Performance requirements for joint filling materials in small element paving

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Abstract:
Joint fillers for small element paving are an important structural part of this type of road pavement, which is not always valued on its true merits. If the paving is to actually perform as a pavement, the joints between the pavers must be filled with suitable material. The nature of the joint filling material and the durability of the joint as a whole are crucial for the long-term stability of a block paving. A distinction is made between traditional unbound materials such as sand and fine aggregates, and bound jointing mortars and grouts. According to EN 13888 "Grout for tiles" [1], bound materials are divided into cementitious grouts and more innovative reaction resin grouts. However, the requirements for these two types of joint filler (with cement or reaction resin) differ widely. Furthermore, the durability-related limit values have been set for ceramic tiles. These small elements of limited thickness are typically used for indoor or outdoor applications with only limited traffic loading (terraces, garden paths). As for joint sealing materials for road pavements with concrete paving blocks and flags (EN 1338 and 1339), clay pavers (EN 1344) or natural stone setts or slabs (EN 1341-1342), there are for the time being no uniform European guidelines, nor any clear performance requirements at the Belgian level. In this context, BRRC undertook a two-year pre-normative study under the acronym PREVOSTRAT [2] (translated as "Performance requirements for innovative joint filling materials in small element paving"), with the support of the Belgian Federal Public Service Economy. The main goal of this study was to define test methods and set corresponding performance limits for bound or unbound innovative joint filling materials used in small element road pavements. This paper will summarize the results of this pre-normative research project and give recommendations for performance requirements to be made on bound or unbound joint fillers at the Belgian level, which may in future be included in standard tender specifications.
Key Words: joint filler; block paving; performance requirements; grout; mortar; road pavement

1. Introduction

The main goal of the research project was to define test methods and set corresponding performance requirements for bound or unbound innovative joint filling materials for use in small element paving. This involved an extension of existing specifications and methods, in four respects:

- extension of requirements for joint fillers to other types of trafficked pavement;
- extension of requirements to new types of joint filling material;
- extension of test methods to weed-suppressing performance [3];
- extension of test methods for the determination of water permeability [4].

More specifically, three important aspects of performance requirements were addressed:

1. Physicomechanical properties and durability testing (bound mortars).
2. Weed-suppressing ability of joint fillers (unbound + bound materials).
3. Functionality-related properties such as the water permeability of bound materials, bond strength between paver and jointing mortar, and the applicability and sensitivity to erosion of joint fillers.

The main research results are summarized below, with recommendations for performance requirements to be made at the Belgian level to joint filling materials for use in small element paving.

2. Existing guidelines and division into product groups

An extensive literature study and analysis of existing standards was made to gain a clear overview of the various possible test methods and corresponding requirements. Table 1 summarizes the most relevant standards and performance requirements in various European countries. As can be seen, they relate to common mechanical testing for bound jointing mortars, such as the determination of compressive and flexural strength, shrinkage, water absorption, freeze-thaw resistance, etc. They were investigated in the first stage of the study.

Table 1. Overview of existing standards and corresponding requirements for bound jointing mortars

Parameter	EN 13888	BS 7533 – 7 & 10	FGSV 618/2	WTA MB 5-21	ZTV Wege-bau FLL	RVS 08.18.01	NF P98-335	SB 250 Sect. 3-74
Compressive strength [MPa]	≥ 15 (45)	≥ 25* ≥ 40*	≥ 45 avg. ≥ 40 ind.	≥ 40 (35-55) ≥ 30 on site	≥ 10-30* (5-25)*	≥ 30	-	≥ 40
Flexural strength [MPa]	≥ 2.5 (30)	≥ 3.5* ≥ 6.0*	-	≥ 6.0	-	≥ 6.0	≥ 3.5 24h ≥7 7d	≥ 6.0
Bond strength [MPa]	-	≥ 1.0* ≥ 1.5*	≥ 1.5 avg. ≥ 1.2 ind. ≥ 0.8 on site	≥ 1.5 ≥ 0.8 on site	≥0.4-1.0* (0.2-1.0)* 0.4-0.5 on site	≥ 1.0	> 2	≥ 1.5
E-modulus (kN/mm²)	-	≥ 18* ≥ 20*	-	20-26	-		-	20
Density [kg/m³]	-	≥ 2,000	-	-	-		-	
Shrinkage [mm/m]	≤ 3 (1.5)	≤ 1	-	≤ 1	-		< Ref/1.5	≤ 1.5
Water absorption [g] after 30 min after 240 min	 ≤ 2 ≤ 5 (0.1)	-	-	-	($k > 10^{-5}$ m/s for epoxy)		-	-
Abrasion resistance (Capon) [mm³ material loss]	< 1,000 (250)	-	-		-		-	-
Freeze-thaw resistance with de-icing salts	-	Resistant	CDF: ≤ 500 g/m²	CDF: ≤ 1,000 ≤ 1,500 ind.	CDF: ≤ 800	Resistant	NF P18-424	-
Field of application	Ceramic tiles	Natural stone and concrete block paving	Block and flag paving in bound construction	Block paving	Block paving, without road traffic	Block and flag paving	Block and flag paving	Fast-drying jointing mortar

* = depending on traffic loading; (…) = for reaction resin mortars

Based on the literature review and contacts with several suppliers, an overview of the products available on the Belgian market was made, as well as a classification into different product groups (Figure 1). From each product group two to four representative products were selected for further testing, depending on the current market situation.

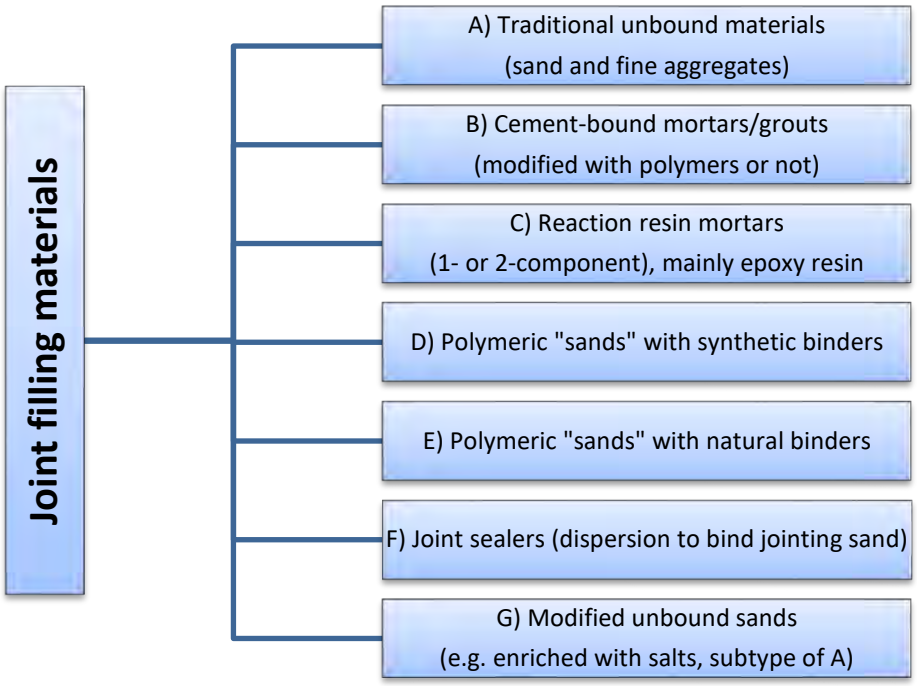

Figure 1. Classification of joint filling materials into product groups

3. Physicomechanical properties and durability of bound jointing mortars

The mechanical properties of some selected cement-bound (group B) and reaction resin (mostly epoxy) mortars (group C) were determined first, because the existing test methods could be applied without modification and the results could be checked against the existing guidelines in various countries (Table 1).

Initially, the test methods and requirements in NBN EN 13888 [1] were taken as starting points and the following properties were investigated:

- compressive and flexural strength (NBN EN 12808-3);
- dry and apparent density (NBN EN 12390-7);
- linear shrinkage (NBN EN 12808-4);
- water absorption (NBN EN 12808-5);
- resistance to abrasion – Capon test (NBN EN 12808-2);
- workable life and stiffening time (NBN EN 13294 and NBN EN 1015-9);
- thermal expansion (NBN EN 1770);
- freeze-thaw resistance with de-icing salts (CEN/TS 12390-9 + NBN EN 1338, Annex D);
- modulus of elasticity in compression (NBN EN 13412).

For the cement-bound mortars it appears in general that water content is crucial in achieving the desired mechanical properties (e.g. higher strength, lower shrinkage, low water absorption) and that this parameter needs to be controlled during execution.

In addition, for both the cementitious and the reaction resin mortars the curing conditions can have a considerable impact on the results obtained. Generally speaking, the standard conditions (20 °C and 60 % RH) will approximate actual work site conditions best (Figure 3).

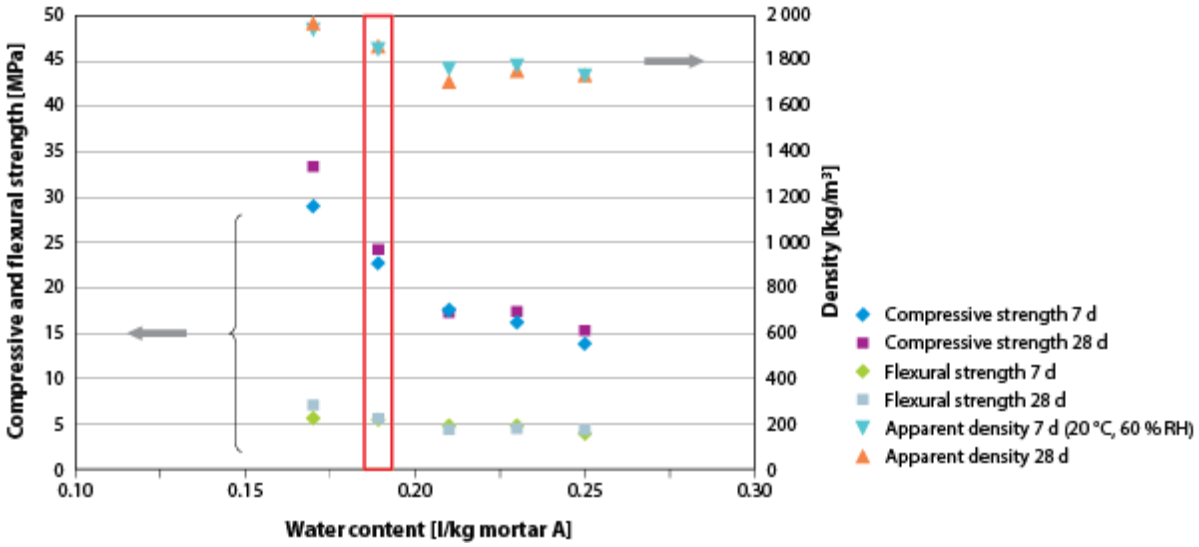

Figure 2. Influence of water content on the mechanical strength of cement-bound jointing mortar

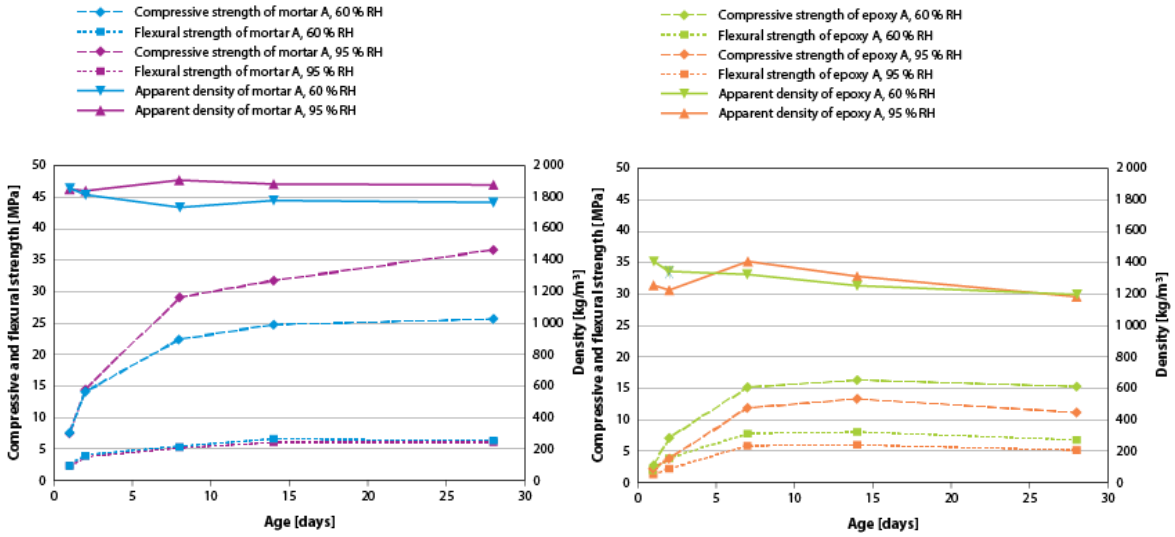

Figure 3. Influence of curing conditions on the mechanical properties of cementitious (left) or reaction resin (right) jointing mortar with epoxy

For freeze-thaw resistance with de-icing salts, a test method slightly adapted to jointing mortars was developed from the reference method for concrete [5] and concrete paving blocks [6] (Figure 4).

It appeared from the results that a nice distinction could be made between samples with good or poor resistance to scaling in the presence of de-icing salts. In addition, for cement-bound mortars a clear correlation could be established with the water absorption value. This means that water absorption – which is easier to determine on construction sites – provides a good measure for the resistance to scaling of cementitious mortars.

Finally, for applications in block paving it is also recommended from a practical point of view to measure other properties such as thermal expansion, which may cause the building up of thermal stresses in the pavement, resistance to abrasion when subjected to traffic, or workable life, which will determine the time frame available for processing the jointing mortar on the work site.

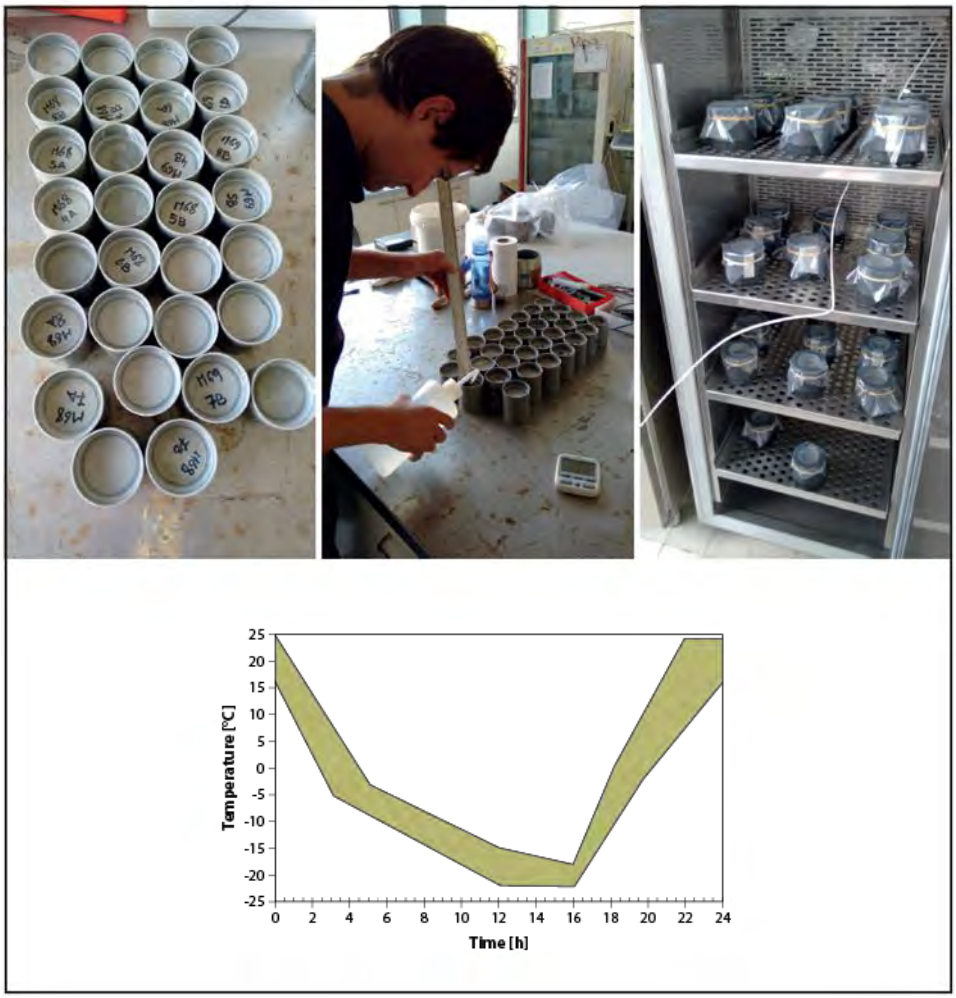

Figure 4. Test method to determine resistance to freeze-thaw cycles in the presence of de-icing salts, adapted to cement-bound jointing mortars

4. Weed-suppressing action

Weed-suppressing action or ability was tested for by Ghent University, in a similar way as in previous research [3]: in addition to testing joint filling materials in the laboratory, "mini-pavements" were used (Figure 5). In both types of test, 15 different joint fillers contaminated or not with organic material were investigated. This organic contamination simulated the pollution the joint will undergo in practice. Laboratory testing involving only the joint filler aimed to assess the influence of different precipitation regimes on weed-suppressing ability. The additional mini-pavement test was set up to see whether the lab tests gave a good indication of the actual performance of the joint filling materials *on site*.

By way of general conclusion, we may state that testing in the climate chamber ("lab test") proves to be a quick, reproducible and cheap(er) method to determine the weed-suppressing action of joint fillers on site. Moreover, the results can be used to make a division into "classes of weed-suppressing action" [7].

The weed-suppressing action of the bound materials tested (cementitious and reaction resin mortars as well as polymeric sands and joint sealers) is mainly owed to the closing of the joint. To prevent weed growth in the long run, however, additional performance requirements may be needed such as lower shrinkage, reduced water absorption, resistance against road sweepers, etc. The weed-suppressing ability should, therefore, also be linked - in this case - to the mechanical properties of the joint fillers.

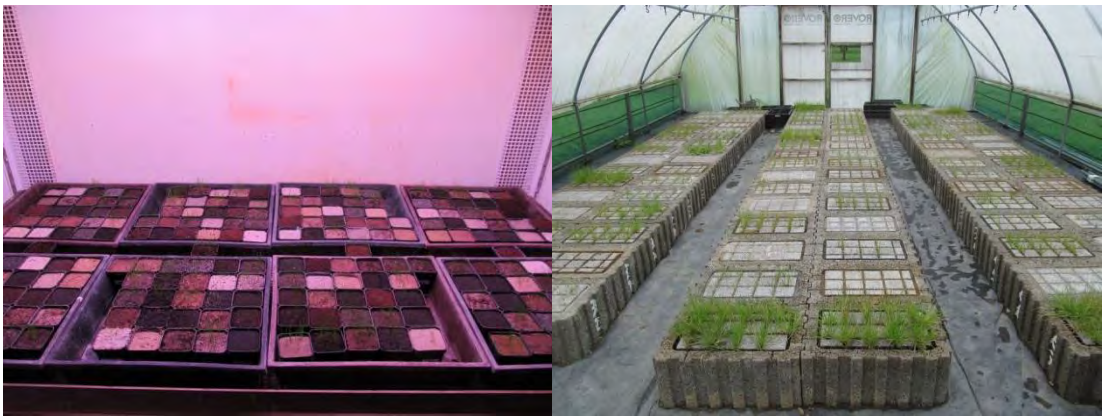

Figure 4. Setups for laboratory testing (left) and mini-pavement test (right) at Ghent University, to determine the weed-suppressing ability of joint filling materials

5. Functional properties

This includes test methods to determine the bond strength between paving block and jointing mortar, the water permeability of polymer-bound jointing mortars and the applicability and/or erodibility of the joint filling material, where interaction with the type of paver and/or the block paving itself (e.g. joint width) might be an important factor.

5.1 Bond strength

To determine the bond strength between paver and mortar, direct pull-off tests following NBN EN 1542 [8] can be performed as a first resort. In this test method, a layer of jointing mortar about 10 mm thick is applied to the sides of a paving block (Figure 5). Subsequently, after 21 days of curing, a hole is drilled through this layer of mortar and to a depth of 15 ± 5 mm into the paver, after which the pulling dolly is glued to the specimen. The pull-off test itself is carried out at an age of 28 days.



Figure 5. Testing to determine the tensile bond strength between a paving block and jointing mortar according to NBN EN 1542

Owing to the low bond strengths observed (especially with concrete paving blocks) and the great influence of small variations in the linearity of the tensile load [9], an adapted test method was developed as well, by using a conical ring in the fresh mortar and/or applying a lower loading rate. This adjusted test method needs to be used when lower values of direct tensile bond strength are expected (< 0.5 MPa). In addition, it is recommended to perform the test on a wet paver, since in practice paving blocks are always wetted before jointing to allow better application of the mortar.

On the other hand, for the cement-bound mortars the influence of wetting the paving blocks was surprisingly not unambiguous and the effect also depends on the type of paver (concrete, natural stone, clay), surface finish and even individual mortar type.

For all combinations of paver and jointing mortar tested under wet as well as dry conditions, failure in the paving block was observed in only two cases, where the bond strength between paver and mortar was greater than the tensile strength of the paving block itself. In all other test cases adhesion failure always occurred at the boundary area between paver and jointing mortar.

As an alternative to the measurement of direct tensile bond strength, the so-called *slant shear test* according to NBN EN 12615 [10] could be used. This test combines shear and tensile stresses (Figure 6) and is more representative of to the actual situation in practice. Although the method is technically more difficult to implement than the pull-off test, it may be used as a fallback option when the pull-off test proves inconclusive about the bond between paver and jointing mortar.

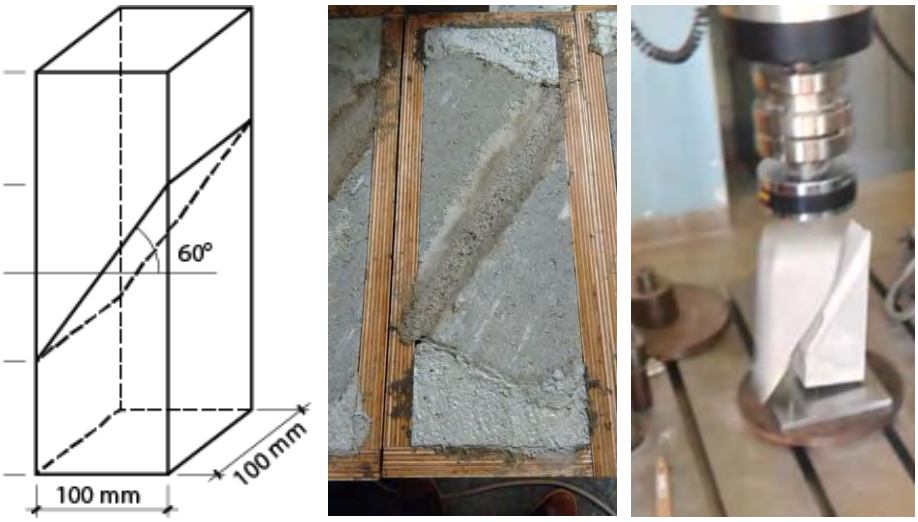

Figure 6. Testing to determine the "slant shear strength" between a paving block and jointing mortar according to NBN EN 12615

5.2 Applicability of joint filling materials

An important prerequisite for a joint to work properly is that it must be filled to its full depth. In the research project, different tentative tests were made to determine the practical applicability of joint fillers (unbound as well as bound), using a number of test crates with concrete paving blocks (Figure 7).



Figure 7. Test crates and vibrating plate to determine the applicability of unbound jointing materials

As a general conclusion we may state that dry joint filling is still the best and that, if such is not possible (as often encountered in practice), the joints need to be refilled several times, for example after a dry period when the initially applied jointing sand has penetrated deeper into the joint.

On the other hand, for the bound jointing mortars tested it was clearly observed that not all were equally successful in filling joints. This was due to inadequate fluidity and workability of the mortar; for instance, the water content recommended by one of the suppliers of cementitious jointing mortar (A) clearly proved be too low to obtain sufficient workability (and, hence, applicability), with only half-filled joints as a result (Figure 8).

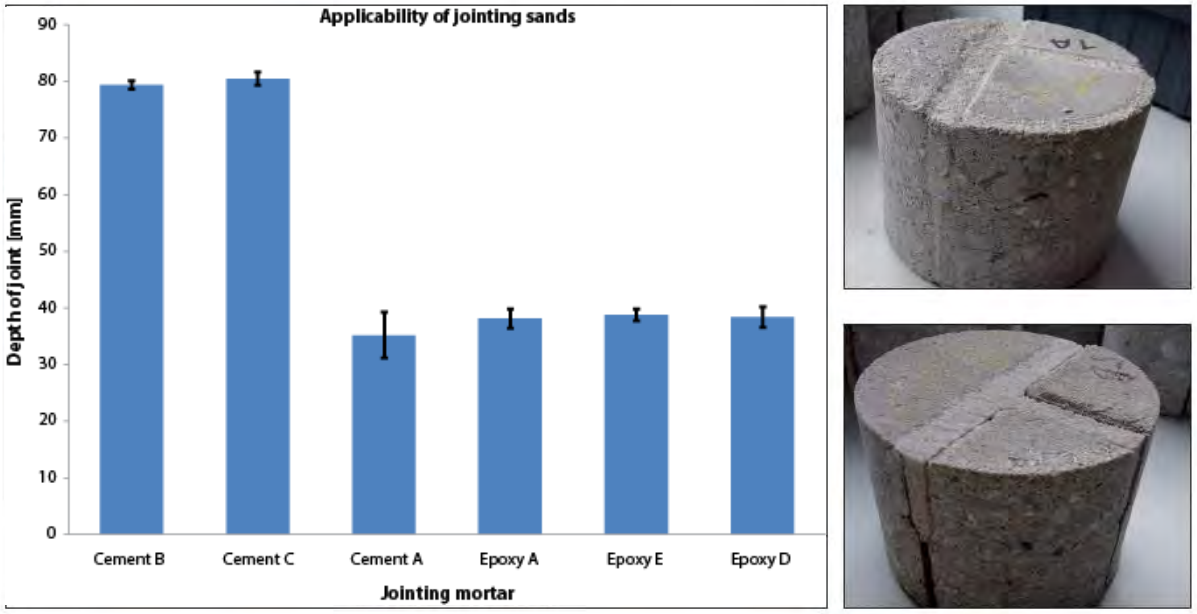

Figure 8. Results for the applicability of jointing mortars in terms of filled joint depth (thickness of paver = 80 mm)

One should be aware that smaller joint widths require a more fluid jointing mortar that does not lose too much material quality (lower strength, higher water absorption …) when water is added. Moreover, depending on the jointing mortar used (especially in the case of reaction resin grouts) a minimum joint width is needed to ensure proper filling of the joint.

5.3 Sensitivity to erosion of jointing mortars

To determine sensitivity to erosion, or erodibility, tests were made with a steel weed brush to simulate the wearing of the pavement during its lifetime (Figure 9). The profile of the paving surface was measured with a laser profilometer both before and after brushing, in order to map out the difference in joint depth caused by brushing.

In general, the results demonstrate that despite the wide variation in the measurement results, the cement-bound mortars resist the brushing action significantly better, with only minimal losses in joint depth. The epoxy-bound mortars are more sensitive to erosion, but in view of the full lifetime the loss of material can still be acceptable in this worst-case scenario.



Figure 9. Testing jointing mortars for erodibility

5.4 Water permeability of bound joint filling materials

The water permeability of *polymer-bound* materials can be tested by the method with active flow-through described in Section 14-4.9 of the Flemish standard tender specifications SB 250 [11], on cores 113 mm in diameter and 10 cm high (Figure 10).

From the results it appears that the water permeability of all tested reaction resin mortars – except for one – satisfies the limit for water-permeable pavements in Belgium *(> 4 * 10^{-4} m/s*). Permeability is lower when the samples are fully saturated with water, but in most cases it is restored to the same level after a dry period – which will also occur in real life.

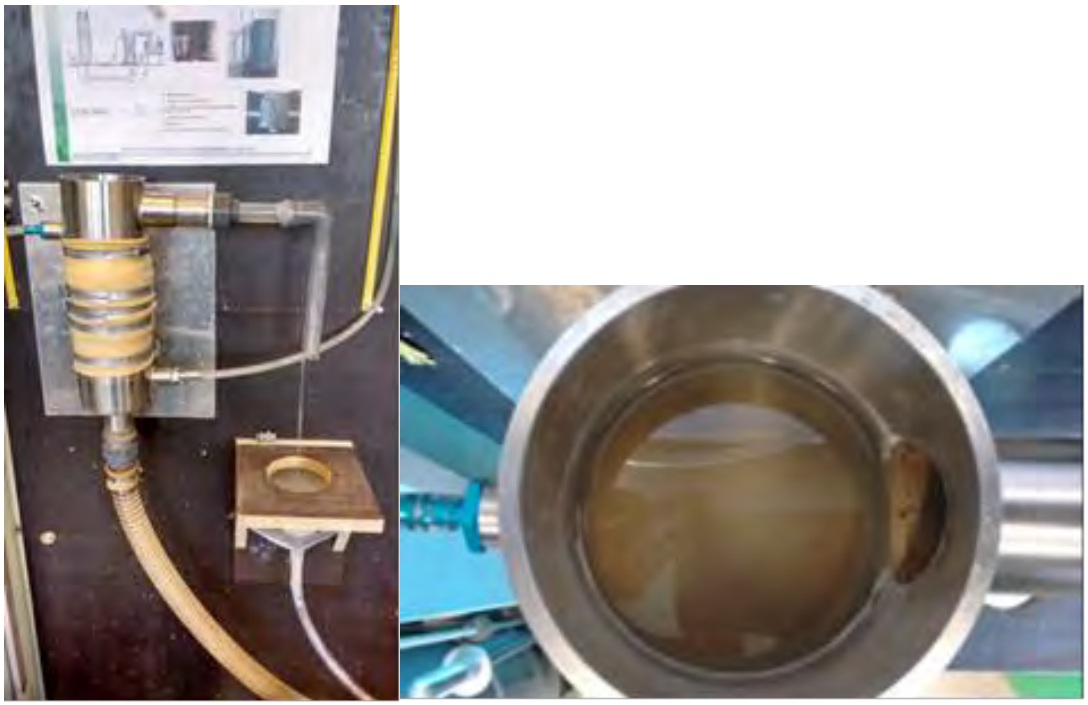

Figure 10. Test to determine the water permeability of porous lean concrete, applied to epoxy mortars

6. Validation of laboratory testing on site

To validate the tests and performance requirements as described above, the results obtained in the laboratory were compared to the results of measurements on test specimens manufactured on site. Some 15 work sites were monitored in total.

For the cement-bound mortars, it appears that controlling the water content is crucial to achieve the targeted strength and (minimum) shrinkage on site. When too much water is added with respect to the optimum content recommended by the supplier, significant loss in strength will occur and the shrinkage measured will be higher as well (see Figure 11).

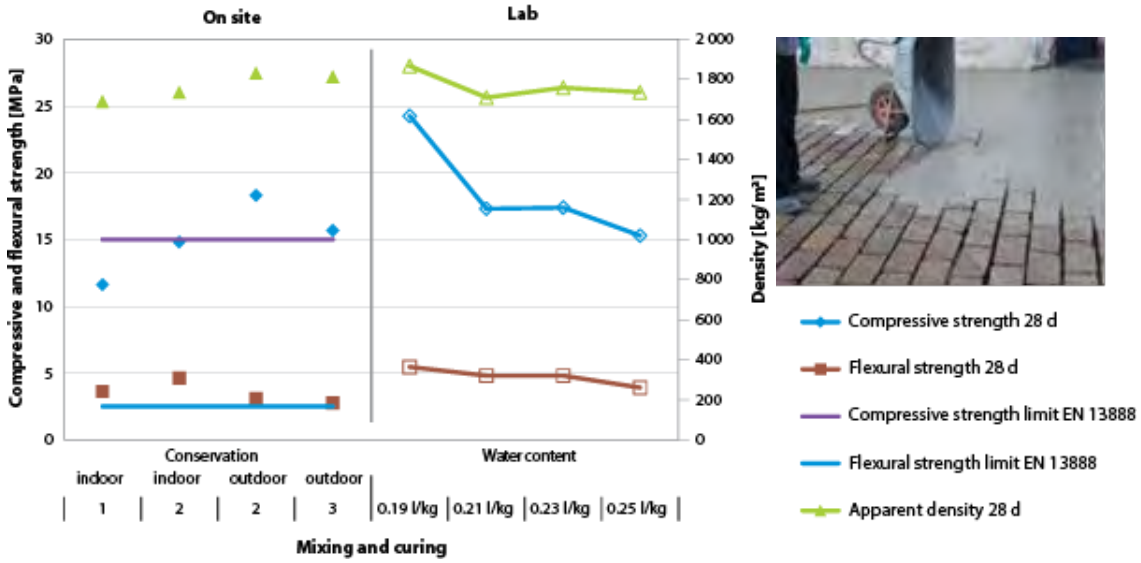

Figure 11. Comparison of compressive and flexural strengths measured on test specimens manufactured on site with cement-bound jointing mortar

The same applies to other properties of the cement-bound mortars, such as water absorption, resistance to scaling and resistance to abrasion. Generally speaking, it can be stated that testing the mechanical properties (compressive and flexural strength, shrinkage, freeze-thaw resistance) in the laboratory under standard conditions of 20 °C and 60 % RH provides a safe measure of what can actually be achieved on site, within a certain margin.

Finally, in small element paving by the "bound" concept, with virtually impervious layers in the structure, checking bond strength between the paver and the jointing mortar prior to construction is certainly still an item to work on in practice (see Figure 12), which must be emphasized to achieve durability in paving.

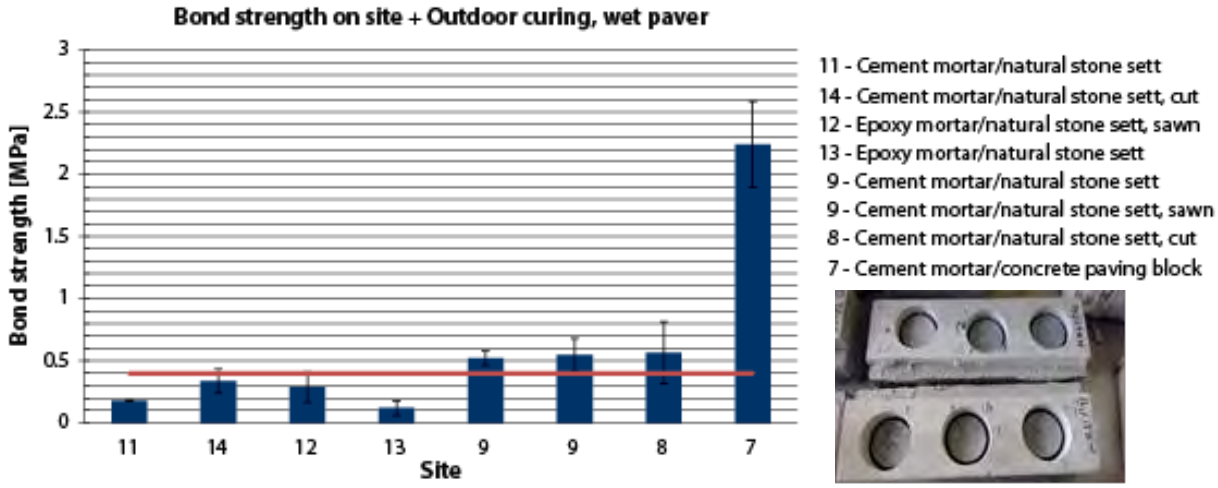

Figure 12. Overview of the results for bond strength between wet pavers and jointing mortars, obtained on test specimens manufactured on site and cured under outdoor conditions

7. Implications and recommendations for practical application

Based on the results from the research, a proposal has been developed for properties that may be tested depending on the type of joint filling material and the relevant fields of application [2].

For *unbound joint filling materials*, reference can be made to the standard tender specifications in the three administrative regions of Belgium and to BRRC's code of good practice A80/09 for the design and construction of concrete block pavements [12], respectively. Additionally, weed-controlling ability can be determined using the method developed by UGent, which also allows classification of the various materials. Applicability is a further important consideration; a tentative test procedure was used in the research project [2]. Finally, the water permeability of unbound materials can also play a part and can be assessed from their particle size distribution and/or by a specific test method [13].

For *newer materials* (polymeric sands with synthetic or natural binders, and joint sealers), further research is needed to characterize their (mechanical) behaviour. They may have to be considered as "improved" bound aggregates, with particle size distribution, sand quality, water content and binder dosage as relevant characteristics (among others). Practical experience will have to show how these materials resist traffic and what durability can be expected for trafficked pavings.

Finally, for *cement-bound materials and resin-bound mortars* (both one- and two-component materials), requirements can be made on jointing materials depending on the traffic category (according to Table 2) of the road in which they are used.

Table 2. Definition of the various traffic categories for small element paving, as given in BRRC's code of good practice A80/09 [12]

Type of traffic				Indicative denotation of traffic category according to the Flemish Government's standard road structures
Category	Pedestrians, cyclists, motorcyclists	Light vehicles (< 3.5 t)	Heavy vehicles (> 3.5 t)	
I	Unlimited	Limited to 5,000 per day	Limited to 400 per day	B6-B7
II	Unlimited	Limited to 5,000 per day	Limited to 100 per day	B8-B9
III	Unlimited	Limited to 500 per day	Limited to 20 per day	B10
IV	Unlimited	Occasional	None	BF

This has been done by analysing all the results of tests for the determination of the mechanical and durability properties (compressive and flexural strength, shrinkage, abrasion, water absorption, et.) of both the cement- and the resin-bound jointing mortars, and by comparing with both the existing requirements in Belgium and abroad (see Table 1) and the results actually obtained on site. A few examples are presented in Figure 13, but also in Figures 11 and 12.

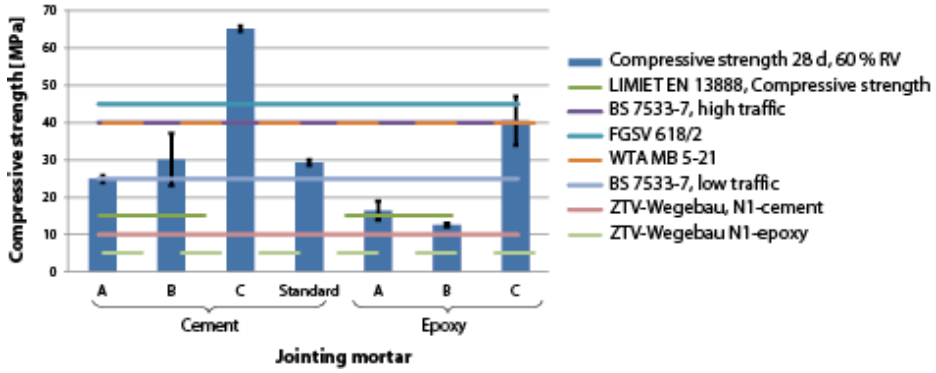

Figure 13. Example of overview of test results for mechanical properties of cement- and resin-bound jointing mortars, and comparison with existing requirements (standard mortar = cement mortar prepared according to European standard EN 196-1)

As regards the water absorption and the freeze-thaw resistance with de-icing salts of cement-bound materials, a choice has to be made; both can be determined in initial testing, but at a lager stage it will, in principle, be enough to check only water absorption, in view of the relation between the two.

Finally, for the properties tested in the research project and the corresponding results obtained on site, Table 3 summarizes our recommendations at the Belgian level, in terms of requirements for bound jointing mortars depending on traffic loading.

Table 3. Recommendations for requirements to be made on bound jointing mortars, depending on expected traffic loading as defined in Table 2

<table>
<tr><th>Traffic category</th><th colspan="7">Requirement</th></tr>
<tr><th rowspan="2"></th><th rowspan="2">Compressive strength after 28d [MPa]</th><th rowspan="2">Flexural strength after 28d [MPa]</th><th rowspan="2">Shrinkage after 28d [mm/m]</th><th rowspan="2">Abrasion by Capon test [mm³]</th><th colspan="2">Water absorption [g]</th><th rowspan="2">Average scaling [kg/m²] by Slab Test</th><th rowspan="2">Bond strength [MPa]</th></tr>
<tr><th>30 min</th><th>240 min</th></tr>
<tr><td>I</td><td>≥ 30</td><td>≥ 6</td><td>≤ 1.0</td><td rowspan="3">≤ 175</td><td rowspan="3">≤ 2</td><td rowspan="3">≤ 5</td><td>≤ 3</td><td>≥ 1.0</td></tr>
<tr><td>II</td><td rowspan="2">≥ 20</td><td rowspan="2">≥ 3.5</td><td rowspan="2">≤ 1.5</td><td rowspan="2">≤ 4.5</td><td rowspan="2">≥ 0.5</td></tr>
<tr><td>III</td></tr>
<tr><td>IV</td><td>≥ 10</td><td>≥ 2.5</td><td>≤ 3.0</td><td>≤ 250</td><td>≤ 5</td><td>≤ 10</td><td>–</td><td>–</td></tr>
<tr><td>Results on site</td><td colspan="7">• Compressive, flexural and bond strength > 80 % of lab value
• Shrinkage < 1.25 x lab value
• Water absorption < 5 g (30 min) and < 10 g (240 min) for categories I through III</td></tr>
</table>

One important consideration is that jointing mortars should be tested (e.g. in the design or preliminary investigation stage) and/or validated (e.g. by technical data sheets) before they are used, to see if they meet the requirements. Moreover, the targeted values must be achieved by mortars with adequate workability, applicability for the joints depths and widths considered, resistance to sweeping and brushing machines, thermal expansion coefficients, etc. These are also important items which must not be neglected when applying joint filling materials in practice.

Finally, some checking on site may be useful to assess whether the material was applied correctly (right water content, good mixing, bond to pavers, etc.). A few indicative values have been included in Table 3 for results to be obtained on site in comparison with the values found in the laboratory.

Anyway, we hope that these guidelines for lab performance requirements to be made on joint filling materials for use in small element paving may benefit the durability of this valuable type of pavement as a whole.

Acknowledgements

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