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Laboratory Evaluation on Interlayer Shear Bonding and Characterization of Microsurfacings

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ABSTRACT

Initiated by research on microsurfacings conducted in the Task Group TG 2 of the International Union of Laboratories and Experts in Construction Materials, Systems and Structures RILEM TC-280 CBE, “Multiphase Characterisation of Cold Bitumen Emulsion Materials,” the interlayer shear bonding of microsurfacings on asphalt and concrete layers was investigated in the laboratory. The paper presents interlayer bonding test results conducted at the Swiss Federal Laboratories for Materials science and Technology, Empa, thus analyzing the influence of bitumen emulsion and aggregate type on the interlayer bonding strength as well as material and surface condition of the underlying layer. The results showed that not only the type, but also the combination of bitumen emulsion and aggregate type greatly influences workability, behavior, and interlayer bond strength of microsurfacings. Additionally, curing time and the surface characteristic of the bottom layer should not be neglected.

Keywords

microsurfacings, cationic bitumen emulsions, shear test, rehabilitation, interlayer bond, surface characteristics

Introduction

At least for two decades, microsurfacings have been a relatively cheap but reliable and effective measures for asphalt pavement rehabilitation. They have been applied mainly for enhancing pavement life through crack sealing, pavement leveling, and improving skid resistance (Broughton, Lee, and Kim[1]; Hein et al.[2]). Despite many positive experiences, in some cases, early failure in terms of aggregate loss and insufficient interlayer bonding to the lower layers have been reported by Hein et al.,[2] Labi et al.,[3] Hesp et al.,[4] and Raab and Partl.[5] Because microsurfacings are specific products that are often specified by the production companies, general testing standards as well as mixture design and application requirements are lacking. The International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM), created a Technical Committee RILEM TC-280 CBE, “Multiphase Characterisation of Cold Bitumen Emulsion Materials,” which was therefore aiming to establish recommendations for mixture design and test specifications, accounting for the characteristics of the individual components (Grilli et al.[6]). Within the framework of this RILEM TC, Task Group 2 was involved in the investigation of various test procedure and guidelines for microsurfacings, including interlayer shear bonding. Because of the fact that microsurfacings are very thin layers up to 15 mm, still no international consensus exists on how interlayer bond testing for this type of mixtures should be performed. Besides studying the specimen preparation and mixing of emulsions, aggregates, and additives such as cement, the task group was also aiming for establishing or improving testing protocols, thus profiting from the advantage of RILEM work that lies in the collective effort and the cooperation between research institutes, laboratories, and companies, including round robin testing of selected materials and specimens.

The objective of this paper is to evaluate and analyze the influence of different components (emulsions and aggregate types) on the interlayer shear bonding strength, including the influence of material and surface condition of the underlying layer. Moreover, the objective was to evaluate a test method that would be able to rank bonding properties of different kind of microsurfacings in a reasonably clear way. Hence, the paper presents an extended laboratory study dealing with specimen preparation and testing as part of the investigation conducted at the Swiss Federal Laboratories for Materials Science and Technology, Empa, within the framework of Task Group TG2 of the RILEM TC-280 CBE, TG2.

Materials and Specimen Preparation and Testing

MATERIALS

Microsurfacings are composed of bitumen emulsion, aggregates, water, and additives, such as cement. For the RILEM study, two different cationic emulsions from Italian producers (EM 1 and EM 2) and basalt aggregates with two different continuous aggregate gradations 0/6 mm and 0/8 mm were chosen. In addition, Empa expanded the study by adding a local emulsion EM 3 and two similarly graded different aggregates, an alluvial gravel of Alpine origin from the French quarry in Bartenheim at the river Rhine near Basel with continuous gradations 0/6 mm and 0/8 mm (subsequently called “Rhen. Alluv.”) and a quartz sandstone from Switzerland with a corresponding gradation of 0/8 mm. In this way, aggregates of both alkaline and acidic nature were considered. **Table 1** gives the main characteristics of the emulsions, and **Table 2** shows characteristics for the individual gradations of the different aggregates. In this investigation, all microsurfacings were composed of 7.1 % water, 12 % emulsion, 2.5 % ordinary portland cement 32.5, and 78.4 % aggregates by weight of which 51 % is 0/2 mm and 49 % is 2/*D* (with *D* maximal nominal aggregate size).

TABLE 1
Emulsion characteristics

	EM 1	EM 2	EM 3
Bitumen content, %	63–67	58–62	65
Efflux time, s (EN 12846)	5–70	5–70	17
Breaking index (EN 13075-1)	110–195	110–195	170–230
Adhesivity, % (EN 13614)	90	≥75	90

Note: EN 12846, *Bitumen and Bituminous Binders - Determination of Efflux Time by the Efflux Viscometer - Part 1: Bituminous Emulsions (2011)*; EN 13075-1, *Bitumen and Bituminous Binders - Determination of Breaking Behaviour - Part 1: Determination of Breaking Value of Cationic Bituminous Emulsions, Mineral Filler Method (2016)*; EN 13614, *Bitumen and Bituminous Binders - Determination of Adhesivity of Bituminous Emulsions by Water Immersion Test (2021).*

TABLE 2

Aggregates characteristics following European Standard EN 13043-04, *Aggregates For Bituminous Mixtures and Surface Treatments for Roads, Airfields and Other Trafficked Areas*

	Basalt			Rhen. Alluv.			Quartz Sandstone		
Size, mm	0/4	0/6	4/8	0/2	0/4	4/8	0/4	4/6.3	4/8
Class	G_A90	G_A90	G_C85/20	GF85	G_A 85	G_C85/15	G_A85	G_C85/15	G_C85/20
Density, MG/m^3	2.68	2.67	2.67	2.6–2.8	2.6–2.8	2.6–2.8	2.64	2.64	2.62
Fine content	f_{16}	NR	f_4	f_{22}	f_{22}	f_1	f_{10}	f_1	f_1
Resist. LosAngeles	NR	NR	NR	LA20	NR	NR	LA17-20	NR	LA20
Water Absorpt., %	0.7	0.91	1.78	0.7–1	0.7–0.9	0.5–0.7	1	1	1

Note: Water Absorpt.: Water absorption; NR: no requirement; f_{22}, f_{16}, f_{10}, f_4, f_1: fine content ≤22%, ≤16%, ≤10%, ≤4%, ≤1%; G: Category (sieve size); A, C, F: all-in, coarse, fine aggregates; numbers 90, 85, …/15, …/20: Upper sieve size 90-99, 85-99; …/lower sieve size 0-15, 0-20; LA: Los Angeles Coefficient; LA-numbers 20, 17-20: LA ≤ 20, LA ≤ 17 to 20.

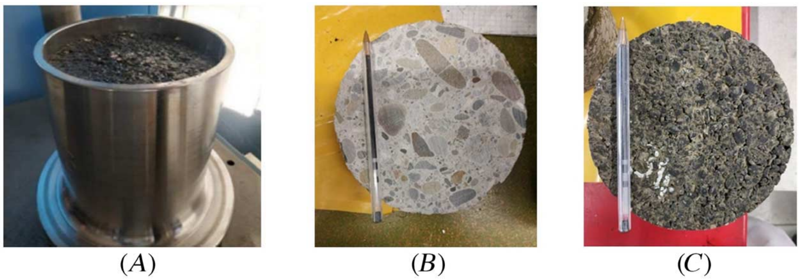
SPECIMEN PREPARATION

In the case of in situ application of microsurfacings, special machinery is used in which the different components are mixed together and directly applied on the existing pavement, whereas mixing and preparation of the specimens in the laboratory is more complex and needs special protocols and guidelines. For studying the interlayer shear bonding strength, emulsions and aggregates were mixed following a protocol developed by RILEM (Mignini, Cardone, and Grazani[7]).

For interlayer shear bonding purposes, the produced microsurfacing mixtures were placed between a bottom and an upper layer. The upper layer was necessary for proper clamping and loading because conventional shear bond testing, according to the European standard EN 12697-48, *Bituminous Mixtures Test Methods - Part 48: Interlayer Bonding*, requires a layer thickness of ≥20 mm, whereas the thickness of the microsurfacing applied to the bottom layer is, by definition, significantly lower and in this study, was targeted to 10 mm. In detail, specimens were successfully prepared by the following special procedure.

For the preparation of a specimen, the selected bottom layer core was placed into a 150 mm gyratory mold by means of a displacement-controlled hydraulic press until the space remaining between the top of the mold and the top of the layer equaled the 10-mm thickness of the microsurfacing layer (**fig. 1*A***). Once the surface of the core was properly cleaned, the calculated amount of microsurfacing was poured on top and evenly distributed over the entire bottom layer surface for obtaining a flat microsurfacing top surface. After the emulsion had broken and after curing for circa 24 h at about 20°C room temperature, the sample was taken out of the mold, and an auxiliary upper asphalt layer was glued on top of the microsurfacing with a two-component epoxy glue for achieving the required thickness of the top specimen part for testing. Asphalt was chosen as upper layer instead of other materials, such as steel, in order to create similar stiffness conditions as in the microsurfacing, considered necessary for homogeneously clamping the top of the specimen in the shear device.

FIG. 1 Bottom layer in the mold before applying the microsurfacing (*A*); bottom layers for interlayer shear testing: smooth concrete core (*B*); and bottom layers for interlayer shear testing: SMA11 core taken from untraveled road pavement (*C*).



Although the choice of the upper layer material is of minor importance, the bottom layer material is crucial for studying shear bonding characteristics. Hence, 150 mm cores from 2 extreme types of bottom material with different stiffness and surface characteristics were selected: a well-hydrated structural concrete with smooth and flat surface and a standard stone mastic asphalt SMA11 taken from a motorway in 1998 before opening to traffic with typical rough surface texture (fig. 1*B* and 1*C*). In this way, the ratio of the nominal maximal aggregate sizes between the two microsurfacings (with gradations 0/6 mm and 0/8 mm) and SMA11 was 0.54 and 0.72, respectively. In selected cases, for comparison, an ordinary asphalt concrete AC22 taken from the same motorway in 1998 was also applied, reducing this ratio to 0.27 and 0.36, respectively.

INTERLAYER SHEAR TEST PROCEDURE

Interlayer shear bonding strength testing was performed with the Layer-Parallel Direct Shear (LPDS) test device shown in figure 2, which is a modified version by Empa of the equipment developed by Leutner[8] in Germany. This device proved more versatile in geometry and more defined in the clamping mechanism as described in Raab, Partl, and Abd El Halim.[9] It has a gap width of 2 mm between the shearing yokes. The test was conducted according to EN 12697-48 with a speed of 50 mm/min and at a temperature of 20°C.

Testing was conducted placing the prepared specimens in such a way that the bottom layer, which was not glued to the microsurfacing, was loaded by the shear yoke (fig. 3). According to the Swiss standard specification, the maximum force in kN for Ø150 mm cores are determined. For each of the results presented in the following sections, at least 3 specimens were tested. Because all specimens had the same diameter, the maximum nominal

FIG. 2

LPDS shear device: schematic drawing (*A*) and photograph with test specimen (*B*).

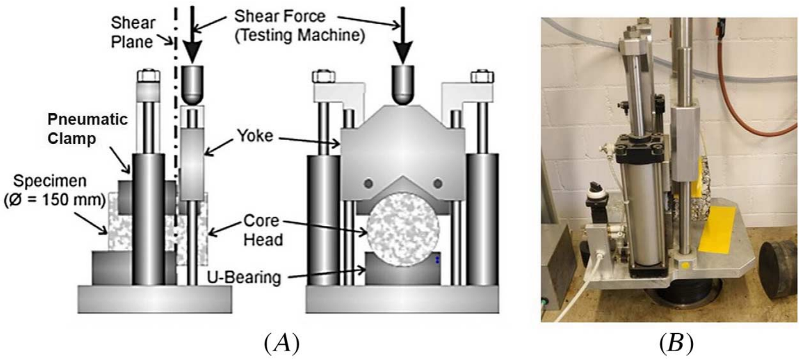
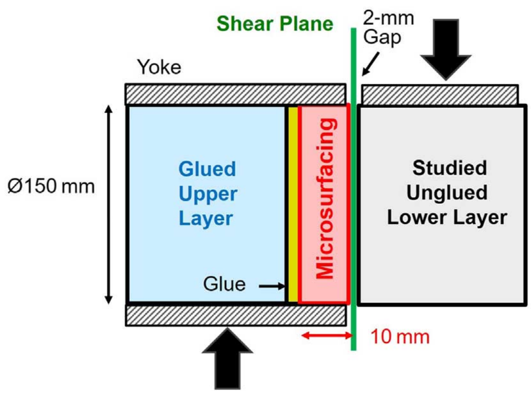


FIG. 3

Schematic view of test specimen.



shear force in kN is directly proportional to the nominal shear strength in MPa by a multiplication factor of 0.057. In addition to the maximum shear force, deformation properties should also be considered. This can be done by evaluation the deformation values at maximum load or by calculating the stiffness indicator *S* from the linear part of the curve as discussed in Kim et al.[10]

Results

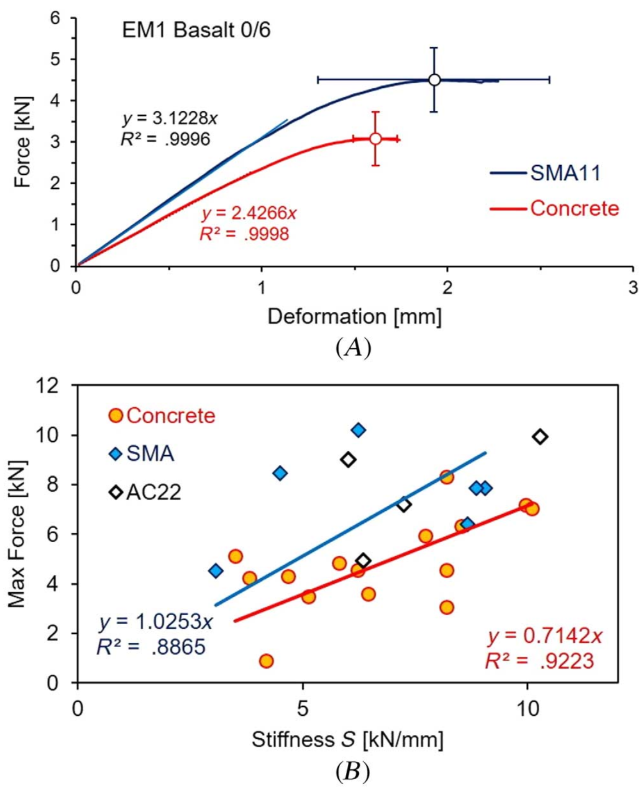
INFLUENCE OF MATERIAL AND SURFACE CHARACTERISTIC OF BOTTOM LAYER

Figure 4*A* presents the mean interlayer shear bonding curves, when the microsurfacing is applied either on a smooth concrete or on a rough surface of a stone mastic asphalt core SMA 11 taken from a trafficked road pavement. For this investigation, the microsurfacing consisted of emulsion EM 1 and basalt aggregates 0/6 mm.

The results in **figure 4*A*** show a clear advantage for the interlayer bond when the underlying layer consists of a "rougher" material, which permits better interlocking of the applied microsurfacing, thus confirming results found on pavement layers (Santagata et al.[11]). In **figure 4*A***, the maximum mean shear force of 4.5 kN for asphalt specimens is 46 % above the mean value of the concrete specimens. The stiffness indicator in the case of SMA11 is 3.13 kN/mm, about 30 % higher than for concrete, because in the first loading phase the asperities of the SMA11 texture must be overcome, whereas in the case of concrete, unhindered slippage on the smooth concrete surface without dilatancy effects can occur. Note that the ratio of the different maximum aggregate size between both the asphalt material on the bottom and the microsurfacing plays a significant role, as shown model-wise in Raab, Abd El Halim, and Partl.[12] There, the difference of maximum shear force between rough and smoother model surface created by large steel balls and small steal balls as model aggregates with diameters $D = 9.5$ mm and $d = 5.5$ mm, respectively, was 25 %. This was certainly lower than the 46 % mentioned here, due to the fact that in the work of

FIG. 4

Average interlayer bond curves of microsurfacing EM1 with basalt 0/6 on different bottom layers (smooth concrete and SMA11 from a trafficked road pavement) (*A*); relationship between mean values of maximum force and stiffness indicator S for all specimens with microsurfacing on asphalt and concrete (*B*).



Raab, Abd El Halim, and Partl,[12] the ratio of the steel balls in the rough case (small on large balls) was $d/D = 0.58$ but in the smoother case (large on small steel balls) was only $D/d = 1.73$ instead of almost infinity in the case of the concrete surface.

Figure 4*B* summarizes the results of all specimens of this microsurfacing study, depicting the overall relationship between maximal force and the stiffness parameter *S*. For comparison, data of a separate study with a selected number of the same microsurfacings on an ordinary asphalt concrete AC22 are also shown. The results suggest that generally the maximum force increases together with the stiffness parameter for all bottom materials. For specimens with microsurfacings on concrete, the maximum force appears not so strongly affected by *S* than in the case of an asphalt bottom layer. From the linear regression curves of this study, it follows that equal maximum shear forces for rough asphalt and smooth concrete bottom layers mean about 40 % higher stiffness for concrete interlayer surfaces. Thus, it appears that in relation to the fracture strength, smooth surfaces show higher stiffness than rough surfaces. However, the correlation between stiffness and maximum force appears much weaker for asphalt than for concrete, probably due to higher variations in the texture of the rough asphalt compared with the smooth concrete surface.

INFLUENCE OF CURING TIME

Because curing time plays a very important role when looking at the performance of cold mixtures, the short-term bond strength development over 7 days was determined as depicted in **figure 5**. Again, the microsurfacing consisted of emulsion EM 1 and basalt aggregates 0/8 mm and was applied on SMA 11 bottom layers.

As expected, the interlayer bond properties clearly develop over time showing an increase of maximum shear force of more than 50 % when comparing the results after 2 and 4 days. After 7 days, the shear force is even more than 3 times higher than at the beginning. However, with increasing curing time, the increase in shear force gradually slows down and should, theoretically, approach an asymptotic value in future. This is the reason for suggesting exponential regression in **figure 5** with an estimated long-term maximal shear force of 14.83 kN, which would be reached after about 1 month in this case.

INFLUENCE OF AGGREGATE TYPE

For the evaluation of the influence of the aggregate type for emulsion, EM 1 was applied using all 3 aggregate types in the gradation of 0/8 mm. In order to have a defined surface, only concrete cores were considered as bottom layers.

Figure 6 presents a top view of the emulsion EM 1 and different aggregate mixtures right after distributing the microsurfacing in the mold. In **figure 7*A***, the results in terms of maximum shear force are shown.

As visible in **figure 6**, the type of aggregate and the type of emulsion, i.e., the emulsion/aggregate reaction, influences the behavior, having a great impact on the workability. From **figure 6**, it becomes obvious that

FIG. 5

Interlayer bond properties after different curing times (single values for EM1 with basalt aggregates 0/8 mm on SMA 11 bottom layers).

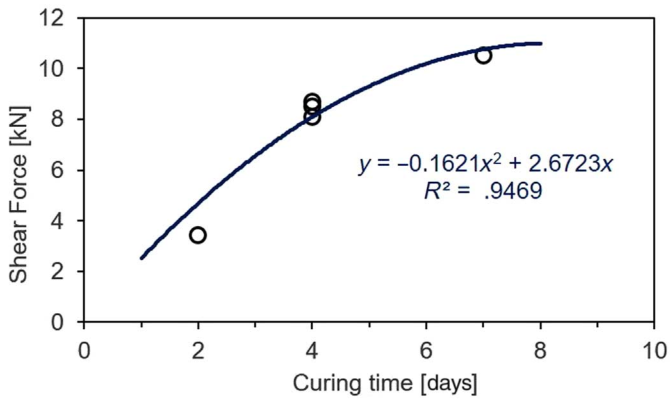


FIG. 6

Surface textures of microsurfacings with EM 1 and different aggregate types.

microsurfacings with basalt or alluvium aggregates from the river Rhine are more fluid and therefore distribute more easily in the mold, whereas those with the Swiss quartz sandstone aggregates require additional effort. Note that in that context, the different aggregate characteristics as shown in **Table 2**, clearly depicting the lowest fine content for the Swiss quartz sandstone.

These effects are also displayed in the test results for mixtures with EM1 made with basalt and Rhen. Alluv. aggregate, having comparable and clearly higher maximum shear forces than the mixtures with quartz sandstone (**fig. 7*A***). As shown in **figure 7*B***, this is not so clear for mixtures with EM2 emulsions, thus demonstrating that the type of emulsion plays a major role. In the case that an emulsion is specifically designed for use with certain aggregates, the ranking of the aggregates can completely change. For example, if combining Swiss quartz sandstone aggregates in microsurfacings with Swiss emulsion EM 3—the combination used in practice in Switzerland—this leads to better workability and increased maximum shear forces (0/8+EM3 in **fig. 7*B***). From **figure 7*B***, one can also deduce that the aggregate size is of eminent importance. As seen from this figure, maximum shear forces are completely different for microsurfacings made of EM1 and basalt of the sizes 0/8 mm and 0/6 mm.

FIG. 7

Interlayer bond properties for mixtures of EM 1 with different aggregates placed on concrete bottom layers (*A*); maximum shear force versus stiffness indicator *S* for microsurfacings on concrete bottom layers (mean values). Dotted lines are visual aids to mark similar mixtures with different aggregates (*B*).

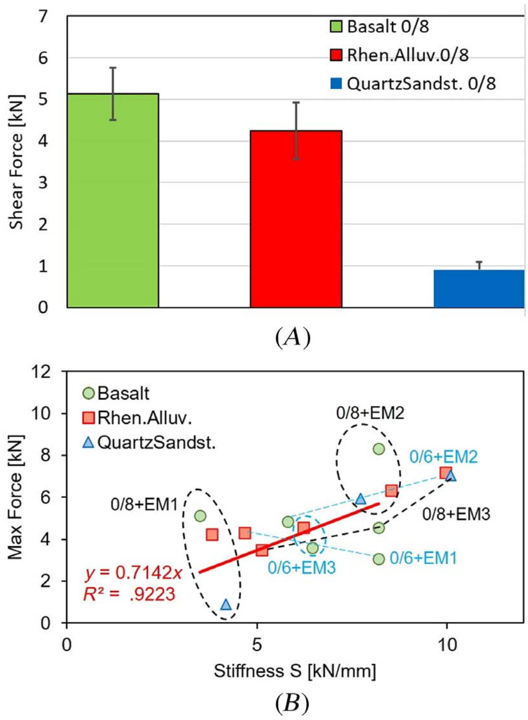
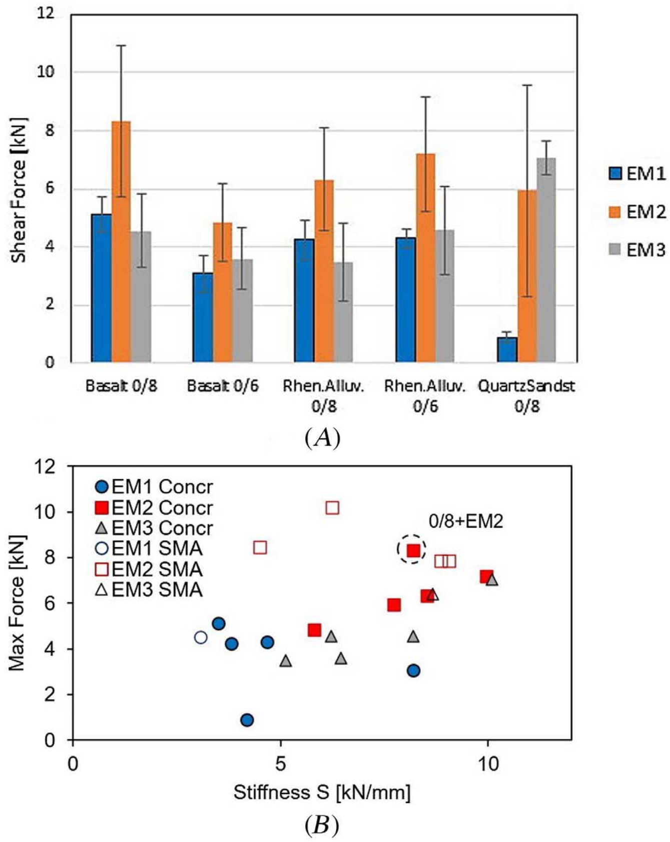


FIG. 8

Interlayer bond properties for mixtures of basalt and Rhenish alluvium 0/6 mm and 0/8 mm and emulsions, EM1, EM2, and EM3 on concrete bottom layers (*A*); summary of mean value results in the diagram showing maximum force versus stiffness indicator *S* for concrete bottom layers. For comparison, results for SMA11 bottom layers are also given (*B*).



INFLUENCE OF BITUMEN EMULSION

In a final part of the investigation, the basalt and the Rhen. Alluv. aggregates in sizes of 0/6 mm and 0/8 mm were combined with emulsions EM 1, EM 2, and EM 3 in order to see the influence of different emulsions on the interlayer bond properties. Here, the microsurfacing was applied on concrete bottom layers. The results are visible in **figure 8*A***, however, partially displaying remarkable scatter, particularly for EM2 in case of quartz sandstone 0/8, in which for operational reasons, only two clearly different test results could be produced. Hence, the significance of this special point must be considered low. Nevertheless, when looking at all results, emulsion EM 2 generally shows the highest maximum shear forces, whereas the best significant combination with regard to maximum shear forces appear to be basalt 0/8 together with emulsion EM 2. This is also visible (marked 0/8+EM2) in the summary of all mean values for concrete and SMA. Generally, EM2 produced higher shear forces in comparison with the microsurfacings with the other emulsions. This is also true for specimens on SMA, which showed highest max shear forces due to the roughness of the interlayer.

Conclusions

Microsurfacings are an effective measure for the short-term rehabilitation of distressed road pavements. Although their advantages are manifold, problems with the bond to the underlying pavement were often reported. The investigations described in the paper therefore concentrate on the interlayer bond properties of such surfacings with regard to the specimens' preparation, curing time, and testing condition, as well as the influence of bitumen emulsion and aggregate type and surface characteristic of the bottom layer.

The following findings and conclusions were established:

- It was confirmed that mixing the individual elements (emulsion, aggregates, and additives) of a microsurfacing requires special and detailed protocols, being an especially great challenge for the laboratory production of such specimens. In this respect, the investigation proved that RILEM TC-280 CBE conducted valuable work, which should lead to further guidelines and standardization.
- Preparation of specimens for interlayer testing of microsurfacing used for this investigation proved successful, in particular regarding the application of the microsurfacing to the bottom layer and how the additional auxiliary asphalt layer was glued on top of the microsurfacings for appropriate shear load application.
- The combination of the emulsion and aggregate type plays a very important role for their behavior, shown here in terms of maximum interlayer shear force and stiffness indicator. For example, when combining Swiss quartz sandstone aggregates in microsurfacings with Swiss emulsion EM 3 that was specifically designed for this case, the maximum interlayer shear force improved significantly. It is therefore very important to choose the appropriate combination of the individual elements, not only paying attention to the characteristic of the element, but also to their interrelationship.
- Sufficient interlayer bonding properties are essential for effectiveness of microsurfacings. The results showed that beside the influence of aggregate and emulsion type, the combination of the surface characteristic of the underlying layer is equally of great importance. A clear advantage for the interlayer bond was found, when the underlying layer consists of a "rougher" material, which permits better interlocking of the applied microsurfacing. Thus, it is recommended to improve surface roughness when overlaying concrete layers or layers with deteriorated texture.
- From the linear regression curves of this study, it follows that for the cases investigated, equal maximum shear forces of microsurfacings on asphalt and concrete layers mean about 40 % higher stiffness in case of smooth concrete than rough asphalt interlayer surfaces. Thus, it appears that in relation to the fracture strength, smooth surfaces show higher stiffnesses than rough surfaces. However, the correlation between stiffness and maximum force appears much weaker for asphalt than for concrete, probably due to higher variations in the texture of the rough asphalt compared with the smooth concrete surface.
- It is a well-known fact that curing time is a key element for cold mixtures, and it was found that with increasing curing time, the increase in shear force gradually slows down and should, theoretically, approach an asymptotic value in future. Hence, the study revealed that the curing time before interlayer bond testing is very important and that the "right time" has to be determined and fixed for standardization.

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