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Suitability study circular SmartCrusher concrete mix for underpass Contactweg in Amsterdam

Report SGS INTRON BV

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WHEN YOU NEED TO BE SURE

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1. Introduction

1.1. General

[redacted] is currently realizing the Contactweg underpass in Amsterdam on behalf of ProRail and the municipality of Amsterdam. In this underpass, a partition wall separates the lanes of the underpass and the elevated cycle path (see figure 1). [redacted] poured this partition wall on
9-9-2021 with the circular concrete mixture SL, supplied by Smart Circular Products (SCP). The circular raw materials are produced with an innovative recycling technique ("Smart Liberator"). The suitability of the circular concrete mixture for the application has been investigated by SGS INTRON in collaboration with SCP on behalf of [redacted].

Figure 1. Artist impression of the Contactweg underpass in Amsterdam.

1.2. Accountability The

suitability investigation is carried out on behalf of [redacted] on the basis of our quotation with [redacted]. The investigation is not yet fully completed. At the request of [redacted] the present progress report is provided.

2. Research design

2.1. Concrete composition

In the suitability study, the durability and strength of the circular mixture are compared with a reference mixture. The circular mixture contains the circular raw materials Freefiller (filler), Freegravel (coarse aggregate) and Freesand (fine aggregate). The reference mixture contains only primary raw materials. The composition of both mixtures meets the requirements of the concrete regulations for the applicable environmental classes (XD3, XF4). Table 1 shows the main characteristics of both mixtures and Annex A shows the complete concrete composition. When calculating the binder content of the circular mixture, 60% of the Freefiller weight has been included. The water/binder factor (wbf) was 0.43 for both mixtures.

Table 1: Characteristics of concrete mixes

Parameter	Circular mixture SL	Reference mixture
Strength class	C30/37	C30/37
Environmental class	XD3, XF4	XD3, XF4
Consistency	F4	F4
Water/binder factor	0.43	0.43
Binder	CEM I 52.5 N + Ecocem	CEM I 52.5 N + Ecocem
Filler	Freefiller	Betofill
Coarse aggregate	100% Freegravel	100% River gravel
Fine aggregate	50% Freesand 50% River sand	100% River sand

2.2 Test program

Table 2 shows the test program performed. It also indicates per test which laboratory (SGS INTRON and/ or SCP) performed the test and whether it has already been completed. The 28-day cube compressive strength is measured by both laboratories.
The results of the investigation by SCP have been recorded in their report "Suitability investigation for the contact road partition wall" of 31-08-2021.
The accelerated carbonation test has been completed for the circular mixture, but not yet for the reference mixture. Whey, an intermediate measurement is available for the reference mixture.

Table 2: Test program

Trial	Description	Test standard	Number of test pieces per mixture	Laboratory	Finished
1	Accelerated carbonation	CUR Recommendation 48	2	SGS INTRON	Partly
2	Accelerated intrusion (RCM)	NT Build 492	3	SGS INTRON	Yes
3	Freeze-thaw salt deterioration (slab test, 28 cycles)	NVN-CEN/TS 12390-9	5	SCP	Yes
4	Water intrusion under pressure	NEN-EN 12390-8	3	SCP	Yes
5	E Modulus	NEN-EN 12390-13	3	SGS INTRON	Yes
6	Cube compressive strength	NEN-EN 12390-3	3	SGS INTRON SCP	Yes

2.3. Production test pieces

The test pieces required for the tests to be carried out by SGS INTRON have all been manufactured in our laboratory in Sittard. SCP has supplied the necessary raw materials to our laboratory. The aggregates are first dried. After cooling, the absorption water was added at least 4 hours before mixing started.
The density (NEN-EN 1097-6) and the water absorption after 24 hours (NEN-EN 1097-6) of the 4 aggregates were first measured in our laboratory in order to be able to draw up a correct mixture design based on these data. The acid-soluble chloride content (titrimetry, in-house method) and the alkali content (Na_2O equivalent according to NEN 196-2) were also determined for the 3 circular products (Freesand, Freegravel, Freefiller).

3. Laboratory test results

3.1. Raw material characterization

The densities and water absorption of the 4 aggregates are shown in Appendix B. The density of the circular aggregate fraction is always lower and the water absorption higher than that of the same primary aggregate fraction.

The chloride and alkali content of the circular raw materials is shown in table 3. Both the chloride and the alkali content of the Freefiller are clearly higher than those of the circular aggregates.

Table 3: Chloride and alkali content circular raw materials

Analysis	Unit	Freefiller	Freesand	Freegravel
Chloride content	% (m/m) d.s.	0.10	0.03	0.02
Alkali content	% (m/m) d.s.	0.134	0.072	0.091

3.2. Concrete mortar properties

Table 4 shows the mortar properties of the different batches of the reference mixture (M1) and the circular mixture (M2). The dosage of the adjuvant ACE 331 was kept constant at all times and the workability was adjusted with Sky 648. The target range of the consistency was F4 (shake size 490 - 550 mm). No ACE 331 was used with M1, because the desired workability could already be achieved with a relatively low dose of Sky 648.

Table 4: Concrete mortar properties

Mixture	Charge	Date	Batch (l)	ACE 331 (kg/m³)	Sky 648 (kg/m³)	Tspecie (C)	Shake size (mm)	Air (%)	Vmas (kg/m³)
M1 (ref)	CH3	02-06-21	26	0.000	1.162	22.8	530 (F4)	1.1	2,400
M1 (ref)	CH4	08-07-21	40	0.000	1.150	23.5	500 (F4)	1.1	2,415
M2	CH1	20-05-21	40	0.800	3.175	25.4	440 (F3)	2.5	2,310
M2	CH2	20-05-21	40	0.800	3.175	23.4	570 (F5)	0.7	2,330

CH = Charge, vmas = voluminous mass

3.3. Mechanical properties hardened concrete

3.3.1. Cube compressive strength

Table 5 shows the mean 28-day cubic compressive strength of both mixtures, as measured by both laboratories. SCP measures a clearly lower strength for the circular mixture (M2) than for the reference mixture (M1). However, the compressive strength of M2 measured by SGS INTRON is significantly higher than that of SCP and almost equal to the reference value (from SCP).

Table 5: Average 28-day cube compressive strength

Characteristic	Unit	M1 (ref) SGS INTRON	M1 (ref) SCP	M2 SGS INTRON	M2 SCP
Cube compression strength	MPa	47.7	54.3	53.1	43.8

3.3.2. Elastic modulus

The 28-day elastic modulus was measured on cylinders (end 150 mm, high 300 mm). After measuring the E-modulus, the cylinders were loaded to failure to obtain the cylinder compressive strength. Table 6 shows the measurement results. The E-module of both mixtures are almost the same.

The stress - deformation diagrams are included in appendix C.

Table 6: Modulus of elasticity and cylinder compressive strength

Sample	E modulus (GPa)	Cylinder compressive strength (MPa)	Sample	E modulus (GPA	Cylinder compressive strength (MPa)
M1-1	34.7	37.0	M2-4	35.9	48.4
M1-2	35.5	38.1	M2-5	35.4	49.9
M1-3	34.4	35.1	M2-6	36.3	49.1
Avg.	34.9	36.7	Avg.	35.9	49.1

3.4 Durability hardened concrete

3.4.1. Accelerated carbonation

The resistance to carbonation is measured with the accelerated test in accordance with CUR Recommendation 48. For this purpose, 2 prisms (100 mm x 100 mm x 400 mm) are made per mixture. After 1 day the prisms were removed from the mold and stored in a water tank until they were 28 days old. The prisms were then dried for 14 days at 20°C and (65 ± 5) % RH. Paraffin wax was then applied to the two ends, the finishing side and the opposite side. The prisms were then exposed at 20°C, 55% RH and a CO_2 content of 4.0% for a maximum of 70 days. In accordance with CUR Recommendation 48, the first measurement of the carbonation depth takes place after 56 days of exposure. For the purpose of this progress report, SGS INTRON carried out an intermediate measurement after 28 to 32 days of exposure. With this intermediate measurement, the carbonation depth of the circular mixture M2 is significantly lower[1] than that of the reference mixture M1.

Table 7: Carbonation depth (mm) after exposure (20°C, 65%, 4.0% CO_2)

Sample	M1 (ref) 32d	M1 (ref) 56d	M2 28d	M2 56d
Sample 1	12.3	14-10-2021	8.7	14.2
Sample 2	14.1	14-10-2021	8.9	14.0
Avg.	13.2	14-10-2021	8.8	14.1

3.4.2. Accelerated chloride penetration

The resistance to chloride penetration was measured with the Rapid Chloride Migration (RCM) test in accordance with CUR Recommendation 48. This measurement was performed in triplicate at an age of 28 days. The measurement result is the chloride migration coefficient Dnssm (10^{-12} m^2/s). Table 8 shows the results. The average value of the circular mixture M2 is significantly lower than that of the reference mixture M1.

[1] *This difference is not due to the small difference in exposure time.*

Table 8: Chloride migration coefficient D_{nssm} (10^{-12} m^2/s) at 28 days of age

Sample	M1 (ref)	M2
1	2.5	1.5
2	3.5	1.7
3	4.6	1.7
Avg.	3.5	1.6
Std Dev.	1.0	0.1

3.4.3. Frost Thaw Salt Resistance

The freeze-thaw resistance has been measured by SCP according to specifications with the 'slab test' method in accordance with NVN-CEN/TS 12390-9. 3 test pieces are examined per mixture. The number of freeze-thaw cycles is limited to 28 cycles. The total weight loss (kg/m^2) due to exfoliation is the final result. The average of the 3 test pieces is shown in table 9. The circular mixture shows a significantly higher exfoliation than the reference mixture.

However, both mixtures meet the requirement for freeze-thaw (salt) resistance belonging to category FT1 from NEN-EN 13877-2 ("Seton pavements - Part 2: Functional requirements for concrete pavements"). For this category, weight loss after 28 cycles must meet:

- Average < 1.0 kg/m2;
- Each individual result < 1.5 kg/m2.

The same requirement is also set for concrete paving stones in NEN-EN 1338.

Table 9: Exfoliation (kg/m^2) during freeze-thaw salt test (measured by SCP)

Cycles	Reference (kg/m^2)		Circular (kg/m^2)	
	Avg.	Std dev.	Avg.	Std. dev.
7 cycles	0.03	0.026	0.17	0.007
14 cycles	0.09	0.003	0.15	0.037
21 cycles	0.14	0.025	0.05	0.013
28 cycles	0.15	0.055	0.24	0.035
Total after 28 cycles	0.41	0.071	0.61	0.036

3.4.4. Water intrusion under pressure

In this test, a cube is exposed on one side to a water pressure of 5 bar for 72 hours. At the end of the test, the cube is split and the maximum penetration depth is measured. Per mixture 3 cubes were tested. Table 10 shows the results. The average value of the maximum water penetration of both mixtures is exactly the same. The low value (:::: 10 mm) shows that the concrete is very dense.

According to SRL 1801, for concrete mortar intended for liquid-tight concrete constructions, the permitted liquid penetration for individual observations must be less than or equal to 50 mm; for the average of three consecutive observations this should be less than or equal to 25 mm. Both mixtures meet this requirement.

Table 10: Maximum penetration depth (mm) of water under pressure (5 bar) at 28 days of age (measurement by SCP)

Sample	Reference	Circular
1	9	9
2	11	9
3	9	11
Avg.	9.7	9.7

4. Preliminary consideration

The suitability assessment has not yet been fully completed. Table 11 shows to what extent the circular mixture is at least equivalent to the reference mixture for the properties tested.

No definitive test results are currently available for the accelerated carbonation. Of the other 4 properties, the circular mixture is not equivalent to the reference mixture only with regard to freeze-thaw salt resistance. However, both mixtures meet the requirement for freeze-thaw salt resistance, which is used for concrete in road construction. It should also be noted that the test is many times stricter than practice in the case of the partition wall. De-icing salt load takes place at the partition wall on a vertical plane (road side). As a result, water saturation will not occur and freeze-thaw salt damage will be significantly lower than with a horizontal surface (as tested in the laboratory).

In the intermediate measurement after 28/32 days of accelerated carbonation, the circular mixture performs better than the reference mixture. A final statement on this sustainability aspect can be made after 14-10-2021.

Table 11: Circular mixture equivalence for the measured properties

Trial	Description	Test standard	Equivalence circular mixture
1	Accelerated carbonation	CUR Recommendation 48	Not yet known
2	Accelerated Chloride Penetration (RCM)	NT Build 492	Yes
3	Freeze-thaw salt deterioration (slab test)	CEN/TS 12390-9	No
4	Water intrusion under pressure	NEN-EN 12390-8	Yes
5	E modulus	NEN-EN 12390-13	Yes
6	Cube compressive strength	NEN-EN 12390-3	Yes

Appendix A Concrete composition

The dosage of the raw materials below has been provided by SCP.

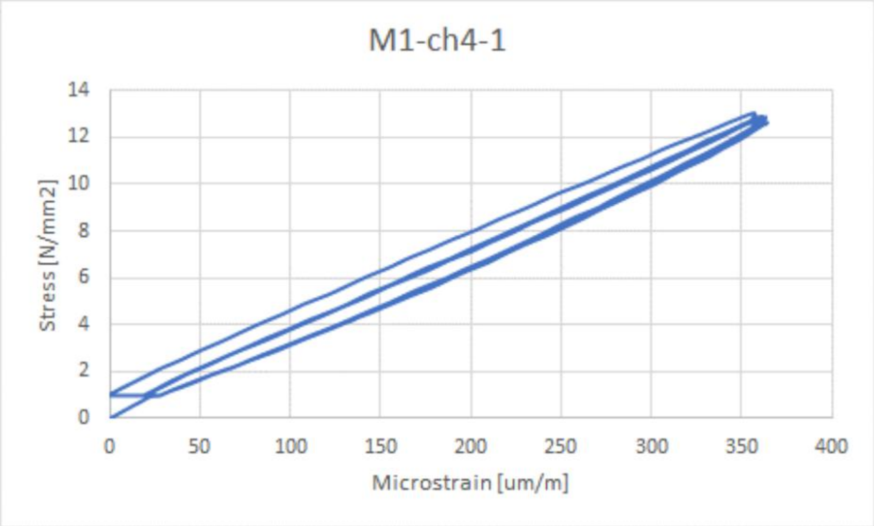
Type of raw material	Product	Supplier	Circular mixture (kg/m3)	Reference mixture (kg/m3)
Binder CEM I 52.5 N		Dykerhoff	94.5	87.5
	Blast furnace slag	Ecocem	220.5	262.5
Filler	Betofill	Euroment		20.0
	Freefiller	SCP	50.0	
Bonus	Sand 0-4 (dry)	Kieswerk Wissel Gmbh	399	774
	Gravel 4-32 (dry)	Kieswerk Wissel Gmbh		1,077
	Milling sand 0-4 (dry)	SCP	391	
	Freegravel 4-22 (dry)	SCP	982	
Excipient	Master Glenium Ace 331 (30%)	Master Builders	0.788	0.875
	Master Glenium Sky 648 (20%)	Master Builders	0.977	1,085
Binder* total			345	350
Water/binder factor			0.43	0.43
Slag content			70%	75%
Sand percentage			45%	42%

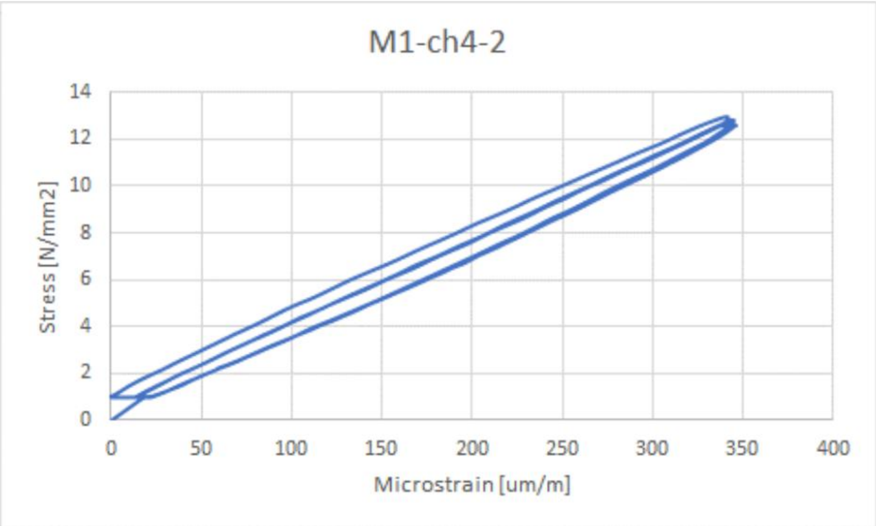
*: When calculating the binder content of the circular mixture, 60% of the Freefiller weight has been included on the instructions of SCP.

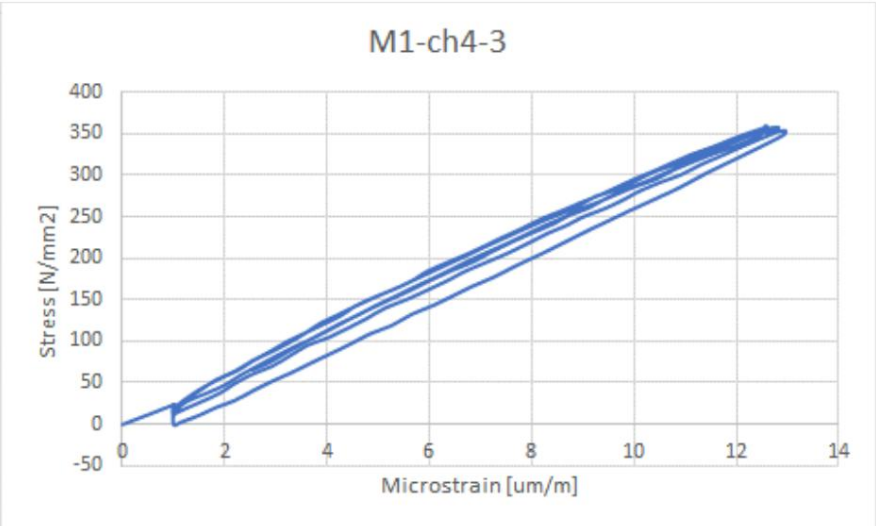
Appendix B Results characterization of aggregates

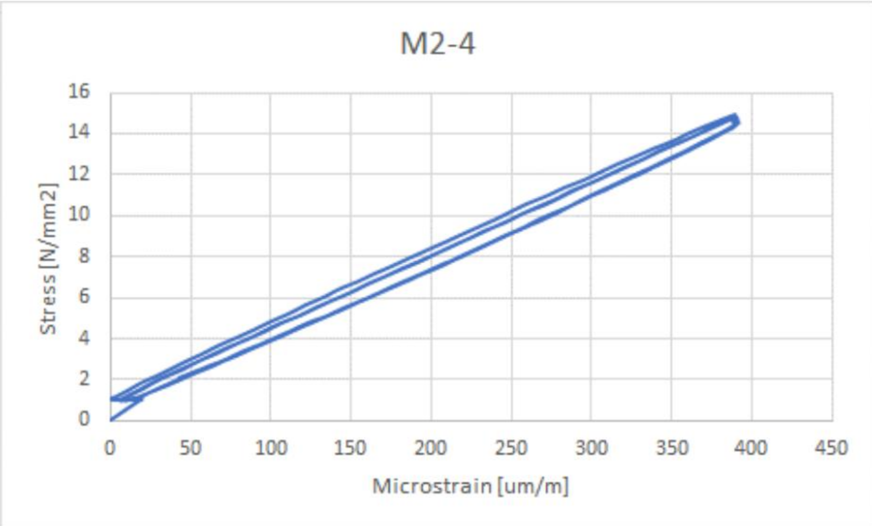
Analysis	Unit	Sand 0-4mm	Gravel 4-32mm	Free sand 0-4mm	Free gravel 4-22mm
Fraction 0 / 4 mm	%(m/m)		4		1
Fraction 4 / 31.5 mm	%(m/m)		96		99
Fraction > 31.5	%(m/m)		0		0
Density fraction 4-31.5 mm (ÿrd)	Mg/m³		2.55		2.48
Density fraction 4-31.5 mm (ÿa)	Mg/m³		2.65		2.64
Density fraction 4-31.5 mm (ÿssd)	Mg/m³		2.59		2.54
Fraction 0 / 63 µm	%(m/m)	0		0	
Fraction 0.063 / 4 mm	%(m/m)	94		96	
Fraction > 4 mm	%(m/m)	6		4	
Density 0.063-4mm (ÿrd)	Mg/m³	2.59		2.35	
Density 0.063-4 mm (ÿa)	Mg/m³	2.63		2.63	
Density 0.063-4mm (ÿssd)	Mg/m³	2.61		2.46	
Water absorption 24 hours	%	0.5	1.3	4.5	2.2

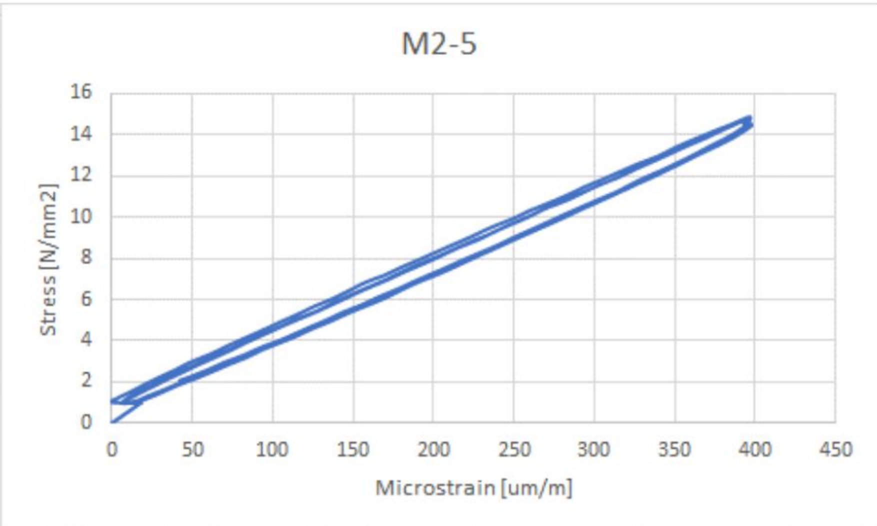
Appendix C Stress – deformation diagrams








M2-4
Stress [N/mm2]
0
2
4
6
8
10
12
14
16
0 50 100 150 200 250 300 350 400 450
Microstrain [um/m]


M2-5
Stress [N/mm2]
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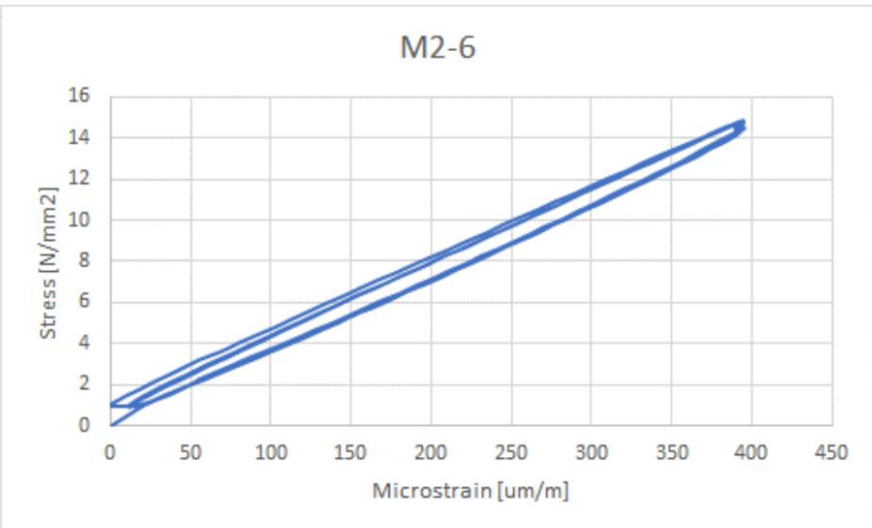
2
4
6
8
10
12
14
16
0 50 100 150 200 250 300 350 400 450
Microstrain [um/m]


M2-6
Stress [N/mm2]
0
2
4
6
8
10
12
14
16
0 50 100 150 200 250 300 350 400 450
Microstrain [um/m]

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