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Chloride migration coefficient of self-compacting concrete

Dana Sedláčková

Abstract

This paper describes a laboratory study on the chloride migration coefficient, which is defined by Tang. Four different types of self-compacting concrete were studied and compared with a normal concrete. All samples were 1 year old and were stored in climate chambers with 60% or 90% relative humidity. The effect of different properties of SCC on the chloride migration coefficient was studied.

1 Introduction

One normal concrete and four self-compacting concrete were studied. All mixtures contained Portland cement. All concrete contained superplasticiser. The first, normal concrete - 40LN0, had a water-cement ratio 0.40. The second, self-compacting concrete 40L00 had a water-cement ratio 0.40 and viscosity agent. In the last three cases, limestone powder was added. The last two concretes contained polypropylene fibres, and differed only in the water-cement ratio 0.40 and 0.42, respectively. The measurements of the chloride migration coefficient, D , were performed by a rapid test method developed by Tang [1].

2 Used materials

Table 1 contains ingredients mix proportions and properties of each type of concrete.

Table 1 – Mix proportions and properties of the individual concretes (kg/m³, etc.)

No	3	4	5	6	7
Concrete	40LN0	40L00	40LK0	40LK2	42LK2
Crushed aggregate 11-16 mm	471	496	475	450	450
Crushed aggregate 8-11 mm	139	146	189	208	208
Natural sand 0-8	1000	1053	913	990	990
Limestone powder			92	97	97
Cement – CEM I 42.5 BV/SR/LA	441	464	431	450	450
Air-entrainment agent (MB Microair)	0.132	0.093	0.086	0.125	0.225
Water	176	186	172	180	193
Viscosity agent (Glenium Stream)		2.3			
Superplasticiser	2.2	4.6	5.6	32.4	33.7
Water/cement ratio	0.40	0.40	0.40	0.40	0.43
Polypropylene fiber				1.5	1.5
Density	2227	2347	2273	2380	2394
Dry density	2049	2156	2097	2179	2178
Binder agent/density	0.215	0.215	0.205	0.207	0.207
Slump (flow) (mm)	180	620	640	600	600
Air content (%)	7.8	3.3	7.3	2.8	3.3
Cylinder strength (MPa)	37	54	63	55	55
Cube strength (MPa)	52	76	87	82	82
Moisture at RH=90% (%)	5,6	5,6	2,5	5,4	5,4
Moisture at RH=60% (%)				3,7	

3 Preparation of specimens

Specimens were cast into standard cylinder forms, 100 mm in diameter and 200 mm in height. Specimens were cured 1 week in water and then stored in climate chambers with relative humidity of 60% and 90% respectively. After one year of storage, the specimens were cut into three pieces. The height of each piece was 50 mm. First 20 mm of 200 mm height was not used.

4 Method

The determination of D was carried out using the equipment developed by Tang [1]. In appendix, the equipment and scheme of the Tang method is shown.

Its principle is based on an external electrical potential, which is applied axially across the specimen and forces the chloride ions outside to migrate into the specimen (Appendix Fig.5). The current belonging to a certain voltage is the driving force for the migration of chlorides. All 3 pieces made from each cylinder are tested together.

Wet specimens are placed into a vacuum container, where a pressure of below 5 kPa is maintained by a vacuum pump (App. Fig 1). The vacuum is kept for 3 hours followed by a limestone water addition and is then carried on for another hour. After this, the normal ambient conditions are ensured and specimens are kept in the lime water for 20 hours.

All specimens are then put into silicone rubber sleeves of the same diameter. The sleeves are fixed by clamps of stainless steel (App. Fig 2). Each clamp is fixed by two screws.

The screws are usually the main source of problems being made of stainless steel. The stainless steel is very soft material in comparison to the normal hard steel used in common screw drivers. The stainless steel makes a proper tightening of the screws very difficult. Such damage of the screw may result in leaching and consequent unreliability of results.

The prepared samples are placed into a cathalytic reservoir - plastic box filed up by 10% NaCl solution (App. Fig 3). The sleeves are filed up above the specimens with 300 ml NaOH solution and electrodes are immersed in 10% NaCl solution and connected to the power supply (App. Fig 4).

When the power is turned on, an initial voltage is set up at 30 V. Initial current through each specimen is recorded. As each concrete has different composition, the voltage must be adjusted. The values are presented in the table (App. Fig 6). Test duration depends on the adjusted voltage, but is usually kept at 24 hours. Also the temperature must be measured at the beginning and at the end of each experiment.

After 24 hours the specimens are split into two pieces and sprayed with 0,1 M silver nitrate solution on a freshly split section. The depth of chloride penetration is possible to observe after 15 minutes. The values are measured according to the scheme presented on the (App. Fig 7).

5 Evaluation of results

D was calculated with the following equation [1]:

$$D = \frac{0.0239 \cdot (273+T) \cdot L}{(U-2) \cdot t} \cdot (x_d - 0.0238 \cdot \sqrt{\frac{(273+T) \cdot L \cdot x_d}{(U-2)}}) \quad (1)$$

D	the non-steady-state migration coefficient ($\times 10^{-12} \text{ m}^2/\text{s}$)
t	the test duration (h)
x_d	the average chloride penetration depth (mm)
L	the thickness of the specimen (mm)
T	the average initial and final temperatures in the anolytic solution ($^{\circ}\text{C}$)
U	the voltage at testing ($10\text{V} < U < 60\text{V}$)

6 Results and discussion

Two experiment cycles were performed. They were marked as I and II. Each cycle studied 5 concretes with 3 samples. Some extra experiments were made in case of high variation of the results. The results showed in Table 2 and in Fig 1 were obtained.

Table 2 – Chloride migration coefficient ($\times 10^{-12} \text{ m}^2/\text{s}$)

No - curing humidity	3 - 60%	3 - 90%	4 - 60%	4 - 90%	5 - 60%	5 - 90%
Concrete	40LN0	40LN0	40L00	40L00	40LK0	40LK0
D	6.97	7.78	6.89	8.92	5.96	6.46
D for sample 1	7.04	8.73	6.74	9.30	5.52	5.30
D for sample 2	6.75	7.23	7.26	8.69	5.99	7.59
D for sample 3	7.12	7.37	6.69	8.76	6.38	6.49

No - curing humidity	3 - 60%	3 - 90%	6 - 60%	6 - 90%	7 - 60%	7 - 90%
Concrete	40LN0	40LN0	40LK2	40LK2	42LK2	42LK2
D	6.97	7.78	4.55	6.06	5.70	7.07
D for sample 1	7.04	8.73	4.68	5.97	5.83	6.94
D for sample 2	6.75	7.23	4.51	5.83	5.72	8.24
D for sample 3	7.12	7.37	4.45	6.39	5.54	6.03

The chloride migration coefficient of self-compacting concrete was at the same level as the one of normal concrete. For concrete with limestone powder even a little better (lower).

Values of D measured in the second cycle, which were measured at samples stored in climate chambers with relative humidity 90%, were always lower than values of D measured at samples stored in climate chambers with relative humidity 60%, but only for the last two concrete with polypropylene fibres is this difference significant. This can be caused by different structure of SCC with polypropylene fibres, where fibres can affect influence of vacuuming, which should probably be longer than 4 hours.

For real structures we should concern that values which were measured at samples stored in climate chambers with relative humidity 90%, because such conditions are more common in real structures.

The concrete containing limestone powder showed a little bit better value of chloride migration coefficient in comparison with the concrete without limestone powder. But only values measured at samples stored in climate chambers with relative humidity 90% obtained a significant difference in this aspect. For values measured at samples stored in climate chambers with relative humidity 60% these values are not always significant. Statistics expression of results can be seen in Fig 2 and Fig 3.

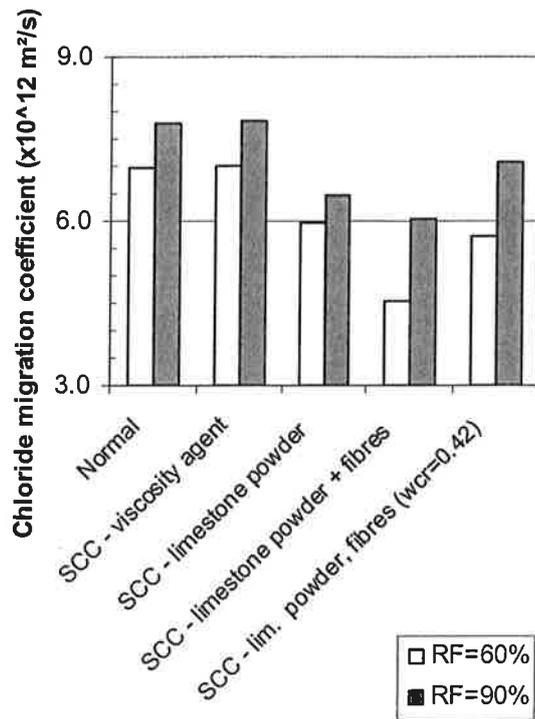


Fig 1 – Comparison of chloride migration coefficient for different concretes

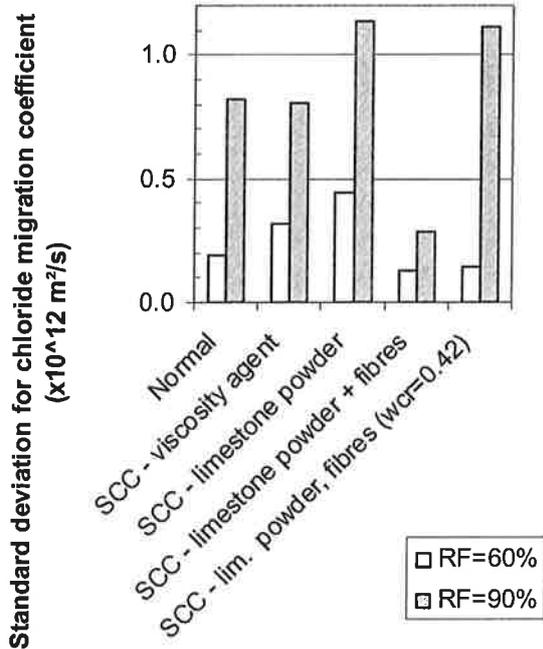


Fig 2 – Statistics expression of results - standard deviation

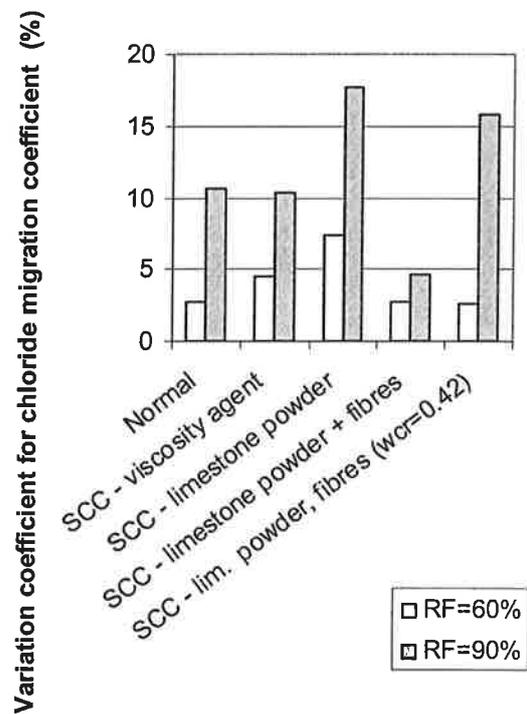


Fig 3 – Statistics expression of results variation coefficient

7 Conclusions

The following conclusions were drawn:

- The chloride migration coefficient of self-compacting concrete is not larger than that of normal concrete. In some cases it may be lower in self-compacting concrete than in normal concrete.
- Only the values which were measured at samples stored in 90% humidity should be concerned, because such conditions are more common in real structures.
- The concrete containing limestone powder showed a little bit lower value of chloride migration coefficient in comparison to the concrete without limestone powder.
- A significant difference between values of SCC containing fibres, which were measured at samples stored under different humidity conditions, should be noticed

ACKNOWLEDGEMENT

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REFERENCES

- [1] Standard - Nordtest method NT Build 492

APPENDIX

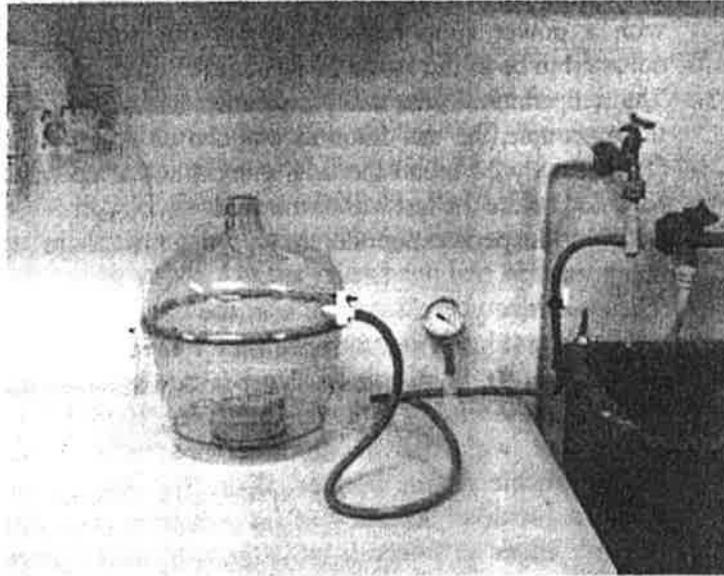


Fig 1 - Vacuum container [1]



Fig 2 – Stainless steel clamp [1]

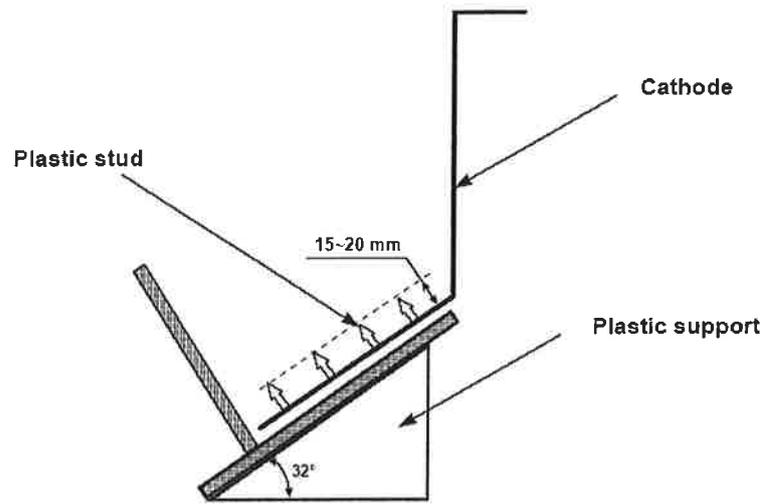


Fig 3 – Scheme of plastic support and cathode [1]

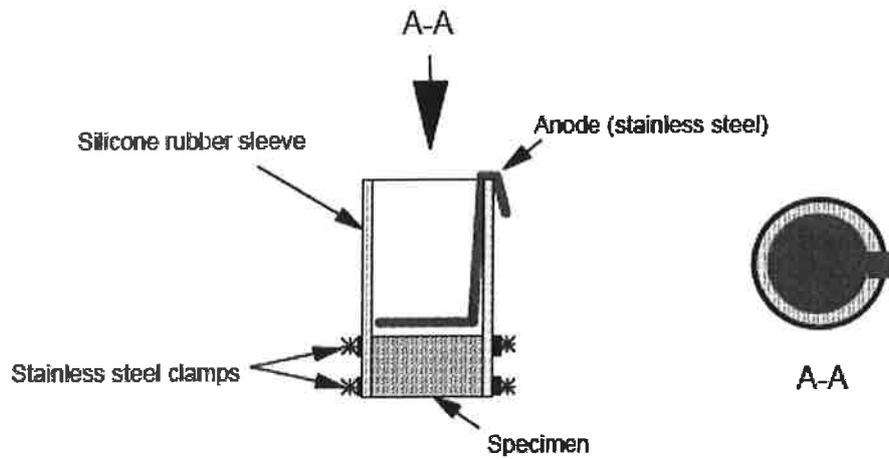


Fig 4 – Rubber sleeve assembled with specimen clamps and anode [1]

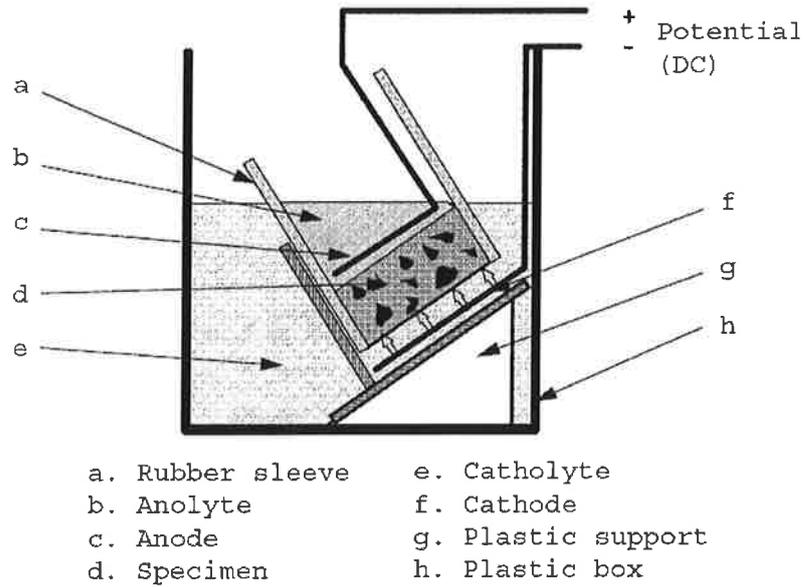


Fig 5 – Complete scheme of Tang method [1]

Initial current I_{30V} (with 30 V) (mA)	Applied voltage U (after adjustment) (V)	Possible new initial current I_0 (mA)	Test duration f (hour)
$I_0 < 5$	60	$I_0 < 10$	96
$5 \leq I_0 < 10$	60	$10 \leq I_0 < 20$	48
$10 \leq I_0 < 15$	60	$20 \leq I_0 < 30$	24
$15 \leq I_0 < 20$	50	$25 \leq I_0 < 35$	24
$20 \leq I_0 < 30$	40	$25 \leq I_0 < 40$	24
$30 \leq I_0 < 40$	35	$35 \leq I_0 < 50$	24
$40 \leq I_0 < 60$	30	$40 \leq I_0 < 60$	24
$60 \leq I_0 < 90$	25	$50 \leq I_0 < 75$	24
$90 \leq I_0 < 120$	20	$60 \leq I_0 < 80$	24
$120 \leq I_0 < 180$	15	$60 \leq I_0 < 90$	24
$180 \leq I_0 < 360$	10	$60 \leq I_0 < 120$	24
$I_0 \geq 360$	10	$I_0 \geq 120$	6

Note: For specimens with a special binder content, such as repair mortars or grouts, correct the measured current by multiplying by a factor (approximately equal to the ratio of normal binder content to actual binder content) in order to be able to use the above table.

Fig 6 – Test voltage and duration for concrete specimen with normal binder content [1]

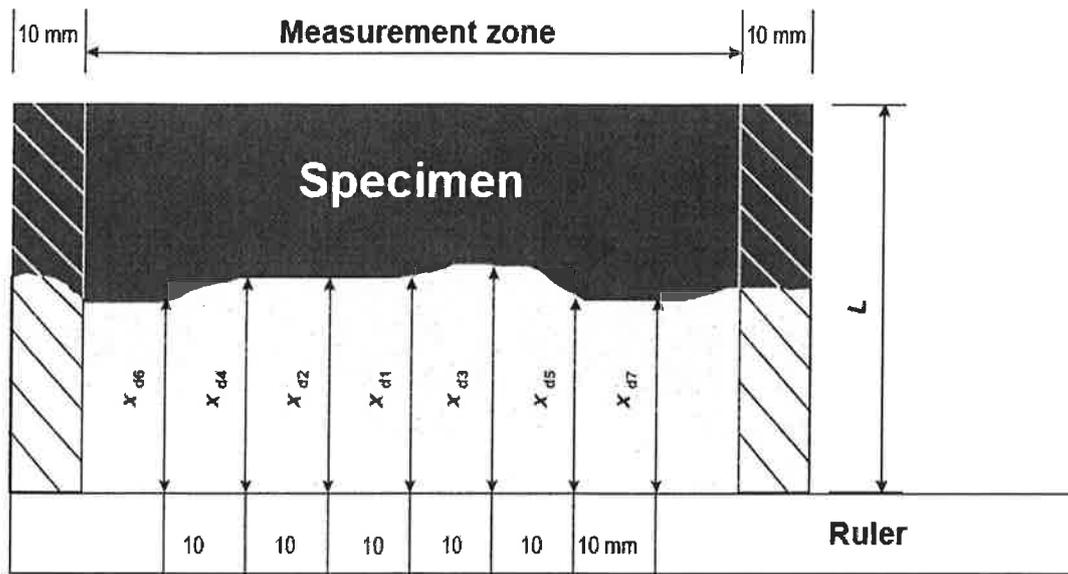


Fig 7 – Illustration of measurement of chloride penetration depths [1]