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RILEM TC RECOMMENDATION

Recommendation of RILEM TC 280-CBE: test method to assess the bonding of microsurfacing mixtures using the shear bond testing (SBT) apparatus

C. Sangiorgi · F. Balzano · P. Tataranni · A. Graziani · C. Raab

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Abstract Microsurfacings are widely recognized as a valid solution for reducing the consumption of energy and raw materials in the construction and maintenance of road surfaces. They require specifically formulated mixtures, designed to compensate for the variability of the substrate and to ensure a durable bond at the interface of the newly applied layer. In fact, the surface texture of the support has a strong effect on the bonding behaviour, as it influences the interlocking and adhesion at the interface. Insufficient interlayer bonding can lead to slippage and to partial or complete delamination of layers. This can impair the functionality of the pavement, as large cracks and potholes can occur. Although several methods for assessing the mechanical performance of microsurfacings are included in the main international standards, there is a lack of standardised guidelines for assessing their bond strength. This recommendation proposes a testing procedure to assess the interlayer bond strength of microsurfacing mixtures using a common shear testing device. In addition to the results of the shear strength, the surface of the substrate can be characterised with regard to its texture using a simple laboratory method.

Keywords Microsurfacing · Shear bond testing · Interface bonding · Surface texture

This recommendation has been prepared by a working group within RILEM TC 280-CBE: Sangiorgi Cesare, Balzano Filippo, Tataranni Piergiorgio, Andrea Graziani, Christiane Raab and further reviewed and approved by all members of the RILEM TC 280-CBE.

TC Chairman: Andrea Graziani, Italy.
TC Deputy Chairman: Alan Carter, Canada.
TC Members: Alan Carter; Eshan V. Dave; Frédéric Delfosse; Katja Dombrowski-Daube; Gilda Ferrotti; Vincent Gaudefroy; Andrea Graziani; James Grenfell; Meng Guo; Bernhard Hofko; Mariusz Jaczewski; Patricija Kara De Maeijer; Miomir Miljkovic; Konrad Mollenhauer; Joel Oliveira; Gabriel Orozco; Jian Ouyang; Marco Pasetto; Emiliano Pasquini; Laurent Porot; Christiane Raab; Simone Raschia; Cesare Sangiorgi; Cezary Szydlowski; Hassan A. Tabatabaee; Piergiorgio Tataranni; Kamilla Vasconcelos; Joelle De Visscher; Adam M. Zofka.

C. Sangiorgi (✉) · F. Balzano · P. Tataranni
Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, Bologna, Italy
e-mail: cesare.sangiorgi4@unibo.it

F. Balzano
e-mail: filippo.balzano2@unibo.it

P. Tataranni
e-mail: piergiorg.tataranni2@unibo.it

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1 Introduction and scope

In recent years, preventive and low-impact maintenance techniques have been developed to reduce the need for major interventions in favour of targeted solutions aimed at extending the service life and restoring the functionality of pavements. Among all these solutions, microsurfacings are widely recognised as an environmentally friendly solution that requires less energy and emissions to produce and less virgin material than traditional hot mix asphalt [1]. Due to their low thickness, which can vary between 8.0 and 12.5 mm, microsurfacings usually require a well-formulated mixture [2]. Moreover, the mixture must be customised to compensate for variations in the existing road surface and to achieve a durable bond at the interface between the newly applied and the existing layer. In fact, the surface texture has a strong effect on the bonding behaviour as it influences the interlocking and adhesion at the interface. Interlocking can be defined as the ability of the bond to resist shear forces caused by the mutual displacement and overlapping of the aggregates of two neighbouring layers. Adhesion is the grip that is created between the two layers due to the penetration of the newly applied mixture and the micro-roughness of the substrate. Insufficient interlayer bonding can lead to slippage and to partial or complete delamination of layers. This can impair the functionality of the pavement, as large cracks and potholes can occur [3]. Debonding failures typically occur on wearing courses, due to the wheel loads, especially in areas where braking or steering actions are more significant. Although several methods for assessing the mechanical performance of microsurfacings are included in the main international standards, there is a lack of standardised guidelines for assessing the bond strength of these compounds. This can lead to poorly bonded applications and the overall quality of the intervention can be jeopardized. In this regard, this recommendation aims to extend the standardized use of a direct shear bond testing device to characterize the bonding performance of a designed (i.e. to be applied) or existing microsurfacing. The proposed methodology also contains a simple laboratory characterization of the surface condition of the substrate, which will be included in the final report.

A. Graziani
Department of Construction, Civil Engineering and Architecture, UNIVPM—Università Politecnica Delle Marche, Ancona, Italy
e-mail: a.graziani@univpm.it

C. Raab
Empa—Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland
e-mail: christiane.raab@empa.ch

2 Definitions, references and symbols

2.1 General definitions

The following definitions are used within this document.

Microsurfacing –is a specific kind of slurry surfacing consisting of a mixture of aggregates, modified bituminous emulsion, water and additives, which is mixed and laid in-place.
Support layer –is a representative sample of the existing road pavement on which the microsurfacing is/will be applied. It may consist of a laboratory manufactured specimen or a field core.

2.2 List of normative references

EN 12273: Slurry surfacing—Requirements
EN 12697–27: Bituminous mixtures—Test methods | Part 27: Sampling
EN 12697–29: Bituminous mixtures—Test methods | Part 29: Determination of the dimensions of a bituminous specimen
EN 12697–31: Bituminous mixtures—Test methods | Part 31: Specimen preparation by gyratory compactor
EN 12697–33: Bituminous mixtures—Test methods for hot mix asphalt | Part 33: Specimen prepared by roller compactor
EN 12697–48: Bituminous mixtures – Test methods | Part 48: Interlayer bonding
EN 13036–1: Road and airfield surface characteristics – Test methods | Part 1: Measurements of pavement surface macrotexture depth using a volumetric patch technique
EN 13036–4: Road and airfield surface characteristics – Test methods | Part 4: Method for meas-

urement of slip/skid resistance of a surface: The pendulum test

2.3 List of symbols and notations

A: Area of the specimen [cm^2]
D: Diameter of the specimen [mm]
MTD: Mean Texture Depth [cm]
V_{RS}: Volume of the retained sand [cm^3]
V_{ES}: Volume of the excess sand [cm^3]
W_{ES}: Weight of the excess sand [g]
V_U: Unit volume of sand [cm^3]
n°V_U: Number of Unit Volume of sand used
W_{UV}: Weight of a unit volume [g]
PTV: Pendulum Test Value
ν_i: Individual values of each swing
L_P: Peak load [kN]
τ_P: Maximum shear stress [MPa]
δ_i: Displacement corresponding to the peak load [mm]

3 Procedure

3.1 General

This section describes the equipment and the principle of the test, the procedures for the preparation, curing and conditioning of the specimens as well as the configuration of the shear bond test.

Figure 1 shows the main phases of the proposed procedure. Firstly, the texture of the support layer is analysed using different test methods. Successively, the microsurfacing mixture is applied and cured. Finally, the conditioned specimens are tested using the shear bond testing apparatus.

3.2 Equipment

The shear bond testing requires the equipment introduced in EN 12697-48 Sect. 7.1 and illustrated in Fig. 2.

It is recommended to characterize the surface texture of the support layer using either the equipment described in EN 13036-1 (Fig. 3) to carry out a "Volumetric Patch Test" or the devices included in EN 13036-4 to perform a "Pendulum Test" (Fig. 4).

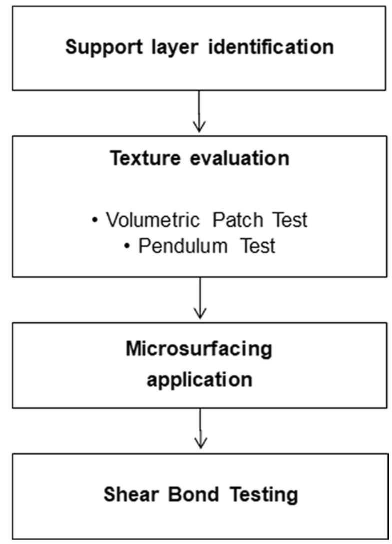

Fig. 1 Flow chart of the testing methodology

Other common laboratory tools and pieces of equipment may be required during the microsurfacing mixture application including spoons, a spatula, pans, a thermometer and a high-precision laboratory scale with the precision of 0.01 g.

A climate chamber with the precision of 0.1 °C for the conditioning of the specimens and the materials and an oven with the precision of 1 °C for curing are needed.

3.3 Preparation of the support specimens

The methodology can be applied to cores or laboratory manufactured specimens. Specimens should be cored from a pavement according to EN 12697-27. The laboratory preparation should be performed by means of a gyratory compactor, in accordance with EN 12697-31, or a roller compactor according to EN 12697-33. In any case, specimens should be regular cylinders with a diameter of 150 ± 2 mm and a thickness of at least 70 mm. The upper surface should be perpendicular to the core's longitudinal axis, while the lateral surfaces should be smooth to allow an adequate placement in the apparatus. At least five replicate specimens should be tested for each type of system (support + microsurfacing).

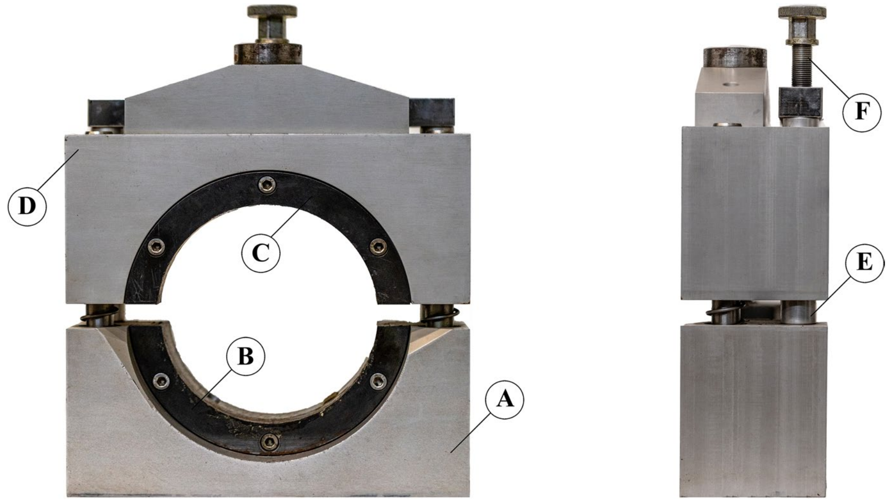

Fig. 2 Schematic representation of the Shear Bond Test apparatus (load is applied on the upper body). Key **A** Base body, **B** Lower shear ring, **C** Upper shear ring, **D** Upper body, **E** Guiding bars, **F** Locking screw (when present)

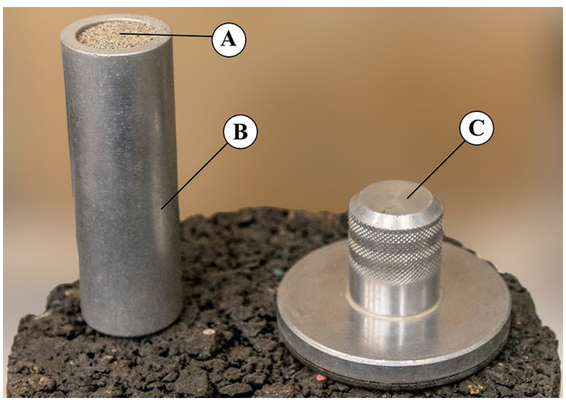

Fig. 3 Volumetric Patch Test equipment. **A** Graded monogranular sand (or glass spheres), **B** Sample cylinder (fixed volume), **C** Spreading tool

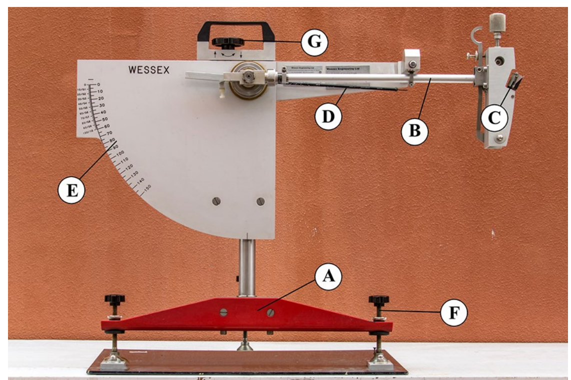

Fig. 4 Pendulum Test equipment (an adequate sample-locking system may depend on the specific equipment; it is not shown in the figure). **A** Frame, **B** Pendulum arm, **C** Slider, **D** Pointer, **E** Unit scale, **F** Levelling screw, **G** Clamp for vertical adjustment

3.4 Texture evaluation: mean texture depth

This section aims to provide a procedure for the evaluation of the macro-texture (wavelength 0.5 mm < λ < 50 mm [4]) of the surface of the support layer, expressed as the "Mean Texture Depth" **MTD**. The method uses the standard tools introduced in EN 13036-1 and other common laboratory equipment, including a laboratory scale with the precision of 0.01 g and a large pan/container.

The Mean Texture Depth **MTD** is determined according to the equation:

$$MTD = \frac{V_{RS}}{A}$$

The test should be performed by applying the following procedure:

- Fill the cylindrical container with sand (or glass spheres) and gently tap the base on a regular surface. Add more material to re-fill the container and level with a straightedge, obtaining the "Unit volume of sand" $\mathbf{V_U} = 25 \pm 0.15$ cm^3. Using the laboratory scale, weigh the mass of the sand inside the cylinder and record the "Weight of the unit volume" $\mathbf{W_{UV}}$;

- Place a pan on the scale and set the tare to zero;
- Place a specimen in the centre of the pan;
- Pour a full cylinder of sand on the surface texture of the support layer and carefully spread it using the spreader tool until the whole surface is covered. Take care that every excess of sand falls inside the pan (Fig. 5);
- Carefully remove the specimen (covered with the testing sand) from the pan. Record the "Weight of the excess sand" $\mathbf{W_{ES}}$;
- Calculate the "Volume of the excess sand" $\mathbf{V_{ES}}$ using the equation:

$$V_{ES} = \frac{W_{ES} \cdot n^{\circ}_{Vu} \cdot V_U}{W_{UV}}$$

- NOTE: For highly-textured supports the volume of 25 cm^3 may be insufficient to cover the whole surface. In this case, double or triple the Unit volume by using 2 or more cylinders of sand.
- The "Volume of the retained sand" $\mathbf{V_{RS}}$ can be calculated using the relation:

$$V_{RS} = n^{\circ}_{Vu} \cdot V_U - V_{ES}$$

3.5 Texture evaluation: pendulum test value

This method aims to estimate the micro-texture level (wavelength $\lambda < 0.5$ mm [4]) of the support by means of the friction recorded on its surface, adopting a Pendulum Test device in accordance with EN 13036-4.

The test should be performed by applying the following procedure:

Fig. 5 Performing the Volumetric Patch Test

- Assemble the pendulum apparatus and locate it on a stable and flat surface following the instructions in the standard;
- Condition the specimen, water and the rubber slider at 20 ± 1 °C for at least 4 h before performing the test;
- Lock the specimen on the bottom plate adequately, to avoid any movement during the sliding of the pendulum. Clamps or other stable supports may be required. Adjust the height of the pendulum arm to ensure the contact with the top surface of specimen over the whole width of the slider and for a sliding length of 126 ± 1 mm. Any contact with the edge of the sample should be avoided in this phase;
- Using a sprayer, wet the top surface of the specimen with a sufficient amount of water before each sliding. The approximately same amount of water should be used for each measurement;
- Record the temperature of the wet contact area before the first sliding of each set of measurements. The temperature correction shown in Table 3 of EN 13036-4 must be applied if the test is performed at a temperature < 19 °C or > 22 °C;
- The energy loss during the sliding, expressed by means of the "Pendulum Test Value" **PTV** should be calculated as the mean of five consecutive swings using the following formula:

$$PTV = \frac{\sum_{i=1}^{5} v_i}{5}$$

3.6 Microsurfacing mixture application

This section describes a methodology to prepare and apply microsurfacing mixtures on the support specimens, in the laboratory. The materials (bituminous emulsion, aggregates and additives) and the microsurfacing formulation itself should meet the needs of the adopted reference standards. Since microsurfacings are extremely sensitive to filler, emulsion, water and temperature variations, taking note of any occurring change during the mixture preparation is recommended.

The following steps provide a laboratory preparation procedure for microsurfacings. The quantity of prepared mixture should be enough to cover one (or more) support specimen(s) (e.g. a mixture based on

600 g of dry aggregates may be sufficient to cover a medium-textured specimen), taking into account the microsurfacing layer thickness and the breaking time of the emulsion.

The microsurfacing should be prepared as follows:

- Dry the aggregates in the oven until the mass remains constant. Pour them through the 2 mm sieve, separating the passing (fine aggregate) and the retained (coarse aggregate) aggregates. Store the aggregates in sealed containers to avoid any moisture infiltration;
- In a wide pan, weigh a larger than strictly necessary amount of fine aggregate. Add 3% (w/w) of water and mix until the particles are homogeneously wetted. This procedure aims to prevent the segregation of filler from sand. Store the wet portion in a sealed container;
- Mix the bituminous emulsion with a stick or with a low-speed mixer for at least 15 min, to avoid the sedimentation of bitumen or polymers. The design temperature of the emulsion should be set as a target and maintained at every moment with a maximum difference of ± 5 °C. Lower or higher temperatures may affect the breaking time of the emulsion, thus hindering the laboratory application. Therefore, aggregates, water, emulsion and additives should be kept in a thermostatic cabinet and conditioned at the design temperature for at least 4 h before their use;
- In order to reassemble the gradation curve, weigh and add the relative portion of dry coarse aggregates in an empty container;
- Add the complementary percentage of pre-wetted fine aggregate and mix accurately with a spoon until the material is homogeneous. Calculate the weight of the dry aggregates by subtracting from the total the 3% (w/w) of the fine aggregate weight;
- Add dry additives (cement, fly ashes, etc.). Their quantity should be based on the weight of the dry aggregates only. Mix with a spoon until the material is homogeneous;
- Add water. Its quantity should be based on the weight of the dry aggregates only. The final percentage of water will include the quantity used for the pre-wetting of the fine aggregates. Mix accurately with a spoon until the material is homogeneous;
- Add bituminous emulsion. Its quantity should be based on the weight of the dry aggregates only. Mix accurately for at least 60 s to obtain a homogenous material. The mixture must be immediately—well before its breaking time—applied on the specimen.

The mixture should be applied on the support specimen as follows:

- Using a marker, mark the top circular edge of the specimen. This step will ease the identification of the interface after the mixture application;
- Place a circular adjustable and not deformable belt/ring (the belt/ring should be adjusted to the support specimen diameter) on top of the specimen and fix it firmly. The upper edge of the belt/ring should be raised far enough above the surface of the sample to allow the microsurfacing application (Fig. 6). The average thickness of the applied layer should be 20 mm;
- Apply the microsurfacing mixture evenly to the upper edge of the belt/ring using a spatula. Apply some pressure to fill the texture of the specimen; Wait 20–30 min before any other manipulation. Carefully remove the belt/ring and cure the newly applied layer at room temperature (e.g. 18 − 25 °C) for at least 2 h;
- Place the double-layered sample (system) (Fig. 7) in an oven and let it cure at 60 °C for 3–8 h until constant mass is reached. Allow the specimen to reach room temperature before any further manipulation;

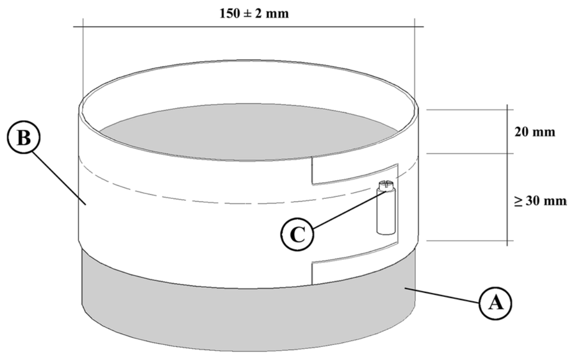

Fig. 6 Schematization of the circular belt/ring (mould). Key **A** Supporting specimen **B** Circular adjustable and not deformable belt/ring. **C** Locking screw

Fig. 7 Double-layered system. **A** Support specimen, **B** Circular adjustable and not deformable belt/ring, **C** Locking screw

- A metal plate, according to EN 12697-48 Sect. 7.1.4, should be glued on top of the microsurfacing before testing, in case the temperature affects performing the test or its results.

3.7 Shear bond testing

This section describes a test procedure to assess interlayer bond strength between the support layer and the newly applied microsurfacing layer.

The test should be performed according to EN 12697-48 for the Shear Bond Test taking care that the following is done:

- Place the prepared double-layered specimens in a climate chamber at a temperature of 20 ± 1 °C for at least 4 h. The shear bond test should be performed within 5 min after the specimen is removed from the climate chamber;

The specimen should be placed in the shear bond testing apparatus, aligning the marked interface in the shear plane, as shown in Fig. 8.

- If metal plate extension is applied, the grooves shall be perpendicular to the direction of applied shear force;
- Tighten the sample holder or the locking screw to avoid any misalignment during the test;
- Adjust the loading frame until the upper shear ring nearly touches the specimen. A minor pre-load may be required to keep the ring in position;

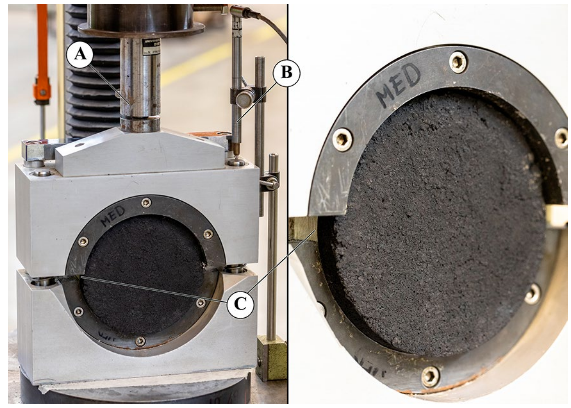

Fig. 8 Shear Bond Testing setup. **A** Loading actuator with load cell, **B** LVDT, **C** Interface alignment (shear plane)

- Initialize the data logging system in a configuration that allows to record load and vertical displacement and start the shear loading with a rate 50 ± 2 mm/min until failure (see EN 12697-48 Sect. 7.3.8);
- The visual inspection of the failure surfaces after the test should be carried out to discard invalid failures (see EN 12697-48 Sect. 7.3.10).

If the testing results and/or the failure surface appearance are not satisfactory, the use of a glued steel plate (see Sect. 3.6) and/or different testing temperatures should be considered. Common satisfactory and unsatisfactory failures are shown in Fig. 9.

It should be taken into account that the testing temperatures will affect the experimental result, therefore, it should always be reported. Results obtained at different temperatures should not be directly compared.

4 Collection, analysis and presentation and evaluation of results

Test results should be presented in tables and graphs as shown in this section.

Results of the Volumetric Patch Test should be collected as shown in Table 1. For each specimen a unique identification code should be selected. The specimen's diameter should be measured according to EN 12697-29. The Mean Texture Depth should be calculated as described in Sect. 3.4.

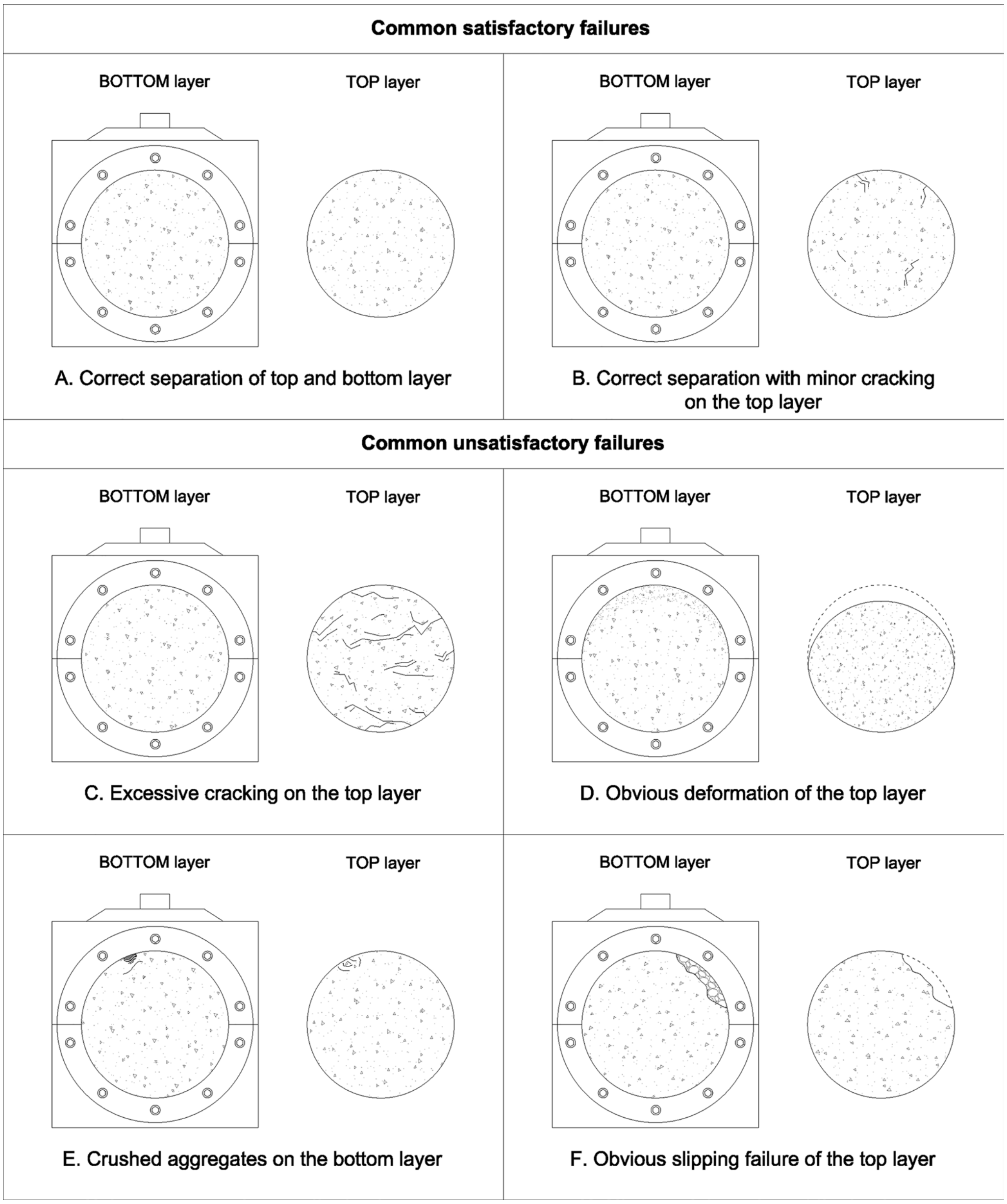

Fig. 9 Common satisfactory and unsatisfactory types of failure

Results of Pendulum Test should be collected as shown in Table 2. For each specimen a unique identification code should be selected. The temperature of the wet top surface should be recorded at the beginning of the test. PTV should be calculated as described in Sect. 3.5.

Results of shear bond testing should include the load vs displacement curve, recorded from the beginning of the test until failure. A common failure curve is shown in Fig. 10. The following parameters should be determined from the graph:

- $\mathbf{L_P}$ is the peak load in kN, expressed to the nearest 0.1;
- $\boldsymbol{\delta_P}$ is the displacement corresponding to the peak load in mm, expressed to the nearest 0.1;

Table 1 Volumetric Patch Test results

ID	Specimen	Diameter (mm)	Notes	$n°_{VU}$	W_{ES} (g)	V_{ES} (cm^3)	V_{RS} (cm^3)	MTD (mm)
1	Specimen 1	150	–	1	15.73	11.06	13.94	0.79
2		–	–	–	–	–	–	–
3		–	–	–	–	–	–	–
…		–	–	–	–	–	–	–
n		–	–	–	–	–	–	–
V_U (cm^3)								25.00
W_{UV} (g)								35.56

Table 2 Pendulum test results

ID	Specimen	Surface Temperature (°C)	ν_1	ν_2	ν_3	ν_4	ν_5	$\frac{\sum_{i=1}^{5} \nu_i}{5}$	PTV
1	Specimen 1	20.2	74	75	75	75	75	74.8	75
2		–	–	–	–	–	–	–	–
3		–	–	–	–	–	–	–	–
…		–	–	–	–	–	–	–	–
n		–	–	–	–	–	–	–	–

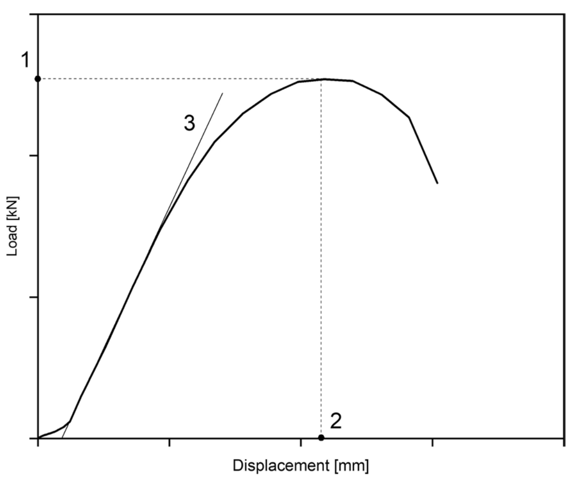

Fig. 10 Example of a shear load vs displacement graph. **1** L_P Peak load, **2** δ_P Displacement at the peak load, **3** Slope of the shear load

- $\boldsymbol{\tau_P}$ is the maximum shear stress, calculated as follows:

$$\tau_P = \frac{L_P}{\pi \cdot \frac{D^2}{4}} \cdot 1000$$

where:

- L_P Peak load [kN]
- D Specimen diameter [mm]
- The slope of the linear part of the load–displacement curve, in kN/mm;

5 Test report

The test report should contain at least the following information:

(a) Reference to this document;
(b) Date of the test;
(c) Test conditions;
(d) Origin of the support layer (field or laboratory specimen);
(e) Material description for both layers;
(f) Volumetric Patch Test results, expressed by means of the **MTD** [mm] as shown in Table 1;
(g) Pendulum Test results, expressed by means of the **PTV** as shown in Table 2;
(h) Shear Bond Test results, including:
(i) Specimen diameter, to the nearest mm;
(j) Layer thickness, to the nearest mm;
(k) Peak load ($\mathbf{L_P}$), to the nearest kN;

(l) Displacement at the peak load ($\boldsymbol{\delta}_{\mathbf{p}}$), expressed to the nearest 0.1 mm;
(m) Slope of the linear part of the load–displacement curve, expressed to the nearest 0.1 kN/mm;
(n) Load vs displacement curve;
(o) Any uncommon failure, cracks or other damage.
(p) Any variation from the test procedure.

6 Sources of uncertainty

The dispositioning of the tested sample may lead to unsatisfactory failure and it is one of main sources of uncertainty. Other sources of uncertainty are those related to the double-layered system preparation/coring, such as:

- Non-representative compaction of the support layer;
- Premature breaking time of the microsurfacing emulsion;
- Non-perpendicular coring axis.

The number of tested samples should be increased, whenever possible.

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Data availability The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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