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THE USE OF FIBRE CEMENT PANELS AS PERMANENT FORMWORK FOR REINFORCED CONCRETE ELEMENTS

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ABSTRACT

Traditional formwork installation and removal is one of the most time consuming and costly procedures in concrete construction. Following formwork removal, concrete elements have to be protected against premature drying in order to facilitate complete cement hydration and develop adequate durability. Permanent formwork eliminates the formwork removal process, provides excellent protection for the underlying concrete, and may also improve the surface quality of the RC element. This research aimed to assess the improved durability of reinforced concrete elements constructed with fibre cement board permanent formwork. To this aim, composite specimens were investigated for shear and tensile bond strength, durability properties and carbonation depth. Bond strength test results indicated that surface preparation (i.e. sandblasting) of the fibre cement boards is vital to achieving sufficient bond between the fibre cement boards and the concrete. Durability index test results showed that fibre cement permanent formwork has an equivalent effect as proper conventional curing methods. Carbonation depth testing results suggested that the fibre cement panels may be used to significantly extend the service life of concrete structures susceptible to carbonation induced corrosion even at higher w/b ratios, and possibly to reduce the required cover depth to the reinforcement.

KEYWORDS:

Fibre cement panels; reinforced concrete durability; permanent formwork; lost formwork

INTRODUCTION

The removal of formwork after concrete has attained sufficient maturity and strength is one of the most time-consuming and costly procedures in the construction of reinforced concrete (RC) elements. In addition, following formwork removal, the concrete elements have to be protected against premature drying, for example using plastic sheets or water curing, in order to facilitate complete cement hydration and develop adequate durability. The use of “lost formwork”, also called “permanent formwork” eliminates the formwork removal process and provides excellent protection for the underlying concrete. This does not only provide a cost- and time-effective alternative to conventional formwork, but also significantly improves the surface quality of the RC element with regards to aesthetics and durability.

The use of fibre cement panels as permanent formwork may stimulate a new way of thinking about the design and use of formwork systems for concrete. Additional benefits of this formwork system could include the use of fibre cement panels loose-laid over void forms as part of the slab depth for concrete slabs-on-ground, improvement of the appearance of cast ceilings, and the allowance of less stringent concrete mix design when fibre cement boards are used as facings for RC elements.

Permanent formwork provides a physical barrier between the RC element and its environment. Therefore, it can be reasonably assumed that permanent formwork limits the ingress of harmful substances that cause steel reinforcement corrosion, such as chlorides, carbon dioxide and moisture. This particular aspect of improved durability of RC members, resulting from permanent formwork, and the associated significant technical advantages, have not been adequately researched to date. The potential applications of this technology can better be realised based on a comprehensive understanding of all the technical benefits to be gained, including the added durability for RC members.

This research aimed to assess the improved durability of reinforced concrete elements constructed with permanent formwork consisting of fibre cement panels. To this aim, composite specimens were investigated for shear and tensile bond strength, durability properties and carbonation depth.

PRELIMINARY INVESTIGATION

A preliminary investigation making use of composite test specimens was conducted on the use of commercially produced cellulose fibre cement boards as permanent formwork. The fibre cement boards used were manufactured using the Hatschek process and were 15 mm thick. Their composition was estimated to be the typical mix of 8% cellulose, 34% cement, 54% silica and 4% aluminium trihydrate (Akers, 2014). The density, compressive strength, and linear expansion for the as-received fibre cement boards were tested and the results are presented in Table 1. The results were consistent with the product specifications provided by Everite Building Products (2012).

Table 1 – Characterisation test results for fibre cement boards

Density (kg/m^3) (SANS 6251, 2006)		1550
Compressive strength (MPa) (ASTM D1037, 2012)	With grain	25.4
	Across grain	36.4
Linear expansion (με) (SANS 803, 2005)	With grain	2250
	Across grain	1250

Preparation of fibre cement boards

Three methods of surface preparation for the fibre cement boards were considered in the preliminary investigation: no surface preparation, resulting in a smooth fibre cement board surface, sandblasting the surface, and roughening using an angle grinder (

Figure 1). Only the surfaces intended to interface with the concrete substrate were prepared.

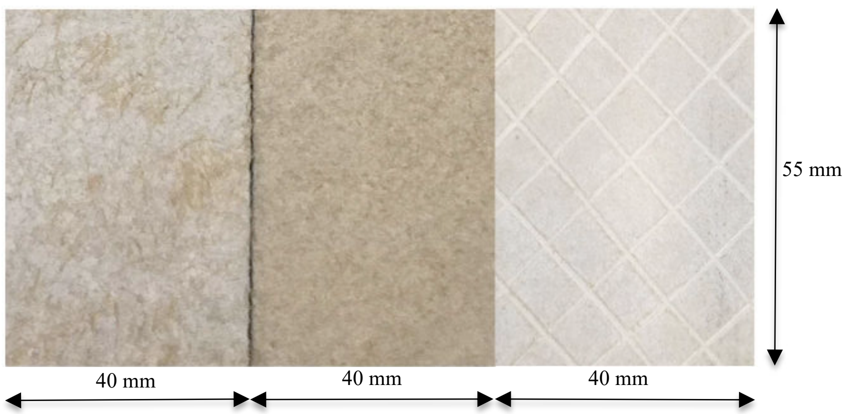

Figure 1 – Smooth (left), sandblasted (middle) and rough surface (right)

Preparation of specimens

The concrete for the composite specimens was of two water/binder (w/b) ratios, 0.45 and 0.65. The mix designs are presented in Table 2.

Table 2 – Composition and characteristics of concrete mix 1 and mix 2 for primary investigation

		Mix 1	Mix 2
Component	**Units**	**Value**	**Value**
w/b ratio	-	0.65	0.45
Water content	L/m³	180	180
Cement (CEM I 52,5N) (SANS 50197-1, 2013)	kg/m³	277	400
Fine aggregate (Philippi Dune Sand)	kg/m³	467	414
Fine aggregate (Crusher Sand)	kg/m³	467	414
Coarse aggregate (19mm Greywacke)	kg/m³	1037	1037
Slump	mm	75	80
Measured 28-day compressive strength	MPa	37.7	56.7
Density	kg/m³	2355	2357

The composite specimens were cast by placing the fibre cement boards vertically into the moulds and thereafter pouring in the concrete to simulate how the boards would be used on site. The specimens were then compacted on a vibrating table and placed under a polyurethane sheet for 24 h. After the 24 h, the specimens were demoulded, covered with plastic wrap, and placed in an environmental room (temperature of 23 ± 2 ºC; relative humidity of 50 ± 2%) until the specimen age of 7 days. At this time, the plastic wrap was removed, and the specimens were placed back into the environmental room for a further 21 days. At a specimen age of 28 days, shear bond and tensile bond strength tests were conducted on the specimens.

Shear bond strength test

For the shear bond strength tests (150 x 150 x 135) mm^3 concrete specimens were cast with a (150 x 150 x 15) mm^3 fibre cement board. The specimens were placed in a compressive strength testing machine with a modified guillotine test set-up for shear bond strength testing shown in Figure 2.

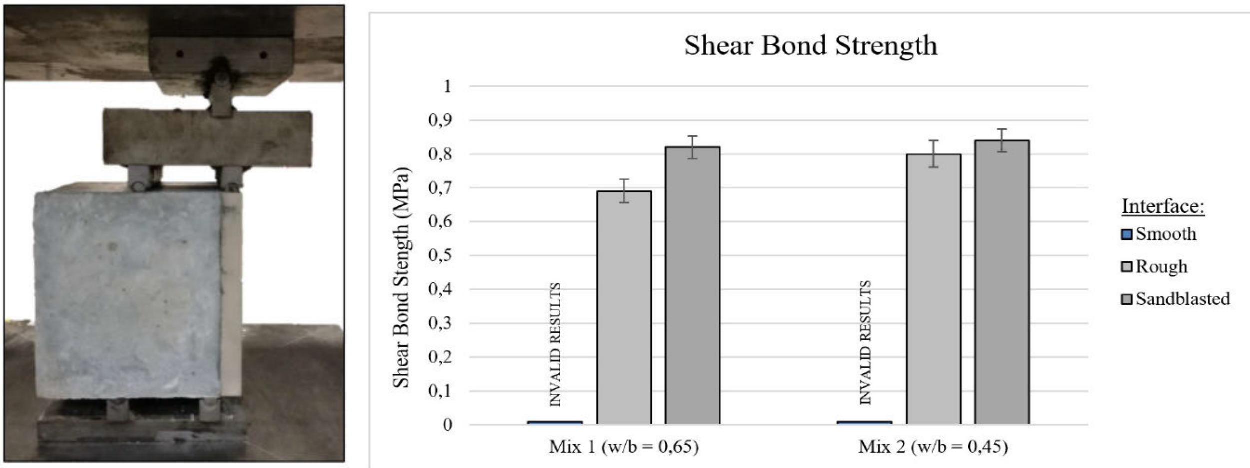

Figure 2 – Shear bond test set-up (left) and test results (right, average values and error bars indicating STDV)

The results of the shear bond strength test are presented in Figure 2. The majority of the smooth fibre cement boards debonded from the concrete substrate before the compressive load was applied on the specimen and therefore could not be tested for the shear bond strength, indicating that sufficient bond between fibre cement board and concrete needs to be established based on providing a rough fibre cement board surface. In contrast, the test results indicate adequate shear bond strength for specimens with a roughened fibre cement board surface. Similar results were obtained with a tensile pull-off test, which will be discussed in more detail in the full research report at a later stage.

SECONDARY INVESTIGATION

Preparation of fibre cement boards

Each fibre cement board was sandblasted on the interface surface before casting with concrete. From the results of the preliminary investigation, sandblasting was deemed the most efficient method to roughen the fibre cement boards in order to yield a good bond with the concrete.

Preparation of specimens

Concrete for the composite specimens was of two water/binder (w/b) ratios, 0.45 and 0.80 (Table 3). The composite specimens were cast as described for the preliminary investigation, except for the hand compaction of mix 1 which was intended to simulate poor quality control and bad on-site practices.

Table 3 – Composition and characteristics of concrete mix 1 and mix 2 for secondary investigation

		Mix 1	Mix 2
Component	**Units**	**Value**	**Value**
w/b ratio	-	0.80	0.45
Water content	L/m³	190	210
Cement (CEM I 42,5N) (SANS 50197-1, 2013)	kg/m³	238	462
Fine aggregate (Philippi Dune Sand)	kg/m³	550	362
Fine aggregate (Crusher Sand)	kg/m³	550	362
Coarse aggregate (19mm Greywacke)	kg/m³	925	1000
Slump	mm	35	80
Measured 28-day compressive strength	MPa	22.4	50.7
Density	kg/m³	2453	2396
Compaction		Hand	Vibration

Durability index tests

The improvement of the surface quality of the concrete cast with fibre cement boards as permanent formwork was investigated by performing durability index tests on the substrate concrete. The tests included the oxygen permeability index (OPI), water sorptivity index (WSI) and chloride conductivity index (CCI) tests.

Two types of specimens were made, composite and non-composite concrete specimens. Composite specimens of dimensions 100 x 100 x 85 mm were cast with a 100 x 100 x 15 mm fibre cement board for each w/b ratio presented in Table 3. In addition, non-composite concrete specimens of dimensions 100 x 100 x 100 mm were produced. Both types of specimens were demoulded 24 hours after casting, wrapped in plastic wrap and placed in an environmental room maintained at a temperature of 23 ± 2 ºC and relative humidity of 50 ± 2%. At a specimen age of 7 days, the plastic wrap was removed, and the specimens were left in the environmental room until the age of 28 days. Each specimen was then cored using a 70 mm core drill.

The fibre cement boards on the composite specimens were saw-cut off the concrete cores which were then sliced into 30 mm disks. For non-composite specimens, 5 mm was sliced off the exterior surfaces of concrete cores after which they were also sliced into 30 mm disks. Subsequent specimen preparation followed the guidelines stipulated in SANS 3001-CO3-1 (2015). The OPI, WSI and CCI tests were carried out on the prepared specimens in accordance with SANS 3001-CO3-2 (2015), the UCT DI test manual (2017) and SANS 3001-CO3-3 (2015) respectively. The OPI, WSI, CCI and porosity test results are presented in Table 4. All 3 tests have been used extensively in research and practice in South Africa and provide a reliable assessment of the concrete pore structure, in particular penetrability, permeability, and pore connectivity.

While a noticeable improvement in the WSI was provided by the fibre cement formwork to the substrate concrete for the 0.45 w/b specimens, no significant change was noted for the other durability indices for this concrete mix. This finding confirms that "curing" concrete with left-in-place fibre cement boards has the same effect on concrete durability properties as keeping the concrete wrapped in plastic for 7 days, which is commonly considered adequate curing when durability is of concern.

Table 4 – Average durability index test results for composite and non-composite specimens (note that for OPI, a higher value denotes higher quality, whereas a lower value denotes higher quality for WSI and CCI)

w/b ratio	0.80	0.80	0.45	0.45
Specimen type	composite	non-composite	composite	non-composite
OPI (log-scale)	9.4	9.4	9.8	9.7
WSI (mm/hr$^{0.5}$)	13.7	13.8	8.0	9.8
CCI (mS/cm)	2.7	2.7	1.3	1.4
Porosity (%)	11.8	11.9	10.3	11.5

Carbonation

Carbonation occurs when carbon dioxide gas from the atmosphere diffuses into the concrete and reacts with the hydrated cement paste in the presence of moisture. The chemical reactions involved in the carbonation process result in a reduction of the pH of the pore solution from a value greater than 12 to a value of 9 for fully carbonated concrete. This reduction in pH causes depassivation of the steel reinforcement and may result in corrosion initiation in the presence of moisture and oxygen.

Specimens for carbonation depth testing were cast as previously discussed for the preliminary investigation. At the age of 20 weeks, the specimens were epoxy coated on the 4 non-exposure surfaces as shown in 3(a). The two exposure surfaces were the surface with the fibre cement board, and the surface opposite to this (for control). The specimens were then placed in the carbonation chamber set at a relative humidity and temperature of 65±5% and 20±2 °C respectively, for preconditioning. After preconditioning for 14 days, carbon dioxide was introduced into the chamber at a concentration of (2 ± 0.1)% and maintained throughout the exposure period of 23 weeks.

At the end of the exposure period, the specimens were removed from the carbonation chamber for testing. The carbonation test was carried out using the phenolphthalein test method, as per BS EN 14630 (2006). The specimens were split perpendicular to the exposure surfaces and phenolphthalein indicator was sprayed on the freshly cut surface as shown in 3(b).

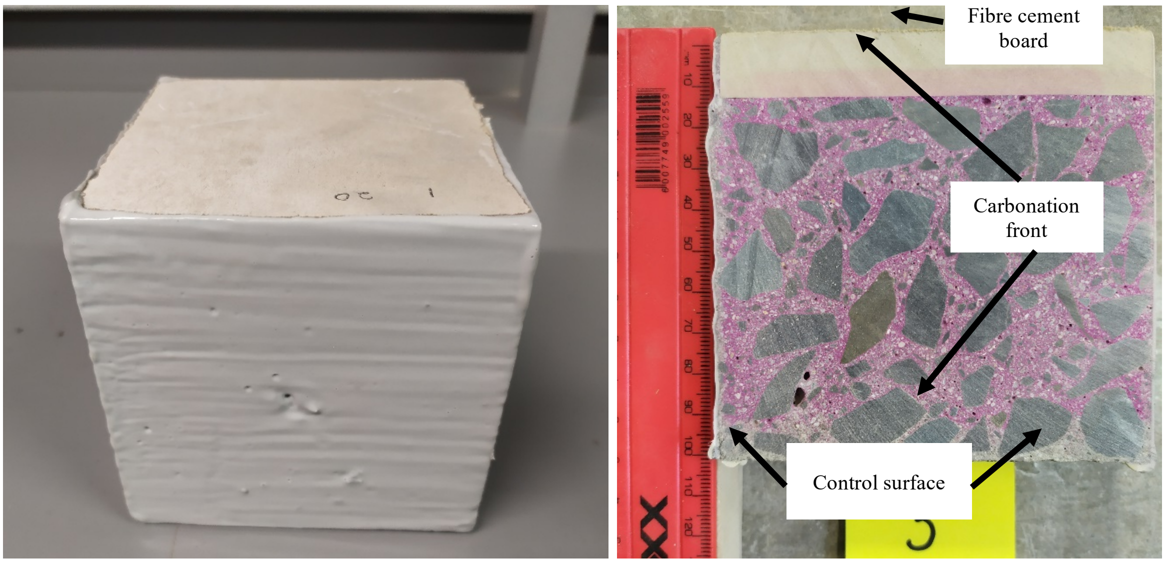

Figure 3 – (a) Epoxy coating on specimen, (b) carbonation fronts on cut surface of specimen

The indicator immediately changes to pink or purple if the concrete is not carbonated and remains colourless if the concrete is carbonated. The carbonation depth is the distance from the external surface to the pink/purple line also referred to as the carbonation front. The carbonation depth was measured at 8 points on each cut surface of the specimen using a Vernier calliper. The carbonation depth of each specimen was taken to be the average of the 8 measurements.

The average and maximum carbonation depths for the control and composite concrete surfaces are summarised in Table 5. Samples labelled M1-X were from mix 1 and samples labelled M2-X were from mix 2.

Table 5 – Summary of carbonation test results (the carbonation depth in the composite specimens denotes the carbonation depth in the fibre cement board, i.e. carbonation of the actual concrete was prevented)

Sample ID	Control concrete		Composite specimens	
	Average depth (mm)	Maximum depth (mm)	Average depth (mm)	Maximum depth (mm)
M1-1	12	16	9	10
M1-2	10	12	9	10
M1-3	13	16	9	10
M1-4	12	14	10	10
M2-1	6	10	9	10
M2-2	10	14	9	10
M2-3	9	12	10	10
M2-4	10	12	9	10

The average and maximum carbonation depths for mix 1 were 11 mm and 16 mm respectively, and for mix 2 were 9 mm and 14 mm respectively. In both cases, there was only a 2 mm difference. This was to be expected as both mixes have a high compressive strength, while a larger difference would be expected if one of the mixes had a low compressive strength. The average and maximum carbonation depths for the exposure surfaces with the fibre cement boards (permanent formwork) were 9 mm and 10 mm respectively. All carbonation occurred within the fibre cement board which has a thickness of 15 mm, and no carbonation of concrete was observed.

The carbonation coefficient describes the rate at which the carbonation front advances through a cementitious material. The rate of carbonation is influenced by the relative humidity of the material's pore structure, temperature, the binder content and composition, as well as the density and pore structure of the material. Maximum carbonation in concrete occurs at a relative humidity between 50% and 70%. The maximum carbonation depth was used to calculate the accelerated carbonation coefficient D_{acc}, from Fick's laws using the equation

$$D_{acc} = \frac{x}{t^n}, \qquad (2)$$

where x is the average carbonation depth, t is the exposure time in years and n is a factor depending on the exposure conditions, taken to be 0.5 in this study (Salvoldi, 2010). For the accelerated tests performed, the exposure time t was 23 weeks. The real carbonation coefficientD_{real}, was then calculated from the accelerated carbonation coefficient according to the equation

$$D_{real} = \frac{D_{acc}}{\sqrt{\frac{CO_{2\_acc}}{CO_{2\_real}}}} \qquad (3)$$

where CO_{2_acc} is the concentration of carbon dioxide during accelerated testing (equal to 2.0%), and CO_{2_real} is the concentration of carbon dioxide in the earth's atmosphere, taken as 0.04% (Salvoldi, 2010). A summary of the accelerated and real carbonation coefficients calculated for mix 1, mix 2 and the fibre cement boards is presented in Table 6.

Table 6– Summary of calculated carbonation coefficients for control concrete and fibre cement boards

Parameter	Mix 1	Mix 2	Fibre cement board
$x\ (mm)$	11	9	9
$D_{acc}\ (mm/\sqrt{year})$	16.5	13.5	13.5
$D_{real}\ (mm/\sqrt{year})$	7.4	6.1	6.1

Recall that during the accelerated testing, the relative humidity, temperature and carbon dioxide concentration were kept constant. From Table 6, the real carbonation coefficients for mix 2 and the fibre cement boards are equivalent, while that of mix 1 is higher. Mix 1 has less cement content than mix 2 due to the higher w/b ratio, and therefore less carbonatable material.

Mix 2 and the fibre cement boards have the same average carbonation depths despite having different cement contents, densities and pore structures. Although this phenomenon needs further investigation, the preliminary results suggest that the fibre cement boards used in this study have a similar resistance to carbonation as OPC concrete of w/b ratio 0.45. Thus, it may be postulated that these fibre cement boards may be used to significantly extend the service lives of concrete with w/b ratios greater than 0.45.

The estimated service life extension for concrete elements susceptible to carbonation provided by fibre cement panels of various thicknesses was calculated using equation (1). D was taken to be the real carbonation coefficient D_{real} for the fibre cement panels given in Table 6, and x the thickness of the panels, varied from 10 to 25 mm. The results are presented in Figure 4.

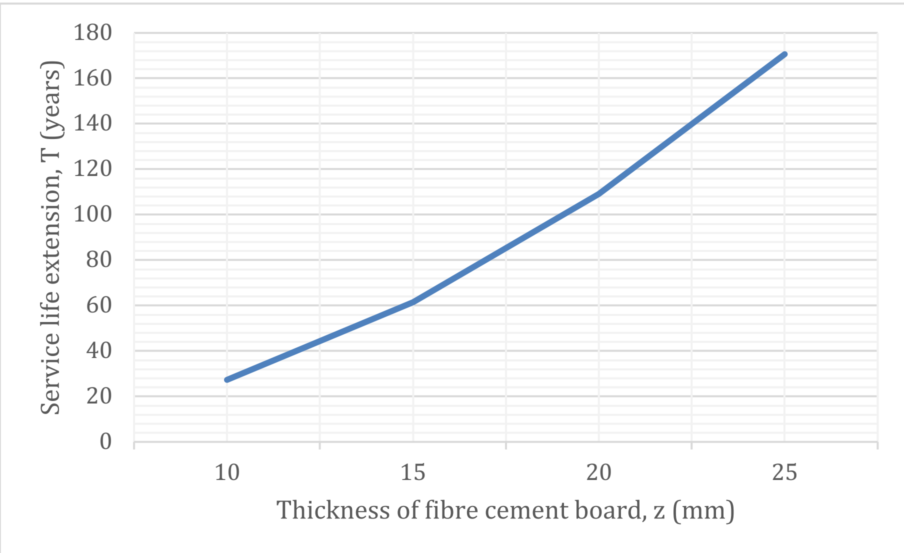

Figure 4 – Estimated service life extension of concrete elements

The calculated service life extension increases with increasing thickness of the fibre cement panel. For example, using fibre cement panels of 15 mm thickness could provide a service life extension of up to 60 years, while using a panel of 20 mm thickness could provide a service life extension of up to 110 years, provided the panels remain in good condition. The values presented assume a time-independent carbonation coefficient. However, in reality the carbonation coefficient would decrease with time, and therefore the values presented may be considered conservative.

CONCLUSIONS

In this paper, the results of an investigation into the use of fibre cement panels as permanent formwork for reinforced concrete elements are presented. The initial shear bond and tensile bond strength test results showed that surface preparation of the fibre cement boards significantly influenced the bond strength between the fibre cement boards and the concrete. The durability index test results revealed that the use of permanent fibre cement boards has a similar effect on durability properties as conventional curing with plastic sheets. The accelerated carbonation depth test results suggest that the fibre cement panels may be used to protect against carbonation-induced corrosion of the rebar and therefore extend the service life of concrete with w/b ratio greater than 0.45. The service life extension provided was determined to be directly proportional to the thickness of the fibre cement panels used.

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REFERENCES

Akers, S., 2014. *Fibre Cement Industry: A Critical Review Of Conversion From Asbestos Cement To New Technology Including Marketing Trends*. [online] Akers.ch. Available at: <https://www.akers.ch/images/inhalt/documents/Fibre_Cement_Industry_A_Critical_Review_of_conversion_from_AC_to_NT_incl._marketing_trends.pdf> [Accessed 7 October 2020].

ASTM D1037-12. 2012. *Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials.* ASTM International, USA.

BS EN 14630. 2006. *Products and systems for the protection and repair of concrete structures – Test methods – Determination of carbonation depth in hardened concrete by phenolphthalein method*. BSI, UK

Everite Building Products (Pty) Ltd. 2012. *Flat Sheets*. Available at: https://docs.wixstatic.com/ugd/155e76_b45b92295eeb4257bdcd0b8480d890db.pdf [Accessed 03 November 2022]

Salvoldi, B. G., 2010. Modeling the Carbonation of Concrete using early age oxygen permeability index tests, Cape Town: University of Cape Town.

SANS 803. 2005. *Fibre-cement boards.* South African Bureau of Standards (SABS), Pretoria.

SANS 6251. 2006. *Concrete tests - Density of hardened concrete.* South African Bureau of Standards (SABS), Pretoria.

SANS 50197-1. 2013. *Cement. Part 1: Composition, specifications and conformity criteria for common cements.* South African Bureau of Standards (SABS), Pretoria.

SANS 3001-CO3-1. 2015. *Civil engineering test methods Part CO3-1: Concrete durability index testing – Preparation of test specimens.* South African Bureau of Standards (SABS), Pretoria.

SANS 3001-CO3-2. 2015. *Civil engineering test methods Part CO3-2: Concrete durability index testing – Oxygen permeability test.* South African Bureau of Standards (SABS), Pretoria.

SANS 3001-CO3-3. 2015. *Civil engineering test methods Part CO3-3: Concrete durability index testing – Chloride conductivity test.* South African Bureau of Standards (SABS), Pretoria.

University of Cape Town (UCT). 2017. Durability Index Testing Procedure Manual. Department of Civil Engineering.

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