Determination of the International Friction Index (IFI) using the Circular Texture Meter (CTM) and the Dynamic Friction Tester (DFT)

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The Circular Texture Meter (CTM) has been developed as a device to measure macrotexture of pavements. The CTM has a CCD laser displacement sensor mounted on an arm which rotates on a circumference of 142 mm radius and measures the texture with approximately 0.9 mm sampling interval. The profile is measured on the same circumference that coefficient of friction is measured with a Dynamic Friction Tester (DFT).

In this study, the macrotexture of 21 asphalt concrete pavements and 14 portland cement concrete pavements were measured by the CTM and the results have been compared with those of the Sand Patch Test and the Sand Track Test. It was found that there is a good correlation between the Mean Profile Depth (MPD) as measured by the CTM and the Mean Texture Depth (MTD) by the Volumetric Method ("Sand Patch Test"). The study also shows that the International Friction Index (IFI) can be calculated from the MPD determined by the CTM and the coefficient of friction at a slip speed of 20 km/h measured by the DFT.

Key words : Circular Texture Meter, Sand Patch Test, Macrotexture, MPD, MTD, Dynamic Friction Tester, IFI

1. Preface

The tire pavement friction of roads and runways plays an important role in the safety of vehicles and aircraft travelling on them. Many devices and methods have been developed around the world to measure the friction and texture of paved road surfaces. [1)] The International Experiment by PIARC was conducted in September and October 1992 in Belgium and Spain for the purpose of comparing and harmonizing the test results obtained from various testing devices. [2)] As a result the International Friction Index (IFI) was developed. [3)] The IFI consists of a Friction Number (F60) and a Speed Constant (Sp) and is reported as IFI (F60, Sp). Once the IFI is obtained, it is possible to calculate Coefficient of Friction F(s) at any speed S.

The Friction Number F60, one of the IFI parameters, indicates friction at a slip speed of 60km/h. There are several methods to measure friction. One is to directly measure the coefficient of friction between tires and road surfaces. [4)] Another is to measure the coefficient of friction between rubber pads and road surfaces as is the case for the DFT [5)] and the British Pendulum Tester (BPT). [6)] On the other hand, the Speed Number (Sp) indicates the speed dependency which is calculated from the macrotexture of the pavement. Macrotexture is defined as the components of the profile which have wavelengths of 0.5 - 50mm [7)] and it is measured by devices such as the Laser Profilometer, the Volumetric Method and Outflow Meter. Before the development of the CTM it was not possible devices to measure the macrotexture at the same spot as the coefficient of friction is measured even though the macrotexture of

pavements is an important factor that determines the speed dependency of friction coefficient.
The Circular Texture Meter (CTM) is a profilometer that measures macrotexture profiles on a circular track of 142 mm radius using a CCD laser displacement sensor. The CTM is a lightweight and portable device and is able to measure macrotexture on the same circumference where the DFT measures coefficient of friction. In addition it is able to measure macrotexture within a short time. In this study, measurements by the CTM on various kinds of asphalt pavement and concrete pavement are compared with the results of the conventional Sand Patch Test. At the same time the IFI (F60, Sp) was calculated from the measurements by the CTM and the DFT. Further, the relationship between the speed dependency of friction obtained from the test result of the DFT and the Speed Number Sp obtained from the CTM was determined.

2. International Friction Index (IFI)

PIARC has developed Friction - Slip Speed Model (PIARC Model) as shown in Figure 1 and determined Golden Values of Speed Number (GS) and Golden Value of Friction (GF60) based on the results of International Experiment. The following steps are taken to calculate value Sp of GS and the value F60 of GF60 from the macrotexture and friction measurement devices that participated in the International Experiment:

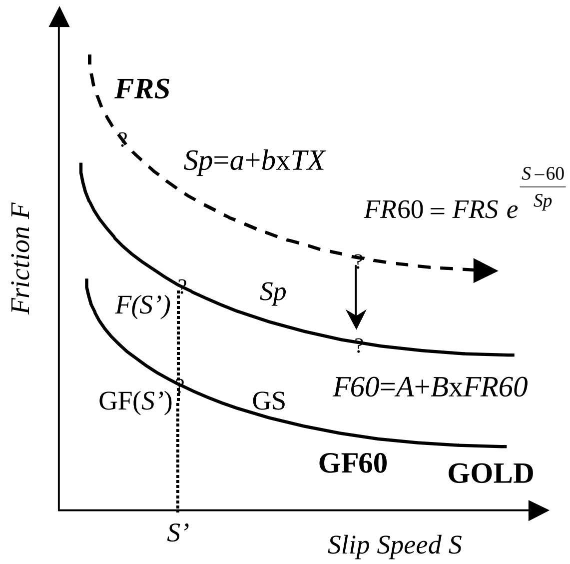


Figure 1. PIARC Model

1. Calculate Sp with using equation (1) from a measurement of macrotexture (TX).

$$Sp = a + b \times TX \qquad (1)$$

In this equation a and b are constants for a specific macrotexture device and TX is the macrotexture parameter reported by the device.

2. The friction measurement reported by the friction measurement device at Slip Speed S is converted to its value at of FR60 at a Slip Speed of 60 km/h using equation (2).

$$FR60 = FRS\ e^{(S-60)/Sp} \qquad (2)$$

In this calculation S is the slip speed of the measurement and FRS is the friction reported by the measurement at a Slip Speed of S.

３. Calculate Friction Number F60 with formula (3).

$$F60 = A + B \times FR60 \qquad (3)$$

In this calculation A and B are constants for a specific friction measurement devices.

When IFI is determined the value F(S') at a any slip speed S' can be calculated using equation (4).

$$F(S') = F60\ e^{(S'-60)/Sp} \qquad (4)$$

3. Description of the Tests

Test Pavements

In this study, the macrotexture and the coefficient of friction of 21 asphalt concrete pavements and 14 Portland cement concrete pavements were measured. The asphalt pavements include dense-graded asphalt mixtures, dense gap-graded asphalt mixtures, fine-graded asphalt mixtures, coarse-graded asphalt mixtures, drainage pavements and other pavements with micro surfacing and grooving treatments. The concrete pavements included PCC pavements with grooving and shot-blast treatments and PCC pavement with no treatment.

Macrotexture Measurement

In this study, Macrotexture is measured using the Sand Patch method, the Japanese Sand Track method and the CTM.

The Sand Patch Test is a method that measures the diameter of a sand circle on road surface created by spreading a known volume sand in a circle on the surface and the MTD (Mean Texture Depth) is obtained by dividing the sand volume by the diameter of the circle.[8)] The Japanese Sand Track Test is a Japan's original measurement method that measures the MTD from the dimension of a rectangular shaped sand of 5 cm width created by a sand spreader.[9)]

The CTM shown in Picture 1 measures 40 cm x 40 cm x 27 cm and weighs 13 kg. As shown in Picture 2, the CCD laser displacement sensor is mounted on an arm that rotates on a circumference of 142 mm radius and measures macrotexture on the same circular track where the DFT measures the coefficient of friction. When the measurement is started the CCD Laser Displacement Sensor rotates. Measured values of profile height are read into a personal computer through RS232C cable after one rotation of the CCD Laser Displacement Sensor. The macrotexture of pavement can be measured in a very short time as the time of measurement and data reading is only 40 seconds. Also, set-up, measurement, display of measurement profile of CTM and calculation of MPD, which will be described later, can easily be done with the exclusive software working on Windows 98.

Picture-1 General View of Circular Texture Meter (CTM)

Picture-2 Laser Displacement Sensor of CTM

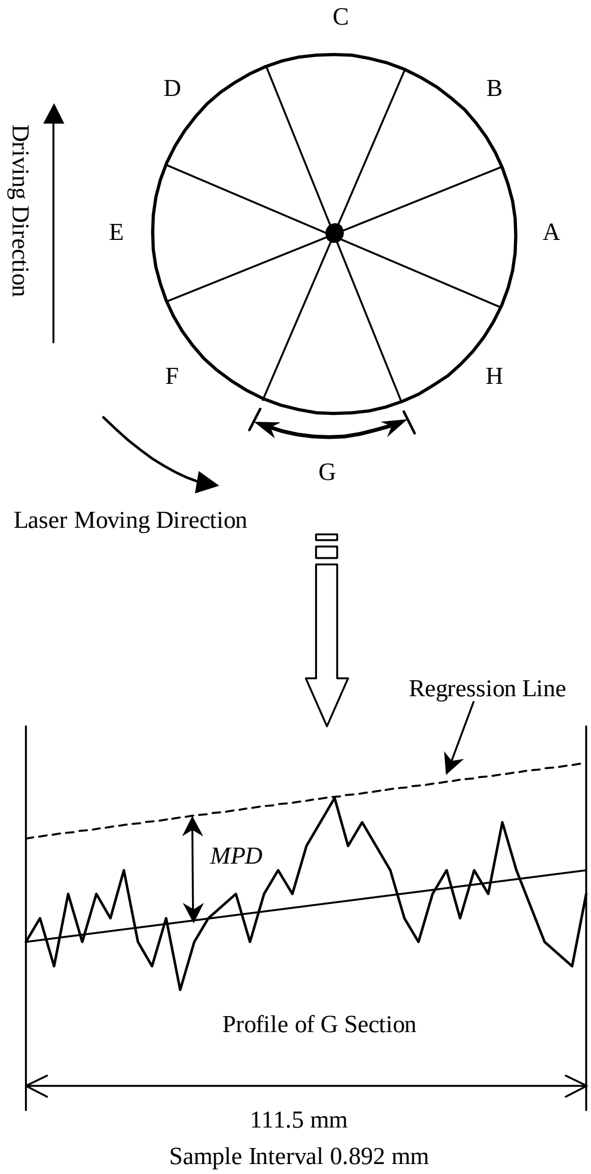


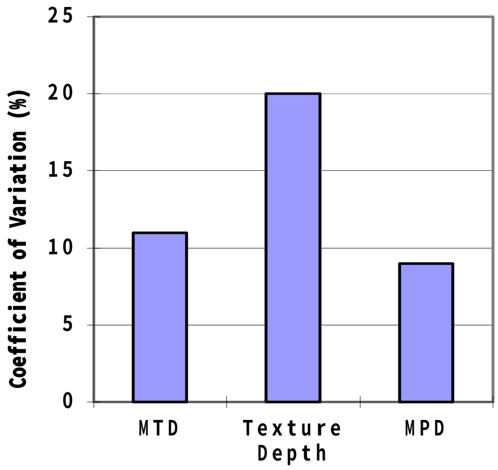
Figure 2. Calculation of MPD from CTM Measurements

The circumference of the profile measured by the CTM is 892 mm and the sampling interval is set to be 0.892 mm, which is 1/1000 of the profile length. The profile measured is divided, as shown in Figure 2, into 8 sections, A - H, of 111.5 mm each and the MPD is calculated for each profile. MPD is indicated as the height above the regression line of the highest peak. The profile measured by CTM is circular so the MPD computed from the A and E sections indicates the macrotexture in the vehicle driving direction and the MPD computed from C and G sections indicates the macrotexture of perpendicular to the direction of travel.

In this study, the objective was to analyze the relationship between the coefficient of friction measured by DFT and the macrotexture measured by CTM and therefore, not only the macrotexture of vehicle direction of travel (A and E sections), but also used the average figures of the MPD calculated from all sections (A through H) were used in the analysis.

Measurement of the Friction Coefficient

The measurement of the coefficient of friction was made by the DFT[5)] at the same location as the CTM measurement was made. The rubber sliders of DFT are set to be right at the profile measured by CTM. In this study the coefficient of friction was measured over a range of slip speeds from 20 to 80 km/h,



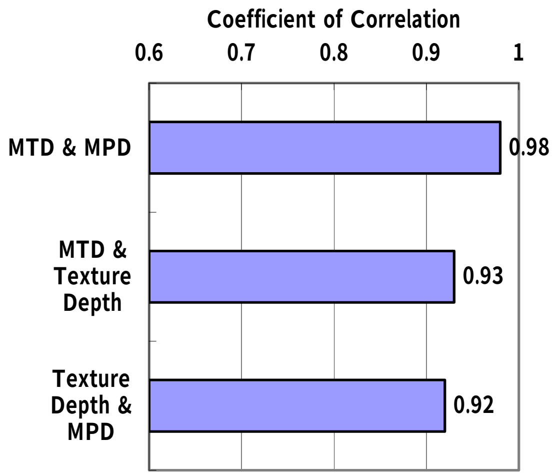


Fig.ure3. Comparison of the Coefficients of Variation

Figure 4. Comparison of Correlation Coefficients

4. Comparison of the CTM, Sand Patch and Sand Track Tests

The coefficients of variation obtained in the Sand Patch (MTD), Sand Track (Texture Depth) and CTM (MPD) Tests are shown in the Figure 3. The Sand Track method had the largest coefficient of variation. The coefficients of variation for the Sand Patch and the CTM were half that of the Sand Track method. The reason for this is that when the Sand Track apparatus is operated on surfaces with high macrotexture, the sand escapes under sides of the apparatus forming a wider track than desired (5 cm). On the other hand, the reliability of the measurement by CTM and Sand Patch is considered to be the same as the coefficients of variation for the MTD and MPD are nearly the same.

The correlation coefficients of the MTD vs. MPD, MTD vs. Texture Depth and Texture Depth & MPD are shown in the Fig.-4. The correlation coefficient is more than 0.9 in all cases. The highest correlation coefficient (0.98) was obtained for MTD vs. MPD by the CTM.

It can be concluded that macrotexture can be measured simply and quickly using the CTM and that the correlation coefficient of the MPD by the CTM and the MTD by the Sand Patch method is very high in addition, the coefficients of variation of the MPD and the MTD are almost the same.

5. Calculation of IFI from the measured values by the CTM and DFT

The International Friction Index (IFI) consists of a Friction Number *F60* and Speed Constant *Sp*. Regression constants (a and b) in Equation (1) and (A and B) in Equation (3) were determined for those devices that participated in the International Experiment in order to calculate the IFI.[3] The constants must be determined for devices which did not participate by calibrating them using the values measured by devices that did participate in the Experiment. The DFT and the Sand Patch MTD did participate and thus they could be used to determine the IFI for each of the test pavements. Using the values for *Sp* as the "true values" it was possible to determine the values for the regression constants (a and b) for the MPD of the CTM. Thus the IFI (F60,Sp) can now be determined using the CTM and the DFT.

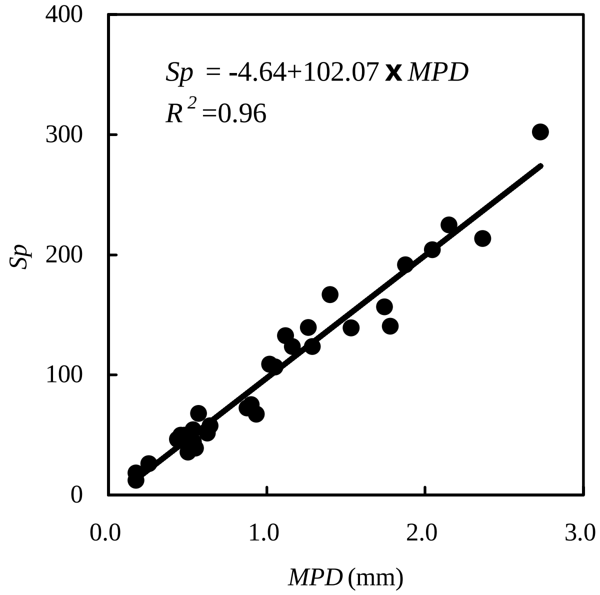


Figure 5. The Relationship between MPD and *Sp*

Calculation of Speed Number *Sp* from the MPD value from the CTM

For each test surface calculate *Sp* using the Equation (1) from the MTD obtained from the Sand Patch Test. The values of a and b were determined in the International Experiment.[3] These values were (a = –11.6) and (b = 113.6) so Equation (1) becomes:

$$Sp = -11.6 + 113.6 \text{ x } MTD \qquad (5)$$

The relationship between the *Sp* calculated by the Equation (5) and the MPD obtained from the CTM measurement is shown in Fig.-5. This provides a relationship for the determination of *Sp* from the MPD of the CTM:

$$Sp = -4.64 + 102.07 \text{x} MPD \qquad (6)$$

The correlation coefficient of this relationship is 0.96 which is quite good.

Calculation of Friction Number *F60* from the measurements by the CTM and the DFT

An analysis is conducted here using DFT20 which provided the best results in the International Experiment[2] with the highest correlation with the Golden Value of Friction Number GF60. DFT20 is the Friction Coefficient at a slip speed of 20 km/h measured by the DFT.

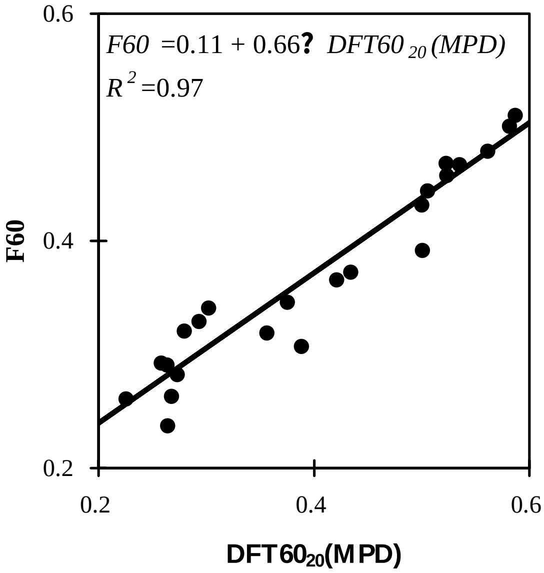


Figure 6. The Relationship between $DFT60_{20}$(MPD) & F60

The Friction Number *F60* is calculated using the regression Equation (7) obtained in the International Experiment after substituting the *Sp* calculated from the MTD in the formula (2) and transforming the DFT20 to Friction Coefficient $DFT60_{20}$(MTD) at a slip speed of 60 km/h.

$$F60 = 0.11 + 0.68 \text{x} DFT60_{20}(MTD) \qquad (7)$$

The relationship between the $DFT60_{20}(MPD)$ which can be obtained by substituting the *Sp* calculated from *MPD* and the F60 from the formula (7) is shown in the Fig.-6. Also, the regression line of the both of them is given by the formula (8).

$$F60 = 0.11 + 0.66 \text{x}\ DFT60_{20}(MPD), \quad R^2=0.97 \qquad (8)$$

It is possible to calculate *F60* with sufficient reliability from the values measured by the CTM and DFT using equation (8). Since the regression constants (A and B) are nearly the same in equations (7) and (8), it can be concluded that the determination of *Sp* using Equation (6) is also quite reliable.

Comparison between *F60* and *DFT60*

The relationship between the *F60* from equation (8) and the *DFT60,* the DFT measured friction at a slip speed of 60 km/h, is shown in the Figure 7. The regression equation is given in Equation (9):

$$F60 = 0.78 \text{x} DFT60 - 0.11, \quad R^2=0.59 \qquad (9)$$

Equation (9) gives fairly good results when the value of *DFT*60 is greater than 0.7, but the deviation from the regression line becomes greater on pavements when the *DFT*60 is less than 0.6.

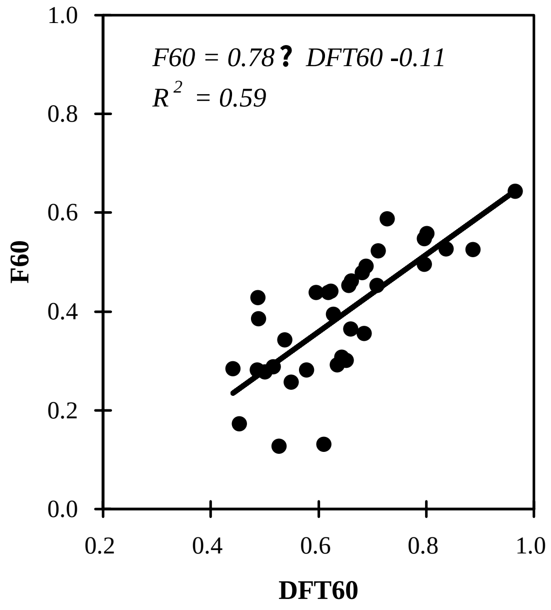


Figure 7. Relationship between DFT60 and F60

*F*60(*DFT*60) is the estimated value of the Friction Number *F*60 calculated using the Equation (9) and *F60(DFT20)* is the value of *F60* using Equation (8). The residual difference between the *F60(DFT60)* and *F60(DFT20)* are shown as a function of *MPD* in Figure 8.

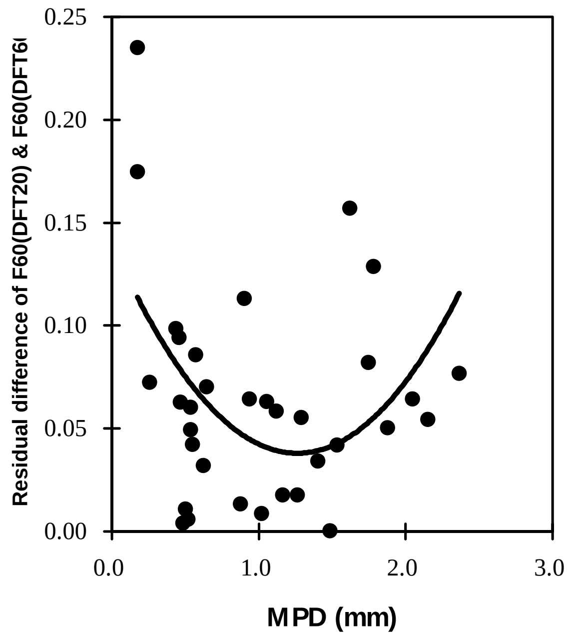


Figure 8. F60 Residuals as a function of MPD

The residuals are less than 0.1 in the MPD range of 0.2 - 2.2mm. However, the residuals tend to be large in the range MPD < 0.2 mm and MPD > 2.2 mm. It is considered to be due to the fact that the speed dependence of the friction coefficient from the measurements by the DFT and the speed dependence of the friction coefficient calculated from the *MPD*, i.e., the Speed Number *Sp* do not agree.

6. Relationship between DFT measurement data and Speed Number *Sp*

The speed dependence of the friction coefficient can be obtained directly from the measured values of the DFT as the DFT measures Friction Coefficient continuously in the range of slip speeds of 0 – 80 km/h. Thus, the speed dependence *Sp*(*DFT*) of the friction coefficient is computed from the measured values of the DFT in the slip speed range of 20 – 40 km/h, 20 – 50 km/h, 20 - 60 km/h, 20 – 70 km/h, and 20 – 80 km/h. However, among the pavements in the study, the locations where friction coefficient increases with speed or the locations where coefficient of friction does not change with speed are excluded from the analysis.

The correlation coefficient between the *Sp*(*DFT*) and the *Sp*(*MPD*) calculated from the MPD for changes in slip speeds from 20 km/h to 40, 50, 60, 70, and 80 km/h are shown in the Figure 9. The correlation coefficients of *Sp*(*DFT*) and *Sp*(*MPD*) on all of the pavements (asphalt and concrete) measured in this study was 0.4 - 0.5 which is not a very good correlation. Thus, the object of the analysis was limited to the Asphalt Pavements, which did not have surface treatments such as grooving and microsurfacing. For these surfaces the correlation coefficient of *Sp*(*DFT*) and *Sp*(*MPD*) increased to 0.7 - 0.8 Therefore, it is necessary to consider the influence of the road undulation characteristics (road wave length, etc.) as the MPD only is not believed to be sufficient to explain the relationship between the speed dependence of friction from the measured value of the DFT and the macrotexture on those pavements. Also, the correlation coefficient between the *Sp*(*DFT*) obtained from the friction coefficient at slip speeds of 20 – 40 km/h, 20 – 50 km/h, and 20 – 60 km/h on the non-surface treated asphalt pavement and the *Sp*(*MPD*) shows an almost constant value, but the correlation coefficient shows a decreasing trend for DFT measurements at high speeds for more than 70 km/h. Therefore, it is considered that using the friction coefficient at a slip speed of 20 – 60 km/h is better than using the friction coefficient in higher speeds.

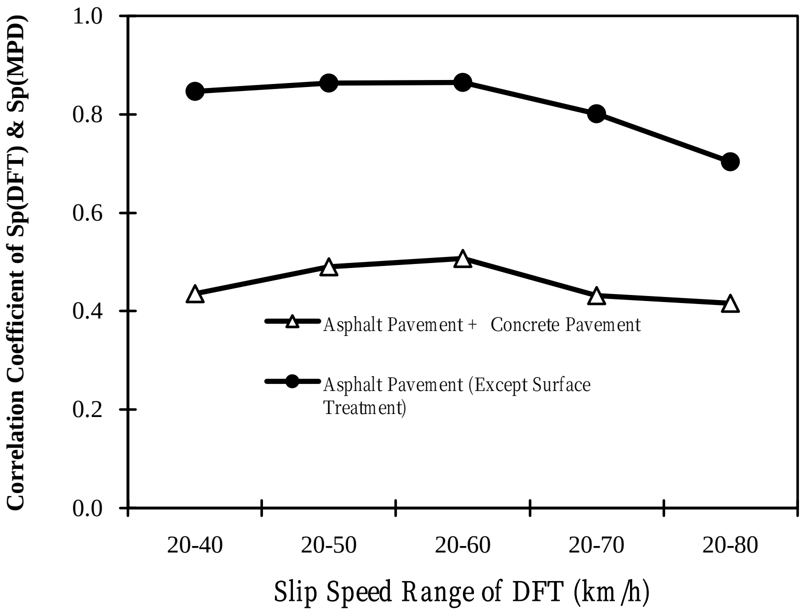


Figure 9. Correlation Coefficients for Sp(DFT) vs Sp(MPD)

The relationship between the *Sp*(*MPD*) and the *Sp*(*DFT*) for which the correlation coefficient of *Sp*(*DFT*) and *Sp*(*MPD*) was the highest was for Asphalt pavements without surface treatment using the DFT slip speed range of 20 – 60 km/h. This is shown in the Figure 10. *Sp*(*DFT*) from the DFT measurement value is larger than the *Sp*(*MPD*) from the CTM measurement value. This means that the friction coefficient from the DFT is less influenced by slip speed than the golden friction value in the PIARC model. The regression line of *Sp*(*DFT*) and *Sp*(*MPD*) is given by equation (10):

$$Sp(MPD) = 0.14x\ Sp(MPD) + 1.45, \qquad R^2 = 0.75 \qquad (10)$$

Departure from the regression line is greatest when the MPD is small. Also, It is hard to say that Equation (10) is the best regression equation as the pavement MPD used as an analytical object in this study seems to be biased. It is necessary to establish more precise regression formula by accumulating more data on various pavement types in the future.

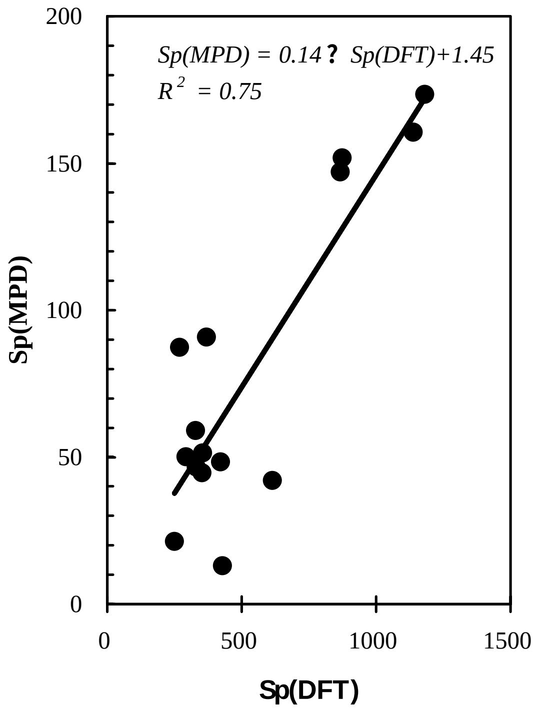


Figure 10. Relationship between *Sp*(*DFT*) and *Sp(MPD)*
Asphalt Pavement, Without Surface Treatment and Slip Speed 20 - 60 km/h

7. Conclusions

In this study, macrotexture measurements by the Sand Patch method, the Japanese Sand Track method and CTM and friction measurement by DFT are conducted on various kinds of asphalt pavement and concrete pavement and the results are analyzed. The conclusion is shown as follows:

- The coefficients of variation of the MPD from the CTM and the MTD by the Sand Patch method are about 10%. Also, the correlation coefficient of the MPD and the MTD becomes 0.98, which is considered to be a very high value. Therefore, it is possible to measure macrotexture easily and readily with the same accuracy as that of the Sand Patch Test using the CTM.

- IFI (*F60, Sp*) can be calculated using the MPD from the CTM measurement and the DFT measurement at a slip speed of 20 km/h (DFT20).

- The regression equation of the friction number *F60* calculated from MPD and DFT20 with the DFT measurement value, *DFT60*, at a slip speed of 60 km/h was determined. The resulting regression equation is in good agreement for pavements having an MPD in the range of 0.2 - .2, but the residuals of the regression formula tend to be large on pavements having an *MPD* of less than 0.2 or more than 2.2.

- The correlation coefficient between the speed dependence of friction coefficient, *Sp* (*DFT*), from the DFT measurements and the speed number *Sp* (*MPD*) calculated from the MPD were determined. The correlations between the *Sp* (*DFT*) on the non-surface treated asphalt pavement and the *Sp* (*MPD*) were good. Also, it is concluded that the correlation coefficient of the *Sp* (*DFT*) and the *Sp* (*MPD*) were the highest for DFT measurements when a slip speed range of 20 - 60 km/h is used.

- The regression equation of the *Sp* (*DFT*) and the *Sp* (*MPD*) had the highest correlation coefficient for asphalt pavements without surface treatment and for a slip speed range of 20 - 60 km/h.

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