Réunion Internationale des Laboratoires et Experts des Matériaux

TC 281-CCC: Carbonation of concrete with SMC
WG4: Effect of combined actions: load + carbonation

The recent progress of WG4

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on behalf of:

Prof. Ling WANG

China Building Materials Academy

Guimaraes, Portugal, March 9th, 2020

Outline

1. The comparative test plan
2. The progress of the first round of the inter-laboratory comparison
3. The status of the annotated bibliography
4. Next steps

1. The comparative test plan

The WG4 members had a serious and in-depth discussion in Prague, Czech Republic on September 17, 2019.

- Venue: Club D at the Prague Convention Center, Prague (17:30-18:00)

  Lobby of the Holiday Inn PCC (18:00-19:00)
- Participants: Ling Wang, Juan Li, Zhendi Wang, Hao Wu, Yin Cao, Nele De Belie, Philip Van den Heede, Ivan Ignjatovic, Siham Kamali-Bernard, Charlotte Thiel, Didier Snoeck, Zengfeng Zhao
- Topics: the annotated bibliography on the combined action of load and carbonation , the loading device setup, and the inter-laboratory comparative test

After the Prague meeting, a detailed test plan was proposed and distributed to all members of WG4 on October 10th, 2019.

A Detailed Description of the Comparative Test Method
—for the first round of comparative test

(1) Scope and Applications

(2) Equipment

(3) Materials and Mix Design

(4) Preparation of Test Samples

(5) Test Procedure

(6) Report

(1) Scope and Applications

- **Scope**
  To determine durability of concrete under combined actions of carbonation and compressive load.

- **Applied compressive load**
  Carbonation and compression simultaneously.
  The pre-defined compressive stress ratio for this first round of comparative testing is 0.45. A comparison will be made with the unloaded condition.

For the second round of comparative testing other compressive stress ratios to consider are 0.30 and 0.60. If available, stress ratio of 0.80 can be also considered.

(2) Equipment

Loading device

- The compressive load shall be applied on a prismatic concrete specimen using a test rig similar to test rigs used for creep loading and described in RILEM recommendation of TC 107-CSP (Fig. 1).
- Different loading rigs are presented for the creep tests, however, the hydro-pneumatic accumulator shown in Fig. 1 is recommended.
- Test rigs, which have the same principle and function and fulfil the requirements of RILEM recommendation of TC 107-CSP can be used as well.
- All test rigs shall guarantee the stability of the external load during the entire test period.

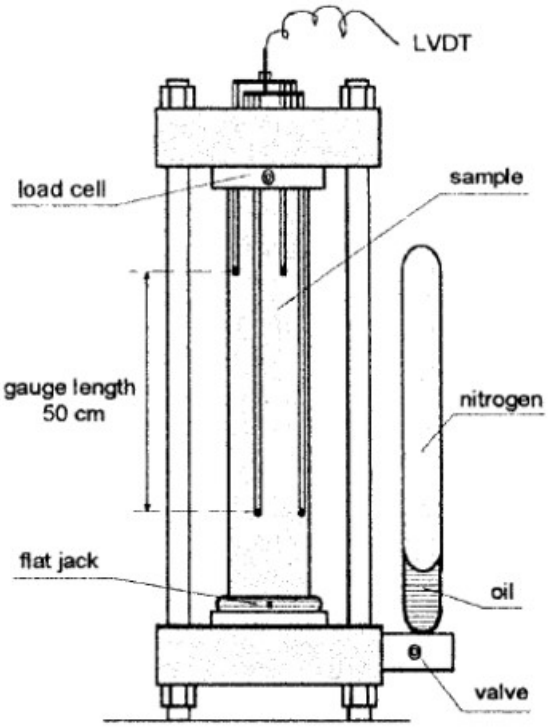
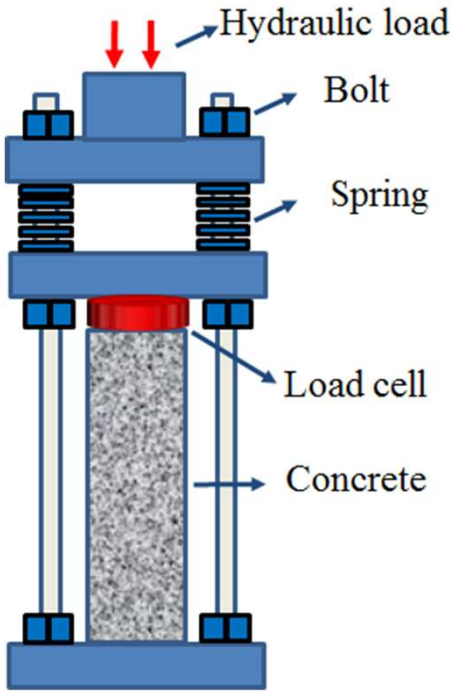


Figure 1. Schematic representation of test rig for compression

Loading device – existing setups

- **Using a torque wrench**
- **Using a bolt-and-spring system**



Carbonation device

The following requirements shall be met:

- Temperature: 20 ± 2 ℃
- Relative humidity: 65 ± 5%
- CO_2 concentration: 2% or 20%

Please note that the carbonation chamber should accommodate at least 9 specimens with loading device (in the second round of comparative test, at least 3 stress ratios 0, 0.30, 0.60 will be considered and 3 specimens for each stress ratio).

In the first comparative test, only CO_2 concentration of 2% is considered.

In the second round of comparative test, natural carbonation and CO_2 concentration of 20% will be also considered.

(3) Materials and Mix Design

Mix proportion

Table1 Mix proportion for the first comparative test

Cement (kg/m^3)	w/c	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Superplastizer (kg/m^3)	Slump (mm)
330	0.6	198	719	1162	(As needed)	110

Cement type: CEM I 42.5

Super-plasticizer: polycarboxylic admixtures, adjust the amount to make the slump of 110±10 mm.

Please note that in the second round of comparative test, CEM III/B (or CEM I + Fly ash) concrete will be tested.

Pre-test on the proposed mix proportion at CBMA

➢ Raw Materials

(1) Cement: CEM I 42.5

Table 2 Chemical composition of cement (%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	Na_2Oeq	f-CaO	Loss	Cl^-
22.89	4.51	3.51	62.85	2.42	0.55	0.86	0.98	0.014

Table 3 Physical properties of cement

Fineness (%)	Density (g/cm^3)	Specific surface (m^2/kg)	Setting time (min)		Flexural strength (MPa)		Compressive strength (MPa)	
			Initial	Final	3d	28d	3d	28d
0.9	3.15	340	193	249	5.2	9.2	25.2	50.7

(2) Fine aggregate

Table 4 Properties of fine aggregate

Apparent density	Bulk density	Fineness modulus
2.68×10^3 kg/m^3	1.59×10^3 kg/m^3	2.9

(3) Limestone

Table 5 Properties of coarse aggregate

Size	Apparent density	Bulk density	Gradation
5-20 mm	2.72×10^3 kg/m^3	1.67×10^3 kg/m^3	5~10 mm: 40% by weight 10~20 mm: 60% by weight

(4) Tap water

(5) Superplastizer

Table 6 Properties of superplastizer

Type	Water-reducing rate	Solid content
Polycarboxylic admixtures	29%	20%

➢ Mix proportion

Table 7 Mix proportion used in the pre-test at CBMA

Cement (kg/m^3)	w/c	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Superplastizer (kg/m^3)	Slump (mm)
330	0.6	198	719	1162	0.5	110

➢ Compressive strength of cubic samples

- 3 d compressive strength: 12.3 MPa
- 7 d compressive strength: 21.2 MPa
- 28 d compressive strength: 33.2 MPa

（4）Preparation of Test Samples

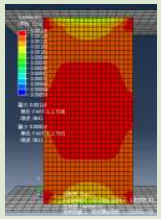
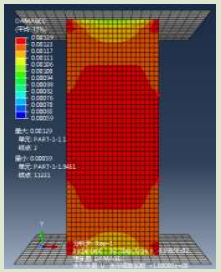
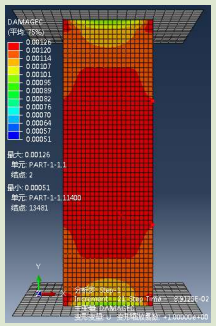
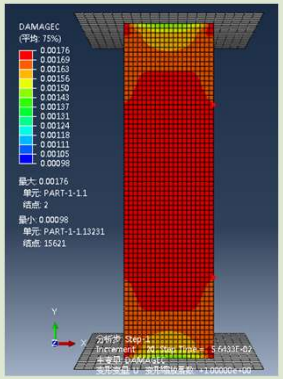
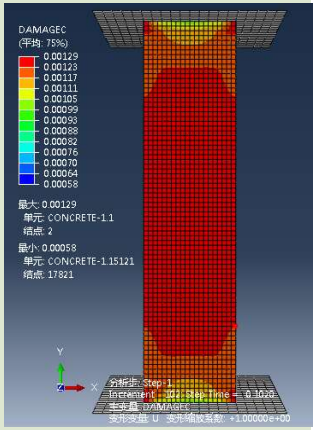
Concrete specimen

- **Plain concrete without reinforcement.**
- **Number: At least 3 cubes and 9 prisms** ($100 \times 100 \times 300$ mm^3) **in one series. The height of the prisms is determined from stress analysis (See the next page).**
  - Group I: 3 cubes for compressive strength test (f_{cc});
  - Group II: 3 prisms for compressive strength test (f_{cp});
  - Group III: 3 for carbonation with the stress ratio 0.45 and 3 for carbonation without load.

If available, more specimens can be made for additional test.

- **Specimens with dimension of 100×100×300 mm³ is recommended.**
  - Meet the requirement of height-to-width ratio.
  - Can get enough samples from the stress-uniformly distributed-area for the following testing and analysis after combined action.

Table 8 Stress analysis results of prisms with different height (cross section 100×100 mm²)

Height of prisms (mm)	200	250	300	350	400
Compression Damage Nephogram (at 0.80 stress level)					
Height of the stress- uniformly distributed-area (mm)	30	90	130	180	240

Casting

- All specimens are cast and compacted on a vibrating table in accordance with the procedure described in pr EN-ISO 2736/2.
- Casting direction for the prismatic samples: horizontal.

Curing

Table 9 Curing process of the concrete specimen in each group

Procedure of the curing	Group I	Group II	Group III
Test aim for each group	3 cubes for compressive strength test (f_{cc})	3 prisms for compressive strength test (f_{cp})	6 for carbonation test with and without load
Curing in the moulds, air temperature of 20 (±2) ℃, covering with a plastic sheet.	1 day	1 day	1 day
In saturated $Ca(OH)_2$ solution at 20 (±2) ℃.	6 days	6 days	6 days
In climate chamber at 20 (±2) ℃ and 65 (±5) % RH.	21 days	21 days	21 days
In carbonation chamber at predefined CO_2 concentration, 20 ℃ and 65 (±5) % RH.	--	--	28 days

In the second round of comparative test, CEM III/B (or CEM I + Fly ash) concrete will be tested. For CEM III/B(or CEM I + Fly ash) concrete, longer curing period is needed before carbonation test, i.e. 7d of optimal curing in saturated $Ca(OH)_2$ solution (lime water) followed by 84 days of curing at at 20 (±2) ℃ and 65 (±5) % RH.

Preconditioning

- **For the loaded specimens (3 specimens in Group III)**
  - Smooth the middle of the upper and lower surfaces for pasting the strain gauges.
  - Fix the strain gauges symmetrically in the middle of the both sides on the purpose of monitoring the strain of the specimen.
  - Cover the two surfaces with 2 layers of aluminum foil.
  - Apply the compressive load with the loading set-ups.
- **For the unloaded specimens (3 specimens in Group III)**
  - Cover the upper and lower surfaces with 2 layers of aluminum foil.
  - Leave the other 2 opposite surfaces open for CO_2 ingress.

(5) Test Procedure

- For Group I, test the 28 d compressive strength of cubes (f_{cc}).
- For Group II, test the compressive strength of prisms (f_{cp}) .
- Put all the specimens of Group III (after preconditioning) in the carbonation device till the carbonation duration.
- Test the 28 d carbonation depth of the specimens .

In the second round of comparative test, additional tests can be done to investigate the loading-induced damage on the micro-scale, changes in chemical composition due to carbonation, etc.

(6) Report

The test report shall contain at least the following information:

- (1) Raw material and composition of the concrete.
- (2) Information of the loading device and the carbonation device.
- (3) Numbers and size of specimens.
- (4) Stress ratio, carbonation environment.
- (5) Test results.
- (6) Any deviation from the procedure described in this method.

2. Progress of the first round of the inter-laboratory comparison

- 7 labs confirmed to join the first round of the comparative test.

NO.	Leader	Lab
1	Yan Yao	The State Key Laboratory of Green Building Materials, CBMA, China
2	Nele De Belie	Magnel Laboratory for Concrete, Ghent University, Belgium
3	Ivan Ignjatovic	Laboratory of materials, University of Belgrade, Serbia
4	Siham Kamali-Bernard	Laboratory of Civil and Mechanical Engineering, INSA-Rennes, France
5	Jingzhou Lu	Yantai University, China
6	Talakokula Visalakshi	Bennett University, India
7	Zuquan Jin	Qingdao University of Technology, China

- In addition to the above, several WG4 members consulted and requested the detailed drawings of the device, showed strong interest.

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Progress Magnel-Vandepitte Laboratory

Prescribed Mix proportion

Table1 Mix proportion for the first comparative test

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330	0.6	198	719	1162	(As needed)	110

Produced Mix proportion

(casting date: 11/12/2019)

Table1 Mix proportion for the first comparative test

Cement (kg/m^3)	w/c	Water (kg/m^3)	Sand 0/4 (kg/m^3)	Limestone 6/20 (kg/m^3)	Superplastizer (kg/m^3)	Slump (mm)
330	0.6	198	719	1162	**0**	**215**

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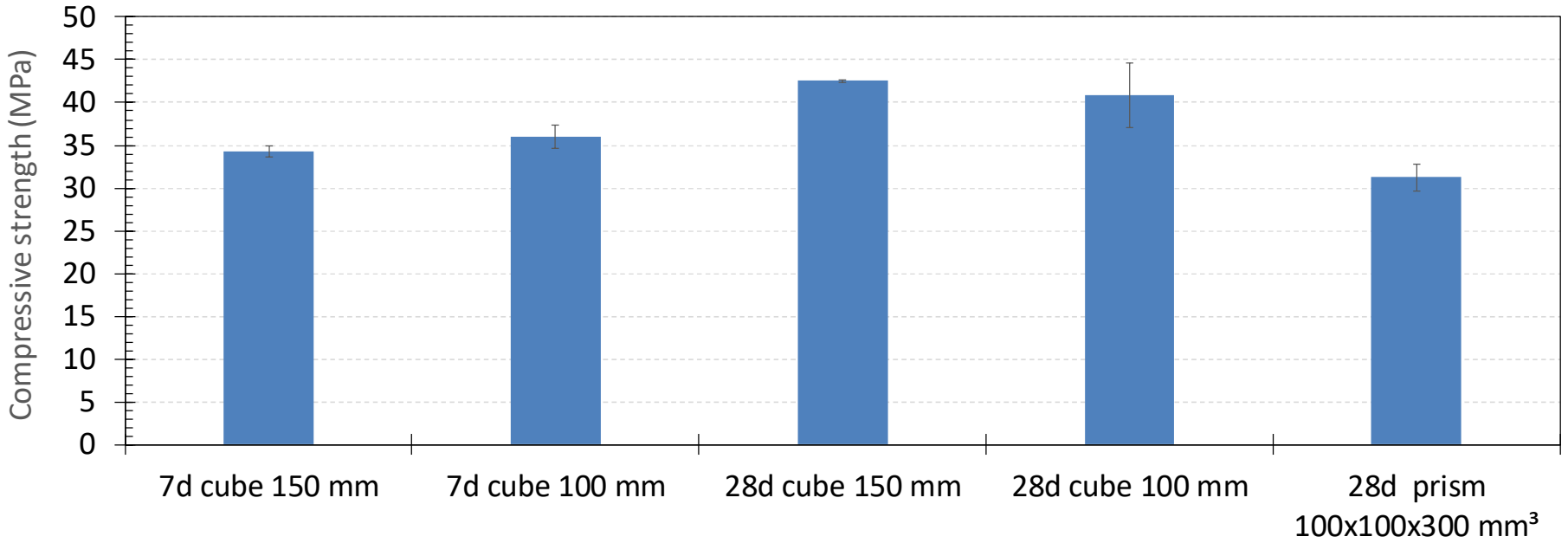
Achieved compressive strength performance



Comparison compressive strength of cubic samples CBMA

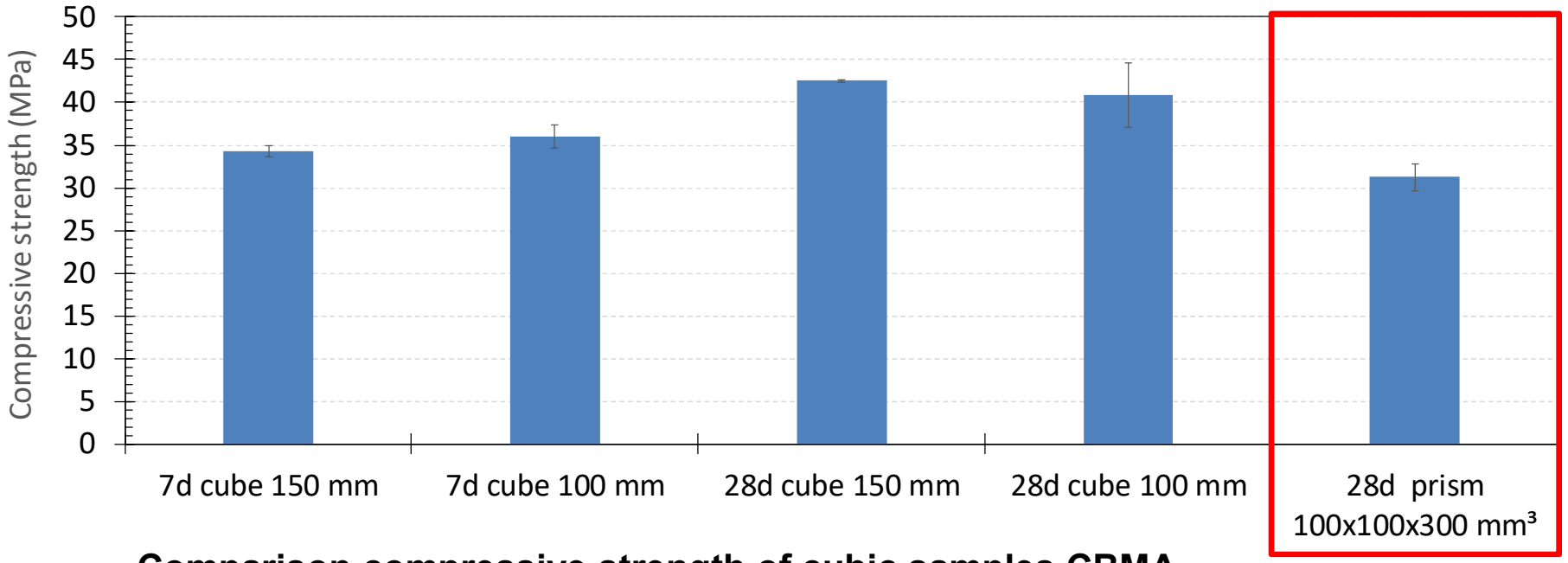
3 d compressive strength: 12.3 MPa

7 d compressive strength: 21.2 MPa

28 d compressive strength: 33.2 MPa

Progress Magnel-Vandepitte Laboratory

Achieved compressive strength performance



Comparison compressive strength of cubic samples CBMA

3 d compressive strength: 12.3 MPa

7 d compressive strength: 21.2 MPa

28 d compressive strength: 33.2 MPa

45% breaking load: 138 kN

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Prescribed curing and testing procedure after casting

Procedure of the curing	Group I	Group II	Group III
Test aim for each group	3 cubes for compressive strength test (f_{cc})	3 prisms for compressive strength test (f_{cp})	6 for carbonation test with and without load
Curing in the moulds, air temperature of 20 (±2) ℃, covering with a plastic sheet.	1 day	1 day	1 day
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In carbonation chamber at predefined CO_2 concentration, 20 ℃ and 65 (±5) % RH.	--	--	28 days

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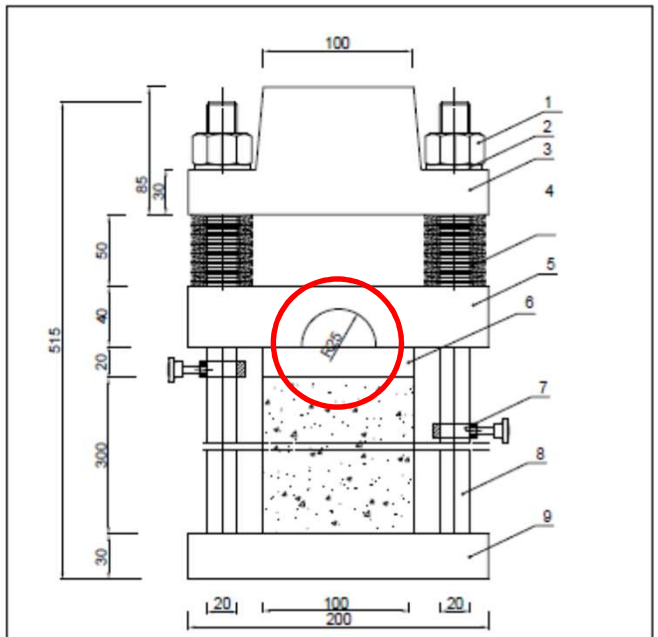
Manufacturing of loading frames



NO	Code	Name	Qua	Materials	Wei.	Remarks
9	CM02-09	Base Board	1	45#		
8	CM02-08	Tension Bar	4	45#		
7	CM02-07	Limited Block	4	Q235A		
6	CM02-06	Spherical Bearing Plate	1	45#		
5	CM02-05	Bearing Plate	1	45#		
4	CM02-04	Disc spring	80			40X20.4X3.15
3	CM02-03	Upper Bearing Plate	1	45#		
2	GB95-85	Gasket	4	Ø20		
1	GB/T1229-91	Nut	4	M20		High Str.

Technical drawing CBMA

Problems encountered:

- Imposed **loading levels** with hydraulic testing machine **could not be maintained**.
- Without presence of a load cell in between upper loading plate and specimen, **loading levels cannot be verified**.
- **Hemispherical pit in upper loading plate** implies significant loss in plate cross-section in the centre. Repeated loading caused **failure of the plate**

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Adopted curing and testing procedure after casting

Procedure of the curing	Group I	Group II	Group III
Test aim for each group	3 cubes for compressive strength test (f_{cc})	3 prisms for compressive strength test (f_{cp})	6 for carbonation test with and without load
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In saturated $Ca(OH)_2$ solution at 20 (±2) °C.	6 days	6 days	6 days
In climate chamber at 20 (±2) °C and 65 (±5) % RH. **60% RH!**	21 days	21 days	21 days **+28d**
In carbonation chamber at predefined CO_2 concentration, 20 °C and 65 (±5) % RH. **60% RH!**	--	--	28 days

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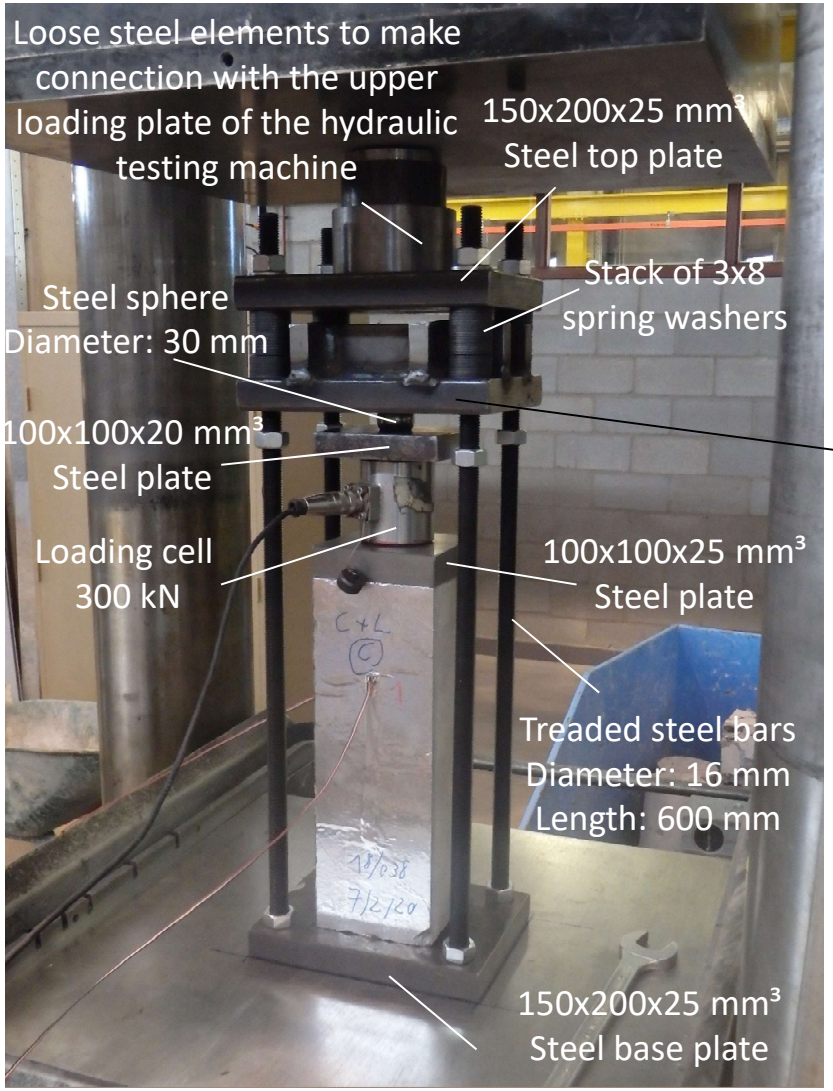

Change of orientation of spring washers every 8 washers per stack

Total weight: ± 37 kg

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Wiring of strain gauges and loading cells connected with an electronic logging device

Wiring of strain gauges and loading cells going through carbonation chamber

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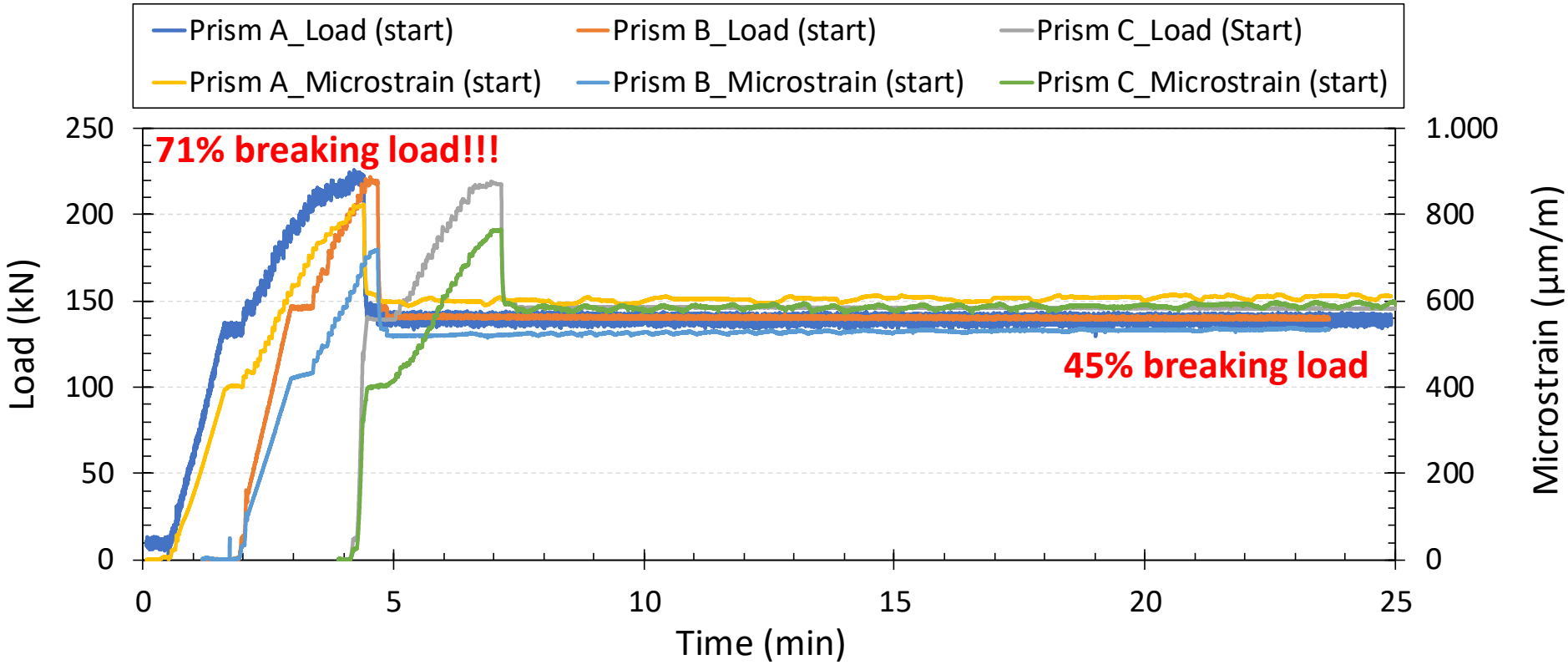
Load cell and strain gauge monitoring (upon loading)



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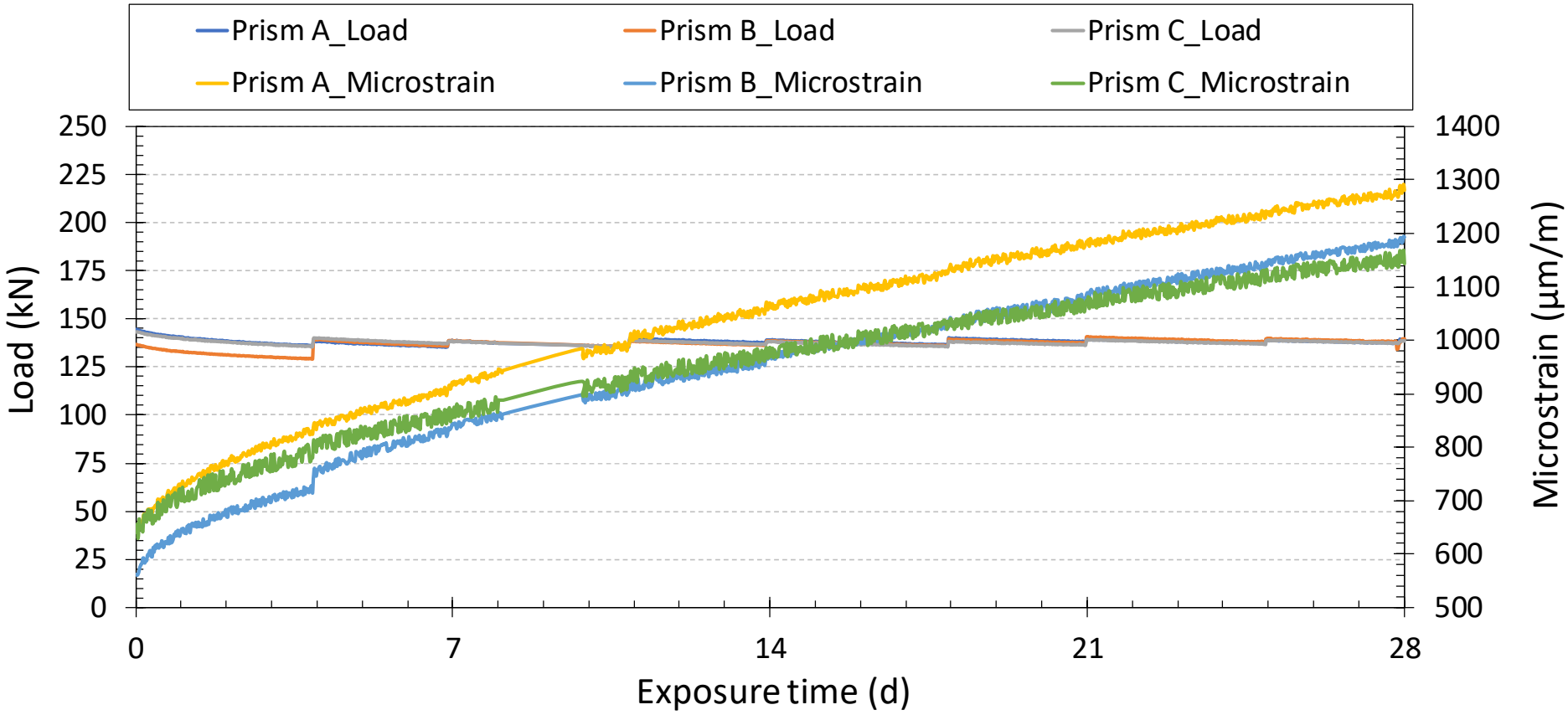
Load cell and strain gauge monitoring (in CO_2 chamber)



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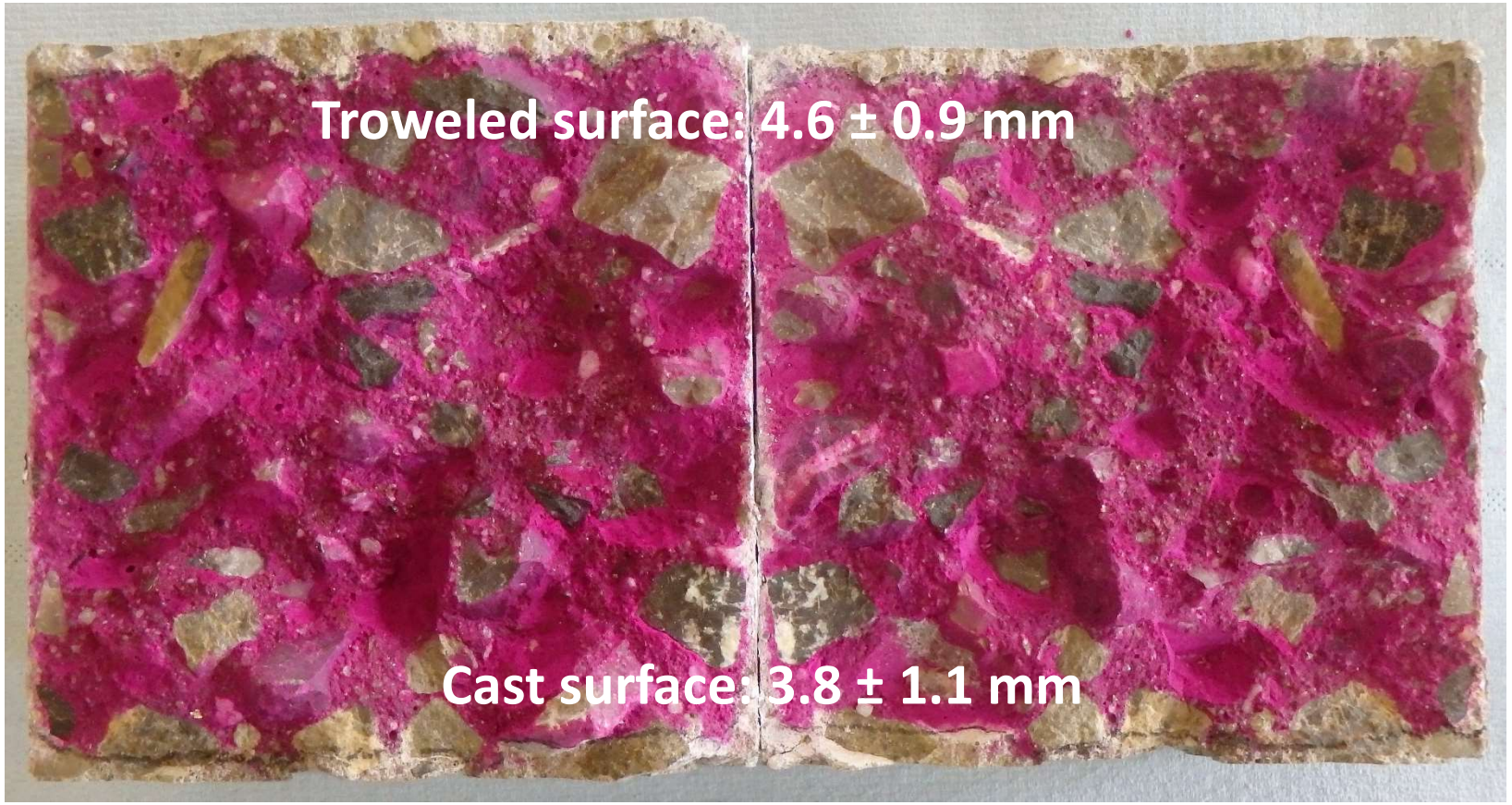
Carbonation depth for unloaded dummy cube after 28d



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In climate chamber at 20 (±2) °C and 65 (±5) % RH. **60% RH!**	21 days	21 days	21 days **+28d**
In carbonation chamber at predefined CO_2 concentration, 20 °C and 65 (±5) % RH. **60% RH!**	--	--	28 days **+28d**

Status and Difficulties

- All labs hav a carbonation chamber that meets the requirements.
- But the manufacture of the new loading device took more time than planned time in all labs.
- Most of the 7 labs had no problem to prepare enough concrete specimens for carbonation.
- The experiment work in the 3 Chinese Labs have been strongly influenced by the COVID-19. All PhD students are not allowed to return to labs due to the particularly serious epidemic. The comparative test in the 3 labs is expected to start again as early as the middle of April.
- Discussion on the test results of the first round comparative test may delay to the Sheffield meeting in August.

3. The status of the annotated bibliography

- A draft of the annotated bibliography was distributed to all WG4 members in Setp.2019.
- Several very valuable comments and suggestion were received. The book has been greatly revised and perfected.
  - A new structure was applied for each subchapters (permeability + load & carbonation + load) : 1. Introduction, 2. Selected papers, 3. Summary.
  - A summarizing table was added in each summary section to giving a well-structured overview on the key parameters of the test methods and key conclusions as described in each selected paper.
  - For all selected papers, Photos/figures/schematics related to the test method were added in addition to the original abstract for all selected papers.
- It will be published after final format check before June 2020.

An Annotated Bibliography:

Publications on Durability of Concrete

under Combined Mechanical Loads and Carbonation

Edited by

Yan Yao, Ling Wang, Guanbao Tang, Yin Cao

March 1, 2020

Content

4. Next steps

Time	Tasks
June 2020	➢ Publish the annotated bibliography
July 2020	➢ Finish the first round comparative test
August 2020	➢ 3rd WG4 meeting in Sheffield, UK in conjunction with 74th RILEM Week ➢ Discussion of the test results of the first round comparative test ➢ Test plan of the second round comparative test
March 2021	➢ 4th WG4 meeting in Paris, France in conjunction with 75 years celebration of RILEM ➢ Discussion of the test results of the second round comparative test

Thanks for your attention !