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Evaluation of skid resistance using CTM, DFT and SRT-3 devices

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Abstract

Evaluation of skid resistance could be based on both microtexture and macrotexture. It is possible to measure this parameter using CTM (Circular Track Meter) and DFT (Dynamic Friction Tester) devices. Macrotexture is characterized by the MTD (Mean Texture Depth) parameter obtained by CTM measurements. Microtexture can be estimated by the coefficient of friction DFT20 at a slip speed 20 kph using low speed friction measurement devices such as DFT. In this paper the possibility of using CTM and DFT for assessment of wearing course made from SMA (Stone Mastic Asphalt), AC (Asphalt Concrete), Slurry Seal and exposed aggregate PCC (Pavement Cement Concrete) is presented. Eleven test sections were considered. In addition, coefficient of friction μ was measured by SRT-3 device with locked wheel at test speed 30, 60 and 90 kph. Good correlation between DFT20 and μ at tested speeds was observed. It found out that SRT-3 device is more sensitive to microtexture changes in the pavement but not to macrotexture. The influence of asphalt mixture composite, texturing method, polishing resistance of coarse aggregates on skid resistance were analyzed. The measured values of the DFT and CTM devices were used to calculate the IFI numbers for each test section according to the ASTM E1960-07(2011) standard. In addition based on IFI, the coefficient of friction F(S) was calculated at various slip speeds S. Consequently, different pavements surfaces were compared in regard to slip speed S. As the result of the analysis it was found that at low speed pavements made of AC had better skid resistance than SMA and exposed aggregate PCC, while at high speeds SMA and exposed aggregate PCC had better skid resistance than AC pavements. This information is valuable for proper maintenance of existing pavements and on the stage of designing.

Keywords: skid resistance; macrotexture; microtexture; road pavement

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1. Introduction

Skid resistance plays an important role in reducing road accidents in wet conditions. Due to this fact it is one of the most important roadway safety parameters. The factors affecting the skid resistance are grouped into pavement surface characteristics, vehicle operational parameters, tire properties, and environmental factors. It has been well known that most important factor is texture considered as macrotexture and microtexture. Texture is deviation from a planar surface. Macrotexture is characterized by the wavelength $\lambda = 0.5 \div 50$ mm and it depends on asphalt mixture properties (shape, size and gradation of aggregate) or texturing method used on concrete pavement surfaces. Microtexture with wavelength $\lambda < 0.5$ mm is related to amount of fine aggregate and polishing resistance of coarse aggregate in wearing course (Hall et al., 2009). Macrotexture provides surface drainage channels for water expulsion from the contact area between a tire and pavement. While microtexture disrupts the continuity of the water film and produces frictional resistance between a tire and pavement. It has been proved that maintenance of required level of both microtexture and macrotexutre reduce number of wet crashes. Therefore evaluation of skid resistance could be based on these two surface characteristics.

Nomenclature

AC	Asphalt Concrete
DFT20	coefficient of friction at slip speed 20kph
PCC	Pavement Cement Concrete
IFI	International Friction Index
F60	Friction Number
F(S)	coefficient of friction at any slip speed S
MPD	Mean Profile Depth (mm)
S	slip speed (kph)
S_e	standard error
Sp	Speed Number (kph)
STD	standard deviation
SMA	Stone Mastic Asphalt
PSV	Polished Stone Value
R^2	coefficient of determination
V	test speed (kph)
V	coefficient of variation (%)
μ	coefficient of friction obtain from SRT-3

Complex evaluation of skid resistance is possible using portable devices like CTM (Circuler Track Meter) and DFT (Dynamic Friction Tester). The CTM measurements allow to estimate macrotexture by the MPD (Mean Profile Depth) parameter. Microtexture can be estimated by the coefficient of friction DFT20 at a speed slip 20 kph. using low speed friction measurement devices such as DFT. An additional advantage of using these devices is possibility of evaluation of skid resistance based on IFI (International Friction Index) according to ASTM E1960 – 07 (2011) standard. Then based on IFI, the coefficient of friction F(S) can be calculated at various slip speeds. It allows to assess and optimize the combined effects of pavement microtexture and macrotexture on the level of skid resistance (Henry, 2000).

The only disadvantage of DFT and CTM is the fact that this methods is slow and requires lane closure. Consequently, it can cause difficulties or create potential safety hazards. It would be very difficult and dangerous to use skidding resistance monitoring program on the road network. Therefore, these devices are most commonly used at laboratories or for calibration other devices which measure coefficient of friction at high test speeds under traffic (Rado, 2009). It should be noted that there are many different devices for assessing skid resistance which are divided into four modes: locked wheel, side – force, fixed slip and variable slip. However the use of measurements with these devices is very difficult or impossible in some sites like curves, roundabouts, junctions entries. In such case for evaluation of skid resistance portable devices such as CTM and DFT could be used (Wasilewska et al., 2014).

In Poland skid resistance is assessed on the basis of coefficient of friction μ measured by SRT-3 device with locked wheel. Measuring trailer is mounted in the middle of the towing vehicle. This makes it difficult to measure in the left or right wheel paths, particular on single carriageway roads with gravel shoulders and roundabout, junctions entries. Furthermore, requirement of skid resistance are based only on SRT-3 measurements.

The primary objective of this research was to compare most popular types of wearing courses in Poland based on measurements on CTM and DFT. In addition, measurements were carried out by SRT-3 device for this purpose to determine the relationship between coefficients of friction μand DFT20.

2. Research program

2.1. Test sections

In this study eleven test sections were considered. Their selection depended on wearing course characteristics like theirs type, maximum aggregates size, PSV of coarse aggregate. Test sections were located on national roads except for sections 5 and 11 which are rural roads. Sections 3, 4 and 10 are dual carriageways. Table 1 shows description of test sections.

Table 1. Description of test sections.

Test section No.	Type of wearing course	Maximum aggregates size (*mm*)	PSV (-)	Date laid	Road No.
1	SMA	12.8	48	2002	DK 65
2	SMA	11	52	2010	DK19
3	SMA	11	53	2010	DK8
4	SMA	11	53	2012	S8
5	AC	11	52	2012	Rural road
6	AC	16	45	2004	DK61
7	Slurry Seal	11	48	2010	DK61
8	AC	16	45	2003	DK79
9	AC	11	53	2010	DK79
10	PCC	8	53	2014	S8
11	AC	11	56	2012	Rural road

2.2. Devices

The CTM is a road surface macrotexture profiler that uses a charge coupled device (CCD) laser-displacement sensor to measure the vertical profile of a pavement surface (Fig. 1). When the measurement is started the CCD Laser Displacement Sensor rotates on a circumference with a 142 mm radius and measures the texture with a sampling interval of approximately 0.9 mm. The CTM software calculates and reports the Mean Profile Depth (MPD) and Root Mean Square (RMS) statistics that characterize profile macrotexture.

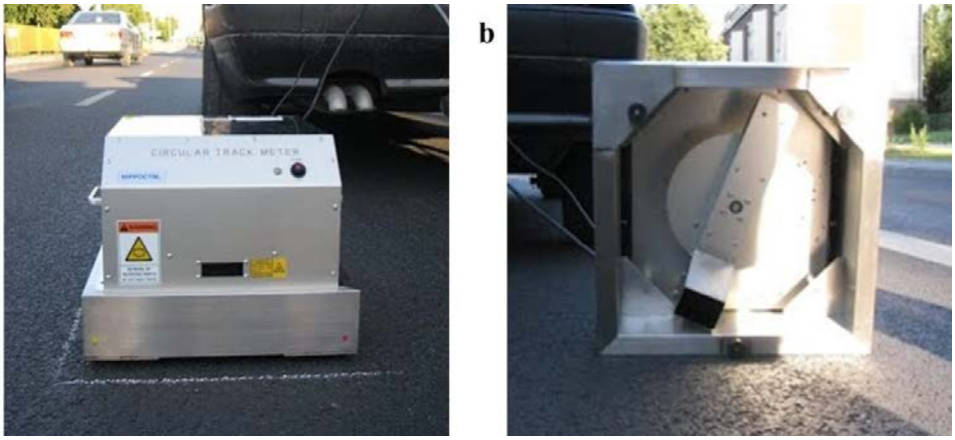

Fig. 1. (a) The CTM device during the measurement; (b) View of laser sensor.

The DFT is a portable device that allows measuring coefficient of friction on the exact same physical areas as the CTM measurements were taken. The DFT consists of a horizontal spinning disk fitted with three spring loaded rubber sliders that contact the surface (Fig. 2). The disk rotates at tangential velocities up to 80 kph. Water flows over the surface being tested. The rotating disk is then dropped onto the wet surface and the coefficient of friction is continuously measured as the disk slows. Measuring is available in the range of start speed 20-80 kph. At the start speed of 80 kph the values of coefficient of friction DFT20, DFT40, DFT60 are calculated, at the speed of 60 kph – DFT40 and DFT20, at the start speed 40 kph only DFT20. In this study tests were carried out at start speed 80 kph.

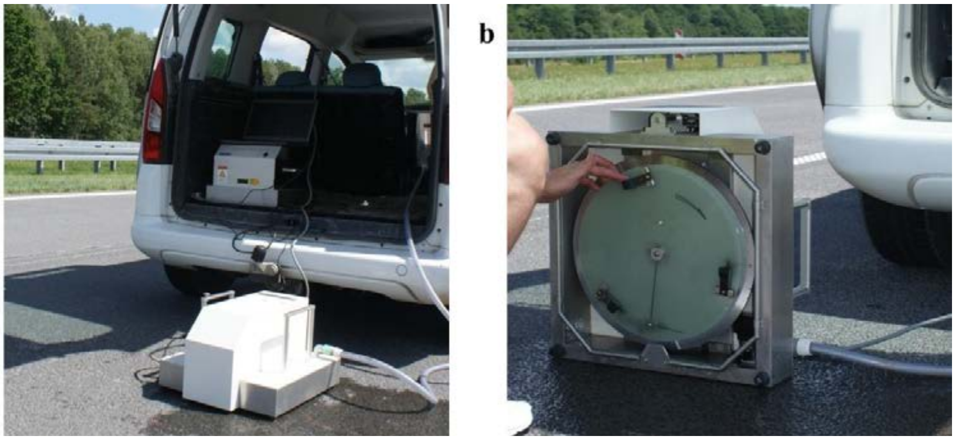

Fig. 2. (a) The DFT device during the measurement; (b) View of disk with rubber sliders.

The SRT-3 device is installed on a trailer which is towed behind the measuring vehicle (Fig. 3). Device is equipped with ribbed tire – PIARC. Measurements are conducted at three test speeds – 30, 60 and 90 kph depending on road type. Measurement is set on automatically or manually by an operator on selected test spot. Water is applied at pressure at 3 atm in front of the test tire and a braking system is forced to lock the tire. Then the resistive drag force is measured and averaged 2 second after the test wheel is fully locked. Length of singular test section where spot measurement of coefficient of friction conducted is about 10 m. Next measurements can be repeated after the wheel reaches a free rolling state again.

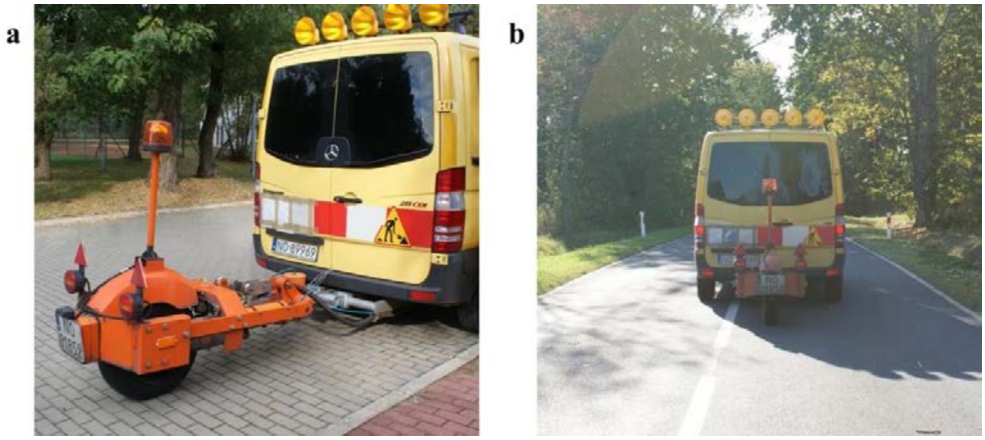

Fig. 3. (a) The SRT-3 device; (b) The SRT-3 during measurement on road.

2.3. Test procedure

The measurements with CTM, DFT and SRT-3 devices were conducted on the section length 1000 m every 100 m. Measurements with the SRT-3 device were made at 30, 60, 90 kph under traffic. In the case of the measurements with CTM and DFT lanes were closed. Three replicate passes were made at each testing spots each devices.

Test spots were selected in such way that all used devices could make measurements. On single carriageways test spots were located on left wheel path, while on dual carriageways on right wheel path. Investigation was conducted during one week (September 2014) and at stable temperatures (18-22 °C).

3. Results and analysis

Average values of MPD, DFT20 and their statistical values are presented in Table 2.

Table 2. MPD and DFT20 and their statistical values.

Test sections No.	Average MPD	Max	Min	STD	V (%)	Average DFT20	Max	Min	STD	*V* (%)
1	1.46	1.66	1.28	0.147	10.09	0.42	0,47	0,39	0.027	6.48
2	1.03	1.13	0.89	0.080	7.76	0.46	0,49	0.42	0.021	4.68
3	0.89	1.05	0.67	0,111	12.43	0.41	0,43	0.38	0.015	3.68
4	0.88	1,24	0.66	0.168	18.98	0.47	0,49	0.44	0.016	3.44
5	0.48	0.56	0.35	0.059	12.47	0.61	0.75	0.49	0.072	11.76
6	0.87	1.14	0.74	0.112	12.89	0.32	0.36	0.30	0.020	6.24
7	0.99	1.24	0.83	0.140	14.08	0.49	0.54	0.40	0.040	8.28
8	0.67	0.75	0.61	0.041	6.06	0.33	0.34	0.31	0.011	3.25
9	0.42	0.49	0.34	0.043	10.34	0.53	0.55	0.51	0.015	2.91
10	1.43	1.90	0.98	0.340	23.84	0.45	0.48	0.40	0.021	4.70
11	0.56	0.76	0.32	0.150	26.86	0.66	0.73	0.60	0.046	6.02

Tables 3-5 contain average μ and their statistical values.

Table 3. Coefficients of friction μ at 30 kph and their statistical values.

Test sections No.	Average	Max	Min	STD	V (%)
1	0.398	0.422	0.377	0.012	3.0
2	0.458	0.474	0.437	0.010	2.2
3	0.404	0.425	0.371	0.011	2.7
4	0.439	0.461	0.417	0.010	2.3
5	0.672	0.713	0.592	0.026	3.9
6	0.431	0.575	0.375	0.067	15.5
7	0.576	0.608	0.535	0.018	3.1
8	0.431	0.448	0.412	0.009	2.1
9	0.558	0.599	0.53	0.018	3.2
10	0.541	0.585	0.519	0.017	3.1
11	0.721	0.774	0.669	0.031	4.3

Table 4. Coefficients of friction μ at 60 kph and their statistical values.

Test sections No.	Average	Max	Min	STD	V (%)
1	0.356	0.373	0.335	0.010	2.8
2	0.392	0.415	0.371	0.011	2.8
3	0.345	0.36	0.318	0.009	2.6
4	0.367	0.384	0.348	0.009	2.5
5	0.549	0.58	0.479	0.023	4.2
6	0.344	0.374	0.319	0.015	4.4
7	0.483	0.513	0.425	0.017	3.5
8	0.357	0.384	0.343	0.009	2.5
9	0.473	0.509	0.44	0.019	4.0
10	0.456	0.506	0.435	0.017	3.7
11	0.625	0.671	0.584	0.020	3.2

Table 5. Coefficients of friction μ at 90 kph and their statistical values.

Test sections No.	Average	Max	Min	STD	V (%)
1	0.329	0.349	0.313	0.010	3.0
2	0.344	0.363	0.324	0.009	2.6
3	0.300	0.32	0.267	0.012	4.0
4	0.314	0.333	0.283	0.013	4.1
5	0.452	0.483	0.389	0.018	4.0
6	0.326	0.346	0.294	0.012	3.7
7	0.434	0.453	0.403	0.014	3.2
8	0.308	0.324	0.273	0.010	3.2
9	0.402	0.434	0.368	0.017	4.2
10	0.410	0.435	0.385	0.015	3.7
11	0.516	0.563	0.483	0.021	4.1

Graphical interpretation of test results is shown in Figures 4 and 5. Average values of MPD, DFT20 and μ at different test speeds and 95% confidence interval are presented.

On most of the in-service roads it proved difficult to find a wide range of levels of texture and skid resistance. However, differences between particular types of wearing course were observed. The highest values of MPD (above 1,40mm) have been received on the SMA (section 1) and exposed aggregate PCC. For other SMA MPD ranged from 0.80 to 1.00 mm. AC is characterized by lower values of MPD than SMA. This is caused by the higher content of coarse aggregate in SMA than AC. The exception was AC on section 6. This was caused by lack of aggregates. The highest variations of MPD were observed on section 10 and 11. Their coefficients of variation *V* are above 20%.

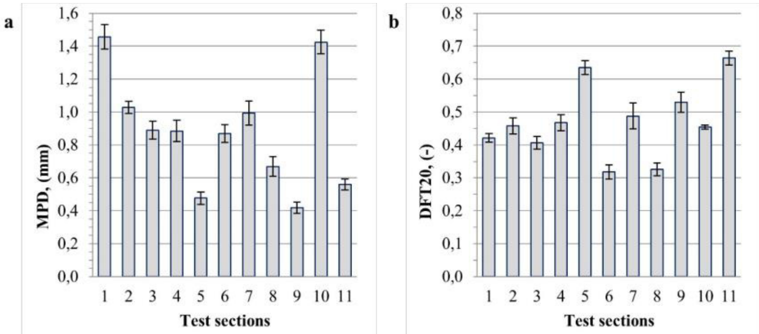

Fig. 4. (a) Average values of MPD with 95% confidence interval; (b) Average value of DFT20 with 95% confidence interval.

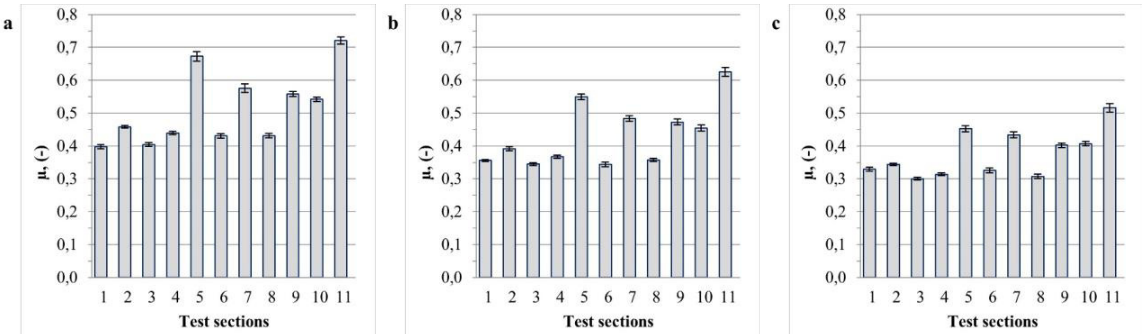

Fig. 5. Average values of μ at test speed (a) 30 kph; (b) 60 kph; (c) 90 kph with 95% confidence interval.

The lowest values of DFT20 were obtained on sections 6 and 8 built of AC, which are under traffic for the longest time. Additionally poor skid resistance could be a result of low polishing resistance of coarse aggregate. In these sections basalt and dolomite were used and these rocks are prone to polishing. Higher DFT20 were obtained on the section 9 built of AC but with PSV above 50, where traffic volume was the same as on section 8. AC on section 5 and 11 have the highest DFT20. But these are rural roads where traffic volume is very low. Currently SMA and AC with PSV of coarse aggregates above 50 are most common types of wearing course in Poland. But requirements of PSV were introduced in 2008. The results obtained in laboratory, which showed that SMA and AC with aggregate of the same PSV are characterized by different coefficients of friction (Gardziejczyk, Wasilewska, 2012). Slight differences of DFT20 values were observed for SMA. It should be noted that DFT20 of section 4 is higher than section 3 despite of the same heavy traffic and characteristic of wearing course. Slurry Seal have higher DFT20 than SMA. Despite of the fact they are built of basalt aggregate with PSV below 50. Good skid resistance of Slurry Seal is a result of positive profile texture.

SRT-3 device gives results with good repeatability. Their coefficients of variation *V* are below 5%. The differences of test results between particular surfaces have the same tendency regardless the test device – DFT or SRT-3. Only μ decrease with speed increase Regression relationship between coefficients of friction DFT20 and μ at three test speeds are presented in Fig. 6.

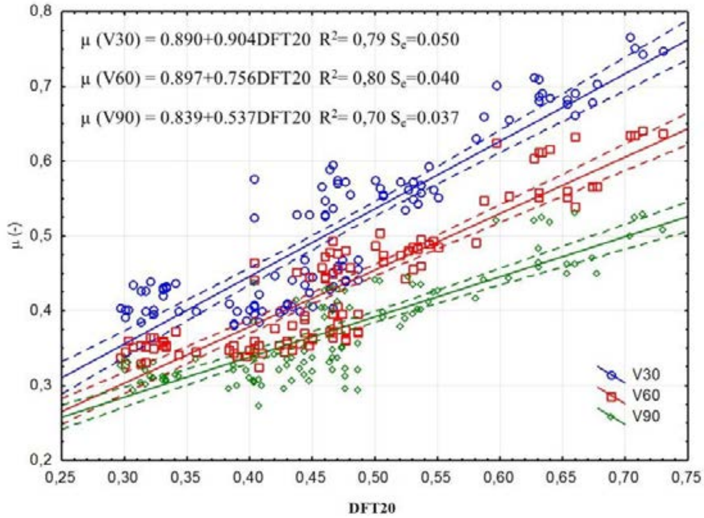

Fig. 6. Relationship between coefficients of friction DFT20and μ at 30, 60, 90 kph.

The relationship is strongly linear with a correlation coefficient R = 0.88 at 30 kph, R = 0.89 at 60 kph and R = 0.84 at 90 kph for 110 data points. It indicates that it would be possible to use DFT device as replacement for SRT-3 on those sites where measurements with SRT-3 are very difficult or impossible. It should be noted that good correlation between DFT20 and μ is a result of influence tire and method measurement of coefficient of friction by devices with locked wheel. Ribbed tire of SRT-3 devices is more sensitive to microtexture changes in the pavement but not to macrotexture (Roe et al., 1998, Hall et al., 2009) Furthermore locked wheel measurement is general not conclusive to reflect changes of both mictotexture and macrotexture.

4. Evaluation of skid resistance using IFI

Skid resistance was assessed based on IFI (International Friction Index). The IFI uses two parameters: Sp and F60 According to ASTM E1960 – 07 (2011) when CTM and DFT are applied these parameters are calculated from the following equations:

$$S_p = 14.2 + 89.7 \cdot MPD \tag{1}$$

$$F60 = 0.081 + 0.732 \cdot DFT20 \cdot EXE\left(\frac{-40}{S_p}\right) \tag{2}$$

Sp and F60 calculated on average values of MPD and DFT20 from test sections are presented in Table 6.

Table 6. Sp and F60 values.

Test sections No.	Sp	F60
1	144.9	0.315
2	106.4	0.311
3	94.0	0.275
4	93.5	0.303
5	57.0	0.302
6	92.1	0.231
7	103.3	0.323
8	74.2	0.220
9	51.8	0.260
10	142.0	0.329
11	64.5	0.336

When F60 and Sp parameters are known, coefficient of friction F(S) at any slip speed *S* can be predicted. Coefficient of friction F(S) at any slip speeds S was calculated from the formula:

$$\mathrm{F}(S) = F60 \cdot EXE\left[\left(60 - S\right) / S_p\right] \tag{3}$$

The calculation results are presented in Fig. 7.

It was found out that at low speed pavements made of AC (expect for section 6 and 8) had higher coefficient of friction than SMA. While SMA had higher coefficient of friction than AC at high speeds. It should be noted that PCC has got slightly higher result then SMA at high speed. It results from the fact that test section of exposed aggregate PCC was only three months under traffic. Coefficient of friction of section 11 is high both at low and high speed because of low traffic. Good results were obtained for Slurry Seal pavement both at low and high speed.

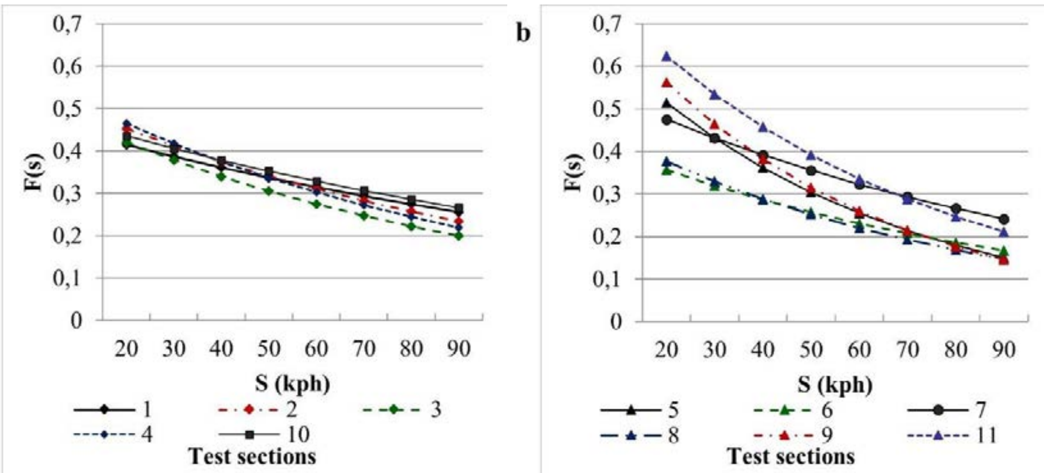

Fig. 7. Coefficient of friction F(S) at any slip speeds *S* (a) test sections: 1, 2, 3, 4 and 10; (b) test sections 5, 6, 7, 8, 9 and 11.

4. Conclusion

Microtexture and macrotexture have a major impact on skid resistance of road pavements. The measured values with the DFT and CTM devices were used to calculate the IFI, which takes into consideration these two surface characteristics. In contrast SRT-3 device solely does not allow to asses comprehensively skid resistance. That is why evaluation of skid resistance should be followed by macrotexture assessment by high speed devices on all types of roads. CTM and DFT devices could be used such spots like junctions, roundabouts or in low speed areas.

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