New Test Method for Measuring Friction Characteristics Between Asphalt Mixtures and Steel

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ABSTRACT: Friction between the steel parts of test device and the tested specimen occurs in many hot mix asphalt test methods. The paper deals with new device called Cylindrical Tribometr used for testing the friction characteristics between steel and hot mix asphalts developed at CTU in Prague. Evidence established by Cylindrical Tribometr can be used as input data characterizing boundary conditions in numerical modelling techniques for finding approximate solutions (FEM). The paper presents particular data of coefficient of friction between steel and hot mix asphalt. The dependence on slip rate, temperature and adhesion of asphalt binder is discussed in this contribution.

KEY WORDS: hot mix asphalt, FEM boundary condition, friction between two materials, Cylindrical Tribometr

1 FOREWORD

The friction between tested specimen made from Hot Mix Asphalt (HMA) and steel occurs in many of currently used test methods, therefore the measured results are affected by this friction. Nowadays this effect is snubbed in most of back calculation procedures. The inclusion of these phenomena should promote the accuracy of interpreted results. (Zak, J., 2011) The cause of this state seems to be test method unavailability and consequently lack of valuable data.

The aim of this contribution is to provide measured data on local common used HMA and description of testing procedure which can be used to measure friction characteristics between HMA and steel. This data can be used in Finite Element Modeling (FEM) to characterize the boundary conditions of modeled issue. The set of boundary conditions is compulsory part of every FEM to address the behavior of solution at the boundary of its domain.

Magnitude of influence of friction should be assessed for each test methodology individually and authors do not deal with this issue.

2 THE FRICTION PHENOMENA BETWEEN HMA AND STEEL DURING TESTING

One of the examples is Hamburg-Wheel Tracking Test. The slab specimen is fixed in 5 sides by steel mould. The wheel reciprocates over the test specimen with position varying sinusoidally over time and causing the permanent deformation in specimen. (ČSN EN 12697-22+A1, AASHTO T324-04) These permanent deformations are effected by friction characteristics of contact between steel and HMA specimen. The contact slip in lateral and transverse direction was modeled by the help of FEM and can be found in the literature (Zak, J., 2011). The trajectory of moving aggregates can be also clearly seen by laboratory technician on the top of the bottom mould steel desk after the end of the Wheel Tracking Test. As seen from figure 1, there is the upper part of the steel mould with significant white streaks caused by moving aggregates.

Let us therefore imagine that on all contact areas epoxy glue will be applied and then the specimen will be fixed in steel mould. In this case the permanent deformation during testing will occur only in HMA and results will surely differ from currently defined in standards.

On this example is show how the result of testing/back calculation simulation can differ by use of boundary conditions. Unfortunately the used approach of Finite Element Method modeling is based on characterization on the boundary conditions as stiff whereas this does not allow any deflection.

In the paper (Huurman, M. and Pronk, A.C., 2012) the accuracy of Four Point Bending test device is discussed on the basis of Finite Element Modeling. Boundary conditions are split into several parts and each is consequently taken in consideration. The authors also deal with the clamps effect and its local impact in restrain of beam's freedom of cross-section deformation. Also in this type of testing (with relatively small contact area between steel and HMA specimen) could inclusion of friction characteristics partly present a solution to irregularities from clamp forces.

Figure1: The steel mould with cannelures from the aggregates

3 CYLINDRICAL TRIBOMETR – TEST DEVICE

For the purpose of testing friction characteristics a test device called Cylindrical Tribometr was developed as a prototype at CTU in Prague. The cross section of the device is shown in the figure 2. Description of components is according to cross section: 1-Steel mould, 2-Steel specimen, 3-Lower steel cover, 4-Upper steel cover, 5-Hydraulic piston, 6-Steel frame, 7-Steel beam, 8-LVDT, 9-Steel hemisphere, 10-Piston of Universal Testing Machine (UTM).
The essence of the device is in pressing a sample of HMA onto the walls of the cylindrical steel mould.

The tested specimen is pressed in the longitudal direction with the pressure which is regulated by a hydraulic piston (5). Stretched specimen (2) in longitudinal direction expands in transverse direction due to the Poisson's effect and pushes its sides onto steel mould (1). This stress, between HMA specimen and steel mould (1), is in the sense of a consequent calculation of coefficient of friction normal stress. The sample is stabilized in its position with the help of upper and lower covers (3, 4) interconnected with stiff steel frame (6). The steel beam (7) with steel hemisphere (9) ensures steady distribution of applied load by the piston of UTM (10) on the steel mould (1). The LVDTs (8) are place outside of the steel mould (1) mounted on the frame (6), so that deformation of steel mould is measured inside this system. The device is at the moment protected by a national patent.

As stated, the normal stress between HMA specimen and steel mould depends on stress applied in longitudal direction on HMA specimen by hydraulic piston. The normal stress was set to 500kPa in accordance with stress between steel underlay desk and HMA slab in Hamburg-Wheel Tracking Test, (Zak, J., 2011).

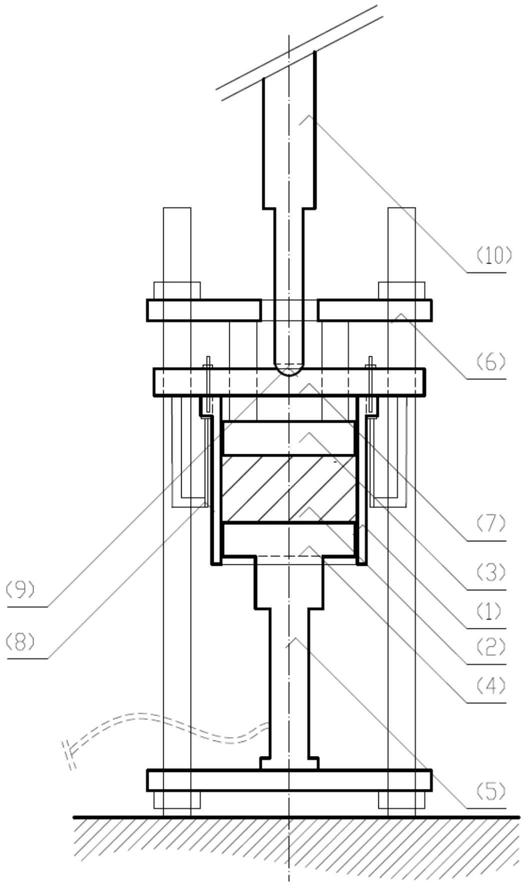

Figure 2: The Cylindrical Tribometr

3.1 Testing procedure

As was stated, the testing device is new so for its application it was necessary to develop a definite testing procedure. The key aspects of the testing procedure are described further.

Specimen preparation:

The specimens at high of 135mm where prepared in Superpave Gyratory Compactor according to (*AASHTO T312-11)*. These specimens were catted with a laboratory saw for half to obtain two pieces of tested specimens from one manufactured specimen. The dimensions of tested specimens were then 100mm diameter and 65mm high. After cutting the specimens were dried with paper towels and deposited for two days at laboratory temperature for rest.

Testing:

1) The hole testing device was placed into air conditioned box with temperature control system capable of controlling the temperature within ± 1°C, the specimens were also in the same box.

2) The temperature was maintain for 2 hours before starting the test and then during the hole testing procedure.

3) The specimen was placed between two steel covers and the steel mould was raised so that the specimen was at least 30mm under the upper level of steel mould. Then the pressure was raised in system to 200Pa by use of hydraulic pump.

4) As the specimen is deformed in steel mould the pressure decreases, so the pressure is maintained in 200Pa by gradually pumping. It was found that after 12 minutes the pressure reaches its equilibrium state.

5) Both LVDTs were placed to its position during testing.

6) The steel beam with steel hemisphere was placed on the top of the steel mould.

7) This assembly is ready to test the friction characteristics. In our case load represented by constant slip rate controlled by UTM was applied.

4 RESULTS

The results are presented in the form of coefficient of friction (CoF) as dimensionless scalar. This characteristic was chosen for its useful implementation in FEM. (*ABAQUS Theory Manual*, 2009) Calculation of CoF is described by the equation (E1), where F_f is frictional force applied by UTM on the steel mould, A_x is the base area of the specimen, ν is Poisson's ratio, F_x is force exerted by the hydraulic pump, A_y is the area of lateral surface of the specimen.

As a representative of assessed material asphalt concrete (type ACO 11+) for wearing course was selected. Maximum grain size was 11mm, binder content 5.2%, air voids 3.5%. The mix was designed in accordance with (*AASHTO T312-11)*.

To neglect the effect of selected Poisson's ratio constant value of 0.35 was used for all temperatures. This value was chosen as the HMAs equilibrium Poisson ratio according to 12minutes loading time.

The effect of slip rate was assessed also in dependence on slip rate in this contribution. All the tests were done at slip rate 0.1, 0.25, 0.5 and 1 mm/s. The trend between slip rate and CoF at given temperature was not found therefore the effect of slip rate on results was not proved.

In the figures 3 and 4 measured data are presented. In this contribution data from 44 samples are used and evaluated. The data are presented in Box-Whisker Plot to show its distribution. The average values marked as diamond points are express also with a value on the right side.

The effect of temperature on the CoF is seen in both figures (3 and 4). As the temperature increase, the CoF also significantly increase. The authors believe that this is due to activation of adhesion with rising temperature nevertheless this hypothesis has to be proven in the future. This was observed also during the heating and manipulation with specimen. As the temperature increase to 60°C the surface of specimen begins to stick to the fingers and must be handled only with grasping the bases.

In terms of the adhesion difference between assessed HMA and used bituminous binder can be also expressed. The HMA ACO 11+ 50/70 (50/70 is a standard bituminous binder with lower penetration and softening point used traditionally for most asphalt mix applications in the Czech Republic) has smaller CoF than ACO 11+ 20/30 (20/30 is a bituminous binder with higher penetration and softening point). The ring and ball test indicates softening point which is linked to processing temperature and adhesion at a given temperature.

$$\mu = \frac{F_f * A_x}{-\mathcal{V} * F_x * A_y} \tag{E1}$$

Temperature	Slip rate	Fx	Ff	Coefficient of friction
[°C]	[mm/min]	[kN]	[kN]	[-]
30	0.1	-12.006	0.2230	0.0204
	0.1		0.6350	0.0581
	0.25		0.1572	0.0144
	0.5		0.4378	0.0401
	0.5		0.4520	0.0414
	1		0.4085	0.0374
45	0.1		0.5497	0.0503
	0.1		0.5659	0.0518
	0.25		0.5860	0.0536
	0.25		0.6106	0.0559
	0.5		0.6624	0.0606
	0.5		0.5033	0.0461
	1		0.6269	0.0574
60	0.1		0.6970	0.0638
	0.1		0.7570	0.0693
	0.25		1.0800	0.0989
	0.25		0.9586	0.0877
	0.5		0.5395	0.0494
	0.5		0.5929	0.0543
	1		0.6696	0.0613
	1		0.6538	0.0598

Table 1: Measured data of coefficient of friction in dependence on temperature for ACO 11+ with bituminous binder 20/30.

Temperature	Slip rate	Fx	Ff	Coefficient of friction
[°C]	[mm/min]	[kN]	[kN]	[-]
30	0.02	-12.006	0.5474	0.0501
	0.02		0.4512	0.0413
	0.25		0.5302	0.0485
	0.25		0.4516	0.0413
	0.5		0.8843	0.0809
	0.5		0.2105	0.0193
	1		0.5474	0.0501
	1		0.6515	0.0596
45	0.1		1.1144	0.1020
	0.1		0.6984	0.0639
	0.25		1.2236	0.1120
	0.25		1.0479	0.0959
	0.5		0.4610	0.0422
	0.5		0.7756	0.0710
	1		1.3780	0.1261
	1		1.0449	0.0956
60	0.1		1.3095	0.1199
	0.1		1.2435	0.1138
	0.25		1.3132	0.1202
	0.25		1.2695	0.1162
	0.5		1.6938	0.1550
	0.5		1.6171	0.1480
	1		0.8271	0.0757

Table 2: Measured data of coefficient of friction in dependence on temperature for ACO 11+ with bituminous binder 50/70.

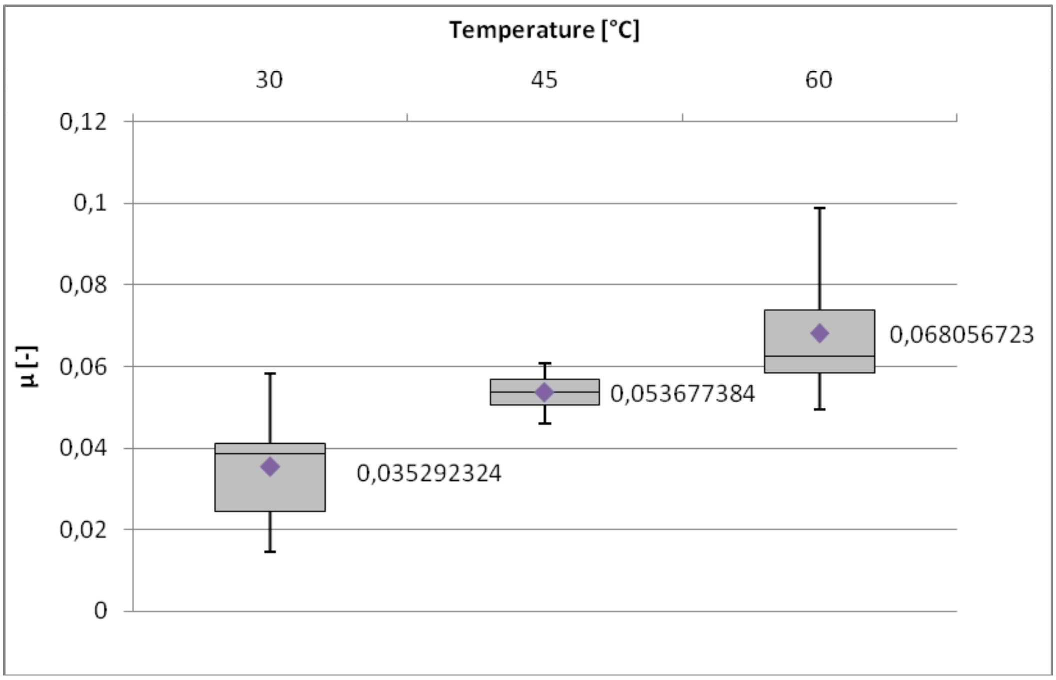

Figure 3: Coefficient of friction in dependence on temperature for ACO 11+ with bituminous binder 20/30.

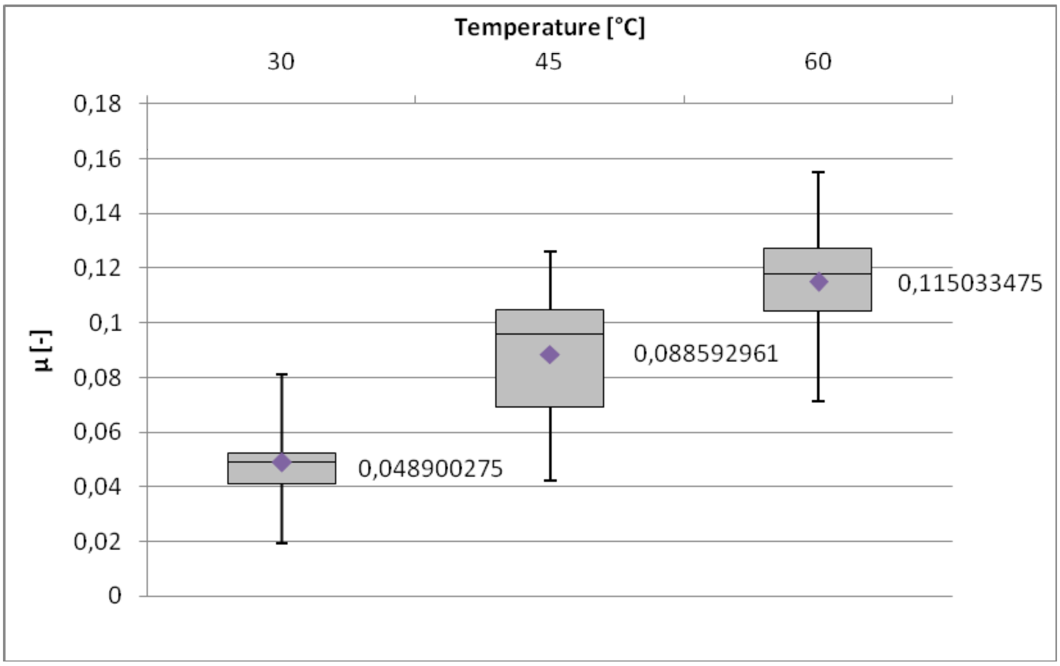

Figure 4: Coefficient of friction in dependence on temperature for ACO 11+ with bituminous binder 50/70.

5 CONCLUSION

The new simple test device and test methodology is described in this paper for determining the friction characteristics between steel and HMA.

As the crucial expression of gained results coefficient of friction was chosen because of its usefulness as input characteristics for contacts between two materials in Finite Element Modeling.

In this contribution particular data of coefficient of friction for asphalt mixture type ACO 11+ with two different asphalt binders (20/30, 50/70) are presented and summarized.

As a the key factor on measured coefficient of friction bituminous binder adhesion at tested temperature can be seen. The temperature effect on measured coefficient of friction was discussed in this paper. In the range of tested temperatures from 30°C to 60°C the coefficient of friction increased with increasing test temperature.

The dependence of coefficient of friction on slip rate was assessed as part of research project by testing at range of slip rate from 0.1 to 1mm/s. The influence of slip rate on CoF was not proved.

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