INSTITUTE OF BUILDING MATERIALS RESEARCH

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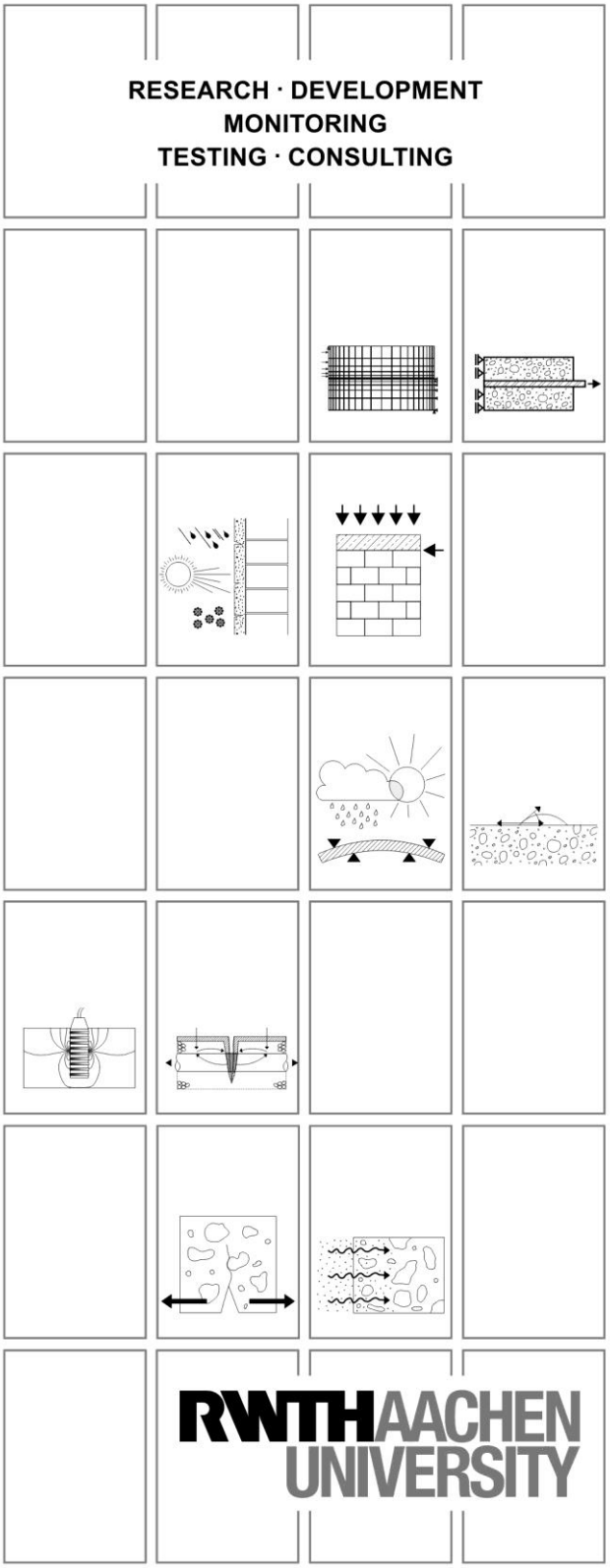

RWTH AACHEN UNIVERSITY

Report
M2153/2

Tests on the reduction of plastic shrinkage

RWTH RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN

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SUBJECT

Tests on the reduction of plastic shrinkage

Report no.

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Project execution

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Contracting authority/Funder

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Your Reference

This report includes 10 pages, among there 5 pages of text.

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1 GENERAL

On 01.12.2015 the 3T GmbH instructed the Chair of Building Materials, Institute of Building Materials Research (ibac), RWTH Aachen University, to perform tests on the reduction of plastic shrinkage of concrete reinforced with short fibres. These tests were performed in accordance with the „Prüfplan für die Zulassungsprüfung von Polymerfasern zur Verwendung in Beton nach DIN EN 206-1 in Verbindung mit DIN 1045-2 mit nachgewiesener Wirksamkeit – Fassung Januar 2013“ from the Centre of Competence for Construction (Deutsches Institut für Bautechnik). On 28.03.2019 the ibac was commissioned to adapt the original report. In addition to the European Standards, similar ASTM Standards of the testing procedures shall be included and all values shall be coverted from SI units into imperial units.

The performed tests and their results will be presented on the following pages.

2 PERFORMED TESTS

2.1 Mix designs

The mix designs of the tested concretes are shown in Table 1 and converted to imperial units in Table 2. Limestone powder was used in the concrete to get an ultra-fines content of 800 kg/m³ (1,348.44 lb/yd³).

Table 1: Mix designs of the different concretes

Parameter	Unit	Concrete mixture	
		IIB	IIA - Kratos
		d_{max} = 8 mm	
1	2	3	4
Content of cement[1)]	kg/m³	360	360
Water content		270	270
Content of aggregates		1,197	1,195
Content of limestone powder		368	368
Content of fibres		-	0.6
Air content (assumed)	% by vol.	2.0	2.0
w/c-ratio	–	0.75	0.75

[1)] CEM I 32.5 R in accordance to DIN EN 197-1

Table 2: Mix designs of the different concretes (converted into imperial units)

Parameter	Unit	Concrete mixture	
		IIB	IIA - Kratos
		d_{max} = 0.32 in	
1	2	3	4
Content of cement[1)]	lb/yd³	606.8	606.8
Water content		455.1	455.1
Content of aggregates		2,017.6	2,014.2
Content of limestone powder		620.3	620.3
Content of fibres		-	1.0
Air content (assumed)	% by vol.	2.0	2.0
w/c-ratio	–	0.75	0.75

[1)] CEM I 32.5 R in accordance to DIN EN 197-1

2.2 Production and storage of specimens

The temperature of the test room, the machines, the storage room and the raw materials during production was 18 to 22 °C (64.4 to 71.6 °F). The mixing process of the raw materials (water, cement, limestone powder and aggregates) was performed in a compulsory mixer with a nominal volume of 150 litres (33.00 Imp.gal.). At first the cement, the limestone powder and the aggregates were homogenized. Afterwards the water was added and mixed for 30 seconds. After a short break the further mixing time was 5 minutes. Afterwards the fibres were added, followed by an additional mixing phase of 1 minute length.

The production of the specimens was performed in accordance with DIN EN 12390-2:2009-02 /DIN09a/, which is similar to ASTM C192/192M-18 /AST18b/. Based on DIN EN 12390-3:2009-07 /DIN09d/ concrete cubes with an edge length of 150 mm (5.91 in) were chosen as specimens. The specimens were stored in a high-humidity climate at 20 °C (68 °F) and a relative humidity ≥ 95 % until demoulding at the age of 24 h. Afterwards they were stored at 20 °C (68 °F) under water for six days and finally at 20 °C (68 °F) and a relative humidity of 65 % till testing.

2.3 Fresh concrete tests

On each concrete mixture the flow table test in accordance with DIN EN 12350-5:2009-08 /DIN09b/ was performed. A similar test is not available in ASTM International Standards. The determination of the air content was performed in accordance with DIN EN 12350-7:2009-08 /DIN09c/, which is similar to ASTM C231/231M-17a /AST17b/, Meter Type B. The fresh concrete density was determined in accordance to DIN EN 12350-6:2011-03 /DIN11/, which is similar to ASTM C138/138M-17a /AST17a/, with a sample size of about 8 l (1.76 Imp.gal). All fresh concrete tests were performed directly after mixing. The test results of the fresh concrete tests are presented in Table A1, page A1, and converted into imperial units in Table A2, page A1.

2.4 Compressive strength tests

The compressive strength of the concrete mixtures IIB and IIA – Kratos was tested in the age of 28 d in accordance with /DIN09d/ on three cubes with an edge length of 150 mm (5.91 in) each. This test method is similar to ASTM C39/39M-18 /AST18a/. The load was applied at a rate of 0.5 MPa/s (72.5 psi/s). The test results for the determination of the compressive strength are shown in Table A3, page A1, and converted into imperial units in Table A4, page A2.

2.5 Tests on the reduction of plastic shrinkage

To proof the positive effect of short fibres on plastic shrinkage the concrete mixtures IIB and IIA – Kratos were tested in the wind tunnel. The fibre dosage of the concrete IIA – Kratos was 0.6 kg/m³ (1.0 lb/yd³).

The plastic shrinkage of each concrete mixture was tested on a slab with the dimensions of 1600 · 600 mm² (62.99 · 23.62 in²) and a thickness of 80 mm (3.15 in) in the laboratory at a temperature of 20 °C (68 °F) and a relative humidity of 50 %. With a steel frame with a steel reinforcement which was fixed on all four sites the slab was subjected to zero displacement boundary conditions thus producing large-scale slab behaviour. After producing the slab, it was covered with a transparent wind tunnel and a constant wind speed of about 5 m/s (16.40 ft/s) was generated.

The effectiveness of the fibres is evaluated by determining the number of cracks, the crack length and crack width. The total crack area was also calculated by the sum (crack length · crack width) of each single crack section. The water evaporation was measured on a slab with the dimensions of 300 · 300 · 80 mm³ (11.81 · 11.81 · 3.15 in³) in the same wind tunnel over 7 hours.

The test results for the reduction of plastic shrinkage are presented in Table A5, page A2, and converted in imperial units in Table A6, page A2. A graphical representation of the temperature, the relative humidity and the wind speed in the wind tunnel is shown in Figure B1 to Figure B4, pages B1 to B2. The water evaporation of the concretes in the wind tunnel is shown in Figure B5 and Figure B6, page B3, and the cracked surfaces of the different concrete mixtures are presented in Figure B7, page B4.

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LITERATURE

/AST17a/ ASTM C138/138M-17a Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete, approved March 15, 2017.

/AST17b/ ASTM C231/231M-17a Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method, approved April 15, 2017.

/AST18a/ ASTM C39/39M-18 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, approved Jan. 1, 2018.

/AST18b/ ASTM C192/192M-18 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory, approved Dec. 1, 2018.

/DIN09a/ DIN EN 12390-2:2009-08 Testing hardened concrete - Part 2: Making and curing specimens for strength tests; German Version EN 12390-2:2009.

/DIN09b/ DIN EN 12350-5:2009-08 Testing fresh concrete - Part 5: Flow table test; German version EN 12350-5:2009.

/DIN09c/ DIN EN 12350-7:2009-08 Testing fresh concrete - Part 7: Air content - Pressure methods; German version EN 12350-7:2009.

/DIN09d/ DIN EN 12390-3:2009-07 Testing hardened concrete - Part 3: Compressive strength of test specimens; German version EN 12390-3:2009.

/DIN11/ DIN EN 12350-6:2011-03 Testing fresh concrete - Part 6: Density; German version EN 12350-6:2009.

ANNEX A

Table A1: Results of the fresh concrete tests

Parameter	Unit	Concrete mixture	
		IIB	IIA - Kratos
1	2	3	4
Flow table test results	mm	470	410
Fresh concrete density	kg/m³	2,220	2,200
Air content	% by vol.	2.0	2.6

Table A2: Results of the fresh concrete tests (converted into imperial units)

Parameter	Unit	Concrete mixture	
		IIB	IIA - Kratos
1	2	3	4
Flow table test results	in	18.50	16.14
Fresh concrete density	lb/ft³	138.59	137.34
Air content	% by vol.	2.0	2.6

Table A3: Results of the compressive strength tests

Parameter		Unit	Concrete mixture	
			IIB	IIA - Kratos
1		2	3	4
Compressive strength	1	N/mm²	34.3	32.2
	2		32.0	33.1
	3		32.5	32.1
	Mean		33.0	32.5

Table A4: Results of the compressive strength tests (converted into imperial units)

Parameter		Unit	Concrete mixture	
			IIB	IIA - Kratos
1		2	3	4
Compressive strength	1	psi	4,974.8	4,670.2
	2		4,641.2	4,800.8
	3		4,713.7	4,655.7
	Mean		4,786.2	4,713.7

Table A5: Results of the tests on the reduction of plastic shrinkage

Parameter	Unit	Concrete mixture	
		IIB	IIA - Kratos
1	2	3	4
Number of cracks	-	12	40
Total crack length	mm	3,132	869
Maximum crack width	mm	2.00	0.10
Medium crack width	mm	0.83	0.05
Total crack area	mm²	2,596.6	43.9
Water evaporation	% by mass	1.22	1.61

Table A6: Results of the tests on the reduction of plastic shrinkage (converted in imperial units)

Parameter	Unit	Concrete mixture	
		IIB	IIA - Kratos
1	2	3	4
Number of cracks	-	12	40
Total crack length	in	123.40	34.24
Maximum crack width	in	0.079	0.004
Medium crack width	in	0.033	0.002
Total crack area	in²	4.025	0.068
Water evaporation	% by mass	1.22	1.61

ANNEX B

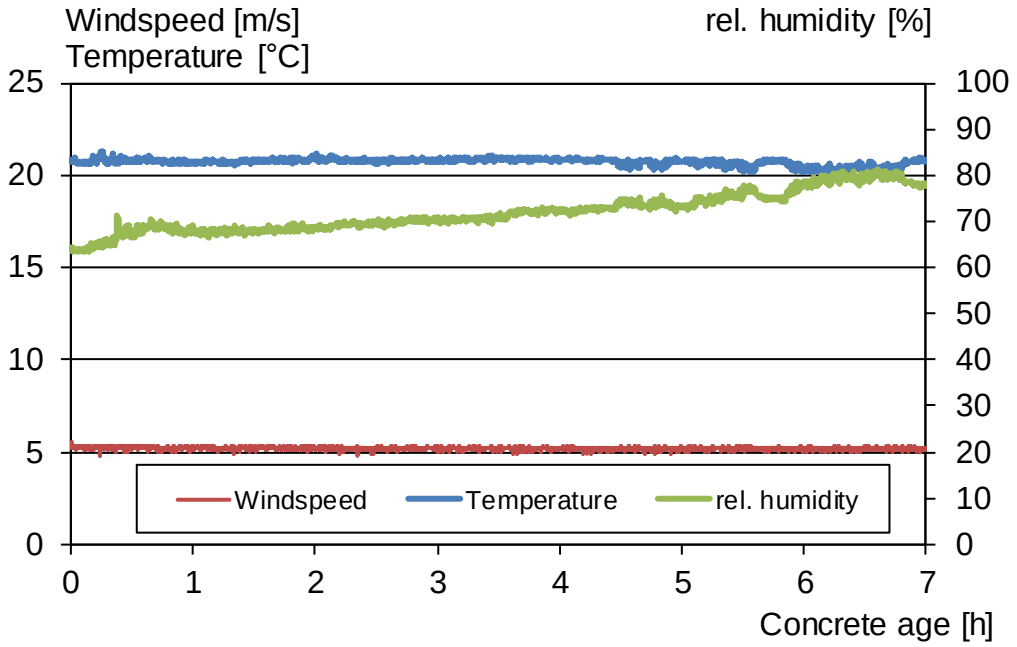

Figure B1: Boundary conditions at the test of concrete IIB

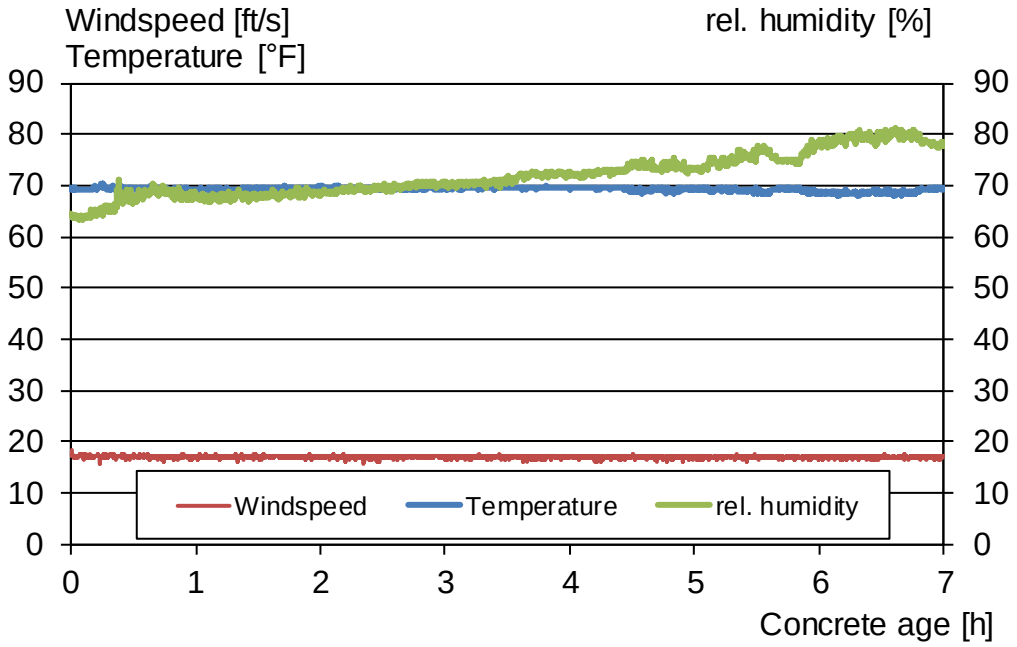

Figure B2: Boundary conditions at the test of concrete IIB (converted into imperial units)

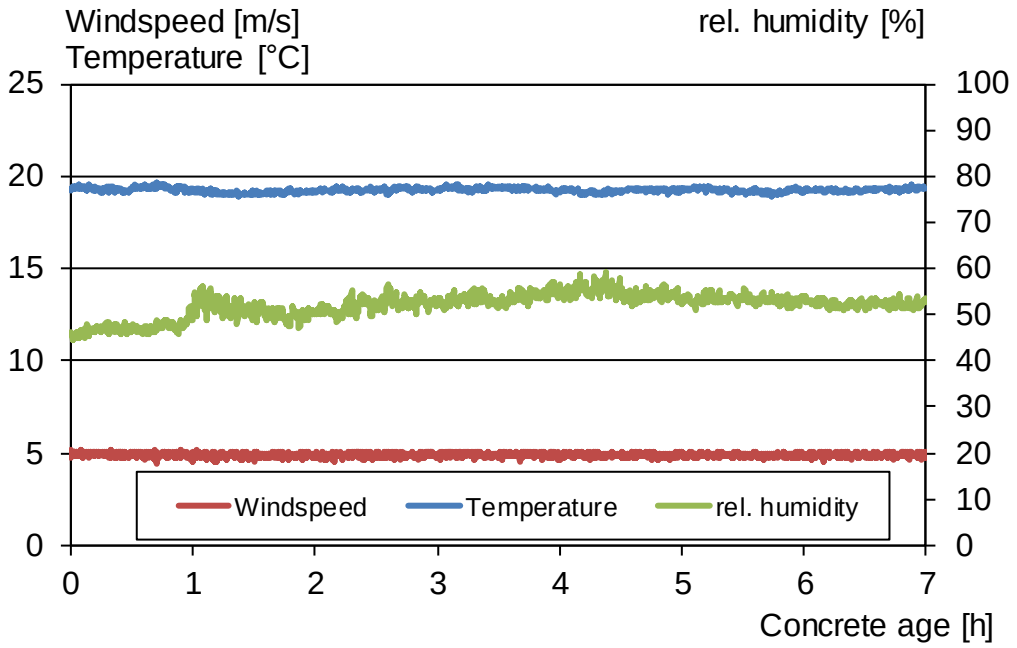

Figure B3: Boundary conditions at the test of concrete IIA – Kratos

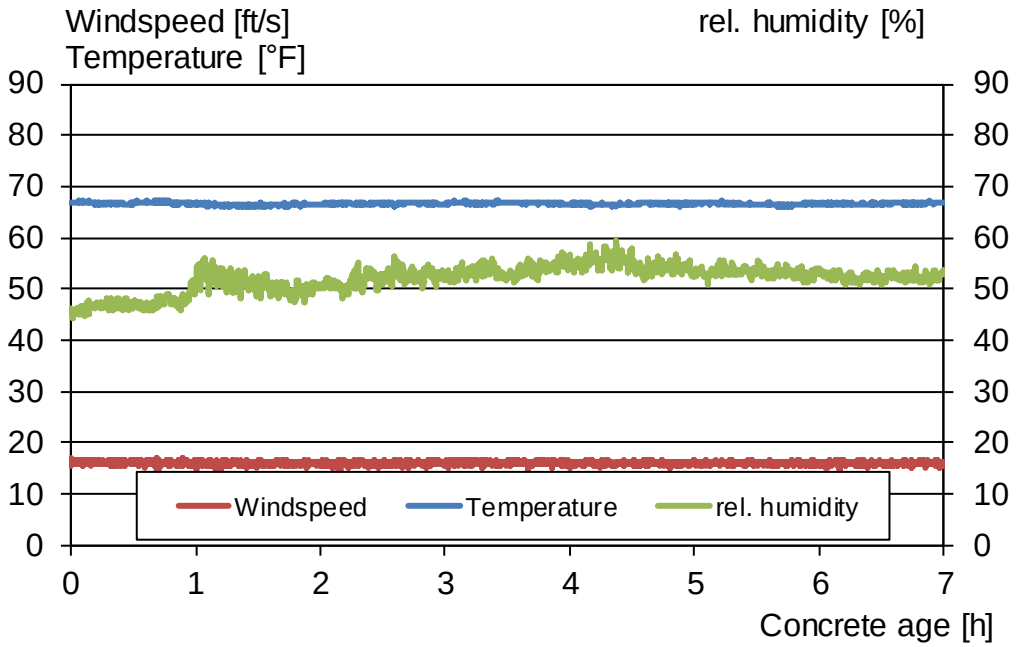

Figure B4: Boundary conditions at the test of concrete IIA – Kratos (converted into imperial units)

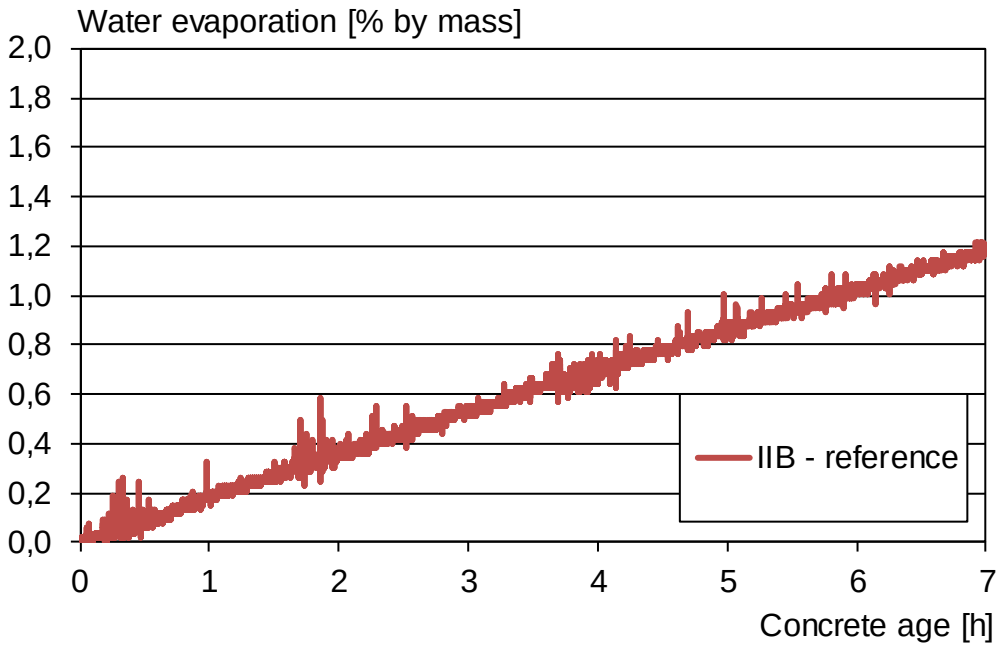

Figure B5: Water evaporation at the test of concrete IIB

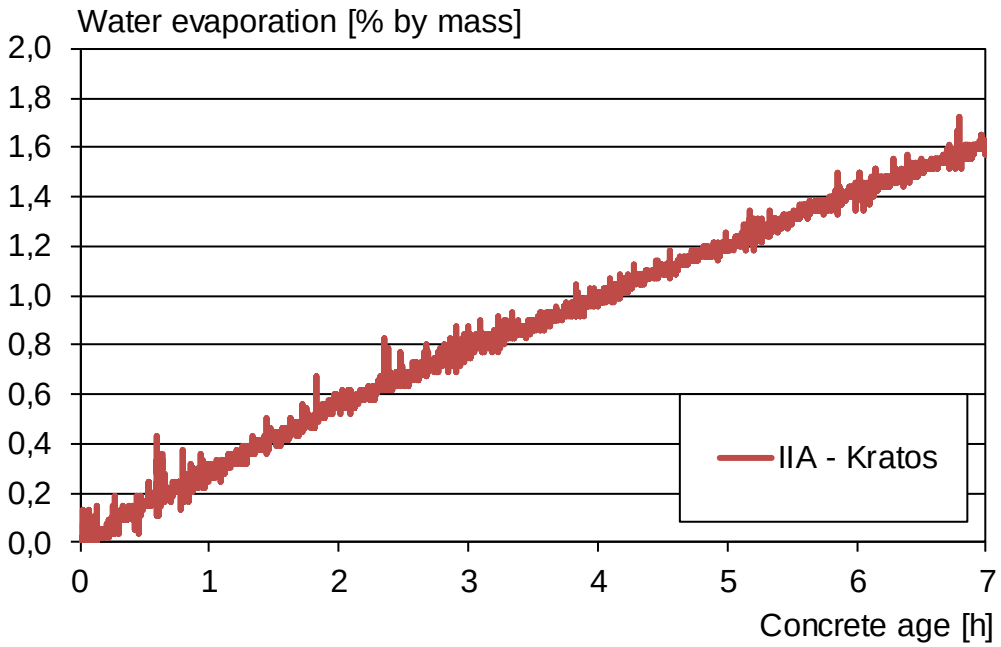

Figure B6: Water evaporation at the test of concrete IIA – Kratos

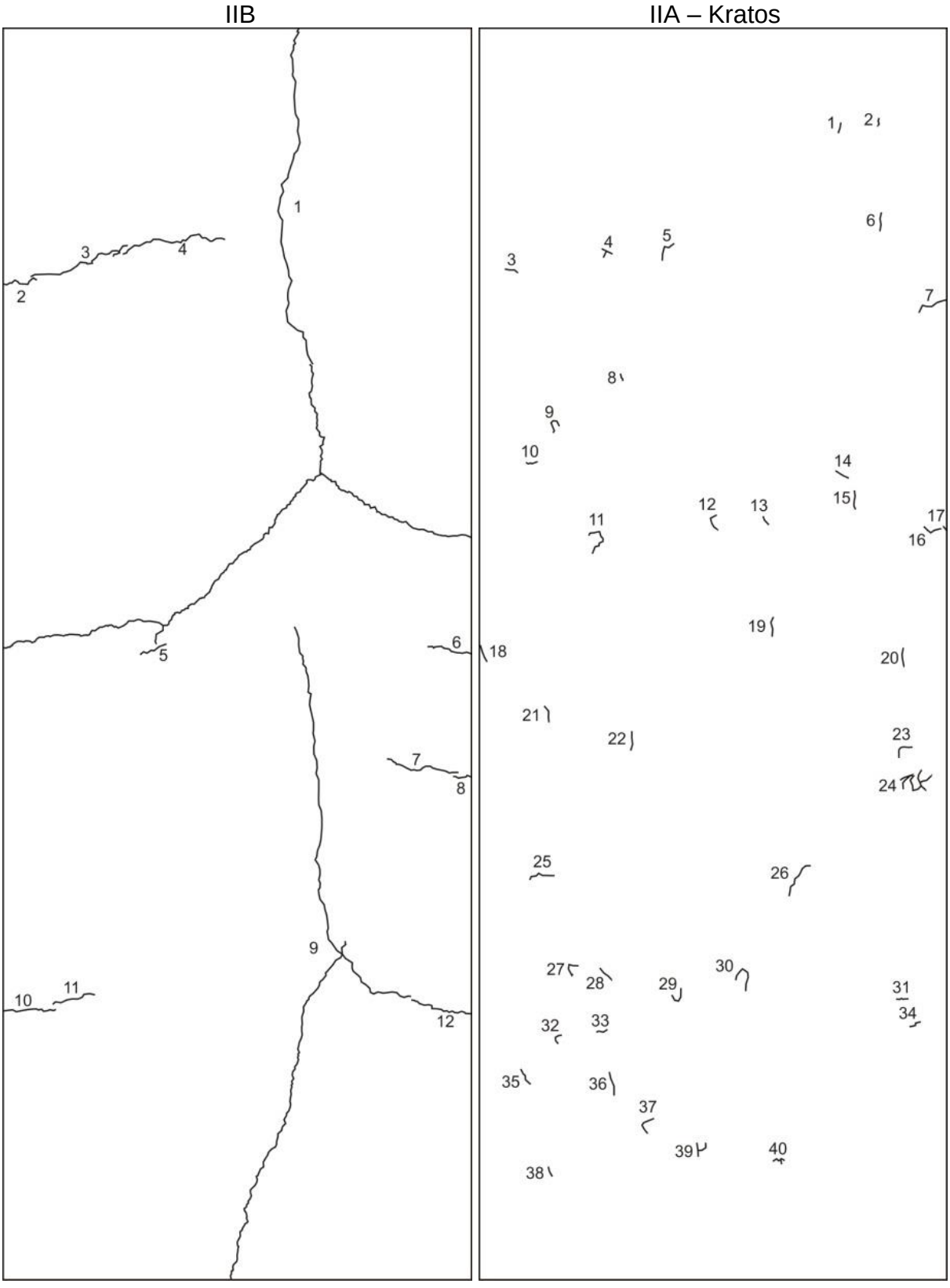

Figure B7: Cracked patterns of the different concretes