Concrete Beton

The Official Journal of
The Concrete Society of Southern Africa

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CONCRETE SOCIETY OF SOUTHERN AFRICA

CONCRETE SOCIETY HEAD OFFICE HAS RELOCATED

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CONCRETE SOCIETY OF SOUTHERN AFRICA

Vision

To be the most relevant forum for all who have an interest in concrete and to promote the concrete related services of the Society's members.

Mission Statement

To promote excellence and innovation in the use of concrete and to provide a forum for networking and for the sharing of knowledge and information on concrete.

President's Message

By the time that many of you receive this copy of Concrete Beton the Christmas Holidays will be a distant memory. We at council hope that you had a well deserved break and are eager to tackle 2008 with new vigor. I wish you all well for the New Year and I think that 2008 is going to prove to be very challenging for all of us.

One of the biggest challenges that our industry will face this year is the shortage of electricity. This will no doubt affect all of us and the way that we conduct our business. However, this could have a significant silver lining for the construction industry. Eskom has recently announced that it plans to spend R390 billion over the next five years on improving the generation capacity. This I am sure can only bode well for us. If we include the planned spending of the government and the respective agencies on infrastructure development, there is almost no sign of a slow down in the construction industry for at least the next 7 years. The share price of listed construction companies also confirms this trend.

As this will unfortunately be my last message that I am writing, I would like to take this opportunity to mention some of the high points during my term as president of the Concrete Society of Southern Africa.

I think the highlight of my term was the 2007 Fulton Awards. This was truly a remarkable experience which I will never forget. We revised the event to be a weekend and not simply a gala dinner. This proved to be extremely well received and it is a format that we will continue to follow. During the Cape Town Fulton review I had the privilege to bestow an Honorary Membership on Prof Mark Alexander. This is a privilege which I firmly believe that he truly deserves for his dedication to the industry.

In October of last year we hosted a national seminar on Concrete Durability. This was a follow up to a similar event that we hosted in 2001. We had in excess of 500 people attending the various functions around the country. This truly highlights the commitment of industry to produce good quality concrete. I would like to thank all the speakers who gave up their time to travel around the country. I would also like to thank all the sponsors and especially Holcim who made this event possible.

There were numerous other events which took place over the last 2 years which proved to be very successful. All in all, over 7000 people attended our events during that time period. This shows the commitment of all our members to the society.

As most of you know Irma Dyssel, our administrator, resigned at the end of last year. This was a sad moment for me as she had put in a lot of effort in making the society a success. Not only was she our administrator but she became a friend to many of us and she will be missed. However we have to go on.

We are in a bit of transition phase with Natalie Van Wulven assisting in the day to day running of the society. We are planning a number of expansion projects this year. I think the biggest one is that we will be appointing a full time director of the society as well as setting up a larger office. This can only improve our sevice and help the society grow to even greater heights. In due course we will elaborate more on the planned expansion program.

Finally I would like to congratulate Francois Bain who is the incoming president, who will take over from me in March at our AGM. Under the leadership of Francois I am confident that the society will continue to grow. However Francois can not do this on his own. He does need the support of a strong council and regional branch committees. This is an area we find it difficult to get help. Please, I urge you to consider joining one of the branch committees and nominate someone to stand as a councilor. You will find it extremely rewarding to give something back to the industry. If you want more information about what is involved, please do not hesitate to contact your local branch chairman or you are more than welcome to contact myself or Francois.

Yours truly,

President
Dave Miles

The Concrete Society of Southern Africa has now been registered as a voluntary association of the Engineering Council of South Africa (ECSA). Our members will derive great benefit from this development. The first of which, is that members will be able to claim CPD (Continued Professional Development) points for attending technical Society events. A reviewing committee will evaluate all technical talks, seminars and conferences before accrediting and allocating points to an event. This practice adheres to the principles of ECSA.

We trust that this will encourage profes-sionals to become members of the Concrete Society.

For more information, please contact the office or visit the website at www.concretesociety.co.za

Inland Branch

Chairman's Award 2007

The winner of the 2007 Inland Branch Chairman's Award was announced at a special breakfast function held on Wednesday 7th November at the Protea Balalaika Hotel, Sandown. This year's recipient is Sebasti Badenhorst, from Afrisam (Pty) Ltd., (Holcim) for "her contribution to the developments in the concrete durability issue".

"Sebasti climbed in with passion and was the largest reason for the changes and latest developments with regards to durability design and testing. She was the driving force behind our workshops and kept the focus on the end goal".

This year's winner, Sebasti Badenhorst with Inland Branch Chairman, Trevor Sawyer In announcing the winner, Trevor Sawyer, Chairman of the Inland Branch, referred to the prime nomination submitted by Hanlie Turner of the Cement and Concrete Institute, which read as follows:
"Sebasti has proven herself as a dynamic presence in the cement and concrete industry over a number of years. This is evident in her numerous presentations at conferences, seminars and workshops, and in particular the technical workshops of the Concrete Society. The most recent of these focused on the new guide to prop removal times for SA National Standards and, during the past month, as part of the team presenting the durability workshops around the country.

Her sound technical knowledge, both as a registered PrEng and as a cement and concrete specialist, coupled with her enthusiasm for, and commitment to the industry, has gained her the respect of all those with whom she comes into contact. Sebasti has made a very worthwhile contribution to the concrete industry and to the good name of concrete itself.

Sebasti keeps herself informed of the latest concrete technology and is a regular visitor to the C&CI Information Centre, where she carries out in-depth research for all the projects she works on. She is the epitome of a balanced, modern day, professional person who conducts herself with credibility, poise and authority at all times".

Congratulations to Sebasti Badenhorst!
from Trevor Swayer - Inland Chairman

In support of this nomination, Zoe Perks, Vice-Chair of the Inland Branch, submitted these words to the Chairman:
"*Sebasti Badenhorst, through her unrelentless efforts over the past 2 - 3 years, and her contribution in preceding years towards the durability of concrete, should be recognised for her efforts. The Concrete Society Inland Branch Chairman's Award is the relevant platform to recognise the huge progress that has been made over this sizeable project, incorporating the design and performance of concrete using extensive materials available throughout South Africa.*

Sebasti has taken this research into various exposure conditions to validate the performance in their respective environments in an attempt to authenticate previous research that has been undertaken over the last decade and, more importantly, substantiate the various categories of exposure and relevance in concrete design. She has brought back international trends to South Africa which have challenged the South African perspective on durability in the construction environment, and which is being demonstrated in new specifications introduced on this topic.

In an effort to better understand durable concrete in aggressive and neutral environments, Sebasti has developed a tool that will assist the design profession to make better informed engineering judgement and decisions on the correct selection of materials and proportioning to optimise the life of the concrete".

This peer review was supplied by Prof. Mark Alexander of the University of Cape Town:
"I would like to strongly support the Chairman's Award to Sebasti and base my motivation on the following:

1. She has brought both intellectual and practical weight and strength to the ongoing development of concrete quality in general, and concrete durability in particular. Her efforts within Holcim to put together a comprehensive concrete package to assist designers is meritorious.

2. She has picked up quickly and comprehensively on new major trends in concrete technology, both materials and design, and has kept thoroughly up to date with both national and international trends. She has used this knowledge to progress the field within her own industry, so that her company is now at the forefront of these developments.

3. Sebasti has given the new developments within South Africa the "weight" needed for industry to take them seriously. She has engaged key players (both consultants and contractors) in such a way as to take them with her and convince them of the need to move forward. Her opinions and inputs are taken seriously in view of the contribution that she has made.

4. She has undertaken a substantial amount of innovative and vital practical research that will be of enormous benefit to the industry and the country".

Inland Branch

Chairman's Breakfast and Special Presentation

The Inland Branch Chairman, Trevor Sawyer hosted a breakfast on 7th November 2007 for 70 members and their guests at the Protea Balalaika Hotel in Sandown, near Johannesburg. The highlight of the event was a special presentation by Pierre Blaauw, SAFCEC's Economist and Northern Branch Manager. It was a riveting talk, which would have brought a smile to even the most pessimistic person attending, with details of the current activity in the civil engineering sector and the upcoming spend by government on upgrading South Africa's infrastructure.

The presentation included:

- Overview of the history of infrastructural activity
- Planned government and private sector investment
- Expected market growth vs. Industry capacity
- Capacity constraints
- Transformation in the construction industry as a whole

In conclusion, Pierre expressed the view that while the future presented many wonderful opportunities for the industry a change of mindset was needed as there are exceedingly more difficult demands in a growth situation than there are in contractions. However, he stressed - "FAILURE TO PERFORM AND DELIVER IS NOT AN OPTION!"

Zoe Perks, Vice-Chair Inland branch, welcomes guests to the breakfast

Chairman of the Inland Branch, Trevor Sawyer, introduces the guest speaker, Pierre Blaauw.

Pierre Blaauw, describing the challenges ahead for the civil engineering sector

Some of the 70 guests at the Chairman's breakfast

CONCRETE SOCIETY
OF SOUTHERN AFRICA

FULTON Awards 2007

Anchor Sponsor
cement & concrete institute

Commendation - Aesthetic Appeal

L'ormarins - Exposed Aggregate Concrete Roads

L'Ormarins is situated in the Franschoek valley well known for its French Huguenot heritage, wine farms and restaurants which make it a premium destination for local and foreign tourists. The farm was granted to its first owner in 1694 and since 1969 it has been owned by the Rupert family. The present owner, Mr. Johann Rupert, has embarked on an extensive renovation and development program in the past two years, to create an icon estate on par with the best in the world.

The contract could be broken up into three definitive areas, being the wine cellars, horse paddocks with stables and a vintage car museum. These buildings are spread throughout the estate and are linked by several kilometres of service roads, the sub-contract that forms this entry.

Wine cellars

New construction involved a state of the art gravity fed red and white wine cellar, with an underground maturation area, an Armagnac distillery and conference and tasting facilities. The old cellar was renovated as well as the outbuildings and homestead.

Stables

To compliment the newly formed paddocks where racehorses are bread, several stables and quarantine facilities were built with stores and workshops for feeds and farming equipment.

Franschoek Motor Museum

A vast collection of vintage cars and more modern collectables were moved to the estate, where facilities had to be constructed to permanently display the cars for public viewing, a workshop to service and rebuild these cars and stores for stock and spares.

Roads and parking areas

The brief to the Architect and Engineer were to find a material and finish to compliment the natural environment, but also to be of superior quality to carry construction traffic for two years and thereafter to serve as the link for farm vehicles and tourism traffic. Low maintenance during its service life was essential as well as a good riding quality.

Concrete was chosen for its superior properties, like its ability to spread loads without the need for thick pavement layers, which would have been impractical for the confined tree lined roads. A normal white concrete finish would have looked out of place in this environment and a wider search was launched to find a more aesthetically pleasing finish to compliment the spectacular backdrop of green paddocks, trees, vines and the majestic Franschoek Mountains.

Exposed aggregate concrete

A finish that is popular on walkways and roads of up market golf estates is exposed aggregate and a brown aggregate from Table Mountain. Standstone is mostly used for this purpose in the Western Cape. This aggregate is crushed from alluvial deposits of river stone which is available in abundance on the Western Cape wine farms. However, the commercially available aggregate from a neighbouring farm was too soft and would not have stood up to the traffic envisaged. A Quartzitic Standstone aggregate from Worcester, named Hex River Stone was chosen. It is of similar colour to the local Table Mountain Sandstone but is much harder and therefore more resistant to abrasion. This aggregate is collected from alluvial standstone deposits by

a front end loader and crushed to size. To further enhance the surface appearance, a sandstone pigmented concrete was used. Coloured concrete forms part of Lafarge's Artevia range of decorative concrete.

Unlike normal exposed aggregate finish where a single size aggregate is used and a deep and uniform exposure is formed. It was decided to use a 13mm blended aggregate mix, with a very mild exposure. This proved to be the aesthetic answer, for riding quality and abrasive resistance.

Construction methods

Whereas normal exposed aggregate finishes are used on a fairly small scale, or else smaller single pours are added together, the extent of this project, 30 000 m², excluded these practices.
Road widths of 4 to 5.5 meters had to be constructed with no access from the sides and to finish the project within the four months construction period, it was opted to go for longer continuous pours of 100 – 200 meters per day, with panels saw cutted every four to five meters. This presented its own unique set of problems which had to be overcome or prevented.

The period of construction was from November to March which is the hottest in the Western Cape, with occasional rain and of course the menace of all concrete contractors, the dry South Eastern Winds. The road stretch from areas of full shade, partial shade and fully exposed, all in one day's pour and methods had to be found to contain evaporation from the surface, plastic shrinkage, drying shrinkage and still achieve a fairly uniform surface finish. These methods included combinations of spray-on curing compounds and retarders and clear plastic coverings.

Continuous concrete roads are mostly constructed using mechanical slipform pavers, but the confined areas made this unsuitable, but ideal for a more labour intensive approach. A team consisting of 14 to 16 labourers was used with a core of experienced concrete placers and finishers. This core shared many years of concrete practice with varied skills as required, but exposed finishing was not done before. Through trial and error however, the right recipe was developed. The balance of the team, was made up of more recent employees with less experience, whom were trained on the project and fully incorporated in the company since then. The team's ability to place and finish large volumes of concrete proved crucial in handling the concrete under the varied conditions as experienced.

The concrete supplied by Lafarge forms part of their Artevia range of decorative concrete's. It was designed with a strength of 30 Mpa, containing a CEM 1 42.5 cement, aggregates comprising of 13mm Hex River Quartzitic Standstone and washed river sand, and a UV stable Bayer's standstone pigment supplied by Chryso. Concrete was batched at the Lafarge Ready Mix Batch Plant in Paarl and transported 20 km to the site in mixer trucks. Care had to be taken to ensure consistent batching and evenly spaced deliveries, in order to minimize the occurrence of cold joints and the possibility of texture and colour variances.

The layer works consisted of 125 mm G3 Base Course compacted to 98% Mod.aashto density, on 150mm G5 Subbase compacted to 95%, on 150mm G7 Selected Subgrade compacted to 93% on 300mm undisturbed G9 Road Bed.

Concrete thickness varied from 160mm for the majority of the contract, to special sections being 180mm for handling heavier traffic. Continuous un-reinforced sections of 100 – 200 meters were cast, 4,5 to 5.5 meters wide with sawcut joints spaced at 4 to 4.5 meter centres. The concrete was finished off with a conventional precast edging on one side and a rainwater channel on the other.

Water management

Being a farm in a very high rainfall area, special care had to be taken to manage surface water. This surface water is from the run off from the paddocks and vineyards adjacent to the roads, but the roads in itself also created a large catchment area with a very fast run off. The roads were constructed with a single crossfall of 2.5% to the rainwater

channels which were further complimented with open channels, built from riverstone, to direct the water to the existing rivers and catchment dams for re-utilisation.

Landscaping

On completion of the roads, extensive landscaping took place, which included the planting of numerous tall trees and thousands of shrubs and plants to compliment the already beautiful natural environment. Looking down the lanes one is presented with a picturesque vista which can only improve with age as the trees grow and the shrubs mature. The meticulous attention to detail and maintenance of the facilities will also ensure a longlasting asset.

Conclusion

As the facilities are being completed and the parts fit together, the coloured exposed concrete roads, not only serve as a link between them, but compliment the architecture and natural environment. The choice of finish is unique and it provides a satisfaction that it was the correct choice and no other material could have served the purpose better.

St George's Reservoir, in Port Elizabeth for which Chryso's Lanko concrete repair products were successfully used in a large-scaled refurbishment project.

PRAISE FOR CHRYSO REPAIR PRODUCTS' PERFORMANCE AT P.E. RESERVOIR

The consulting engineers for the rehabilitation of the St George's Reservoir in Port Elizabeth have expressed extreme satisfaction at the performance of Chryso's Lanko concrete repair products which were specified for the project.

The R6m refurbishment of the reservoir, completed in 2006, was commissioned by the Nelson Mandela Metropolitan Municipality and carried out by PAB Contracts of Port Elizabeth. The project involved the repair and renovation of the entire structure, including subterranean concrete columns, floors, surface decks, promenades and balustrades.

Chryso's Lanko concrete repair products were specified by consulting engineers, Afri-Coast, after Afri-Coast had completed extensive laboratory testing, aided by input from Chryso's Eastern Cape regional manager, Malcolm Tinley.

In a recent letter to Chryso, Mike Hammond, director of Afri-Coast, says that after 15 months of use, internal inspection revealed that the Lanko systems had performed "extremely well".

Hammond says cracks in the roof – which had to be waterproofed to prevent surface water contamination of the potable water in the reservoir – were sealed using bandages of Lanko 228 with Ecofelt reinforcement. The construction joints in the floor were sealed with a 'putty' made from Lanko 228 mixed with fine washed sand which provided a strong, but still flexible sealant grout. The porous floor was sealed with a thinned coat of Lanko 228 and then waterproofed by over-coating with Lanko 228 applied to specification. "This has waterproofed the floor extremely well while leaving a surface that can be brush-cleaned and hosed during reservoir maintenance. All in all, the use of Lanko 228 has resulted in a very satisfactory repair in the challenging conditions experienced on this project," Hammond added.

The more than a century-old water reservoir in St George's Park is fed by a Cape Road service dam, part of the Sand-Palmiet-Bulk Rivers Water Scheme, established in 1903.

For more information: Hannes Engelbrecht, tel 011-395 9700, www.chryso.com.

Evaluation of Plastic Shrinkage Cracking of Self-Consolidating Concrete

by Philippe Turcry and Ahmed Loukili

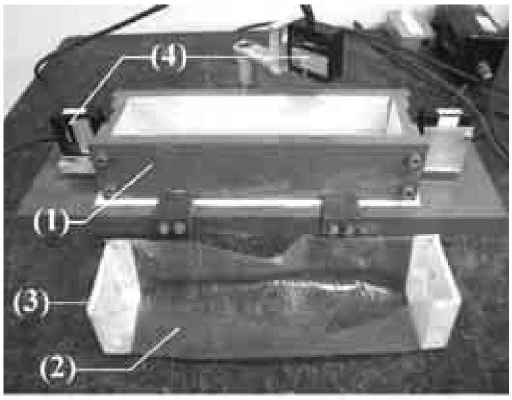
This paper is published courtesy of ACI Materials Journal July/August 2006

This paper describes an experimental investigation of plastic shrinkage cracking of self-consolidating concrete (SCC). Five SCC mixtures with compressive strengths ranging from 30 to 50 MPa were compared to five ordinary concrete (OC) mixtures. Free and restrained plastic shrinkage tests were performed in drying conditions. Depending on evaporation rate, plastic shrinkage occurs before setting (wind), or before and during setting (no-wind). In the presence of wind, SCC and OC mixtures have almost the same plastic shrinkage. Moreover, restrained shrinkage tests reveal that cracks of SCC tend to be less wide than cracks of OC. Nevertheless, when evaporation rate is low, SCC mixtures exhibit a higher plastic shrinkage than OC mixtures, due to their lack of bleeding. Consequently, SCC could be more vulnerable to shrinkage cracking, especially during setting. Thus, curing is recommended to protect SCC against evaporation at the fresh state.

***Keywords**: concrete; plastic shrinkage; self-consolidating concrete; shrinkage cracking.*

INTRODUCTION

Self-consolidating concrete (SCC) is a fluid concrete cast without vibration. This construction material is increasingly being employed in flat structures, such as slabs or industrial floors, due to its self-leveling ability. This type of construction, however, is vulnerable to plastic shrinkage cracking, especially when concrete is exposed to hot and/or windy conditions.[1] Plastic shrinkage is the contraction that occurs in fresh concrete before and during setting. Plastic shrinkage is often explained by the presence of water menisci on the concrete surface, when the evaporation rate is greater than the bleeding rate.[2] Water menisci generate a negative capillary pressure that tends to pull the solid particles together and consequently causes shrinkage. Capillary pressure can also be created by self-desiccation, inside concrete, due to cement hydration.[3] In most structures, plastic shrinkage is restrained. As a result, tensile stresses develop and concrete may crack if stresses exceed cracking capacity. The risk of plastic shrinkage cracking is high for concrete with high binder content (cement and filler content) and low waterbinder ratio (*w/b*). In this paper, ordinary concrete (OC) means vibrated concrete designed with the same materials and having the same compressive strength as the associated SCC mixture. A literature review reveals that SCC mixtures usually contain higher binder content than ordinary concrete mixtures.[4,5] Normally, binder content of SCC ranges from 450 to 650 kg/m^3, while binder content of OC ranges from 280 to 400 kg/m^3. In the same way, the *w/b* of SCC is usually lower than the *w/b* of OC. As a result, some SCC is suspected to be more sensitive to early-age cracking.[6] Recent studies seem to confirm this claim.[7,8] Indeed, some SCC mixtures were found to have greater plastic shrinkage than some OC mixtures.



1: 70x70x280 mm mold; 2: plastic sheet
3: reflecting plate; 4: laser sensors

Fig. 1 - Plastic shrinkage measurement device

RESEARCH SIGNIFICANCE

SCC is often used in horizontal applications, structures that are vulnerable to plastic shrinkage cracking. SCC is a priori more susceptible to crack at the fresh state than OC because of higher binder content and lower *w/b*. This study aims at verifying this hypothesis. Five SCC mixtures were investigated and compared to OC mixtures designed with the same constituents and with the same compressive strength. Plastic shrinkage of each composition was measured in various environmental conditions. Cracking was also studied with a restrained shrinkage test.

EXPERIMENTAL PROGRAM

The test procedures and materials used in the study are described in the following.

Free plastic shrinkage test

As shown in Fig. 1, the specimen setup for plastic shrinkage measurement consists of two elements: 1) a steel mold of inner size 70 x 70 x 280 mm, whose internal sides are covered by Teflon; and 2) an envelope formed by two PVC plates, called reflecting plates, attached to a plastic sheet. Concrete is cast in this envelope positioned in the mold. Talc is powdered between the plastic sheet and the mold to limit friction between concrete specimen and mold. When the specimen shrinks, for example because of drying, the reflecting plates are dragged along by the concrete. Two

laser sensors are used to measure the plates' displacement, from which the horizontal deformation is calculated, that is, plastic shrinkage (Fig. 2). A third laser sensor above the specimen is used to measure the displacement of a thin Teflon 10 x 10 mm square plate, which is placed on the concrete surface. Because Teflon is denser than water but less dense than concrete, the thin plate stays on the concrete top layer in spite of any bleeding. From this measurement, the vertical deformation, that is, settlement, is deduced. The relative precision of measured deformations is ±5%. During testing, evaporation is measured in terms of weight loss of a cylindrical sample 70 mm high with a 100 mm diameter. The main driving force of plastic shrinkage is a negative pore water pressure, called capillary pressure, generated by menisci at the surface of concrete (due to desiccation) or inside (due to self-desiccation). Thus, the knowledge of capillary pressure development is important for the comprehension of shrinkage phenomena.[2,9] For this reason, the test setup described in Fig. 3 was developed. Two porous ceramic cups were placed horizontally in a mold 70 mm high with a 100 mm diameter, located at 10 and 35 mm below the concrete top surface. The ceramic cups were connected to pressure sensors through thin water pipes.
Tests started 20 minutes after adding water in the mixing process. All data (plastic shrinkage, settlement, temperature, weight, and capillary pressure) was logged on a computer at 5-minute intervals for a period of 24 hours.

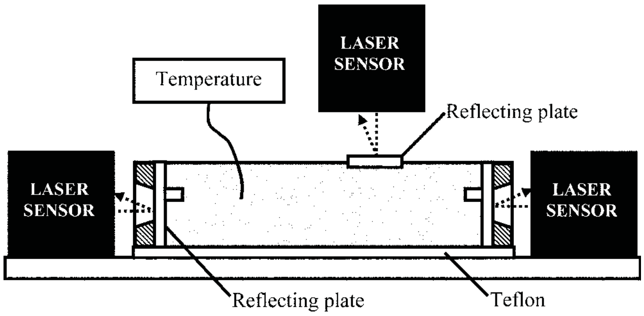


Fig. 2 - Schematic section view of plastic shrinkage measurement

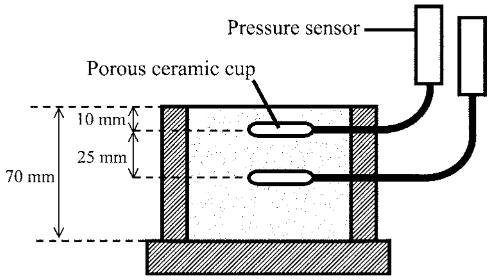


Fig. 3 - Schematic section view of capillary pressure measurement

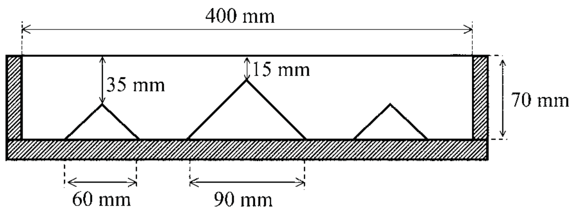


Fig. 4 - Schematic section view of restrained shrinkage device

Restrained plastic shrinkage test

The restrained plastic shrinkage test used was derived from the procedure followed by Soroushian and Ravanbakhsh[10] The device consists of a 70 x 200 x 400 mm mold with three stress risers used to provide restraint and promote cracking (Fig. 4). Cracking is created above the central riser through the depth and across the width of the slab. It is worth noting that the plastic shrinkage test depends on the specimen geometry and the drying surface. Several tests on this device showed that only concrete having a deformation larger than 2200 μm/m can crack. During testing, the time at which the concrete surface starts cracking is recorded. Six hours after concrete placement, maximum crack width is measured with a hand-held microscope (accuracy ±50 μm).

Environmental conditions of tests

Tests are performed in an air-conditioned room with a temperature of 20 ± 1 °C and a relative humidity of 50 ± 5%.
Free plastic shrinkage tests can be performed in the following environmental conditions:
1) Sealed condition—The top surface of the specimen is covered by a plastic sheet to prevent drying. Measured shrinkage is an autogenous shrinkage, that is, only caused by cement hydration.
2) No-wind condition—The top surface is allowed to dry in the room. Shrinkage is caused by both drying and hydration.
3) Wind condition—A fan producing a wind speed of 5 m/s is placed 40 mm from the specimen to accelerate evaporation rate.

Restrained plastic shrinkage tests are done in the wind condition. In fact, this kind of passive device can produce cracking only in severe drying conditions, that is to say, when wind is applied.

Materials and concrete mixtures

Five SCC mixtures were investigated. Table 1 summarizes the mixture proportions, the fresh concrete properties, and the compressive strength for the various mixtures. Produced in concrete plants in France, these mixtures are made of different constituents (cement types, nature of aggregates) and have various 28-day compressive strengths (ranging from 25 to 50 MPa). An OC composition was derived from each SCC composition (Table 1), that is, designed with the same constituents. The specifications for OC were the following: approximately the same 28-day strength as the associated SCC composition, and a slump between 100 and 150 mm. The materials of each SCC and OC pair are described in Table 2. It should be noted that all of SCC mixtures were made with limestone filler.

RESULTS AND DISCUSSION

Origin of plastic shrinkage

Plastic shrinkage can be caused by both water evaporation

Table 1—Proportions and properties of studied mixtures

	SCC and OC pair name									
	C1		C2		C3		C4		C5	
	SCC1	OC1	SCC2	OC2	SCC3	OC3	SCC4	OC4	SCC5	OC5
Gravels, kg/m^3	792	1060	825	1100	742	1030	790	1070	906	990
Sand, kg/m^3	811	720	950	845	857	760	860	780	768	810
Cement, kg/m^3	315	350	330	282	350	350	350	360	292	300
Filler, kg/m^3	160	0	110	30	130	0	150	0	204	50
HRWRA, kg/m^3	3.75	0.35	4	1.18	6	1.7	5.4	1	5.4	1.5
VEA, kg/m^3	0.5	0	0	0	0.5	0	3.4	0	0.5	0
Water, kg/m^3	190	180	180	170	195	175	187	170	160	170
w/c	0.61	0.51	0.55	0.60	0.57	0.50	0.53	0.47	0.54	0.57
w/b	0.41	0.51	0.41	0.54	0.41	0.50	0.37	0.47	0.32	0.49
V_{paste}, L/m^3	352	291	326	271	357	286	354	284	332	285
Slump, mm	—	150	—	140	—	150	—	100	—	110
Slump flow, mm	680	—	680	—	700	—	680	—	760	—
Laitance, %	5	—	8	—	6	—	15	—	5	—
f_{c28d}, MPa	30	30	40	37	42	41	48	53	47	45

Notes: HRWRA = high-range water-reducing admixture; VEA = viscosity-enhancing agent; b = binder (cement + filler); V_{paste} = volume of paste. Percentage of laitance is result of screen stability test proposed by AFGC.[11] Segregation resistance decreases when percentage of laitance increases. Below 15% of laitance, segregation resistance is considered good.

Table 2—Constituents of concrete mixtures

	SCC and OC pair name				
	C1	C2	C3	C4	C5
Gravel	6.3/20 mm rolled gravel	6/10 mm crushed gravel	6.3/20 mm rolled gravel	4/12.5 mm rolled gravel	3/8 mm rolled gravel
Sand	0/4 mm river sand	0/4 mm sea sand	0/4 mm river sand	0/3 mm sea sand	0/4 mm river sand
Cement	CEM2 32.5	CEM2 42.5	CEM1 52.5	CEM1 52.5	CEM1 52.5
Filler	Limestone	Limestone	Limestone	Limestone	Limestone
HRWRA	Polycarboxylate	Polycarboxylate	Polycarboxylate	Polycarboxylate	Polycarboxylate
VEA	Organic polymer	—	Organic polymer	Nano silica	Organic polymer

Notes: HRWRA = high-range water-reducing admixture; and VEA = viscosity-enhancing agent.

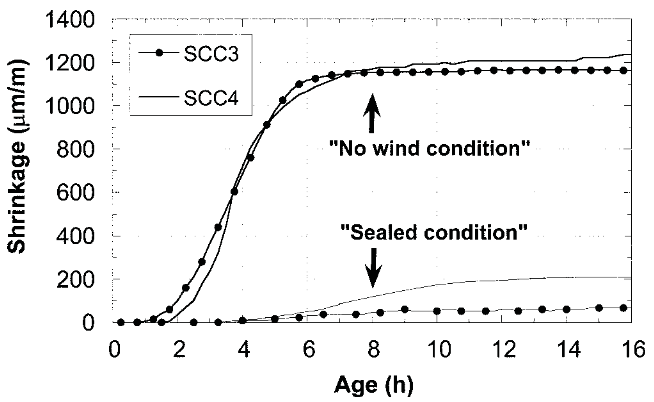


Fig. 5 - Plastic shrinkage versus time for Mixtures SCC3 and SCC4

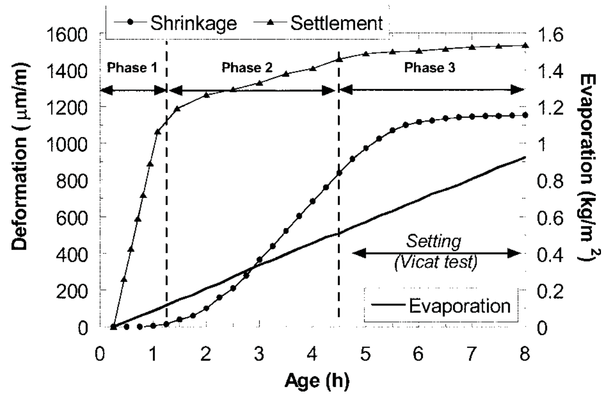


Fig. 6 - Development of plastic shrinkage, settlement, and evaporation for no-wind condition (Mixture SCC3)

and cement hydration. In the case of low water-cement ratio (w/c) concrete, such as high-performance concrete (HPC), the autogenous part of shrinkage is important. In the case of SCC, one can assume that plastic shrinkage is mainly a drying contraction when the w/c is high (more than 0.5). To verify this hypothesis, two SCC mixtures (SCC3 and SCC4) were tested in the sealed condition (Fig. 5). At the age of 16 hours, autogenous shrinkage represents less than 15% of total shrinkage in the case of Mixture SCC4 and less than 5% of the total shrinkage of Mixture SCC3. As a result, one could conclude that evaporation is the main cause of plastic shrinkage of our mixtures.

Interpretation of plastic shrinkage curves

Before comparing SCC and OC behaviors, one should first understand basic shrinkage phenomena. The interpretation

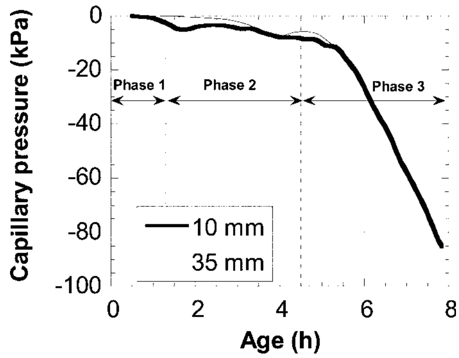


Fig. 7 - Capillary pressure at 10 and 35mm depth for nowind condition (Mixture SCC3)

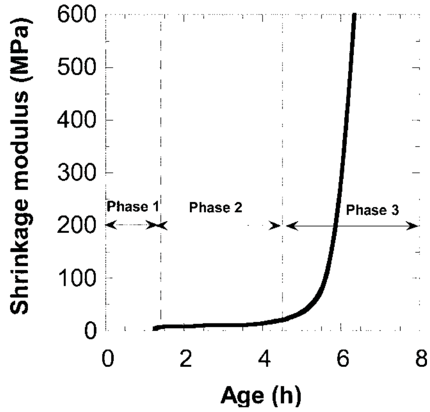


Fig. 8 - Shrinkage modulus for no-wind condition (Mixture SCC3)

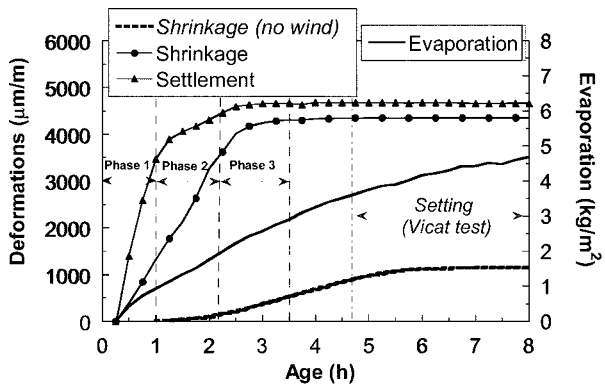


Fig. 9 - Plastic shrinkage, settlement, and evaporation for wind condition and plastic shrinkage for no-wind condition (Mixture SCC3)

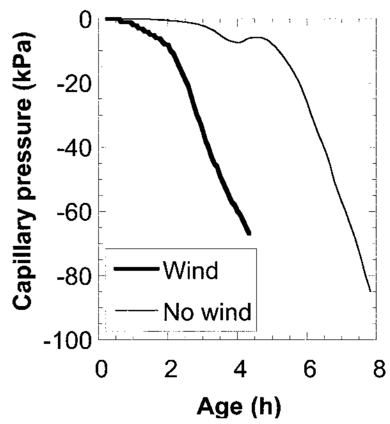


Fig. 10—Capillary pressure evolution in both no-wind and wind conditions (Mixture SCC3).

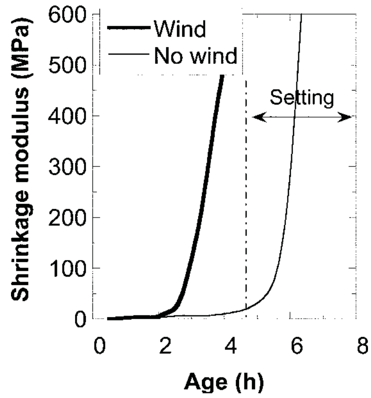


Fig. 11—Shrinkage modulus for both no-wind and wind conditions (Mixture SCC3)

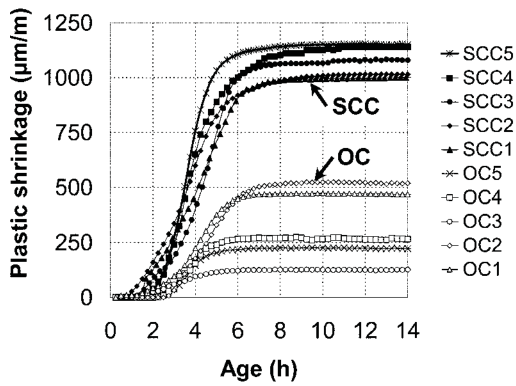


Fig. 12—Plastic shrinkage of SCC and OC mixtures in no-wind condition.

of curves derived from shrinkage measurements is also important. Figure 6 presents typical shrinkage, settlement, and evaporation curves for Mixture SCC3 for the no-wind condition. It can be observed that evaporation rate is almost constant during shrinkage development (approximately 0.1 kg/m²/h). Therefore, any change in deformation rate is only caused by changes in concrete microstructure. Three phases can be distinguished. This agrees with results in the literature.[12-15]

Phase 1—A high settlement rate is recorded. This deformation results from a chemical shrinkage because the absolute volume of hydration products is less than the total volume of the reactants. Settlement is also the effect of gravity. This consolidation leads to an increase of packing density of concrete, which forces water to percolate to the top surface. As a result, bleeding may occur during this phase, and settlement rate data can be used to assess bleeding rate. When settlement rate decreases (at the age of 1 hour), the sample begins to support its own weight. During this phase, no shrinkage can be observed.

Phase 2—Volumetric contraction is transmitted horizontally little by little. The beginning of shrinkage first indicates that

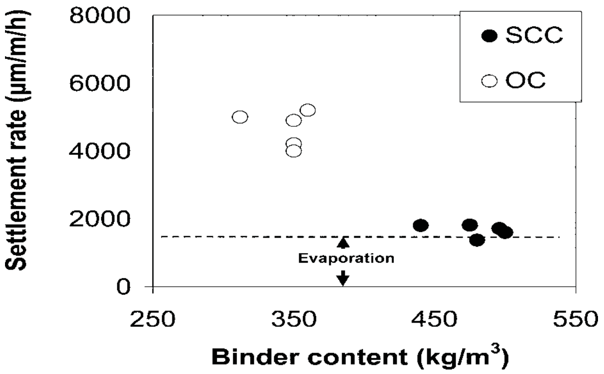


Fig. 13—Initial settlement rate versus powder content of SCC and OC mixtures for no-wind condition.

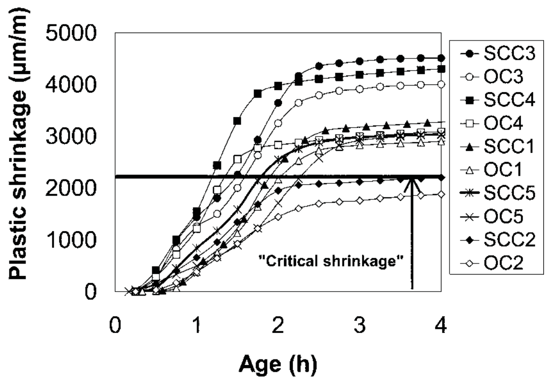


Fig. 16—Plastic shrinkage of SCC and OC mixtures in wind conditions ("critical shrinkage" indicates approximate shrinkage value beyond which specimen cracks)

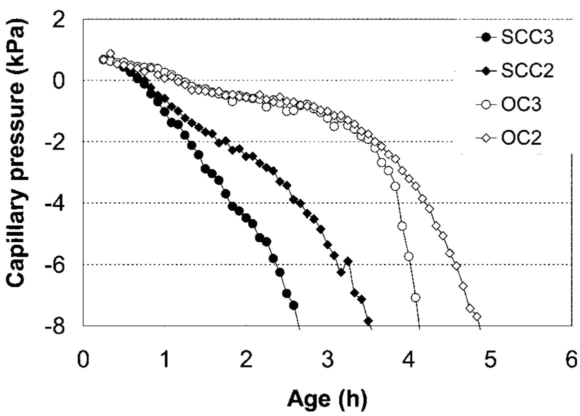


Fig. 14—Capillary pressure of SCC and OC mixtures in no-wind condition.

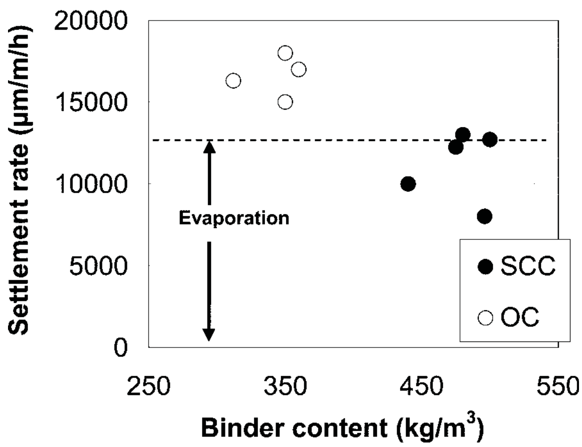


Fig. 17—Initial settlement rate versus powder content of SCC and OC mixtures of wind condition.

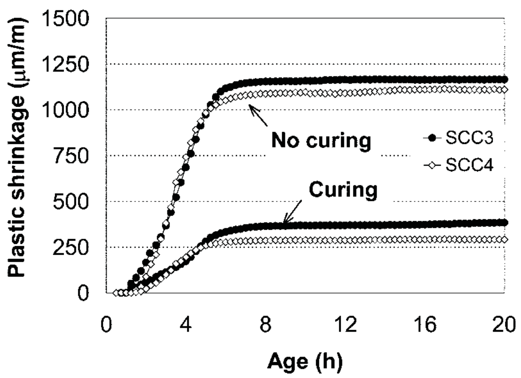


Fig. 15—Plastic shrinkage with and without curing in no-wind condition (Mixtures SCC3 and SCC4)

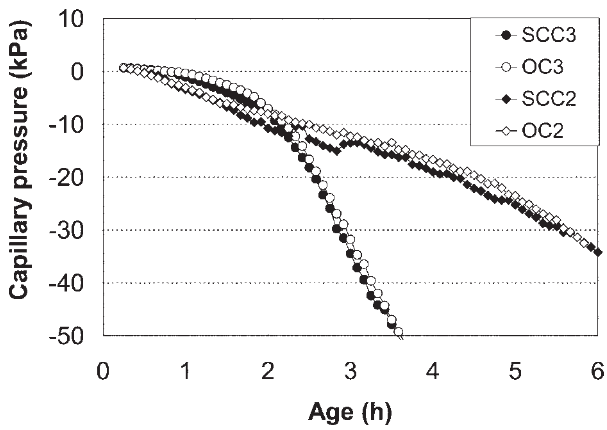


Fig. 18—Capillary pressure of SCC and OC mixtures in wind condition.

pore water pressure is decreasing, as revealed in Fig. 7, due to a complex menisci system on the drying surface. As shown by Radocea,[16] capillary forces are not large enough to create horizontal deformation. Shrinkage also means that the concrete internal friction angle is adequately high. In other words, concrete particles must interact. Granular interactions are gradually favoured by consolidation, an increase of solids volume (hydration), and a decrease of water content (consolidation, hydration, and evaporation). During Phase 2, shrinkage rate increases until it remains almost constant.

Phase 3—Because of setting, volumetric contraction is increasingly hindered and, consequently, the shrinkage curve flattens. Initial and final setting times were measured by the Vicat needle apparatus in accordance with European Standard EN-196-3 on a mortar mixture proportioned using the concrete-equivalent-mortar (CEM) method.[17] Vicat test results confirm that the third phase fits well with setting (initial setting equals approximately 4.7 hours and final

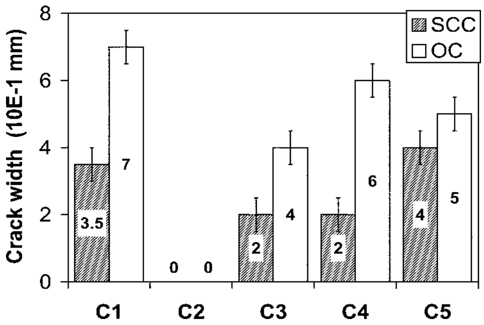


Fig. 19—Maximum crack width of all SCC and OC pairs.

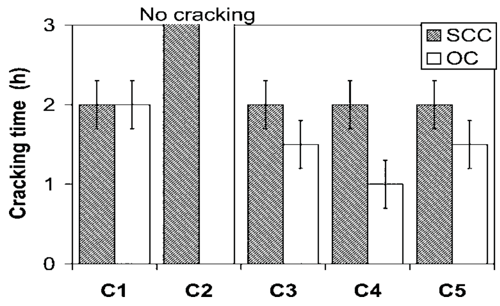


Fig. 20—Cracking time for all SCC and OC pairs.

setting equals approximately 8 hours). Radocea[9] defined shrinkage modulus as the ratio of an increment of capillary pressure and the corresponding increment of plastic shrinkage. Shrinkage modulus increases rapidly during this stage (Fig. 8). This is caused by an increase of skeleton stiffness owing to setting.

Figure 9 presents typical plastic shrinkage, settlement, and evaporation curves for the SCC3 mixture under the wind condition. The evaporation rate is initially 0.9 kg/m^2/h. Consequently, shrinkage amplitude at 8 hours is approximately four times higher than it is in the no-wind case. Moreover, the deformation kinetics is changed when wind is applied; the previously described phases appear but are shifted in time.

Phase 1 and 2—Like evaporation rate, initial settlement rate is multiplied approximately by nine. Settlement is mainly a consequence of drying. Thus, one could expect that bleeding water evaporates instantly at the concrete surface. This is confirmed by capillary pressure measurement because water pressure decreases almost immediately at the start of the test (Fig. 10). As a result, horizontal deformation appears very quickly.

Phase 3—Like in the case of the no-wind condition, the shrinkage curve flattens. Nevertheless, this occurs long before setting. Figure 11 shows the change of shrinkage modulus with and without wind. The evolution of shrinkage modulus depends on environmental conditions. Therefore, shrinkage modulus is not necessarily linked to setting.

Before setting, concrete can be considered a granular media, like a soil. The drying shrinkage curve of a soil is known to typically present two stages.[18,19] During Phase 1, volumetric contraction is proportional to water loss (like in Phase 2 described previously). During Phase 2, contraction is less than water loss that results in a flattening of the shrinkage curve (as observed in Phase 3). Phase 2 corresponds to a shrinkage limit; the granular media has been packed during Phase 1 so that it is then dense enough to resist the capillary pressure. Based on results in the literature, Phase 3 of shrinkage curve can be explained, in the wind condition, by an increase of packing density of concrete.

Finally, the important thing to note from this analysis is that, depending on evaporation rate, plastic shrinkage may stop before or during setting.

	SCC1	OC1	SCC2	OC2	SCC3	OC3	SCC4	OC4	SCC5	OC5
Time, hours	8.5	7.5	9.5	8	7.5	5	8	6	7	5.5

Table 3—Time to reach maximum shrinkage

Comparison of SCC and OC in no-wind condition

Figure 12 presents a noteworthy result: in the no-wind condition, plastic shrinkage of SCC mixtures is at least twice as high as plastic shrinkage of OC mixtures. Measurements confirm the a priori concerning SCC mixture design and plastic shrinkage. The other experimental results reveal some elements to explain the difference between SCC and OC.

- Bleeding rate can be evaluated by settlement rate[20] (that is, initial slope of the settlement curve). As bleeding is known to be dependent on fine elements content,[20,21] settlement rate was plotted versus binder content in Fig. 13. It appears that settlement rate of SCC is lower than settlement rate of OC. Moreover, settlement rate of SCC is approximately equal to evaporation rate (evaporation rate of 0.1 kg/m^2/h is equivalent to a deformation rate of 1570 μm/m/h, if drying is totally transformed in a vertical deformation). Hence, bleeding of SCC must be almost zero, contrary to OC, and the high binder content of SCC undoubtedly gives an explanation for its lack of bleeding. The lower settlement rate could be also correlated to the presence of viscosityenhancing agent (VEA) in some SCC mixtures. Indeed, VEA increases the pore water viscosity[22] and, as result, should decrease solid particles sedimentation.[20]
- Capillary pressure decreases faster in the case of SCC (Fig. 14). This results first from the lack of bleeding. This could be also the effect of a lower w/b of SCC because capillary pressure is inversely proportional to pore diameter, according to the Laplace equation.
- In the no-wind condition, Phase 3 is related to setting. Due to higher high-range water-reducing admixture dosage, setting of SCC is delayed compared to setting of OC. As a result, the period allowed for shrinkage development may be longer for SCC. Table 3 reveals that shrinkage final amplitude is actually reached later in the case of SCC. All of the tested SCC mixtures exhibit higher plastic shrinkage than the OC mixtures. Thus, SCC mixtures are likely more vulnerable to plastic shrinkage cracking. This could not be verified with the restrained shrinkage test used in this study. As previously noted, this device cannot produce cracking when the critical

shrinkage amplitude, approximately 2200 μm/m, is not reached during Phase 3, defined in Fig. 6. It must be emphasized that these results are based on a limited set of mixtures. They provide only trends regarding SCC behavior. Nevertheless, from a practical point of view, these results indicate that it is preferable to limit evaporation of SCC at the fresh state. One way to reduce evaporation is to apply a curing compound. Such compounds should be sprayed on the concrete surface after casting, where it rapidly produces a very thick membrane, preventing moisture loss. In this study, a curing compound made of copolymer diluted in solvent was tested. Figure 15 shows a comparison of the plastic shrinkage between the SCC3 and the SCC4 mixtures in the no-wind condition with and without curing. The curing agent was found to be efficient because the final amplitude of shrinkage was reduced by three times. Finally, cured SCC mixtures have plastic shrinkage of the same order of magnitude as OC mixtures.

Comparison of SCC and OC in wind condition

When drying conditions become severe, the difference between the amplitude of plastic shrinkage of the SCC and the OC mixtures, made of the same constituents, decreases considerably (Fig. 16). The previous points can be discussed again.

- Settlement rates of SCC and OC mixtures are slightly different when wind is applied (Fig. 17). Evaporation rate exceeds bleeding rate for all mixtures and, therefore, OC mixtures are not protected any more against drying by a layer of bleed water.
- As shown in Fig. 18, capillary pressure evolution is identical for an SCC mixture and the associated OC mixture.
- In the wind condition, all plastic shrinkage occurs before setting. The difference in setting time between SCC and OC mixtures does not produce a difference in shrinkage.

Figure 19 and 20 show the results of the restrained shrinkage tests performed in the wind condition. The amount of cracking was found to be lower for the SCC mixtures; the crack width of SCC mixtures is smaller than the crack width of the OC mixtures (Fig. 19). Moreover, SCC mixtures tend to crack later (Fig. 20). It is worth noting that Mixtures SCC2 and OC2 did not crack because the maximal shrinkage value was lower than 2200 μm/m. This result seems to be coherent with the shrinkage and capillary pressure measurements as Mixtures SCC2 and OC2 have the lowest shrinkage and the slowest capillary pressure development. The difference in constituents, particularly the cement type, could provide an explanation for the difference in behavior between C2 mixtures and the other mixtures. For instance, it is likely that the pores are larger in the C2 mixtures.

In spite of little variation in plastic shrinkage in the wind condition, the tested OC and SCC mixtures do not exhibit the same behavior, in most cases, regarding cracking. Therefore, it appears that plastic shrinkage measurements do not necessarily accurately predict concrete cracking potential at the fresh state. Hammer12,23 proposed to study plastic cracking phenomenon with a load and capacity concept, where the load is plastic shrinkage and the capacity is the strain capacity of concrete. It is believed that the highly fluid consistency of SCC mixtures results in high strain capacity.

SCC mixtures more easily accommodate restrained plastic shrinkage by plastic flow.[24]

CONCLUSIONS

Based on the experimental results presented in this paper, the following conclusions concerning the tested SCC and OC mixtures can be made:

1. When the evaporation rate is moderate (drying at 20 °C and a relative humidity of 50%), plastic shrinkage occurs before and during setting. In this environmental condition, drying shrinkage is higher in the case of SCC than for OC.
   As revealed by settlement measurements, the difference in shrinkage between the two types of concrete is mainly due to the difference in bleeding. While bleedwater offers to OC a natural protection (curing) against evaporation, bleeding of SCC is very low because of its high binder content and the presence of VEA. Consequently, capillary pressure in SCC can develop at a faster rate. The difference in shrinkage may also come from the lower w/b of SCC, which may generate rapid capillary pressure, and from the higher high-range water-reducing admixture content of SCC, which may delay setting; and
2. When the evaporation rate is high (windy condition), plastic shrinkage occurs only in the plastic state, that is, before setting. In this case, SCC and OC mixtures made of the same constituents exhibit almost the same plastic shrinkage.
   In fact, all differences in shrinkage due to mixture design effects (bleeding, setting) vanish when the evaporation rate becomes high. Restrained shrinkage tests performed in the windy condition revealed that SCC tends to have less cracking than OC. Because of its fluid consistency, SCC is thought to have a greater strain capacity than OC in the fresh state.

This study gives certain trends in SCC behavior at the fresh state. Because limited sets of concrete mixtures were tested, these results should be confirmed on other SCC and OC mixtures. Following this research, a study is in progress to evaluate the influence of paste volume, addition type, and addition/cement ratio on plastic shrinkage cracking. From the practitioner's point of view, curing of SCC used in horizontal applications should be recommended to compensate for the lack of bleeding and then to reduce the potential of cracking. In the future, a study on plastic shrinkage cracking of SCC should be carried out in different ways. Restrained shrinkage tests could be undertaken with a more sophisticated apparatus[23,25] (active restrained shrinkage test) to compare strain capacity of SCC and OC in various environmental conditions. Modeling could also be a way to better understand early-age shrinkage cracking.

ACKNOWLEDGMENTS

This study was sponsored by the French National Project on Self- Compacting Concrete (PN B@P) and by the VM Materiaux Company, which are gratefully acknowledged.

REFERENCES

1. Uno, P. J., "Plastic Shrinkage Cracking and Evaporation Formulas," ACI Materials Journal, V. 95, No. 4, July-Aug. 1998, pp. 365-375.

2. Wittmann, F. H., "On the Action of Capillary Pressure," Cement and Concrete Research, V. 6, No. 1, 1976, pp. 49-56.

3. Turcry, P., and Loukili, A., "Can the Maturity Concept be Used for Separating Autogenous Shrinkage and Thermal Deformation of a Cement Paste?" Cement and Concrete Research, V. 32, 2002, pp. 1443-1450.

4. "Self-Compacting Concrete," Proceedings of the First International RILEM Symposium on Self-Compacting Concrete, Stockholm, Sweden, 1999.

5. "Self-Compacting Concrete," Proceedings of the Third International RILEM Symposium on Self-Compacting Concrete, Reykjavik, Iceland, 2003.

6. Hammer, T. A., "Cracking Susceptibility Due to Volume Changes of Self-Compacting Concrete," Proceedings of the Third International RILEM Symposium on Self-Compacting Concrete, Reykjavik, Iceland, 2003, pp. 553-557.

7. Gram, H. E., and Piiparinen, P, "Properties of SCC—Especially Early Age and Long Term Shrinkage and Salt Frost Resistance," Proceedings of the First International RILEM Symposium on Self-Compacting Concrete, Stockholm, Sweden, 1999, pp. 211-225.

8. Turcry, P., and Loukili, A., "A Study on Plastic Shrinkage of Self- Compacting Concrete," Proceedings of the Third International RILEM Symposium on Self-Compacting Concrete, Reykjavik, Iceland, 2003, pp. 576-585.

9. Radocea, A., "A Model of Plastic Shrinkage," Magazine of Concrete Research, V. 46, No. 167, June 1994, pp. 125-132.

10. Soroushian, P., and Ravanbakhsh, S., "Control of Plastic Shrinkage Cracking with Specialty Cellulose Fibers," ACI Materials Journal, V. 95, No. 4, July-Aug. 1998, pp. 429-435.

11. AFGC, "Recommendations for the Use of Self-Compacting Concrete," French Civil Engineering Association (AFGC), 2000.

12. Hammer, T. A., "The Relationship between Settlement and Plastic Shrinkage of High Strength Concrete," presented at the 2002 ACI Fall Convention, Phoenix, Ariz., Oct. 2002, pp. 89-102.

13. Wang, K.; Shah, S. P.; and Phuaksuk, P., "Plastic Shrinkage Cracking in Concrete Materials—Influence of Fly Ash and Fibers," ACI Materials Journal, V. 98, No. 6, Nov.-Dec. 2001, pp. 458-464.

14. Kronlöf, A.; Leivo, M.; and Sipari, P., "Experimental Study on the Basic Phenomena of Shrinkage and Cracking of Fresh Mortar," Cement and Concrete Research, V. 25, No. 8, 1995, pp. 1747-1754.

15. Holt, E. E., and Leivo, M., "Methods of Reducing Early-Age Shrinkage," Proceedings of the International RILEM Workshop on Shrinkage of Concrete, 2000, pp. 435-447.

16. Radocea, A., "Autogenous Volume Change of Concrete at Very Early Age," Magazine of Concrete Research, V. 50, No. 2, June 1998, pp. 107-113.

17. Schwartzentrüber, A., "La méthode du mortier de béton équivalent (MBE): Un nouvel outil d'aide à la formulation des bétons adjuvantés," Materials and Structures, V. 33, No. 32, June 2000, pp. 475-482.

18. Naser Abu-Hejleh, A., and Znidarcic, D, "Desiccation Theory for Soft Cohesive Soils," Journal of Geotechnical Engineering, V. 121, No. 6, June 1995, pp. 493-502.

19. Konrad, J.-M., and Ayad, R., "An Idealized Framework for the Analysis of Cohesive Soils Undergoing Desiccation," Canadian Geotechnical Journal, V. 34, 1997, pp. 477-488.

20. Josserand, L., "Bleeding of Concrete," PhD Thesis, Ecole National des Ponts et Chaussées, 2002, 163 pp. (in French)

21. Neville, A., Properties of Concrete, Eyrolles Edition, 2000, 844 pp.

22. Khayat, K., and Ghezal, A., "Effect of Viscosity-Modifying Admixture- High-Range Water-Reducing Admixture Combination on Flow Properties of SCC Equivalent Mortar," Proceedings of the Third International RILEM Symposium on Self-Compacting Concrete, Reykjavik, Iceland, 2003, pp. 369-385.

23. Hammer, T. A., "On the Strain Capacity and Cracking Mechanisms of High Strength Concrete at Very Early Age," Creep, Shrinkage and Durability Mechanics of Concrete and other Quasi-Brittle Materials, F.-J. Ulm, Z. P. Bažant and F. H. Wittmann, eds., Elsevier Science, 2001, pp. 657-662.

24. Turcry, P., "Shrinkage and Cracking of Self-Compacting Concrete," PhD Thesis, Ecole Centrale de Nantes, 2004, 220 pp. (in French)

25. Iragashi, S.; Bentur, A.; and Kovler, K., "Autogenous Shrinkage and Induced Restrained Stresses in High Performance Concrete," Cement and Concrete Research, V. 30, 2000, pp. 1701-1707.

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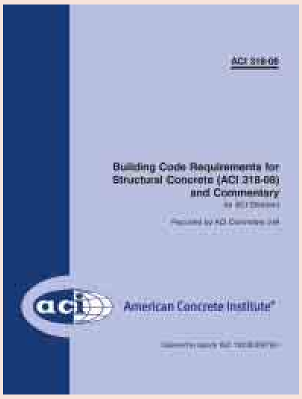

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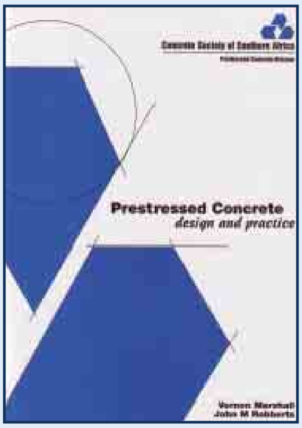

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Specifying Durability Index Limits for Reinforced Concrete Construction

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Y. Ballim, University of the Witwatersrand
K. Stanish, Walker Restoration Consultants, Elgin, Illinois, USA

Following the successful Durability Seminar that was held nationally in October 2007, this is a paper thet Prof Mark Alexander presented

Abstract
The paper summarises the latest recommendations regarding how to specify durability index limits to avoid corrosion in reinforced concrete members. The recommendations are based on so-called durability indexes, developed in South Africa, and deal mainly with a 'deemed-to-satisfy' approach. Steps in this approach are clearly outlined, and illustrated with a typical example. While much work remains to be done, the approach represents a rational advance in attempting to improve reinforced concrete durability.

1.0 Scope

The paper presents the current recommendations for determining and specifying appropriate durability index limits for minimising or avoiding corrosion in reinforced concrete, gives ways for evaluating compliance, and provides guidance on conformity criteria.

(For detailed background to the approach and recommended values contained herein, including the statistical derivations, the reader is directed to a paper entitled "A Framework for Use of Durability Indexes in Performance-based Design and Specifications for Reinforced Concrete Structures", by the authors.[1])

2.0 Introduction

Efforts have been underway in South Africa for more than a decade to improve the quality of reinforced concrete construction, mainly in respect of avoidance of premature steel corrosion. A programme of university-based research was put in hand in the early 1990's, taking an engineering approach to find practical solutions. The work has involved the characterisation of materials, development of appropriate test methods, and models for predicting durability performance. Industry and practitioners have tentatively adopted some of the research results and introduced durability clauses into some performance-based specifications.

Three durability index tests have been developed: oxygen permeability, chloride conductivity and water sorptivity. The test methods are contained in the Durability Index Testing Procedure Manual, downloadable from the UCT Civil Engineering Department website, follow links: Research Groups, Concrete and Cement-based Materials.

In this document, only the OPI and chloride conductivity values are considered. Water sorptivity has not yet been related in the present research directly to concrete deterioration, and is not related to a design parameter at this stage.

This position paper:

- Outlines the steps required by an owner/designer to establish appropriate Durability Index values required for a specific structure
- Provides guidance on what these values should be, and
- Recommends a procedure for implementing their use as a quality control measure.

The recommendations contained herein can be used as a basis in drawing up performance specifications based on the durability index approach.

3.0 Establishing Required Performance Parameters (Durability Index Values)

Concrete durability must be related to the structure and the environment in which it will be used. For reinforced concrete structures, durability relates largely to the concrete quality and the cover depth. These parameters need to be established by the owner/designer prior to specifying concrete durability index limits.

A distinction also needs to be made between material potential and as-built construction quality. The former refers to the potential ability of the material to produce a durable structure, while the latter refers to the durability exhibited by the actual structure in service. Ultimate durability performance will be a function of the material potential and the construction quality, and these two separate but related aspects must be allowed for in design and construction.

The effects of the construction process are more significant for R.C. durability than they are for strength, because they critically influence the surface zone of the concrete. The relevant transport mechanisms which govern corrosion operate mainly in this zone. The core, which primarily governs strength, is much less affected by these processes. See Figure 1.

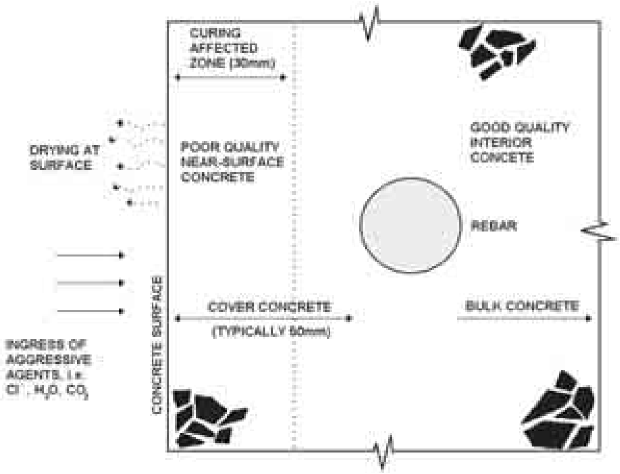

Figure 1: Schematic of cover zone, showing influence of environment and curing

[1] *The paper will be published in Materials & Structures (RILEM Journal), but a preview copy can be obtained by emailing Mark.Alexander@uct.ac.za.*

To establish the required durability index values, the designer must consider
- the exposure conditions
- the service life of the structure
- the materials to be used
- an appropriate cover
- depending on the type of structure, either a deemed-to-satisfy approach or a rigorous approach to determine appropriate values.

3.1 Exposure Conditions
The natural environmental classifications according to EN206 [1] are being adopted in South Africa. The environments relevant for reinforced concrete corrosion, i.e. carbonating conditions, and marine conditions, are given in Table 1, which gives EN206 clauses modified for South African conditions.

Table 1. Environmental Classes (Natural environments only) (after EN206)

Carbonation-Induced Corrosion	
Designation	Description
XC1	Permanently Dry or Permanently Wet
XC2	Wet, Rarely Dry
XC3	Moderate Humidity (60-80%) (Ext. conc. sheltered from rain)
XC4	Cyclic Wet and Dry

Corrosion Induced by Chlorides from Seawater	
Designation	Description
XS1	Exposed to airborne salt but not in direct contact with seawater
XS2a*	Permanently submerged
XS2b*	XS2a + exposed to abrasion
XS3a*	Tidal, splash and spray zones
XS3b*	XS3a + exposed to abrasion

**These sub clauses have been added for South African coastal conditions*

3.2 Desired Service Life
The owner ultimately determines the design life, but a guideline for typical values is provided by EN 1990 [2], in Table 2. For reinforced concrete structures, the most relevant categories are 4 and 5, i.e. 50 or 100 years design life.

Table 2. Recommended Service Life for Different Structure Types (after EN 1990)

Design Working Life Category	Indicative Design Working Life	Examples of Structures
1	10 years	Temporary
2	10 to 25 years	Replaceable Structural Parts
3	15 to 30 years	Agricultural and Similar Structures
4	50 years	Buildings and Other Common Structures
5	100 years	Monumental Building Structures, Bridges and Other Civil Engineering Structures

3.3 Cover Thickness
Concrete cover thickness and quality are the two principal parameters governing durability performance of reinforced concrete structures. For practical purposes, the cover depth is usually restricted to between 25 mm and 80 mm. The actual value must be specified by the designer, but typical minimum cover depths are 30 mm for a carbonating environment and 50 mm for a seawater environment.
Cover thickness and quality need to be specified by the designer and achieved by the constructor. These two parameters represent a trade-off between each other, so that lower cover must be accompanied by higher quality. The balance will usually be dictated by practical and economic considerations.

4.0 Specifying Durability Index Values
Two possible approaches to specifying durability index values are:
- A deemed-to-satisfy approach.
- A rigorous approach.

The former should be adequate for the vast majority of reinforced concrete construction and represents the simpler method. The latter will be necessary for durability–critical structures, or when the design parameters assumed in the first approach are not applicable to the structure in question.

4.1 Deemed to Satisfy Approach
This approach mimics structural design codes: the designer recommends limiting values which, if met by the structure, result in the structure being 'deemed-to-satisfy' the durability requirements. Durability index values are recommended based upon standard conditions for a limited number of options, which have been evaluated using service life models to give the limiting DI values. These models have been developed in South Africa and are based on work done mainly on Western Cape concretes and structures

4.1.1 Carbonating Exposure
Although work is still required, the carbonation resistance of concrete (including blended cement concrete) appears

to be sufficiently related to the early age (28 d) Oxygen Permeability Index (OPI) value, so that OPI can be used in a service life model. The environments that require OPI values to be specified are XC3 and XC4 (Table 1), with XC4 considered the more critical because steel corrosion can occur under these conditions. For XC1 and XC2, provided there is a minimum of 30 mm cover, carbonation-induced corrosion should not occur in the structure.
Two design scenarios with standard conditions and required minimum OPI values are shown in Table 3. For common structures, an OPI of 9.70 and minimum cover of 30 mm should suffice for a 50-year corrosion free life. For Monumental Structures, two options are shown. In the first, the cover is kept at 30 mm and the required concrete quality is increased. In the second, the concrete quality (i.e. OPI) is kept constant but the cover is increased.

Table 3. Deemed to Satisfy Values for Carbonating Conditions

	Common Structures	Monumental Structures	
		(1)	(2)
Service Life	50 years	100 years	100 years
Minimum Cover	30 mm	30 mm	40 mm
Minimum OPI[1]	9.70	9.90	9.70

[1]This is the minimum OPI value that must be achieved in the as-built structure, tested on samples removed at 28 days

4.1.2 Seawater Exposure

Chloride resistance of concrete is related to its chloride conductivity, and therefore this index can be used to specify concrete performance in seawater environments. The standard conditions for the two design scenarios are shown in Table 4. These conditions result further in Tables 5 and 6, which give chloride conductivity limits for different binder types, since chloride conductivity depends strongly upon binder type. The horizontal rows give approximately equal performance (i.e. chloride resistance) in seawater conditions for the different binders. Binder types are restricted to blended cements for seawater exposure, since CEM I on its own has been shown to be insufficiently resistant to chloride ingress. Due to limitations in the current state of knowledge, it is recommended that a maximum water:binder ratio (w/b) of 0.55 be accepted, even when the deemed-to-satisfy index values may indicate that higher w/b may be acceptable.

Table 4. Conditions used to establish Deemed-to-Satisfy Values for Seawater Exposure

	Common Structures	Monumental Structures
Service Life	50 years	100 years
Minimum Cover	50 mm	50 mm

Table 5. Maximum Chloride Conductivity Values[1] (mS/cm) for Different Classes and Binder Types: Deemed to Satisfy Approach – Common Structures (Cover = 50 mm)

EN206 Class	70:30 CEM I:Fly Ash	50:50 CEM I: GGBS	50:50 CEM I: GGCS	90:10 CEM I:CSF
XS1	3.00	3.50	4.00	1.20
XS2a	2.45	2.60	3.25	0.85
XS2b, XS3a	1.35	1.60	1.95	0.45
XS3b	1.10	1.25	1.55	0.35

[1]These are the maximum values that should not be exceeded in the as-built structure, tested on samples removed at 28 days

Table 6. Maximum Chloride Conductivity Values[1] (mS/cm) for Different Classes and Binder Types: Deemed to Satisfy Approach – Monumental Structures (Cover = 50 mm)

EN206 Class	70:30 CEM I:Fly Ash	50:50 CEM I: GGBS	50:50 CEM I: GGCS	90:10 CEM I:CSF
XS1	2.50	2.80	3.50	0.80
XS2a	2.15	2.30	2.90	0.50
XS2b, XS3a	1.10	1.35	1.60	0.35
XS3b	0.90	1.05	1.30	0.25

[1]These are the maximum values that should not be exceeded in the as-built structure, tested on samples removed at 28 days

Notes to Tables 5 and 6:-
Fly Ash = Type F; GGBS = Ground granulated blast furnace slag; GGCS = Ground granulated corex slag; CSF = condensed silica fume

4.2 Rigorous Approach

Using this approach, the specifying authority would use the relevant service life models developed in the concrete durability research programme in South Africa. The designer can use the models directly and input the appropriate conditions (cover depth, environmental classification, desired life, and material). The advantage of this approach is its flexibility – it allows the designer to use values appropriate for the given situation rather than a limited number of pre-selected conditions. However, it requires more expertise on the part of the user to ensure that the models are used correctly and the results interpreted properly.
(The service life models are available on the UCT website www.civil.uct.ac.za, follow links: Research Groups, Concrete and Cement-based Materials (Lifecycle Spreadsheets). The developers of the models should be consulted whenever the models are used. Their details are included on the website.)

5.0 Evaluating Compliance with Durability Requirements

Two components are key to the production of durable concrete in as-built structures – the concrete supplied and the on-site processing. The various construction processes (transporting, placing, compacting, curing, etc used by the constructor influence the durability properties of the final product more strongly than strength and therefore these two key components must be evaluated.

5.1 Material Potential Quality

To evaluate the material, standard specimens (e.g. cubes) should be prepared from the concrete supplied. These should be kept in the mould for one day, and then mowet-cured (23 ± 2°C) for an additional 27 days, giving a total of 28 days of moist curing. They can be used for oxygen permeability and/or chloride conductivity tests.

As a general rule, concrete in the as-built structure may be of lower quality compared with the same concrete cured under the controlled laboratory conditions described above. To account for the improved performance of laboratory concrete over site concrete, the characteristic values for the durability indexes of the laboratory concrete shall be:

a) For OPI: a margin of at least 0.10 greater than the value determined in Sect. 4.1.1 or 4.2.
b) For chloride conductivity: a factor no greater than 0.90 times the value determined in Sect. 4.1.2 or 4.2.

5.2 As-Built Quality

Samples should be taken from the structure between 28 and 35 days of age. They should be tested following the methods in the Durability Index Testing Procedure Manual. The characteristic values of these indexes shall:

a) For OPI: equal or exceed the value determined in Sect. 4.1.1 or 4.2 ,
b) For chloride conductivity: equal or be less than the value determined in Sect. 4.1.2 or 4.2.

5.3 Testing Frequency

The testing frequency should be project-specific, and therefore could vary. It is suggested that initially, testing frequency should be greater. Once it has been established that the criteria are being consistently achieved, the testing frequency can be decreased. For example, initially one set of tests may be required for every 50 m^2 of in-situ concrete surface area placed, with a minimum of one test for each element.[2] This could reduce subsequently to, say, one set of tests for every 150 m^2 of in-situ concrete surface area, or possibly a greater value. In selecting the locations within the structure at which cores are taken for testing, small areas with obvious physical defects should be avoided. Furthermore, unavoidable spatial variations in concrete quality across a section (e.g. vertical variations in a single pour height of a wall) should be acknowledged, for example by not taking cores from the very top or bottom of a single lift of a wall or column. The location within the structure at which cores are taken for testing shall be directed by the engineer.

6.0 Conformity Criteria for Durability Index Values

The values required for material potential (as established in Section 5.1) are characteristic values, not target (average) values. The owner requires this level of performance for the structure so that the desired service life is achieved with an adequate probability of success. The inherent variability in concrete performance needs to be considered when interpreting test results and evaluating concrete mixture designs, similar to the approach that is adopted with strength specimens. Thus, it is proposed that two criteria be used to allow for this variability, such that:

1) the average of any three consecutive test results must be 'better' than the required characteristic value, and
2) no single test result is "poorer" than the characteristic value by more than a specified margin.

The material supplier should aim at target values that will achieve the required characteristic values with adequate probability. Since durability is a serviceability criterion, the limitations may need to be less stringent than for strength. According to ACI 318, current limitations for strength imply a 1 in 100 chance that the average of three consecutive tests would be below the required characteristic value, and a 1 in 100 chance that an individual test value would be 3.45 MPa or more below the required value. At this stage, it is proposed that a 1 in 10 chance be adopted for the durability index tests with a margin of 0.3 below for OPI, and 0.2 mS/cm above for chloride conductivity. This results in the equations below for determining target durability index test values. (These equations are more completely developed in the Appendix to the paper referred to in Section 1.0).

6.1 Small Number of Results (< 30 results)

In the absence of other information, the coefficients of variation used can be based upon Mwandla [3], in order to establish the target average test value so as to meet the acceptance criteria in Sect. 7.0.

OPI: The target average index value shall be:

$$OPI_{Target} = OPI_{Char,\ Mat'l\ Potential} + 0.22$$

(Note that for OPI, the logarithmic transformation results in a constant factor being added to the characteristic value).

Chloride Conductivity: The target average value (in mS/cm) shall be the lesser of:

$$C_{Target} = 0.90\ CC_{Char,\ Mat'l\ Potential}$$

$$C_{Target} = 0.82\ CC_{Char,\ Mat'l\ Potential} + 0.2$$

[2] *Note that a valid test result is the mean value from a minimum of 3 (preferably 4) individual determinations, i.e. from 3 (or 4) concrete disc specimens*

6.2 Large Number of Results (> 30 results)

When a large number of test results on similar concrete is available (>30), the results can be analysed statistically and the standard deviation (s) determined and used to set the target value. The resulting equations are:

OPI: The target average value shall be the greater of:

$OPI_{Target} = OPI_{Char,\ Mat'l\ Potential} + 0.75s$

$OPI_{Target} = OPI_{Char,\ Mat'l\ Potential} + 1.30s - 0.3$

Chloride Conductivity: The target average value shall be the lesser of:

$C_{Target} = C_{Char,\ Mat'l\ Potential} - 0.75s$

$C_{Target} = C_{Char,\ Mat'l\ Potential} + 1.30s + 0.2$

7.0 Acceptance Criteria

For acceptance of a set of test results, the obtained values must be compared with the required characteristic values for Material Potential (Sect. 5.1) and for as-built quality (Sect. 5.2). Thus the oxygen permeability test results are considered satisfactory if both

1) the average of any three consecutive test results exceeds the characteristic value 90% of the time, and
2) no single test result is less than the characteristic value by more than 0.3

The chloride conductivity test results are considered satisfactory if both

1) the average of any three consecutive test results is less than the characteristic value 90% of the time, and
2) no single test result is greater than the characteristic value by more than 0.2 mS/cm

In both cases the characteristic value is either that determined in Sect. 5.1 for material potential quality, or Section 5.2 for as-built quality.

A flowchart illustrating the various steps and necessary durability index values for each step is given in Figure 2. It allows the designer to follow the processes described to arrive at the final acceptance criteria.

Flowchart illustrating Establishment of Acceptance Criteria, assuming Deemed-to-Satisfy Approach followed. (Subscripts refer to step in the process in which the relevant value was derived.)

1	Environment (Table 1)	Sect. 3.1	Owner/ Designer Decisions
↓			
2	Desired Service Life (Table 2)	Sect. 3.2	
↓			
3	Required Cover (Table 3 or 4)	Sect. 4.1.1 or 4.1.2	Controlled Parameter
↓			
4	Required DI Test Value# (OPI, CC - Table 3, 5, 6)	Sect. 4.1.1 or 4.1.2	Establishing Criteria
↓			
5	Material Potential Value# (OPI_4 + 0.10) (CC_4 x 0.90)	Sect. 5.1	
↓			
6	As-Built Value# (OPI_4) (CC_4)	Sect. 5.2	
↓			
7	Mix Design Target Value (OPI & CC: From Sect. 6.1 or Sect. 6.2 using OPI_5 or CC_5)	Sect. 6.1 or 6.2	Establishing Target (Average) Values for Concrete Mixture
↓			
8	Acceptance Mat'l Pot.: OPI_5, CC_5 As-Built: OPI_6, CC_6	Sect. 7.0	Acceptance

These are Characteristic Values

8.0 Practical Example

An example of how the procedures can be implemented may assist in making the previous discussion clear. The desired quality of the structure must first be established in terms of the performance criteria. This can be done using the deemed-to-satisfy approach (Sect. 4.1) or more rigorously using service life models, considering environment, concrete cover and desired life (Sect. 4.2). In this example, assume that for chloride resistance a maximum chloride conductivity of 1.35 mS/cm is required, and a minimum OPI of 9.70 is required for carbonation resistance. (Both values need not necessarily be specified for a single structure, and should be based on the environment and the expected deterioration mechanism.) These are the characteristic values that must be achieved by the as-built structure, and the average of any three consecutive test results from the structure must pass these values 90 % of the time.

The materials supplier must meet more stringent criteria. For chloride conductivity, the material potential value as determined on laboratory specimens must be no greater (i.e. better quality) than that determined according to Sect. 5.1 – that is no greater than (1.35 x 0.90 =) 1.22 mS/cm. For the OPI, the material potential value must be not less than that determined according to Sect. 5.1 – that is no less than (9.70 + 0.10 =) 9.80.

The materials supplier, to achieve these values at the required level of certainty, must target better values on average. These are calculated according to Sect. 6.1. This gives target values of (0.90 x 1.22 =) 1.10 mS/cm for chloride conductivity and (9.80 + 0.22 =) 10.02 for OPI. These values are summarized in Table 7.

Table 7. Summary of Values for Example

Parameter	Responsibility	Chloride Conductivity (mS/cm)	OPI
Required Quality Limit	Designer/Owner	1.35	9.70
As-built Quality: Characteristic Value	Constructor	1.35	9.70
Material Potential: Characteristic Value	Materials Supplier	1.22	9.80
Material Potential: Target Value	Materials Supplier	1.10	10.02

By way of summary, the equations used for calculating the various durability index values to achieve the necessary durability are given in Table 8.

Table 8. Equations for Calculated Values

	Chloride Conductivity	OPI
As-built Limit (Characteristic)	$CC_{As\text{-}built}$ From Service Life Model	$OPI_{As\text{-}built}$ From Service Life Model
Mat'l Pot'l Limit (Characteristic)	$CC_{Mat'l\ Pot'l} = 0.90\ CC_{As\text{-}built}$	$OPI_{Mat'l\ Pot'l} = OPI_{As\text{-}built} + 0.10$
Material Target Value (Average)	Lesser of: $0.90\ CC_{Mat'l\ Pot'l}$ $0.82\ CC_{Mat'l\ Pot'l} + 0.20$	$OPI_{Mat'l\ Pot'l} + 0.22$

9.0 Phased Implementation

Currently the statistical factors required to determine target values for the material supplier so that the constructor can be expected to meet as-built requirements are only provisionally established and need further investigation before full implementation. Also, the approach contained in this paper needs to be tested against practical experience on various construction sites over time. Thus it is recommended that provisions based on this approach be used developmentally. Realistic limiting values should be set with due cognisance of the uncertainties inherent at present. If it is desired that payment be linked to the achievement of the limiting values, it may be appropriate to use less stringent values initially until practitioners become proficient in the approach, without sacrificing the intent of the owner and designer to improve construction quality. Most importantly, it is recommended that a process of education of all concerned be implemented in construction, and that realistic limiting values be the subject of on-the job agreement between all the parties.

During this transition period, the information from cube results, in-situ results and relevant site parameters (e.g. curing type and duration, temperature, humidity, site location, etc.) should be collected systematically. Once sufficient information is available, this can be reviewed and more appropriate margins can be established.

10.0 Closure

The durability index values given in the paper are "best-estimate" values based upon present experience. It is inevitable, and indeed desirable, that the values should be modified with time as experience grows and greater insight is gained into the practicalities of the methods proposed. However, it is important that information from laboratory specimen results, in-situ results and relevant site parameters (e.g. curing type and duration, temperature, humidity, site location, etc.) be collected.

11.0 References

[1] EN206-1, Concrete – Part 1: Specification, performance, production and conformity. CEN, Brussels, 2000.

[2] EN1990, Eurocode – Basis of structural design. CEN Brussels.

[3] Mwandla, S., Variation of the Durability Index Test Values between Nominally Identical Ready-Mix Concrete Batches, B.Sc. Thesis, Dept. of Civil Engineering, University of Cape Town, 2004.

Concrete Durability in the Western Cape Part 1 – Alkali Silica Reaction (ASR)

Introduction

Alkali-aggregate reaction involves chemical reactions between alkalis and certain reactive minerals found in some aggregates. In the Western Cape, and elsewhere in South Africa, the reaction involves reactive silica and the reaction is therefore known as alkali-silica reaction (ASR). The term alkali-silicate rock reaction is still sometimes seen, but it is now almost universal practice to refer to alkali-silica reaction.

Alkali-carbonate rock reaction has been identified elsewhere in the world but not in South Africa.

The reaction product of ASR is a hygroscopic alkali-silica gel which expands when it absorbs moisture. The expansion causes the characteristic cracking of the concrete and it is not uncommon for some of the gel to weep from the cracks. Depending on exposure conditions, the first signs of cracking are seen after about three to five years.

Three conditions must occur simultaneously and be sufficiently adverse for ASR to occur. If any one condition is absent, deleterious expansion of the concrete will not occur. These three conditions are:

- The presence in the aggregate of deleteriously reactive minerals
- Sufficient alkalis in the concrete mix
- Sufficient free moisture in the pores of the concrete to maintain the relative humidity at more than approximately 65%. Exposure to continual dampness or cyclic wetting and drying will obviously fulfil this condition.

1. Potentially reactive aggregates

The following aggregate types have been tested and found to be potentially alkali reactive:

- Greywacke and hornfels from the Malmesbury Group (commonly known as “Malmesbury shale”). These aggregates are classified as “rapidly reactive”.
- Quartzites and sandstones from the Quaternary Period. These aggregates are usually sourced from crushed river boulders and river gravels. They are less reactive than the aggregates from the Malmesbury Group and are classified as “slowly reactive”.
- Some quartzites from the Cape Supergroup. If reactive, they are classified as slowly reactive.
- Very rarely, granite from the Cape Granite Suite. Current (2001) commercial sources of granite in the Western Cape can, in practice, be regarded as being non-reactive.

All aggregates from the first two categories should be regarded as potentially alkali reactive, unless proven otherwise.

There is a standard SANS test method to assess the potential reactivity of aggregates(1). Allowing for time for sample preparation, this test takes three weeks to complete.

The terms “rapidly expansive” and “slowly reactive” refer to the rate of expansion of the different aggregates in this standard test, not to the rate of expansion of concrete in the field.

It is interesting that naturally occurring river, pit and dune sands have not yet been found to be alkali-reactive.

2. Sufficient alkalis in the concrete mix

In this context alkalis are defined as sodium oxide equivalent:

$$\% \; Na_2O \text{ equivalent} = \% \; Na_2O + 0{,}658 \times (\% \; K_2O)$$

The major source of alkalis in the mix is usually the cement, although some may be contributed by the mixing water, or the aggregates, or sea spray, or chemical admixtures.

The important factor is the total amount of alkali in the concrete, not the alkali content of the cement. (SANS EN 197-1, unlike the old SANS 471, does not distinguish between “high-” and “low-” alkali cements)

The total alkali content of the concrete, contributed by the cement, is calculated as follows:

$$A = N \times C/100$$

A = Alkali content of the concrete from the cement, kg/m^3
N = % Na_2O equivalent of the cement
C = cement content of the concrete, kg/m^3

The alkali content of concrete made with rapidly expansive aggregates should not exceed 2,1 kg/m^3, and that of concrete made with slowly reactive aggregates should not exceed 2,8 kg/m^3.

3. Environmental conditions

In order for the alkali-silicate gel to expand it must absorb water. If concrete is allowed to dry out and is kept dry, there will be no deleterious expansion.
The conditions that promote expansion and cracking are continual dampness, cyclic wetting and drying, and high ambient temperatures.

Remedial measures

Once expansion has started and cracking becomes evident there is little that can be done. Further expansion and cracking of affected structures can be mitigated by preventing ingress of free water through construction joints and service ducts and applying a hydrophobic surface treatment such as a silane to the structure or parts of the structure. The hydrophobic surface treatment repels external free water while allowing free moisture in the concrete to evaporate.

Preventing alkali-silica reaction in new construction

If the environment is such that there is a possibility of occurrence of ASR, the following precautions can be taken:

- Replace the reactive aggregate with a non-reactive one, or
- Design the concrete mix to contain less than the critical amount of alkali for that particular aggregate. This could involve using cement with a low alkali content, or reducing the cement content of the concrete. Cement contents can be reduced by using sand with a low water requirement, by increasing the coarse aggregate size, and by using a water reducing agent.
- Use a cement blend containing, by mass:
- At least 50% Ground Granulated Corex Slag (GGCS), or
- At least 40% Ground Granulated Blastfurnace Slag (GGBS), or
- At least 20% Fly Ash (FA), or
- At least 15% Condensed Silica Fume (CSF).
- Pay attention to the design of joints, weepholes, etc to provide good drainage of the structure.

References and further reading:

1. SANS Method 1245:1994, Potential reactivity of aggregates with alkalis (accelerated mortar prism method), Pretoria: South African Bureau of Standards, 1994.
2. Commentary on SABS 1083:1984, Midrand: Cement and Concrete Institute, 1995.
3. R E Oberholster, Chapter 10, Fulton's Concrete Technology, 8th Edition, Midrand: Cement and Concrete Institute, 2001, Editors: B J Addis & G Owens.

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Concrete Durability in the Western Cape
Part 2 – Corrosion of reinforcing steel

Introduction

The most common cause of deterioration of reinforced concrete worldwide is corrosion of reinforcing steel, the repair of which is both time consuming and expensive. The coastal areas of SA are no exception and the occurrence of corrosion of reinforcing steel is common.
This TIP briefly describes the corrosion process and the role of the various "C's".

The process of steel corrosion in concrete

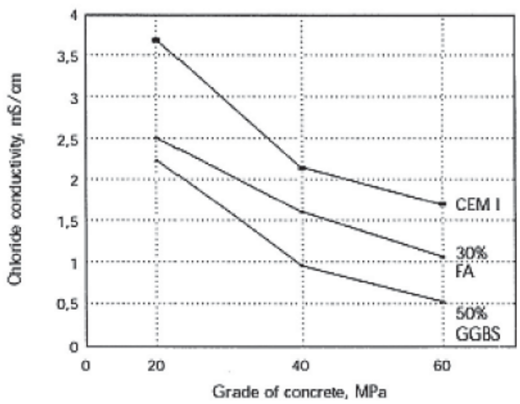
Uncarbonated cement paste is highly alkaline, with a pH in excess of 12,5. This high alkalinity protects embedded reinforcing steel from corrosion by forming a stable layer of gamma ferric oxide on the surface of the steel. Under these conditions the steel will not corrode, even if exposed to water and oxygen (both of which are required for corrosion to occur, the water being the electrolyte and the oxygen combining with the steel to form rust). If the alkalinity of the paste drops, the layer of ferric oxide becomes unstable and the steel becomes susceptible to corrosion. Any chlorides present act as catalysts in initiating and accelerating the corrosion process.

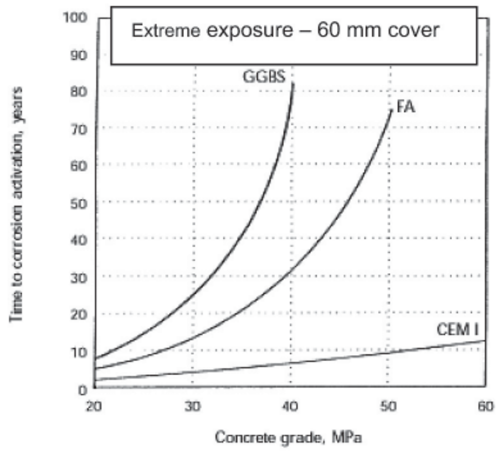
The role of the various "C's" in the corrosion process

- Cement: type, content and ratio to mixing water:

Extreme exposure – 60 mm cover

The above curves from Mackechnie (1) illustrate the effects of concrete grade (i.e. cement content and w/c ratio), and cement or binder type, on the chloride conductivity and time to corrosion activation of concrete.





Generally speaking blended cements significantly outperform type I cements, provided the concrete is properly cured.

- Cover to the steel:

The cover to the steel influences the time until corrosion activation. Obviously the thicker the cover, other factors being equal, the longer it takes for any aggressive agents to reach the steel. There are, however, practical limits to the thickness of cover that can be used and it is unusual to see covers of more than 60-mm being specified. Cover refers to minimum cover, and end cover to bars is often problematical. Cover tolerances are given in SABS 0100 Part 2 and SANS 1200G.
The quality of the cover concrete is also very important and depends on the compaction and curing of the concrete.
The use of impermeable cover blocks is also essential. High strength concrete blocks give the best results.

- Compaction of the concrete:

The more thorough the compaction, the denser will be the concrete. Compaction related defects such as honeycombing, and to some extent blowholes, effectively reduce the effective cover as well providing large voids through which aggressive agents may pass.

- Curing of the concrete:

Assuming no large voids are present in the cover concrete, aggressive agents can enter the capillary pores and in time migrate to the reinforcement. Good curing effectively

blocks the capillary pores provided the water/binder ratio does not exceed about 0,6.
Good curing also reduces the gel porosity and permeability of the paste.
Good curing is particularly important for gaining the maximum potential durability when using blended cements as the hydration rates of extenders are generally slower than that of cement at early ages.
Tests and experience have shown that curing during the first three to four days is critical to long term performance irrespective of binder type.

- Carbonation:

Carbonation is the process whereby carbon dioxide from the atmosphere penetrates the concrete and reacts with the calcium hydroxide produced during the cement hydration reactions to form calcium carbonate. The results are that the paste shrinks slightly and the pH drops. As the carbonation front reaches the reinforcement, and the pH drops, the protective layer on the steel becomes unstable and corrosion could begin if oxygen and moisture are present. The simultaneous presence of chlorides, see below, accelerates the corrosion process.
Concrete that is completely dry, or completely saturated, does not carbonate to any great degree. Carbonation occurs most rapidly when the relative humidity is in the 40 to 60% range.

- Chlorides:

The effect of soluble chlorides, for example from sea spray, is to raise the pH at which corrosion of the steel can occur. The higher the chloride concentration at the surface of the steel, the higher the pH required to protect the steel. In other words carbon dioxide and chlorides often work in tandem:

- Carbonation reduces the pH, and
- Chlorides can initiate corrosion at a higher pH than would otherwise have been the case.

The other problem with chlorides, from a corrosion point of view, is that they are catalysts in the process and are not used up. They can therefore migrate and set up corrosion cells elsewhere.

- Chemicals (other than chlorides):

On rare occasions chemical induced corrosion is encountered. Specialist literature should be consulted. Generally speaking dry chemicals are not corrosive, moisture is required to transport the corrosive agent to the steel.

CONCLUSION

Experience worldwide has shown that attention to the basics of good concrete practice can reduces the occurrence of reinforcement corrosion by up to 80%. The basics are:

- Cement (binder) type, content, and water/binder ratio
- Cover
- Compaction
- Curing

All of which will affect the effects of:

- Carbonation, and
- Chlorides, and
- Chemicals

REFERENCES

1. Mackechnie, J.R.," Predictions of reinforced concrete durability in the marine environment", Doctoral research monograph, University of Cape Town, 1997.

Acknowledgement:

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Concrete Durability in the Western Cape - Part 3 – Deterioration of concrete from exposure to various chemical agents

Introduction

Chemical attack on concrete is sometimes encountered in the Western and Northern Cape. The types of attack that have occurred are, apart from alkali silica reaction (ASR):

- Sulphate attack
- Sulphuric acid attack (in sewers)
- Soft water and acid water attack
- Crystallisation of salts
- Attack by industrial chemicals (acids, fertilisers etc)
- Attack by organic waste (lactic acid etc)

Generally speaking deterioration of concrete is either by spalling of the concrete, i.e. "spalling corrosion", or by leaching of the hardened cement paste, i.e."leaching corrosion".
This tip describes the different types of attack in very general terms and it is recommended that specialist literature be consulted in specific cases.

A list of references is included.

Sulphate attack

Soluble sulphates, usually from ground water, react with tricalcium aluminate in cement to form calcium sulpho-aluminates. The reaction is expansive and the cement paste is disrupted, often appearing spongy and exfoliated.
The common approach in the past was to use a sulphate-resisting cement* (tricalcium aluminate content < 3,5%) but some sulphates, notably magnesium and ammonium sulphate, are particularly aggressive to portland cement paste and the use of sulphate-resisting cement is ineffective.
Sulphate resisting cements are no longer produced in South Africa and the use of an appropriate substitution of GGCS, GGBS, FA or CSF for CEM I is recommended when environmental sulphate contents are high. In many cases protective barrier coatings will also be necessary.
(A specific cause of failure due to sulphate attack is the practice of mixing proprietary gypsum-based plasters into cement plaster in order to accelerate stiffening of the plaster. When exposed to moisture the gypsum attacks the cement. The attack may take some time to occur but the eventual result is disintegration of the plaster.)
*The SANS EN 197-1 specification for common cements does not cover sulphate-resisting cements.

Sulphuric acid attack

Sulphuric acid attack can occur in mining and industrial processes, and in sewer manholes, pipes and culverts.

In the case of mining and industrial processes exposure to sulphuric acid is by spillage. The extent of protective measures should be evaluated with due regard to the risk of spillage and the consequences of exposure to the acid.

In the case of sewage initiated exposure, the exposure mechanism is indirect. Under anaerobic conditions hydrogen sulphide is generated from sulphur compounds in the sewage by micro-organisms. The hydrogen sulphide gas dissolves in water which has condensed on the manhole, pipe or culvert walls forming sulphurous acid. The sulphurous acid is oxidised by sulphur-oxidising bacteria to form sulphuric acid which in turn dissolves the cement paste. In the case of concrete pipes the severest damage occurs just above the normal sewage flow level and at the crown of the pipe.
While some sulphate attack may be present, the use of low C3A cements is not effective against sulphuric acid attack and the type of cement used is largely immaterial.
Practical methods to reduce corrosion in concrete sewer pipes include:

- Using calcareous aggregates to spread the attack to the aggregates as well as the cement paste. This will extend the lifetime of the pipe by a factor of two or three.
- Maintaining self-cleansing velocities in the sewer to reduce build up of sludge in which the sulphide producing organisms live and to reduce retention time to a minimum.

In the case of pump station wet-wells sacrificial plaster coatings or suitable protective coatings may be used.

Soft and acid water attack

Very pure (soft) water is aggressive to concrete, especially if it also contains dissolved carbon dioxide. The water leaches calcium hydroxide from the cement paste in order to achieve chemical equilibrium between the calcium carbonate, calcium bicarbonate and carbon dioxide in the water. The resulting drop in pH of the paste destabilises the calcium silicate hydrate and further leaching occurs.

This type of water is fairly common in the western and southern areas of the Western Cape province.
Another common problem in the mountainous regions of the Western Cape is attack by acidic water. The acidity is caused by dissolved humus in the water and the water is in fact humic acid. These waters, brown in colour, can have a pH less than 4.

Again sacrificial or protective coatings are necessary if the consequences of failure are likely to be severe.

Salt crystallisation

Salt crystallisation attack can occur in the western, arid parts of the Northern Cape where the ground water is highly mineralised; between high and low water levels in structures exposed to saline water; and in concrete exposed to repeated splashing with saline water. It has also been observed in masonry where the brickwork is exposed to onshore salt-laden winds.
The mechanism of failure is that salt water penetrates the concrete, the water subsequently evaporates and the salts (which need not be sodium chloride alone) crystallise in the pores of the concrete. Salt crystallisation is an expansive phenomenon and the expansive forces produced during crystallisation cause surface spalling of the concrete which results in an unsightly finish and, in the case of reinforced concrete, reduced cover to the reinforcement.
In the writer's experience the effect of salt crystallisation seems to depend primarily on the pore sizes present near the surface of the concrete. Dense, well-compacted, well-cured concrete shows little or no distress while more porous concrete can be badly damaged in a relatively short time.

Industrial chemicals

Many common chemicals can cause serious deterioration of concrete, and in some cases reinforcement too. In general powdered or granular materials will not affect concrete unless water, or some other solvent, is present to act as a transport medium.
The need for, and the type of, protective measures vary widely and it is recommended that specialist literature be consulted. References are listed below.

Organic Wastes (lactic acid, wine, blood etc)

Organic wastes derived from dairy products, wine, blood, excrement and foodstuffs can be highly aggressive to concrete. Generally the type of attack is leaching attack by organic acids and it generally occurs on floors.
The most effective preventive measure, short of using coatings, is to wash the concrete thorougly and regularly.

Notes on the use of protective sealants and coatings

Sealants and coatings should be used strictly in accordance with the manufacturer's instructions. Proper surface preparation of the concrete is essential. Some sealants and coatings are toxic and must not be used in storage facilities for foodstuffs or potable water. Some materials are toxic while curing and should be applied in well-ventilated areas only.
Concrete coated with opaque barrier systems should be carefully inspected regularly (where practicable) as it is possible for corrosion of the concrete and reinforcement to proceed behind the coating without it being readily visible to the casual observer.

References

1. Fulton's Concrete Technology, 8th edition, Cement and Concrete Institute, Midrand, 2001
2. Basson J J, Deterioration of concrete in aggressive waters – measuring aggressiveness and taking countermeasures, Portland Cement Institute (now Cement and Concrete Institute), Midrand, 1989
3. SANS 0100 The structural use of concrete, Part 2 Materials and execution of work, SA Bureau of Standards, 1992 (amended 1994), Annex A. (This document is currently being amended)
4. ACI Committee 515, Report ACI 515.1R-79 (Revised 1885), A Guide to the Use of Waterproofing, Dampproofing,

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Eastern Cape Branch Diary - Chairman: Louis Visser, Tel: 041 453 2813 or Cell: 082 491 8562	
Date	Function
Mid February	FIFA Stadium Site Visit
Mid April	Port of Ngqura Site Visit
End of June	Denver Quary Site Visit
Beginning of August	Denver Quary Site Visit
Mid September	Golf Day
End of November	Shukuma Flooring Site Visit

Diary of Forthcoming Branch Events 2008

Inland Branch Diary - Chairman: Trevor Sawyer, Cell: 082 851 1531			
Date	Event	Date	Event
07 Feb	Branch Committee meeting	07 Aug	Branch Committee meeting
06 Mar	Branch Committee meeting	14 Aug	Mini-seminar
13 Mar	Mini-seminar and AGM	04 Sep	Branch Committee meeting
03 Apr	Branch Committee meeting	13 Sep	Annual Concrete Boat Race Day
08 May	Branch Committee meeting	02 Oct	Branch Committee meeting
15 May	Mini-seminar	16 Oct	Mini-seminar
05 Jun	Branch Committee meeting	06 Nov	Branch Committee meeting
03 Jul	Branch Committee meeting	07 Nov	Chairman’s Banquet

Kwa-Zulu Natal Branch Diary - Chairman: Ken Brown, Tel: 031 205 2707 or Cell: 082 554 5460			
Date	Function	Venue	Convenor
07 Feb	New Dbn Stadium Site Visit	Walter Gilbert Rd	Garth / Raj
29 Feb	Concrete Fun Day	Durban Rovers Club	Full Committee
20 Mar	AGM / KZN Achiever	Assagay Hotel	Garth / Rolf
17 April	Durban Harbour Site Visit	Harbour Entrance	Raj / Patrick
15 May	Slab Curling	UKZN - Room 124	Raj
29 May	KZN Golf Day	Bluff Country Club	Garth / Patrick / Edwin
19 June	Umgeni Viaduct Site Visit	Bridge Site	Dion
17 July	C&CI Architectural Concrete	UKZN - Room 124	Rolf
21 Aug	Cement Specifications	UKZN - Room 124	Rolf
18 Sept	New Dbn Airport Site Visit	La Mercy	Rolf
16 Oct	TBA		Patrick
20 Nov	TBA		Ken

Note: Committee meetings are held on the 3rd Thursday of every month at UKZN Centenary Building. For suggestions or requests please contact Dion Kuter 082 5793667.

Western Cape Branch Diary - Chairman: Lawrence Hendriks, Tel: 021 556 3255 or Cell: 082 578 8264		
Date	Meeting/Event	Venue
05 Feb	Branch Committee Meeting	3rd Floor, Ninham Shand Building
21 Feb	Site visit	Airport ACSA - Grinaker LTA
13 Mar	AGM & Committee Meeting	UCT
01 Apr	Branch Committee Meeting	3rd Floor, Ninham Shand Building
15 Apr	Annual Golf Day	Parow Golf Club
24 Apr	Site visit	Greenpoint Stadium
06 May	Branch Committee Meeting	3rd Floor, Ninham Shand Building
15 May	Site visit	Concrete Units Airport Industria
03 Jun	Branch Committee Meeting	3rd Floor, Ninham Shand Building
19 Jun	MTM - Monthly Technical Meeting	Stellenbosch University - B Boshoff - PCP
01 Jul	Branch Committee Meeting	3rd Floor, Ninham Shand Building
17 Jul	MTM - Monthly Technical Meeting	UCT - Snape Building
05 Aug	Branch Committee Meeting	3rd Floor, Ninham Shand Building
19 Aug	Cube Crush-in Casting	n/a
21 Aug	MTM - Monthly Technical Meeting	UCT - Concrete Repairs Muizenberg Buildings
02 Sep	Branch Committee Meeting	3rd Floor, Ninham Shand Building
18 Sep	Cube Crush-in	Stellenbosch University
07 Oct	Branch Committee Meeting	3rd Floor, Ninham Shand Building
16 Oct	Site visit	Unconfirmed
04 Nov	Branch Committee Meeting	3rd Floor, Ninham Shand Building
20 Nov	MTM - Monthly Technical Meeting	UCT - Snape Building
02 Dec	Branch Committee Meeting	3rd Floor, Ninham Shand Building

Announcement

The Department of Education has again granted its accreditation to the Concrete Society of Southern Africa's journal

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