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Durability of Concrete. New Admixtures for Quality and Durability Improvement of Concrete

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Abstract. The lifetime of any concrete structure is limited by any environmental attack, engineering design, concrete composition and application. The attack on the concrete is initiated from outside, and any 'failure' of the surface properties can be a possible start for the deterioration of the whole structure.
The surface quality of concrete is partially controlled by the mix design and the hydration process of the cement. Concrete needs water for the chemical reaction and produces significant heat while hydrating. Expansion and contraction due to temperature changes can cause serious cracks. The possible evaporation of excess mixing water is a function of time, relative humidity and wind exposure. The drying out of a non-protected concrete surface is a well-known phenomenon which contributes to the reduction of surface quality and is the major factor for drying shrinkage. Bonding to this surface is minimised, and shrinkage cracking with a low degree of hydration is common.
Here will now be described a possible way of reducing these negative influences by means of the addition of a specially designed admixture to the fresh concrete at the batching plant. The addition of this admixture seems to overcome the compromise between a high water-cement ratio and too little water at the surface. Both decrease the lifetime of the whole concrete structure.

1. Introduction

The durability of any concrete structure is related to the design (engineering) of the construction as well as the concrete mix and to proper production and application of concrete. Additionally, its service life is limited by the exposure to mechanical loads and physical or chemical attacks. In order to improve the durability of concrete and therefore the quality of any concrete-based structure, some of the weak points of concrete should be minimised or eliminated.

One of the big application problems of fresh concrete is the loss of water by evaporation from the surface. This behaviour can reduce the amount of water in the concrete surface to below a critical limit and thus prevent a complete hydration of the cement clinker. A major problem is the formation of small cracks during the early stage of hardening which negatively influences tightness, freezing and thawing resistance, porosity and water absorption.

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A porous and poor concrete surface quality is one of the most critical factors for physical or chemical attack, *e.g.*, carbonation. Bonding of subsequent layers of concrete or any other structural coating will be significantly reduced, and the penetration of liquids or gases will be facilitated. These problems become much more critical in the case of sprayed concrete used in underground construction. There, the addition of setting and hydration accelerators leads to faster heat development in the concrete and then to accelerated water evaporation. The application of sprayed concrete is often done in multiple layers each with a thickness of 5–30 cm. The cement content is relatively high (350–500 kg/m^3) and the water-cement ratio relatively low (<0.5 preferred). The combination of these factors, together with the ventilation in the tunnel, causes a considerable reduction of the quality of the concrete structure.

2. Curing of Concrete

To prevent the quality reduction previously described, the concrete has to be cured adequately. ACI 308, Standard Practice for Curing Concrete, defines this procedure as: 'maintaining satisfactory moisture content and temperature in concrete during its early stages, so that the desired properties may develop'.

In nearly all cases, freshly produced concrete contains enough water for the hydration immediately after application. However, the water can be absorbed by dry substrate and/or sucking aggregate, or by evaporation from the surface area. The last tendency will be increased by higher temperatures, low humidity and external ventilation.

However, in a normal concrete, more than enough water is available for the chemical reaction. There is an excess in the bulk and a possible lack in the surface area. For proper handling, the water-cement ratio has to be considerably higher than that which is chemically required. The problem is the low mobility of the water in the concrete matrix. If it were possible to improve the exchange of water from the bulk material to the surface, the problem of lower hydration rates could be managed.

Tunnel and other underground construction projects have some of the worst conditions for the concrete hydration process:

1) The ventilation which continuously blows dry air into the tunnel face
2) A high cement content (more heat development) in the mix
3) The addition of the accelerators (fast cement reactions)
4) Last but not least, the rough surface of the sprayed concrete with a much higher evaporation area than a smooth surface.

Therefore, sprayed concrete should always be properly cured by means of an efficient curing agent. Such curing agents have to be free of organic solvents, have to have no negative influence on the bonding between two layers and have to be applied immediately after placing of the concrete.

As sprayed concrete, as a permanent structure, is used more frequently, long-term quality and durability performance requirements are becoming more important. Additional requirements are high bonding strength between the different concrete layers, high final density and strength to ensure freezing and thawing resistance as well as low permeability and water penetration.

Fulfilling these requirements will also provide good chemical resistance and water tightness and therefore provide a structure with a high degree of safety.

3. Internal Curing

Traditional plastic sheets, continuous wetting or film-forming materials are widely used to reduce the evaporation of water.

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All these methods are employed selectively and have their individual benefits and drawbacks. Wax suspensions, for instance, are easy to apply; however, the procedure for their removal is time-consuming and expensive. Continuous wetting of the surface is problematic due to the washout of surface particles and is often not applicable. All described methods normally require two time-consuming working operations, firstly the application and secondly the cleaning or removing of the curing agent from the sprayed concrete layer, if more than one layer or a coating has to be applied.

A much easier way to obtain a good quality of the concrete surface is the incorporation of an admixture into the concrete mixture at the batching plant; *i.e.*, the use of an internal curing agent [1]. Many different materials, such as waxes, latexes or other water-retaining materials and binders, may be used to achieve the desired properties. In the present case, there was used a combination of a high molecular weight water-soluble polyglycole for improving the water supply to the surface, combined with a hydrophobic paraffin wax emulsion to reduce the penetration of contaminants into the concrete. The required performance improvements were identical to the results that could be achieved with traditional techniques.

The performance of a curing agent is tested by checking the water-retaining effect with and without the curing agent by measuring the mass of water loss. The test is simple, but does not directly evaluate the improvements, which should be changed by this 'coating'. It is much more important to investigate the hydration of the cement minerals, the bonding to the substrate, the permeability and other relevant properties. The water-retaining effect is an indirect way of achieving a good concrete quality.

Table 1. *Results: Cores of Two Sprayed Concrete Layers*

Concrete Mixture	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Portland cement [kg/m^3]	425	425	425	425
Aggregate 0–8 [kg/m^3]	1 670	1 670	1 670	1 670
Plasticizer [% bmc]	1.2	1.2	1.2	1.2
Accelerator [% bmc]	5.0	5.0	5.0	5.0
Curing admixture [% bmc]			1.0	1.0
External curing		yes		
Concrete Properties				
Spread [cm]	48	48	45	41
Air content [%]	4.1	4.1	4.3	4.8
Compressive strength 28 d [MPa]	28	26	29	29
Bonding 10 d to substrate [MPa]	0.86	0.27	1.58	1.33
Bonding 28 d to substrate [MPa]	1.02	0.18	2.30	2.22

Table 2. *Results: Middle East* (by *LPM AG*, March 18, 1993)

Uncured sample		Internal curing	Internal curing	Internal curing
0.6 MPa	(Ø of 7)	2.5 MPa	3.3 MPa	1.8 MPa

Table 3. *Concrete Mixture*

Cement type CEM I 42.5	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Cement content [kg/m^3]	410	410	410	410	410	410
Sand and aggregate [mm]	0–8	0–8	0–8	0–8	0–8	0–8
Silica fume slurry 50% [% bmc]	10	10	10	10	5	5
Superplasticizer [% of bmc]	1.5	1.5	1.5	1.5	1.5	1.5
Hydration control [% of bmc]	0.2	0.2	0.2	0.2	0.2	0.2
Lignosulfonate [% bmc]	0.5	0.5	0.5	0.5	0.5	0.5
Air temperature [°]	17.5	17.5	17.5	17.5	18	18
Concrete temperature [°]	22.5	22.5	22.5	22.5	20.5	20.5
Spread [cm]	38.5	38.5	38.5	38.5	44.5	44.5
Air content [%]	3.2	3.2	3.2	3.2	4.6	4.6
Density [kg/dm^3]	2.341	2.341	2.341	2.341	2.297	2.297
W/C	0.49	0.49	0.49	0.49	0.47	0.47
Alkali-free accelerator [% of cement]	4.0	–	4.0	–	4.0	–
Accelerator [% of cement]	–	4.0	–	4.0	–	4.0
Concrete improver [kg]	–	–	–	–	5.0	5.0
Curing compound [kg/m^3]	–	–	0.128	0.128	–	–

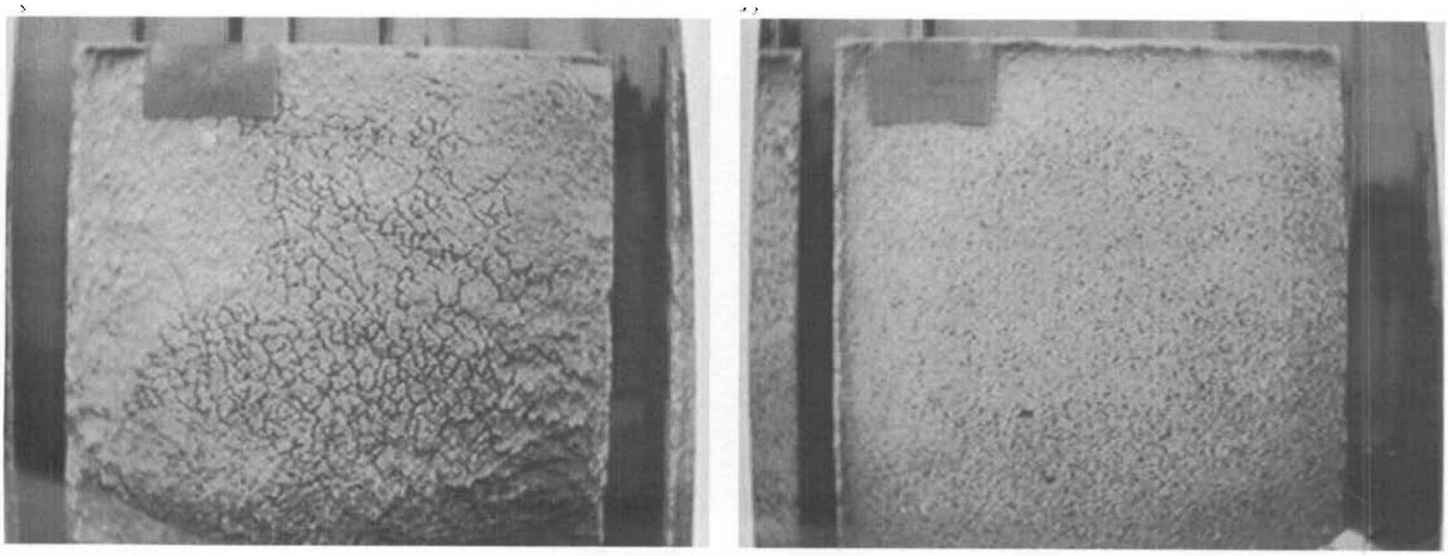

Fig. *Crack formation with and without the admixture* MEYCO® *TCC 735*; *a)* panel without any curing admixture, *b)* panel with the curing admixture

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Table 4. *Storage Conditions*

0–24 h	1–7 d	7–28 d
Spraying tunnel: 15–20° / 50% r.H.	Defined conditions: A: normal room (20°/65% r.H.) B: extreme conditions. (25°/65% r.H., 1.5–2 m/s air stream) C: under water	Norm conditions: 20°/65% r.H.

Table 5. *Water Penetration in mm* (according DIN 18551)

Concrete sample	Uncured	External curing	Internal curing
Accelerator1 / Storing A	10	13	20
Accelerator1 / Storing B	13	13	18
Accelerator2 / Storing A	29	46	47
Accelerator2 / Storing B	32	36	29

Table 6. *Water Absorption*

Concrete sample [absorption in g/cm²]	10 min	1 h	6 h	24 h	7 d
Accelerator1 / Storing A / uncured	0.06	0.14	0.26	0.40	0.58
Accelerator1 / Storing A / ext. curing	0.04	0.12	0.27	0.38	0.50
Accelerator1 / Storing A / int. curing	0.04	0.08	0.15	0.22	0.32
Accelerator1 / Storing B / uncured	0.05	0.12	0.25	0.44	0.69
Accelerator1 / Storing B / ext. curing	0.05	0.14	0.29	0.49	0.73
Accelerator1 / Storing B / int. curing	0.06	0.11	0.19	0.29	0.43
Accelerator2 / Storing A / uncured	0.07	0.12	0.23	0.34	0.53
Accelerator2 / Storing A / ext. curing	0.08	0.16	0.28	0.44	0.67
Accelerator2 / Storing A / int. curing	0.05	0.09	0.14	0.21	0.35
Accelerator2 / Storing B / uncured	0.07	0.14	0.26	0.43	0.70
Accelerator2 / Storing B / ext. curing	0.08	0.16	0.27	0.43	0.69
Accelerator2 / Storing B / int. curing	0.06	0.12	0.16	0.24	0.37

Table 7. *Strength Development*

Accelerator 1	Storage A External curing	Storage A Internal curing	Storage B External curing	Storage B Internal curing
Time after application	Compr. strength [MPa]	Compr. strength [MPa]	Compr. strength [MPa]	Compr. strength [MPa]
1.0 h	0.21	0.23	0.21	0.23
3.0 h	0.38	0.59	0.38	0.59
6.0 h	3.57	3.79	3.57	3.79
12.0 h	13.40	15.84	13.40	15.84 (18 h)
24.0 h	20.08	19.39 (18 h)	20.08	19.39
7 days	40.00	37.40	42.10	40.10
28 days	59.89	54.37	53.22	52.16

Accelerator 2	Storage A External curing	Storage A Internal curing	Storage B External curing	Storage B Internal curing
Time after application	Compr. strength [MPa]	Compr. strength [MPa]	Compr. strength [MPa]	Compr. strength [MPa]
1.0 h	0.38	0.38	0.38	0.38
3.0 h	0.92	0.92	0.92	0.92
6.0 h	10.29	13.38 (8 h)	11.76 (8h)	9.09
12.0 h	17.93	17.00 (18 h)	17.93	17.00 (18 h)
24.0 h	20.89	18.04	20.89	18.04
7 d	27.00	30.20	30.90	27.50
28 d	36.03	31.75	30.43	29.46

Here is, the development of a new system for a more efficient and economical 'curing' of wet-mix sprayed concrete, repair mortars as well as concrete. Concrete which includes this admixture shows a better hydration than an uncured reference concrete sample.

4. Comparison of Different Methods

Intensive laboratory and field tests and a master's degree project at the University of Innsbruck [2] have been carried out to verify the performance improvements of the new admixture. Results have shown that the bonding strength and the cracking behaviour are significantly improved.

The bonding strength between two sprayed concrete layers, for instance, is increased from 1 MPa (uncured) to more than 2.0 MPa for internally cured samples. Only 0.2–0.3 MPa could be measured on a normal prepared concrete surface with a paraffin-based external curing compound (Table 1).

The reduction of crack formation was demonstrated on special panels (*Fig.*).

Similar results to those achieved in the laboratory were also obtained at a job site in the Middle East (*Table 2*) and in mines in South Africa, where significantly improved bonding strengths and reduced crack formation were reported.

The quality improvement of concrete with either internal or external curing was tested by checking the surface of the concrete (carbonation, freezing and thawing resistance, crack formation, bonding and water tightness and absorption) and its bulk properties (early strength development, compressive strength, freezing resistance and shrinkage). The effect of the admixture on the surface and the bulk quality was checked by comparing samples cured with an ordinary curing agent based on a paraffin emulsion and mixtures with the special admixture type (*Table 3*). The test was carried out under different storage conditions (*Table 4*) and with two types of accelerators.

Surface Quality

All curing methods improve the surface quality of the sprayed concrete. A very important factor is also the type of accelerator used.

With respect to carbonation, no significant difference was found between the external cured concrete and the mixtures with the internal curing agent. All curing methods had a positive effect on the depth of carbonation. Differences between the individual methods were minor, but all

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clearly showed better results than did the uncured samples. In addition, the freezing and thawing resistance test did not show a significant difference. The results from the water penetration tests showed that all samples were tight and had a penetration depth of less than 50 mm. The absolute values (*Table 5*) showed the significant impact of the accelerator used. With respect to water absorption, the concrete admixture provided a better result than any other curing method (*Table 6*). After cleaning the concrete surface with high-pressure water, the bonding to the concrete was, in this case, neither influenced by the accelerator nor by the curing agent. A similar result was also achieved for the bonding between two concrete layers.

Concrete Quality

Bulk properties of concrete are also strongly influenced by the type of accelerator. The values obtained for freezing resistance are acceptable for all tested mixtures of the concrete and curing compounds. Overall, there was observed to be no difference in moduli of elasticity of concrete cured by the two curing methods.

A comparison of the externally cured concrete with the internally cured material showed that neither of the two methods has a negative influence on the strength development or the final compressive strength (*Table 7*).

The degree of shrinkage of the concrete was positively improved by the use of a curing system. Both methods showed a reduction of the drying shrinkage as compared to the plain concrete (*Table 8*) in the initial phase.

Table 8. *Shrinkage Behaviour* [μm/‰]

Accelerator 1		6 d	19 d	27 d	54 d
Storage A	Ext. curing	43/–0.17	101/–0.40	122/–0.49	162/–0.65
	Int. curing	39/–0.16	110/–0.44	121/–0.48	159/–0.64
Storage B	Ext. curing	78/–0.31	143/–0.57	143/–0.57	175/–0.70
	Int. curing	71/–0.28	130/–0.52	143/–0.57	175/–0.70
Accelerator 2		6 d	19 d	27 d	54 d
Storage A	Ext. curing	59/–0.23	125/–0.50	136/–0.54	185/–0.74
	Int. curing	55/–0.22	128/–0.51	135/–0.54	188/–0.75
Storage B	Ext. curing	85/–0.34	151/–0.60	147/–0.59	185/–0.74
	Int. curing	82/–0.33	147/–0.59	147/–0.59	183/–0.73

Table 9. *Thin Section Results TFB 23.02.96* (1 = excellent, 6 = bad)

Curing method	Position	Hydration	Capillarity	Bonding	Cracks	Quality
Accelerator 1	Storage A					
Ext. curing	Top	2.5	3.25	1.5	1.5	2.1
	Medium	1.5	3.25	2.0	1.5	2.0
	Bulk	1.5	3.5	2.25	1.5	2.1
Int. curing	Top	2.0	3.25	1.5	2.0	2.1
	Medium	1.5	3.25	1.5	2.5	2.1
	Bulk	1.5	3.25	1.5	2.0	2.0
Accelerator 1	Storage B					
Ext. curing	Top	2.0	3.25	2.0	2.5	2.4
	Medium	1.5	3.0	1.5	1.5	1.8
	Bulk	1.5	3.0	1.5	1.5	1.8
Int. curing	Top	1.5	3.5	2.25	2.25	2.3
	Medium	1.5	3.5	2.25	2.0	2.3
	Bulk	1.0	3.5	2.5	2.25	2.3
Accelerator 2	Storage A					
Ext. curing	Top	2.0	3.25	2.0	2.25	2.3
	Medium	1.5	3.25	2.0	1.5	2.0
	Bulk	1.5	3.25	2.25	1.5	2.1
Int. curing	Top	1.5	3.25	2.0	2.5	2.3
	Medium	1.5	3.5	2.0	2.0	2.2
	Bulk	1.5	3.25	2.0	1.5	2.0
Accelerator 2	Storage B					
Ext. curing	Top	2.0	3.5	2.75	2.25	2.6
	Medium	2.0	3.5	2.75	1.5	2.4
	Bulk	2.0	3.5	2.75	2.5	2.6
Int. curing	Top	2.0	3.5	2.5	2.5	2.6
	Medium	2.0	3.5	2.5	2.5	2.6
	Bulk	1.5	3.5	2.5	2.5	2.5

Petrographic Analysis

Additionally, thin sections of the samples from the surface (0–25 mm), the upper layer (85–110 mm) and the bulk material (185–210 mm) were prepared, and tests were carried out to investigate the degree of hydration, the capillarity of the cement paste, the bonding between cement paste and aggregate and the formation of micro-cracks.

A summary of the results is given in *Table 9*. The type of accelerator as well as the different concrete treatments applied (curing and storage) significantly affected the concrete microstructure.

The following observations may be made:

- The type of accelerator plays a major role
- The curing conditions have an impact on the quality of the concrete microstructure. The cured concrete samples (internally or externally) provide the best microstructure quality development
- The most homogeneous cement paste is obtained from the concrete mixed with the internal curing agent (*MEYCO*® TCC 735).

Summary

The tests of water absorption and shrinkage/cracking behaviour brought the clearest results for the positive influence of the different curing methods. The shrinkage values after seven days were taken as a basis for the comparison of the different methods. The investigation has shown that both curing methods improve several performance characteristics of concrete. The concrete improver (*MEYCO*® TCC 735) showed similar results to those obtained with an simple paraffin-based external curing agent.

It can be concluded that the use of such a concrete improver is a valuable and economical alternative to the traditional curing methods.

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[1] R.K. Dhir, P.C. Hewlett, J.S. Lotta, T.D. Dyer, *Materials and Structure* **1994**, *27*, 606.
[2] W. Oberdörfer, Master's degree project, University of Innsbruck, 06/96.