Asphalt mixture performance and testing

Possibilities of optimizing the Wehner/Schulze method (FAP) for skid resistance prognosis of asphalts

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Abstract

Every road user expects a skid resistance road surface, even in wet conditions. To achieve this, it is necessary to ensure that the specified requirements for skid resistance are met throughout the entire service life of a road surface. The "Determination of friction after polishing (FAP)" (EN 12697-49) is provided in the currently valid versions of EN 13108: "Bituminous mixtures — Material specifications", categories FAPmin for the "minimum friction after polishing ", which are based on experience in various countries, are listed. In a research project, the skid resistance of 21 asphalt surfaces was investigated. A further test was then carried out on individual sections after a service life of three years. It was demonstrated that the application of an additional mechanical load in excess of the 90.000 passes specified in EN 12697-49 resulted in a further reduction in skid resistance. The investigations confirm that a "final FAP)" can only be determined unerringly after at least 270.000 passes. The investigations also show that the sample preparation to be carried out in accordance with EN 12697-49 is not sufficient for the Wehner/Schulze method. For this reason, a specific sample preparation was developed, which can be applied to every test specimens. The developed test system provides practical and reproducible results that allow a skid resistance prognosis of asphalts before a construction project starts. In order to be able to reliably guarantee the requirements for skid resistance at the end of the service life, it is recommended to require a final FAP of more than 0.25 after 270.000 passes. The minimum categories specified in the European asphalt standards are not sufficient here. With the proposed system, the construction and asphalt industry can integrate the friction after polishing into the asphalt design and thus offer the road construction administration unerringly skid resistance asphalts.

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4. INTRODUCTION

The test method "Determination of Friction after Polishing (FAP)" (EN 12697-49 [1]) is the first standardised laboratory method to predict the skid resistance prognosis of asphalt on a laboratory scale. Categories FAP_{min} for the "Minimum Friction after Polishing" are specified in the currently valid versions of EN 13108-1; -5 and -7: "Bituminous mixtures - Material specifications" [2, 3, 4]. These categories are based on experience in the various countries listed in the standards. These requirements have not yet been considered in Germany as a basis of contracts.

Control tests to check these possible requirements can be carried out using representative samples, test specimens made of asphalt mixed in the laboratory or specimens obtained from drilled cores. The asphalt surfaces produced in the laboratory usually require preparation. Previous research work [5, 6] has shown that the method of test specimen preparation has a significant effect on skid resistance. The skid resistance determined on laboratory specimens does not always correspond to that of drilled cores.

To make an accurate skid resistance prognosis for a given asphalt surface, it is necessary to develop a practical laboratory method for sample preparation which realistically produces the actual surface condition for the prediction time in question. The method should deliver reproducible results.

5. EXAMINATION METHOD

5.1 Creation of an evaluation background

An evaluation background had to be created for the types and sorts of asphalt used in Germany with regard to their skid resistance behaviour. For this purpose, the **skid resistance** and the **mean profile depths** for three different stages (EP, MW, BK) were determined and statistically evaluated on 21 construction sites [8] distributed throughout Germany.

In 16 cases the tests were performed using Stone Mastic Asphalt (5 x SMA 11 S, 2 x SMA 8 LA, 9 x SMA 8 S). In four cases an Asphalt Concrete (3 x AC 11 D S, 1 x AC 11 D N) was considered and a Mastic Asphalt MA 5 S was used once.

- The stage **(EP)** represents the asphalt mixture design. The asphalt mix and the test specimens were produced in the laboratory.
- In stage **(MW),** the asphalt mix produced in the asphalt mixing plant was removed during paving and used to prepare test specimens in the laboratory.
- In stage **(BK)**, drilled cores were taken at the points where the asphalt mix from stage **MW** had previously been removed.

Furthermore, in [9] it was clarified whether the surface conditions of the specimens tested in the laboratory simulate the actual condition of the road owing to the action of the environment and traffic over time. For this purpose, drilled cores (stage BK-3J) were extracted from seven test sites after a three year`s traffic load.

Contrary to the specifications in EN 12697-49 [1], which requires a skid resistance measurement after 90.000 wheel passes, the surface of the drilled core / test body was polished to a final pavement skid resistance of a least 270.000 passes [5]. In addition, the skid resistance of the asphalt surface were determined after significantly shorter stress levels intervals, especially at the beginning of skid resistance evolution.

The **pavement skid resistance development** (Figure 1) was approximated by a logarithmic function depending on the number of wheel passes (duration of stress) until the stress level was reached the **final pavement skid resistance (**$\mathbf{PWS_{270}}$) after 270.000 passes [5].

The **texture (Mean Profile Depth (MPD)) measurement** was carried out using ELAtextur®. The measuring instrument used was modified to a measuring circle with a diameter of 180 mm (Figure 2) which corresponds exactly to the diameter of the rotating head with the three sliding blocks which is lowered onto the watered surface to be tested during the skid resistance measurement according to EN 12697-49 [1].

5.2 Variation in asphalt composition

The effect of asphalt composition on skid resistance was examined using the two asphalt types SMA 8 S and AC 11 D S each with eight variations in composition and type testing of the original mixture (Table 1) [9]. In order to achieve the greatest possible spread of the final pavement skid resistance, the variations corresponded to the calculated boundary values (extreme values) for the parameters (bitumen content, filler content, content of fine and coarse aggregate) which resulted from the initial test and the tolerances of the national technical regulations ZTV Asphalt-StB 07/13 [10].

The surfaces of the test specimens were prepared with sandblasting as defined in EN 12697-49 [1], the skid resistance development and the change in the texture were determined and recorded until the final pavement skid resistance (PWS_{270}) was reached after 270.000 passes [5].

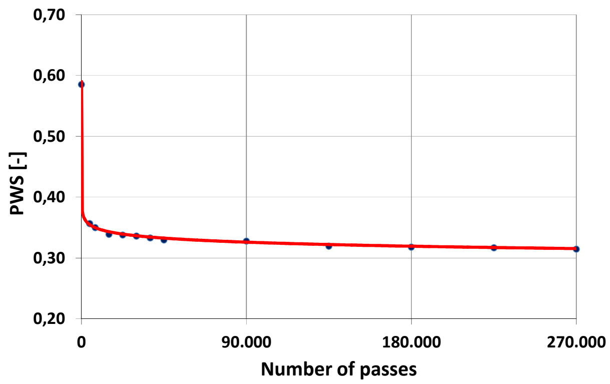

Figure 1: Logarithmic pavement skid resistance development PWS

Figure 2: Modified ELAtextur® measuring instrument

Table 1: Compilation of asphalt variations for asphalt types SMA 8 S and AC 11 D S

Variation	Asphalt	Variations in asphalt composition Difference from type testing
9-0	SMA 8 S	type testing
9-1		+ 0,4 wt.% bitumen
9-2		- 0,4 wt.% bitumen
9-3		+ 3,0 wt.% filler
9-4		- 3,0 wt.% filler
9-5		+ 8,0 wt.% fine aggregates
9-6		- 8,0 wt.% fine aggregates
9-7		+ 8,0 wt.% coarse grain
9-8		- 8,0 wt.% coarse grain
14-0	AC 11 D S	type testing
14-1		+ 0,4 wt.% bitumen
14-2		- 0,4 wt.% bitumen
14-3		+ 3,0 wt.% filler
14-4		- 3,0 wt.% filler
14-5		+ 8,0 wt.% fine aggregates
14-6		- 8,0 wt.% fine aggregates
14-7		+ 5,0 wt.% coarse grain
14-8		- 5,0 wt.% coarse grain

6. RESULTS

6.1 Results of the investigations on skid resistance prognosis - evaluation background

For the 21 construction sites, the skid resistance PWS after 90.000 passes PWS_{90} (light columns) and 270.000 passes PWS_{270} (dark columns) in stages the EP, MW and BK are shown in Figure 3. It can be seen that the final pavement skid resistance PWS_{270} after 270.000 passes (single value) are up to 0.029 units below the skid resistance PWS_{90} after 90.000 passes. It could be shown that the application of an additional mechanical stress, over the 90.000 passes provided according to EN 12697-49 [1], results in a further reduction in skid resistance. The investigations confirm the results of an older research investigation [5] that a "final pavement skid resistance (final polishing value)" can only be determined after at least 270.000 passes.

The results for the final pavement skid resistance PWS_{270} are shown here as an example for the SMA 11 S in Figure 4. If the final pavement skid resistance determined on the stages of a site spread by more than 0.010 units, the stages are assigned to different levels. The final pavement skid resistance of the stage BK (drill cores) always have the highest value regardless of the section, i.e. the asphalt design.

The mean final pavement skid resistance for the BK stage is mostly above the average of the EP (type test) or MW (mixing plant) stages which are at a similar level.

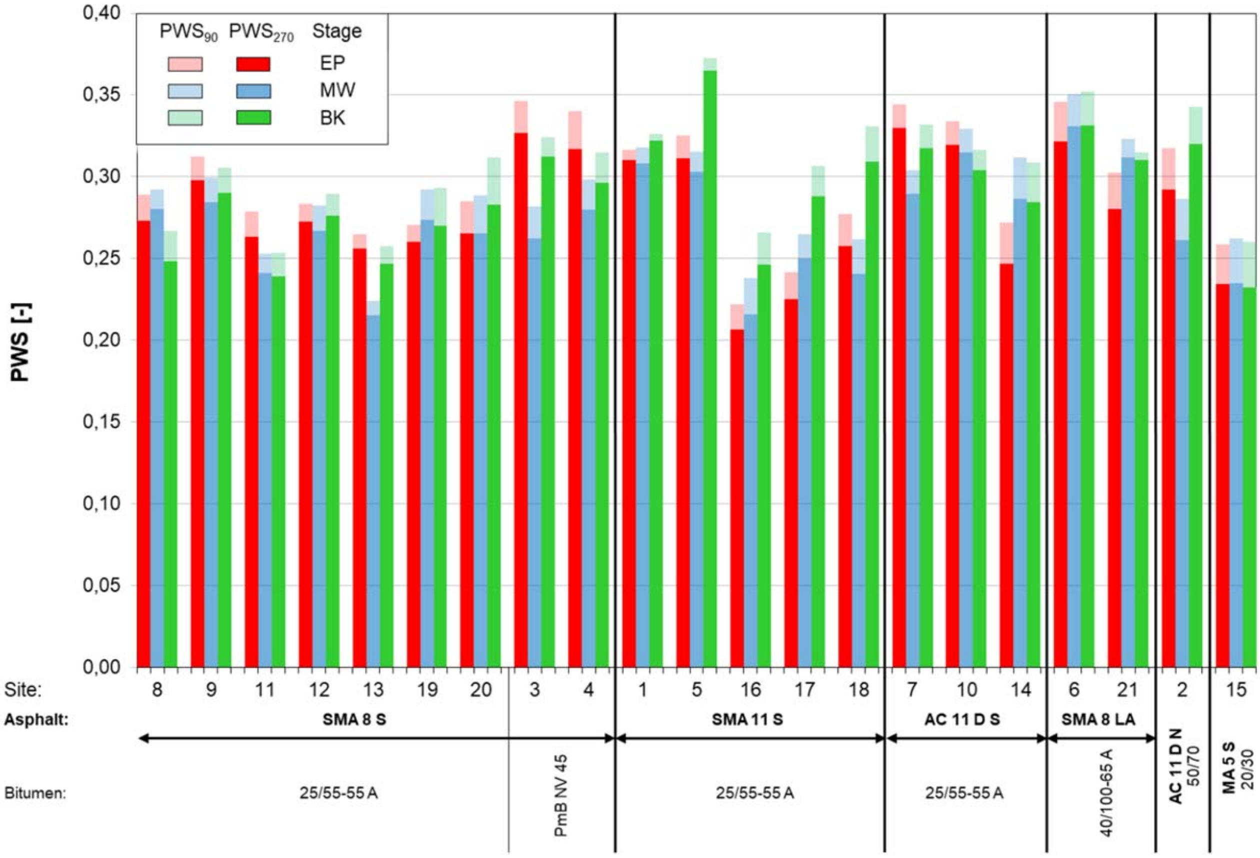

Figure 3: Skid resistance after 90.000 (PWS_{90}) or 270.000 (PWS_{270}) passes grouped in asphalts for all construction sites [8]

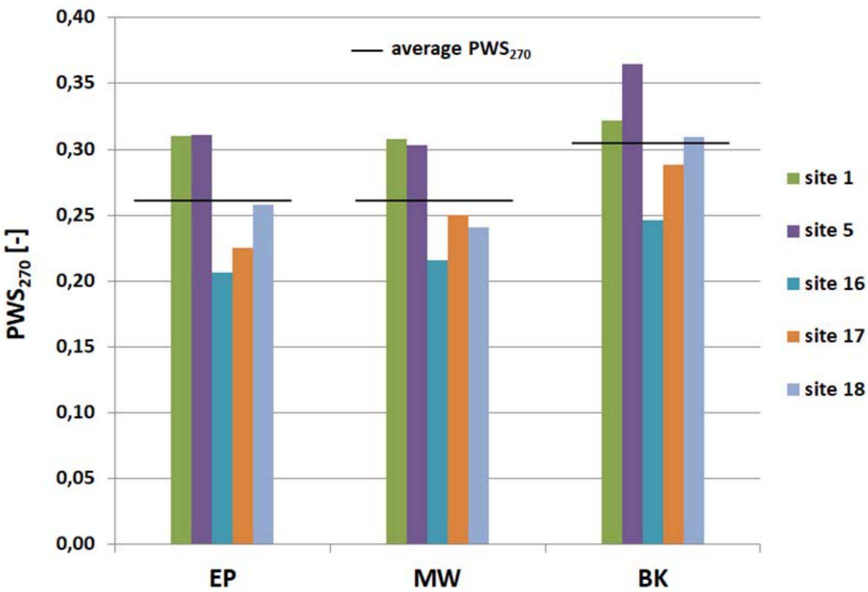

Figure 4: Final pavement skid resistance PWS_{270} SMA 11 S

The averages of the Mean Profile Depth (MPD) (Figure 5) show a similar behaviour. It is not yet possible to determine a conversion factor between test specimens produced in the laboratory (stage EP, MW) and the drilled cores due to the small number of samples.

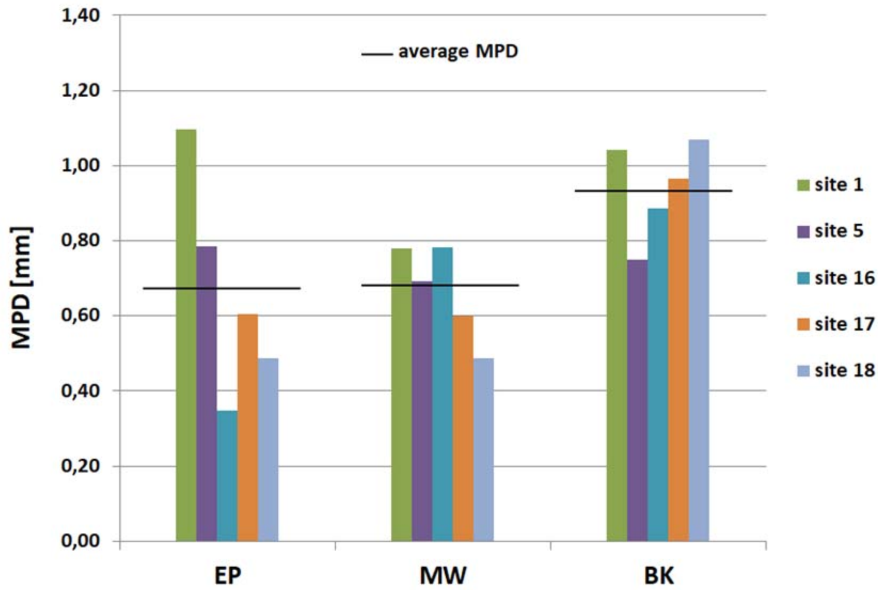

Figure 5: Mean Profile Depth (MPD) SMA 11 S

It is apparent that, in addition to the construction sites (asphalt design), the stage (test specimen production) has a decisive effect on the final pavement skid resistance. In order to clarify this, the surfaces of the specimens before and after polishing were examined. For example, the test specimen surfaces of the EP stage in the sandblasted condition (no passes) and after 270.000 passes are shown in Figure 6 for site 17.

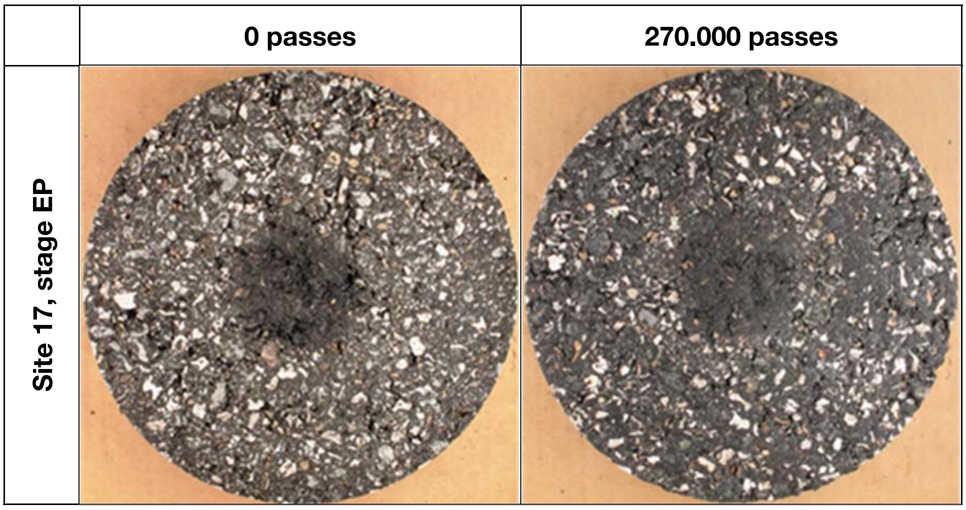

Figure 6: Surface of the specimen after 0 und 270.000 passes, site 17, stage EP

During polishing, bitumen and mastix reach in varying degrees the test specimen surface of the SMA 11 S at 4 of 5 construction sites at the stages EP and MW. This affects the results of the skid resistance measurement. The specimen preparation must therefore be reconsidered or modified.

Mathematical-statistical evaluation

In order to interpret the test results after 270.000 passes, the skid resistance values μ_{PWS} were evaluated statistically. To identify significant differences between the examined stages (EP, MW, BK), simple variance analyses are performed with a modified LSD-Test (Least Significant Difference Test).

The evaluation of the SMA 11 S (Table 2) shows that the stages EP, MW and BK for construction site 1 belong to a homogeneous group. Thus, the three stages do not affect the result of the final pavement skid resistance. This is also reflected in the results of the multiple variance analysis.

On the other hand, the stage BK for the other sites is - as already indicated above - in its own homogeneous group. For three of the five sites (sites 5, 17 and 18), the stages MW and EP can be combined to form a homogeneous group, i.e. the stages MW and EP provide similar results.

Accordingly to the multiple variance analysis, the factor stage affects the test results by 19 %. The individual site has the largest effect at 73 %, the interaction of stage and site has at 5 % a very smaller effect. For all five sites, a bitumen 25/55-55 A was used for the SMA 11 S. Thus the effect of bitumen was not be investigated.

Table 2: Statistical analysis pavement skid resistance μ_{PWS} after 270.000 passes for SMA 11 S [8]

SMA 11 S			single variance analysis	LSD-Test (EP, MW, BK) ranking in homogen groups: 1. group	2. group	3. group	multiple variance analysis: factor	rejection H_0-Hypo.	%
μ_{PWS} after 270.000 passes	1	25/55-55 A	n. signifi.	BK, EP, MW			stage	yes	18,9
	5	25/55-55 A	signifi.	BK	MW, EP		site	yes	72,6
	16	25/55-55 A	signifi.	BK	MW	EP	stage/ site	yes	4,8
	17	25/55-55 A	signifi.	BK	MW, EP				
	18	25/55-55 A	signifi.	BK	MW, EP		error		3,7

The results of the PWS_{270} final pavement skid resistance determined for the 21 construction sites in the three stages can be summarised as follows.

- The type testing has a considerable statistical effect on the final pavement skid resistance with 22% to 77%.
- The SMA 11 S in particular has an effect on the test specimen production.
- All averages of the final pavement skid resistance PWS_{270} for the stages EP, MW and BK for the rolled asphalts are above 0.25.
- The categories introduced in Europe for the minimum skid resistance after polishing with values between 0.30 and 0.50 are regarded as too high for German asphalts.
- A correlation between the mean profile depths after 270.000 passes and the final pavement skid resistance PWS_{270} could not be found.

6.2 Variations in asphalt composition

On the basis of the results [9] of the investigations carried out on SMA 8 S and AC 11 D S, it can be shown that with regard to the characteristics bitumen content, filler content, contents of fine or coarse aggregates and coarse grain content, only the content of fine aggregate has a significant effect on the final pavement skid resistance PWS_{270}. There is a greater effect for SMA 8 S than AC 11 D S.

The log-linear plot (Figure 7 and 8) is advantageous for the description and interpretation of the calculated skid resistance graphs. The gradient of the straight line shows a decrease in skid resistance between 0 and 270.000 passes. The initial and final pavement skid resistance of the asphalt variations can also be distinguished more easily and presented in a clearer way.

The lowest and highest final pavement skid resistance of the SMA 8 S (Figure 7) were measured for asphalt variations 9-5 and 9-6, respectively. For these variations, the content of fine aggregate was increased or decreased by 8.0 wt.% compared to the initial composition 9-0. The straight lines in the figure for the variations 9-3, 9-5 and 9-6 are almost parallel and thus have comparable gradients and reductions in skid resistance. However, they end at a different level. So far, the opinion has been expressed that the skid resistance of SMA is almost independent of the fine aggregate. However, if the asphalt composition is selected on the basis of the calculated extreme values for the fine aggregates, an effect on skid resistance can be observed.

For the AC 11 D S (Figure 8), the straight lines are within a narrower bandwidth. As a result, the variations in asphalt composition in the AC 11 D S are not as pronounced as in the SMA 8 S. The skid resistance of the AC 11 D S apparently decreases uniformly for all variations investigated. This is reflected by the straight lines which are almost parallel. The highest or lowest final pavement skid resistance value is exhibited by compositions 14-5 and 14-6 with the highest or lowest contents of fine aggregate. As for SMA 8 S, it is apparent that the content of fine aggregate in asphalt concretes affects skid resistance.

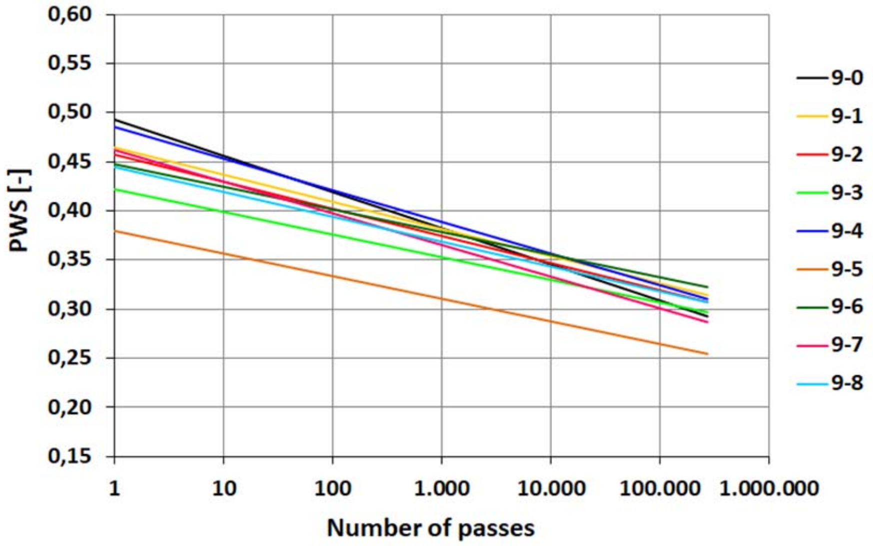

Figure 7: Log-linear skid resistance graph PWS of the asphalt variations SMA 8 S

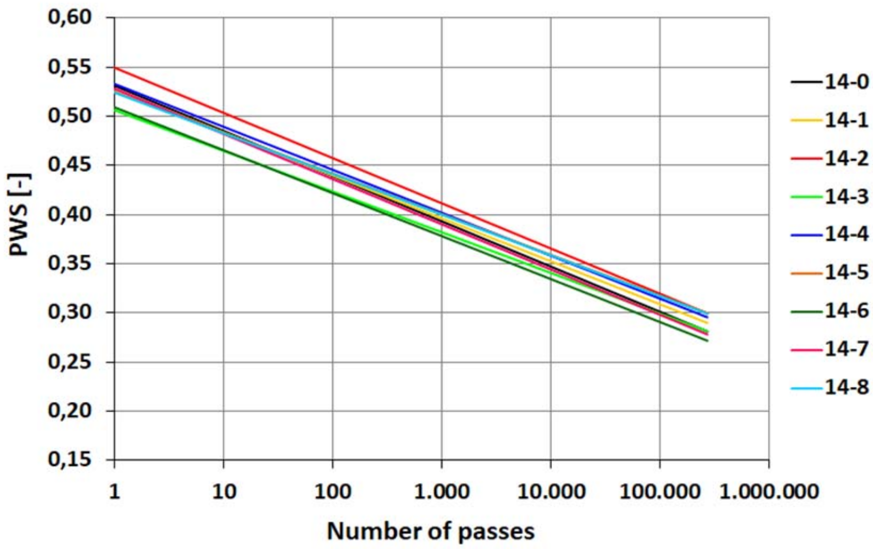

Figure 8: Log-linear skid resistance graph PWS of the asphalt variations AC 11 D S

6.3 Variations in specimen preparation

To obtain an accurate skid resistance prognosis for an asphalt surface, a practical laboratory specimen preparation is necessary which realistically produces the field surface condition at the prediction time. It was shown that the bitumen residues cannot be completely removed from the surface to be tested by the sample preparation carried out in accordance with EN 12697-49 [1] (sandblasting cycle at (+5 ± 3) °C with a duration of (120 ± 10) s) (Figure 9).

The evaluation [9] of the various stress variations performed show that the required surface condition can only be achieved by mechanical stress from two sandblasting cycles (blasting time per cycle (120 ± 10 s) at (-20 ± 3) °C). If this specimen preparation method is used, which is considered to be the most effective, the bitumen film can be completely removed from the surface of the coarse aggregate particles with short blasting times and less mortar removal.

This specimen preparation was applied to specimens produced in the laboratory from asphalt mixtures or to drilled cores (reserve samples) extracted from road pavement not exposed to traffic [9]. The samples were designated EP-2Z, MW-2Z and BK-2Z after the second sandblasting cycle.

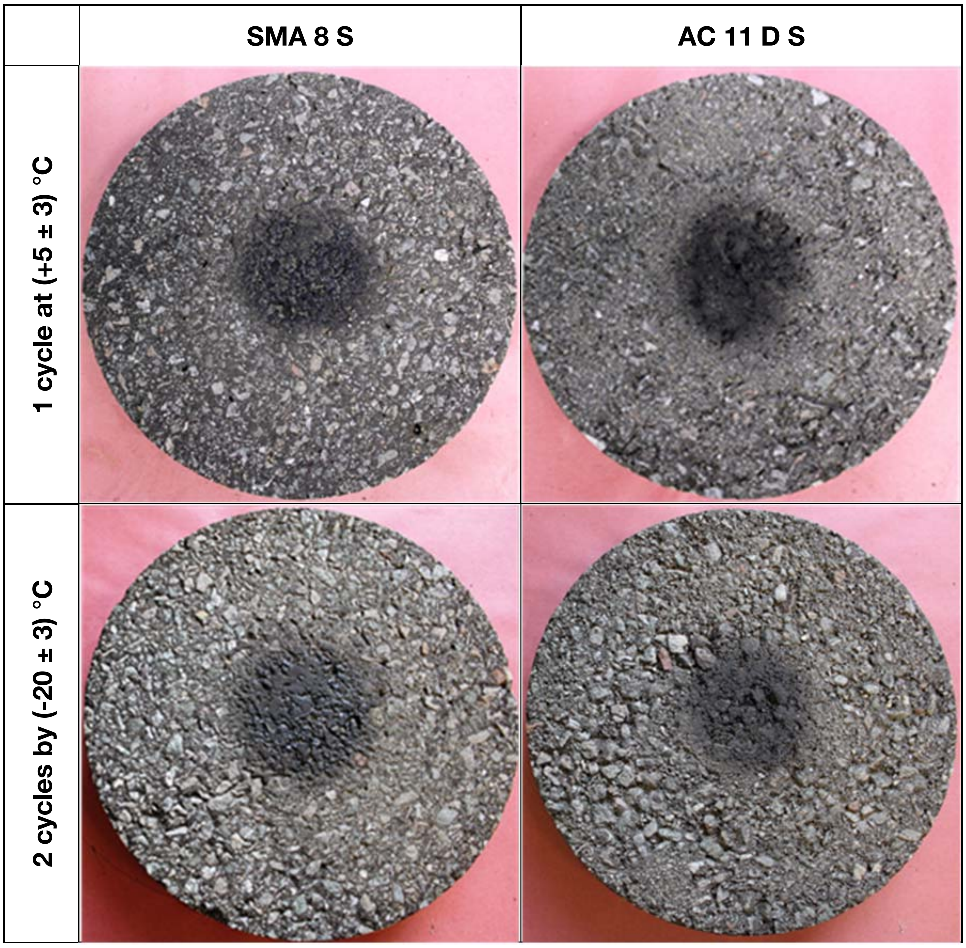

Figure 9: Specimen surfaces SMA 8 S or AC 11 D S after one sandblasting cycle at (+5 ± 3) or after two cycles at (-20 ± 3) °C

A skid resistance prognosis was then carried out for the test specimens and then the final pavement skid resistance obtained compared with those for the stages EP; MW, BK and a statistical analysis performed. The initial skid resistance at 0 passes for the stages with the new specimen preparation (EP-2Z, MW-2Z and BK-2Z) is above that of the investigated SMA 8 S (Figure 10) and below that of the AC 11 D S (Figure 11) for the associated stages (EP, MW and BK) of the original specimen preparation.

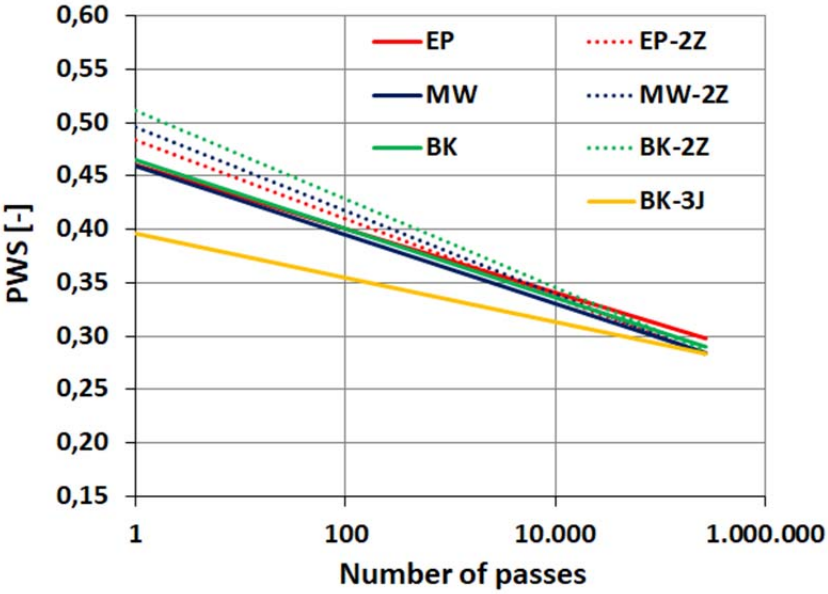

Figure 10: Log-linear skid resistance graph PWS, SMA 8 S of site 9

This is not surprising because the bitumen film on the coarse aggregate particles of the SMA was almost completely removed - the micro-roughness of the coarse GK is thus completely removed. In the case of the AC 11 D S the mastix / mortar, and thus parts of the skid resistance-determining component sand, were removed.

The initial skid resistance of the trafficked road (stage BK-3J) after 3 years always lies between the skid resistance values μ_{PWS} of the other stages determined after 0 or 4.500 passes. With the exception of stage EP, all straight lines for the AC 11 D S seem to meet at an intersection point corresponding to the final pavement skid resistance after 270.000 passes. This is also the reason why in future the skid resistance should be determined after 270.000, and not after 90.000 passes as provided for in the regulations where considerably larger ranges of skid resistance values are possible. The test standard must be adapted accordingly.

The finial pavement skid resistance PWS_{270} of the stages EP, MW and BK with the original sample preparation (range greater than 0.010 units) are at different levels (Table 3). In contrast, the final pavement skid resistance for the stages EP-2Z, MW-2Z and BK-2Z determined with the newly developed specimen preparation has values which are almost identical at the same level as the final PWS_{270} of the traffic-loaded road (stage BK-3J) after 3 years.

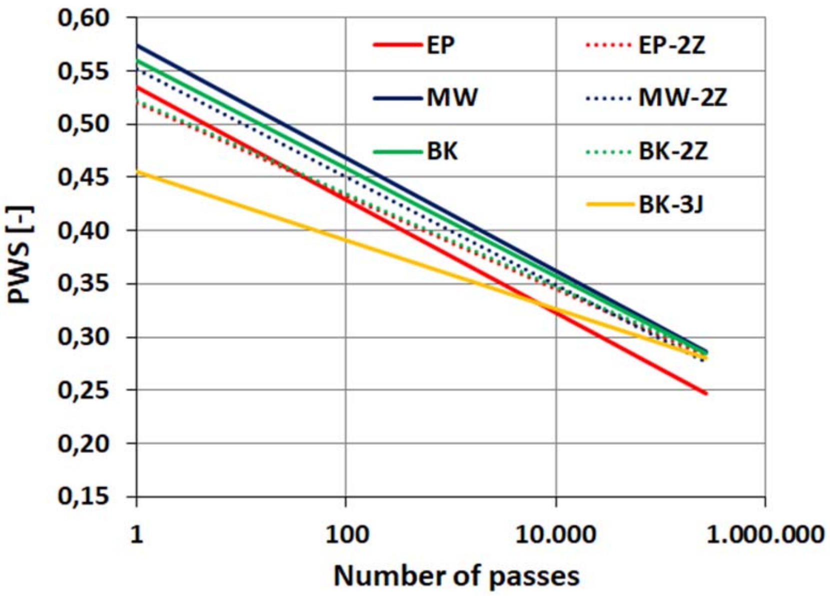

Figure 11: Logarithmic skid resistance graph PWS, AC 11 D S of site 14

The calculated ranges of the final pavement skid resistance of the stages EP-2Z, MW-2Z and BK-2Z were reduced to a quarter compared to the ranges of the stages EP, MW and BK. With the SMA 8 S, the coefficients of determination (R^2) of the stages EP-2Z, MW-2Z and BK-2Z were in some cases significantly increased compared to the stages EP, MW and BK.

Table 3: Final pavement skid resistance PWS_{270}, averages, ranges and coefficients of determination R^2 for the investigated stages of the SMA 8 S and AC 11 D S

	SMA 8 S				AC 11 D S			
Stage	PWS_{270}	Average	Range	R^2	PWS_{270}	Average	Range	R^2
EP	0.298	0.291	0.014	0.87	0.247	0.273	0.039	0.98
MW	0.284			0.90	0.286			0.98
BK	0.290			0.93	0.285			0.98
BK-3J	0.284	-	-	0.91	0.280	-	-	0.95
EP-2Z	0.284	0.284	0.003	0.99	0.282	0.281	0.008	0.97
MW-2Z	0.283			0.98	0.276			0.99
BK-2Z	0.286			0.98	0.284			0.98

The statistical evaluation for the SMA 8 S for the stages EP-2Z, MW-2Z, BK-2Z shows that these stages can be assigned to a homogeneous group. Thus there are no significant differences between the individual stages (Table 4).

The final pavement skid resistance PWS_{270} determined for the stages are at the same level for drill cores and plates produced in the laboratory - despite different methods of test specimen production.

As a result, it is possible to make a reliable skid resistance prognosis. The final pavement skid resistance PWS_{270} can therefore be determined with sufficient certainty on test specimens produced in the laboratory prior to the construction work.

Table 4: Results of the statistical analysis pavement skid resistance values μ_{PWS} after 270.000 passes for an SMA 8 S, site 9, newly developed sample preparation [7]

SMA 8 S	single variance analysis	LSD-Test: EP-2Z, MW-2Z, BK-2Z; ranking in homogen groups		
		1. group	2. group	3. group
μ_{PWS} after 270.00 passes	n. signifi.	EP-2Z, MW-2Z, BK-2Z		

Analogous to the SMA 8 S, statistical evaluation [7] for the stages EP-2Z, MW-2Z and BK-2Z for the determined skid resistance values μ_{PWS270} after 270.000 passes was carried out to validate the test results. The results confirm the statistical evaluation for the stages EP, MW and BK of site 14 [8].

For SMA 8 S and AC 11 D S, it was found that the modified sample preparation offers the following advantages over the production of test specimens specified in EN 12697-49 [1]:

- The bitumen film on the surface of the test specimens is removed completely.
- There is no longer a risk of bitumen reaching the surface of the specimen during polishing.
- The calculated coefficients of determination of the continuous skid resistance development are improved for SMA 8 S.
- The final pavement skid resistances for the stages EP-2Z, MW-2Z and BK-2Z are almost identical.
- The final pavement skid resistance for the EP-2Z and MW-2Z stages has lower values than those of the BK-2Z and BK-3J stages. As a result, the final pavement skid resistance can be determined with a certain degree of certainty in the run-up to the construction project, for the stages EP-2Z and MW-2Z with sufficient certainty.
- The range of the final pavement skid resistance between the stages shows clearly lower values.

7. SUMMARY

Every road user expects a good skid resistance of the road surface even in wet conditions. To achieve this, it is necessary that the specified requirements for skid resistance are adhered to throughout the entire service life of a road surface.

The test method "Determination of Friction after Polishing" (EN 12697-49 [1]) is the first standardised laboratory method to predict the skid resistance of asphalt on a laboratory scale. Categories FAP_{min} for the "Minimum Friction after Polishing" are specified in the currently valid versions of EN 13108-1; -5 and -7: "Bituminous mixtures - Material specifications" [2, 3, 4]. These categories are based on experience in various countries, but for the asphalts used in Germany, they are considered to be inappropriate.

To create an initial evaluation background, the skid resistance values of the asphalt surface layer for the stages of asphalt mix design (stage EP), asphalt mix production (stage MW) and after asphalt paving (stage BK) were determined for a total of 21 construction sites [8] and evaluated mathematically and statistically. In addition, after 2 to 3 years in service, drilled cores (stage BK-3J) were again extracted from seven test sites in the right-hand traffic lane.

It could be proven that by applying an additional mechanical load beyond the 90.000 passes provided according to EN 12697-49 [1], a further reduction in skip resistance is achieved. The investigations confirm the results of an earlier research [5] that a "final pavement skid resistance (final polishing value)" can only be determined with sufficient accuracy after at least 270.000 passes.

The measured initial skid resistance for stage BK-3J always lies between the skid resistance values determined after 0 or 4.500 passes of the test specimens stressed in the laboratory. From this it can be concluded that a polishing stress with a maximum of 4.500 passes can be used to simulate an approximate decrease in skid resistance on specimens subjected to laboratory stress as a result of a three-year exposure period to traffic.

The effect of asphalt composition and sample preparation on skid resistance was investigated. For the asphalt types SMA 8 S and AC 11 D S it was found that the content of fine aggregate in the SMA 8 S had a significant effect on the final pavement skid resistance PWS_{270}. In order to predict the skid resistance of an asphalt surface accurately, a practical sample preparation is required which produces the field surface condition in the laboratory as realistically as possible at the time of prediction. The evaluation of the various stress variations investigated show that the required surface condition can only be achieved by mechanical stress using two sandblasting cycles (blasting time per cycle (120 ± 10 s) at (-20 ± 3) °C). If this preparation technique is used, the bitumen film can be completely removed from the surface of the test specimens with short blasting times and less mastix / mortar removal.

The final pavement skid resistance PWS_{270} of the specimens prepared in this way are at an almost identical for drilled cores and plates produced in the laboratory - despite the different types of specimen production. As a result, the final pavement skid resistance PWS_{270} can be determined with sufficient accuracy on test specimens produced in the laboratory prior to the actual construction work.

In order to predict skid resistance, it is necessary to record the entire course of the skid resistance development of an asphalt surface until the "final pavement skid resistance" is reached. For this purpose, skid resistance measurements must be carried out for the stress levels after 4,500, 7.500, 15.000, 22.500, 30.000, 37.500, 45.000, 90.000, 135.000, 180.000, 225.000 and 270.000 passes [5,6].

8. CONCLUSION

The specimen preparation for the Wehner/Schulze test method in accordance with EN 12697-49 must be described as non-satisfactory. For this reason, a specific specimen preparation method was developed which can be applied to asphalt mix specimens produced in the laboratory or to drill cores extracted from pavement.

The test system developed provides practical and reproducible results with the test method "Friction after Polishing (FAP)". With the proposed method, the construction and asphalt industry can integrate the friction after polishing into the asphalt design process. This provides the road administration authorities with sufficient values of skid resistance.

REFERENCES

[1] DIN EN 12697: Asphalt - Prüfverfahren für Heißasphalt - Teil 49: Messung der Griffigkeit nach Polierung; Deutsche Fassung EN 12697-49:2014

[2] DIN EN 13108: Asphaltmischgut – Mischgutanforderungen - Teil 1: Asphaltbeton; Deutsche Fassung EN 13108-1:2016

[3] DIN EN 13108: Asphaltmischgut – Mischgutanforderungen - Teil 5: Splittmastixasphalt; Deutsche Fassung EN 13108-5:2016

[4] DIN EN 13108: Asphaltmischgut – Mischgutanforderungen - Teil 7: Offenporiger Asphalt; Deutsche Fassung EN 13108-7:2016

[5] Böhnisch, S.; Wörner, Th.: Untersuchung zur Qualifizierung von Geräten zur Prognose von Griffigkeitsmess-werten – Vorstudie. Schlussbericht F-5013 zum Forschungsauftrag FGSV- Nr. 5/ 2002, München, 2003

[6] Wörner, Th.; Wenzl, P.; Schmalz, M.; Bösel, P.: Bewertungshintergrund für Verfahren zur Griffigkeitspro-gnose, Forschung Straßenbau und Verkehrstechnik, Heft 1044 BMVBW, 2010

[7] Prüfbericht-Nr.: 6/3554/2016, HNL, „Projekt – über die statistischen Auswertung von Griffigkeitsversuchen", 29.08.2016, unveröffentlicht

[8] Roos, R. et al:: Repräsentative Ermittlung der performance-relevanten Asphalteigenschaften als Grundlage neuer Vertragsbedingungen, Berichte der Bundesanstalt für Straßenwesen, Straßenbau Heft S 121

[9] Patzak, Th.:, Möglichkeiten der Optimierung des Wehner/Schulze-Verfahrens zur Prognose der Griffigkeits-entwicklung von Asphalten, 2018, http://nbn-resolving.de/urn/resolver.pl?urn:nbn:de:bvb:91-diss-20180730-1429711-1-3

[10] Zusätzlichen Technischen Vertragsbedingungen und Richtlinien für den Bau von Verkehrsflächen aus Asphalt (ZTV Asphalt-StB 07/13), Ausgabe 2007 / Fassung 2013 Forschungsgesellschaft für Straßen- und Verkehrs-wesen, Köln – FGSV 799