

# Evaluation of Skid Resistance of Wearing Course Made of Stone Mastic Asphalt Mixture in Laboratory Conditions

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**Abstract.** This paper presents the comparison of skid resistance of wearing course made of SMA (Stone Mastic Asphalt) mixtures which differ in resistance to polishing of coarse aggregate. Dolomite, limestone, granite and trachybasalt were taken for investigation. SMA mixtures have the same nominal size of aggregate (11 mm) and very similar aggregate particle-size distribution in mineral mixtures. Tested SMA11 mixtures were designed according to EN 13108-5 and Polish National Specification WT-2: 2014. Evaluation of the skid resistance has been performed using the FAP (Friction After Polishing) test equipment also known as the Wehner/Schulze machine. Laboratory method enables to compare the skid resistance of different types of mixtures under specified conditions simulating polishing processes. Tests were performed on both the specimens made of each coarse aggregate and SMA11 mixtures containing these aggregates. Measuring of friction coefficient  $\mu_m$  was conducted before and during polishing process up to 180 000 passes of polishing head. Comparison of the results showed differences in sensitivity to polishing among particular mixtures which depend on the petrographic properties of rock used to produce aggregate. Limestone and dolomite tend to have a fairly uniform texture with low hardness which makes these rock types susceptible to rapid polishing. This caused lower coefficient of friction for SMA11 mixtures with limestone and dolomite in comparison with other test mixtures. These significant differences were already registered at the beginning of the polishing process. Limestone aggregate had lower value of  $\mu_m$  before starting the process than trachybasalt and granite aggregate after its completion. Despite the differences in structure and mineralogical composition between the granite and trachybasalt, slightly different values of the friction coefficient at the end of polishing were obtained. Images of the surface were taken with the optical microscope for better understanding of the phenomena occurring on the surface of specimen. Results may be valuable information when selecting aggregate to asphalt mixtures at the stage of its design and maintenance of existing road pavements.

## 1. Introduction

Skid resistance plays an important role in reducing road accidents in wet conditions. It influences keeping vehicles on the road, as it gives drivers the ability to manoeuvre their vehicles in a safe manner. Skid resistance is related to pavement surface texture which includes the wavelength ranges described by macrotexture and microtexture. Macrotexture depends on a type of asphalt mixture in particular the contents of the individual aggregate fractions or texturing method of concrete pavement. While microtexture depends on changes of aggregate surface used for wearing coarse under the actual traffic conditions. It is mainly related to the polishing of the coarse aggregate which depends on the hardness of minerals, texture, structure of rocks [1,2]. Due to the fact that the texture is related to the



characteristic of the wearing course, it is necessary to evaluate the skid resistance at the stage of its design. This may allow to avoid the use of materials that would contribute to the slipperiness of the road pavement.

Different methods have been developed to check the suitability of individual technologies for the wearing course. The advantage of these methods lie in comparing and ranking of different types of mixtures in relation skid resistance under the same polishing procedure in laboratory. These methods consist of two stages. In the first one it is a simulation of the polishing phenomenon that occurs on the surface under the influence of tires, water and fine impurities is conducted. And then the friction coefficient is measured. The methods differ from the polishing procedure and the equipment used to measure friction coefficient [3,4,5,6,7]. The FAP (Friction After Polishing) test equipment popularly known as the Wehner/Schulze machine is the most used in Europe. It was developed in Germany over 30 years ago. In 2014 the method was adopted as a harmonized European Standard EN 12697-49 as the Friction after Polishing test [8]. The device simulates the phenomenon of polishing on the wearing course. Rubber cones under the influence of water and quartzite powder polish the surface of the specimen. Then coefficient friction is measured. In the actual conditions on the wearing course, such as weathering, abrasion, aging of the asphalt binders are also occurring. Studies on the simulation of these phenomena in laboratory conditions and their effect on skid resistance are presented in the paper [9]. Due to cost, the FAP test equipment is not widely used in most European countries. However, there are many publications available for the assessment of wearing course commonly constricted in particular the countries [3,5,10,11].

SMA (Stone Mastic Asphalt) is the most popular mixture intended for wearing courses of road pavement for medium and heavy traffic loads in Poland. The primary advantage of wearing course made of SMA is better resistance to permanent deformation than conventional dense-graded asphalt mixtures. This is possible because the SMA is characterized by a strong skeleton due to the high content of coarse aggregate in the mineral mixture (from 70 to 80%). It causes high macrotexture of wearing course made of SMA mixtures. This is important for good skid resistance at high slip speeds. Whereas low amount of fine aggregates in mineral mixtures causes that changes microtexture is almost completely dependent on resistance to polishing of coarse aggregates. It should be noted that microtexture affects skid resistance both at low and high slip speeds. Currently in Poland only at the stage of designing of wearing course the criteria for the *PSV* (Polished Stone Value) of coarse aggregate is required. It is used as an indirect method to assess microtexture. Aggregate with the minimum *PSV* 50 should be used for wearing course of pavement for medium and heavy traffic loads and minimum *PSV* 44 for low traffic loads. The *PSV* test is the most commonly applied method to determine the resistance to polishing of aggregates in laboratory conditions. However, it does not allow to evaluate effect of resistance to polishing of aggregate on skid resistance of road pavement [5,6,10]. Additionally, it is proven that friction coefficient has lower values on bends and junctions than on straight road segments on the same type of pavement. It is due to the fact that these segments the frequency of braking is higher [12]. Therefore, studies have been carried out to show the differences between skid resistance of SMA mixtures subjected to the same polishing simulation in laboratory using aggregates with *PSV* above and below the limit value.

This paper presents the comparison of skid resistance of wearing course made of SMA mixtures which differ in the resistance to polishing of coarse aggregate using the FAP test equipment.

## 2. Research program

### 2.1. Coarse aggregate

In this study coarse aggregates from dolomite, limestone, granite and trachybasalt were used. Their selection depended both on petrographic characteristics of rocks and physical properties (Table 1 and Table 2). The selected aggregate differ in resistance to polishing, which was determined on the basis of the *PSV*. In the case of granite and trachybasalt aggregate their properties are very similar, but the

decision was made to include into studies also these two types of aggregates due to the differences in rocks structure.

**Table 1.** Aggregate characteristics

Rock type	Genetic classification	Structure
<b>Dolomite</b>	Sedimentary	Crystalline
<b>Limestone</b>	Sedimentary	Crystalline
<b>Granite</b>	Igneous	Holocrystalline
<b>Trachybasalt</b>	Igneous	Hypocrystalline

**Table 2.** Physical properties of coarse aggregate

Properties	Test method	Dolomite	Limestone	Granite	Trachybasalt
<b>Resistance to polishing, <math>PSV</math> [-]</b>	EN 1097-8	44	36	52	53
<b>Resistance to wear, <math>M_{DE}</math> [%]</b>	EN 1097-1	10	16	9	8
<b>Resistance to fragmentation, <math>LA</math> [%]</b>	EN 1097-2	15	27	25	12
<b>Resistance to freezing and thawing, <math>F_{NaCl}</math> [%]</b>	EN 1367-6	5	15	1	1
<b>Density, <math>\rho_a</math> [Mg/m<sup>3</sup>]</b>	EN 1097-6	2.74	2.67	2.66	2.70
<b>Water Absorption, <math>WA_{24}</math> [%]</b>	EN 1097-6	0.8	1.9	0.5	0.5

## 2.2. SMA mixtures

Tested SMA11 mixtures with four types of coarse aggregate were designed according to EN 13108-5 and Polish National Specification WT-2: 2014. For all mixtures asphalt binder PMB 45/80-55 was used. Each of SMA11 mixtures was designed with the similar aggregate particle-size distribution (Table 3). Volumetric parameters of SMA11 mixtures are presented in Table 4.

**Table 3.** Aggregate particle size distribution

Sieves [mm]	Passing fraction [%]			
	Dolomite	Limestone	Granite	Trachybasalt
<b>16</b>	100	100	100	100
<b>11.2</b>	96	92	99	92
<b>8</b>	59	57	50	57
<b>5.6</b>	41	41	38	41
<b>4</b>	28	32	32	32
<b>2</b>	23	23	23	23
<b>0.125</b>	11	11	11	11
<b>0.063</b>	9.0	9.0	9.0	9.0

**Table 4.** Volumetric parameters of SMA11 mixtures and their asphalt binder content.

Parameters	Test method	Dolomite	Limestone	Granite	Trachybasalt
<b>Density <math>\rho_m</math> [Mg/m<sup>3</sup>]</b>	EN 12697-5	2.460	2.340	2.370	2.417
<b>Bulk density <math>\rho_{bssd}</math> [Mg/m<sup>3</sup>]</b>	EN 12697-6	2.400	2.290	2.300	2.361
<b>Air voids <math>V_m</math> [%]</b>	EN 12697-8	2.5	2.1	3.0	2.3
<b>Voids filler with binder <math>V_{FB}</math>, [%]</b>	EN 12697-8	85.4	87.3	83.5	86.7
<b>Voids in mineral aggregate <math>V_{MA}</math>, [%]</b>	EN 12697-8	17.4	16.8	17.9	17.4
<b>Asphalt binder content <math>B</math>, [%]</b>	-	6.4	6.6	6.7	6.6

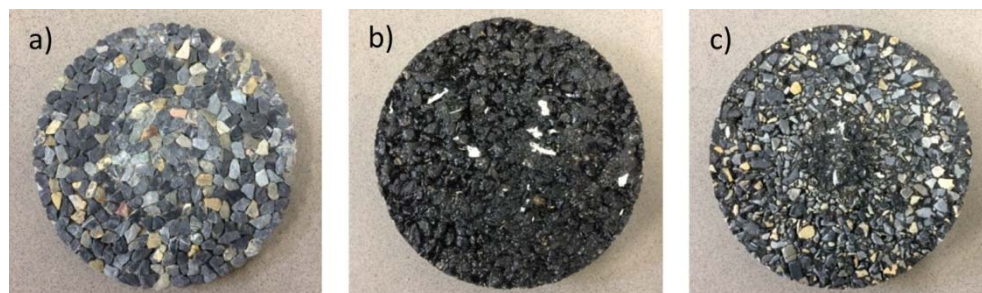
### 2.3. Test procedure

The FAP equipment (figure 1a) consists of two heads: for polishing and for measurement of friction coefficient  $\mu_m$ . The polishing action is performed by means of three rubber cones mounted on rotary disc and rolling on the specimen surface (figure 1b). A water-quartz powder mix is projected during the polishing process. The second measuring head is composed of three small rubber sliders disposed at  $120^\circ$  on the rotary disc (figure 1c). The disk rotates at tangential velocities up to 100 kph. Water flows over the surface being tested. The rotating disk is then dropped onto the wet surface and the coefficient of friction  $\mu_m$  is measured. Measuring of  $\mu_m$  was conducted before polishing and after 2000, 4000, 6000, 8000, 10 000, 20 000, 40 000, 60 000, 80 000, 100 000, 160 000, 180 0000 passes of polishing head. In this study coefficient of friction  $\mu_m$  at slip speed 60 kph was taken. Before starting the test, the function of the measuring device was tested using the glass control plate (figure 1 d). If the results of coefficient of friction  $\mu_{ref}$  is not in the range from 0.096 to 0.126, the rubber sliders should be exchanged.



**Figure 1.** a) The FAP test equipment b) polishing rotary head, c) friction measuring rotary head, d) glass control plate

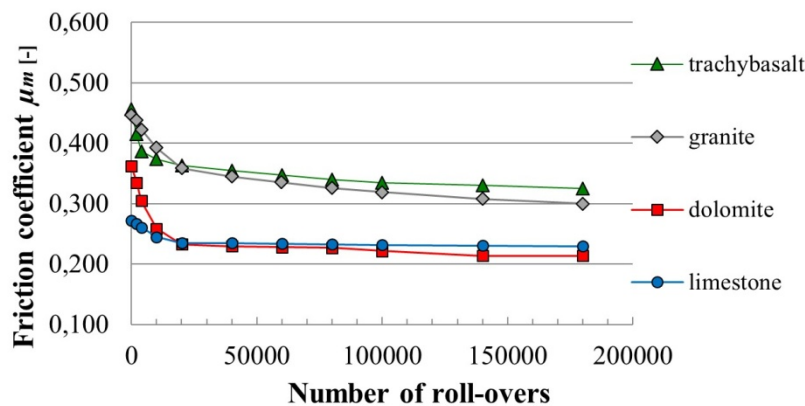
Three specimens from each type of coarse aggregate and mixture were made. In the case of new asphalt specimens, bitumen from aggregates should be removed by using the grid blasting cabinet. Exemplary specimens of coarse aggregate and SMA11 mixtures are shown in figure 2.



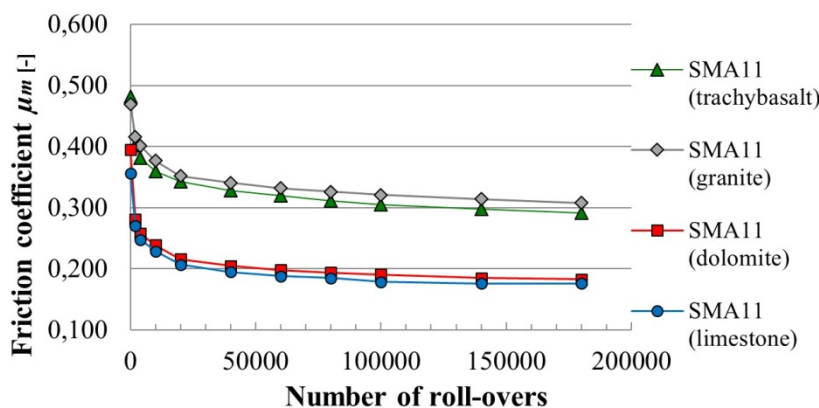
**Figure 2.** Specimens a) dolomite aggregate b) SMA11 before grinding c) SMA11 at the end of polishing process

### 3. Results and discussions

The results of friction coefficient  $\mu_m$  of coarse aggregate and SMA11 mixtures during polishing process are presented in figure 3 and 4.



**Figure 3.** Changes of friction coefficient  $\mu_m$  of coarse aggregate in polishing process



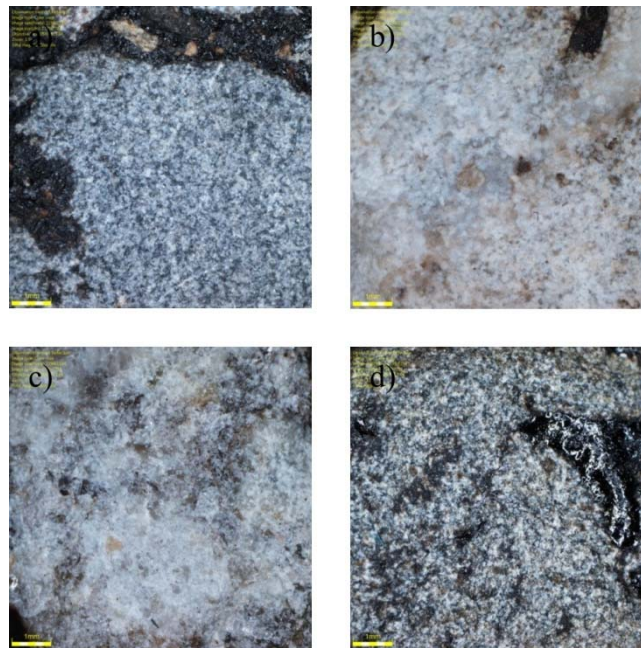
**Figure 4.** Changes of friction coefficient  $\mu_m$  of SMA11 mixtures in polishing process

Before polishing process each aggregate is characterized by higher values of  $\mu_m$  than at the end of polishing process. It is related to the structure of rocks and the mechanical properties of particular minerals (cleavage or fracture). But significant differences were noted among tested aggregates. The highest values of  $\mu_m$  both before and after polishing were received for granite and trachybasalt aggregate. The lowest value of  $\mu_m$  was obtained for limestone and dolomite. It should be noted that limestone aggregate had lower value of  $\mu_m$  before starting the process than trachybasalt and granite aggregate after its completion. Dolomite and limestone aggregates were affected by polishing more quickly the granite and trachybasalt. It is due to the soft mineral content and structure of the rock which aggregate produced. In the case of resistance to polishing on the basis of the PSV dolomite and limestone differ from each other (table 2). But in the case of  $\mu_m$  the significant differences were not registered. This may be related to some differences in the procedures of these tests. However, a study showed good correlation between results from the PSV test and the FAP test [5].

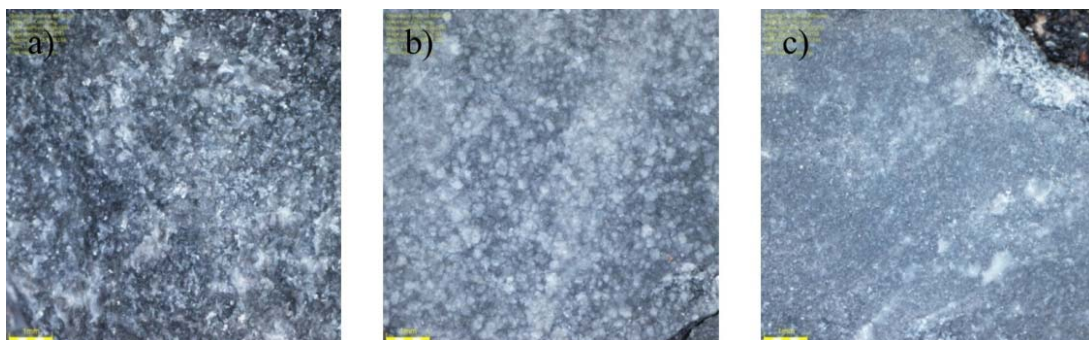
A similar trend was observed for  $\mu_m$  values obtained for SMA11 mixtures with tested aggregates. The highest values of  $\mu_m$  were obtained for all tested SMA11 before test. Because prior to polishing the surfaces of specimens were subjected to treatment consisting in grinding using a pressurized stream of corundum fed. If the treatment had not have been performed, the asphalt layer would not be removed from the aggregate grains. It is supposed to simulation the phenomena abrasion in actual road



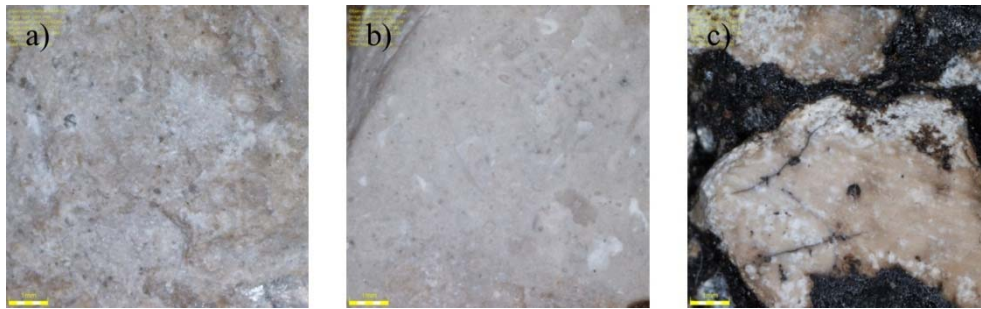
traffic conditions. This has a significant effect on the coefficient of friction particularly in the case of mixtures with modified and highly modified asphalts [13]. But on the basis of observations of images of surfaces of grains from these aggregates it was noticed that minerals changed their original appearance. This is visible when comparing images of surfaces of aggregate after grinding of SMA11 specimens (figure 5) with surfaces of aggregate specimens before test (figure 6a - 9 a). The surfaces of each type of aggregates after grinding are mat and have numerous abrasion marks. Also images of surface of coarse aggregate specimens (Figure 6b – 9 b) and surface of aggregate in SMA11 specimen at the end of the test (Figure 6c – 9 c) were made using the optical microscope.



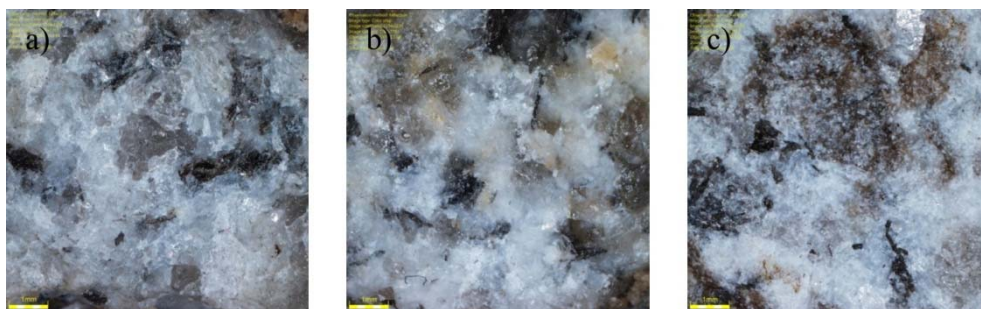
**Figure 5.** Surfaces aggregates after grinding of SMA11 specimens a) dolomite, b) limestone, c) granite, d) trachybasalt



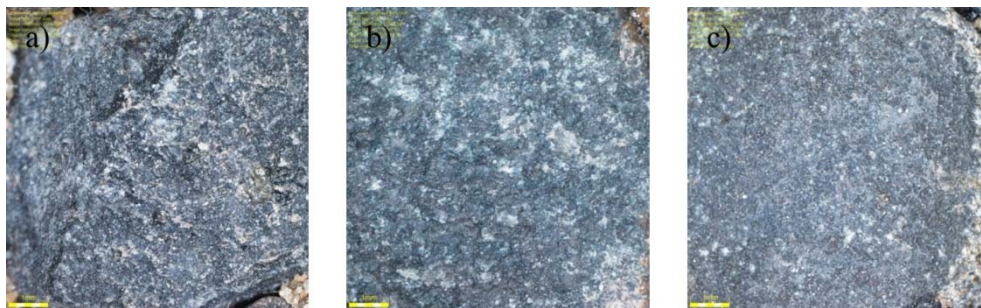
**Figure 6.** Surface of dolomite aggregate a) before, b) after polishing; c) in SMA11 mixture after polishing



**Figure 7** Surface of limestone aggregate a) before, b) after polishing;  
c) in SMA11 mixture after polishing



**Figure 8** Surface of granite aggregate a) before, b) after polishing;  
c) in SMA11 mixture after polishing



**Figure 9** Surface of trachybasalt aggregate a) before, b) after polishing;  
c) in SMA11 mixture after polishing

The significantly changes due to polishing can be noticed on these images. It should be noted that due to the shape of the aggregate grains, the polishing process occurs only on a part of aggregate grains which has direct contact with the rubber cones. This has been proved by image analysis [14]. There are more glossy areas, which are typical for polished surface of minerals on aggregate grain in the case of aggregates specimens than for SMA11 specimens (images b) vs c) on figures 6 - 9). In future studies it would be useful to evaluate the impact of the initial grinding on the microtexture in relation to different types of aggregates and its impact on skid resistance. The effect of aggregate resistance to polishing caused that friction coefficients of SMA11 with trachybasalt and granite higher about 0.1 unit than coefficients of mixtures with limestone and dolomite.

#### 4. Conclusions

The FAP test equipment enables to compare the skid resistance of different types of mixtures under the specified conditions simulating polishing processes. Tested SMA11 had the similar aggregate particle-size distribution in mineral composition and the same type of asphalt binder. The only

variable in this research was aggregate resistance to polishing. Performing of such experiment in actual conditions is very difficult. It has been shown that the friction coefficient of SMA11 mixtures with limestone and dolomite is significantly lower than for SMA11 with granite and trachybasalt aggregate. Because of this fact it is important to determine the friction coefficient before construction of wearing course to avoid the use of materials that could contribute to the slipperiness of the road pavement especially on sections where polishing by traffic is more intensive (junction, roundabout and crossing approaches or bends).

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