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Structural and durability properties of concrete made with Corex slag

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Contents

Acknowledgements *4*

Introduction 5

Historical background 5

Characterisation of slag 7
  Chemical composition 7
  Physical properties 7

Mix design for Corex slag concrete 10

Properties of fresh and hardening concrete 14
  Setting times 14
  Bleeding 14
  Plastic cracking 15
  Heat of hydration 16

Construction practice 16

Compressive strength characteristics 18

Other structural properties 20

Durability properties 22
  Chloride resistance 22
  Carbonation 24
  Alkali silica reaction 25

Economic advantages of using slag concrete 26

Conclusions 27

References *29*

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INTRODUCTION

A new cementitious material has recently become available in South Africa. This product is a ground slag produced by the Corex* process at the Saldanha steel plant in the Western Cape. The manufacturing technology is able to produce a material with enhanced performance characteristics that differ from those of other slag binders. Detailed analysis of the raw material as well as characterisation of the properties of concrete made with Corex slag was therefore undertaken to provide useful practical information for engineers and users.

Results from the laboratory research show that Corex slag not only enhances concrete durability but also produces good early strength and improves other structural properties. This research monograph provides information on selected key performance properties of Corex slag concretes. Guidance is also given on how best to use Corex slag in concrete to produce sound, economical and durable structures. Topics covered include mix design, fresh and hardened properties, and good construction practice. These guidelines were formulated for Western Cape materials and conditions.

The availability of this new slag source in the Western Cape since October 1999 has made a major impact on the durability and economy of concrete construction in the region. The high performance nature of the material has allowed durable concrete to be produced without compromising structural properties and at no additional cost.

HISTORICAL BACKGROUND

The reactivity of blastfurnace slag was first discovered in Germany in 1862 and it has been used as a cementitious material for over 100 years[1]. Originally, the use of blastfurnace slag was limited to structures not exposed to drying because of doubts about the material's strength development in air. Later it was shown that slag concrete could be used in many different conditions. Slag has increasingly become an important part of the cement market both internationally and in South Africa where 850 000 tons of blastfurnace slag are produced per annum.

Slag is a by-product of the iron manufacturing process. In a blastfurnace, the iron oxide is reduced to metallic iron using, as a fluxing agent,

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* Corex is a registered trade mark of Voest-Alpine.

limestone or dolomite, which combines with the silica and alumina constituents to form a molten slag. This material is then drawn off and quenched with water jets or in a water bath. The water-quenched product is called granulated slag and consists of sand-size glassy particles, which are then ground to a fine powder to produce Ground Granulated Blastfurnace Slag (GGBS).

The new Saldanha Steel Plant (Figure 1) uses a more environmentally friendly process to produce iron, namely the Corex process. This system replaces coke ovens and a blastfurnace with a direct reduction shaft and a melter-gasifier. Injection of oxygen into the melter-gasifier is an essential part of the process. This plant also yields a quenched slag – called Corex slag – as a by-product of the iron making. Changes in the manufacturing process inevitably result in subtle differences between slags produced by either the blastfurnace or Corex system.

Figure 1: View of Saldanha steelworks

Considerable effort has gone into optimising the quality of slag produced at Saldanha. Guidelines were established to limit the raw material properties such that a consistent quality slag could be maintained. A purpose-built grinding mill was also designed to optimise the particle size distribution of the Ground Granulated Corex Slag (GGCS). These controls have helped to produce a high performance slag that would be commercially viable in the Western Cape construction industry. GGCS has been produced since 1999 and is available as a constituent of pre-bagged cement or as a separate cementitious material sold in bulk. Approximately 240 000 tons of GGCS are now being produced annually at Saldanha.

CHARACTERISATION OF SLAG

Slag consists mainly of silica and alumina derived from iron oxide ore, and lime added as a fluxing agent. Rapid cooling of slag using water quenching produces a glassy material that is slowly reactive with water. Slag is a latent hydraulic binder in that it hardens very slowly in water but is much more reactive when activated by alkalis, for example calcium hydroxide, one of the products of Portland cement (PC) hydration. The performance of slag as a cementitious material depends on the chemistry of the material, the glass content, and fineness of the ground slag.

Chemical composition

The hydraulic reactivity of ground slag is influenced by the chemical and mineralogical composition of the material. Compounds that increase reactivity include CaO, MgO and Al_2O_3 while SiO_2 reduces slag hydraulicity. Results of Oxide analyses on Portland Cement (PC), GGBS and GGCS by standard XRF techniques are compared in Table 1 [2]. Analysis showed that GGCS had higher CaO, Al_2O_3 and MgO concentrations than GGBS, and lower levels of SiO_2. These differences in composition indicate that GGCS should have higher hydraulic activity than GGBS of equivalent fineness, when compared on the basis of most accepted hydraulic activity formulae [3].

Physical properties

The reactivity of slag in cementitious systems depends not only on its chemistry, but also on its fineness (finer materials have higher reactivity). Surface area of the binders used was determined by Blaine and BET fineness techniques. BET fineness results are significantly higher than

Blaine values because adsorption also occurs on internal surfaces and microcracks. GGCS was found to be consistently finer than GGBS when measured by either BET or Blaine fineness tests (see Table 2). Particle size distribution of the two slags was also measured and showed that GGCS had a higher proportion of ultra-fine particles in the range 1-10 microns. The increased fineness of GGCS can be expected to promote more rapid reaction than is commonly found with conventional slag materials.

Table 1: Oxide analysis of binders used in experimental work (% by mass, XRF analysis)

Oxides	*PC*	*GGCS*	*GGBS*
CaO	67.2	37.2	34.0
SiO_2	22.3	30.8	35.5
Al_2O_3	4.4	16.0	15.4
MgO	1.01	13.7	9.4
TiO_2	0.22	0.51	1.2
Fe_2O_3	3.4	0.87	0.98
MnO	0.08	0.09	0.88
K_2O	0.56	0.35	0.87
Na_2O	0.21	0.12	0.16
SO_3	0.58	3.19	2.49

Table 2: Physical properties of Portland cement and slag powders

Method	*PC*	*GGCS*	*GGBS*
BET fineness (m^2/kg)	-	1145	991
Blaine fineness (m^2/kg)	310	467	390
% passing 1 micron	-	7	6
% passing 10 micron	-	51	45

Dry powder samples were examined using an analytical scanning electron microscope at magnifications of 2500 and 10000 times. Both types of slag were found to have angular particles with conchoidal faces as is typical for the material. GGCS grains were however slightly more chunky in shape and had a higher proportion of ultra-fine particles compared to GGBS (shown in Figure 2).

(a)

(b)

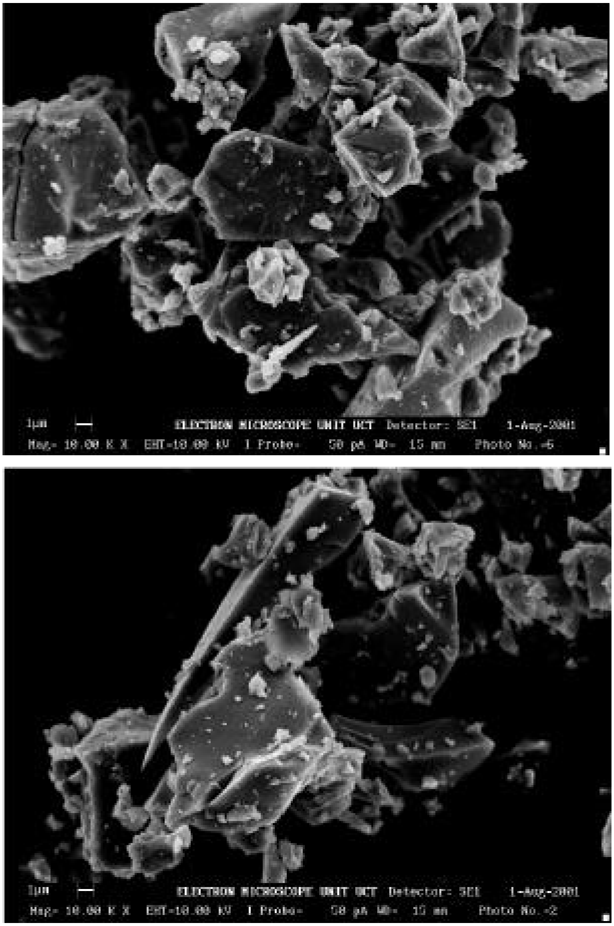


Figure 2: SEM micrographs of (a) Corex and (b) blastfurnace slag (x10000)

The consequences of the higher fineness of GGCS, in terms of lower bleed rates of concrete and slightly shorter final setting times of GGCS pastes compared with similar GGBS materials, will be covered later. Generally, some allowance needs to be made for the slower development in microstructure and strength of slag concretes within the first few days compared with PC concrete.

MIX DESIGN FOR COREX SLAG CONCRETE

The level of replacement of cement with slag depends on a number of factors that include required structural performance, construction constraints and technical properties of the material. Typical replacement levels range from 30 to 70% with an optimum level (based solely on compressive strength) generally being at about 50%. However, the optimum replacement level depends on the age at which a given strength is desired, and also on w/b ratio, as can be seen in Figure 3. Figure 3 also illustrates that GGCS concretes attain higher strength at an earlier age than similar GGBS concretes.

On the practical side, high levels of slag replacement may result in excessive delays in setting times and strength development. Similarly, lower replacement levels may not produce all of the technical benefits possible with slag concrete. Table 3 shows the applications of slag concrete at different replacement levels of cement with slag.

Table 3: Cement replacement levels for slag concretes

Replacement	*Applications*	*Benefits*	*Notes*
0 – 20%	Pre-bagged cements General building and civil work	Similar properties to plain PC	Little technical advantage
21 – 35%	Pre-bagged cement, general building and civil work under moderate exposure conditions	Minor delays in setting times and strength gain	Reasonable technical advantages
36 – 55%	Structural, durability, building work	Good technical advantages	Optimum replacement level
56 – 70%	Long-term strength, mass concrete, sulphate resistance	Lower heat of hydration (GGBS)	Early strengths not important, curing essential!

The use of slag in concrete results in improved workability due to the thixotropic nature of cement/slag pastes, and better particle dispersion and lubrication of the mix by the finer slag grains. Slag particles are however angular, unlike spherical fly ash particles, and produce only a slight reduction in water demand. With GGBS, the water reduction is typically between 5-10 l/m^3 for equivalent workability whereas with

GGCS, no significant reduction in water demand is apparent. Typical water requirements for structural concrete, made with well-crushed greywacke or granite coarse aggregate and well-graded pit sand are shown in Table 4. These water requirements assume moderate levels of plasticiser in the concrete (or in the case of CSF, moderate levels of superplasticiser).

Table 4: Typical water requirements for Western Cape concretes (l/m³)

Binder type	*Crane mix (slump = 75 mm)*	*Pump mix (slump = 150 mm)*
100% PC	175	185
10% CSF	185	195
30% FA	160	170
50% GGCS	175	185
50% GGBS	170	180

Design of slag concrete mixes can be done in the same manner as for standard Portland cement concrete mixes. Mix proportions shown in Table 5 are based on the C&CI method[4] except that the coarse aggregate fraction is held constant. This represents the practical upper limit for crushed stone in the Western Cape. Concrete mixes are based on a characteristic strength of 30 MPa with mean target strength of 37.5 MPa at 28 days. Concrete made with Corex slag requires the least amount of binder and should also be the most economical (see later under Economic advantages of using slag concrete).

Table 5: Typical mix proportions for Grade 30 concrete, Western Cape aggregates (kg/m³)

Material	*PC*	*CSF*	*FA*	*GGCS*	*GGBS*
Cement	275	225	210	120	137
Extender	0	25	90	120	138
Sand	860	845	855	880	865
Stone	1100	1100	1100	1100	1100
Water	175	185	160	175	170
Total binder	275	250	300	240	275
w/b ratio	0.64	0.74	0.53	0.73	0.62

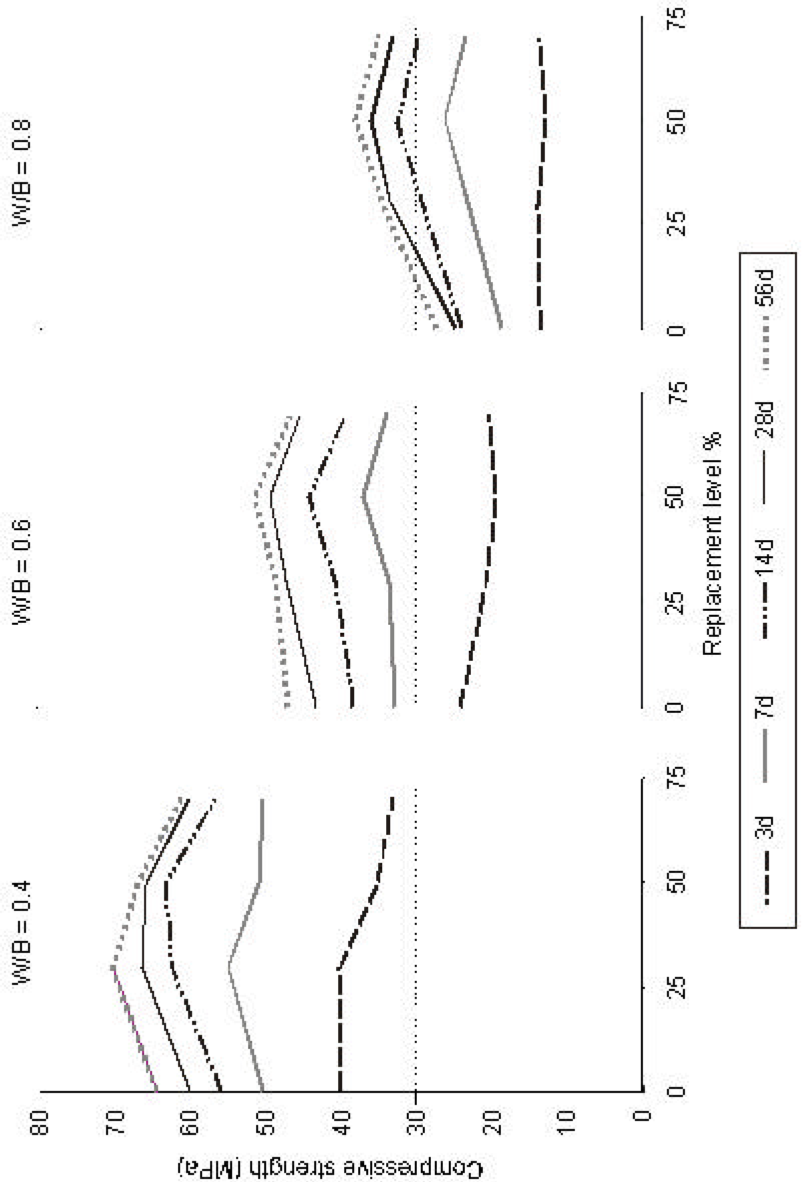


Figure 3a: Compressive strength of GGCS concretes as a function of slag replacement level and w/b ratio

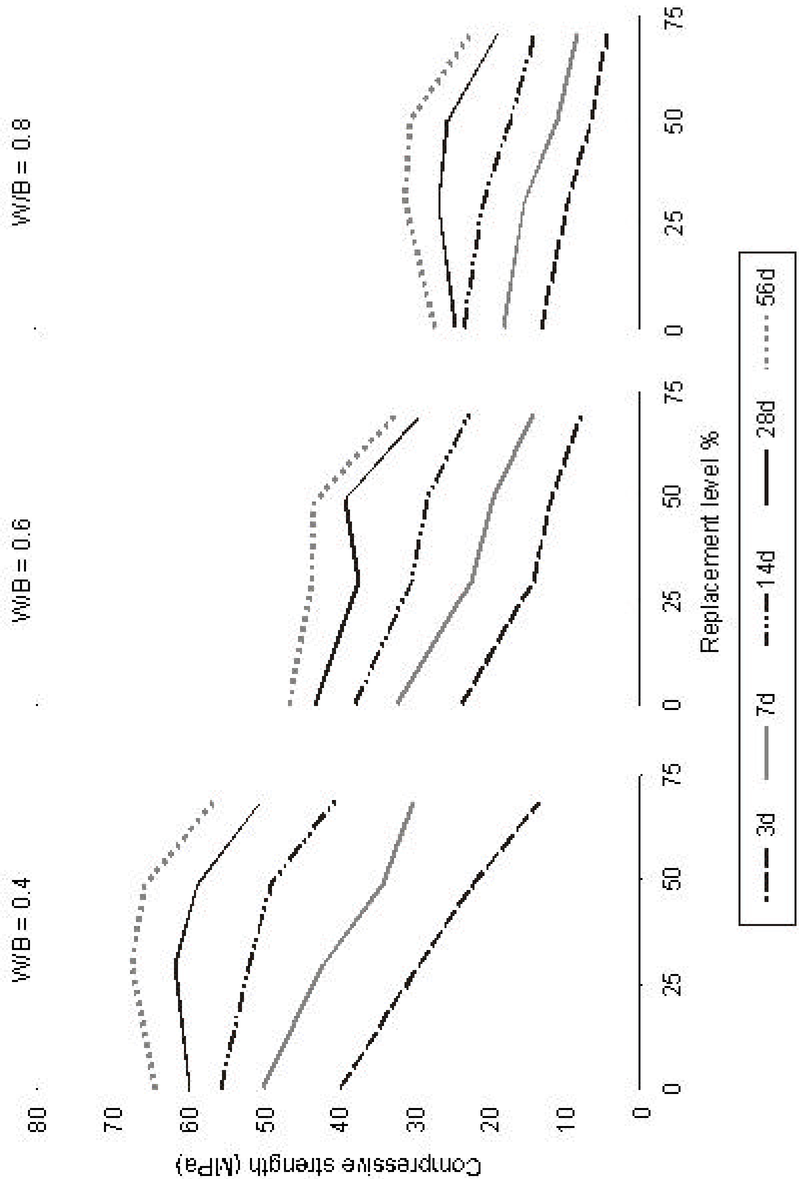


Figure 3b: Compressive strength of GGBS concretes as a function of slag replacement level and w/b ratio

PROPERTIES OF FRESH AND HARDENING CONCRETE

The workability and pumpability of Corex slag concretes are not significantly different from PC concretes of similar composition. Slag concretes may however have slightly lower water demands than PC concretes despite the fineness of slag particles. This has been ascribed to the fact that slag adsorbs less water than cement particles. Slag concretes are also more cohesive than similar PC concretes because of the fineness of the slag.

Setting times

The use of Corex slag in concrete will result in an increase in setting times as the initial rate of reaction between slag and water is slower than that of cement and water. Increase in setting time has the advantage of allowing a greater window within which to place and compact fresh concrete, but will cause delays in finishing operations of up to two hours or more. It is imperative that constructors appreciate these differences in fresh properties when working with slag concrete. Typical initial and final setting times[5] for PC and GGCS concretes are shown in Table 6.

Table 6: Initial and final setting times for standard cementitious pastes

Property	*100% PC*	*30% GGCS*	*50% GGCS*	*70% GGCS*
Initial set (min)	170	240	270	265
Final set (min)	255	325	355	420

Bleeding

The bleeding characteristics of concrete containing slag are influenced by the physical properties of the binders, water / binder ratio and replacement level. Slag concretes generally show lower bleed rates and capacity than similar PC concretes. This has been ascribed to the ability of the finer slag particles to hold water in the mix, and the more cohesive paste reducing segregation. Slag concretes do however bleed for longer periods due to increased setting times. Typical measurements of bleeding[6] for Western Cape concretes are shown in Figure 4.

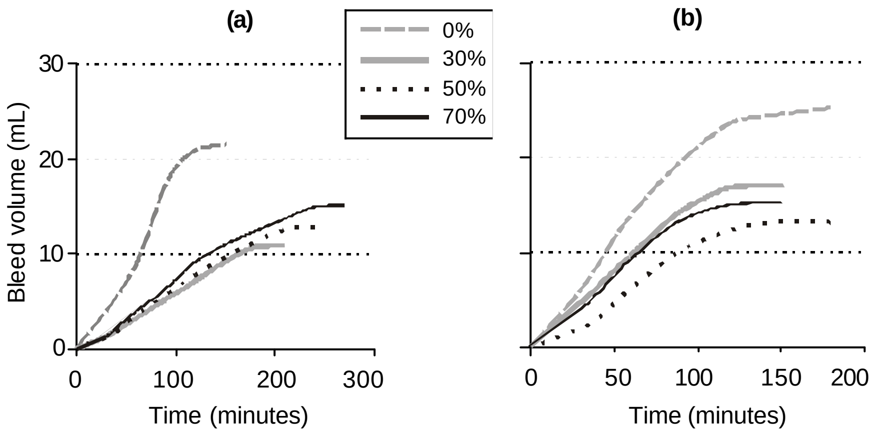


Figure 4: Bleeding characteristics for various Corex slag contents, at w/b ratios of (a) 0,4 and (b) 0,6)

Plastic cracking

Excessive bleeding will adversely affect the quality of concrete by causing bleed channels and lenses to form within the microstructure. Where concrete is restrained from settlement (e.g. above reinforcement or at changes in section) plastic settlement cracking may result. Slag concretes, which have lower levels of bleeding than PC concretes, are less likely to be affected by plastic settlement cracking. In cases where there is a high risk of plastic settlement, re-vibration of concrete should be specified to avoid plastic cracking.

All concretes that are exposed to severe drying during placing are prone to plastic shrinkage cracking. This occurs during hot and windy conditions when evaporation rates exceed bleed rates and plastic shrinkage occurs before the material has stiffened sufficiently. Concrete made with slag requires special treatment after placing to avoid possible plastic shrinkage cracking. This is because slag concretes have reduced bleed rates and longer setting times compared with PC concretes, thereby increasing the risk of early-age cracking. When evaporation rates exceed 1.0 kg / m^2 / hr, plastic shrinkage cracking will be almost inevitable unless stringent precautions are taken immediately after placing concrete, such as plastic covering, fog spraying, or sheltering the concrete.

Heat of hydration

Concrete made with GGBS has the advantage that the development of heat of hydration is not as rapid or intense as that displayed by PC concretes. This lower rate of heat development is beneficial since it reduces the risk of thermal cracking in large concrete pours.

However, concrete made with GGCS does not show this characteristic due to the higher reactivity of this slag material. Heat of hydration of GGCS concretes should be assumed to be similar to that achieved by similar PC concretes at the same binder contents. However, for concretes of equivalent compressive strength, the heat of hydration of Corex slag concrete will be lower than that of PC concrete because of the significantly lower binder content of the mix. Figure 5 shows typical adiabatic total heat plots for PC and slag concretes [7]. Replacement levels for GGCS and GGBS of 18 % and 50 % were used, as well as a control CEM I 42,5 cement.

CONSTRUCTION PRACTICE

Good construction practice is essential on site, regardless of the concrete type, to ensure adequate structural performance and durability. This includes proper handling and placing of concrete, correct cover to reinforcement, good compaction to remove entrapped air and adequate curing to ensure maximum cement hydration. It should be emphasised that the improvements possible by good materials selection and mix design are far smaller than the damage that is possible by poor site practice.

Slag concrete is more vulnerable to poor curing than PC concrete due to the longer setting times and slower rate of cementing reactions. The near-surface regions of slag concrete are most vulnerable to the effects of poor curing since premature drying prevents sufficient hydration within the microstructure. It is important therefore that special attention is given to curing of slag concrete structures. The sensitivity to curing tends to diminish with decreasing water/binder ratio (i.e. increasing grade), since this has the effect of increasing the rate of hydration and improving the quality of the microstructure.

The response of Corex slag concretes to curing is illustrated in Figure 6, using the index of water sorptivity. This index reflects the near surface properties of concrete, and has been shown to be sensitive to the nature and degree of curing. (Water sorptivity is one of a suite of three recent-

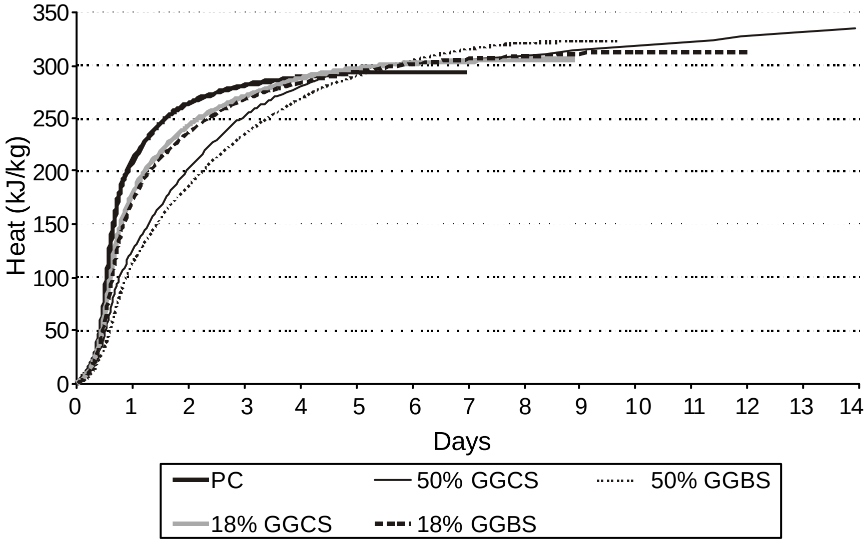
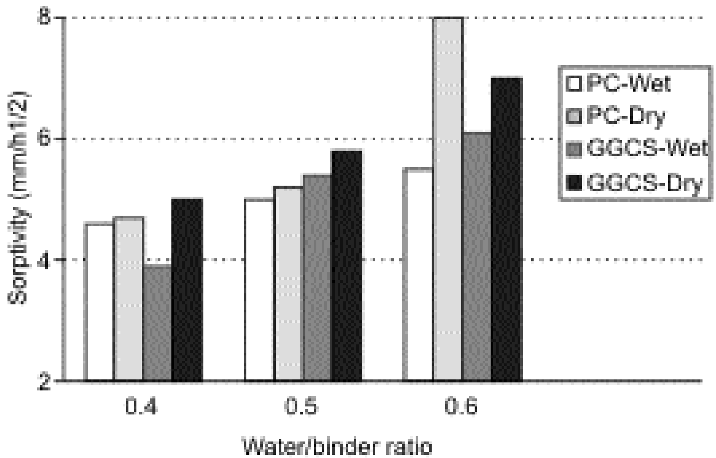


Figure 5: Heat of hydration for different slag binder combinations (Total heat produced)



Note: "Wet curing" refers to 28 d of wet curing, while "dry curing" refers to only 1 d of in-mould curing, in a laboratory environment. Lower sorptivity values represent better quality concrete.

Figure 6: Water sorptivity results for PC and slag concretes [2]

ly developed durability index tests that are sensitive to important material, environmental and processing factors that affect durability. These techniques include oxygen permeability, water sorptivity and chloride conductivity and are fully documented in Monographs 2, 3 and 4 [8,9,10]. Durability index tests are sensitive to changes in concrete pore structure that influence durability and may therefore be used to assess the quality of site concrete at early-ages (typically 28 days).)

The amount of curing required for concrete depends on the application, environment and service life expectations of the structure. A minimum of three days effective moist curing is often stipulated for PC concrete although this is seldom achieved in practice. With slag concrete however it is essential that a minimum of three days moist curing is achieved, but seven days curing is recommended. This may not be practical for all applications but it is important that some allowance is made for any lack of curing.

Curing of concrete is an activity that should commence immediately whenever possible. This is particularly important for flatwork such as slabs and panels that are prone to plastic shrinkage cracking. Special curing procedures are critical when casting in hot, dry and windy conditions when high evaporation rates are likely. High quality curing compounds, mist sprays, or plastic sheeting should be applied as soon as the surface sheen starts fading from the concrete surface.

The hydration reactions of slag in concrete form iron and manganese sulphides that give slag concrete its distinctive blue-greenish colour[11]. In contact with air the sulphides are oxidised and the blue colour disappears. Well-cured concrete will maintain its colour longer than poorly cured concrete that dries and allows air into the material. The surface coloration of slag concrete may therefore be used as a rough assessment of the effectiveness of curing. With time the blue colour will fade and will only be present at depth in high quality concrete.

COMPRESSIVE STRENGTH CHARACTERISTICS

Later-age compressive strength of concrete made with Corex slag is generally higher than similar PC concrete at replacement levels of up to 70%. Optimum strength performance at 28 days is achieved at a replacement level of approximately 50%. It is therefore possible to reduce total binder contents by up to 10% when using Corex slag. Figure 7 gives a design chart for achieving 28-day compressive strength with Western

Cape materials. (The strengths are average, not characteristic, strengths.)

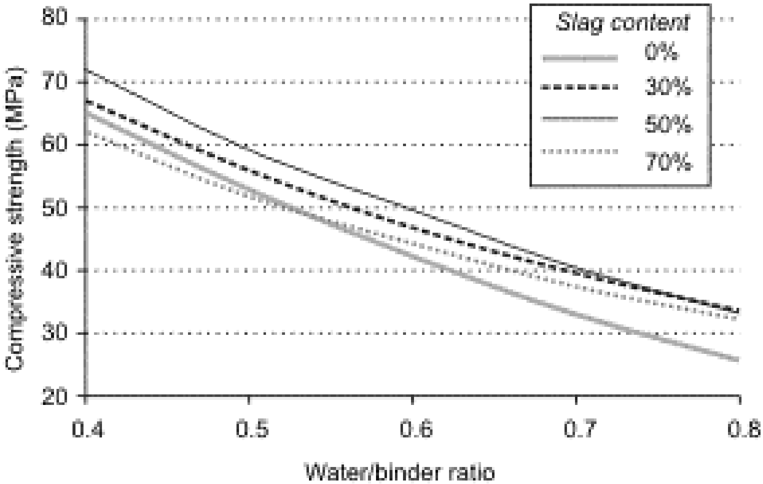


Figure 7: Design chart for 28 day compressive strengths of Corex slag concrete

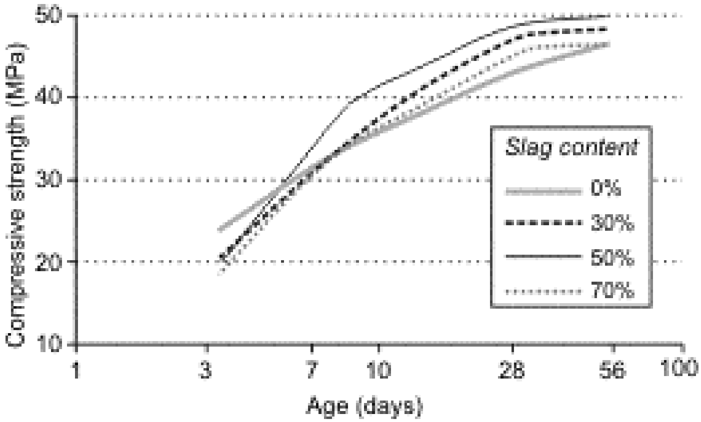


Figure 8: Strength development with time (w/b = 0.6)

Strength development of Corex slag concrete is more rapid than generally found for other slag concretes. GGCS concrete shows slower initial strength development up to about 3 days, but by seven days the rate increases dramatically with strengths well above those achieved by similar PC concrete. Long-term strength development of GGCS concrete after 28 days is however reduced compared to rates achieved by PC concretes or GGBS concretes. Strength development curves for different replacement levels of Corex slag are shown in Figure 8.

The rapid strength development of GGCS concrete has major advantages for many structural applications where slag concretes traditionally required long periods before de-propping, stressing or loading. Even at 70% replacement levels, the achievement of three-day strengths above 15 MPa is easily achieved. It should be noted however that one day strengths of GGCS concrete are likely to be considerably lower (e.g. 30-40% lower) than those achieved by PC concrete.

OTHER STRUCTURAL PROPERTIES

Other structural properties of slag concrete such as elastic modulus, drying shrinkage and creep are covered in this section. Importantly, the effect of aggregate type on these properties is often more significant than the effect of binder type.

Elastic modulus of concrete is a measure of the short-term stiffness of the material and is affected by aggregate type, mix proportions and paste quality. For precise estimates of structural deflections and likely deformations it is important to assess the concrete directly by means of testing. More general estimates of elastic modulus for slag concrete using Western Cape aggregates are shown in Table 7 [12,13,14].

Table 7: 28-day elastic modulus values for Corex slag concrete (GPa)

Aggregate type	*Concrete grade*				
	20 MPa	*30 MPa*	*40 MPa*	*50 MPa*	*60 MPa*
Greywacke	28	31	34	36	39
Granite	25	28	31	33	36
Sandstone	20	21	22	23	24

Concrete usually contains more water than can combine chemically with cement, and hence moisture is lost during drying causing drying shrinkage. Excessive shrinkage of concrete may result in cracking and undesirable deformations and therefore needs to be minimised. Higher strength concrete made with Corex slag should have slightly lower drying shrinkage (10-15% less) than similar PC concrete (see Figure 9). At water / binder ratios of 0.6 and above no significant difference in drying shrinkage should be expected between PC and GGCS concrete. Standard methods of predicting drying shrinkage can therefore be used for Corex slag concrete structures.

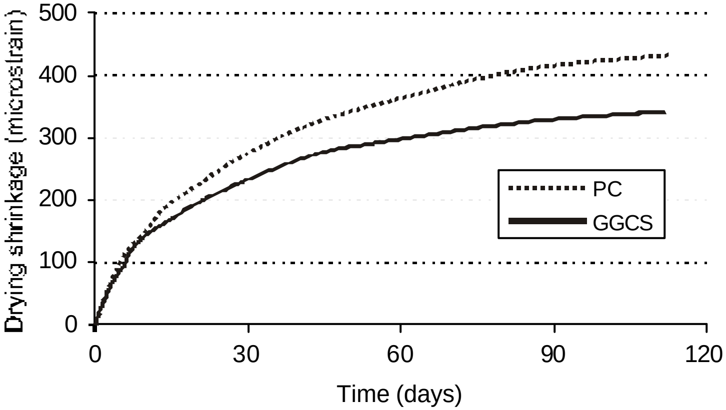


Figure 9: Drying shrinkage of concrete with w/b = 0.5 (drying environment 23°C and 60% R.H.)

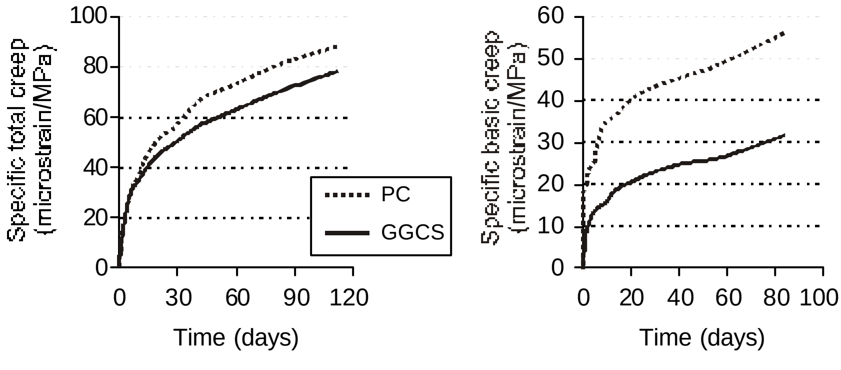


Figure 10: Specific creep (total and basic) of concrete with w/b = 0.5 (23°C and 60% R.H.)

Concrete under sustained load will continue to deform and creep with time. For deflection-sensitive concrete structures, allowance must be made for this long-term deformation to ensure satisfactory serviceability. Corex slag concrete exhibits low creep characteristics, due partly to the material's rapid strength development, producing somewhat lower creep factors than PC concrete. When considering basic creep (i.e. creep under constant moisture conditions) Corex slag concrete has significantly lower creep potential than PC concrete. These properties are illustrated in Figure 10 using laboratory data under environmental conditions of 23°C and 60% R.H.

DURABILITY PROPERTIES

Concrete structures made with slag have been used in many countries for decades thereby providing a good database for assessing long-term performance of the material. The durability of slag concrete structures has generally been very good, even in harsh exposure conditions such as marine environments.

The potential durability of concrete may be assessed at early-ages using durability index tests such as oxygen permeability, sorptivity and chloride conductivity. These techniques are able to measure transport processes such as permeation, absorption and diffusion that influence deterioration of concrete. Durability index tests are also sensitive to important material, processing and environmental factors affecting concrete durability [8,9,10].

Figure 11 shows typical durability index curves for corex slag, in terms of OPI, water sorptivity, and chloride conductivity. Oxygen permeability index is sensitive to compaction and curing of the concrete. Water sorptivity measures the rate of movement of a wetting front through concrete and is particularly sensitive to the influence of curing on near-surface concrete. Slag concretes required good moist curing, otherwise a poor surface layer will be produced that allows easy penetration of water and harmful agents. Chloride conductivity is a good measure of the chloride resistance of the concrete. In keeping with other slag concretes, corex slag concrete has excellent chloride resistance, and should be used for any structures in proximity to the sea.

Chloride resistance

Deterioration of reinforced concrete structures in marine environments is predominantly the result of chloride-induced steel corrosion. Potential durability may therefore be defined by the protection provid-

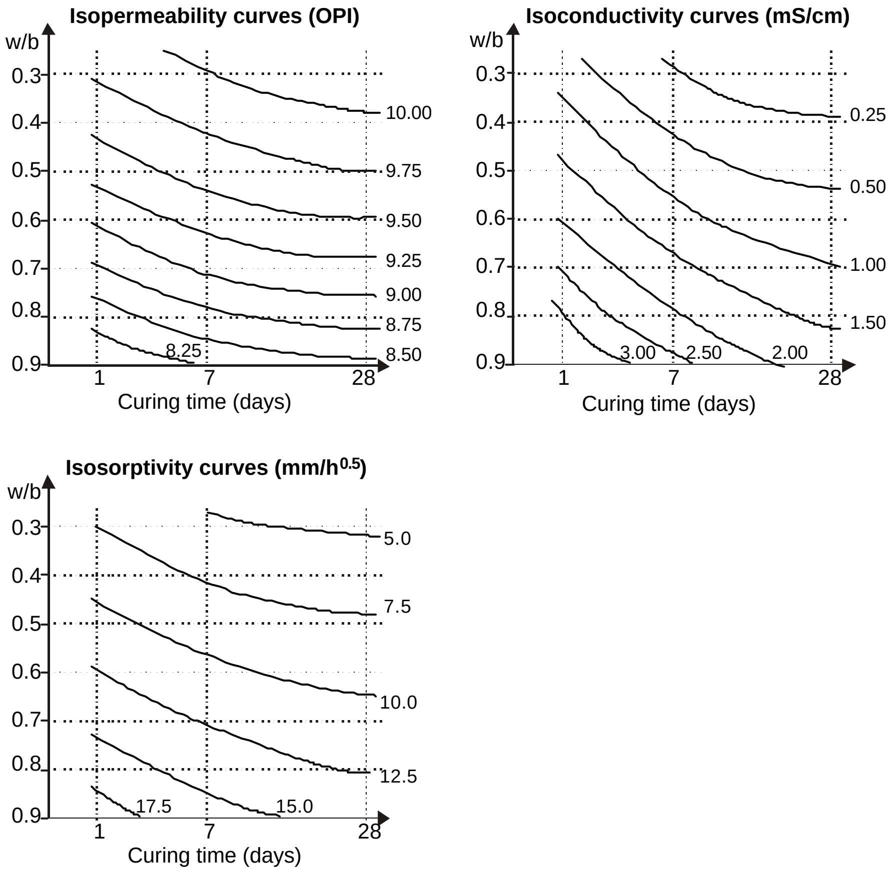


Figure 11: Iso-index charts for GGCS concretes

ed by the concrete cover to the reinforcement. The type of binder used in marine concretes has a major influence on durability since the materials affect the rate at which chloride ions move through concrete. Improved chloride resistance may be the result of refinement of the pore structure, such as occurs with silica fume concretes, or may be due to increased chloride binding by aluminate phases contained in materials such as fly ash and slag.

Slag concretes have excellent chloride resistance and provide far greater protection to steel than similar PC concretes. It should be noted that optimum chloride resistance is achieved at replacement levels of

50% and above, while replacement levels below 25% will provide little increase in chloride resistance. Requirements for achieving a predicted 50 year corrosion-free service life for different binder types are shown in Figure 12 (based on an empirical chloride prediction model) [15].

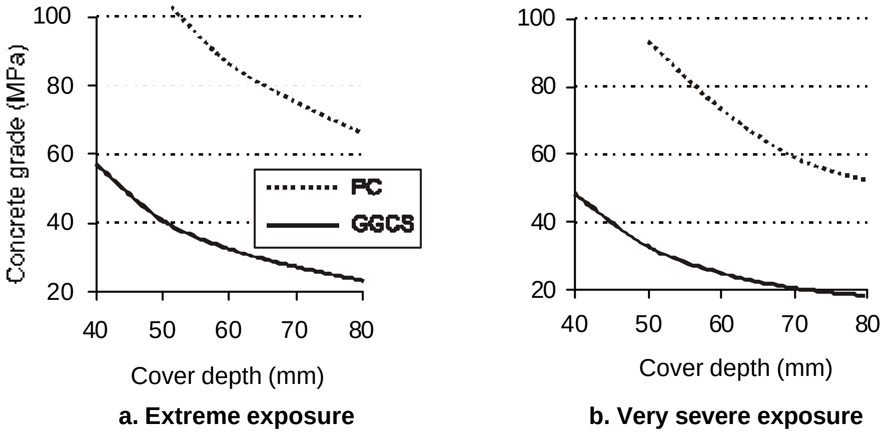
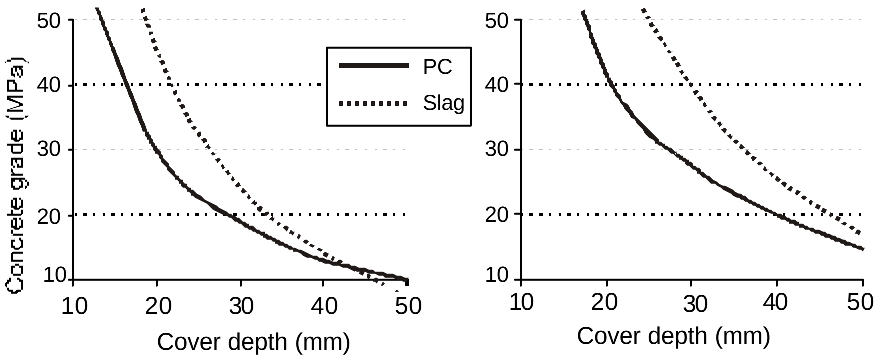


Figure 12: Cover and strength requirements for 50 year service life under S.A. marine conditions.
(See ref. 15 for a description of exposure conditions)

Carbonation

General corrosion of embedded reinforcement is caused by penetrating gases such as carbon dioxide and sulphur dioxide, which lower the pH of concrete. Gaseous diffusion of carbon dioxide into concrete causes carbonation, converting alkaline calcium hydroxide into more neutral calcium carbonate. This process is fairly slow through good quality concrete and the resulting corrosion is generally much milder than chloride-induced corrosion.

Slag concretes generally have higher carbonation rates than similar PC concretes as there is less carbonatable material and the concrete may be slightly more permeable to gases. Accelerated carbonation exposure of Corex slag concrete found that carbonation resistance was higher than equivalent PC concrete [2]. It may however be prudent to use blastfurnace slag carbonation characteristics until long-term exposure data becomes available. Requirements for 50 year corrosion-free service for PC and slag concrete under Cape Town environments (80% R.H.) and drier inland conditions (60% R.H.) are shown in Figure 13 [16]. Despite the poorer carbonation resistance of slag concrete, adequate protection from carbonation-induced corrosion is possible using only a moderate grade concrete and moderate cover depths.



a. Cape Town environment (80% RH) **b. Dry inland conditions (60% RH)**

Figure 13: Cover and strength requirements for 50 year service life under carbonating conditions

Alkali silica reaction

The use of slag in concrete is accepted worldwide as a means of reducing the risk of expansion due to alkali silica reaction (ASR). Amelioration of ASR expansion by slag concretes is thought to be due to the lowering of the pore water alkalinity and reducing the mobility of ions. It is recommended that 50% replacement of cement with Corex slag be specified to prevent ASR damage when using reactive greywacke aggregate (Malmesbury shale). Figure 14 shows ASR expansion measurements using SABS Method 1245 (accelerated mortar prism test) [17], which states that potential ASR is non-problematic provided expansion in the test at 12 days is less than 0,10%.

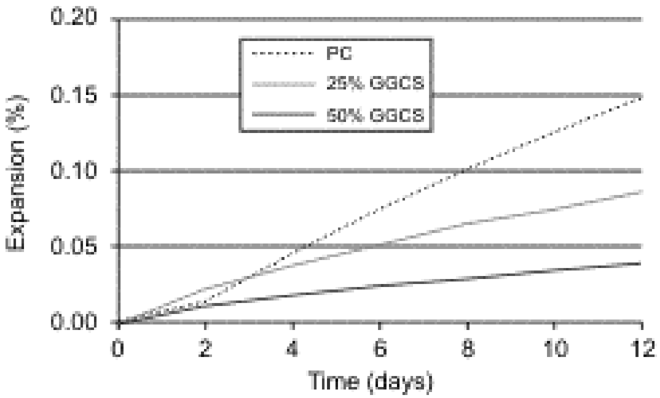


Figure 14: ASR expansion of PC and GGCS binders with reactive Greywacke aggregate

ECONOMIC ADVANTAGES OF USING SLAG CONCRETE

Cost comparisons of concrete structures should preferably be done using Life Cycle Costing techniques. On this basis, slag concretes will in most circumstances prove to be very economical, particularly in aggressive environmental conditions. However, the economic advantages of using slag concrete can be demonstrated even in the short-term. The high reactivity of Corex slag means that less total binder is required for any given compressive strength. Figure 15 shows the materials costs of PC and GGCS concretes required for achieving a range of structural strength grades (based on August 2002 material prices in the Western Cape).

Cost comparisons made on the basis of durability performance show the significant advantage of using slag concrete in marine environments. Figure 16 shows typical materials costs for concrete exposed to very severe marine environments. This costing analysis assumes similar cover depths will be selected for both types of concrete; in reality PC concrete will require higher cover depths with associated further costs for the structure and possible technical problems such as susceptibility to cracking.

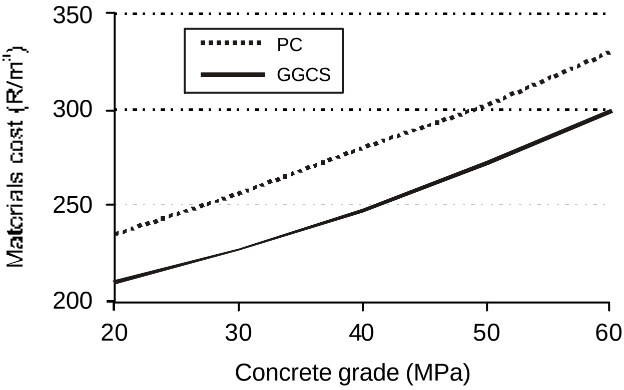


Figure 15: Materials costs (Rands/m³) of concrete for various concrete grades

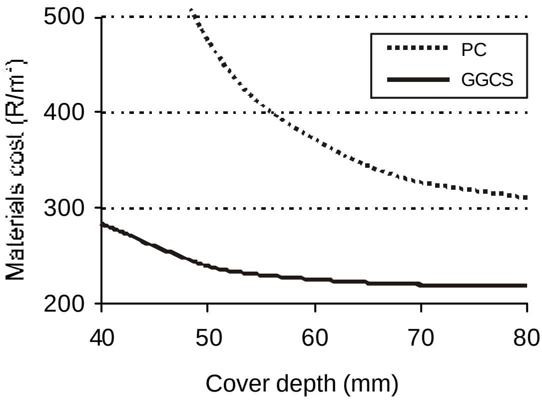


Figure 16: Materials costs (Rands/m³) for very severe marine environments

CONCLUSIONS

Extensive testing of Corex slag concretes found that GGCS displays all of the technical advantages expected when used in concrete. The improved fineness and chemical composition of the material produce rapid strength development after 3 days, and help to make the concrete somewhat less vulnerable to poor curing compared with other slags. Most structural properties of concrete made with Corex slag are similar or better than equivalent PC concretes. Provided reasonable precautions are adopted during placing and finishing of GGCS concrete, a sound and durable material can be achieved.

The use of Corex slag in concrete significantly improves the durability of the material, particularly with regard to chloride resistance. Reinforced concrete structures using GGCS can be made with moderate strength grades and reasonable cover to reinforcement without compromising on durability. With adequate replacement levels of slag it is also possible to negate the effects of alkali silica reaction when using reactive aggregates.

Corex slag has already had a major impact on the concrete market in the Western Cape. The product has been widely accepted because of economic, technical and environmental imperatives. Intelligent use of the material by engineers, specifiers and constructors should assist in ensuring high quality concrete construction in the region.

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