THE EFFECT OF MIX DESIGN
ON MACROTEXTURE AND SKID RESISTANCE
OF ASPHALT CONCRETE

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SUMMARY

The International Friction Index (IFI) consists of a Friction Number (*F60*) and a Speed Constant (*Sp*). The Friction Number *F60*, one of the IFI parameters, indicates friction at a slip speed of 60km/h. On the other hand, *Sp* indicates the speed dependency of the friction coefficient and is influenced by the macrotexture of the pavement.
In this study, 38 asphalt concretes were prepared in a laboratory and the macrotexture was measured by the Sand Patch Test and by the Circular Texture Meter (CTM). The IFI can be calculated from the Mean Profile Depth (*MPD*) determined by the CTM and the coefficient of friction measured by the Dynamic Friction Tester (DFT). The study shows that the friction quality of pavement can be evaluated using the IFI. Based on the results, a computer software that operates in Windows has been developed for evaluation of pavement surfaces on site.

1. PREFACE

The tire pavement friction of roads and runways plays an important role in the safety of vehicles and aircraft traveling on them. Many devices and methods have been developed around the world to measure the friction and texture of pavements. The International Experiment by PIARC was conducted in 1992 for the purpose of comparing and harmonizing the test results obtained from various testing devices. As a result, the International Friction Index (IFI) was developed (PIARC, 1995). The IFI consists of a Friction Number (*F60*) and a Speed Constant (*Sp*) and is reported as IFI (*F60, Sp*).

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 (ASTM E-274, 1999). Another method is to measure the coefficient of friction between rubber pads and road surfaces as is the case for the DFT (ASTM E-1911, 1999) and the BPT (ASTM E-303, 1999). The Speed Number (*Sp*) indicates the speed dependency which can be determined from the macrotexture of the pavement. Macrotexture is defined as the components of the profile which have wavelengths of 0.5-50mm (ISO 13473-1, 1997) and it is measured by such devices as the Laser Profilometer, the Volumetric Method and the Outflow Meter. The macrotexture of pavements is an important factor that determines the speed dependency of friction coefficient.

The CTM is a profiling device that measures macrotexture profiles on a circular track of 142mm radius using a CCD laser displacement sensor. The CTM is a portable device and is able to measure macrotexture on the same circumference where the DFT measures coefficient of friction. Before the development of the CTM, it was not possible to measure the macrotexture at exactly the same location where the coefficient of friction was measured.

In this study, the macrotexture of the various asphalt concretes prepared in a laboratory was measured by the Sand Patch Method and by the CTM. Also, the coefficient of friction was measured by the BPT and the DFT. The friction characteristics of the asphalt concretes were evaluated by the IFI calculated from the measured data of the CTM and the DFT.

2. INTERNATIONAL FRICTION INDEX (IFI)

PIARC has developed a Friction - Slip Speed Model (PIARC Model) as shown in Fig. 1 and determined the Golden Values of Speed Number (GS) and the Golden Values of the Friction Number (GF60) based on the results of the 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:

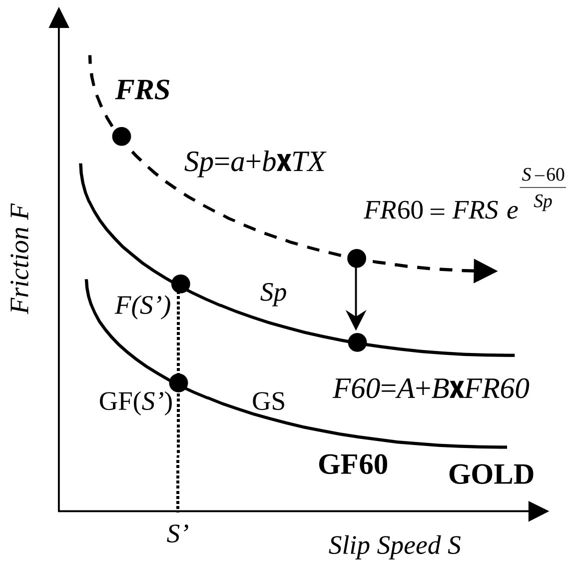

Fig.1 The PIARC Model

1. Calculate *Sp* 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 (*FR60*) at a slip speed of 60km/h using equation (2).

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

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

3. Calculate Friction Number *F60* using equation (3).

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

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

3. DESCRIPTION OF THE TESTS

3.1 Asphalt Concretes

In this study, 38 asphalt concretes were prepared in a laboratory. The type of asphalt concrete, the coarse aggregate, the maximum grain size, the characteristic and the method of roller compaction are shown in Tab.1.

Sandstone and diabase were used as coarse aggregates in the dense-graded asphalt concrete, the dense-gap-graded asphalt concrete, the porous asphalt concrete and the neat asphalt concrete. After mixing, the asphalt concrete was put into a form of 45 x 45cm and compact the asphalt concrete with steel rollers. The breakdown rolling with steel rollers and the second rolling with rubber wheels were used. Non-skid surface treatments included grooving and shot-blasting in addition to the neat method.

Tab. 1 Asphalt concretes tested in the laboratory

Notation	Asphalt Concrete	Coarse Aggregate	Maximum Grain Size	Characteristic	Roller Compaction
D11	Dense-Graded	Sandstone	13mm		Steel
D12	Dense-Graded	Sandstone	13mm		Rubber
D22	Dense-Graded	Diabase	13mm		Rubber
D31	Dense-Graded	Sandstone	20mm		Steel
D32	Dense-Graded	Sandstone	20mm		Rubber
D41	Dense-Graded	Diabase	20mm		Steel
D42	Dense-Graded	Diabase	20mm		Rubber
G11	Dense-Gap-Graded	Sandstone	13mm		Steel
G12	Dense-Gap-Graded	Sandstone	13mm		Rubber
G21	Dense-Gap-Graded	Diabase	13mm		Steel
G22	Dense-Gap-Graded	Diabase	13mm		Rubber
P11	Porous	Sandstone	13mm		Steel
P12	Porous	Sandstone	13mm		Rubber
P21	Porous	Diabase	13mm		Steel
P22	Porous	Diabase	13mm		Rubber
P81	Porous	Sandstone	8mm		Steel
P82	Porous	Sandstone	8mm		Rubber
SM1	Stone Mastic	Sandstone	13mm		Steel
SM2	Stone Mastic	Sandstone	13mm		Rubber
SM3	Stone Mastic	Sandstone	8mm		Rubber
N18	Neat	Sandstone	5.0 - 8.0mm		
N15	Neat	Sandstone	2.5 - 5.0mm		
N28	Neat	Diabase	5.0 - 8.0mm		
N25	Neat	Diabase	2.5 - 5.0mm		
R11	Hot Rolled	Sandstone	13mm	$10kg/m^2$	
R12	Hot Rolled	Sandstone	13mm	$7kg/m^2$	
R20	Hot Rolled	Sandstone	20mm	$10kg/m^2$	
GR1	Dense-Graded with Grooving	Sandstone	13mm	25mm interval	
GR2	Dense-Graded with Grooving	Sandstone	13mm	40mm interval	
GR3	Dense-Graded with Grooving	Sandstone	13mm	50mm interval	
GR4	Dense-Graded with Grooving	Sandstone	13mm	40 x 40mm	
SH0	Dense-Graded	Sandstone	13mm		
SH1	Dense-Graded with Shot-Blast	Sandstone	13mm	1m/min, 1.4 - 1.7mm	
SH2	Dense-Graded with Shot-Blast	Sandstone	13mm	2m/min, 1.4 - 1.7mm	
SH3	Dense-Graded with Shot-Blast	Sandstone	13mm	3m/min, 1.4 - 1.7mm	
SH4	Dense-Graded with Shot-Blast	Sandstone	13mm	1m/min, 2.0mm	
SH5	Dense-Graded with Shot-Blast	Sandstone	13mm	2m/min, 2.0mm	
SH6	Dense-Graded with Shot-Blast	Sandstone	13mm	3m/min, 2.0mm	

3.2 Macrotexture Measurement

In this study, macrotexture was measured using the Sand Patch Test and the CTM. The Sand Patch Test is a method that measures the diameter of a sand circle made by spreading a known volume of sand on the road surface and calculates the circle area covered. Dividing the volume by the area of sand provides the *MTD* (Mean Texture Depth).

The CTM shown in Picture 1 measures 40 x 40 x 27cm and weighs 13kg. As shown in Picture 2, the CCD laser displacement sensor is mounted on an arm that rotates on a circumference of 142mm radius and measures macrotexture on the same circular track where the DFT measures the coefficient of friction (Henry, 2000). 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 within 40 seconds.

The circumference of the profile measured by the CTM is 892 mm and the sampling interval is set to be 0.871 mm, which is 1/1024 of the profile length. The profile measured is divided, as shown in Fig.2, into 8 segments, A-H, of 111.5 mm each. A linear regression of the profile values for each segment is performed and regression line is subtracted from the profile values of the segment. Each segment is further divided into two equal lengths of 55.75mm and the maximum value of the profile is determined for each of the 55.75mm subsegments. These two values are averaged arithmetically to obtain the mean segment depth. The average value of the mean segment depths for all segments of the measured profile is averaged to obtain the Mean Profile Depth (*MPD*).

Picture 1 General View of CTM

Picture 2 Laser Displacement Sensor of CTM

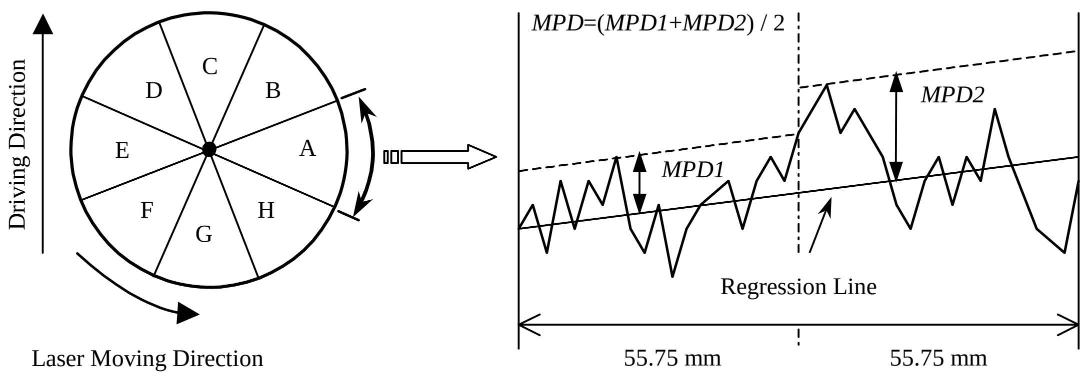

Fig.2 Calculation of MPD from CTM Measurements

3.3 Measurement of the Friction Coefficient

The measurement of the coefficient of friction was made by the DFT at the same location where the CTM measurement was made. The rubber sliders of the DFT are set at the location where the profile was measured by the CTM. In this study the coefficient of friction was measured over a range of slip speeds from 20 to 80km/h. Also, the BPN of the same asphalt concrete was calculated from the data measured by BPT after temperature correction.

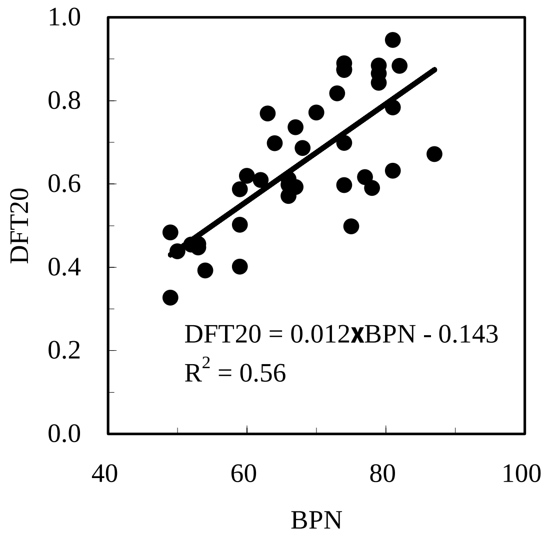

Fig.3 The Relationship between *DFT20* and BPN

The relationship between the BPN and the friction coefficient measured by the DFT at 20km/h (*DFT20*) is shown in Fig.3. The R^2 value the BPN and the *DFT20* was 0.56. Accuracy of regression line between the BPN and the *DFT20* was high in a range where the skid resistance was small while the deviation from the regression line became large in a range where the skid resistance was large.

4. COMPARISON OF THE CTM AND SAND PATCH

The relationship between the *MTD* obtained from the Sand Patch Test and the *MPD* calculated from the profile measured by CTM is shown in the Fig.4. The regression line of the *MTD* and the *MPD* becomes equation (4).

$$MTD = -0.08 + 1.08 \times MPD \qquad (4)$$

Because the R^2 value of the regression equation is large enough, *MTD* can be estimated from the *MPD* obtained by the CTM measurements.

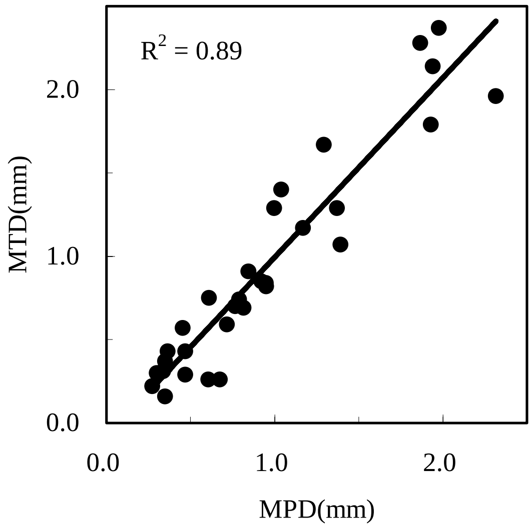

Fig.4 The Relationship between *MTD* and *MPD*

5. CALCULATION OF IFI FROM THE CTM AND DFT DATA

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. 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 from the data obtained by the CTM and the DFT.

The *Sp* was calculated from equation (1) by using the *MTD* obtained from the Sand Patch Test. The values of *a* and *b* were determined in the International Experiment (ASTM E-1960, 1999).

$$Sp = -11.6 + 113.6 \times MTD \tag{5}$$

The following equation can be obtained by substituting equation (4) into equation (5).

$$Sp = -20.7 + 122.7 \times MPD \tag{6}$$

The resulting equation (6) is proposed for estimating *Sp* from the CTM measurements instead of equation (5).

An analysis was conducted using *DFT20* which is recommended for predicting the F60 with the highest correlation between the Golden Value and the Friction Number GF60 in the International Experiment. The Friction Number (*F60*) is calculated from *DFT20* measurements and *Sp* by using equation (7) which is combined equations (2) and (3), noting that for this case S = 20km/h:

$$F60 = 0.08 + 0.73 DFT20 e^{\frac{20-60}{Sp}} \tag{7}$$

The constants 0.08 and 0.73 are the calibration constants for the DFT, which were obtained from the results of the International Experiment and have been standardized by ASTM (ASTM E-1960, 1999). It is possible to determine *F60* from the *DFT20* and the *MPD* by substituting equation (6) into equation (7).

$$F60 = 0.08 + 0.73 DFT20 e^{\frac{20-60}{-20.7+122.7\times MPD}} \tag{8}$$

6. EVALUATION OF FRICTION QUALITY OF PAVEMETS

The friction quality of pavements can be evaluated using the IFI (*F60*, *Sp*). If the decision makers establish intervention levels for IFI: [IFI* (*FR60**, *Sp**)], the requirements for a minimum texture level and a minimum friction measurement can be formulated.

Select the intervention values for IFI* (*FR60**, *Sp**) and substitute them into the equations (1) and (2). The minimum required friction measurement (FR_{min}) and the minimum texture requirement (TX_{min}) can be calculated from the following equations (9) and (10).

$$FR_{\min} = \frac{FR60^* - A}{B} \times e^{\frac{60-S}{a+b\times TX}} \tag{9}$$

$$TX_{\min} = \frac{Sp^* - a}{b} \tag{10}$$

The equation (9) is a relationship between FR_{min} and TX and the equation (10) determines TX_{min}. For example, in case of $FR60^*$ = 0.3, Sp^* = 100km/h, the minimum required friction measurement by DFT (DFT_{min}) and the minimum texture requirement by CTM (MPD_{min}) are shown as Equations (11) and (12). In case of DFT, the constants are A = 0.08, B = 0.73 (ASTM E-1960, 1999). In case of CTM, the constants, a = -20.7 and b = 122.7, are obtained from the analyzing results mentioned above.

$$DFT_{\min} = \frac{0.3 - 0.08}{0.73} \times e^{\frac{60-20}{-20.7+122.7\times MPD}} \tag{11}$$

$$MPD_{\min} = \frac{100 + 20.7}{122.7} = 0.984 \tag{12}$$

The evaluation results by the DFT_{min} and MPD_{min} on the friction qualities of non-surface treated asphalt concrete are shown in Fig.5. A coordinate plane expressed in *DFT20* and *MPD* is divided into 4 regions by the DFT_{min} and MPD_{min}. They are, *Sp & F60 Good* region, *Sp Low* region (improve macrotexture), *F60 Low* region (improve microtexture) and *Sp & F60 Low* region (improve both macrotexture and microtexture).

All hot rolled asphalt concretes (R11, R12, R20) are included in the *Sp & F60 Good* region. Porous asphalt concretes of the maximum 13mm grain size are almost included in the *Sp & F60 Good* region, but porous asphalt concretes of the maximum 8mm grain size are evaluated as *Sp Low*. Thus, it is considered that the larger the maximum grain size becomes, the higher the friction quality of porous asphalt concretes will be. The friction quality of D11, D12, D22, D31, D32, D41, D42, G11, G12 and G21 is evaluated as *F60 & Sp Low*. Both macrotexture and microtexture should be improved on the dense-graded asphalt concretes and dense-gap-graded asphalt concretes regardless of coarse aggregate, maximum grain size and type of roller compaction. It is considered that the friction quality of stone mastic asphalt concrete is increased by the rubber roller compaction as SM2 is in *Sp Low* region while the friction quality of SM1 and SM3 is in *Sp & F60 Low* region.

The friction qualities of the asphalts concrete with such surface treatment as neat method, shot -blast, grooving, etc. are shown in Fig.6. Neat method (N15, N25, N18, N28) and grooving (GR1, GR3, GR4) are evaluated as *Sp & F60 Good* in friction quality. *DFT20* and *MPD* of asphalt concretes with shot-blast treatment (SH1, SH2, SH3, SH4, SH5, SH6) are larger than those of asphalt concretes without shot-blast treatment (SH0). However, shot-blast treatments used in this study should be improved furthermore as the friction quality of shot-blast treatments is evaluated as *Sp Low*.

In this study, friction quality is evaluated on the assumption of intervention levels of $F60^*$ = 0.3, Sp^* = 100km/h. However, evaluation of the friction of the pavements primarily depends on decision makers. Because $F60^*$ and Sp^* are decided by the decision makers, they must properly decide $F60^*$ and Sp^*, which are necessary for the road user's safety.

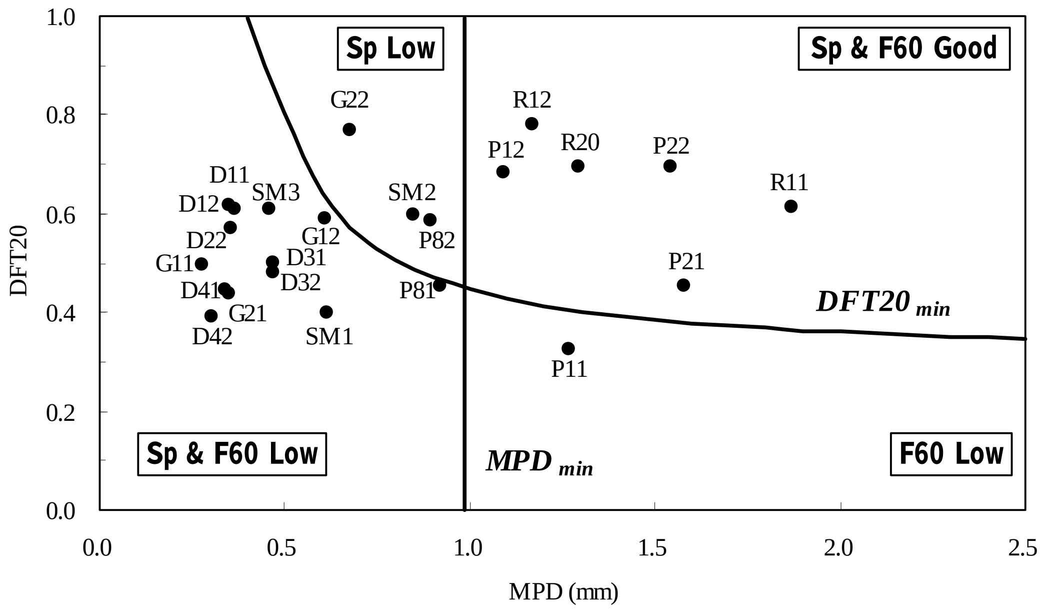

Fig.5 Evaluation of Friction Qualities (Non-Surface Treatment, *F60** = 0.3, *Sp** = 100km/h)

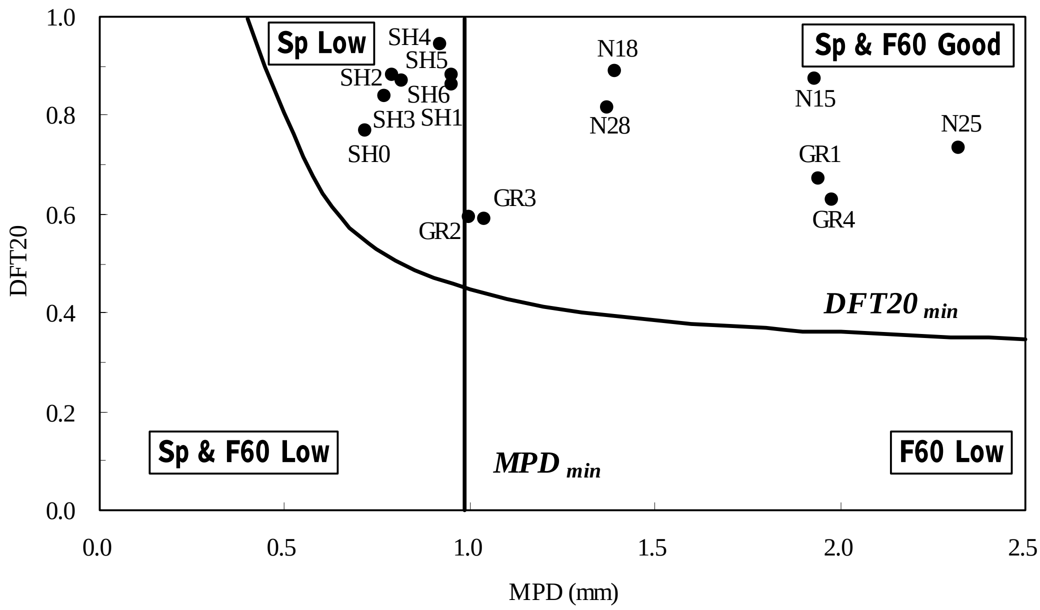

Fig.6 Evaluation of Friction Qualities (Surface Treatment, *F60** = 0.3, *Sp** = 100km/h)

7. SOFTWARE DEVELOPMENT FOR FRICTION QUALITY EVALUATION OF PAVEMENTS

In this study, ~~a~~ software that can evaluate the friction quality of pavements from the IFI calculated from the measured data by the CTM and the DFT has been developed. The software developed works in Windows98. The flow Diagram of the software is shown in Fig.7. The software consists of 3 steps, i.e., a) Macrotexture Analysis, b) IFI Calculation and c) Friction Quality Evaluation. Friction Quality Evaluation can be done instantly on site by calculating IFI of pavements from the measured data of CTM and DFT with this software.

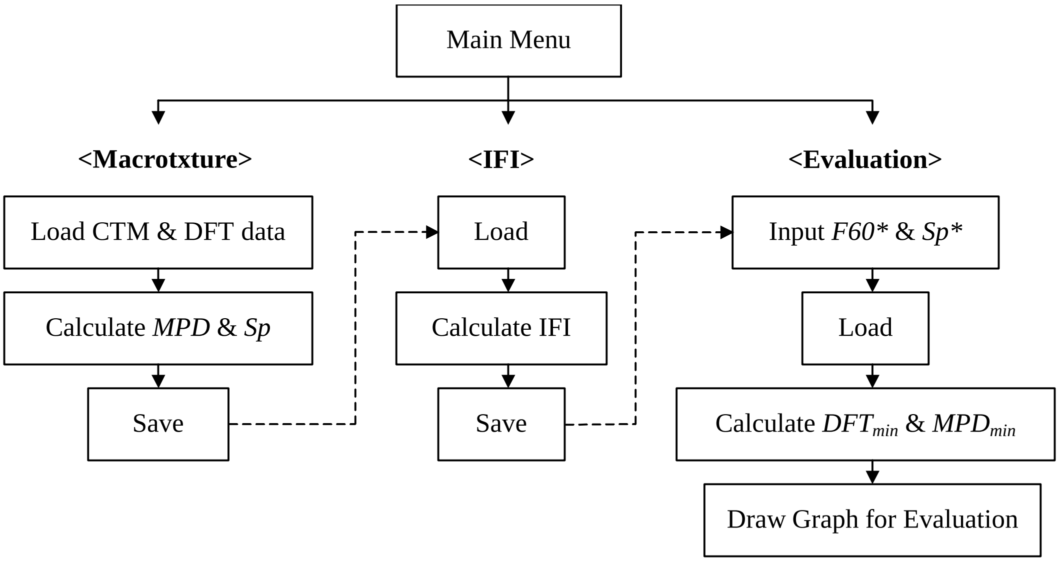

Fig. 7 Flow Diagram of the Software

8. CONCLUSIONS

In this study, 38 types of asphalt concrete were prepared in a laboratory and the macrotextures were measured by the CTM and the Sand Patch Test, and also the coefficients of friction were measured by the DFT. Further, friction was evaluated by calculating IFI from the measured data.

The conclusions and the results of this study are as follows.

- A regression equation of *MTD* obtained from the Sand Patch Test and MPD obtained from the CTM has been established. *MTD* can be estimated accurately from the *MPD* obtained from the CTM measurements as the accuracy of the R^2 value of the regression equation established is very high.
- An equation to calculate *Sp* from *MPD* was established. It was shown that the IFI was calculated by the *Sp* estimated form the CTM measurements and from the friction value of *DFT20* measured at 20 km/h by the DFT.
- The minimum required friction measurement by DFT (DFT_{min}) and the minimum texture requirement by CTM (MPD_{min}) were calculated for the case of $F60^* = 0.3$, $Sp^* = 100$km/h. The friction qualities of the all asphalt concretes were evaluated using the DFT_{min} and MPD_{min} calculated. In case of non-surface treated pavements, the friction quality of the hot rolled asphalt concretes and the porous asphalt concretes were *Sp & F60 Good*. Also, the macrotexture and the microtexture were found to be improved on the dense-graded asphalt concrete and dense-gap-graded asphalt concrete as their friction quality was *Sp & F60 Low*.
- On the other hand, in case of surface treated pavements, the pavements with neat method and grooving treatment were evaluated as *Sp & F60 Good*.
- The software that works in Windows98, can analyze macrotexture, calculate IFI and evaluate friction quality has been developed. It is possible to evaluate the given pavement surfaces on site by using the personal computer.

9. REFERENCES

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