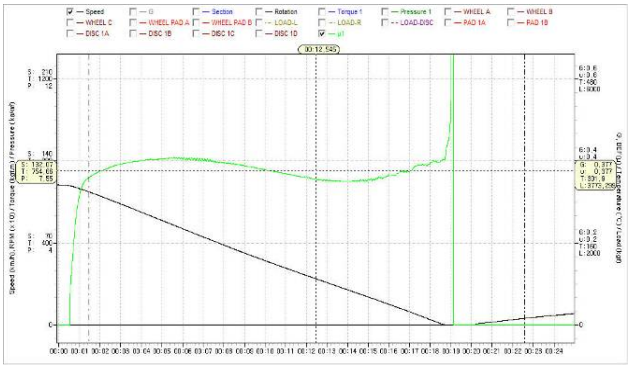


Fig.18 the change on instantaneous coefficient of friction in braking initial speed 120 [km/h] (at disc contact force 15 [kN])

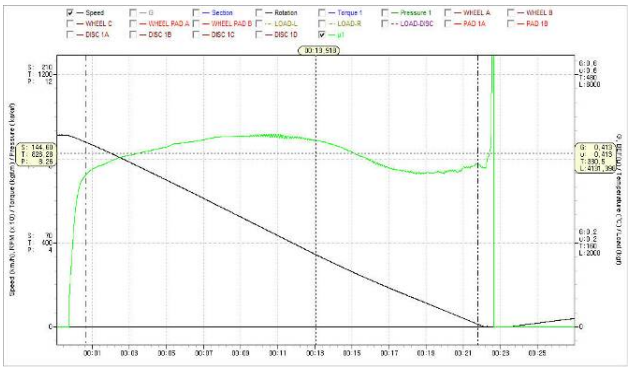


Fig.19 the change on instantaneous coefficient of friction in braking initial speed 160 [km/h] (at disc contact force 15 [kN])

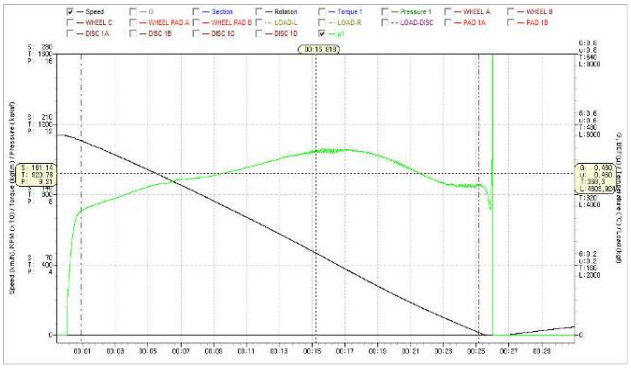


Fig.20 the change on instantaneous coefficient of friction in braking initial speed 200 [km/h] (at disc contact force 15 [kN])

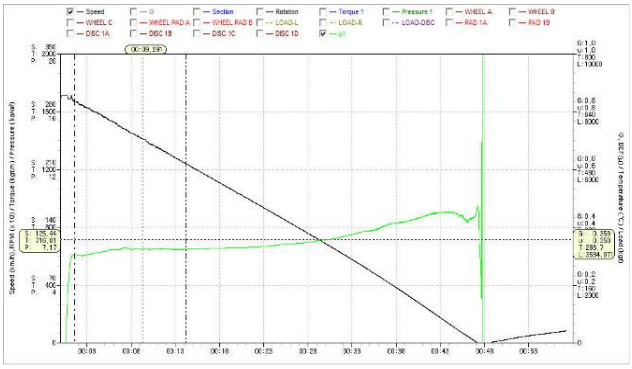


Fig.21 the change on instantaneous coefficient of friction in braking initial speed 300 [km/h] (at disc contact force 15 [kN])

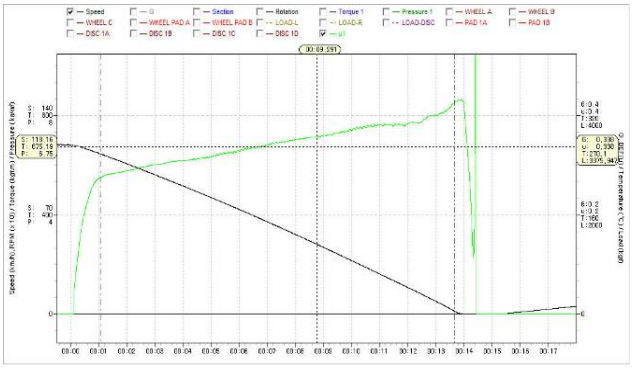


Fig.21 the change on instantaneous coefficient of friction in braking initial speed 120 [km/h] (at disc contact force 22.5 [kN])

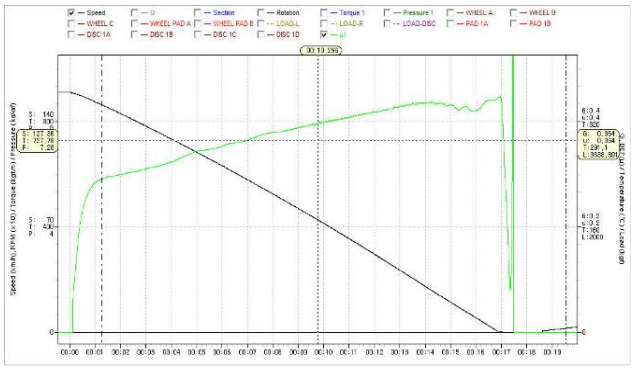


Fig.22 The change on instantaneous coefficient of friction in braking initial speed 160 [km/h] (at disc contact force 22.5 [kN])

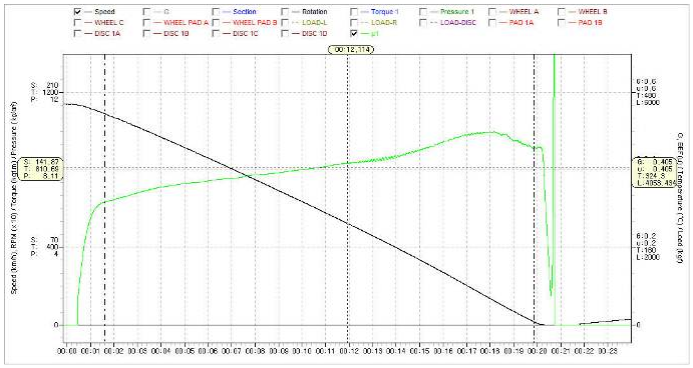


Fig.23 The change on instantaneous coefficient of friction in braking initial speed 200 [km/h] (at disc contact force 22.5 [kN])

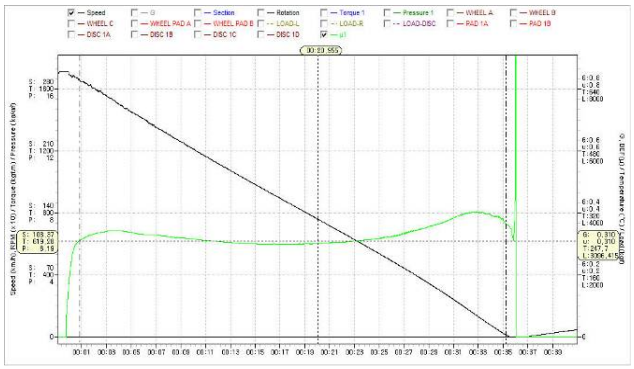


Fig.24 the change on instantaneous coefficient of friction in braking initial speed 300 [km/h] (at disc contact force 22.5 [kN])

Friction coefficients were obtained ranging from 0.360 to 0.462 in the condition of air pressure force 15[kN] (the air pressure force is lower than above condition), we can get the result that high friction coefficient was obtained in the condition of low air pressure force.

VI. Conclusion

In this paper, measurement test of coefficient of friction was introduced about braking shoe and disc pad for development of performance test technology using 400 [km/h]-grade high-speed braking performance tester. And test standard of braking friction material using high-speed tester was summarized.

Also, braking characteristics of friction material on the top speed 300 [km/h] were considered, average and instantaneous coefficient of friction was obtained.

It is possible to secure performance test technology for conducting performance test of the future new braking based on the result of this study. It have been identified that can be utilized not only evaluation on friction characteristics of braking friction materials but also braking disc or development of wheel.

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