Report
Determination of some material properties of a Senso Terrazzofloor

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1 Introduction

This report describes the determination of some material properties of a Senso Terrazzofloor made by Senso B.V. (Senso). TÜV Rheinland Nederland B.V. (TÜV Rheinland) offered the tests by means of offer form 38572, dated October 28th, 2013, which was signed and agreed upon by Senso on October 30th, 2013. After completion of the tests offered in offer form 38572, Senso decided to run an additional crack bridging / stone break test with samples which have an additional rubber layer in between the stone substrate and the layer of Senso Terrazzofloor (new system). This additional test was offered by means of offer form 38844 dated December 18th, 2013. Senso agreed on the quotation by e-mail on December 18th, 2013. The samples for this additional test were supplied in January 2014. Table 1 gives an overview of tested samples.

Table 1, Test samples

Sample description	Number submitted samples:		
	Formulation 1 (harder version) TÜV sample number: 13.0087/1	Formulation 2 (elastic version) TÜV sample number: 13.0087/2	New system Formulation 2 (elastic version) with an extra rubber layer TÜV sample number: 14.0006/1
Samples for compression tests (25,4 x 25,4 x 50,8 mm)	12	-	-
Samples for tensile strength testing (Sample type C of ASTM D638)	-	13	-
Samples for wear resistance tests (95 x 95 x 6 mm)	5 (these samples are treated with an extra topcoat)	-	-
Thermal expansion (61 x 8.5 x 10 mm)	-	4	-
Crack bridging / stone break test samples (200 x 60 x 10 mm on stone. In the middle the width is reduced to 45 mm)	-	3*)	-
Crack bridging / stone break test samples with extra rubber layer between the stone and the terrazzofloor (200 x 60 x 10 mm on stone. In the middle the width is reduced to 45 mm)	-	-	4

*) One of the stone samples was broken on arrival at TÜV Rheinland

Remark: Formulation 2 was submitted as a set after formulation 1 was submitted as a set.

2 Background information

According to Senso, terrazzo floors come in two varieties. A version based on a concrete binder and a version based on an epoxy binder. According to Senso, both varieties have advantages as well as disadvantages. A disadvantage is that both systems cannot be applied without seams. Therefore Senso has set herself the challenge to develop a crack-bridging terrazzo floor system, which should solve this disadvantage.

In order to evaluate the crack bridging properties, Senso ordered a.o. the execution of an additional test in which a stone substrate with the terrazzofloor on top is broken in a tensile tester. After the substrate breaks the behaviour of the terrazzofloor is evaluated. Because the initial test result did not meet the goals of Senso, an additional test was executed with samples in which an additional rubber layer was applied in between the terrazzofloor and the stone substrate.

3 Investigations and results

Senso ordered the execution of the following tests (including additional test):
- Compressive strength according to ASTM D 695
- Tensile strength according to ASTM D 638
- Wear resistance according to ASTM D 6040
- Crack bridging / Stone break test
- Thermal expansion coefficient according to ASTM 696

The tests are described in more detail in the following paragraphs.

3.1 Compressive strength according to ASTM D 695

The compressive strength of formulation 1 (relatively harder version) has been determined according to ASTM D 695. This test is usually executed in 5-fold, using rectangular cubes of sample material with a bottom and top surface of approximately 12,7 mm x 12,7 mm and a height of approximately 50,8 mm.
In this particular case however, the material is not homogeneous, but instead the material consists of a polymeric binder filled with marble stones.
In order to obtain more reliable results the dimensions described for syntactic foam were to be applied (cylindrical d=25.4 mm and 50.8 mm high). In order to get a better mean value the test was executed in 10-fold.
Because the preparation of square samples 25.4 x 25.4 x 50.8 mm is much easier compared to the preparation of cylindrical samples, first the results of measuring two square and two cylindrical samples were compared (samples 1 up to and including 4). Because no significant differences were found in the measuring results, the remaining samples were tested as square samples. The results are summarized in table 2.
The samples upon completion of the compression test are shown on photo 1 in appendix A.

Table 2, Results of the compression tests according to ASTM D 695

Test	Compressive strength (N/mm²)	Compressive strength (PSI)
1	15.58	2422
2	16.80	2145
3 (cylindrical)	16.70	2260
4 (cylindrical)	14.79	2436
5	16.53	2397
6	16.03	2325
7	16.26	2359
8	16.81	2438
9	16.41	2380
10	15.89	2305
Mean	16.18	2347
Standard deviation	0.64	92

3.2 Tensile strength according to ASTM D 638

The tensile strength of formulation 2 (relatively elastic version) has been determined according to ASTM D 638. The determination has been executed in 10-fold.
Test pieces were made according to type three of the ASTM standard. This type allows for the typical thickness of the terrazzofloor material as it is applied under practical circumstances. Also in this test the inhomogeneous nature of the material could cause deviations in the test results. In order to compensate for this effect, the test was executed in 10-fold instead of the prescribed 5-fold.
At a test speed of 5 mm/s breaking occurred within the prescribed time interval.
The results of the tensile tests have been summarized in table 3.
The samples upon completion of the test are shown on photo 1 in appendix B.

Table 3, Results of the tensile test according to ASTM D 638

Test	Tensile strength (N/mm²)	Tensile strength (PSI)	Elongation at break (%)
1	4.50	652.0	3.1
2	4.53	656.7	1.8
3	4.52	655.6	4.1
4	4.88	708.2	2.4
5	3.51	508.7	2.7
6	4.59	665.7	4.2
7	4.61	668.1	4.2
8	4.89	708.6	2.9
9	4.85	703.8	2.1
10	4.99	722.9	3.1
Mean	4.59	665.0	3.1
Standard deviation	0.42	60.9	0.9

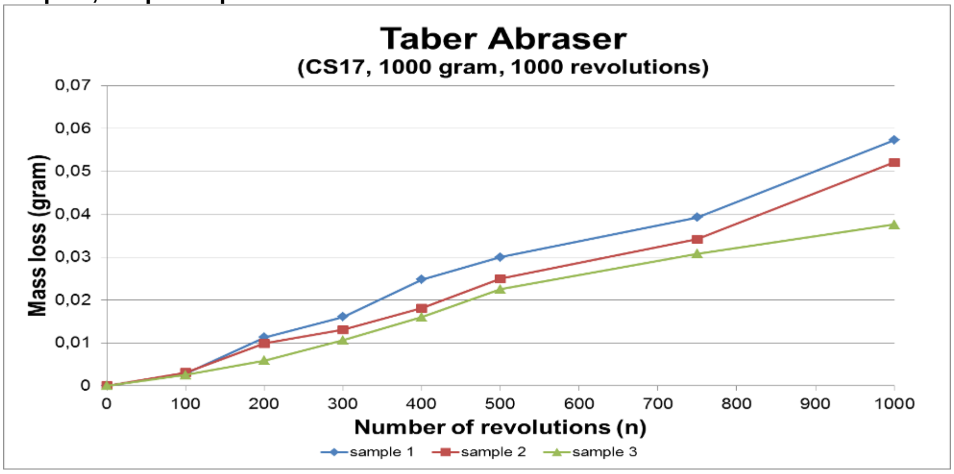
3.3 Wear resistance according to ASTM D 6040

The abrasion resistance of formulation 1 (relatively harder version) with a topcoat has been determined according to ASTM D 4060, using a so called Taber Abraser. The Taber Abraser consists of a horizontal sample table with a diameter of approximately 105 mm.
Above this table two arms are positioned for mounting the abrasion wheels. Depending on the type of sample material and its practical application, abrasion wheels as soft as rubber, as hard as grinding wheels, or several grades in between, can be chosen. In this investigation, the tests have been executed with wheels of type CS17, which are made of rubber filled with an abrasive powder.
With weights on the arms the effective working load on the abrasive wheels during the test can be set at 250, 500 or 1000 grams. In this investigation the chosen load was 1000 g/wheel.
The sample table turns with a speed of approximately 60 revolutions/minute. The abrasive wheels rest on the sample's surface. Due to the rotations of the sample table, the abrasive wheels also start turning. Because the abrasive wheels are positioned eccentrically on the sample table the abrasive wheels cause friction on the sample's surface, which becomes visible as circular tracks.
The abraded material is removed by means of a vacuum cleaner. By cleaning and resurfacing the abrasion wheels after a number revolutions, remainders of the abraded sample material are removed from the wheels ensuring a constant abrasiveness of the wheels. The abrasion has been determined by weighing the mass loss of the test panels after 100, 200, 300, 400, 500, 750 and 1000 revolutions. The test has been executed in triplicate. The results are summarized in table 4 and presented in graph 1.

Table 4, Results of the abrasion test according to ASTM D 6040

Number of revolutions (n)	Mass loss (gram)		
	Sample 1	Sample 2	Sample 3
100	0.0028	0.0031	0.0025
200	0.0113	0.0099	0.0059
300	0.0161	0.0131	0.0106
400	0.0248	0.0181	0.0160
500	0.0300	0.0250	0.0225
750	0.0393	0.0342	0.0308
1000	0.0573	0.0521	0.0376

Graph 1, Graphical presentation of the results in table 1.



3.4 Crack bridging / stone break test

Formulation 2

The crack bridging properties of formulation 2 (more elastic version) have been evaluated. When the terrazzo floor is applied on a concrete floor it can happen that small cracks develop in the concrete.
For the appearance of the terrazzo floor it is important that small cracks in the substrate do not propagate into the terrazzo floor. In time, cracks will collect dirt and show up as dark lines. Especially if the floor has a white or light colour, cracks can have an adverse impact on the appearance.
In order to obtain an impression of the sensitivity to crack propagation, samples of coated concrete were broken in a tensile tester. The samples consist of a concrete substrate in the shape of a tensile test sample of which the outer ends were not coated (only concrete). After placing the samples in the clamps of a tensile tester the sample was elongated at a speed of 1mm/min. As soon as the concrete cracked the tensile tester was stopped and the terrazzo floor layer above the crack in the concrete was investigated for crack propagation. Then a small additional displacement was applied and the sample was left for 30 minutes in the tensile tester. After these 30 minutes the terrazzo floor was investigated visually once more for signs of crack propagation. Photos (see Appendix C) were made to measure the width of the crack under the terrazzo floor. The test was executed in duplicate. The results are summarized in table 5.

Table 5, Results of the stone break test

Sample:	Appearance of the terrazzofloor after break of the concrete	Appearance of the terrazzofloor after extra displacement + 30 minutes	Crack width measured from photo (mm)
1	intact	intact	Approx. 0.4
2	intact	intact	Approx. 0.4

Because crack propagation is a time dependant property the test pieces were removed from the tensile tester and then fixed on a steel bar. While fixing the samples onto the steel bar the cracks were widened a bit. Then the samples were stored at room temperature to study the effect of crack width in time on the terrazzo floor. The results are summarized in table 6.

Table 6, Results of additional time on the stone break test

Sample:	Applied width (mm)	Appearance of the terrazzo floor at the start of the test	Appearance of the terrazzo floor after X hours
1	0.6	Cracking visible at one side of the sample (photo 4 Appendix C)	After 3 hours, severe cracking is visible on the terrazzo floor surface (photo 5 Appendix C)
2	0.4	Intact (photo 6 Appendix C)	After 6 hours, no further crack development is visible (photo 7 Appendix C)

New system
Additional tests were executed with a modified terrazzo floor system.
Because Senso requires better crack bridging properties compared to those obtained with formulation 2, Senso developed a new concept for elevating the crack bridging properties to a much higher level. A new system build-up was created by adding an additional rubber layer in between the concrete substrate and the terrazzo floor. In this way the very elastic rubber absorbs the highest stresses, which occur directly across the crack and divides the stresses over a much larger area in the terrazzo floor. In this way the terrazzo floor is no longer directly exposed to the high stress concentrations.
The supplied test pieces (new system) showed some irregularities in the tapered ends. These defects were of such a magnitude that breaking was likely to occur at these irregularities instead of in the middle of the samples. In consultation with Senso, it was decided to make a cut (notch) in the back of the test pieces (in the concrete substrate) to initiate a breaking point in the middle of the test pieces, see photos 1 and 2 in Appendix D.

The execution of the tests was almost identical to the tests described for formulation 2. Because the new samples behaved much more elastic, the tensile tester was not stopped immediately after the concrete broke, but instead the elongation was slowly increased in time and the behaviour of the samples was studied. Photo 3 shows that the new system is able to bridge much wider cracks. On photo 4 it is visible that the rubber starts to tear at a really wide crack in the substrate. At this point the tensile tester was stopped and the behaviour of the samples was studied. The tear in the rubber layer grew relatively fast. At a certain point the terrazzo floor also cracked, see photo 5.

The test was executed in duplicate. The results are summarized in table 7.

Table 7, Results of the stone break test with the new samples

Sample:	Appearance of the terrazzofloor after break of the concrete	Crack width at which the first tearing in the rubber occurred	Behaviour after half an hour.
1	intact	6.75 mm	Sample completely broken
2	intact	8.05 mm	Sample completely broken

By comparing the samples on photo 4 and 5, it is clear that a lot of deformation occurred in the terrazzo floor. Under normal circumstances this kind of deformation is not possible.
As can be seen on photo 4, the rubber absorbs a lot of deformation over the whole length of the sample. As a result, the deformation across the length of the terrazzo top layer is less than across the rest of the sample (see also photo 6, were the same phenomenon can be observed). This means that, as with the samples with formulation 2, the time dependant behaviour is also important. Therefore the same test with placing the samples on a steel bar was repeated with the new system.
In a first approach the width of the crack was set on 5 mm. After 60 hours the terrazzo floor cracked.
Then, based on the observed behaviour and the dimensions of the test samples, an estimation was made of the impact of the elongation on the terrazzo floor. Based on this estimation the width was set on 2.60 mm, which resulted in a lasting crack bridging on the sample (see photo 6). The results are summarized in table 8.

Table 8, Results of additional time test on the stone break test with the new system

Sample:	Applied crack width (mm)	Appearance of the terrazzo floor at the start of the test	Appearance of the terrazzo floor after X hours
3	5	intact	After 60 hours the sample cracked
4	2.6	Intact	After 336 hours a small tear in the rubber is visible but the terrazzo floor itself is still intact (see photo 6 in Appendix D)

3.5 Thermal expansion coefficient

The thermal expansion coefficient has been determined according to ASTM 696.
Samples of 61 x 8.5 x 10 mm were cooled and warmed from -30°C up to +30°C with a rate of 2°C/min, while the length of the samples was measured. The test was executed in triplicate.
From the change in dimensions the thermal expansion coefficient has been calculated. The results are summarized in table 9.

Table 9, Results of the determination of the thermal expansion

Sample:	α (10^{-6}/K)	Average (10^{-6}/K)	St. dev. (10^{-6}/K)
1	30.04	30.33	0.25
2	30.50		
3	30.44		

4 Discussion of results and conclusions

Test results

The results of the compression strength tests showed that the strength of the harder formulation was approximately 16.2 N/mm² / 2347 PSI.

The results of the tensile strength tests showed that the strength of the more elastic formulation was approximately 4.6 N/mm² / 665 PSI. Remarkable is the fact that the lowest elongation at break occurred at 1.8%.

The results of the wear resistance tests show a mass loss of approximately 0.049 gram when tested during 1000 revolutions with CS 17 wheels and a 1 kg load.

The crack bridging / stone break test shows that a 0.4 mm wide crack in formulation 2 can be bridged by the Senso Terrazzofloor, while a crack of 0.6 mm in the concrete almost certainly will develop cracks in the Senso Terrazzofloor.
The results of the tests with new samples with the new system (with additional rubber layer in between the terrazzo floor and the concrete) show a crack bridging capability of approximately 2.6 mm.
This is a significant improvement compared to the Senso terrazzofloor without rubber. The samples however show some significant deformation, which has to be compensated for. Photo 6 in appendix D,

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clearly illustrates that the terrazzo floor layer did not completely follow the deformation of the concrete substrate.
Additional tests (long term elasticity of the terrazzo layer itself, e-modulus of the rubber layer, etc.) can provide the values needed for calculating the required compensation. Even after this compensation, a significant improvement compared to the terrazzo floor without rubber will be obtained.

As a consequence of the more flexible rubber layer under the terrazzo floor layer, the layer thickness of the terrazzo floor as well as of the rubber layer, have to be within a narrow band width to avoid stress concentrations. This is important because the terrazzo floor itself can no longer (like the concrete) divert its stresses to the other layer.

Because the very flexible rubber layer under the terrazzo floor allows for more deformation when the floor is heavily loaded, some care has to be taken into account regarding this aspect. According to Senso the Senso Terrazzofloor will be applied in public areas only and therefore will not be exposed to heavy loads.

5 Signatures

Author	Signature
A.M. Agterberg, B.Sc. Specialist Coatings	
Peer review	Signature
R. van der Kaaden, B.Sc. Specialist Coatings	

(This is the end of this report),

Appendix A, Samples upon completion of the compression strength test

Photo 1, Samples upon completion of the compression strength test.

Appendix B, Samples upon completion of the tensile strength test

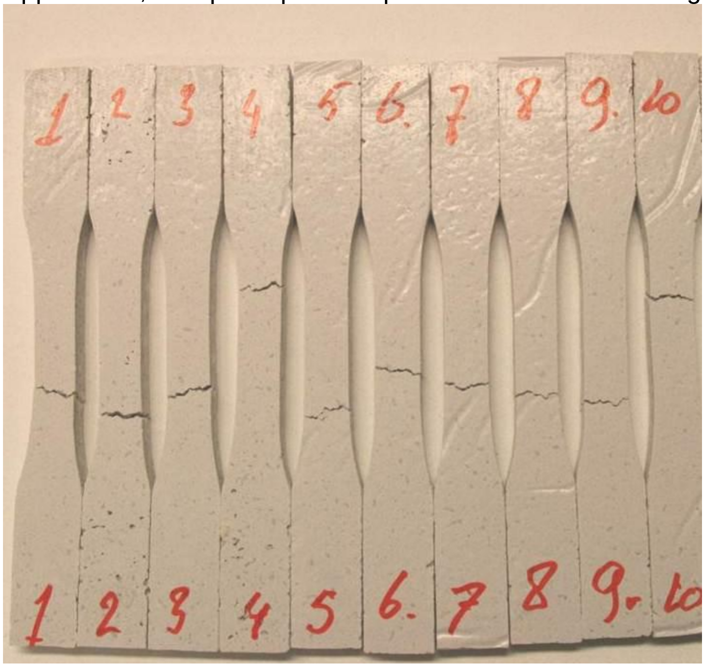

Photo 1, Samples upon completion of the tensile strength test.

Appendix C, Photos of the bridging / stone break test

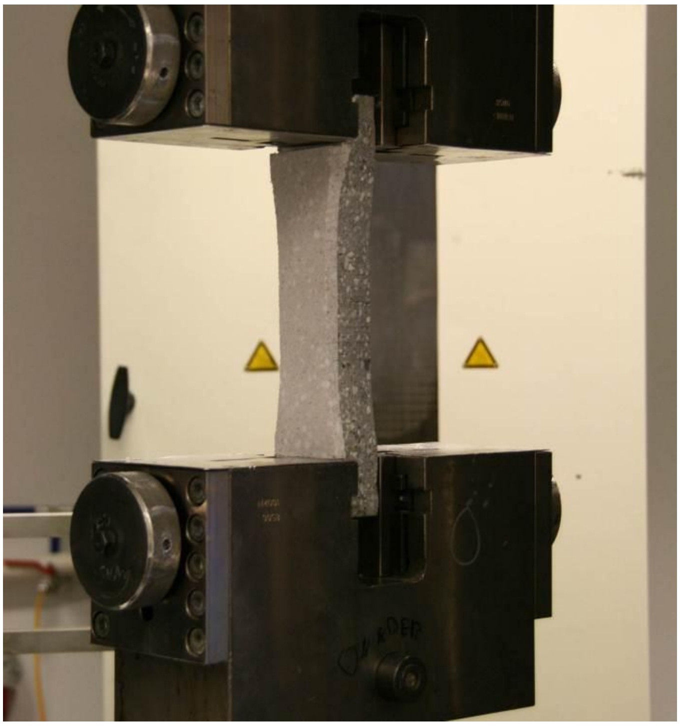

Photo 1, Stone break test.

Photo 2, Measuring the width of the crack.

Appendix C (continuation), Photos of the bridging / stone break test


Photo 3, Measuring the width of the crack after extra displacement (approx. 0.4 mm).

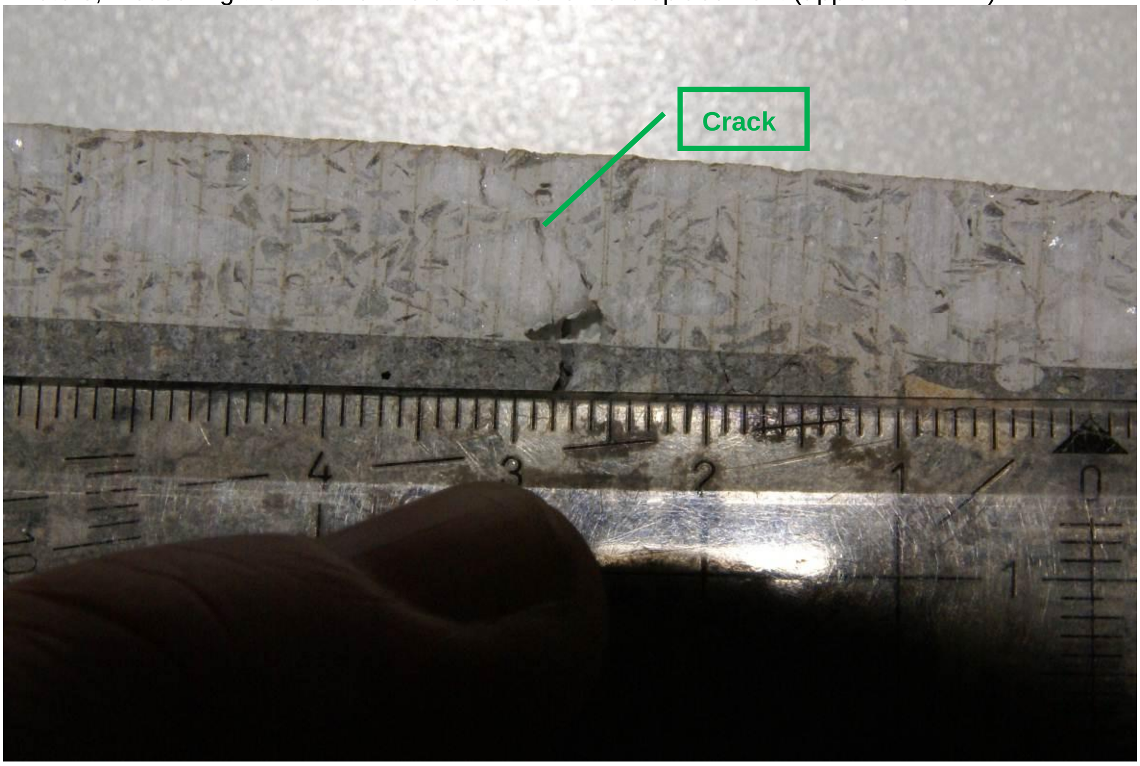

Photo 4, Measuring the width of the crack in the additional test (approx. 0.6 mm).

Appendix C (continuation), Photos of the bridging / stone break test.

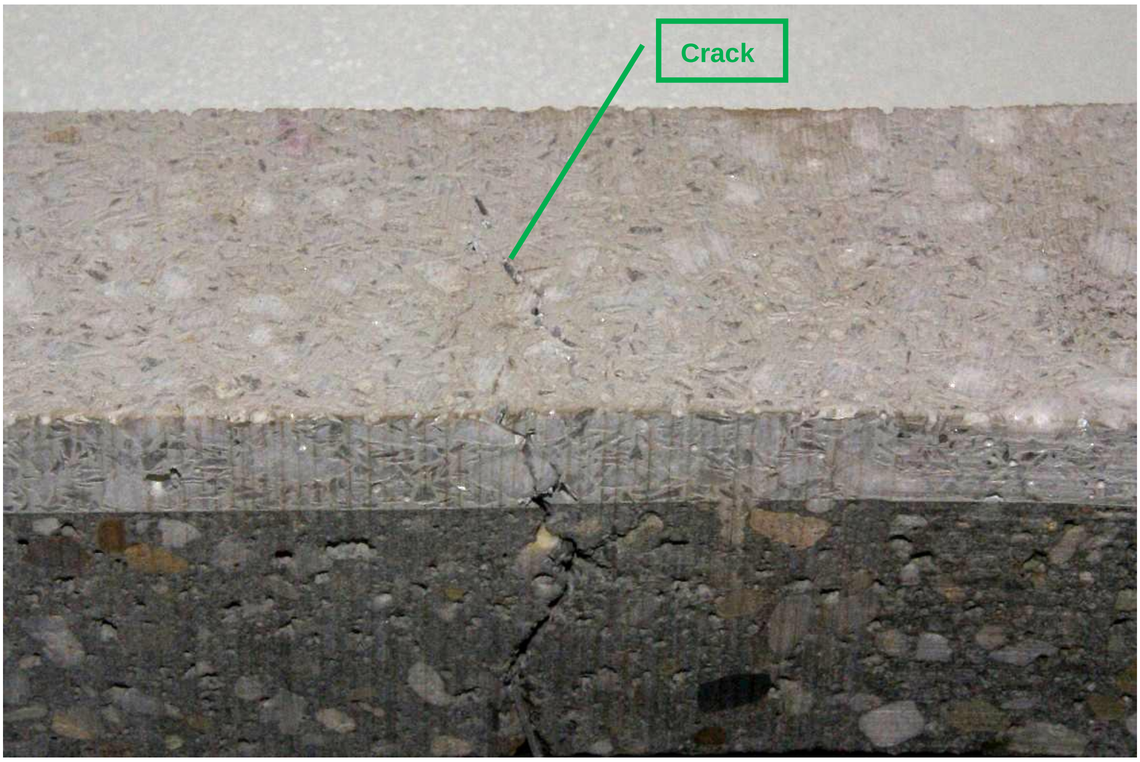

Photo 5, Severe cracking of the terrazzo floor after 3 hours.

Photo 6, Intact over a 0.5 mm wide crack in the additional test.

Appendix C (continuation), Photos of the bridging / stone break test.

Photo 7, No crack development over a 0.4 mm wide crack after 6 hours in the additional test.

Appendix D, Photos of the bridging / stone break test on new system

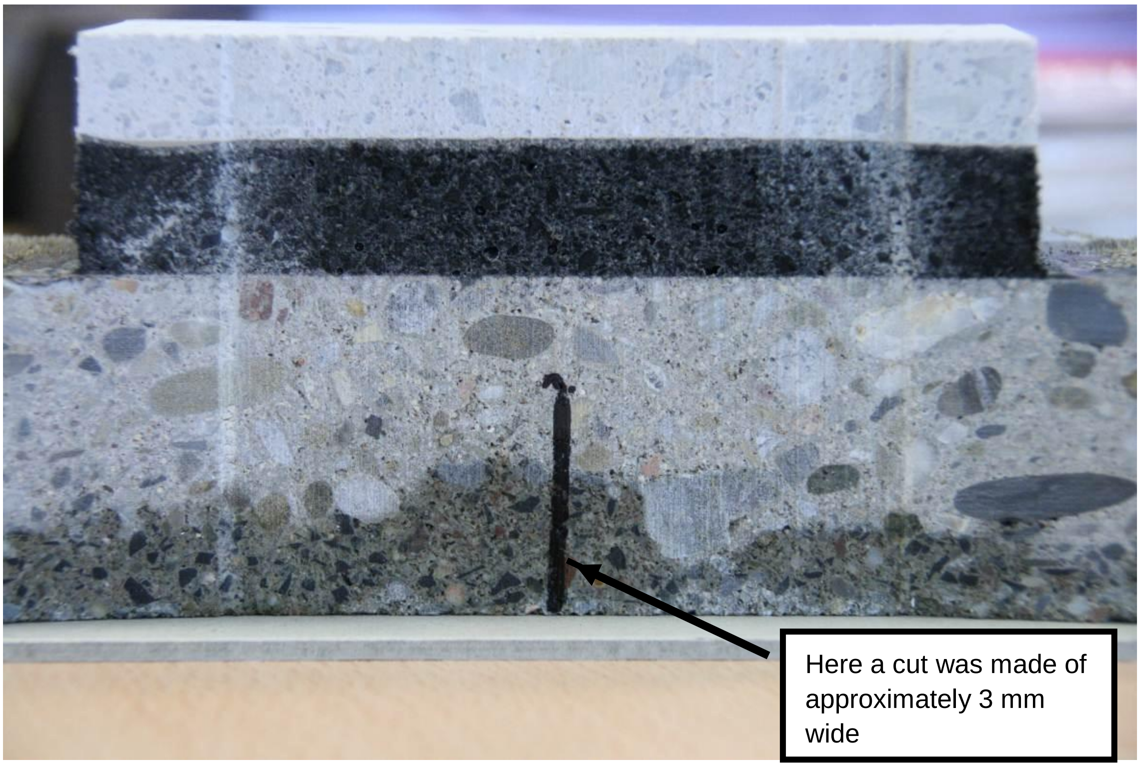

Photo 1, Place where the cut was made to initiate the breaking of the sample.

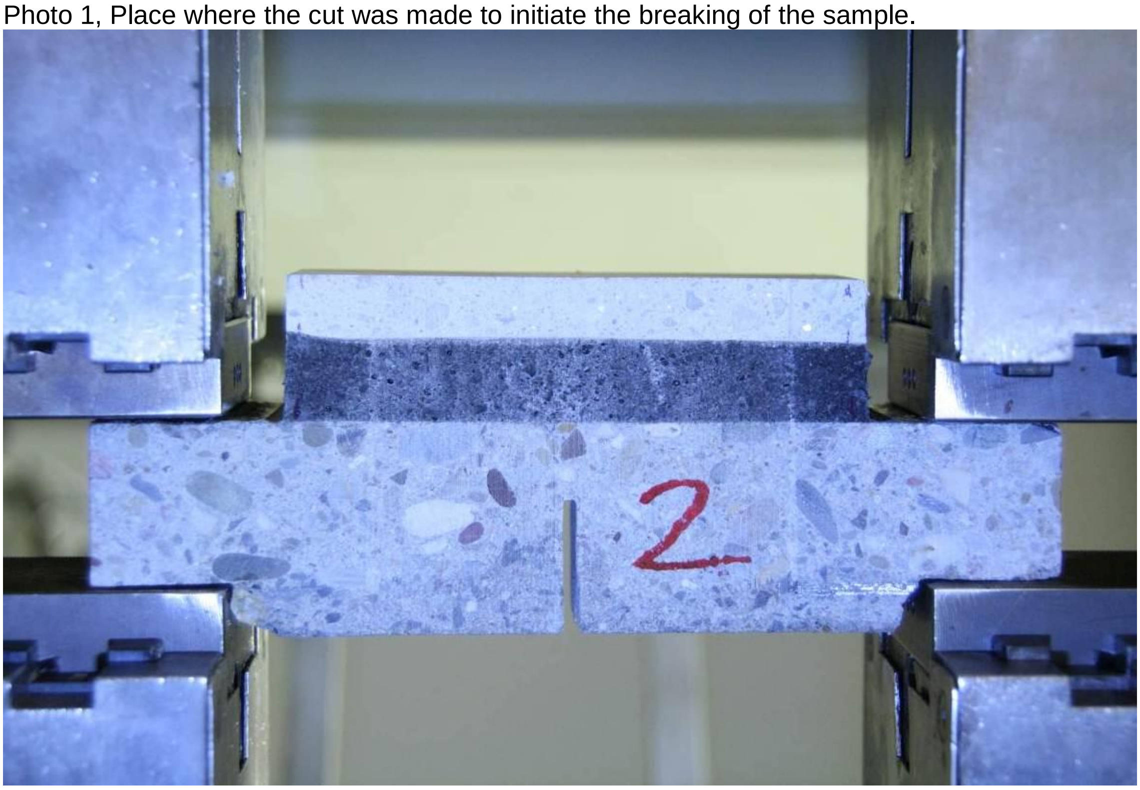

Photo 2, Start position of a test, with cut in the concrete.

Appendix D (continuation), Photos of the bridging / stone break test on new system

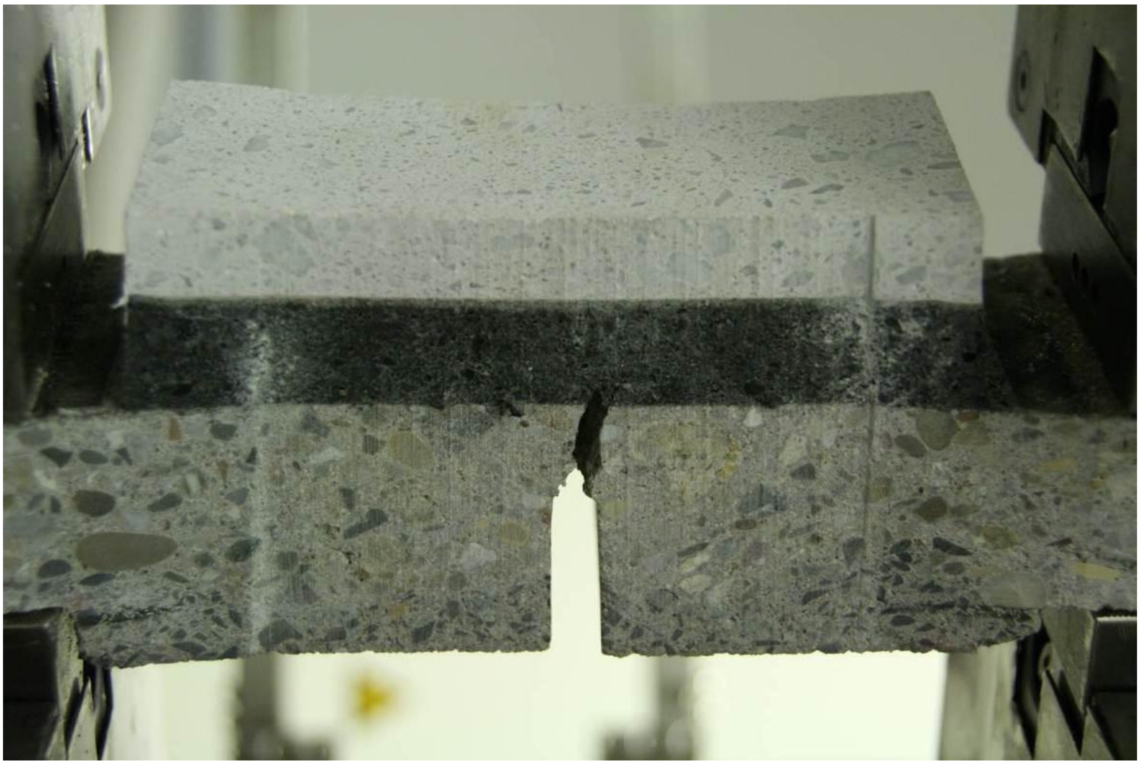
Photo 3, The rubber absorbs a lot of the stresses.

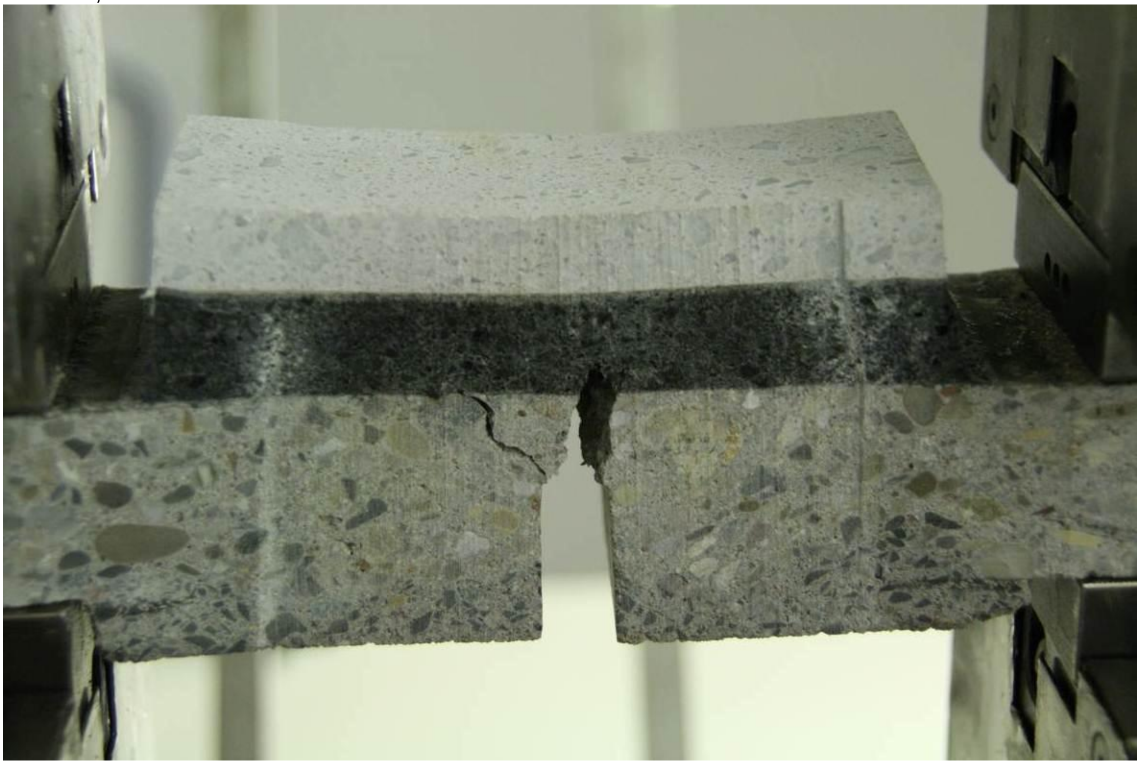
Photo 4, At a certain point the rubber starts to tear. Deformation is visible on sample surface.

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Appendix D (continuation), Photos of the bridging / stone break test on new system

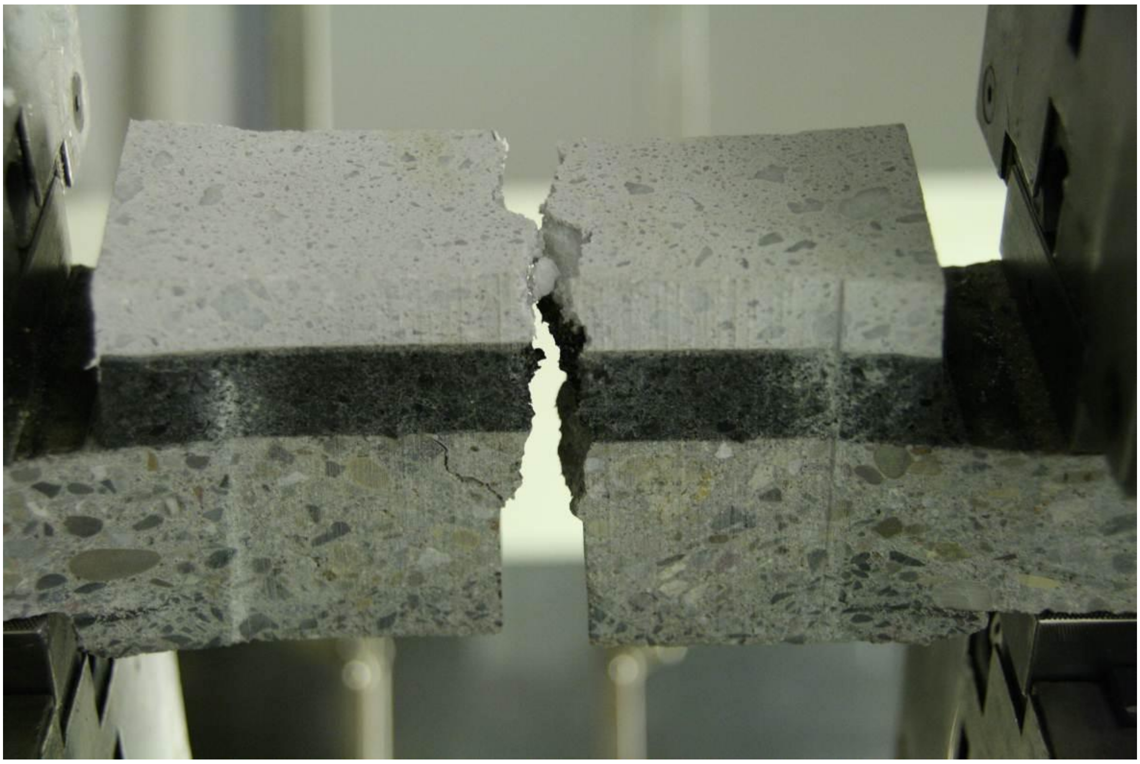

Photo 5, Sample upon completion of test.

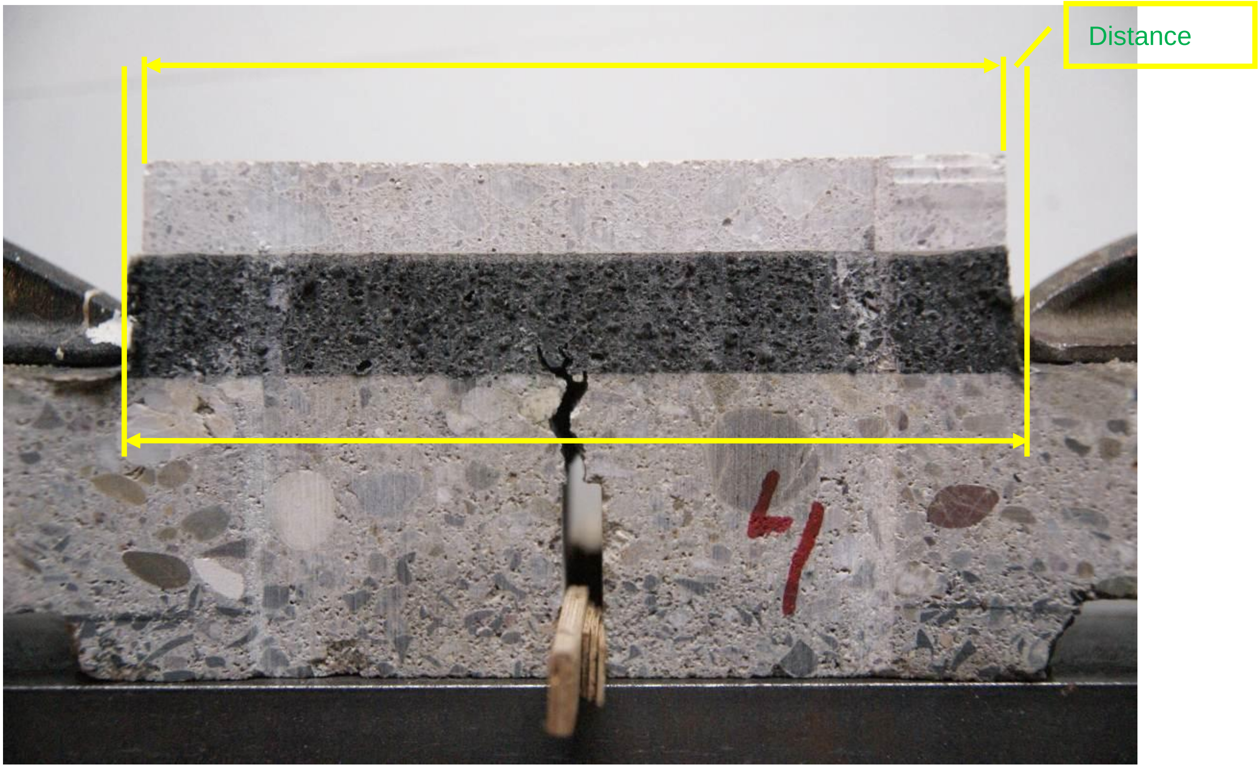

Photo 6, Lasting crack bridging over a crack of 2.6 mm wide.