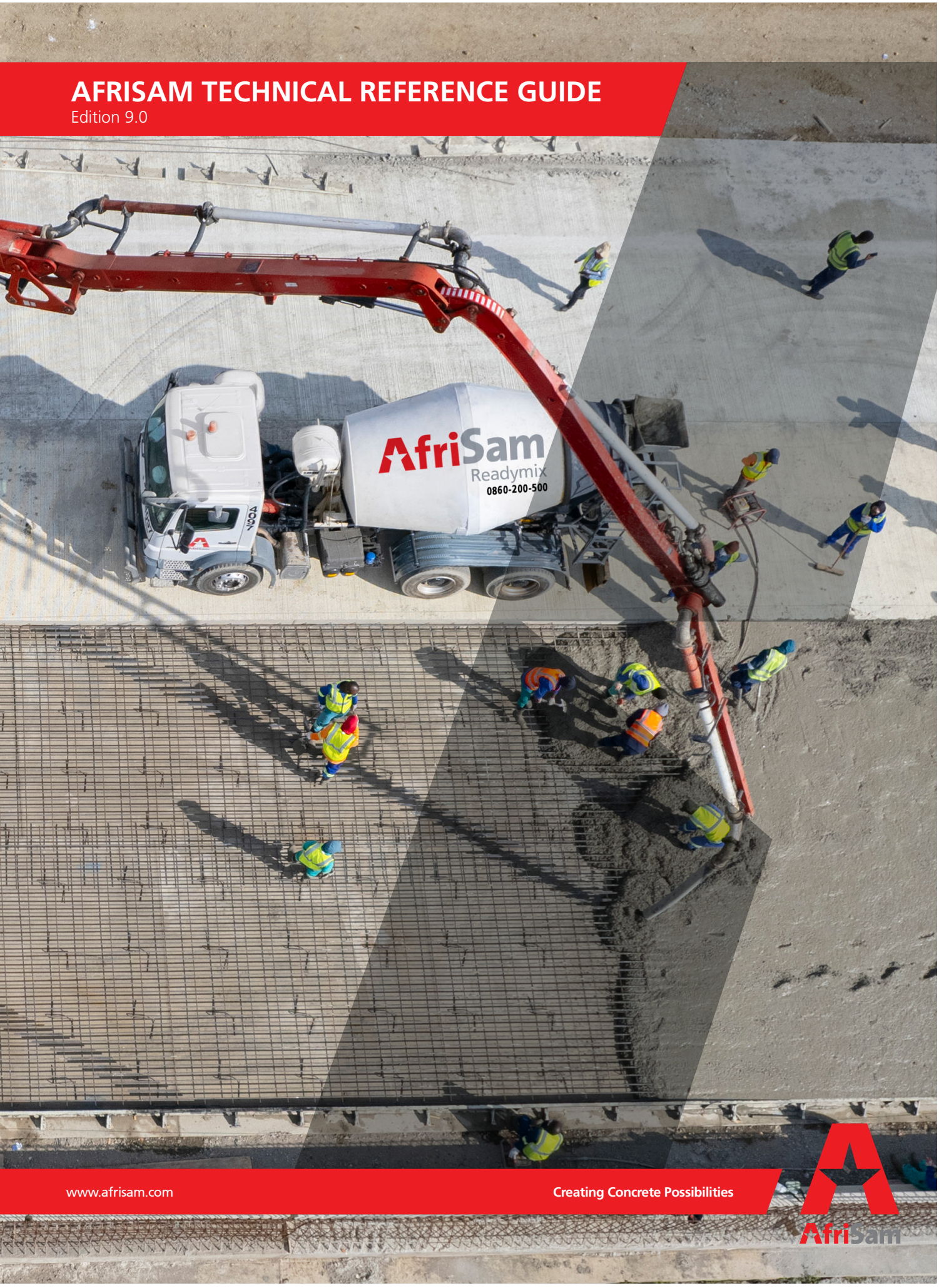
AFRISAM TECHNICAL REFERENCE GUIDE

Edition 9.0



www.afrisam.com

Creating Concrete Possibilities

AfriSam

On the cover:
Zeitz MOCAA

Once an agricultural export facility the Grain Silo Complex in Cape Town is gaining a second life as a contemporary art museum. One of the most important aspects of reviving this magnificent building is to maintain its historic industrial character, celebrating its heritage and bringing the past, present and future together.

As a proud sponsor of this space for contemporary African art AfriSam is delighted to enable the Zeitz MOCAA's innovative designs with our equally innovative materials. With AfriSam's help the possibilities of this amazing structure are becoming a reality.



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Every effort has been made to ensure the accuracy of the data and information presented, and no liability is accepted for errors or omissions.

AFRISAM
TECHNICAL REFERENCE GUIDE

A guide to the use of our products for both the professional and the enthusiast.





To add value to our unique product range, we give you access to the combined knowledge of all our staff members.

Foreword



The origins of the AfriSam Technical Reference Guide go back fifteen years to an A4 ring-bound file, which included information from Hippo Quarries' publications on aggregates, relevant readymix information, and a brief Alpha Cement section. The Holcim Materials Handbook 2005 (with its 2006/2007 update) and the subsequent AfriSam Technical Reference Guide 2009, amplified the value of the original publication by adding more product information and a concise summary of our products.

In this new AfriSam Technical Reference Guide, we have not only updated information about our Cement, Aggregate and Readymix products, we have updated and moved all the information formerly split into different categories (specification, manufacture, handling and applications) into the relevant sections, i.e. the Cement section now includes details on the manufacturing process, cement chemistry, specifications, handling and applications.



Eric Diack
Executive Chairman
AfriSam (South Africa) (Pty) Ltd



The Concrete section gives the reader guidelines to achieving good concrete practices for both readymix and site-batched concrete, and the section on the properties of hardened concrete covers other intrinsic and extrinsic factors that can affect strength, deformation and durability, and the measures that can be taken to minimise or avoid these factors.

We hope that this new format with its accompanying electronic version will be of even more use to our customers, students and everyone involved in the construction and related industries.

The AfriSam Technical Reference Guide continues to be the repository of the combined knowledge of both past and present staff members, and I would like to thank all involved for their input.

AfriSam Shared Service Centre (Head Office)

T: (011) 670 5500

A: Constantia Office Park,
Cnr 14th Avenue & Hendrik Potgieter Road,
Weltevreden Park

Contact us for all your cement, aggregate and readymix concrete requirements.



Reg No. 2006/005910/07 | VAT No. 4710234701

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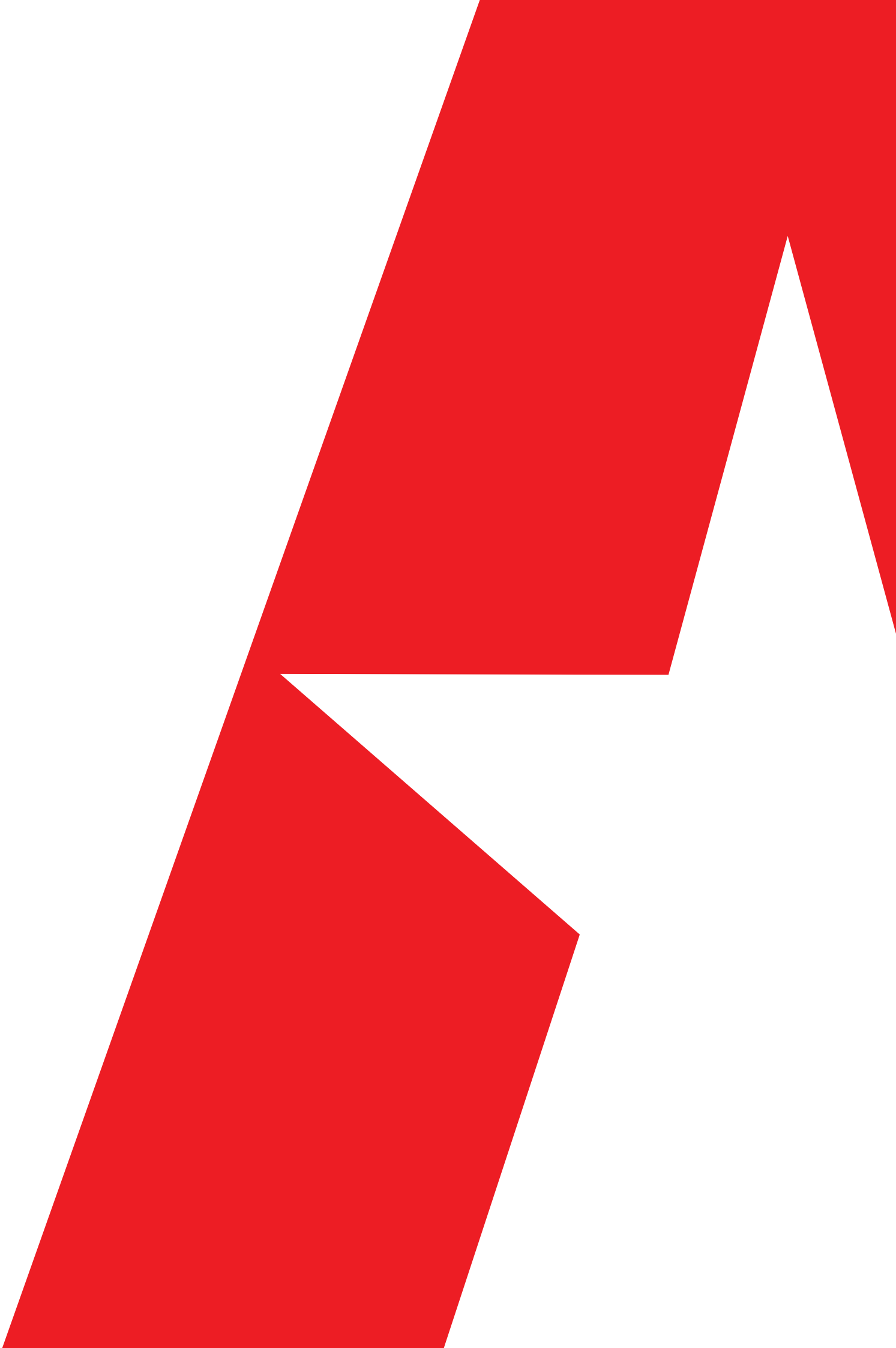
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Corporate



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Corporate



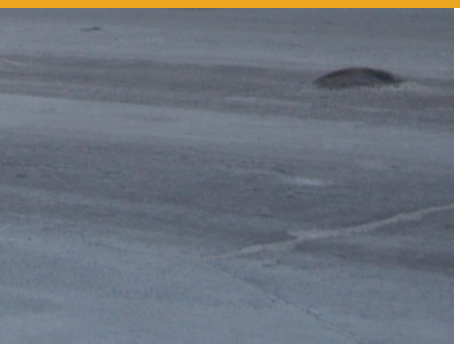
Founded in 1934, AfriSam has established itself as a formidable company committed to making growth on the African continent possible. Today, we continue to be the leading supplier of superior quality construction materials and technical solutions.

AfriSam is passionate in the collective cause to conserve our planet and has the utmost respect for the environment. As such, we use natural resources in a deliberated way and actively pursue activities that support sustainable development. We direct much effort towards environmental stewardship, ensuring life for future generations.

We embrace our cultural heritage and see ourselves as part of the communities within which we operate.

AfriSam is committed to producing quality construction products.





We strive for a responsible and engaging approach with all stakeholders and support the communities in the areas within which we operate through ongoing community upliftment initiatives.

To deliver value to our customers, we are uncompromising in our drive to deliver superior performance on all frontiers. We are renowned for our technical expertise, providing superior quality construction materials and services and always striving to exceed the expectations of our customers. We conduct our business with unquestionable integrity, ethics and professional standards.



> “AfriSam captures the essence of what we are: ‘Afri’ refers to our African heritage, and ‘Sam’ relates to the word cement in six of South Africa’s official languages.”

AfriSam Cement, Aggregate and Readymix operations have ISO 9001 certification. In addition, our cement operations have ISO 14001 and OHSAS 18001 certification, and the Centre of Product Excellence laboratories at our Roodepoort operation has ISO 17025 accreditation.

Core values

People: We strive to conduct business dealings and communication with integrity and in a professional, courteous and honest manner.

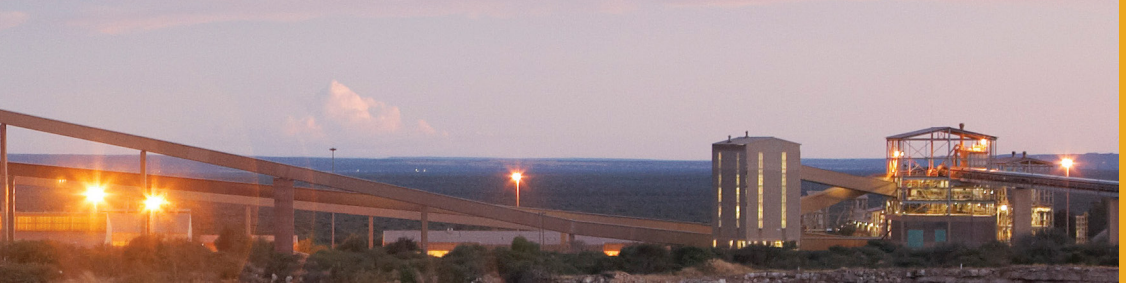
Planet: We are responsible for the impact of our actions on the community and environment. We embrace our cultural heritage and have a responsible approach to all stakeholders. We use natural resources in a way that will sustain life for future generations.

Performance: We are uncompromising in our professionalism and strive to be the best in everything we do. We utilise our time, energy and resources to make a valuable contribution to our customers, colleagues and business partners.



For more detailed information regarding AfriSam activities, see our website: **www.afrisam.com**

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Quality control

AfriSam offers customers cement, aggregate and readymix concrete products of the highest possible quality and, in order to do this, we apply a range of quality control tools.

Quality control services include process control testing of cement, readymix and aggregate products, ongoing monitoring of the performance of cements in concrete and involvement in ongoing and special research projects. Results of all these tests are closely monitored for deviations beyond pre-set tolerances, and are analysed to identify trends in order to implement preventive action and to continuously improve our products.

Plant laboratories based at AfriSam Cement, Aggregate and Readymix operations carry out ongoing process control testing on our products.

Quality control during manufacture, and quality assurance support.

Cement laboratories

Routine chemical and physical tests are carried out on an ongoing basis on raw meal, in-process material and end product to assist the production staff to control cement quality during the entire process, from selection of blast sites in the quarry, through raw meal proportioning, adjustment of kiln temperatures and grinding parameters, to blending proportions and final product.

Aggregate laboratories

Samples are taken on an ongoing basis and subjected to grading analysis and flakiness index testing (in the case of stone) to ensure that no non-conforming aggregate leaves the quarry or crushing plant. Grading and density results form the basis of concrete mix designs.

Readymix laboratories

Samples of concrete leaving the plant (and where required, on-site) are subjected to slump tests to check workability against customer requirements, and made up into cubes for testing compressive strength to ensure ongoing compliance with strength requirements.

Non-conforming results are reported immediately to management for in-depth investigation. In addition, results are captured to centrally-based customised computer systems for analysis and preventive/corrective action.

Quality assurance

AfriSam's Centre of Product Excellence (CPE), based in Roodepoort, provides extensive quality assurance services and support to all AfriSam's business units, interacting with sales and technical staff and responding to direct requests from our customers.

Technical assistance

The CPE develops and tests products to comply with requirements for specialised applications and project specifications, and also conducts extensive analyses and forensic investigation to determine the root causes of shortcomings and develop solutions.

Technical advice includes assistance in designing mixes for specialised applications. CPE consultants are available countrywide to provide trouble-shooting services and technical assessment of materials and processes at the customer's site. Where required, our consultants arrange for trial mixes and other testing services to be carried out in controlled laboratory conditions at Roodepoort.

The department is able to conduct detailed investigations into situations where concrete has not achieved the required performance characteristics for which it was designed.

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Centre of Product Excellence (CPE) laboratories

The CPE Chemical, Physical and Materials Laboratories carry out a wide range of tests on cements and concrete, including mix optimisation and durability index testing.

Process control test results from all AfriSam plant laboratories are captured to a cement monitoring programme. In addition, the performance of AfriSam and other cements in concrete is monitored by ongoing compressive strength testing using standard reference materials. The electronic monitoring report correlates all these results and gives managers immediate access to trend analysis reports, with the consequent ability to make decisions concerning raw meal proportioning to ensure that the required performance criteria are maintained at all times.

Product development

Projects researching different properties of cements, supplementary cementitious materials, aggregates and concrete, are initiated and carried out in conjunction with customers, universities and other bodies. Current projects include an eight-year assessment of the effects of highly-corrosive environments on concretes made with differing proportions and types of raw materials. These test results form the baseline for a custom-built computer programme which enables architects and contractors to specify the correct grade of concrete for the prevailing environmental conditions. This programme is available on request; contact the CPE or visit the AfriSam website for further details.

CPE Training Academy

Internal training is provided by the CPE to assist sales and other staff members who deal directly with customers, covering product knowledge and best construction practices to assist them in adding value during customer interactions.

External training typically results from investigation into problems encountered on-site, and focuses on taking product and application knowledge to AfriSam customers, as well as ensuring that customers are aware of correct sampling and testing issues.

Universities and technikons

The CPE runs an annual programme to promote Civil Engineering student interaction with AfriSam processes at various levels. Courses, practicals and site visits for students from the Universities of the Witwatersrand, Johannesburg and Pretoria, as well as UNISA ensure that these students gain detailed knowledge of cement manufacturing processes, our products and quality controls, and a better understanding of concrete durability issues.

This programme includes organising access to AfriSam laboratories in the Cape, KwaZulu-Natal and Gauteng for UNISA Civil Engineering students completing their practical assignments.

Input to industry boards

The CPE provides critical professional input to numerous industry boards, and also serves on various committees including South African Bureau of Standards (SABS), The Concrete Institute of South Africa and Association of Cementitious Materials Producers (ACMP), playing a leading role in the different technical work groups.



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Environmental

AfriSam's first environmental policy was published in 1994, committing us to ongoing optimal utilisation of resources and to rehabilitating our mining sites to self-sustaining, positively-usable landforms on final closure.

We conduct our operations in such a way that we minimise any potentially adverse effects of the processes involved in manufacturing cement, readymix concrete and aggregate on the environment, the community and ourselves. We promote eco-efficiency, conservation of non-renewable resources and recycling of waste materials.

The current worldwide focus on reducing carbon emissions has been an environmental target for AfriSam for more than a decade. Accurate technical reporting has further enabled AfriSam to calculate both total (gross) and specific (CO_2 per ton of cement) emissions since 1990. This measurement, coupled with our benchmarking programme for energy saving and emission reduction, has enabled management to set ambitious CO_2 reduction targets.

Significant CO_2 reductions have resulted from reduced clinker content of cement, increased fuel efficiencies resulting from improved kiln firing, heat recovery and more efficient mining equipment. In addition, capital investment in electrically-efficient cement plant equipment has decreased electrical consumption dramatically.

To assess our performance against our policy goals, AfriSam subscribes to scheduled audits of environmental systems by certification bodies such as SABS and SGS. We also participate in industry association improvement programme conducted by ASPASA and ACMP. Our environmental policy commitment to continual improvement is assured by implementation of corrective and preventive actions stemming from these audits, and via regular management reviews.

AfriSam is committed to producing environmentally-responsible building materials without compromising on product function or performance. In continuing to seek ways to improve systems and processes to surpass environmental norms, we have not only quantified the CO_2 footprints of our production facilities and products, we have even quantified the footprints of our administrative offices in Gauteng, Western Cape and KwaZulu-Natal.

AfriSam mining

In terms of mining, both for raw materials for cement and for aggregate, by adopting the principles the International Chamber of Commerce "Business Charter for Sustainable Development", AfriSam reconciles the "finiteness" and, as such, non-sustainability of our mineral resources with the policy goal of supporting "sustainability".

Planning and foresight govern our surface mining, and the subsequent rehabilitation of mines is a land use transformation that not only contributes to current needs for construction materials, but also allows the return of the mined land to a new land use once mining operations end.

All AfriSam mines operate in terms of approved Environmental Management Programme that encourage optimal utilisation of resources. A Trust Fund provides for rehabilitation on closure to a positively useful or self-sustaining landform. Typically this includes the development of office parks, shopping complexes, sports facilities, residential areas, water storage, or even landfills for waste generated by surrounding communities.

AfriSam Cement

AfriSam can accurately calculate CO_2 emissions for the cement business unit, and constantly strives towards remaining one of the lowest CO_2 generators per ton of cement in Africa. As a result of our energy efficiency and clinker reduction programme, AfriSam has been able to reduce specific CO_2 emissions per ton of cement produced by more than 30%, making a significant contribution to minimising potentially adverse effects on the community, the environment and ourselves. By conducting extensive research into the effect of increased contents of secondary materials from other industries, we not only decrease the CO_2 footprint of cements, but also decrease the amount of usable material that would otherwise end up in landfills.

The CO_2 footprint rating stamps on AfriSam cement bags, an industry first, are the result of calculation of the CO_2 footprint in g/kg of each cement product from each plant by an independent consultant in terms of the Cement CO_2 Protocol developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The Cement Sector Initiative CO_2 methodology used takes into account not only production data on raw materials, fuel consumption and kiln running costs, but also internal transport costs for each AfriSam Cement operation (scope 1, 2 and 3 emissions).

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Table 1: AfriSam's achievements

Year	Programme	Industry status
1992	Environmental department established	First
1994	Environmental policy published and principles of Sustainable Development	SA first
1994 to 1996	Participation in TC207, SA Technical Committee informing 14001 development process	SA first
2000	"Project Green Cement" implemented: significant reduction of clinker content of cements, reduction in use of non-renewable resources, cement compliance with SABS specifications	SA first
2002	Annual spot measurement of metals, dioxins, furans and PCBs in kiln emissions introduced	SA first
2002 to 2005	OPSIS continuous emissions monitoring system installed in cement stacks	SA first
2002 to 2008	ASPASA About Face Environmental Management Programme: top awards	Leader
2003	Bag filters installed at Lichtenburg cement plant	SA first
2005	Energy Efficiency Accord signatory	Leader
2006 to date	Environmental Awareness Programme run for all employees	Leader
2008	NBI Energy Efficiency Sector winners of electrical energy savings	SA first
2009	CO_2 footprint quantified at all 17 quarries and 40 readymix operations	World first
2010	Cement CO_2-rating system calculating CO_2 generated per ton of each AfriSam cement introduced	Leader
2010	EC Standard 76/2000/EC emission limits for kilns utilising alternative fuels met	World first
2010	Eco Building Cement with carbon footprint less than half world average launched	Industry first
2010	Eco Readymix concrete products launched	Industry first
2010	Nedbank Green Mining Award in Environmental Category for CO_2 reduction and labelling initiative	Ongoing improvement
2011	Mail & Guardian Greening the Future Awards in the Energy Efficiency and CO_2 Management categories	
2011	Green Star acceptance in the South African Building Industry	
2011/12	CRF Institute's Best Employer Certification	
2012	Signing up for the Eskom 49M initiative	Leader

"Currently our Eco Building Cement and All Purpose Cement products' average carbon footprints are nearly half the 960 calculated for manufactured CEM 1."

See *Cement* for average carbon footprint scoring.

Dudfield Quarry topsoil is replaced in depleted shallow workings, and the mined land is returned to grazing within two years.

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Continuous improvement

We continue to improve our performance by numerous benchmarking programmes and initiatives including:

- **New kiln technology**
- **Kiln efficiencies**
- **Reduced particulate emission**
  Our OPSIS Continuous Emission Measuring equipment on kiln stacks measures 13 gas streams on a minute-by-minute basis. In addition, we conduct annual measurements on 13 metals as well as on dioxin, furan and PCB emissions, all of which fall within international and World Health Organisation limits.
- **Installation of bag-house filter technology** for reducing kiln emissions.
- **Process optimisation**
  AfriSam actively pursues the use of alternative fuels and resources (AFRs) as safe substitutes for fossil-derived fuels and non-renewable resources in production processes.

> *Dudfield Kiln 3 upgrade reduced energy consumption by 15%.*

AfriSam Aggregate

In 2009, the CO_2 footprints of all AfriSam quarries were quantified. To assist in reducing the quarry carbon footprint, an agreement was reached with AfriSam's Gauteng readymix plants to increase standard stone size to 22mm, with an ongoing added benefit being that the production of larger stone sizes requires less energy!

All AfriSam Aggregate operations participate in the Aggregate and Sand Producers of South Africa's (ASPASA) About Face Environmental Management Programme. This programme is run across the industry every two years and is audited by independent environmental auditors under the leadership of an accredited Lead Auditor. AfriSam has occupied top award positions in this competition since its inception.

AfriSam Readymix

The CO_2 footprints of all AfriSam Readymix plants have been quantified since 2009. We have also quantified the carbon footprints of our readymix products, and are now able to compare our AfriSam Readymix concretes with typical industry products, and show the percentage reduction in carbon emission of each.

To effect ongoing improvement in environmental issues in Gauteng, we have increased the standard nominal stone size (19mm to 22mm, and 26,5mm to 37,5mm) to give mix designs with reduced water content. This means a reduction in the amount of cement for the same water:cement ratios (W/C), and thus further reduces the carbon footprint of the concrete.

In addition, a target for all AfriSam Readymix plants is to move towards the goal of Zero Effluent. Where possible, return-load concrete is recycled at our plants or quarries, and at most operations fresh water consumption has been significantly reduced through recycling of water on-site, in some instances by up to 70 litres/m^3 of concrete.
See *Readymix* for current product CO_2 ratings.

Environmental sponsorships

AfriSam is a patron member of the Wildlife and Environment Society of South Africa (WESSA) and a Corporate Member of the Worldwide Wildlife Foundation of South Africa (WWF-SA). We have been active members of these organisations donating land with high conservation status, and building and subsequently upgrading an educational facility chalet for WESSA in the Umgeni Valley, Howick.

Our investments in the community include sponsoring diverse environmental education initiatives such as:

- The National Qualifications Framework accredited Teacher's Training course at Delta Environment Centre, Delta Park, Johannesburg.
- The AfriSam Activity Centre at the Two Oceans Aquarium in Cape Town.
- Four bursaries covering all aspects of study and accommodation for deserving conservationists at the South African Wildlife College.

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Health and **safety**

AfriSam recognises the right of employees, contractors and customers to a safe and healthy working environment and therefore strives for Zero Harm to all. Appropriate health and safety programmes are implemented at each cement, readymix and aggregate production operation, with operation-specific occupational health and safety objectives.

Health and safety objectives and targets are set annually. Performance is monitored, evaluated and measured on a continuous basis to improve health and safety structures, with the emphasis on performance measurement and review to ensure that health and safety activities are more closely aligned with the overall risk management framework.

Appropriate health and safety training is provided for all employees and contractors in order to foster suitable levels of competency, enabling them to undertake work activities safely and responsibly. AfriSam employees are encouraged to participate in health and safety structures and forums to enable them to identify and measure key safety behaviours in the workplace.

In addition, all AfriSam operations aim to act as "exemplars" in health and safety matters in relation to AfriSam stakeholders. This includes setting health and safety contractual obligations and standards for suppliers and contractors to "push" health and safety compliance down the supply chain, and making arrangements to monitor compliance with those standards.



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Corporate social **responsibility**

We place a high priority on our community involvement, and believe that, as a responsible corporate citizen, it is our role to help uplift communities in which we operate.

A clearly defined mission guides our corporate social responsibility (CSR) initiatives:

- Understand the needs of societies and communities in areas where we do business, and make meaningful and sustainable contributions to their upliftment.
- Concentrate efforts where we believe we can be most effective, and select projects that will, over time, be sustained from within the community itself.
- In the education area, aim to empower and equip communities with knowledge and skills, while providing them with tools and facilities to become self-reliant and sustainable.
- Empower host communities in environmental matters affecting our common heritage and livelihoods.

In addition, we are actively involved in initiatives that seek to establish and promote provincial and national programmes supporting AfriSam's business objectives and our community involvement policy, including HIV/Aids projects, low-cost housing and provision of assistance for disasters such as floods.

Employee Involvement Programme

Recognising that our employees are major stakeholders in providing additional value to our CSR initiatives, we have implemented an ongoing Employee Involvement Programme, through which employees can become active participants in the quest to give back to the community. The programme, called Mbeu, which is a Tshivenda word meaning seed, aims to further our vision of building strong foundations in the communities in which we operate. The initiative involves staff participation programmes in which employees raise funds for various causes and in some instances, get down to physical labour to assist charity organisations.

AfriSam CSR involvement includes:

- Whole School Development Programme, aimed at improving the running of nominated disadvantaged schools, and turning them into community-friendly centres of knowledge and practical life skills.
- Entrepreneurial development projects to train community members (particularly the youth), providing them with skills to obtain employment or open up small businesses.
- Tertiary education and learnerships for engineering students.

Applicable specifications

ISO 9001:2008/Cor 1:2009: Quality management systems – Requirements
ISO 17025:2005: General requirements for the competence of testing and calibration laboratories
SANS 14001:2005/Cor 1:2009: Environmental management systems – Requirements with guidance for use
OHSAS 18001:2007: Occupational health and safety management systems – Requirements

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Cement





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Cement

With operations in Southern Africa, we have the capacity to produce and deliver over five million tons of cement annually. We continuously monitor, review and improve our production processes to ensure optimal efficiency with the lowest possible impact on the environment.



AfriSam's cement products have been used in South Africa for three quarters of a century.





Operation and depot locations:

1 Vanderbijlpark
2 Bloemfontein
3 Brakpan
4 Dudfield
5 East London
6 Lichtenburg
7 Maseru
8 Matsapha
9 Queenstown
10 Roodepoort
11 Ulco
12 Port Elizabeth



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Introduction

AfriSam products are the result of years of thorough research and development by a dedicated team of cement technicians. The performance of our cement products is constantly monitored to maintain quality and strength in compliance to the requirements of SANS 50197.

In addition to ISO 9001 certification of all manufacturing and blending operations, all AfriSam cement has the SABS mark, and is subject to ongoing sampling, testing and monitoring to rigorous standards. Both quality control and quality assurance systems are in place. See also *Corporate*.

As part of AfriSam's dedication to best practice in the industry, a CO_2 rating scheme has been implemented and is maintained for all our cement products. The rating stamp on each AfriSam cement bag indicates the carbon footprint of each product relative to manufactured CEM I cement.

> *In this edition of the AfriSam Technical Reference Guide, CO_2 ratings are based on calculation of values, and CO_2/ton. Request current CO_2 footprint values from the AfriSam Centre of Product Excellence, e.g. for Green Star-rated projects.*

In addition, a customer support service is offered to make AfriSam's product knowledge base available to professionals involved in design, specification and construction where cement, aggregates and readymix or site-batched concrete are used. The service is aimed at providing information and promoting good concrete practice. See also *Corporate*.

For more information about the effect of good site practice on concrete quality, see *Concrete*.

> *Brochures giving guidance on using the products are available on request.*
>
> *For actual information on product composition and performance, request current data from the AfriSam Centre of Product Excellence.*

Volume **mixes**

To ensure that concrete made with our cement achieves the required workability and potential strength, the following standard volume mixes are printed on each All Purpose Cement and Starbuild bag:

- Concrete: Mixes for different strength classes and applications.
- Mortar: Mixes for Class 1 and 2 mortars.
- Plaster: Mixes for interior and exterior plastering.

Cement **products**

To simplify identification and make best use of the different product features, AfriSam products are identified by brand names, and by colour-coding on bags or bulk transport seals.

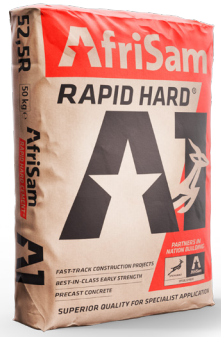
Table 2: AfriSam brand name products

Brand name	Classification	
Rapid Hard Cement	CEM I	52,5R
High Strength Cement	CEM II	42,5R & 52,5N
All Purpose Cement	CEM II and CEM V	42,5N
Starbuild	CEM II and CEM V	32,5N
Roadstab Cement	CEM II	32,5N

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Rapid Hard Cement (RHC)



RHC is ideal for use in the precast concrete industry where faster demoulding times are required, as well as for fast-track construction projects to facilitate earlier stripping of formwork, earlier bridge launching or higher sliding rates.

The secret to its faster strength development is the milling of the cement to a carefully controlled fineness as well as the inclusion of a performance modifier.

Features, applications and benefits

- **High early strength**
  RHC is ideal for the precast industry (faster demoulding), fast-track construction projects (earlier stripping of formwork) and for bridge launching with faster sliding rates. It can also be used for post-tensioned and pre-stressed members.

- **Cold weather concreting**
  High early liberation of heat due to hydration can offset the retardation effect of low temperatures. Where durability is of paramount importance, RHC can be further blended on-site with GGBFS, Fly Ash (FA) or condensed silica fume (CSF).

Table 3: Typical physical characteristics

Typical physical characteristics	
Relative density, g/ml	3,12
Loose bulk density after consolidation, kg/l	1,26

Table 4: Typical chemical composition

Typical chemical composition	RHC 52,5R
Source	Gauteng, North West
	CEM I 52,5R
Loss on ignition	3,02
Silicon dioxide, SiO_2	21,26
Aluminium oxide, Al_2O_3	5,08
Calcium oxide, CaO	66,27
Iron oxide, Fe_2O_3	2,82
Magnesium oxide, MgO	2,64
Titanium Dioxide, TiO_2	0,26
Manganese oxide, Mn_2O_3	0,13
Sodium oxide, Na_2O	0,01
Potassium oxide, K_2O	0,30
Sulfur oxide, SO_3	2,20

Table 5: Typical performance in relation to SANS 50197-1 criteria

Typical performance in relation to SANS 50197-1 criteria		SANS 50197 requirement
Physical		
2 Day (Early strength), MPa	33,6	≥ 30
28 Day, MPa	59,8	≥ 52,5
Setting time, min	170	≥ 45
Soundness (Le Chatelier Expansion), mm	< 1	≤ 10
Chemical		
Sulphate content, %	2,2	≤ 4
Chloride content, %	0,04	≤ 0,10

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High Strength Cement (HSC)



HSC is a specially developed cement for use in brick- and block-making, reservoirs, precast operations, structural concrete, shotcrete and mining operations.
The strength development of this cement is more than sufficient to allow normal progress of building operations, and is ideal for use in specialised applications.

Features, applications and benefits

- **Versatility**
  Whether on its own, extended with selected mineral components or used with plasticisers, HSC can be used by concrete product manufacturers for readymixed or site batched concrete to produce a wide range of cost-effective solutions in terms of workability, strength and durability. Applications include flowable or self-compacting concrete, and pumped concrete for slabs on the ground.

- **High early-age strength**
  The typical high early-strength of HSC offers outstanding benefits in terms of time-saving and meeting production deadlines. Applications include post-tensioned and prestressed members, early stripping of formwork in fast-track construction and concreting in cold weather.

- **Workability and durability**
  The mineral components used in HSC improve the durability of concrete in aggressive environments, such as sewage treatment works and concrete structures in marine environments. The extremely fine particles of the mineral components act as nuclei for the formation of calcium silicate, giving a fine-filler effect to produce a more dense and more homogenous microstruture in the hardened cement paste and in the aggregate-paste interfacial zones.

Note: Request specialist technical advice before concreting in aggressive environments.

Table 6: Typical physical characteristics

Typical physical characteristics	
Relative density, g/ml	2,96
Loose bulk density after consolidation, kg/l	1,26

Table 7: Typical chemical composition

Typical chemical composition	HSC 52,5N & 42,4R		
Source	Northern Cape, Lesotho	Gauteng, North West	Eswatini
	CEM I 52,5N	CEM II/A-M (V-L) 42,5R	CEM II/B-M 42,5R
Loss on ignition	3,04	3,20	2,71
Silicon dioxide, SiO_2	20,95	25,43	27,71
Aluminium oxide, Al_2O_3	4,65	8,20	9,68
Calcium oxide, CaO	64,13	58,16	54,36
Iron oxide, Fe_2O_3	2,16	2,85	3,48
Magnesium oxide, MgO	2,93	2,68	2,37
Titanium Dioxide, TiO_2	0,27	0,31	2,37
Manganese oxide, Mn_2O_3	1,57	0,17	0,1
Sodium oxide, Na_2O	0,11	0,01	0,15
Potassium oxide, K_2O	0,56	0,30	0,13
Sulfur oxide, SO_3	2,54	2,57	1,62

Table 8: Typical performance in relation to SANS 50197-1 criteria

Typical performance in relation to SANS 50197-1 criteria	Northern Cape, Lesotho	Gauteng, North West & Eswatini	Eswatini	SANS 50197 requirement
Physical	CEM I 52,5N	CEM II/A-M (V-L) 42,5R	CEM II/B-M 42,5R	
2 Day (Early strength), MPa	29,1	27,1	25,3	≥ 20
28 Day, MPa	61,9	56,1	52,7	"≥ 52,5 (52,5N) or ≥ 42,5 ; ≤ 62,5 (42,5R)"
Setting time, min	164	215	226	"≥ 45 (52,5N) or ≥ 60 (42,5R)"
Soundness (Le Chatelier Expansion), mm	< 1	< 1	<1	≤ 10
Chemical				
Sulphate content, %	2,5	2,6	1,62	≤ 4
Chloride content, %	0,01	0,04	0,04	≤ 0,10

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All Purpose Cement (APC)



A specially engineered composite, high quality cement for use in a wide variety of different building and masonry applications. Consistent strength, workability and durability give consistently excellent results every time.

Features, applications and benefits

- **Versatility**
  Applications include brick- and block-making, reservoirs, swimming pools, precast operations and shotcrete, as well as structural concrete, plaster and mortar.

- **Improved cohesiveness**
  The addition of GGBFS, FA or limestone to Portland cement has a fine-filler effect, giving mortars and plasters made with APC improved water demand. This increases the cohesiveness of the mix, and improves its workability.

- **Reduced permeability**
  Mineral components improve concrete density, reducing the potential of penetration of harmful substances such as oxygen, moisture, carbon dioxide, chlorides or sulphates, thus minimising the risk of corrosion and improving durability.

- **Mass concrete structures**
  For low heat of hydration.

APC has been specially formulated to use less water, thus increasing the workability and strength of the concrete.

Table 9: Typical physical characteristics

Typical physical characteristics	
Relative density, g/ml	2,79
Loose bulk density after consolidation, kg/l	1,19

Table 10: Typical chemical composition

Source	Northern Cape, North West	Gauteng, Eswatini	Lesotho
	CEM II/B-M (L)	CEM V/A (S-V)	CEM II/B-M (V-L)
Loss on ignition	9,56	1,73	2,19
Silicon dioxide, SiO_2	20,50	33,41	31,92
Aluminium oxide, Al_2O_3	4,35	13,15	13,08
Calcium oxide, CaO	64,10	43,15	46,65
Iron oxide, Fe_2O_3	2,08	2,62	2,55
Magnesium oxide, MgO	3,55	3,78	2,73
Titanium Dioxide, TiO_2	0,26	0,46	0,37
Manganese oxide, Mn_2O_3	1,68	0,35	1,11
Sodium oxide, Na_2O	0,20	0,05	0,01
Potassium oxide, K_2O	0,57	0,47	0,44
Sulfur oxide, SO_3	2,51	2,20	1,50

Table 11: Typical performance in relation to SANS 50197-1 criteria

Typical performance in relation to SANS 50197-1 criteria	Northern Cape, Lesotho	Gauteng, North West & Eswatini	Eswatini	SANS 50197 requirement
Physical	**CEM II/B-M (L)**	**CEM V/A (S-V)**	**CEM II/B-M (V-L)**	
2 Day (Early strength), MPa	21,5	15,2	16,0	≥ 10
28 Day, MPa	45,8	44,1	46,2	≥ 42,5 ; ≤ 62,5
Setting time, min	177	350	221	≥ 60
Soundness (Le Chat-elier Expansion), mm	< 1	< 1	< 1	≤ 10
Chemical				
Sulphate content, %	2,5	2,2	1,5	≤ 3,5
Chloride content, %	0,01	0,06	0,01	≤ 0,10

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Starbuild



AfriSam's STARBUILD is a 32,5N cement and cost-effective alternative for applications not requiring high early-strength development. It is suitable for a limited range of applications in the build environment where it offers consistent performance.

Features, applications and benefits

- It delivers normal performance, durability and workability
- It has moderate strength gain (16MPa at 7 days)
- It is an economical alternative for residential application mix designs
- It has a low carbon footprint from its use of mineral components
- With the correct mix designs, this cement can produce high strength concrete, medium strength concrete and low strength concrete and mortar and plaster mixes



Table 12: Typical chemical composition

Typical chemical composition	Starbuild 32,5N	
Source	Northern Cape, North West	Gauteng
	CEM II/B-M (L)	CEM V/B-M (S-V)
Loss on ignition	13,54	1,10
Silicon dioxide, SiO_2	20,15	36,44
Aluminium oxide, Al_2O_3	4,04	16,53
Calcium oxide, CaO	67,09	37,50
Iron oxide, Fe_2O_3	2,45	2,32
Magnesium oxide, MgO	2,53	4,40
Titanium Dioxide, TiO_2	0,31	0,45
Manganese oxide, Mn_2O_3	0,32	0,45
Sodium oxide, Na_2O	0,05	0,03
Potassium oxide, K_2O	0,29	0,49
Sulfur oxide, SO_3	2,72	2,02

Table 13: Typical performance in relation to SANS 50197-1 criteria

Typical performance in relation to SANS 50197-1 criteria			SANS 50197 requirement
Physical			
			≥ 16
7 Day, MPa	26,8	18,41	
28 Day, MPa	34,6	35,35	≥32,5 ; ≤ 52,5
Setting time, min	227	396	≥ 75
Soundness (Le Chatelier Expansion), mm	< 1	< 1	≤ 10
Chemical			
Sulphate content, %	2,7	2,0	≤ 3,5
Chloride content, %	0,02	0,06	≤ 0,10

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Roadstab Cement



Roadstab Cement is a specially engineered composite, high quality cement for use specifically in road stabilisation, ensuring uniform distribution of the stabilising agent throughout the stabilised layer.

Consistent stabilisation properties give bound material significant strength results for road sub-bases every time.

Features, applications and benefits

Roadstab Cement has been developed and tested to achieve superior performance across a broad range of road material types, reducing the plasticity of the soil and ensuring durability, stability and strength.

Proven performance

Roadstab Cement's binder composition fulfils the following requirements of a stabilising agent:

- Reduces the plasticity of soil.
- Ensures durability, stability and strength.
- Works across a range of different road materials.

Roadstab Cement also allows for longer setting times in the 32,5 strength class, even with soils with plasticity indices greater than 12, making it ideally suited for applications requiring longer placing and compacting times.

Table 14: Typical physical characteristics

Physical characteristics	
Relative density, g/ml	3,05
Loose bulk density when fluidised, kg/m^3	1 100
Loose bulk density after consolidation, kg/m^3	1 500

Table 15: Typical proportions

Typical chemical composition		
Source	**Northern Cape, North West**	**Gauteng**
	CEM II/B-M (L)	CEM II/B-V
Loss on ignition	10,97	2,12
Silicon dioxide, SiO_2	20,45	32,62
Aluminium oxide, Al_2O_3	4,29	13,62
Calcium oxide, CaO	64,08	44,01
Iron oxide, Fe_2O_3	2,06	2,45
Magnesium oxide, MgO	3,67	3,99
Titanium Dioxide, TiO_2	0,25	0,40
Manganese oxide, Mn_2O_3	1,71	0,41
Sodium oxide, Na_2O	0,41	0,01
Potassium oxide, K_2O	0,55	0,45
Sulfur oxide, SO_3	2,48	2,42

Table 16: Typical performance in relation to SANS 50197-1 criteria

Typical performance in relation to SANS 50197-1 criteria			SANS 50197 requirement
Physical			
			≥ 16
7 Day, MPa	29,5	24,4	
28 Day, MPa	39,0	43,9	≥32,5 ; ≤ 52,5
Setting time, min	183	373	≥ 75
Soundness (Le Chatelier Expansion), mm	< 1	< 1	≤ 10
Chemical			
Sulphate content, %	2,5	1,4	≤ 3,5
Chloride content, %	0,01	0,01	≤ 0,10

Soil stabilisation is the process of mixing a stabilising agent such as Roadstab Cement with sub-standard soil, then dampening and compacting the sub-base layer to provide a strong and durable road base, with potential savings (materials, costs, future maintenance) in the road surfacing layers.

As stabilisation projects are generally site-specific, the required spread (bags/kg per m^2) of Roadstab Cement must be based on laboratory testing of the in-situ soil.

For more information on soil stabilisation processes, see *Concrete*.

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Slagment (GGBFS)



On its own, Ground Granulated Blastfurnace Slag (GGBFS) will not hydrate on contact with water or harden at the same rate as Portland cement (CEM I), but requires the presence of an alkaline activator such as milled clinker to initiate its inherent cementitious reactions.

Commercially available composite cements contain a percentage of secondary cementitious materials such as GGBFS in varied amounts as prescribed by SANS 50197-1.

The advantages of using slag in concrete, either as a component of composite cements or as part of the mix proportions in a site blend, include improved durability as a result of:

- Improved impermeability.
- Improved freeze/thaw characteristics.
- Resistance to chemical attack.
- Reduced potential for alkali-aggregate reaction.
- Lower heat of hydration.
- Reduced creep and shrinkage.

Chemical characteristics

The chemical compounds in slag are similar to those in cement clinker, but the proportions of the constituents in the two materials are different.

In essence slags have complex mineralogical structures, but the chemical composition of GGBFS is generally very consistent, as the iron-making process and the composition of the slags are interdependent. Fortunately, slag requirements for quality iron coincide with those for good cementitious properties.

Slagment is the registered trade name for GGBFS produced by AfriSam. AfriSam's Vanderbijlpark plant produces over 800 000 tons of GGBFS annually.

Slagment applications

Many readymixed concrete operations use slag in addition to cement as part of the cementitious or binder material in their mix designs. Bulk slag is delivered to the plant by tanker, pumped into silos and then automatically weighed and batched at the same time as the cement.

Slagment can successfully be used as a binder for backfill in the mining industry, generally for cut-and-fill or room-and-pillar backfilling where high early strength gain is not required.

Note: Contact AfriSam CPE for specialised technical advice.

Table 17: Typical chemical composition

Typical chemical characteristics	
Silicon dioxide, SiO_2	36,83
Aluminium oxide, Al_2O_3	16,52
Calcium oxide, CaO	34,15
Iron oxide, Fe_2O_3	0,80
Magnesium oxide, MgO	8,63
Titanium Dioxide, TiO_2	0,41
Manganese oxide, Mn_2O_3	1,14
Sodium oxide, Na_2O	0,05
Potassium oxide, K_2O	0,73
Sulfur oxide, SO_3	2,61

Table 18: Typical physical characteristics and performance in relation to SANS 55167 criteria.

Typical performance		SANS 55167 requirement
Relative density, g/ml	2,9	
Loose bulk density after consolidation, Kg/m3	1000	
Compact bulk density, Kg/m3	1200	
Fineness (Blaine), cm2/g	> 3000	> 2750
Absorption	Not hygroscopic	
Glass content, %	> 85	> 67
7D Reactivity,%	> 50	> 45
28D Reactivity, %	> 75	> 70

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AfriSam Premixes

AfriSam's premix range of products offer a complementary range of high quality branded products comprising of AfriSam Concrete Mix, AfriSam Plaster Mix, AfriSam Screed Mix and AfriSam Building Mix. These products are easy to use and correctly formulated – just add water. They are blends of quality aggregate material and cement in a bag.

AfriSam Concrete Mix



This product is suitable for small concrete repair jobs, footings, foundations, fence and washing line posts and other minor structural applications.

AfriSam Plaster Mix



This product is suitable for general plaster or repairs and offers reduced cracking and improved workability.

AfriSam Screed Mix



This product is suitable for general floor levelling under ceramic tiles. It is designed for domestic use and is easy to place and finish.

AfriSam Building Mix



This product is suitable for making mortar for general brick and block laying. It can be used with all types of bricks and offers proven quality.

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Cement specifications

Technological advances in the production of cement, such as performance modifiers, plant control systems and alternative fuels, have given the cement producer the flexibility to use a wider range of supplementary cementitious materials. SANS 50197 allows the use of GGBFS, FA and limestone in different proportions within specified limits with Portland cement, to produce cement with improved technically-acceptable properties.

Requirements for the composition, rate of early strength gain, 28-day mortar prism strength, and other physical and chemical properties are defined by the specification for each type and strength class of cement, and the product code is required to indicate this.

All components of cement products manufactured and sold in South Africa are obliged by law to comply with the following performance-based national specifications:

- SANS 50197 for cements.
- SANS 55167 for GGBFS.
- SANS 50450 for FA.
- SANS 1841 for bag mass compliance.

> “All AfriSam cements are SABS approved. In addition, all cement bags bear the E-mark and indicate the carbon footprint of each product.”

This assures the customer that:

- The performance of the cement is controlled.
- The product complies with specified performance and compositional requirements.
- A formal management and process control system is in place.
- The mass of each bag complies with strict tolerances.

Cement types available in South Africa

- CEM I Portland cement.
- CEM II Portland-composite cement.
- CEM III Blastfurnace cement.
- CEM IV Pozzolanic cement.
- CEM V Composite cement.

Table 19: Cement class strength requirements

	Compressive Strength, MPa				Initial Setting Time, min	Soundness (Expansion), mm
	Early Strength		Standard Strength			
Strength Class	2 days	7 days	28 days			
32,5 N		≥ 16,0	≥ 32,5	≤ 52,5	≥ 75	≤ 10
42,4 N	≥ 10,0		≥ 42,5	≤ 62,5	≥ 60	≤ 10
42,5 R	≥ 20,0		≥ 42,5	≤ 62,5	≥ 60	≤ 10
52,5 N	≥ 20,0		≥ 52,5	-	≥ 45	≤ 10
52,5 R	≥ 30,0		≥ 52,5	-	≥ 45	≤ 10

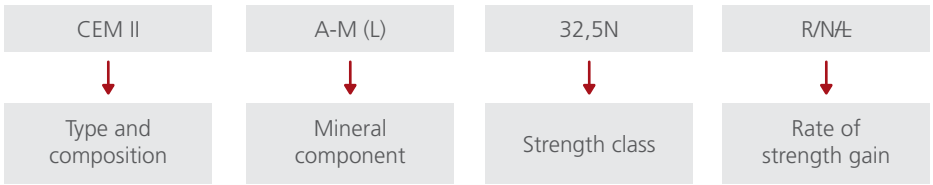


Figure 1: Cement type and composition

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SANS 50197 requirements: Composition

The range of proportions of each constituent material is specified for each cement type, e.g. CEM II A-M (L) consists of clinker with 6 to 20% GGBFS. Included in the range of permitted mineral components may be up to 5% additional constituents.

Description		Composition % 0 – 100
Portland cement	CEM I	6
Portland composite cement	CEM II A-M CEM II B-M	20 35
Blastfurnace cement	CEM III A	65
	CEM III B	80
	CEM III C	95
Pozzolanic cement	CEM IV A	11 35 30
	CEM IV B	55
Composite cement	CEM V A	18 18 30

GGBFS Clinker Limestone Fly Ash

Figure 2: Cement type and composition

In practice the proportions of GGBFS (S), limestone (L) and FA (V) are generally fixed within the limits of the specification. Therefore the quantities of the mineral components do not vary significantly in the short-term and are continuously adjusted over time to ensure consistency of performance, i.e. proportions of supplementary cementitious materials in the different products may vary within the specified limits.

Strength class

Cement is produced in 32,5; 42,5 and 52,5 strength classes. Standard strength tests are routinely conducted on mortar samples made with a standard sand and fixed water:cement ratio, to define and verify the performance of different strength classes of cement in terms of mortar strength, setting time and soundness (expansion). The cement in each strength class must meet the requirements given in Table 23 of this document.

Note that cement strength classifications do not indicate potential concrete strength. To verify compliance with SANS 50197-1 strength requirements, mortar prisms made under carefully controlled laboratory conditions are tested in accordance with SANS 50196-1 (see *Figure 3*).

The actual strength of the concrete made with a cement relates to cement performance, water:cement (W/C) ratio, admixtures and properties of the actual aggregate used, and is tested by carrying out compressive strength testing on concrete cubes in accordance with SANS 5863.
See also *Properties of hardened concrete.*



Figure 3: Mortar prism test

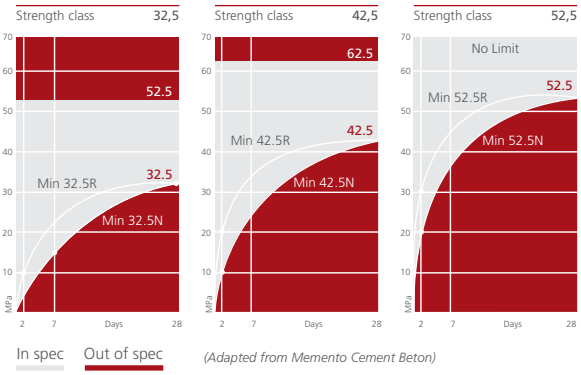
Our sales consultants can advise you, and will arrange to supply samples of the cements available in the different geographical areas.

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Rate of strength gain

The suffix N, R or L at the end of the description of a cement type indicates rate of early strength gain: Normal, Rapid or Low. Rapid requires a higher mortar prism compressive strength at two days (see *Table 23* and *Figure 4*).



(Adapted from Memento Cement Beton)

Figure 4: Rate of strength gain for Normal and Rapid cement classes

Specifying the correct cement

The proportions of different mineral components impart different properties to the cements and consequently to the concrete (or other applications) made with these cements. Prior to specifying cement type/product and entering into contractual negotiations, on-site trials using the specified aggregate and admixtures should be carried out to verify that the actual concrete, mortar or plaster made with the cement performs as required in practice.

When selecting the most advantageous cement for a specific application, the specifier, engineer or architect should:

- Understand what SANS 50197, 55167 and 50450 mean in terms of specified physical requirements in the final product.
- Understand how these properties affect the properties of the fresh and hardened concrete (or other product) required for the project.
- Apply this knowledge to the cements available in different geographical areas.
- Factor in additional savings gained by using alternative cement and/or aggregate types, or using chemical admixtures.

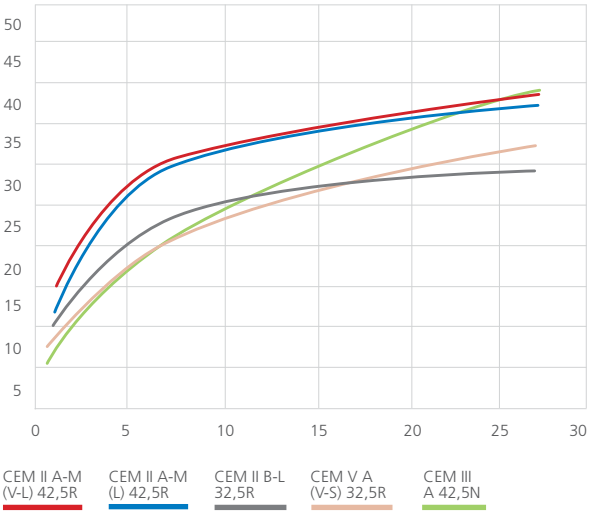


Figure 5: Same final strength, different cements

Any special requirements such as early strength of concrete or durability requirements must be indicated in the project specifications to ensure that the mix design takes these requirements into account.

- The early rate of strength gain varies with different types of cement. If early strength is of importance for early stripping of formwork or precast moulds, the concrete specification must indicate a minimum early strength gain requirement, e.g. 8MPa at three days.
- Specifying concrete to achieve long-term durability in aggressive environments, e.g. marine wharfs, requires special attention.

See also *Concrete*.

Where sulphate attack, chloride ingress, permeability and/or Alkali-Aggregate Reaction (AAR) are of concern, composite cements containing GGBFS and/or FA are recommended.

See also *Properties of hardened concrete*.

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Cement **manufacture**

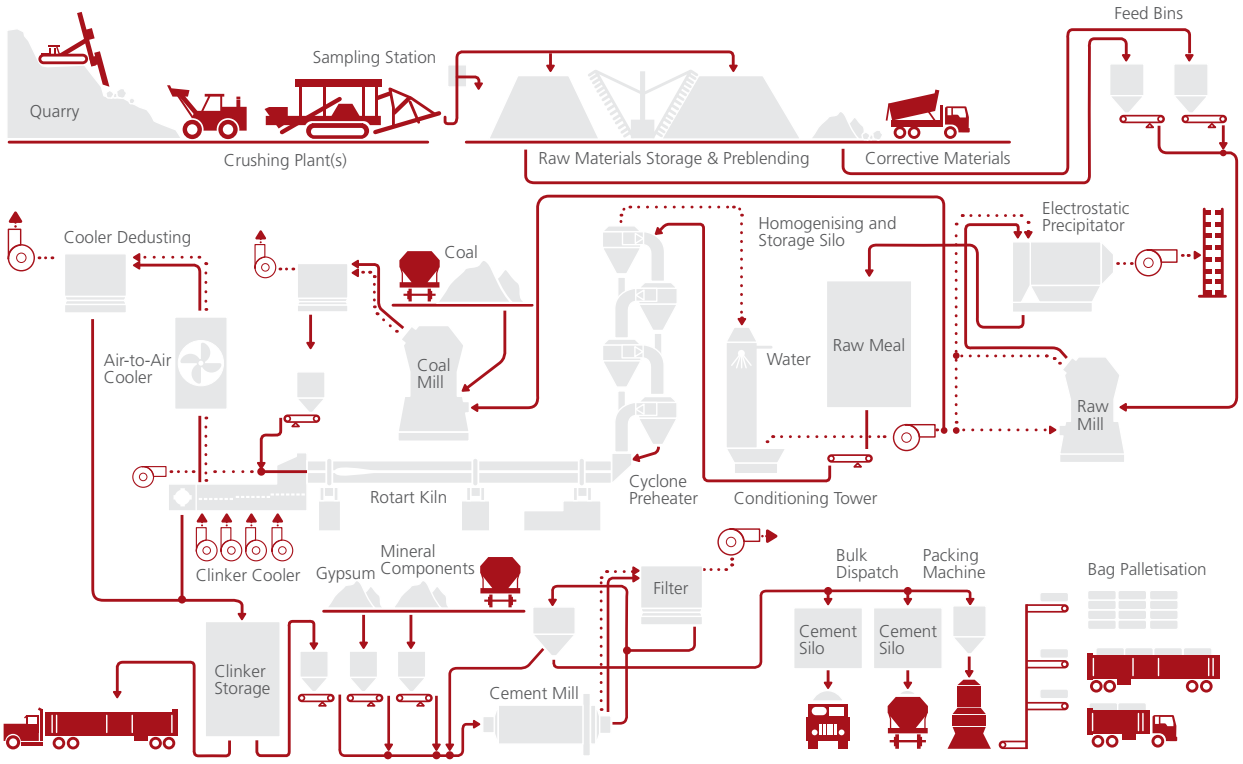


Figure 6: Typical cement manufacturing process

Materials used in the manufacture of cement

Cement is manufactured from a carefully controlled mixture of calcium oxide, silica, alumina and iron oxide. Calcium is generally obtained from limestone. Silica, alumina and iron are generally obtained from clay or shale and iron oxide.

To make cement with specific characteristics, these minerals must be carefully proportioned. These raw materials occur naturally so their chemical make-up can vary, meaning a great deal of care must be taken in their selection and in post-mining blending.

Special materials are often added to the base (Portland) cement to modify its qualities. These materials include GGBFS, FA, Condensed Silica Fume (CSF) and limestone.

A small amount of gypsum is also added to the cement to control the setting time of the final product.

Typical cement manufacturing process

- **Raw material preparation – mining and crushing**
  Limestone is mined in open-cast quarries using drilling and blasting techniques. The limestone is then reduced in size by crushing to smaller than 75mm particles. The limestone is stacked onto special homogenising stockpiles to obtain as consistent material as possible.

- **Additives**
  Depending on the mineral content of the limestone, additional silica and/or iron oxide are added prior to the milling process to ensure that the chemical composition is within tight tolerances.

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Cement

- **Milling**
  The various components are milled and dried in a vertical roller or mill. Heavy rollers are positioned over a rotating table and the coarse material is milled until it is fine enough to be conveyed by air to a homogenising raw meal silo.

- **The burning process**
  The milled blended raw material is transported to the top of the kiln preheater tower. The kiln is fired by finely ground coal or AFRs and is designed to maximise the heat transfer from the ignited coal to the clinker. In the preheater, the raw materials are heated rapidly to a temperature of about 800°C, where carbon dioxide is driven off from the limestone.

$$CaCO_3 + heat = CaO + CO_2$$

  Once this process is complete, the material drops into the rotating kiln where its temperature is raised to 1 450°C. At this stage the various minerals start to fuse together to form predominantly calcium silicate crystals (clinker). This semi-molten material is then cooled as rapidly as possible in a cooler and stored in a clinker silo ready for final milling.

Reactions during the cooling of clinker

The cooling process plays a decisive role in the quality and grindability of the clinker. Rapid cooling stabilises the C_3S and improves the quality of the aluminate phases.

Slow cooling leads to the transformation of C_3S into free CaO and C_2S with low hydraulicity. The kinetics of the cooling process play a major role in the subsequent grindability of clinker. Depending on the type of cooler in use, the clinker is cooled from about 1 100˚C to between 50˚C and 300˚C.

Cement milling

Cement mills are rotating tubes filled with steel balls. A roller press is sometimes used to assist in the size reduction process before the clinker is fed into the mill to produce a very fine grey powder. Vertical roller mills such as those installed at Roodepoort are a new development and are known for their energy efficiency.

Controlling the cement fineness assists in determining the rate of strength gain rate of the cement in mortar and concrete. During milling, gypsum is added to control the cement's setting time.

The base cement is stored in homogenising silos to ensure the most consistent product possible.

Blending

At this point, the required proportions of supplementary cementitious materials such as GGBFS and/or FA are blended with the cement to produce the final products.

The manufacture of slagment (GGBFS)

In the manufacture of iron, blastfurnaces produce molten iron and liquid slag. The liquid slag floats on the top of the pool of molten pig iron, and is periodically tapped from the furnace. The slag has potentially cementitious properties, but these can only be achieved by quenching the very hot (1 450°C) material with water. This rapid cooling converts the slag into an amorphous granular material or Granulated Blast Furnace slag.

The granulated particles are dried to less than 1% moisture, and are then ground in a ball mill to a Blaine fineness of 3 500cm^2/g. This minimum specific surface area is tailored to match those of South African cements and provide the optimal combination of reactivity, workability and economy.



Chemistry of **Portland cement**

Portland cement is a hydraulic binding material. When water is added to cement, hydration takes place and the cement paste which is formed sets and hardens, producing strong, hard and durable cement-based composite building materials such as concrete, mortar and plaster.

Portland cement is made by intergrinding clinker and a set regulator (generally gypsum).

Portland cement clinker

Clinker results from calcination at high temperature (1 300 to 1 450˚C) of a homogenous fine mixture consisting mainly of limestone and clay (see *Cement manufacture*).

Mineralogical composition of Portland clinker

Portland cement clinker is an artificial stone composed mainly of minerals, also called clinker phases:

- Alite phase: Ca_3SiO_5 or $3CaO.SiO_2$ (C_3S).
- Belite phase: Ca_2SiO_4 or $2CaO.SiO_2$ (C_2S).
- Tricalcium aluminate phase: $Ca^3Al_2O_6$ or $3CaO.Al_2O_3$(C_3A).
- Tetracalcium alumino-ferrite phase: $Ca_4Al_2Fe_2O_{10}$ or $4CaO.Al_2O_3.Fe_2O_3$ (C_4AF).

Pure clinker phases are products of high temperature reactions of a stoichiometric mixture of CaO, SiO_2, Al_2O_3 and Fe_2O_3.

Industrial clinker minerals contain several minor impurities resulting from minor impurities in the raw materials and in the fuels.

Reactions taking place during clinker formation

From 100 to 1 000˚C, as the raw materials in the kiln are heated, the following reactions occur:

- At 100 to 300˚C, the raw meal loses its physical and adsorbed water, H_2O.
- Between 300 and 400˚C, clay raw material begins to dehydrate, i.e. the clay loses chemically bound H_2O.
- Between 400 and 600˚C, the dehydration process intensifies and finishes, and the clay mineral undergoes structural modification.
- Between 500 and 700˚C, the $MgCO_3$ decarbonates.
- At 600 to 900˚C, the decarbonation of limestone $CaCO_3$ takes place.
- At 900 to 1 000˚C, new crystalline phases such as spinel and cristobalite are formed.

$$CaCO_3 \quad CaO + CO^2 - Q \; (Q = 1\,800\ J/g)$$

Solid-solid reactions between 1 000 and 1 450°C

At this stage, the following solid phase reactions take place:

- **CaO and SiO_2 reactions**

$2CaO + SiO_2 \rightarrow$ 500 to 1 100˚C	$2CaO.SiO_2$ (C_2S)
$C_2S + CaO \rightarrow$ 1 000 to 1 200˚C	$3CaO.SiO_2$ (C_3S)
$CaO + SiO_2 \rightarrow$ 1 100 to 1 300˚C	$CaO.SiO_2$ (CS)

- **CaO and Al_2O_3 reactions**

$3CaO + Al_2O_3 \rightarrow$ 600 to 1 100˚C	C_3A

- **CaO + Al_2O_3 and Fe_2O_3 reactions**

$CaO + C_3A + Fe_2O_3 \rightarrow$ 500 to 1 200°C	C_4AF

Solid-liquid reactions between 1 338 and 1 450˚C

At these temperatures:

- The aluminates melt.
- Alumino-ferrites phases are initiated.
- The liquid phase becomes 25 to 35% of the sintering mass.
- Crystal growth of C_2S and CaO is followed by an intensification of their transformation into C_5S.
- Recrystallisation and growth of C_3S and C_2S follows.
- Volatile compounds are completely evaporated.

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Reactions during the cooling of clinker

The cooling process plays a decisive role in the quality and grindability of the clinker. Rapid cooling stabilises the C_3S and improves the quality of the aluminate phases.

Slow cooling leads to the transformation of C_3S into free CaO and C_2S with low hydraulicity. The kinetics of the cooling process play a major role in the subsequent grindability of clinker.

Depending on the type of cooler in use, the clinker is cooled from about 1 100˚C to between 80 and 300˚C.

The hydration products of Portland cement are far from being the pure hydrates that we describe here. They contain impurities, which may play an important role in mortar or concrete, particularly when admixtures are used.

The role of water in the cement paste

Water is a chemical reagent, reacting with the cement phases to produce different hydrates.

Generally, the amount of water necessary for complete hydration is 20 to 22% of the mass of the cement.

For a cement paste with normal consistence, more water than that involved as a "chemical reagent" is required. This supplementary water is used as a rheology agent and plays a physical role by lubricating the cement paste. Supplementary water evaporates, leaving pores in the concrete or voids between the aggregate particles, which are detrimental to the mechanical strength and durability of concrete.

Table 20: Chemical composition of Portland cement

Main oxides, %	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	R_2O*
	45 to 65	20 to 25	4 to 8	2 to 4	<5	<3,5	<1
*R = 0.568K + Na							

Table 21: Mineralogical composition of Portland cement

Percentage of	C_3S	C_2S	C_3A	C_4AF
Minimum	40	5	2	0
Maximum	70	25	15	15
Average	60	15	9	8

Hydration of the silicate phases

The mechanisms involved in hydration of silicate phases can be explained as:

- $C_3S + 3H_2O \rightarrow CaO.SiO_2.H_2O$ (CSH) + $3Ca(OH)_2$
- $C_2S + H2O \rightarrow CSH + Ca(OH)_2$

Calcium silicate hydrate (CSH) fibres form a network in the cement paste, leading to an impermeable, dense structure. CSH is responsible for the strength of the cement paste, mortar or concrete.

There are two main types of CSH, depending on the lime:silica ratio present in the cement:

- CSH (I), if: $0.7 < CaO/SiO_2 < 1$
- CSH (II), if: $1.0 < CaO/SiO_2 < 1.5$

$Ca(OH)_2$ is one of the mechanisms through which chemical attack of the concrete occurs. It reacts with different aggressive chemical agents, liquid or gas, causing damage to the concrete structures (see *Properties of hardened concrete*).

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The hydration of ferrite and aluminate phases

In the absence of gypsum, the reaction between the aluminate and ferrite phases and water is fast and highly exothermic.

The reaction produces hexagonal calcium alumino-hydrates, C_2AH_8 and C_4AH_{13}. At ambient temperature these hydrates are unstable and transform into cubic and thermally-stable calcium alumino-hydrates, C_3AH_6:

$$2C_3A + 21H_2O \rightarrow C_2AH_8 + C_4AH_{13} \rightarrow 2C_3AH_6 + 9H_2O.$$

Hydration in the presence of gypsum

Gypsum is interground with clinker to regulate the setting process of cement.

$$C_3A + 3CaSO_4.2H_2O + 26H_2O \rightarrow C_3A.3CaSO_4.32H_2O,$$
ettringite, tri-sulphoaluminate (TSA).

The C_4AF is believed to react in the same way as C_3A to produce a type of ettringite with iron content, tri-sulpho-alumino-ferrite (TSAF).

If the amount of C_3A present in hydrating cement is more than required and when gypsum is totally consumed, ettringite reacts with C_3A and transforms into mono-sulphoaluminate (MSA):

$$C_3A.3CaSO_4.32H_2O + 2C_3A + 4H_2O \rightarrow 3(C_3A.CaSO_4.12H_2O)$$

Microstructure of the main product of hydration: CSH

Micro-calorimetry proves that the Portland cement hydration process is governed by the hydration of calcium silicates. Thus CSH plays a major role in concrete or mortar.

Flash set

In the absence of gypsum or in the presence of an insufficient amount of gypsum, cement undergoes a quick set generally called "flash set".

The phenomenon is characterised by intense evolution of the heat of hydration and loss of workability, with subsequent poor strength development.

Set regulators of cement other than gypsum

The following chemical admixtures are used to accelerate or slow cement hydration reactions during concreting operations, e.g. for specific placing and finishing requirements (see also *Concrete*).

- Retarders are generally used to slow cement hydration reactions, e.g. where extended setting times are required for special concrete applications. Hydroxycarboxylic acids or salts and lignosulphonates are commonly used organic retarders.

  Some inorganic salts such as borates, phosphates, Pb and Zn salts are strong retarders.

- Accelerators shorten the setting time of cement and, in many cases, increase the rate of early strength development. Triethanolamine (TEA), oxalic acid and gluconate are used as accelerators. However, their accelerating ability depends on the dosage.

  Inorganic salts such as carbonates and chlorides accelerate the setting and hardening of cement. Depending on the dosage, carbonates may also lead to a strong retardation.

False set

In the presence of an excess of hemihydrate $CaSO_4.0.5H_2O$, cement undergoes another type of rapid set called "false set" or the rehydration of hemihydrate with a subsequent formation of gypsum $CaSO_4.2H_2O$.

Intense mixing can reverse false setting, allowing the cement paste, mortar or concrete to regain its original plasticity. Strength development is not seriously affected.

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Handling **cement**

Depending on customer requirements, our products are:

- Loaded into road or rail bulk tankers for delivery to cement depots or customer silos.
- Loaded from cement depot silos into mini bulk silos for delivery to construction sites.
- Packed via sophisticated packing machines into 25kg or 50kg bags, and palletised. The palletised bags are wrapped in plastic and dispatched on trucks to hardware stores, building yards or building sites.

Advantages of using bulk cement delivered in tankers include:

- The elimination of loss through the breakage of bags.
- The elimination of extra handling: direct transfer from the transporting vehicle to the silo to the mixer.
- Reduced labour complement on-site.
- Improved housekeeping, with no unsightly empty bags littering the site.
- Automatic first-in, first-out use of stock.
- Weatherproof storage: the cement will not be exposed to moisture and will not hydrate even after relatively long storage periods.
- Maximum security and control of stock.
- Appropriate methods of transport and storage on-site.

Bulk cement product identification

To ensure that the correct product and amount of cement is received and offloaded into the correct silo, check that:

- The seals on the tanker are intact.
- The colour of the seals corresponds with the assigned product colour.
- The number on the seal corresponds with the number on the AfriSam cement delivery note.

Tankers are sealed. Before accepting the load, check that the seal is intact, and that the seal number corresponds with that on the delivery note. Break the seal and ensure that the tanker offloads into the correct silo.

Transporting bulk cement

Road transport and rail transport both offer timeous and convenient delivery of bulk cement.

Road transport

To ensure reliable distribution throughout our market area, our road transport system consists of:

- Thorough mass-measuring procedures for loading at plants and depots as well as offloading on-site, ensuring that orders and deliveries can be accurately reconciled.
- An efficient computerised transport management system.

Rail transport

A close partnership exists between AfriSam and Spoornet to ensure that trucks and tankers transported by rail are delivered to key distribution points around the country.

Handling bulk cement

Storage of bulk cement either in the customer's bulk silos or in mini bulk silos provided by AfriSam involves close liaison between customer and supplier. Factors such as providing adequate vehicle access, filters, foundations and seals, etc. need to be discussed in advance.

- **Vehicle access**
  The gross vehicle mass of a fully-loaded road cement tanker is up to 60t, the length may be 22m and the diameter of the turning circle is approximately 20m. Good access to the offloading point is essential, and ideally, the left-hand side of the tanker should be adjacent to the silo connection coupling.

- **Bulk silos**
  When establishing new bulk cement silos on-site, a registered structural or civil engineer should ensure that adequate foundations provide structural stability under all load combinations and weather conditions.

  Alternatively, the road tanker should be able to reverse so that the back of the tanker is next to the silo connection coupling.



A silo aeration system is recommended for all silos holding more than 50t. The air supplied to the silo for aeration should be clean and dry. It is normally only necessary to aerate a silo at the beginning of a shift. The cement will then stay sufficiently fluid for trouble-free extraction, provided that regular extractions are made during the shift.

Silos are resupplied by bulk tanker in pay-loads of 34t.

- **Mini bulk silos**
  The mini bulk silo system (certain areas only) obviates AfriSam customers laying out working capital for conventional cement silos or cement storage sheds.

  An AfriSam vehicle delivers the silo to site. Depending on the user's specific requirements, the silo may be empty or preloaded with up to 10t of cement. The vehicle places the silo on a pre-laid concrete slab or on its own base plate extensions.

  Make sure that the site is level and accessible by an articulated bulk vehicle for silo delivery, collection or filling. In all cases, ensure that ground conditions will support the loads induced by the silo footings or the vehicle tyres, even after prolonged rainfall.

  In addition to cost advantages, the silo can be padlocked to provide complete stock control and security. An internal hand-operated paddle allows accurate monitoring of stock holding levels so that timeous reordering can take place to ensure continuous production.

  Provision needs to be made for the silo-placing vehicle to gain access to the site at the end of the contract to remove the silo.

- **Steel supply pipes to silos**
  These should always be kept as short as possible and should be either horizontal or vertical to keep tanker discharge times to a minimum. Pipes should enter the silo tangentially and the air vent pipe should originate from the centre of the silo. Each pipeline should be clearly marked with the AfriSam colour code and name of the relevant cement product.

- **Silo filters and silo safety pressure release valves**
  Inspection and maintenance of silo filters, safety valves and air release pipes should be carried out at regular intervals. Failure to do this can result in excess dust being discharged from the silo, long discharge times and, in the worst case, the silo exploding because of pressure build-up during filling.

Hot cement

Hot cement or even warm cement direct from the cement factory can be very fluid. A shut-off valve should be fitted between the silo and the screw feed when the friction provided by the screw feed is not strong enough to stop free-flowing cement.

Stock control and reconciliation

The bulk density of cement varies considerably depending on whether it was freshly pumped into the silo or has been allowed to consolidate overnight. Consequently, always determine the "height of cement" in the silo when the cement is in the same state of fluidisation.

To improve accuracy, determine cement levels in a silo at the start of each working shift before any fluidisation or extraction of the cement takes place. Run silos empty as often as possible. As soon as they are empty, reconcile the amount of cement used since the silo was last empty against the amount used in production.

Check that scales for weighing cement are calibrated beyond their normal operating range. A scale that is under-reading can rapidly lead to excess cement being used.

- Use leftover cement – do not scatter on-site.
- To avoid increasing CO_2 levels, do not burn empty cement bags. Put them in rubbish bins to be used as landfill.

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Cement

Cement is a non-renewable resource. Maximise its potential by:

Reducing our Carbon Footprint

Storing cement bags correctly

- Store bags in a closed shed or area – keep windows and doors closed.
- Store bags off the ground (e.g. on pallets or plastic sheeting).
- Do not pack more than 12 bags high, and do not pack against outside walls.
- Remove and use bags in first-in, first-out sequence.
- Shelf-life is approximately three months (see date stamp on bag).
- Discard cement with lumps you cannot easily break by hand.

Using cement responsibly

- Mix (or for readymixed concrete: order) only enough concrete to keep up with your placing team.
- Place and compact before the concrete starts setting.
- If concrete starts setting/hardening before it can be placed, do not use/remix: discard.
- Do not leave left-over mortar or plaster overnight and then retemper (add cement, water) the next morning: mix only enough for use in the next few hours.

- Use barrier cream or safety gloves and goggles when exposed to cement dust.
- Cement dust irritates the eyes. Irrigate eyes with large amounts of water.
- Cement bags are heavy. Avoid neck and back injuries by using appropriate bending and lifting action.

Applicable specification

SANS 1841: Control of the quantity of contents in prepacked packages within the prescriptions of legal metrology legislation
SANS 50197-1: Cement. Part 1: Composition, specifications and conformity criteria for common cements
Part 2: Conformity evaluation
SANS 50450: Fly Ash for concrete Part 1: Definitions, specifications and conformity criteria
Part 2: Conformity evaluation
SANS 55167: Ground granulated blast furnace slag for use in concrete, mortar or grout
Part 1: Definitions, specifications and conformity criteria
Part 2: Conformity evaluation

Test methods

SANS 50196-1: Methods of testing cement
Part 1: Determination of strength
SANS 50196-2: Methods of testing cement
Part 2: Chemical analysis of cement
SANS 50196-3: Methods of testing cement
Part 3: Determination of setting times and soundness
SANS 50196-4: Methods of testing cement
Part 4: Quantitative determination of constituents
SANS 50196-5: Methods of testing cement
Part 5: Pozzolanicity test for pozzolanic cement
SANS 50196-6: Methods of testing cement
Part 6: Determination of fineness
SANS 50196-7: Methods of testing cement
Part 7: Methods of taking and preparing samples of cement

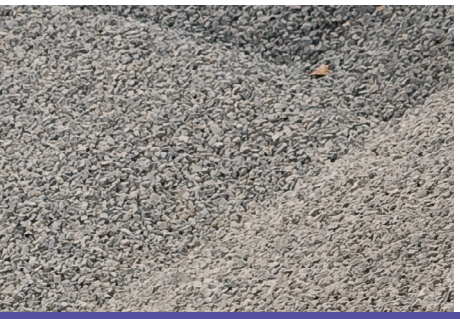
Aggregate



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Aggregate



AfriSam Aggregate products are available in Gauteng, Mpumalanga, KwaZulu-Natal and the Western Cape, allowing builders, developers, architects and engineers access to AfriSam expertise, technical backup and quality assurance, based on years of experience in the aggregate market.

Our Customer Service Centres in Johannesburg, Cape Town and Durban, and all AfriSam Aggregate operations, including the plant laboratories have ISO 9001 certification, ensuring that our aggregates are fully compliant with the relevant specifications and with the customer's requirements.

AfriSam has the capacity to produce over 10 million tons of aggregate per anum from our quarries and crushing plants.





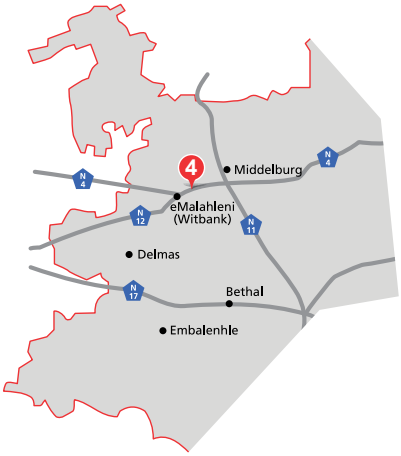
As members of ASPASA, our plants are subject to regular inspection, and our ASPASA and DMRE awards are on display in the relevant plant offices. We are also fully committed to complying with relevant statutory and regulatory requirements, as well as our own AfriSam Environmental, Health and Safety, and B-BBEE policies.

The AfriSam Aggregate product range ensures that every need in the aggregate field is met:

- Roadstone is a high quality product with specific grading, shape and wearing properties for asphalt and road surfacing applications.
- Concrete aggregates include a wide range of stone sizes within target gradings, as well as washed and unwashed crusher sands for use in all on-site and readymixed concrete applications.
- Road-layer works material includes the base and sub-base materials that provide the supporting, interlocking structure in road design. The different categories of graded material cater for varying load designs.
- Speciality aggregate include railway ballast, gabion and other larger sized crushed stone used in erosion protection, architecture and landscaping.



AfriSam Aggregate **plant locations**





Western Cape

1 Peninsula
2 Rheebok



Gauteng and Mpumalanga

1 Eikenhof
2 Jukskei
3 Rooikraal
4 Zeekoewater



KwaZulu-Natal

1 Coedmore
2 Pietermaritzburg
3 Umlaas Road
4 Verulam

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Products and properties: **Gauteng and Mpumalanga**

Product		Plant and rock type							
		EIKENHOF Andesite	FERRO (Pretoria) Meta-quartzite	JUKSKEI (Midrand) Granite	OLIFANTSFONTEIN Dolomite	ROODEKRANS (Brak-pan) Granite	ROOIKRAAL Dolerite	SUB-NIGEL (Nigel) Reef quartzite	ZEEKOEWATER (Wit-bank) Felsite
Concrete aggregate	22mm								
	13,2mm								
	9,5mm								
	6,7mm								
Crusher sand	Unwashed								
	Washed								
	-5mm washed		CLOSED		CLOSED	CLOSED		CLOSED	
	-6mm								
	-8mm								
Base	G1								
	G2								
	G3								
Sub-base	G5								
	G6								
	G7								
Roadstone	19mm								
	13,2mm								
	9,5mm								
	6,7mm								
Ballast	Minus 73mm								

Specials								
Builder's blend								
Dumprock selected								
Dumprock unselected								
Shot rock								

Properties	Eik	Ferro	Juk	Oli	Rood	Rooi	Sub-N	Zeek
RD	2,94		2,66			3,0		2,67
Water absorption, %	0,2		0,2			0,3		0,2
ACV, % (dry)	4,6		18,2			5,7		9,2
10% FACT, kN (dry)	737		239			590		418
PSV	55		0			52		52
Los Angeles Abrasion, %	0		0			9,6		12,9

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Products and properties: **Western Cape**

Product		Plant and rock type		
		PENINSULA (Durbanville) Meta-greywacke	PHILIPPI Meta-greywacke	RHEEBOK (Malmesbury) Granite
Concrete aggregate	53mm			
	37,5mm			
	26,5mm			
	19mm			
	13,2mm			
	9,5mm			
	6,7mm			
Crusher sand	Unwashed			
	Washed			
Base	G1			
	G2			
	G3			
Sub-base	G5			
	G6			
	G7			
Roadstone	19mm			
	13,2mm			
	9,5mm			
	6,7mm			
Ballast	53mm			
	73mm			

CLOSED

Specials*			
6mm Flats			
Gravel, 25mm			
Grit, -4mm/2mm			
Gabion			
Overburden			
9/25 ROC			
9mm UTFC			

Properties	Peninsula	Rheebok
RD	2,72	2,62
Water absorption, %	0,3	0,4
ACV, % (dry)	6,9	10,3
10% FACT, kN (dry)	560	390
PSV	54	52
Los Angeles Abrasion, %	11,7	13,4

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Products and properties: **KwaZulu-Natal**

Product		Plant and rock type						
		COEDMORE (Bellair) Ortho-quartzite	LADYSMITH Dolerite	LADYSMITH Siltstone	NEWCASTLE Dolerite	PIETERMARITZBURG Dolerite	UMLAAS ROAD (Camperdown) Tillite	VERULAM Tillite
Concrete aggregate	53mm							
	37,5mm							
	26,5mm							
	19mm							
	13,2mm							
	9,5mm							
	6,7mm							
Crusher sand	Unwashed		CLOSED	CLOSED	CLOSED			
Base	G1							
	G2							
Sub-base	G4							
	G5							
	G6							
	G7							
Roadstone	26,5mm							
	19mm							
	13,2mm							
	9,5mm							
	6,7mm							
Rolled-in chips	19mm							
	13,2mm							
Ballast	63mm							
	53mm							

Specials							
Builder's blend							
Dumprock							
First crush							
Handstone							

Properties	Coed	Lady (dol)	Lady (silt)	Newcastle	PMB	Umlaas Rd	Verulam
RD	2,7				2,92	2,96	2,69
Water absorption,	0,3				0,2	0,2	0,4
ACV, % (dry)	23				13,7	10,6	9,5
10% FACT, kN (dry)	240				281	296	425
PSV	53				0	0	52

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Aggregate **production**

Most commercially available coarse aggregate and crusher sands in South Africa are materials processed from a wide range of geological rock types, rather than naturally found deposits of pebbles, etc. Sands may be from natural sources, e.g. pitsand or river sand, or may be produced by crushing and screening in an aggregate plant.

The production of crushed aggregate may include quarrying (drilling and blasting) from solid rock, or may start with selected secondary material from mines, building rubble or the metallurgical industry, etc.

The sourced material is reduced into smaller particles by a primary crusher (Nordberg, Symons). This material is moved onto an intermediary stockpile or surgepile to ensure that the crushing plant has a constant supply of raw material via conveyer belts.

Crushing plant equipment settings are changed in response to the aggregate product required. The secondary crushers reduce rock particles further, after which the product is screened through different sized sieves to separate the particles into specific gradings. The different sized stones fall onto conveyor belts which move the material to the different saleable product stockpiles, e.g. 26,5mm or 9,5mm stone, or sand, or to be blended with other material, e.g. for basecourse material or builder's blend.

During processing, material is sampled and tested to assist in optimising crusher settings and checking screen integrity. As part of the quality control regime, each final product is tested against target gradings, dust content, fineness modulus and flakiness index to ensure that no non-compliant material leaves the plant.

Throughout the production processes:

- Fine material (sand) falls onto conveyors or stockpiles to be moved to a stockpile (unwashed crusher sand) or to a washing plant for removal of excess fines and dust (washed crusher sand).

- Oversize material is diverted back to the previous process.

Roadstone is generally subject to washing to remove excess dust, drying and further crushing/shaping by passing through a tertiary crusher (Barmag, Hazemag).

The different grades of road base materials (G1 to G10) relate to specific proportions of parent and non-parent rock as given in the COLTO specification, and are produced by layering different stone and sand materials on large stockpiles, and then cutting down through the layers to achieve the required pre-compaction gradings.
See *Figure 7*.

Technical **support**

Our Product Technical Managers offer technical advice ranging from assistance in choosing the correct aggregate product for the application and troubleshooting, to facilitating trial runs using AfriSam materials.

Regular testing is carried out in accordance with standard test methods for compliance of all aggregate products from each plant with relevant national and internal specifications. Grading results are captured daily to a central computerised system for continuous analysis to ensure consistence in product quality. Test results are available on request.

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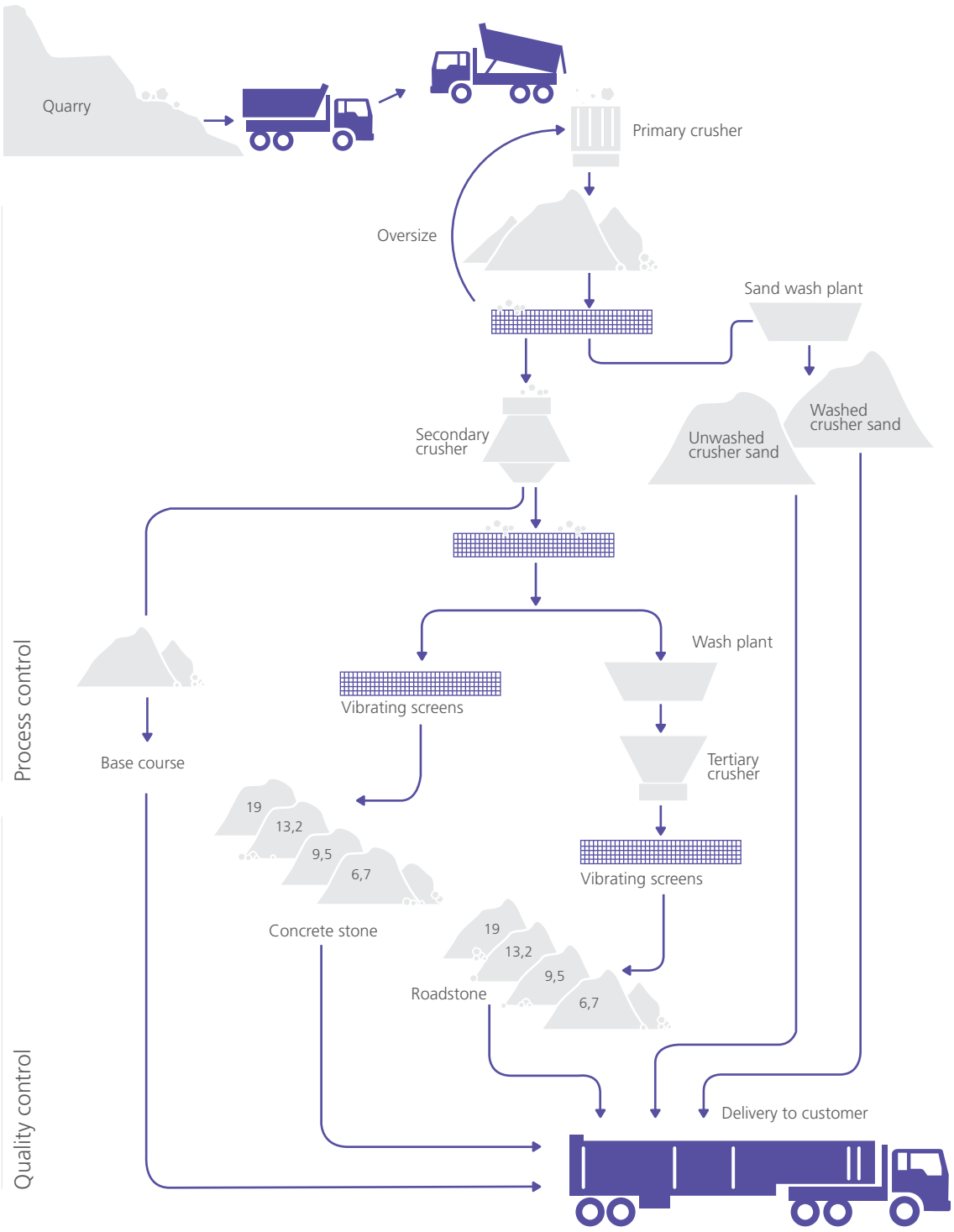


Figure 7: Typical quarrying and crushing processes
(Note that product range for specific plants differs due to rock type, equipment, etc. Not all plants produce all of the products given schematically.)

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Properties and **characteristics of aggregate**

To assist in choosing the correct product for the application, some technical detail regarding the influence of various characteristics and properties of aggregate in relation to the required application is necessary.

Apparent relative density

Relative density influences the choice of an aggregate for a specific application where concrete density is an important factor, e.g. concrete used for radiation shielding is made from high-density aggregate. In addition, the relative density of the aggregate is used in calculating the absolute or solid volumes of materials in a concrete mix and thus the yield.

The apparent relative density of aggregate generally varies between 2.5 and 3.

Water absorption

The extent to which pores in the aggregate structure can fill with water may affect the performance of concrete made with these aggregates. An aggregate with a water absorption of less than 1% is unlikely to influence concrete performance, but values above 1% may lead to slump loss and cause difficulties with concrete placing, as well as affecting shrinkage and creep.

The percentage water absorption of aggregates can also potentially influence the amount of bitumen used in asphalt mixes.

ACV and 10% FACT

The tests for Aggregate Crushing Value (ACV) and FACT (10% Fines Aggregate Crushing Test) measure the crushing strength of broken rock. These results do not necessarily relate to the flexural or compressive strength of concrete made with that aggregate, but are a useful index of overall quality.

Normal values for ACV range from 14 to 30%, and for 10% FACT from 100kN to 300kN. There is generally good correlation between ACV and 10% FACT values.

Polished Stone Value and Los Angeles Abrasion

The Polished Stone Value (PSV) is indicative of a stone's ability to offer skid resistance, while values for Los Angeles Abrasion of aggregate relate to resistance to abrasion. Both values are important indicators in the provision of hard, sound and durable materials for use in asphalt roadworks.

High abrasion resistance of aggregate is of less importance in concrete roadworks, as it does not seem to be an indicator of good abrasion resistance of the concrete.

See also *Properties of hardened concrete.*

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Applications **and requirements**

Aggregate for concrete

Table 22: Quick guide to stone sizes for different concreting applications

26,5mm	Foundations Deep suspended slabs Industrial floors thicker than 120mm
22 or 19mm	Floors, paths, patios and driveways
13,2 or 9,5mm	Thin suspended slabs, precast lintels, flagstones, bricks, blocks; also other elements with section thicknesses ranging from 40 to 50mm

Coarse and fine aggregate for use in concrete should comply with specified grading requirements (see *Tables 24* and *25*). Compliance with these requirements assists in ensuring that mix designs are both economical and produce concrete with the required strength and other properties.

The grading of both stone and sand has a major influence on the workability, cohesiveness and bleeding properties of concrete, and particle shape and surface texture have a significant effect on the water requirement of the mix.

The water demand of the sand is also important. It affects the cement content: the lower the water demand or "thirstiness" of the sand, the lower the amount of cement required for a given strength.

Concrete, mortar or plaster shrinkage may be affected by the type of aggregate used. For more information on the effect of aggregate properties on concrete, see *Properties of hardened concrete.*

The following definitions apply:

- **Water demand of sand**
  The volume of water (measured to the nearest 5 litres) to provide a slump of 75mm to 100mm using 22mm stone and commonly used cement at a water:cement ratio of 0:6.
- **Water requirement of concrete**
  The volume of water (measured to the nearest 5 litres) to provide the target slump ±15mm using the materials provided, taking the water demand of the sand into account.
- **Dust content**
  Material passing the 75µm sieve.
- **Fines content**
  Material passing the 4,25µm sieve.
- **Clay content**
  Particle size <5µm.

Deleterious impurities

During storage and batching, ensure that the aggregate has not been contaminated by leaves, excess dust or by commingling with other products as this will affect the potential strength of the concrete.

The following tests can be carried out to assess the degree of contamination:

- Organic impurities.
- Presence of sugar in natural sand.
- Soluble deleterious impurities in natural sand.
- Chloride content.

The strength of mortar or plaster may be affected by:

- Solid deleterious impurities: The strength of mortar specimens should be at least 85% of the strength of washed sand mortar specimens.
- Organic impurities: Unless the sand complies with requirements for solid deleterious impurities, the colour of the liquid above the sand should not be darker than the reference sample.

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Stone and sand for concrete, mortar and plaster

Coarse and fine aggregates used in concrete should comply with SANS 1083, and sands used for mortar and plaster should comply with SANS 1090.

Table 23: Requirements for coarse aggregate (stone)

Property	Requirements								
Grading limits, % m/m passing sieve sizes, mm	Normal aggregate size, mm								
	75,0	53,0	37,5	26,5	22	19	13,2	9,5	6,7
75	100	100							
53	0 - 50	85 - 100	100						
37,5	0 - 25	0 - 50	85 - 100	100					
26,5	0 - 5	0 - 25	0 - 50	85 - 100	100	100			
22,4					80 - 100				
19		0 - 5	0 - 25	0 - 50	50 - 80	85 - 100	100		
13,2			0 - 5	0 - 25	0 - 20	0 - 50	85 - 100	100	
9,5				0 - 5	0 - 5	0 - 25	0 - 55	85 - 100	100
6,7						0 - 5	0 - 25	0 - 55	85 - 100
4,75							0 - 5	0 - 25	0 - 55
2,36								0 - 5	0 - 25
1,18									0 - 5
Dust content, % (m/m) max	2								
Flakiness index, % max	35								
10% FACT, kN min	110 In concrete subject to surface abrasion, reinforced concrete structural elements or prestressed concrete								
	70 For concrete not subject to surface abrasion								
ACV, % max	29								

> “Where required, and subject to commercial practicalities, AfriSam Aggregate plants blend and/or produce products to comply with specific customer requirements and specifications.”



Table 24: Requirements for fine aggregate (sand)

Property		Sand for plaster	Sand for mortar	Sand seals				
				Fine slurry, grade:			Coarse slurry, type:	
				Fine	Medium	Coarse	1	2
		Requirements						
Grading limits, % (m/m) passing sieve sizes, mm	13,2							100
	9,5						100	85 - 100
	6,7				100	100	85 - 100	70 - 90
	4,75	100	100	100	82 - 100	70 - 90		60 - 80
	2,36	90 - 100		90 - 100	56 - 95	45 - 70		40 - 60
	1,18	70 - 100		65 - 95	37 - 75	28 - 50	25 - 45	
	0,600	40 - 90	40 - 100	42 - 72	22 - 50	19 - 34	15 - 30	
	0,300	5 - 65	5 - 85	23 - 48	15 - 37	12 - 25	10 - 20	
	0,150	5 - 20	5 - 35	10 - 27	7 - 20	7 - 18	6 - 15	
	0,075			4 - 12		2 - 8	4 - 10	
Fineness Modulous (FM)								
Drying shrinkage of mix, % max	0,10*	0,12*						
Dust content, % m/m max	7,5	12,5						
Clay content, % m/m max	2,0							
Methylene blue absorption value, max	0,7							
Sand equivalent, min			35					

SANS 1090 COLTO

Notes:

- If the sand complies with the methylene blue or clay content requirements, the limits for dust content may be increased.
- If the dust content exceeds the limits, test for methylene blue adsorption. If the adsorption value exceeds the limits, test for clay content. If the clay content exceeds the limits, discard the sand.
- *For mild exposure conditions or if the sand has been used safely in the past, drying shrinkage limits may be increased.

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Aggregate for concrete masonry units

Before settling on an aggregate source for precast units, bricks or blocks, carry out trials using the relevant, specific equipment to check:

- The performance of the aggregate or blends during manufacturing processes.
- Achievement of the "green" strengths required for demoulding, handling during curing and stacking operations, and transporting to site.
- The quality of the final product in terms of surface texture, arrises, uniformity of size and shape and density, and percentage handling breakages.
- Achievement of the required ultimate strengths of the masonry units.

Where possible, take the following factors into account:

- **Particle shape and surface texture**

  An elongated particle shape resists the flow of concrete due to particle interlock and high internal friction, whereas rounded shapes with smooth textures produce concrete that flows and fills moulds easily. On the other hand, elongated particle give extruded or demoulded units the "green" strength they need to avoid distortion and collapse.

  Flaky particles are always unacceptable: they resist flow, reduce internal friction and tend to create layers or planes of weakness in the concrete.

- **Grading**

  Coarse gradings (i.e. larger particle size, low fines content) produce open- or rough-textured units, which can be easily demoulded but may not have adequate green strength.

  Fine gradings (i.e. small average particle size, high fines content) will produce a close or fine-textured unit, but compressive strengths may be low. Excessive fines can result in "sticky" mixes, and the recommended FM is from 3.2 to 4.2.

  Consistent gradings of both stone and sand reduce the need to constantly adjust mix proportions and equipment settings.

- **Stone size**

  The largest practical stone size should be used: reduced water requirement gives better strengths using the same cement content. Maximum stone size used is normally 13,2mm, but stone size should not exceed ⅓ of the maximum hollow unit shell, i.e. 6,7mm for a 25mm shell thickness.

  Also, stone size should not be so large that the mix segregates in the mould, or that particles are plucked from the surface.

- **Blends**

  A practical solution to finding the "ideal" aggregate for concrete masonry units in terms of availability, grading and cost is often to blend up to three aggregates. Specialist advice may be required in order to calculate ultimate voids content and thus an optimum blend.

  An AfriSam brochure on brick and block making is available on request.

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Aggregate for road layerworks

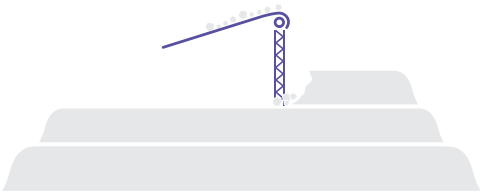
Crushed-stone base and sub-base materials provide the support structure in roads and pavements. Material classification is given in Table 26.

Requirements for approved target grading

SANS 1200-M and COLTO requirements state that the aggregate for bases and sub-bases should be derived from hard, sound and durable rock.

Approved target gradings are determined by laying a trial section using material complying with the grading limits given in Table 27. Prior to compaction, six samples of the material in situ are taken and subjected to grading analysis. The resultant (smoothed) grading curve is then classified as the approved target grading for that specific project.

All future grading results are evaluated against the approved target grading (within specified tolerances).



Build pile radially in horizontal layers, working from materials as dropped from conveyor belt. A rock ladder may be needed in this setup.



Place material so that aggregate remains where placed and does not run down slopes.

Figure 8: Construction of a road base material stockpile

Table 25: G1 to G7 classification

Use	Classification	Normal maximum size, mm		Aditional fines allowed
Base and sub-base	G1	37,5		Only from parent rock
	G2	37,5 or 26,5		Up to 10% natural fines
	G3	Crushed: Uncrushed:	37,5 or 26,5 53	Up to 15% natural fines
Pavement layers	G4	Crushed: Uncrushed:	53 63	Natural materials
	G5	Crushed: Uncrushed:	53 ⅔ Of compacted layer thickness	
	G6	Crushed: Uncrushed:	75 ⅔ Of compacted layer thickness	
	G7			N/A

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Table 26: Requirements for roadstone

Properties	Road layer works						Asphalt		Surfacing						
Grading limits, % (m/m)	G1 to G3	G3	Tolerances on approved G4 target		In-crushed	G5 to G7			Grades 1 and 2						
			Crushed				Rolled-in chips (additional req)		Grade 3: as for Grades 1 and 2 with exceptions: 0 - 5; 0 - 10						
	37,5	26,5	37,5	26,5	53		19	13,2	26,5	19	13,2	9,5	6,7	4,75	2,36
75						Prescribed grading modulous			100						
53					100				85 - 100	100					
37,5	100		100		85 - 100				0 - 30	85 - 100	100				
26,5	84 - 94	100	84 - 94	100					0 - 5	0 - 30	85 - 100	100			
19	71 - 84	85 - 95	71 - 84	85 - 95	60 - 90		100			0 - 5	0 - 30	85 - 100	100		
13,2	59 - 75	71 - 84	59 - 75	71 - 84			0 - 20	100			0 - 5	0 - 30	85 - 100	100	
4,75	36 - 53	42 - 60	36 - 53	42 - 60	30 - 65		0 - 5	0 - 20				0 - 5	0 - 30	85 - 100	100
2	23 - 40	27 - 45	23 - 40	27 - 45	20 - 50		0 - 1	0 - 5						0 - 3	
0,425	11 - 24	13 - 27	11 - 24	13 - 27	10 - 30		0,5 max	0,5 max					0 - 5	0 - 5	0 - 100
0,075	4 - 12	5 - 12	4 - 12	5 - 12	5 - 15										

Flakiness index, % max	(-26,5 + 19) and (-19 + 13,2) mm fractions 35 (G1: all faces fractured; G2 and G3: at least one fractured face on half of stone particles)				Flakiness index, % max	Grade 1		25		30				
Hardness	100% FACT, min			ACV, % max		Grades 2 and 3		30		35				
	Dry, kN	Wet, kN	Wet/dry relation-ship %		Fines content, max	Grade 1	0,5	0,5	0,5	0,5	0,5	1	15
Aranaceous rocks, without siliceous cementing mix	140		75	27		Grade 2	1,5	1,5	1,5	1,5	2	2,5	15
Aranaceous rocks, with siliceous cementing matrix	110		75	29		Grade 3			2	2	3	3,5	15
Diamecitites (tillite)	200		70	21	Dust content, max	Grade 1							2
Argilaceous rocks	180	125		24		Grade 2	0,5	0,5	0,5	0,5	1,5	1	2
Other rock types	110		75	29		Grade 3			1,5	1	5	1	2





Hardness

The hardness of aggregate used in road layer works is of importance for obvious reasons, and the particle shape influences the workability, compaction and density achieved.

Soluble salt requirements

For quartzite, tillite, shale and G1 to G4 materials, measure the soluble salts against pH or electrical conductivity.

- Use the material if the pH is >10 after treatment at the crushing plant, and subsequently remains = 8.0.
- If the pH is <6.0, treat with lime until the pH is = 10.0 before use.

For natural gravel and other crushed aggregate, use the material if the electrical conductivity (EC) is 0.15Sm^{-1}, but pay particular attention to design and construction if the pH is = 6.0.

For stabilised material:

- If the pH is = 6.0, the EC is 0.02Sm^{-1} and sulphates are not a problem, use the material. If not, analyse the material in accordance with the customer's instructions, and submit a proposal for use to the customer for approval.
- Where the salinity of water added for compaction causes the salinity of the material to increase, determine soluble salinity within 24 hours of compaction, before prime coat is applied.



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Aggregate for asphalt/roadstone

Asphalt is a mixture of inert mineral matter such as aggregate, mineral filler and bituminous binder in predetermined proportions.

Types of asphalt

Continuously-graded asphalts are mechanically mixed asphalts in which the aggregate and the filler are distributed in size from coarse to fine fractions within a specific smooth grading envelope.

Typical continuously-graded asphalts are:

- **LAMBS (Large aggregate mixes for bases and surfaces):**
  A graded asphalt containing large aggregate up to 37,5mm and meeting prescribed engineering properties for use as base coarse material.

- **BTB (Bitumen treated base):**
  A graded base-course layer with aggregate up to 26,5mm mixed with bituminous binder.

- **ACM (Asphalt continuously-graded medium):**
  An asphalt layer with aggregate up to 13,2mm.

- **ACF (Asphalt continuously-graded fines):**
  An asphalt with aggregate up to 9,5mm.

- **Slurry Seal:**
  An ultra-thin layer with sand and bitumen, applied in a flowable form.

Gap-graded and semi-gap-graded asphalt are mechanically mixed asphalts from which some intermediate aggregate sizes are omitted to comply with a stepped grading envelope. These asphalt layers either contain a 19mm or 26,5mm maximum aggregate size.

Open-graded asphalt (aggregate skeleton mixes) are mixes which normally require single-sized crushed aggregate (see *Table 27*). The asphalt is constituted to give a rough surface texture in the compacted state and is mechanically mixed. This design normally focuses on very single sized material (either 13,2mm or 9,5mm) combined with a minus 3mm sand with a high dust content.

Typical open-graded asphalts are:

- SMA (Stone mastic asphalt).
- Novachip.
- Gripphalt.
- BRASO (Bitumen rubber asphalt semi-open).
- BRAC (Bitumen rubber asphalt course).

This type of layer is also used when ultra-thin pavements are constructed using pavers.

Requirements for aggregate used in asphalt

Due to the importance of the aggregate in the mix, understanding the impact of the following properties is critical:

- Grading.
- Angularity of stone and sand particles.
- Clay content (cleanliness).
- Toughness and/or hardness.
- Soundness.
- Deleterious material.
- Water absorption and relative density.
- Particle shape and surface texture.

When selecting an aggregate source, in addition to cost and availability of materials, take the following factors into account:

- Transport costs.
- Physical properties, such as grading limits, fines and dust content, flakiness index, FACT values, ACV and PSV.
- Geological properties.
- Skid resistance and traffic load.
- Moisture sensitivity and climate.
- Local experience.

Coarse aggregate for asphalting should comply with SANS 1083 (see *Table 24*), and fine aggregate with SANS 1090 (see *Table 25*). Additional requirements for rolled-in chips are given in Table 27.

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Aggregate

Aggregate for surfacing

Aggregate used in the production of surface layers or seals for roads is usually applied by chip spreaders. Bitumen binder is sprayed onto a prepared base-course layer, and aggregate particles are applied immediately and rolled in to achieve a mosaic pattern, causing the binder to move into the voids between the particles.

- **Single seals**
  Used in the construction of new surfaces as well as rehabilitation of existing surfaces. Traffic volume determines the aggregate size, and a second binder layer may be applied if stone size exceeds 13,2mm. Precoating may improve adhesion.

- **Double seals**
  Constructed in two layers, with the top layer containing smaller aggregate than the bottom. Use larger aggregate sizes for roads carrying heavy traffic.

- **Slurry seals**
  Used to achieve uniform texture on roads with varying surfaces, and also for pretreatment before applying single or double seals (although this is not advisable). Slurry seals should not be used on smooth-textured surfaces.

- **Sand seals**
  Used in low-cost construction, for low-traffic roads, as dust palliatives and also as pretreatment for single and double layer surfaces. Water may be required to assist in the screening process and to clean the sand of excess fines.

  Single-sized aggregate for surfacing and sands for slurry and sand seals should comply with COLTO requirements (see *Table 27*).

In addition, the following requirements apply:

- **Hardness**
  When tested in accordance with standard test methods, the ACV should not exceed 21% and the 10% FACT (dry) value must be at least 210kN. The wet:dry ratio should be at least 75%.

  The PSV should be at least 50 unless otherwise specified or approved by the engineer.

- **Particle shape**
  Where stated in the project specifications, the average least dimension (ALD) should comply with the figure indicated.

- **Sand properties and sand equivalent**
  Sand for slurry should be an approved crusher sand obtained from parent rock with an ACV not exceeding 30%, or a mixture of crusher sand and not more than 25% clean natural sand.

  Sand for sand seals must comply with project specifications, and may be crusher sand complying with COLTO requirements or natural sand.

  For the best results, sand for fine and coarse slurries and seals should be clean, tough, durable and angular in shape, and the sand equivalent should be above the minimum specified.



Special products

Our range of special aggregate products can be supplied either ex-stock (see *Product availability and properties*) or produced to order.

Selected dump rock is produced and supplied for:

- Architectural features in home and office block construction, etc.
- Landscaping to protect or improve environmental aspects, e.g. as low-maintenance filters and channel linings.
- Gabions.

Builder's Blend and Block Mix (ungraded) is supplied to small, often informal businesses in the residential construction and brick- and block-making industries.

Other products such as Novachip and 6mm Flats are crushed and screened to comply with specific customer grading envelopes and other required properties.

Handling aggregate on-site

The following guidelines help ensure that our aggregate products remain within specification after tipping:

- Stockpile aggregates close to where they will be used, but not exposed to excessive dust.
- Before starting to tip the aggregate, clear the area so that no debris, grass, mud or dirt contaminate the stone or sand.
- If possible, provide a slightly sloped concrete base to allow for drainage.
- Keep access roads to stockpiles clear so that FELs do not track mud into the stockpiles.
- Keep stockpiles separate to avoid intermingling.
- If aggregate has segregated during transport, remix.
- Clearly identify stockpiles and bins: type, size, supplier.
- Build up stockpiles in layers (see *Figure 8*) and do not over-tip.
- Remix road base material before use.

Guidelines to sampling aggregates on-site

Where samples are required for grading analysis, etc., take a representative sample.

- **Stockpile**
  Take at least ten increments from different parts, working from the bottom of the stockpile upwards. Avoid sampling in segregated areas, or from the surface.

- **Bins or bays**
  Remove and discard 100mm to 150mm of material from the surface, then take at least eight increments evenly spaced over the area.

- **Vehicles**
  Dig a trench across each of three approximately equal sections, at least 300mm deep and approximately 300mm wide, then take four increments equally spaced from the bottom of each trench (push shovel down vertically).

- **Belt conveyor**
  Stop belt, remove approximately 1m length across the width of the belt.

Combine all the increments, mix and use the coning-and-quartering method or a riffler box to work the sample down to the amount specified in the relevant test method. Place the sample in a clean, dust-free container, and label to indicate aggregate size and/or type, source, date sampled and tests required before dispatching to the testing laboratory.

- Don't stand behind lorries discharging loads.
- Don't climb into the loadbed of a lorry at any time.
- Use protective equipment to avoid excessive exposure to dust.

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Aggregate

The following contaminants can affect the performance of aggregate in concrete by causing set retardation:

- Tea residue thrown on stockpiles.
- Stockpiles used as urinals.
- Transporting aggregate in trucks used to haul sugar, etc., or contaminated with other aggregate products like sand.

Applicable specifications

COLTO Standard Specifications for Road and Bridgeworks for State Road Authorities, 1998
SANS 1083:2006: Aggregates from natural sources – Aggregates for concrete
SANS 1090:2009: Aggregates from natural sources – Fine aggregates for plaster and mortar
SANS 1200-M:1996: Standard specification for civil engineering construction. Section M: Roads (general)

Test methods

SANS 197:2006: Preparation of test samples of aggregates
SANS 201:2008: Sieve analysis, fines content and dust content of aggregates
SANS 202:2006: Chloride content of aggregates
SANS 794:2009: Aggregates of low density
SANS 5832:2006: Organic impurities in fine aggregates (limit test)
SANS 5833:2006: Detection of sugar in fine aggregates
SANS 5834:2006: Soluble deleterious impurities in fine aggregate (limit test)
SANS 5835:2006: Estimation of the effect of fine aggregate on the water requirement of concrete
SANS 5838: 2006: Sand equivalent value of fine aggregates
SANS 5841:2008: Aggregate crushing value of coarse aggregates
SANS 5842:2006: FACT value (10% fines aggregate crushing value) of coarse aggregates
SANS 5844:2006: Particle and relative density of aggregates
SANS 5845:2006: Bulk densities and voids content of aggregates
SANS 5846:2006: Abrasion resistance of coarse aggregates (Los Angeles machine method)
SANS 5847:2008: Flakiness index of coarse aggregates
SANS 5848:2008: Polished-stone value of aggregates
SANS 5849:2008: Total water soluble salts contents of fines in aggregates
SANS 5854:2006: pH value of fines in aggregates for base-courses
SANS 6239:2012: Aggregate impact value of coarse aggregate
SANS 6240:2008: Electric conductivity of fine aggregate
SANS 6242:2008: Acid insolubility of aggregates
SANS 6243:2008: Deleterious clay content of the fines in aggregate (methylene blue adsorption indicator test)

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Readymix



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Readymix

AfriSam Readymix products are available from plants situated in Gauteng, Mpumalanga, KwaZulu Natal and the Western Cape. Customers are able to maintain a competitive edge in the construction marketplace by making use of AfriSam's expertise in choosing and proportioning suitable and compliant raw materials, computerised weigh-batching, concrete pumping services, technical backup and quality assurance.

AfriSam Readymix plants have ISO 9001 certification, and AfriSam Readymix is a member of associated industry related bodies.





Our Product Technical team is available for on-site technical advice for issues relating to concrete technology, optimisation of mixes, and research and development.

AfriSam Readymix plants across Southern Africa have the capacity to produce over 1 million m^3 of readymixed concrete annually. Our fleet of 200 mixer trucks and pumps ensures that concrete is delivered, discharged and placed on-site on time and as close to its final position as humanly possible.

Carbon footprint of readymix concrete

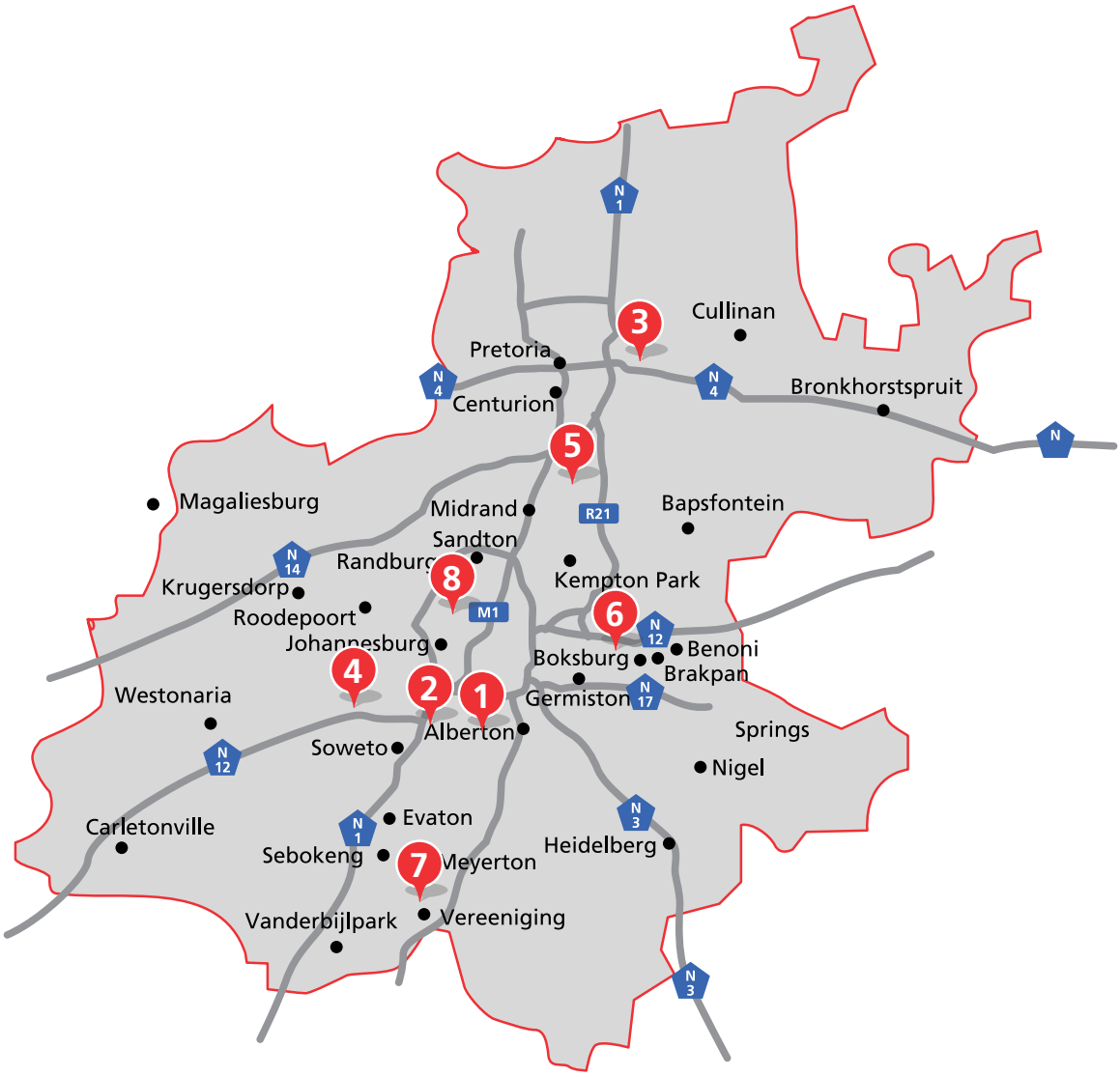
Since 2009, the CO_2 footprints of AfriSam Readymix plants and our application branded products have been quantified and monitored.

CO_2
Reducing our Carbon Footprint

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AfriSam Readymix **plant locations**



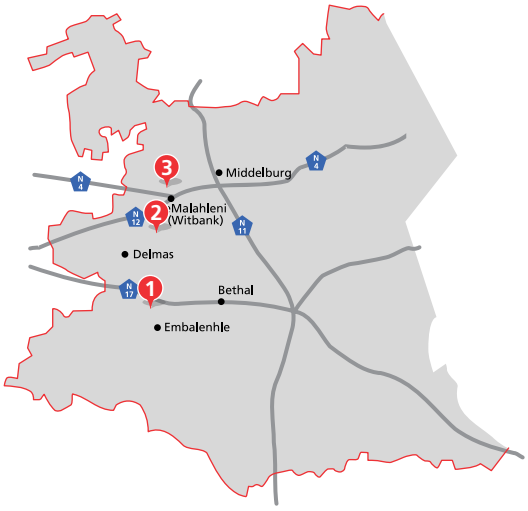
Gauteng

1 Eikenhof
2 Ferro
3 Jukskei
4 Olifantsfontein
5 Prolecon
6 Sub-Nigel
7 Vereeniging
8 Wynberg A

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Readymix



Mpumalanga

1 Evander A
2 Ogies A
3 Witbank



Western Cape

1 Bellville
2 City A
3 Peninsula



KwaZulu-Natal

1 Coedmore
2 Ottawa
3 Pietermaritzburg

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AfriSam Readymix: **Application brands**

By carefully designing and producing application-branded mixes to comply with SANS 878, and for optimal performance in terms of workability and rate of strength gain as shown in Table 31, AfriSam Readymix takes the uncertainty out of decisions regarding cost-effective and environmentally sound solutions for concrete for residential and non-residential construction, and also for the Starmix brand for smaller residential projects where specified strength relates directly to the application.

In addition, all our readymixed concrete products (with the exception of Foundation Mix) can be designed for placing by pump (see *Pumpable concrete*).

Table 27: Application brand performance matrix

Rate of strength gain	**Rapid**	Surfacebed Mix	Retainer Mix Suspended Slab Mix Column Mix Post Tension Mix
	Enhanced	Surfacebed Mix	Retainer Mix Suspended Slab Mix Column Mix
	Standard	Blinding Mix Foundation Mix Starmix	Retainer Mix
Target slump: Slump details available on request			

The different strength gain options relate directly to the following application requirements.

Table 28: Strength gain solutions

Application brand	Typical requirements
Foundation Mix	Concrete does not normally require quick stripping times
Starmix	Concrete needs to stiffen and gain strength rapidly for power-floating and joint cutting
Retainer Mix	Concrete requires enhanced strength to facilitate stripping of formwork
Surfacebed Mix	Rapid strength gain to achieve the required 3-day hurdle and to allow for tensioning (see *Figure 9*)
Suspended Slab Mix	
Column Mix	
Post Tension Mix	

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Foundation Mix

Foundation Mix is a branded product with specific focus on strength gain and workability that can be used for all foundations. Foundation Mix has a target strength of between 10MPa and 35MPa, and a target slump of 100mm.

Features of Foundation Mix

- Will flow into difficult areas and shapes.
- Has increased resistance to aggressive environments due to the GGBFS and/or FA content in the mix.
- Is a cost-effective solution.

Benefits of Foundation Mix

- Faster placing into irregular shapes improves productivity.
- More durable concrete with less likelihood of concrete deterioration.

Retainer Mix

Retainer Mix is a branded product with specific focus on strength gain and workability, to ensure the mix is ideally suited to concrete wall applications. Retainer Mix has a target strength of between 25MPa and 45MPa, and a target slump of 125mm.

Features of Retainer Mix

- Suitable for direct, crane or skip discharge.
- Flows easily.
- Provides an excellent off-shutter finish.
- Has increased resistance to aggressive environments due to the GGBFS and/or FA content in the concrete mix.
- Quick discharge due to high workability.

Benefits of Retainer Mix

- Improved off-shutter finish requires less remedial work.
- Allows for more durable concrete with less likelihood of concrete deterioration.
- Minimal vibration required.

Surfacebed Mix

Surfacebed Mix is a branded product with specific focus on strength gain, finishing and workability for slabs on the ground, e.g. factories, shopping centres and parking areas, as well as road paving elements such as culverts, drains, etc.

Surfacebed Mix has a target strength of between 20MPa and 40MPa, and a target slump of 100mm.

Features of Surfacebed Mix

- Easily compacted, floated and finished.
- Optimal cutting time.

Benefits of Surfacebed Mix

- Optimal cutting time improves productivity.

Column Mix

Column Mix is specially designed with additional, selected fine material for increased paste and improved rheology to ensure effective pumpability and placeability. The concrete flows easily through areas congested with reinforcement to give excellent protection of steel, impermeable cover to steel and good finish without honeycombing.

Column Mix is available in rapid and enhanced strength gain options, and has a target slump of 125mm.

Features of Column Mix

- Pumpable due to high workability.
- Excellent flow of concrete into steel cages and around rebar.
- Excellent surface finish.

Benefits of Column Mix

- Improved cohesion results in better off-shutter finished.
- Denser, less permeable concrete to prevent penetration of moisture and rusting of steel.
- Minimises honeycombing at foot of columns.

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Suspended Slab Mix

Suspended Slab Mix is a branded product with specific focus on strength gain and workability suitable for all slabs above ground, for high-rise buildings, parkades and hollow-block systems. Suspended Slab Mix has a target strength of between 20MPa and 40MPa with a target slump of either 100mm or 125mm.

Features of Suspended Slab Mix

- Pumpable due to high workability.
- May be easily placed.
- Makes for easy compaction.
- A good surface finish is easily achieved.

Benefits of Suspended Slab Mix

- Allows for more efficient use of labour as a result of easier placing, compacting and finishing.
- Improved cohesion results in better off-shutter finishes.

Stripping of formwork

How long the formwork should remain in place to provide the required finish is normally specified. Table 29 should be regarded as a guide only. In cool weather, stripping times are determined by interpolation between the periods specified for normal and cold weather.

Post Tension Mix

Post Tension Mix is a branded product with specific focus on strength gain, finishing and workability that can be used for all post tension applications or areas where early strength gain is a construction requirement.

Rapid strength gain is required in order for Post Tension Mix to achieve the three-day hurdle, and allow for tensioning of the slab. Figure 9 shows a typical strength curve of the expected MPa achievement over the 28-day cycle.

The product offers a target strength of no less than 30MPa at 28 days, and a guaranteed 18MPa after three days (i.e. 72 hours after completion of pour) under standard curing conditions. Target slump is 125mm.

Features of Post Tension Mix

- Pumpable due to high workability.
- May be easily placed.
- Makes for easy compaction.
- Is easily finished.
- May be power floated.

Benefits of Post Tension Mix

- Guaranteed early strength performance (see *Figure 9*).
- Allows for more efficient use of labour as a result of easier placing, compacting and finishing.
- Improved cohesion results in better off-shutter finishes.

Post Tension Mix is available with a target slump of 125mm.

Table 29: Guideline to stripping times

Strength gain category	Rapid		Enhanced	
	Normal	Cold	Normal	Cold
Slabs with props left in place	4	7	6	10
Beam soffits with props left in place and ribs of a floor construction	7	12	10	17
Slab props including cantilevers	10	17	10	17
Beam props	14	21	14	21

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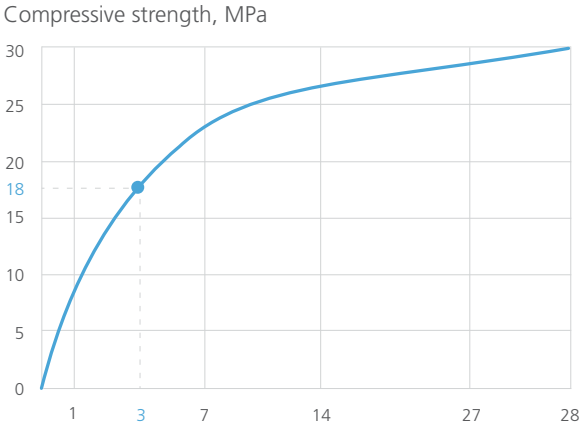


Figure 9: Typical minimum 28-day strength curve for 30MPa Post Tension Mix

Special requirements for branded products

The mix designs for the products described above can be modified on request to comply with special requirements, e.g. low carbon-footprint concrete for environmental requirements, or for products to be placed by pump.

Starmix

Starmix is designed as the lowest-cost fit-for-purpose readymixed concrete solution for non-reinforced residential and non-residential building applications, and is manufactured in accordance with SANS 878 and 2001-CC1 specifications.

Starmix is available to the builder at the specified time and place, in the correct quantities, in amounts from as little as one cubic metre. By simply ordering Starmix and specifying strength requirements, the builder has the solution to all concreting applications.

- Unreinforced foundations (10MPa to 15MPa)
- Reinforced foundations (20MPa to 25MPa)
- Non-wearing driveways (20MPa to 25MPa)
- Suspended slabs (25MPa)

Depending on strength grade, excess or left-over Starmix can safely be used for other residential applications, e.g. garden pathways, DIY projects, etc.

Table 30: Other applications

Application brand	Excess application-brand concrete can be safely used for the following construction elements:				
	Foundations	Retaining walls	Surfacebeds, non-wearing	Columns	Suspended slabs
Foundation Mix		Vibrate thoroughly			
Retainer Mix					
Surfacebed Mix					If same strength
Column Mix					If same strength
Suspended Slab Mix				If same strength	
Post Tension Mix					

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Eco Concrete Mix

AfriSam's industry-first range of low carbon footprint, environmentally responsible readymixed concrete is produced from a specially formulated blend of high-performance cement and carbon-neutral chemically activated mineral components.

All our fit-for-purpose branded products for foundations, retainer walls, surfacebeds, columns and suspended slabs can be designed to incorporate the environmental advantages encapsulated in Eco Concrete Mix. Ultra-high performance Eco Concrete Mix with strengths of above 70MPa can be supplied.

Features of Eco Concrete Mix

- Cost-effective building solutions for both short- and long-term compliance with Green Star system requirements.
- Enables shorter building cycles (early strength gain).

Benefits of Eco Concrete Mix.

- All of the environmental advantages of using concrete, with an extremely low carbon footprint.

Specify Eco Concrete Mix for any construction projects where a low-carbon footprint is important.

Table 31: Eco Concrete Mix carbon footprint (based on 2011 values)

Concrete strength, MPa	CO_2, kg/m^3		Reduction in CO_2
	Typical concrete	Eco Concrete Mix	
25	227	122	46
30	227	141	49
35	309	152	51

Table 32: AfriSam application brands by strength

				MPa								
			Slump	10	15	20	25	30	35	40	45	50
Strength Gain	Rapid	Post Tension Mix	125mm slump					30	35			
		Surfacebed Mix	100mm slump			20	25	30	35	40		
		Suspended Slab Mix	125mm slump			20	25	30	35	40		
		Column Mix	125mm slump			20	25	30	35	40	45	50
	Enhanced	Post Tension Mix	125mm slump					30	35			
		Retainer Mix	125mm slump			20	25	30	35	40		
		Surfacebed Mix	100mm slump			20	25	30	35	40		
		Suspended Slab Mix	125mm slump			20	25	30	35	40		
		Column Mix	125mm slump			20	25	30	35	40	45	50
	ECO	Retainer Mix	125mm slump			20	25	30	35	40		
		Foundation Mix	100mm slump	10	15	20	25	30	35	40		
		Starmix	125mm slump	10	15	20	25					

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AfriSam Readymix: **Speciality products**

To incorporate the full benefits of using speciality concretes for specific applications, our Product Technical team offers access to AfriSam experience and knowledge from design stage through laboratory and site trials onwards.

The following are typical examples of concretes designed in response to constantly changing industry and therefore customer requirements.

Hi-spec durability-grade concrete

Designed to comply with today's stringent durability requirements, this concrete has optimal cement contents to meet required durability specifications.

The use of new-generation admixtures allows for a reduction in design water content thereby improving durability and compressive strength characteristics.

Self-compacting concrete

A combination of the following fresh concrete properties defines self-compacting concrete (SCC):

- **High fluidity and deformability**
  By limiting the coarse aggregate content, the increased paste content and the addition of superplasticisers provide the necessary flow under self-weight.

- **Resistance to segregation**
  Because of a reduction in the water:powder content and where necessary the addition of viscosity-modifying agents, SCC resists segregation during flow and at rest after placing.

- **Ability to pass "obstacles" without blocking**
  SCC passes through and around reinforcing bars without requiring additional mechanical vibration.

Trial mixes are recommended in a controlled laboratory environment or on-site to achieve optimal SSC properties. A slump flow or spread diameter (mortar flow cone) of 65cm and V-funnel flow time of 10 to 20 seconds are considered adequate to achieve the above properties.

Flowcrete

A specially modified, highly workable, cohesive readymix concrete designed to meet specific placement and performance requirements for concrete with enhanced fluidity without promoting the segregation normally found in highly fluid mixes, allowing greater flexibility in both design and construction. This concrete is designed for strengths from 15MPa upwards for normal placing or pumping, and can be pumped from the bottom of the formwork upwards.

Once placed, the mix requires minimal compaction and is virtually self-levelling, with no segregation and minimal bleeding. The rate of strength gain and attainment of specified 28-day compressive strengths are the same as for normal concrete. Durability is enhanced due to improved compaction, and very high quality off-shutter surfaces are obtained. Shrinkage characteristics are similar to normal concrete.

Features and benefits

- Faster discharge and ease of placement.
- Less site equipment.
- Flows through narrow spaces and irregular shapes, congested reinforced concrete members, and into areas not accessible to poker or other vibration, e.g. underground.
- High quality off-shutter finshes.
- Increased free fall limits and deeper lifts without segregation.
- Improved level tolerances of floors and slabs.
- High quality finishes can be achieved.
- Excellent workability.
- No segregation or workability is achieved without compromising cohesion.
- Greater productivity or flexibility and efficient use of labour.

Placement benefits

- Ability to flow laterally up to 15m without mechanical propulsion.
- Lower pumping pressures and longer pipelines allow for less relocation of the pump during pours.
- May be pumped over longer distances, due to its fluidity and ability to flow past obstacles without segregating.
- May be pumped at a faster speed over distance.
- Stable in fresh state, i.e. no segregation during pour due to external factors.
- Use of retarders allows extended pour periods.



Fibre-reinforced concrete

AfriSam's multiple-component fibre-reinforced concrete with an even distribution of polypropylene and/or steel fibres throughout the mix is designed to comply with specific project specifications provided by the engineer for:

- Floor slabs, including heavy industrial applications.
- Concrete roads.
- Industrial and commercial parking areas.
- Warehouses.
- Channel linings.

In the hardened state, the fibres enhance the properties of concrete:

- Inclusion of polypropylene fibres in the matrix reduces plastic-shrinkage cracking.
- Reduced bleeding.
- Reduced surface permeability.
- Crack control.
- Increased toughness, ductility and impact resistance.

Special attention must be paid to joint detailing and adequate surface finishing.

Poolmix

Poolmix is a semi-dry readymixed concrete specifically designed for handpacking pools. A high cement and low water content allows for high early strength development. The mix facilitates handpacking and complex shaping, and is very cohesive, allowing the walls and floor to form a monolithic unit.

No specialised equipment is needed, and noise and dust pollution is eliminated. This makes Poolmix ideal for the construction of swimming pools, water features, koi ponds and drainage channels in domestic and other environments.

Recommended strength for most applications is 30MPa. Poolmix uses a cement that promotes rapid strength gain.

See *Concrete for specific requirements for placing Poolmix.*

Mortars and plasters

AfriSam Readymix supplies readymixed mortars and plasters in the following classes:

- Class I for highly stressed masonry incorporating high-strength structural units in multi-storey buildings and for reinforced masonry.

- Class II for normal load-bearing applications as well as parapets, balustrades, retaining structures and free-standing garden walls, as well as other walls exposed to possible severe dampness.

Benefits of using readymixed mortar or plaster

This service provides the same advantages as readymixed concrete, including:

- Consistent product: the correct mix proportion every time.
- Guaranteed strength.
- Savings on plant and labour costs.
- No cement required on-site: extra ordering, storage, handling and pilferage.
- Reduced wastage: the exact quantity required, in amounts from as little as one cubic metre.

In addition, retarded mortar with up to 36-hour workability can be supplied on request.

Blinding Mix

Blinding Mix is available on request to provide a level surface over compacted subgrade to facilitate further construction activity.

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Readymix services

Pumping Service

AfriSam Readymix can be placed using our range of dedicated pump fleet to service your individual requirements. Pumping allows for the uniform placement of concrete into areas not easily accessible by other means. Pumped concrete is flowable and yet highly cohesive to allow for easy placing, compaction and finishing. AfriSam pumps have some of the longest boom reaches in the country, with outputs varying from 18m³ to 70m³ per hour, depending on the speed of the placing team and length of the pipeline used.

Reasons for pumping

- The site or element to be concreted may be difficult to reach.
- Pumping allows for high speed of placing.
- Pumps are suitable for highly congested sites with limited space for transporting concrete.
- Pumps are suitable for high-rise projects and allows for placing of concrete at various levels.
- Pumping offers a cost-effective solution in terms of reducing labour costs and saving time.
- Pumping is a convenient option as concrete can be placed where it's needed, easily and efficiently.
- For residential applications, pumping eliminates the need to build ramps for wheelbarrows, to break down walls and to disturb established gardens.

Factors that need attention when deciding to pump

- There needs to be close communication between the contractor and AfriSam to ensure the requirements of the project are met.
- AfriSam needs to determine site accessibility for the truck-mounted pump and truck mixers.
- A wash-out area must be provided to allow for the truck chutes to be cleaned and the pump and pipeline segments to be washed out. NB: This water should not be allowed to drain into sewerage systems. If there is no place to wash-out, prepare a sandbagged area.
- Safety aspects need to be respected at all times as high pressures are used to force the concrete through the pipeline. Staff not directly involved should keep clear of the pumping area include the area underneath the boom.
- As far as possible, it is important for AfriSam to do a pre-pump inspection as this allows us to check that all the requirements for pumping will be met.



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Concrete





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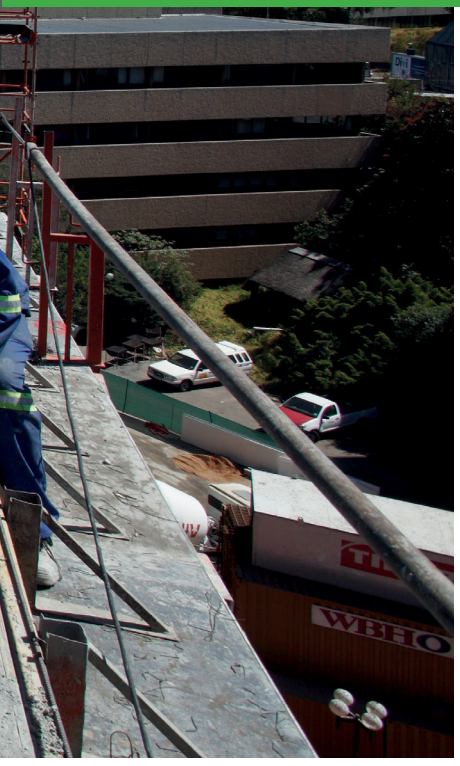
Concrete

Whether readymixed or site batched, concrete is in a fresh state for only a few hours. About three hours after water is added, concrete loses workability then gradually starts to set, changing slowly from a plastic state into a rigid solid that, with adequate curing, will continue to gain strength.

The properties of fresh concrete are important. They influence the handling, ease of compaction and the uniformity of distribution of the concrete constituents, each of which influences strength and durability of the hardened concrete.

Concrete is the second-most widely used material on earth.





Workability of concrete may be defined as that property of freshly mixed concrete which determines the ease with which it can be mixed, placed, consolidated and finished to a homogenous condition, i.e. workability must relate to the way the concrete is handled on site. The concrete must be capable of being transported by the designed method, must be easily compacted, even into difficult sections, and must provide an acceptable surface finish, either off-shutter or by power floating.

- **Workability**
  is a composite property, and difficult to measure directly. It can, however, be assessed in terms of consistence and cohesiveness.

- **Consistence**
  describes mobility or ease of flow and is related to the wetness of the mix. Wetter concrete is usually more workable than dry concrete, but concretes of the same consistency may vary in workability.

- **Cohesiveness**
  describes the tendency to resist segregation and bleeding. There is a worldwide tendency to produce concrete of higher workability to facilitate compaction and speed up the construction process. AfriSam Readymix produces flowcrete with a slump in excess of 200mm (flow of 500mm to 600mm), as well as self-compacting concrete for special applications.



Concrete, a sustainable resource

Sustainability is about balancing the associated economic, social and environmental factors, not only at inception but during use.

From an economic viewpoint, although cement is costly to produce in both financial terms and in terms of embodied energy, the amount of cement used in concrete is only about 10% of the total raw materials. In turn, the combined embodied impact of cement, aggregates, water and admixtures used in concrete accounts for only 10% of the impact of the operating phase of conventional buildings.

In the long-term, concrete's durability, low maintenance and reusability coupled with a myriad of other environmental advantages have very positive long-term economic and environmental effects. In the construction industry this balance is of great importance not only before and during the construction stage, but is also about making the right decisions at the design stage, and choosing materials and construction methods to ensure long-term sustainability.

A model available freely from www.theconcreteinstitute.org.za takes into account "cradle-to-grave" emissions of common raw materials used in concrete, including transport of those materials, and gives average emission numbers expressed in kg CO_2/ton of material produced. By using this data, the designer can experiment with different material combinations to minimise the environmental impact and quantify the effect of the material properties on cost per cubic metre of concrete.

For more about concrete's innate cost-effectiveness, energy efficiency, thermal mass, light reflectance, fire resistance, low maintenance, acoustic performance, pollution reduction, water conservation, construction flexibility, retrofitting, recycling and reusing, see the Concrete Institute's series of booklets on sustainable concrete.



Reducing our Carbon Footprint

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Factors affecting **workability**

Workability is affected by water content, actual proportioning of raw materials, aggregate and cement types and characteristics, admixtures, time elapsed after mixing, and ambient and concrete temperatures.

- **Water content**
  In an average concrete mix using 19mm stone, a total water content of about 210 litres/m^3 gives a slump of 75mm. In a well-proportioned mix, an increase in water content will make the concrete more mobile or flowable.

- **Cement content and type**
  Generally, mixes with low cement contents are less workable and more difficult to finish; mixes with high cement contents, typically above 500kg/m^3, tend to be sticky and lose workability quickly.

  Using cements containing Fly Ash (FA) gives concrete improved workability.

- **Sand**
  If the sand content is too low, the concrete will be harsh. The sand content needs to be sufficiently high and contain about 30 to 40% material finer than 300µm. Coarse sands are often blended with fine sands to overcome this deficiency.

- **Aggregate characteristics**
  The characteristics of stone and sand influencing workability are shape, surface texture, average particle size, grading and fines content.

  Rounded particles with a smooth surface texture improve workability (but in some instances may be detrimental to strength).

  The use of stone with a smaller maximum size improves workability, as does graded as opposed to single-sized particles.

  The use of continuously-graded as opposed to single-sized sands improves workabiity.

- **Admixtures**
  The use of water-reducing admixtures allows for increased workability without increasing the water content of the concrete. In some instances, a considerable reduction in water content can be achieved while maintaining workability. See *The use of admixtures in concrete.*

Measuring consistency

The slump test is the universally accepted method of measuring consistency. Other methods incorporated into SANS standard test methods include the Vebe and Compacting Factor tests for low-workability mixes, as well as the Flow Test for high-workability concrete.

With the advent of self-compacting concrete, other tests such as the slump flow, Y-funnel and L-box are frequently used.

Control of consistence

For a mix of given proportions and materials, consistency is mainly affected by the water content, which in turn affects the water:cement ratio and strength. Slump test results have conformance limits; see *Concrete specification requirements.*

Concrete has a "shelf life" of about three hours from adding water to initial set.

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Bleeding

Bleeding is a form of segregation in which some water migrates to the surface as the solid particles settle. This may result in a layer of clear, greenish water forming on the surface of the concrete. This will continue until the concrete has stiffened sufficiently to prevent further settlement.

The use of high extender contents and retarding admixtures will prolong the setting time and thus increase the time during which bleeding may occur.

Defects attributed to bleeding include:

- Formation of voids under aggregate particles and reinforcing steel.
- Sand streaking resulting from the bleed water rising up the surface of formwork, taking fine particles of sand and cement with it.
- The trowelling-in of bleed water on the surface of a slab resulting in a weak dusty layer.
- Settlement cracking.

Bleeding may be reduced by:

- Increasing the binder content.
- Using Condensed Silica Fume (CSF).
- Reducing the water content.
- Increasing the amount of minus 300µm material in the sand.
- Using an air-entraining admixture.

Basic production requirements are the same for both site-batched and readymixed concrete. However, on a daily basis the readymix producer accommodates:

- A greater variety of plant and process technology.
- A wider range and combination of cements and/or extenders, aggregates and admixtures.
- Varying mix requirements in the fresh and hardened states.
- A wide variety of specifications.
- Predetermined delivery times.
- Environmental restraints.

The advantages of using readymixed concrete vs site-batching

- The supplier has the resources and technical expertise to provide a wide range of mixes.
- The supplier can more easily meet changes to the construction programme.
- Better quality control: computerised weigh batching offers better ultimate concrete performance.
- Time, labour and cost-effective: no purchasing, receiving, stockpiling of cement, stone and sand on site: less pilferage.
- Concrete can be supplied to several locations at the same time.
- Less labour required for loading mixers and transporting concrete on-site.
- Speed of discharge meets tight construction deadlines and high rates of delivery are possible.
- The supplier takes responsibility for raw material and process control testing during the production process.
- Availability of backup supply.
- Reduction of risk.

Although site batching is frequently seen as a more economical option than readymixed concrete, the following factors should be costed into site batching:

- Wastage and theft of materials.
- Handling and storage of materials.
- Plant hire/depreciation.
- Plant establishment and removal.
- Plant operation.
- Labour.
- Supervision.
- Technical requirements.
- Site transport equipment available to other trades at all times rather than tied up transporting concrete on-site.

Site-batched concrete is not subject to SANS 878 requirements.

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Quality **control**

The quality of readymixed concrete is controlled by compliance with SANS 878, both during production (process control) and acceptance (or compliance) control.

The principal elements of control include:

- Identifying the properties of suitable raw materials and monitoring these properties.
- Proportioning these materials to produce concrete of the required quality in the fresh and hardened states.
- Identifying process variability to allow correct target strengths to be achieved.
- Adequate sampling and testing.
- Statistical evaluation of results.
- Corrective action in the event of non-compliance.

In order to comply with SANS 878 requirements, the following factors should be in place:

- **Contract**
  Types of concrete mixes, whether designed, prescribed, or designed with special requirements (such as minimum cement content or maximum water:cement ratio) together with the minimum required information, should be supplied by both purchaser and supplier to ensure that quotations accurately reflect requirements.

- **Materials should comply with the following specifications:**
  - Cements: SANS 50197-1.
  - GGBFS: SANS 55167-1.
  - FA: SANS 50450-1.
  - CSF: SANS 53263-1.
  - Aggregates: SANS 1083, or have a proven record of satisfactory use in concrete.
  - Chemical admixtures: International standards such as ASTM C494/C494 -08a.
  - Water: SANS 51008. Test if the quality is in doubt. Where wash-out water is used in concrete, water density should be closely monitored to restrict solids content.

- **Batching tolerances should be specified, typically as follows:**
  - Cement: Cumulatively by mass to within 2%.
  - Aggregate: To within 3%.
  - Admixtures: To within 2% or 50ml.
  - Water: To within 2%.

- **Plant and equipment**
  Storage of raw materials: Designed to minimise segregation, contamination or deterioration.

  Weighing equipment: Calibrate and check regularly, with monitoring devices clearly visible to the operator.

  Mixers (stationary or truck-mounted): Keep in good repair, check ability to fully mix concrete within the required time.

- **Production and delivery**
  Batch solid materials by mass. Batch liquids by mass or volume. Make appropriate adjustments for moisture in aggregates, particularly sand. Control amount of mix water by measurement and maintenance of slump within specified tolerances. Concrete should be delivered with sufficient workability for placement and compaction. Slump tolerances should be within the specified tolerance range for a period of three minutes from arrival on site.

Table 33: Slump tolerances

Specified slump, mm	Tolerance, mm
50 And less	-15 to +25
More than 50, up to 100	± 25
More than 100	± 40
Where applicable, air content tolerance: ±1.5%	

It is common practice to use at least two cementitious materials, two fine and coarse aggregate products and more than one admixture in the production of concrete. To control the combined effects imparted to concrete by all these constituents, comprehensive quality control programmes have become essential.

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- **Sampling and testing freshly mixed concrete**

  Should be strictly in accordance with the relevant standard test methods.

- **Compressive strengths for process and acceptance control**

  Process control tolerances: No individual result should fall below the characteristic strength minus 3MPa, and the average of 30 valid cube results should exceed the specified strength by at least 1.64 times the current standard deviation.

  Acceptance control is carried out by the customer on-site to verify process control.

  Tolerances: No individual compressive strength result should fall below the characteristic strength minus 3MPa, and the average of three consecutive and overlapping results should be at least equal to the specified strength plus 2MPa.

  If acceptance control values are not met, cores may be taken to verify strengths. Cores are generally drilled to verify the strength of defective concrete (i.e. potential low strengths, honeycombing, cracks, etc.). They may also be drilled to verify the strength of concrete where no other data is available, e.g.:

  - When doing a condition survey to evaluate the health of an existing or damaged structure.
  - When cube specimens or results go missing.
  - If an owner wishes to impose additional load on an existing structure and needs to get some idea of the inherent strength of the existing concrete elements.

AfriSam Readymix process control testing

All AfriSam Readymix plants have sampling protocols to ensure that sufficient slump and compressive strength test results are available for statistical analysis by an advanced customised computer programme, allowing full evaluation of all results and indicating the status of concrete performance on an ongoing basis. These results are available on request.

To ensure that the delivered concrete meets the specified requirements in the hardened state, the customer or sub-contractor must take full responsibility for all subsequent on-site actions (see *Handling concrete on-site*).

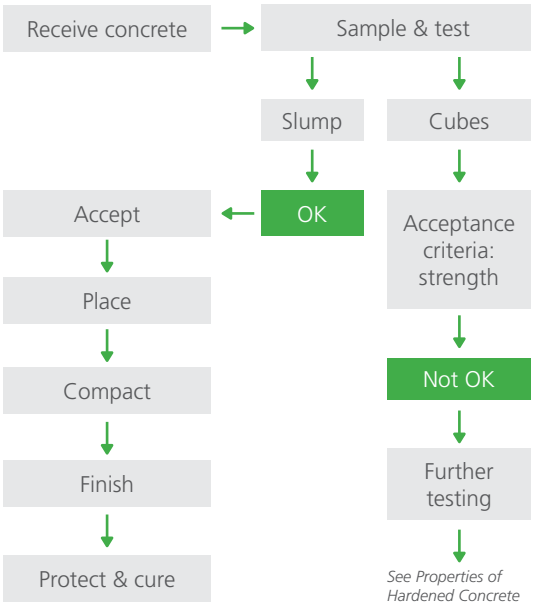


Figure 10: Accepting concrete on-site

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Sampling and testing guidelines

Sampling of freshly mixed concrete (SANS 5861-2)

- Avoid taking samples from the first or last 10% of the contents of the mixer.
- Do not allow the mix to drop through a height of more than 500mm before the sample is taken.
- Ensure that the sample is at least 1.5 times the amount required for test specimens.

Dimensions, tolerances and uses of cast test specimens (SANS 5860)

- The tolerance on the basic dimension between each face of a specimen is 1.0%.
- The basic dimension should be at least four times the maximum aggregate size.
- Load-bearing surfaces to be flat to within 0.0005d.

Making and curing test specimens (SANS 5861-3)

- Prepare three specimens per test per age.
- Ensure thorough compaction.
- Label each specimen with a unique identification.
- Prevent the top surface from drying out for the first 24 hours.
- Demould the cube and place under water at a temperature of 22 – 25ºC.
- During transportation to the laboratory, prevent loss of moisture and damage.

Coring concrete on-site

Problems encountered during drilling may include:

- Shattering already distressed concrete, with subsequently loosened concrete particles jamming the barrel of the core drill.
- Cutting into rebar, which will "snatch" or break off the core drill, resulting in skewed, banana-shaped or too-short cores.
- Drilling through prestressed and (particularly dangerous) post-tensioned concrete, which may cause the slab to collapse, or may result in a safety hazard due to the catapulting effect of the suddenly-released energy.

The inherent difficulties of drilling into defective concrete combined with often restricted access and other very difficult conditions on-site make the following pre-drilling checks very important:

- Get the engineer's permission to core – drilling may cause structural damage.
- Use the best equipment possible for coring.
- Check plans and use a metal detector/electrical conductor detector to ensure that you do not drill into electrical conduits, water pipes or areas where groundwater flooding may be a hazard.
- Check for rebar using a cover meter: the problem often is not identifying where the rebar is, but rather identifying areas where there is NO steel. If possible, try to drill into the area with the deepest cover meter reading.
- The minimum core diameter is ideally at least four times the size of the aggregate in the concrete, i.e. a 100mm core is good for 19mm stone, but not where 37,5mm stone has been used.
- Unless coring for durability index (DI) testing, drill core specimens as long as possible: the surface concrete may not have been adequately cured. If necessary, cut away any reinforcing steel to reveal a representative specimen of pure concrete from deep within the structure.

Use an experienced coring contractor, and during the drilling operation ensure that:

- The drill is anchored by at least one rawlbolt to ensure rigidity.
- Plenty of water is used to flush out the core barrel.
- Drilling proceeds cautiously, carefully, diligently and with great patience.
- Cores are labelled as soon as they have been drilled, and core identification is cross-referenced to the building plan.
- Fragments of shattered core specimens are reassembled in the order they were extracted (i.e. as they existed within the structure) and stored in suitable, labelled core boxes.



Concrete **production**

The production of concrete, whether site batched or readymixed for delivery to a construction site, involves the activities outlined in Figure 11.

Prior to initiating the production process on-site or ordering readymixed concrete, it is necessary to check:

- Specifications, drawings and bill of quantities for the performance requirements of the concrete.
- Methods of handling fresh concrete on-site, together with other construction requirements, e.g. early strength for post-tensioning.

  Once the requirements have been identified, the contractor or readymix supplier selects suitable raw materials, calculates mix proportions and carries out trial mixes. Materials and mix proportions usually require approval from the site engineer.

Production activities

- **Raw material specification requirements**

  Cements: See *Cement.* Stone and sand: See *Aggregates.*

- **Materials handling and storage**

  An appropriate sampling and testing procedure for raw materials should be in operation.

  Cementitious products, aggregate and admixtures must be checked as far as this is practical to ensure compliance with the purchase order, both in terms of quality and amount, before discharged into the correct bay, bin, silo or store.

  Storage and handling should minimise contamination, segregation or deterioration.

  Clean drinkable water should be available for use as mixing water in concrete. If not, check suitability against SANS 51008.

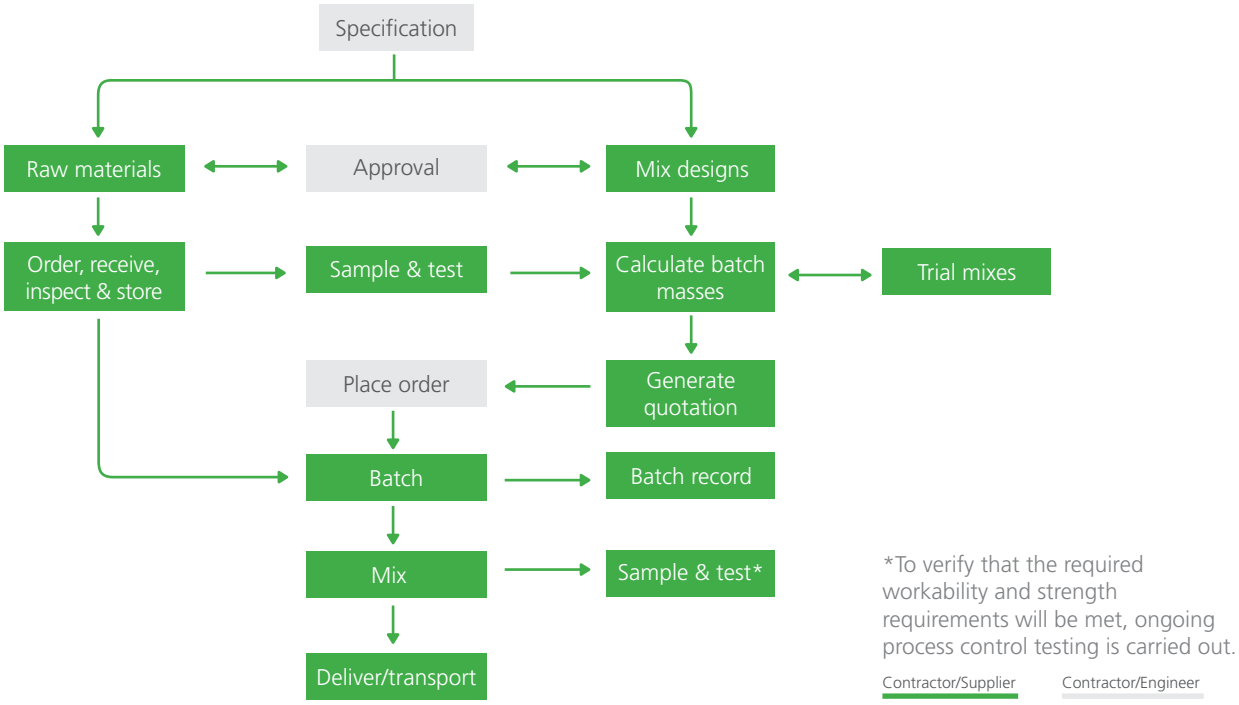


Figure 11: Producing concrete

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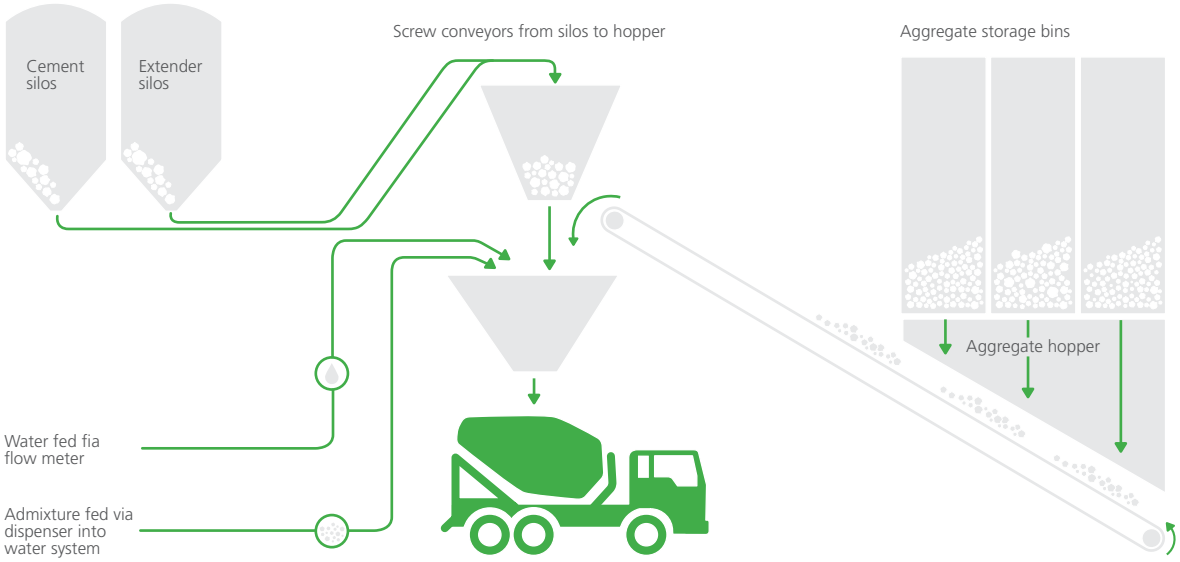


Figure 12: Production equipment

Batching by mass

Batching by mass is preferable to volume batching, although liquids are often batched by volume.

Cementitious materials should be batched cumulatively in the same hopper.

For aggregate, the amount of moisture, particularly in the sand, must be taken into account when calculating the amount of water required to attain the specified slump and W/C ratio.

Various mass measuring systems are available. Irrespective of the system used, it is essential that all batching equipment is routinely maintained, and that load cells or scales are regularly calibrated and frequently checked to ensure compliance with required batch tolerances (see *Quality control*).

Batch instructions giving the correct amounts of each raw material specified by the mix design for individual mixes must be available at the plant. Batch details are simple for a site operation with few mixes, but more complex for a readymix operation where a large number of mixes are routinely available.

The batching operation may be manual, semi- or fully-automatic. Manual batching is suitable for low production rates, but for most applications semi- or fully-automatic computerised systems are preferable. Interlocks should be provided to ensure proper operation of the system and traceability.

Effective stock and yield control is possible when using batch computers capable of recording actual amounts of material batched. Computerised management systems are then used to analyse this data to generate automatically downloaded batch exception warnings, correlate batch weights with slump test and 28-day compressive strength results, and allow for scientific mix optimisation.



Batching by volume

For mix proportions for low-, medium- and high-strength concrete, request our DIY brochures on concreting, bricklaying, brick and blockmaking, and plastering.

Generally, 19mm and 26,5mm stone sizes are commonly available, but check with your supplier as stone sizes are currently under review.

Only enough water should be added to give the required consistency or slump. Adding extra (excessive) water will reduce the concrete strength.

The overall strength of the concrete is significantly influenced by the quality of the sand. Where possible, single-sized sands and sands with excessive fine material should not be used.

Machine mixing

Mixing is usually carried out by a machine, the common types being non-tilting, tilting, reversing drum, split drum, horizontal shaft and pan mixer.

Materials are loaded in a specific sequence to minimise mixing time, and a mixing time is established for the mixer used. The mixing cycle includes time to charge, mix and discharge the mixer.

Undermixing can increase the variability of the concrete from a workability and strength perspective, but overmixing has minimal effect.

Mixing is done until the concrete is of uniform consistence, colour and texture. All batches should be inspected visually prior to being released.

- Empty the mixer completely after each batch.
- Clean the mixer/drum thoroughly after discharge.



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Adjusting mixes on-site

The mix proportions are calculated using average materials.

Check the first batch of concrete. If the mix is difficult to compact and it is not possible to achieve a smooth finish, the mix is probably too stony. If the mix is too sandy, the wearing properties of flat slabs may be reduced.

- Concrete is too stony if stones protrude above the surface when the concrete surface has been floated. In this case, reduce the stone volume by half a wheelbarrow and increase the sand by a similar amount.
- If a thickness of mortar of more than a few millimetres is available at the surface when the concrete is floated, the concrete is too sandy.

  In this case, increase the stone content by half a wheelbarrow and decrease the sand by a similar amount.

Figure 13 gives examples using APC, 19mm stone and crusher sand.

AfriSam All Purpose Cement 42,5N FOR GENERAL PURPOSE APPLICATIONS

SUGGESTED MIX PROPORTIONS	Cement	Sand	Stone
ULTRA HIGH STRENGTH CONCRETE 45MPa Columns, water retaining-structures	2	2	2
HIGH STRENGTH CONCRETE 25-30MPa Columns, slabs, garage floors, parking areas	2	$2^{1/2}$	$2^{1/2}$
MEDIUM STRENGTH CONCRETE 15-25MPa Concrete floors, patios, footpaths, driveways	2	3	3
LOW STRENGTH CONCRETE 10-15MPa Concrete foundations, footings, fencing, poles	2	4	4
MORTAR AND PLASTER: INTERIOR/DRY CONDITIONS Mortar and plaster exposed to dampness Mix designs is based on the use of good quality sands	2	$4^{1/2}$	
MORTAR AND PLASTER: INTERIOR/DRY CONDITIONS Mortar and plaster exposed to dry conditions Mix designs is based on the use of good quality sands	2	6	

*CO_2 footprint after dilution with sand , stone and water (g/kg).
For design of specialised structures, please consult a registered engeneer

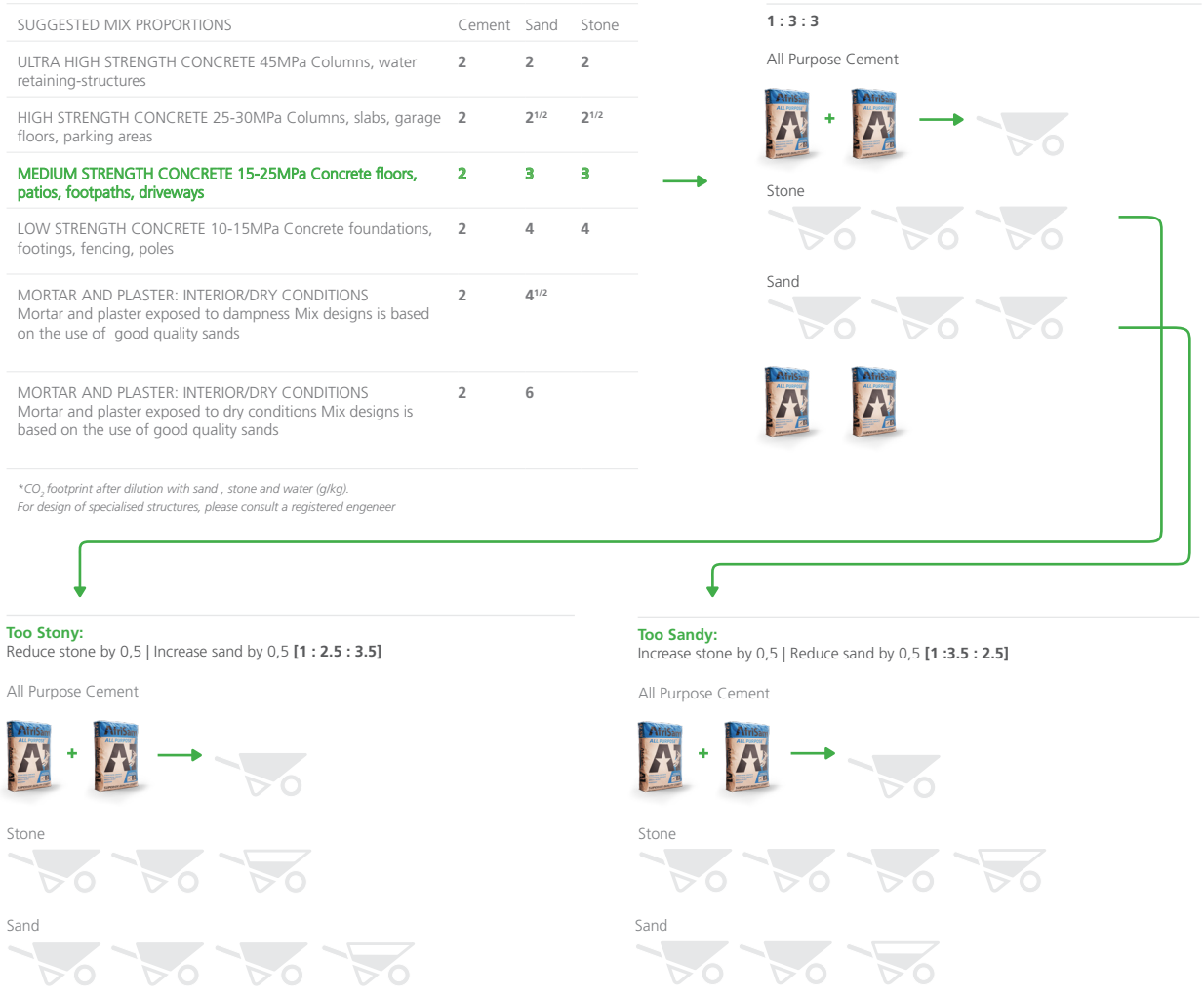


Figure 13: Mix adjustment

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Handling **concrete on-site**

Good concrete practice on-site is essential to ensure that:

- The quality of the fresh concrete, whether readymixed or site batched, is maintained.
- The hardened concrete reaches its optimal potential strength and durability.

On-site activities relating to handling concrete include ordering the correct concrete (site batched or readymixed), transporting, placing, compacting, finishing and curing.

The scale of these activities ranges from high-rise buildings entailing the use of sophisticated equipment such as concrete pumps, poker vibrators, power floating and spray-on curing membranes to simple labour-intensive low-cost housing, but the principles outlined here are the same for all concreting activities on-site or at precast yards.

An example of a site checklist is given below.

Ordering readymixed concrete

When an AfriSam customer requests and accepts a quotation for readymix concrete, a tentative date is booked for delivery. When the customer confirms the date the site will be ready to accept the concrete, loads are supplied from AfriSam plants (generally from the plant/s closest to site) at specified intervals, e.g. first load at 10:00 am, with subsequent loads every hour thereafter.

Table 34: Pre-concreting check list

Site: **Inspected by:**		**Area to be concreted:** **Date:**	
Item checked:	Yes	No	Action
Formwork restrained against movement in all directions?			
Formwork correctly aligned and levelled?			
Are all the props plump and at right spacing?			
All inserts and cast-in fixings in right position and secure?			
Void formers firmly fixed or tied down?			
All stop ends properly secured?			
All joints sealed to avoid grout loss, especially against kicker?			
Forms clean and free of rubbish (tie-wire cuttings, bits of timber or metal)?			
Release agent applied?			
Correct release agent?			
Correct reinforcement?			
Enough spacers?			
Correct depth of cover?			
All kicker bars straight and correctly positioned?			
Sufficient access for placing concrete?			
Adequate access for compaction?			
All toe boards provided?			
Guard rails provided?			
Curing materials available?			

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To take full advantage of this service, the customer should be aware of the following factors:

- A truck mixer takes approximately 30 minutes to discharge a full load.
- Concrete for foundations is usually poured directly from the truck mixer chute into the trench.
- Make sure that good access is provided and that the edges of the trenches are firm enough to take the weight of the fully-loaded truck, i.e. approximately 30 tons.
- If it is necessary to move the concrete on-site by wheelbarrow, 15 to 20 wheelbarrows will be required for each cubic metre. Organise labour in advance.
- Ensure that site preparation is complete, e.g. required formwork has been erected and is clean and adequately supported to retain the mass of the concrete, and that steel reinforcing is adequately secured before accepting the concrete.

Transporting concrete on-site

When selecting a suitable transporting method, assess:

- Site conditions.
- Availability of site equipment such as cranes, especially where used for moving formwork, etc.
- Rate and volume of concreting.
- Use of site-batched or readymixed concrete.

Whatever method is used to transport concrete, the following points need consideration:

- The method must be appropriate for the type of mix.
- Hourly rate must be compatible with mixing and placing operations.
- Transporting should be fast enough to prevent drying out or loss of workability.
- Delays must be minimised to prevent the formation of cold joints.
- There should be no contamination of the mix.
- Segregation, including loss of fine material, must be kept to a minimum.

> Concrete used in suspended slabs to fill areas between elements and as a topping is generally pumped. The precast slab or block supplier will supply details regarding propping and the depth of concrete specified. Note that the heavy pressures placed on support work by "wet" (fresh) concrete make sufficient, accurately vertical propping essential.

Placing

Ideally the time between mixing and placing a batch should not exceed 45 minutes. During delays, if the workability cannot be restored fully by turning the concrete over a few times with spades, discard the batch.

Extra water added to the mix to restore workability (retempering) weakens the concrete.

During placing, the aim is to maintain the quality and uniformity of the concrete, i.e. prevent segregation.

- For foundations, dampen trenches before placing the concrete.
- For reinforced foundations, ensure that the reinforcing is fixed firmly to avoid displacement during pouring. Use spacers to lift the steel off the bottom of the trench. Consider pumping concrete into place to ensure adequate cover to reinforcement.
- For non-wearing floor slabs, place the concrete onto well-compacted and slightly damp fill (no standing water).
- For driveways (and large slabs), divide the area into panels, e.g. 3m by 3m (not more than 4.5m by 4.5m) to prevent the formation of unsightly cracks due to contraction during hardening. Lay alternate panels (1, 3 and 5) on the first day, then remove crossforms and lay fill-in panels against the hardened concrete the next day or later. Place the concrete as close as possible to its final position, and work the concrete right into the corners and along edges with a spade or trowel.
- Check for segregation when concrete is discharged from a skip, chute or conveyor.
- Check for damage or displacement of reinforcement, stressing ducts and formwork.

Flash set and false set: see *Cement*.

If the concrete is to be placed a considerable distance from where the truck is parked, consider pumping. In this case, order the concrete and the pump at least two weeks in advance.

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Pumping concrete

The advantages of pumping concrete include:

- Placing concrete faster. Pumped concrete is flowable, yet highly cohesive, allowing for easy placing, compaction and finishing.
- Placing concrete in areas not readily accessible, e.g. into heavily-reinforced elements, underground or for high-rise buildings.
- Convenience. On residential building sites, no ramps are required to move concrete to first floor decks, and there is no need to break down garden walls to allow truck mixer access.

In addition to the normal procedure for ordering concrete, the customer needs to take the following factors into account:

- Maintain close communication with the readymix company/site batch operator throughout the pumping process.
- Order the pump and the readymix concrete at least two weeks in advance, confirm date and time of pour 72 hours in advance.
- Liaise with the concrete supplier if the site will not be ready in time to start the scheduled pump job (to within 30 minutes).
- Where different concrete strengths are required for different elements, supply a marked-up site plan indicating placing requirements.
- For larger or more complicated pours, a pre-site inspection may be arranged to assess access, pump and pipeline requirements, specific safety aspects on site and special site requirements.

"Hidden" costs

- For tenders, include the cost of setting up the pump. If a static pump is required, a foundation may be required.
- To ensure minimal blockages, the pump and pipeline are lubricated with a priming slush immediately prior to pumping the first load.
- Additional compacting and finishing equipment may be required as concrete is discharged faster by pumping.

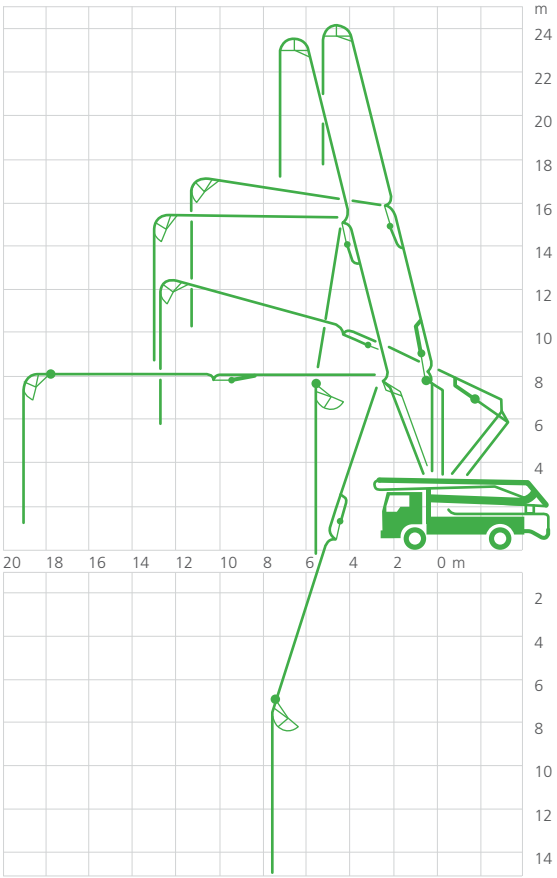


Figure 14: Boom reach

The pump operation

The pump rig arrives on-site about 30 minutes prior to scheduled pour, and the pump operator sets up the equipment. A truck-mounted pump and truck mixers need good, firm-access roads into the site. A truck mixer loaded with 6m³ weighs 30t. The vehicle is 8m long and 2.5m wide.

The pump, boom and pipeline are primed, and the slush is discarded. Pumping commences within 15 minutes of discharge of the readymix concrete into the pump hopper.

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The pump operator is in charge of the entire pump operation, including:

- Pump equipment. Only the pump operator is authorised to operate the pump.
- Communication with the hose-handling crew with regard to boom position, rate of discharge and "breaking-back" pipe segments.
- Communication with the concrete supplier with regard to delivery rate of concrete to site, and, where required, return of unpumpable concrete to the plant.
- Locating and clearing blockages. Note that long delays may result in emptying, washing out and repriming the pump, boom and pipeline.
- Relaying last load ("finals") requirements to the supplier. To avoid costly delays, estimate this while the third-last truck is discharging.
- Presenting delivery notes collected from each truck driver to the site representative for checking and signing. Invoicing is for the amount of concrete delivered at the rate quoted, plus set-up costs.

The pump operator and crew place the concrete as close as possible to the final position. If it is necessary to move the concrete by shovel, labourers should not be allowed to throw the concrete into place or use poker vibrators to prod the concrete into place.

Clean-out area

Truck chutes, pumps and pipelines should be washed out or cleaned with compressed air (where available) in a designated area. No washout water should drain into sewage systems – if necessary, prepare a sandbagged area.

- High pressures are used to force the concrete through the pipeline. Only staff involved in the pumping operation are allowed in the area, and no one is allowed under the boom.
- If conditions are unsafe, the pump operator is authorised to terminate the pump operation.

Compaction

After placing, compact and finish the surface of the concrete prior to initial hardening. Entrapped air reduces the concrete strength, e.g. 4% air voids may cause 25% reduction in potential strength. Full compaction of concrete maximises strength and impermeability, and ensures a good off-shutter finish.

Before compaction, ensure that:

- Forms are tight-fitting to avoid loss of grout.
- Depths of vertical sections are shallow enough to ensure complete compaction of each layer.

For successful hand-compaction by tamping or rodding, concrete slump should be at least 100mm.

Mechanical vibration is usually carried out on larger jobs, using internal (poker) vibrators, surface or vibrating beams for floor slabs and sometimes form-mounted vibrators in precast yards.

Stiff (low slump) mixes contain more air than high slump concrete and therefore require more compactive effort.

Using poker vibrators, do not over-vibrate: insert the vibrator at about 400mm intervals and compact for 10 to 15 seconds.

To ensure a dense and durable surface, slabs must be well-compacted, either using vibrating beams or a timber beam with a tamping and sawing motion, with additional compaction at edges and corners.

Finishing

Floors to be carpeted or tiled should be as smooth and level as possible using wooden floats and avoiding over-working. At no stage should neat cement or cement:sand mixtures be trowelled into the surface to soak up bleed water.

Driveways: Use a wood float or a hard brush to texture the surface.

Steel trowelling gives hard, smooth finishes, e.g. for industrial floors, parking garages, etc.



Steel trowelling must not start until:

- Bleeding of the mix has ceased.
- All bleed water on the surface has evaporated or been removed.
- The surface has started to stiffen.

Only then should steel trowels be applied, using considerable pressure on the tools. Several trowellings spread over a period of up to two hours may be required. For large areas, power-operated machines should be used. Trowelling should continue until the surface has attained an even, fine matte finish. Only if a "polished" finish is specifically required should trowelling be continued thereafter.

Small amounts of water flicked on with a brush may be applied to the surface to aid finishing but, as this tends to weaken the surface, it should be done as little as possible and only where trowelling alone does not produce the desired results.

Planning of the work should take into account that the delay period before steel trowelling can start is likely to be two to three hours and longer in cold weather. During the delay period, drying of the mix (as opposed to evaporation of bleed water) must be avoided as this may lead to cracking.

For hard non-slip areas, steel trowel as above and subsequently lightly texture the surface with carpet-faced floats or soft brushes.

- Use a barrier cream on hands when handling fresh concrete.
- Wear protective footwear when laying floors.

Curing

To allow the concrete to reach its full potential strength, adequate curing is essential. Curing maintains a satisfactory moisture content and a favourable temperature in the concrete to ensure ongoing hydration of the cement and thus development of optimal strength and durability.

Commence curing activities immediately after completion of surface finishing.

- Keep the top surface of trenches damp by covering with plastic sheeting for seven days or until building starts (the bottom and both sides of the concrete are essentially in a self-curing environment).
- Floor slabs, driveways and suspended slabs should be subjected to continuous curing (plastic sheeting, damp sacking or damp clean sand, or continuous spraying) for seven days for a durable, wear-resistant surface in addition to maximum compressive strength.

This also applies to pumped concrete, even though the concrete may appear to be wetter than normal.

To avoid the (temporary) variations in colour that tend to occur when plastic sheeting is laid directly on a wet concrete surface, the sheeting may be supported clear of the surface by timber battens for the first 24 hours of curing.

Wind must not be allowed to blow under the sheeting. Light foot traffic may be allowed over new work 24 hours after finishing, provided that the plastic sheeting is not damaged or displaced.

Curing may also be accomplished by applying a fine mist spray or curing compound, immersing the concrete element in water or delaying removal of formwork.

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Special handling considerations

Self-compacting concrete (SSC)

SSC requires a prolonged mixing time due to reduced frictional forces and to:

- Fully activate the super plasticiser.
- Improve dispersion of the high amount of fines in the mix.

On arrival on-site, check workability retention.

Self-levelling concrete (e.g. flowcrete)

- Increased pumping rates, increased speed of casting and lower viscosity of self-levelling concrete place greater lateral pressure on formwork. This should be addressed prior to formwork erection on-site.
- In addition, special attention must be paid to sealing formwork joints to avoid grout leakage.
- For closed elements and narrow sections, points for air expulsion must be provided.

Fibre-reinforced concrete (e.g. Polyfibre Mix)

- Special attention must be paid to adequate finishing of the surface and to joint detailing.

Poolmix

Poolmix is an extremely dry mix, and requires special handling techniques including the following:

- Have Poolmix delivered early in the morning to allow enough time for the concrete to be used before setting and to ensure that the pool can be packed in one day.
- Have sufficient labour on-site to pack the entire shell at one time, thereby eliminating joints.
- Cure the concrete adequately.

Poolmix is thrown onto the floor and walls using shovels, then compacted and smoothed using hand tools. Use all the concrete before it starts to set. Do not retemper by adding water.

It is important to place the shell in one continuous operation. Construction or cold joints are undesirable because they are difficult to seal and may weaken the structure. It is necessary to maintain the correct wall thickness and ensure the concrete is well compacted.

Poolmix finishes

- **Conventional plaster**

  Mix 1½ wheelbarrows of sand to one bag of cement. Only good quality, fairly coarse plaster sand should be used.

- **Paint**

  Use high quality acrylic pool paint made by a reputable manufacturer and apply this in accordance with their recommendations. Epoxy paints give reasonable service, but recoating is difficult.

- **Marblite pool plaster**

  Mix Marblite incorporating Plastomar additive with clean water to a stiff, workable plaster. After the walls have been plastered, continue with the floor. The entire pool surface should be plastered in one day.

Immediately after finishing, protect the concrete by covering with plastic or a shadeport. The concrete must be kept wet for at least a week to allow it to gain its potential strength.



The use of **GGBFS in concrete**

Many readymixed concrete and site-batch operations use GGBFS as part of the binder material (cement) in their mix designs. Bulk GGBFS is delivered to the plant by tanker, pumped into silos and then automatically weighed and batched at the same time as the cement.

> On its own, GGBFS will not hydrate on contact with water or harden at the same rate as Portland cement; it requires the presence of an alkaline activator such as Portland cement to initiate its inherent cementitious reactions. The hydration is similar to that of Portland cement and produces similar hydration products (see chemistry of Portland cement), but is more complex. In the hardened state, a GGBFS-Portland cement paste is denser than a CEM I-paste, increasing the density and thus impermeability of the concrete.

The advantages of using GGBFS in concrete, either as complementary material in the cement or as part of the mix proportions in a site blend, include improved durability as a result of:

- **Reduced permeability**
  As a result of slower early-age strength development, the pore structure within the concrete tends to be more refined, decreasing permeability and providing a greater protective pore ratio (see *Figure 15*).

- **Improved freeze/thaw characteristics**
  Reduced pore size and pore refinement improve freeze/thaw durability.

- **Resistance to chemical attack or attack by aggresive agents**
  Because the rate of chloride ion diffusion through concrete is dependent on pore structure, GGBFS gives concrete improved resistance to chloride and sulphate attack. In addition, it is resistant to sulphate and soft water ahydroxide content.

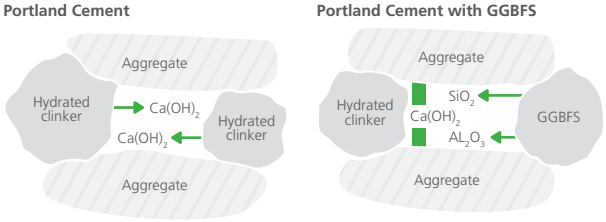


Figure 15: Mantel's model of the hydration of GGBFS

- **Reduced potential for alkali-aggregate reaction (AAR)**
  Studies carried out by CSIR show that 30 to 40% replacement of CEM I with GGBFS prevents deleterious expansion due to AAR by tying alkali salts produced by cement hydration into the insoluble CSH gel.

- **Lower heat of hydration, and control of heat differentials in mass concrete**
  Thermal cracking relates to the differences in temperature as a result of hydration between the core and the surface of the concrete. Using GGBFS/CEM I mixes with between 50/50 and 70/30 proportions reduces the risk of thermal cracking by slowing and minimising heat generation.

- **Reduced creep and shrinkage**
  Studies indicate that in normal-strength GGBFS-extended concretes with adequate curing, concrete creep and shrinkage are reduced, and the concrete has the ability to curb higher strains.

See also *Soil-stabilisation and Properties of hardened concrete.*

The use of supplementary cementitious materials such as GGBFS in concrete affects site practice:

- **Water:cement (W/C) ratio**
  Most cements require only 28% of their own mass in water for full hydration. Anything over this amount is usually only required to improve workability of the mix. For a given mix design, the higher the water content, the higher the cement content; also the more heat generated, the shrinkage and the number of voids.

  GGBFS particles have a smooth, even surface texture and these concretes require less compactive effort than CEM I concretes, thus providing scope for lower water contents to achieve workability requirements.

- **Curing**
  Good curing ensures the internal durability of concrete, and also prevents the moisture loss from the surface which can cause plastic-shrinkage and surface cracks. When using mixes containing complementary materials such as GGBFS, the importance of adequate curing cannot be over-emphasised.

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The use of **CSF in concrete**

Condensed Silica Fume (CSF) is used in concrete to improve impermeability, as well as abrasion and chemical resistance of high-strength and high-durability concrete.

The main advantages of using CSF include:

- Improved resistance of steel reinforcement to corrosion via improved concrete electrical resistivity.
- Improved bond between paste and aggregate, with reinforcing steel and with steel or polypropylene fibres.
- Reduced wear on concreting equipment: pumps, moulds, mixers, etc.

The use of CSF is highly recommended for the following applications:

- Structures exposed to marine and chemical environments.
- Power stations and hydro electric plants.
- High rise buildings.
- Industrial floors (readymixed concrete to be pumped).
- Mining and tunnelling.
- Motorway bridges and dams, see *Alkali aggregate reaction (properties of hardened concrete).*
- Precast concrete industry.

Due to its pozzolanic nature, CSF can be used to enhance the qualities of both fresh and hardened concrete. This improvement is due to the formation of additional Calcium Silicate Hydrate (CSH) binder, through the reaction of the Silica Fume with the free lime ($Ca(OH)_2$) present in the cement. Silica fume is very rich in silicon dioxide (>85%).

Hydration

When water is added to Portland cement, hydration takes place. CSH is formed, and calcium hydroxide or free lime is released as a by-product of the chemical reaction (see *Chemistry of Portland cement*). When CSF is included in a concrete mixture, the reactive silicon dioxide (SiO_2) component reacts with calcium hydroxide to form additional CSH.

In comparing CSF-modified concrete to concrete containing FA, we see that the higher efficiency of CSF results in the pozzolanic action being evident much earlier. Furthermore, there is a greater degree of strength gain achieved when CSF is used. Typically, the main contribution to strength development in CSF concrete at normal 100 000 spheres per cement grain curing temperatures will take place from about 3 to 28 days. Sensitivity to curing temperatures is less pronounced in CSF concrete than in FA concrete.

The presence of CSF in concrete accelerates the hydration of the cement, improving the bond between the aggregate and the cement matrix, and producing a denser paste microstructure.

Addition rates

The normal addition rates of CSF are between 6 and 10% by weight of the cement content of the mix. In certain shotcrete and gunite applications, this percentage has been increased to between 12 to 15%, to make the mix even more cohesive and further reduce the rebound.

Where the addition rate exceeds 6%, a superplasticiser is recommended so that the required slump can be achieved at the required water:cement ratio. The dosage rate of superplasticiser ranges between 1 and 2% of the cement content, depending on the degree of workability required.

CSF can be used either to replace an equal weight of cement or it can be added over and above the existing cement content. In very highly aggressive environments, it is recommended that CSF is added in addition to the existing cement in order to substantially increase the chemical resistance and durability of the concrete. Even though addition is more expensive than cement replacement, the improvement in the long-term performance of the concrete structures far outweighs the slightly higher initial expenditure on cement.



Effect on fresh concrete properties

- **Water demand**
  Due to the high surface area of CSF particles, water demand may be affected. However, no significant effect on water demand has been identified where less than 5% by mass of cement is used.

- **Workability**
  CSF has a thixotropic effect. Concrete is more cohesive and less prone to segregation, with improved pumpability and advantages in underwater pours. In order to compensate for apparent loss of slump, increase initial slump by 20mm to 50mm. Ask for advice in the use of admixtures with CSF, and measure workability by using the Vebe test method.

- **Bleeding**
  Greatly reduced, almost eliminated. The high surface area of the CSF particles takes up some of the water which may bleed upwards, and the formation of silica gel effectively blocks capillary pores.

- **Plastic shrinkage**
  Take extra care to cover surfaces in high ambient temperatures, low humidity and areas where high wind speeds may be expected, to minimise formation of plastic-shrinkage cracks. Carry out finishing and tooling activities as soon as possible after placing and compaction.

- **Curing**
  Start curing the concrete as soon as possible after finishing, and maintain adequate curing for at least three to seven days to ensure that all the combined advantages of using CSF are achieved.

- **Setting times**
  CSF does not noticeably affect setting times. Where admixtures are required, dosage may require adjustment: carry out trial mixes and request expert advice, e.g. larger dosages of air-entrainer are required in CSF concrete.

Effect of CSF on hardened concrete properties

- **Porosity**
  CSF in a concrete mix refines the pore structure of the hardened concrete, with the number of large pores being significantly reduced.

- **Impermeability**
  The addition of CSF makes hardened concrete significantly less permeable, and thus more resistant to chloride attack, freeze/thaw damage and chemical deterioration.

- **Cement paste/aggregate transition zone**
  CSF gives greatly improved durability and enhanced strength to the hardened concrete due to improvements to the aggregate/paste transition zone.

- **Structural advantages**
  Using CSF in concrete with compressive strengths in excess of 80MPa allows for increased spacing between bridge and support columns, with potential modification of column dimensions and reinforcement requirements. See also *Durability (Properties of hardened concrete).*



- When working directly with CSF, use an approved dust respirator.
- CSF dust irritates the eyes. Irrigate with large amounts of water.
- Skin contact is not hazardous.

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The use of **admixtures in concrete**

Plasticisers and superplasticisers

Superplasticisers (SPs) or High Range Water Reducers (HR-WRs) are water-soluble organic polymers used in concrete, generally at low dosages (<1% by mass of cement), in order to:

- Increase the workability at a given mix proportion to enhance placing characteristics (workability) of fresh concrete.
- Reduce the amount of water used at a given cement content and workability, and therefore increase concrete strength and W/C durability.
- Reduce both the water and cement contents at a given workability and strength, to reduce the creep, drying shrinkage and thermal strains caused by heat of hydration in mass concrete structures.
- Provide cohesive, low viscosity concrete with extended workability and high fluidity, and minimise mix segregation.
- Reduce requirements for mechanical vibration for placing and compacting, thus reducing noise levels on-site.
- Provide smooth shutter finish on columns despite highly congested reinforcement.
- In precast concrete products, aiding fast placement and quick mould turnaround time, while giving a high-quality finish with reduced blemishes.

SPs are generally used to achieve a combination of some or all of the above concrete properties. The high reduction of water content considerably improves density, impermeability, mechanical performance and durability characteristics (chemical and physical) of self-compacting concretes.

SPs are available as aqueous solutions to facilitate dispersal in the mix. Accurate, reliable and automatic dispensing at the batch plant is essential, as is controlling and monitoring the mix.

Effects of superplasticisers on fresh concrete

The aim with using SPs for self-compacting concrete is to produce robust, non-sensitive mix designs that can be easily implemented.

Where used in conjunction with dry batch plants, there is little room for error as the mix design has to be correct the first time. Technical advice from suppliers is essential in evaluating available raw materials, selection of the appropriate SP, and optimisation of mix design to meet concrete and budget requirements. The admixture supplier should be capable of matching SPs with the specific cement chemistry in terms of soluble alkalis and sulphates.

Slump

Depending on the dosage and type of polymer, SPs can reduce the water content for a given workability by up to 35%.

The slump retention may last for about two hours, after which the concrete reverts to its original consistency, plasticity or workability. The rate of the slump loss depends on various factors including:

- Type of admixture/s.
- The initial slump.
- Ambient and concrete temperatures.
- Type and chemical composition of cement.
- Type and amount of mineral additions.
- Effect of any other chemical admixtures used in the concrete.

Setting times

SPs generally retard the initial and the final setting times of concrete but this retardation is not excessive. The retardation effect depends on the type and dosage of SP, the type of cement and the amount of mineral components present in the concrete. Where high amounts of FA or GGBFS are present, SPs may cause excessive retardation.



Segregation

Segregation may be defined as differential concentration of concrete raw materials resulting in non-uniform proportions in the concrete mass, i.e. the mass is not homogenous. With higher-workability concrete, care must be taken to proportion the materials correctly to minimise segregation. In flowing concrete, segregation may occur if there is not sufficient fine material present.

Air content

SPs generally increase the air content in concrete, but the amount of air entrained depends on the type and dosage.

Bleeding

Bleeding may be defined as the autogenous flow of the mixing water and its emergence from newly placed concrete caused by the settlement of solid materials within the concrete mass. As SPs reduce the water content, there is generally no undue bleeding observed in self-compacting concrete. In most cases, bleeding is reduced.

Pumpability

SPs allow concrete to be pumped for long vertical or horizontal distances. For horizontal applications, slump flows from 600mm to 650mm are required for swift and easy coverage of large surfaces and flat toppings. Vertical applications require much "wetter" concrete, with 700mm to 750mm slump flows.

Compatibility issues

To avoid adverse effects on concrete, SPs must be compatible, i.e. perform well when used together with other chemical admixtures and should be used with care. Not all SPs perform well when they are pre-blended or used together in the same concrete mix. SPs are sensitive to the cement type and its aluminates, sulphates and alkali contents. Trial mixes are always recommended prior to use on-site.

Effects of other admixtures

- Accelerators speed up the chemical reaction of the cement and water, and consequently also the rate of setting or early strength gain in concrete.
- Retarders slow down the chemical reaction of the cement and water, leading to longer setting times and slower initial strength gain.
- Air-entrainers introduce bubbles into the mix where maximum protection against freezing and thawing is required, and are also used to increase workability.

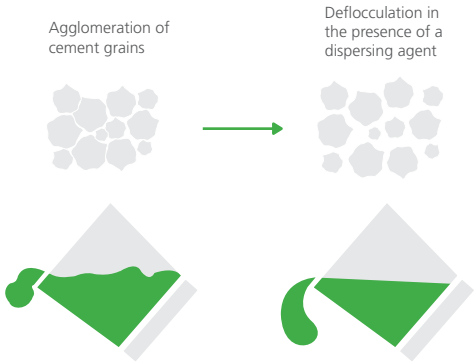


Figure 16: Fluidity effect of adding SPs



Figure 17: Potential effect of plasticisers on concrete

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Minimising **cracking**

Cracks appearing in concrete within the first few hours after placing are early-age thermal shrinkage cracks, plastic-shrinkage cracks or plastic settlement cracks. It is necessary to identify the type of crack and possible factors causing the cracks before applying measures to minimise the problem.

Plastic-shrinkage cracks

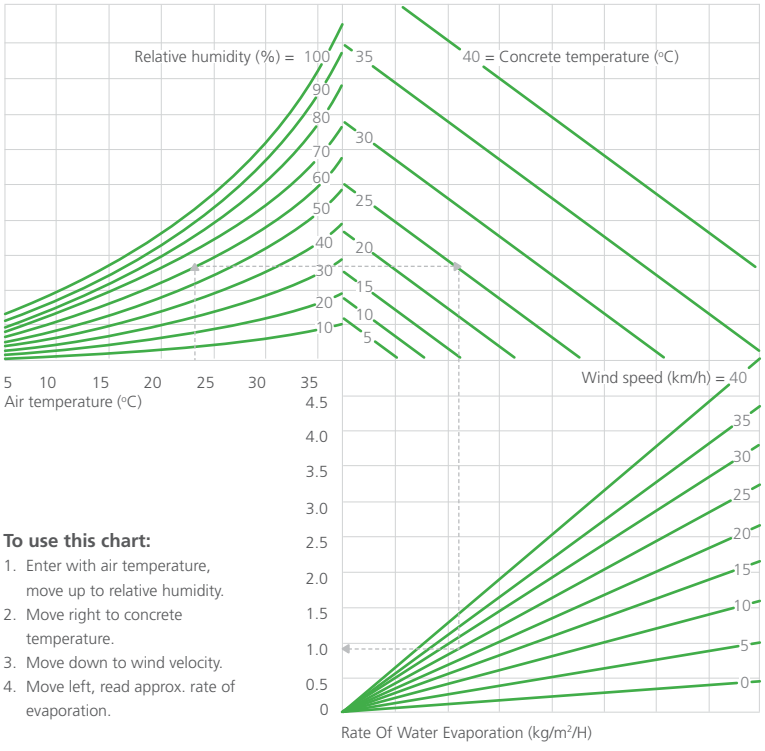
Plastic-shrinkage cracks form while the concrete is still plastic, i.e. has not set. They occur when the rate of evaporation of moisture from the surface exceeds the rate at which moisture is being supplied, i.e. via bleeding. Concretes with low bleed potential (e.g. low-slump mixes containing a high proportion of fine material such as fine aggregate or CSF) are more prone to plastic-shrinkage cracks, but high bleed characteristics may promote plastic settlement cracking, crazing, delays in finishing processes and greater long-term shrinkage. Retarded concrete is also more prone to plastic-shrinkage cracking due to increased time in the plastic state.

The rate of evaporation is affected by environmental factors such as temperature, relative humidity and wind speed. The cumulative effect of these factors can be assessed using the nomograph shown in Figure 18.

A recent study indicates that daily temperature fluctuations, especially at early ages, contribute to thermal strain and the formation of cracks as well as to the severity of cracking.

Plastic-shrinkage cracks are not always evident during finishing operations and may only be discovered the next day. They may form in a random manner or be roughly parallel to each other (see *Figure 19*). The cracks are often almost straight, and usually 300mm to 600mm long (but can be from 25mm to 2m long) and up to 3mm wide at the surface.

These cracks generally taper quickly over their depth but may penetrate right through a concrete element, forming a weakness which widens and/or extends due to subsequent drying shrinkage and thermal movement, and may lead to water penetration problems.



To use this chart:

1. Enter with air temperature, move up to relative humidity.
2. Move right to concrete temperature.
3. Move down to wind velocity.
4. Move left, read approx. rate of evaporation.

Note: Evaporation rates approaching 1.0 kg/m²/h are likely to necessitate precautions against premature drying.

Figure 18: Effect of concrete and air temperatures, relative humidity and wind speed on the evaporation of surface moisture from concrete

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Plastic-shrinkage cracks rarely occur near the edges of a slab where the concrete is free to move.

The key to minimising plastic-shrinkage cracking is controlling the rate of drying of the surface:

- Dampen subgrade and formwork before placing concrete.
- In hot weather, lower the temperature of the fresh concrete.
- Protect surfaces from drying out, e.g. erect windbreaks.
- Commence curing regime promptly after finishing and continue for the specified period.

See also *Concreting in adverse temperatures, and Polyfibre Mix (Readymix).*

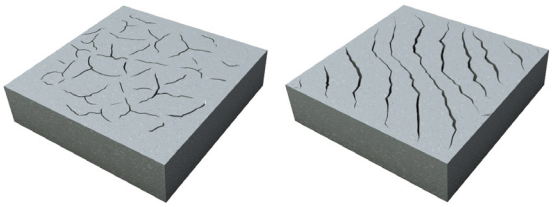


Figure 19: Typical plastic-shrinkage cracks



Figure 20: Typical plastic settlement cracks

Plastic settlement cracks

Plastic settlement cracks show a distinct pattern, typically mirroring the pattern of the restraining elements such as reinforcement. The cracks occur when concrete is plastic, frequently while bleed water is still rising and covers the surface, and tend to roughly follow the restraining element or changes in the concrete section.

After concrete is placed, the solids settle downwards and the mix water bleeds up to the surface. If there is no restraint this merely results in a slight lowering of the water: cement ratio at the concrete surface. If the concrete is locally restrained from settling while the adjacent concrete continues to settle, there is the potential for a crack to form over the restraining element (see *Figure 20*). A void may also form under the restraining element, affecting the local bond.

Plastic settlement cracks can be quite wide at the surface, but taper in width until they reach reinforcing steel or other restraining elements. They seldom extend beyond the restraint. In exposed conditions this may increase risk of corrosion of the reinforcement and pose a threat to durability. Cracks may develop further due to subsequent drying shrinkage, leading to possible full-depth cracking of the concrete member.

To minimise the risk of plastic settlement cracking:

- Adjust mix proportions to control bleeding, (e.g. lower slump, better cohesiveness).
- Increase the ratio of cover to reinforcing bar diameter, (i.e. increase depth of cover or decrease the size of bars).
- Dampen the subgrade before placing concrete to avoid excessive loss of water from the base of the element.
- Fix formwork accurately and rigidly to avoid movement during placing.
- Place concrete in deep sections. First allow to settle, then place and compact top layers, ensuring that the two layers blend together.
- Compact the concrete adequately.
- Cure the concrete promptly and adequately.

Revibrating the affected concrete at the right time can eliminate settlement cracks, especially in columns and deep sections. Where there is an abrupt change in section, concreting can be planned to allow for settlement to occur in the deeper section prior to concreting the shallower one.



Concrete in **adverse temperatures**

Adverse temperatures which may affect the setting and strength gain of concrete, exist in the following conditions:

- The average ambient temperature exceeds 35°C.
- The ambient temperature is 25°C accompanied by:
  - Low relative humidity and high wind velocity.
  - Solar radiation.
  - High concrete temperatures.
- The average ambient temperature is expected to be below 5°C.

The following guidelines assist in using appropriate techniques to minimise the adverse effects of extreme weather conditions.

Hot-weather concreting

Hot-weather concreting is not an unusual or specialised process as it is a common occurrence throughout the country for some months of the year.

When concreting in hot weather, there is typically an increased rate of water evaporation and thus slump loss from the fresh concrete, giving rise to potential problems during handling and finishing processes.

In addition:

- Setting times tend to decrease.
- There may be a small increase in water requirement and early strengths tend to be higher.
- There may be an increased incidence of plastic-shrinkage cracks.

> Although it is often stated that later strengths may be reduced, a recent study showed no strength reduction for concrete temperatures ranging from 23 to 33°C using various binder types.

Steps during batching and mixing to minimise problems of hot weather:

- Use higher extender contents.
- Use suitable retarding admixture.
- Aggregate should be kept cool (e.g. by shading stockpiles). Coarse aggregate may be sprayed with water, but spraying fine aggregate is not practical and can lead to problems with adjustment of water content.
- Cement temperature has a minimal effect due to the low amounts used, but white silos tend to minimise the effects of high temperatures.
- The temperature of the mixing water has a substantial effect on reducing concrete temperature, so keep water as cool as possible. In extreme conditions some or all of the mixing water may be replaced by crushed ice.
- Batching plants should be shaded as far as possible, and preferably painted white.
- Efficient materials handling will limit temperature rise during production.
- Though expensive, some concretes have been successfully cooled by the injection of liquid nitrogen.

On-site:

- Limit transport time and take appropriate steps to eliminate delays in handling.
- As far as possible shield the area to be concreted from high winds and direct sunlight.
- Schedule concreting for the cooler parts of the day.
- Provide adequate curing as soon as possible.

Estimating concrete temperature

The temperature T of the fresh concrete can be estimated from the expression:

> $T = 0.22 (TaWa + TcWc) + TwWw$
> $0.22 (Wa + Wc) + Ww$
> where:
> T = temperature of material, °C
> W = mass of material, kg
> a, c and w = aggregate, cement and water

This formula is applicable to estimating concrete temperature in hot and cold conditions.

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Cold-weather concreting

Although not as much of a problem as experienced in many parts of the world, cold-weather concreting does occur in South Africa on occasion, and failure to adequately protect the concrete can result in substantial strength reduction.

The effect of concrete freezing at early ages depends on whether the concrete has set, and what strength has been achieved when freezing occurs.

- If concrete which has not set is allowed to freeze, there will be an increase in volume due to the expansion of mix water. After thawing, the concrete will set with a high voids content.

- If freezing occurs before the concrete has attained a strength of 3MPa to 5MPa, expansion will cause disruption of the microstructure and a substantial reduction in strength and durability.

From the above, we can see that in extremely cold conditions fresh concrete should be maintained at a suitable temperature until a strength of about 5MPa has been achieved.

From a practical point of view, concrete should have a temperature in excess of 7°C at time of placing. To achieve this, steps can be taken to increase the concrete temperature, e.g. by:

- Protecting aggregate with a suitable covering.
- Heating aggregate by steam injection.
- Heating mixing water.
- Limiting transporting time.

On-site steps need to be taken to:

- Avoid temperature loss due to slow placing.
- Apply protection measures to maintain the temperature of the placed concrete. These may include the use of insulated formwork, covering exposed surfaces with insulation material or the erection of covers with internal heating.
- Delay finishing activities such as powerfloating due to the longer stiffening times.



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Concrete industrial floors

Concrete is used for industrial floors because of high wear resistance, adequate flexural strength and good dimensional stability.

These properties are dependent on and influenced by:

- The selection and proportions of concrete materials.
- The handling of the concrete in the fresh and early stages of hardening.
- Appropriate finishing and effective curing.

Selection of concrete materials

Cement

In floors with sawn joints, concrete must achieve a certain strength to allow for sawing of joints. The longer the period between casting and saw-cutting, the greater the possible moisture loss from the concrete and the higher the risk of shrinkage cracks occurring before the concrete can be sawn. This is also dependent on the effectiveness of curing. To prevent such cracking, only cements with a relatively high early strength should be used in concrete for floors.

High extender contents should be avoided as they reduce the early strength of the concrete, and concrete containing high extender contents requires significantly more effective curing for longer periods to ensure adequate abrasion resistance.

The following AfriSam High Strength Cements are recommended:

- **CEM II A-M (L) 52,5N**
- **CEM II A-M (V-L) 42,5R**

Industrial floors are often subjected to potentially aggressive agents such as sulphates, acids, chlorides and abrasion. Select a cementitious material that will improve the resistance of the concrete to these aggressive agents. See also *Sulphate resistance.*

Aggregate

The aggregate used for concrete floors influences:

- Potential abrasion resistance.
- Drying shrinkage of the concrete.
- "Saw-ability" of joints, i.e. prevention of ravelling and/or plucking during cutting. The harder the aggregate, the higher the early strength requirement.

Table 35: Strength requirement for early joint cutting for different aggregate types

Aggregate Type	Early strength required before sawing
Granite or quartzite Dolerite or andesite Felsite	3MPa – 5MPa 4MPa – 6MPa >8MPa

Other important properties for aggregate used in concrete industrial floors are:

- **10% FACT values**
  The aggregate used for concrete subjected to abrasion should comply with SANS 1083 requirements.

- **Bleeding of concrete**
  The amount of bleed water is influenced by the grading and particularly the fineness of the sand used. If a concrete bleeds excessively and the bleed water is trowelled in, the surface W/C ratio is lowered and this may result in a loss of abrasion resistance. When bleeding is likely to be excessive, the use of a suitable fine blending sand should be considered.

- **Drying shrinkage**
  Drying shrinkage is influenced by the type and source of aggregate. All AfriSam Aggregates have a history of suitability for use in industrial floors. With regard to other properties, aggregate used for concrete floors must comply with the requirements of SANS 1083.

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Admixtures

The use of chemical admixtures may improve the properties of concrete. However, their use should be based on an evaluation of their effects on specific materials and combinations of materials, including strength development, particularly within the first 24 hours after casting.

In environments with high evaporation rates, concretes with delayed strength development should be avoided.

See also *The use of admixtures in concrete.*

Handling concrete in the fresh state and during hardening

All good intentions and efforts put into the mix selection and proportioning may be wasted if placing and compaction requirements are not adequately addressed (see *Handling concrete on-site*).

It is almost always a combination of the following factors that result in unexpectedly bad behaviour of concrete in floors:

- Casting floor under exposed conditions.
- Adverse ambient conditions.
- Timing of finishing i.e. too early: powerfloating before the concrete surface is hard enough, or too late: after the concrete is no longer workable.
- Inappropriate finishing techniques.
- Ineffective curing, a lack of curing or late application thereof, also see *Curing.*
- "Late" cutting of contraction joints.
- Floor cast on plastic sheeting (note that the use of plastic sheeting should be avoided).
- The selection of an inappropriate concrete mix.

AfriSam Readymix recommends the use of Surfacebed Mix for floors, see Readymix.

Other concrete mixes with lower early strengths have also been used very successfully. However, if the ambient conditions are adverse and/or curing is not started as early as possible and/or is not effective, the concrete is more likely to crack and the use of concrete with lower early strength is a greater risk.

The importance of curing cannot be overstated. Most problems investigated relate to ineffective curing. The question to ask is not "Did the contractor cure the concrete?" but rather "How did he cure the concrete?"

Detailed information about concrete industrial floors is available from the Concrete Institute.

What is effective curing?

Preventing the loss of moisture from the concrete from the time of placing for at least seven days after casting.

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Mass concrete **on-site**

Mass concrete may be considered to be any volume of concrete with dimensions large enough to require special measures to minimise cracking by accommodating the heat differential between core and surface temperatures, and attendant volume change.

Generally, special precautions may need to be taken in respect of heat of hydration for any pour with a least dimension of 500mm.

Large pours, often in excess of 100m^3, have become common for structural applications such as raft foundations, large bridge piers, nuclear pressure vessels, etc.

For large pours, attention to logistical and technical considerations involves:

- Concrete supply.
- Casting sequence.
- Cold joints.
- Heat of hydration.
- Early-age thermal cracking.

The principal benefits of mass pours are savings in cost and time as a result of fewer joints and faster construction. The disadvantages of cracks which might occur when construction joints are not used appear to be minor.

Planning for mass pours

Planning considerations include:

- Concrete production and supply.
- Using concrete pumps to allow for rapid placing to various parts of the pour.
- Labour.
- Placing sequence.
- Compatibility between rate of supply, placement, compaction and finishing.

Heat of hydration

One of the main concerns with mass concrete pours is the temperature rise (which may exceed 50°C) within the concrete. See also *Chemistry of Portland cement*.

In conjunction with the temperature rise, internal or external thermal stresses are generated by restraint to thermal movement.

- **Internal restraint**
  arises from temperature differentials that occur when the concrete surface cools to ambient conditions while the centre remains at a much higher temperature. Cracks resulting from this temperature differential may be external or internal.

- **External cracks**
  form when an excessive differential occurs during the cooling phase.

- **Internal cracks**
  may develop if the differential is exceeded during heating.

External restraint may be imposed by the immediate environment such as a rigid base or adjacent pour. This type of cracking is most common in walls cast onto rigid foundations.

See also *Thermal movement (Properties of hardened concrete)*.

Mass pours are ideal for readymixed concrete, as concrete can be delivered from several batching plants and scheduled to arrive on-site at a rate that ensures continuous pouring.

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Temperature rise

Factors which influence temperature rise include:

Cementitious material

The type and source of milled clinker component, the use of mineral components (FA, GGBFS) and the total cementitious content all affect the rate of heat generation within mass concrete.

In general terms, concrete should be designed to have the lowest milled clinker content combined with the highest mineral component content. However, as mineral component content is increased, the total cementitious content required to achieve the required compressive strength may have to be increased.

Specifying compressive strength testing at later stages can offset this to some degree.

Pour size, particularly minimum dimension

Maximum temperatures are generally recorded in the centre of sections having a least dimension of about 2m.

To avoid excessive temperature differentials, the surface of mass concrete elements is often covered with insulating material, e.g. thermal blankets. Thinner concrete elements lose heat more easily. A pour thickness of 1m will need to be insulated for about five days, while a 4.5m thick section will need insulating for 21 days.

Formwork type

Where plywood forms are used, even for relatively thin sections, care must be taken to avoid thermal shock when the formwork is removed, especially during winter.

Ambient and concrete temperature

Reducing the concrete placing temperature reduces the rate of hydration and subsequently the peak temperature within the mass concrete element. Specifications often limit peak temperature to a maximum of 70°C.

Thermal strain

The thermal expansion coefficient of concrete is mainly dependent on aggregate type. Siliceous aggregate has higher coefficients, dolerite and lower limestone values. The thermal expansion coefficient of concrete is higher than that of the aggregate itself.

Tensile strain capacity (crack resistance) also varies with aggregate type. The expansion coefficient and tensile strain capacity can modify the temperature differential, which will cause cracking from 20°C for gravel aggregate to 39°C for limestone.

Where possible, aggregate from a specific source should be selected to give lower coefficients of thermal expansion of the concrete.

See *Aggregates and Thermal movement.*



Soil **stabilisation**

Stabilisation is the process of mixing cementitious material with granular material in predetermined proportions to improve the engineering properties of the granular material. Compacting and curing the mix results in a bound material with significant strength results.

Adding a stabiliser to soil that is unsuitable for road construction has economic benefits relating to elevating sub-standard in-situ soil to comply with specific application requirements. Strengthening the road sub-base lower layers can also result in cost savings in surfacing layers.

> This section only refers to stabilisation with cement e.g. Roadstab; stabilisation with lime and bitumen are beyond the scope of this document.

Cement for soil stabilisation

Stabilisation projects are generally site-specific. Developing a solution requires assessing the performance of the in-situ material and using fundamental analysis and design procedures to determine a cost-effective solution.

The selection of a cement type and content is then based on laboratory testing with the granular materials and two to three cement types available in the area of construction. All laboratory testing should be carried out using standard TMH1 and CSIR test methods.

> The availability of the cement type in the area of construction should be confirmed to prevent unnecessary laboratory testing.
>
> Please contact AfriSam for samples of suitable product available in the area of construction for pre-site trials.

Cement content

A minimum of 2% cementitious material is required to ensure a uniform distribution of the stabilising agent throughout the stabilised layer. Cement contents lower than this may result in strengths not being achieved in practice regardless of the results of laboratory testing.

The selection of the cement type influences the "working time", defined as the time between placing and compaction of the stabilised layer (see *Figure 21*). Cement starts hydrating as soon as it is in contact with moisture. If most of the hydration has occurred by the time the material is compacted, the chemical bonds that have been formed between the cement and the soil will be broken down by the compaction process and further chemical bonding will be limited.

This limitation may result in lower in-situ strength of stabilised layers.

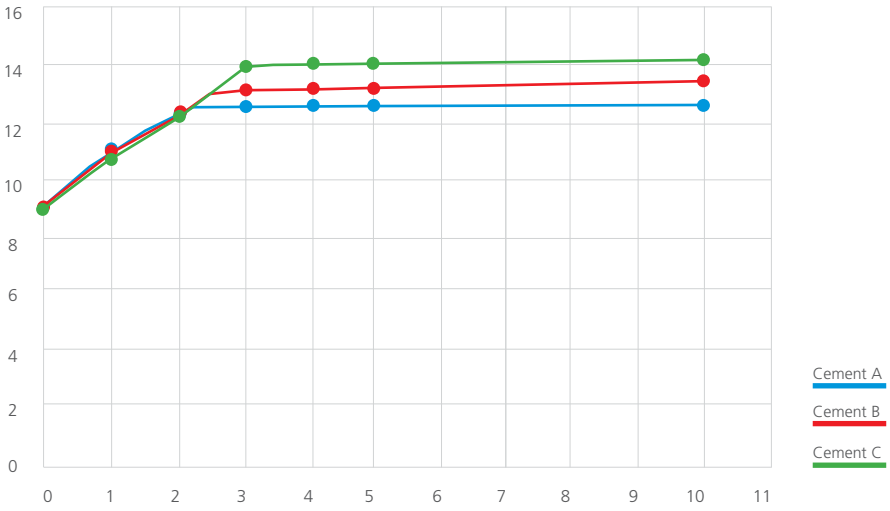


Figure 21: Reduction of pH of in-situ material using different cement

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Spreading

Distribution of cement can be done either by bag or bulk spreading.

The uniformity of application of stabiliser needs to be verified by means of:

- Weighing the amount of cement that was deposited onto a mat or tray placed at specified intervals during the spreading operation on the layer to be stabilised (see *Figure 22*).
- Balancing the total amount of stabiliser against the specified percentage of stabiliser and the stabilised area.
- Confirming percentage of stabiliser deposited per area to be stabilised.



Figure 22: Amount of deposited stabiliser weighed to check coverage

Compaction

Compaction should start immediately after final mixing and should be completed within the working time of the stabiliser. The working time is influenced by the cement type, soil type and ambient conditions. An indication of working time may be obtained by establishing a strength vs time relationship for the stabilised soil, as indicated in Figure 23. The engineer may then decide on an acceptable working time to limit the risk of strength loss.

Cement with extended setting times, e.g. Roadstab or a composite cement in the 32,5 strength class, is suitable for soil stabilisation applications because of the longer working times required to place and compact the material.



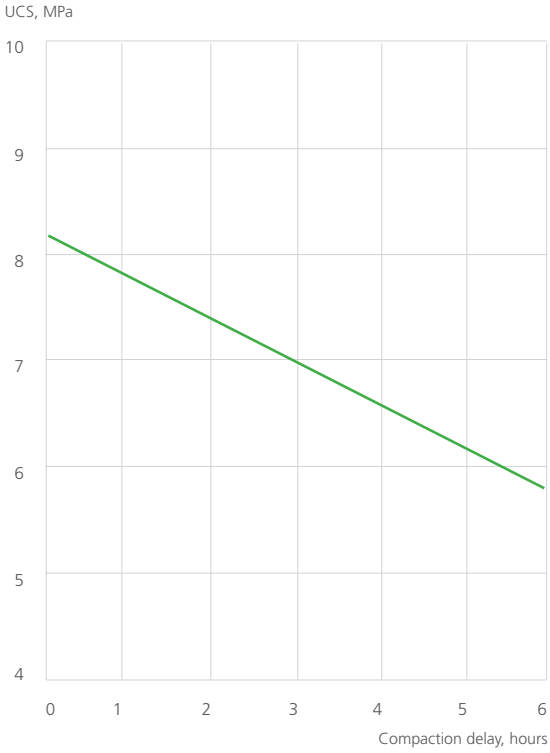


Figure 23: Typical strength vs time relationship

Curing

Curing is necessary to ensure that:

- The required strength is achieved.
- Adequate water is available for hydration.
- Drying shrinkage is limited at early stages.

The stabilised layer is cured for three to seven days after construction to allow the layer to harden before subsequent layers are placed.

Curing is done by means of:

- Maintaining the surface in a moist condition by light sprinkling and rolling when necessary.
- Sealing the compacted layer with a bituminous prime coat.

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About **concrete floors**

Technology has evolved to allow for the creation of beautiful concrete floors that can be made in a simple and economic way. Processes like concrete grinding and polishing have progressed significantly while the hardening process derived from the diamond polishing has other benefits too. These benefits include scratch resistance, ease of cleaning and good light reflection, which makes it an ideal choice for many facilities. Paints, urethanes and epoxy coatings look great in the beginning but suffer badly from scratching and general wear, and tear very soon afterwards.

About concrete and its effects on floors

Concrete is basically a combination of cement, stone, sand and water. Sometimes additives may be used to accomplish certain objectives such as workability, etc. For concrete to prove durable, all components must be in a proper balance. Too much or too little of any component can cause problems later. For example, let's look at the water component.

Water serves to react (hydrate) the cement, make the mix homogeneous and make the concrete workable and placeable. But too much water can result in excessive shrinkage and weakened concrete.

All concrete mixes contain more water than is actually needed to hydrate the cement. The excess water eventually evaporates. One primary objective is to retain the water until the cement is fully hydrated, then let it evaporate slowly over a prolonged period of time. This moisture retention process is called "curing" the concrete.

As concrete loses moisture it shrinks in dimension, usually at the rate of 3mm in every 6m of slab. If concrete were left as it is placed, it would crack in random crack patterns. To avoid random cracking we create joints at regularly spaced intervals, thus weakening the slab in a grid pattern. These joints, called control (or contraction) joints, force the cracking to occur in straight lines beneath the joint, actually producing a designed crack.

Concrete slabs shrink at a relatively slow rate because all the moisture must evaporate through the top of the slab. A reasonable shrinkage rate estimate is:

- 30% in the first 30 days.
- 50-60% in the next 335 days.
- 80-90% in the first year.

In other words, the slab is still shrinking long after you have taken occupancy. Thus joints will continue to open up and new random cracks may occur at any point in the first year or two. When we create the control joints, we caused interruptions in what would otherwise ideally be a continuous surface. To restore the floor's surface continuity for the purpose of material handling vehicle flow, we must refill the joints. The filler must accommodate two conflicting objectives:

- Be hard enough to support hard-wheeled traffic.
- Allow the joint to continue to open until the shrinkage process is complete.

The four attributes of a **good floor**

1. Flatness

The efficiency of the operations carried out by forklifts on floors depends on the speed of travel of the forklifts. Forklifts can travel faster on floors that are flat. Flatter floors also allow for higher racking in very narrow aisles (VNA) which increases stockholding, as well as contributing to higher safety levels and internal lighting improvement due to reflection.

Achieving surface flatness

Flatness is a measure of the waviness or smoothness of a slab. The floor flatness that is required needs to be assessed in terms of Properties I, II, III and IV as defined in the UK Concrete Society Technical Report TR34 that is used to define surface regularity. For most applications the FM2 classifications are suitable. This must be discussed with the client. The FM2 Classification is used for free movement floors whereas the DM classification is used for defined movement on very narrow aisles and racking height of up to 18m. The FM2 specification is achievable with the laser screed method and hence most popular worldwide.

The flatness and levelness is achieved with a quality concrete mix design using suitable workmanship, attentive supervision and the use of the latest techniques in floor placement. Equipment such as the Somero Laser Screed, bump cutter or highway straightedge is needed.

Information courtesy of CLF, specialists in concrete flooring and an AfriSam Group company.

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2. Hardness

Surface hardness provides resistance to abrasive wear from the imposed loads, giving the slab a long life and providing efficiency of operation.

Achieving surface hardness

The floor hardness and abrasion resistance is achieved using finishing processes such as burnished finish. This process involves the almost continual finishing of the surface of the slab using ride-on power trowels during the initial setting process following pouring. Immediately thereafter, Pentra-Sil® surface treatment can be applied to the surface of the floor.

The hardness achieved using this method has been tested by the Chaplin Abrasion Tester and the Mohs test to fall into the extremely hard category. This method does not use floor hardeners to achieve floor hardness and thus difficulties associated with application of the hardener are avoided. As a result, the floor without surface hardeners results in significant cost reductions for the client.

3. Joint detailing

Most slabs that fail do so at or adjacent to joints. Correct detailing and coordination of joints reduces the potential for damage to the slab surface.



Avoiding problems with joints

The fact that joints show up as the facility professional's most perplexing problem is not at all surprising. Most floors have joints every 4 to 6m. This means that a 10 000m² warehouse will have approximately 3 to 4 000m of joints. Additionally, there are many things that can go wrong with joints. For example; spalling of joint edges from hard wheel traffic since most modern-day material handling vehicles use solid polyurethane wheels that are extremely hard-wearing on joints.

The concept of a steel fibre reinforced concrete floor with large panel sizes also dramatically reduces the number of joints in a warehouse floor. The fewer joints in a floor, the less serious joint defects there are.

Large panel sizes are known to cause increased shrinkage movement at the joints. Although it is widely acknowledged that larger panel sizes will cause increased movement at the joints, this movement is not as large as one thinks since we are not dealing with normal concrete. Steel fibres offer a three-dimensional reinforcement mechanism within the concrete matrix to redistribute shrinkage stresses within a defined panel. This has the effect of reducing the shrinkage movement at joints.

Tips to achieve durable joints for hard wheel traffic

1. Keep the number of joints to a minimum i.e. use steel fibres to produce larger panels.
2. Use the Viper Joint Armoured Edge System.
3. Reduce the number of construction joints i.e. use laser screeds to pour large bays of 2 000m² plus.
4. Diamond dowel the construction joints to minimise curl and preserve load transfer under the influence of dynamic load.
5. Square dowel the sawn contraction joints.
6. Keep joint width to a minimum – 3mm saw cut.
7. Protect new joints with Durojoint Protector.
8. Strengthen the concrete edges of the joints i.e. use steel fibres and Pentra-Sil® Lithium Chemical Hardener.
9. Use the correct joint filling i.e. do not use elastomerics for hard wheel traffic areas; rather use MM80.

4. Maintenance costs and repairs

Costs associated with maintenance and repairs of the slab and maintenance of the forklifts are reduced with quality joint detailing and a high quality level surface finish.

They all depend on the concrete floor

One definition of productivity might be the time it takes to move a given amount of product from point 'A' to point 'B'. No matter how you place your racks, where you position the product on the racks and what MHVs you are using, the

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product must be able to move from A to B on a pre-established path on the floor. If this path were blocked by pallets or other obstacles, you would remove the obstacle. The same logic should be applied to the floor. Where you have minor to moderate floor defects, your MHV operator will slow down to minimise the bump. Where the defect is severe enough, he will detour to the next aisle and come up the unaffected aisle. Once you think about it, it's clear that less than quality floors can reduce your productivity.

Curing compounds for floors

Curing compounds are liquids which are brushed, squeegeed or sprayed onto the concrete surface. They are formulated from resins, waxes or synthetic rubbers dissolved in a solvent or emulsified in water. After evaporation of the solvent or water, a thin membrane forms on the surface of the concrete which retards moisture loss.



The effect of curing is to hold water within the concrete by minimising evaporation losses, thereby maximising hydration. This process is an extremely important part of concrete production as it:

- Reduces dusting.
- Reduces plastic cracking.
- Increases abrasion resistance.
- Increases strength.
- Increases durability.

Where fly ash or slag are used, the 7-day curing requirements may be extended to as long as 14 days; conversely where silica fume is used it may be reduced to as little as one day. Hence, curing compounds are particularly useful with fly ash and slag concrete as they eliminate the need for long periods of curing by ponded water, damp hessian or polythene sheeting.

Application of curing compounds

Curing compounds are most effective when applied as soon as bleeding has stopped and visible water sheen has disappeared, but the concrete is still damp. If applied beforehand, the compound, particularly if water based, will become diluted by the bleed water. If applied later, it is likely to be absorbed and the membrane will not form.

Practical tips for curing:

- Where surface temperature could become high due to UV exposure, use light-coloured curing material (e.g. don't use black plastic).
- Plastic cracking can occur very quickly, hence, where susceptible, be sure to apply a curing compound as soon as possible after finishing.
- One must apply the curing compounds after bleeding is complete but before the concrete has hardened, ie use spray applicators with a long nozzle.
- Where practical, retain formwork for as long as possible. If removed before the end of the specified curing period, immediately apply the curing compound.
- Use of wet hessian and plastic sheets are only effective when kept in contact with the concrete surface. Gaps lead to wind tunnels which cause rapid drying.
- Steam curing precludes the need for additional curing.
- On tilt-up construction, use a curing compound that will act as a debonder.

The importance of eliminating vertical joint movement and allowing two-way lateral movement:

Joints in floor slabs are unavoidable and are required for the following reasons:

- As day joints, necessitated by the daily floor output restrictions.
- Accurately levelled formed joints are required to enable flatness specifications to be met.
- To control shrinkage and warping stresses in the concrete.
- Differential vertical movement between adjacent bays of concrete results in joint arris breakdown.
- Lack of lateral dowel movement causes random cracking.

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All joints need either dowel bars or tie bars through them to maintain load transfer and eliminate vertical movement. Even if contraction joints are provided at 6mm centres without reinforcement, shrinkage of up to 2mm can occur.

This is outside the limit at which 'aggregate interlock' can provide load transfer and consequently design safety factors have to be raised. Joints can be "tied" to reduce shrinkage to under 1mm, at which it is accepted that load transfer is maintained. Joints can be "tied" by using suitably anchored reinforcing steel.

A "tied" joint can only be used where contraction of the slab is allowed elsewhere, through the use of 'contraction' or 'free-movement' joints (or perimeter-isolation joints). Such joints must have reinforcement and must be debonded on one half to allow the slab to contract. This is traditionally achieved through the use of a round steel bar which is coated on one half with a debonding compound or debonded with a proprietary circular plastic sleeve.

Consider a common detail where a debonded induced transverse contraction joint crosses a long formed contraction joint at right angles. The true movement of the slab at the corner of the two joints, if it were free to do so, would be at 45 degrees, not 90 degrees, to either joint. The traditional round dowel, which has to be installed to provide load transfer, effectively constrains the slab at this point, completely defeating the object of the design.

All current joint details ignore any differential sideways movement (ie parallel to the joint) which must occur whilst none of the recommendations for shrinkage control takes these additional stresses into account. Joints at right angles tend to lock a slab at the corners.

The patented Norton Diamond Dowel system is very easy to install accurately and allows for both horizontal and transverse movement while prohibiting vertical movement, thereby creating very effective load transfer across the joint and minimising long-term joint damage.



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20 Steps to **avoid common floor deficiencies**

While problems found in floors may differ in severity, they are seldom unique and tend to be the result of the same mistakes over and over again. The recommendations offered in this section won't prevent all floor problems, but these may help avoid very common and preventable problems. Here are a few tips to help alleviate these problems:



Problems in the design phase:

1. Loosely drafted construction documents

It is essential to have a tightly drafted floor spec and complete floor details before starting the job. Wide open material and procedural specs lend themselves to problems as they tend to allow problems to creep into the design of the floor. It is essential to submit a proposed joint layout, provide complete jointing details and specify allowable concrete additives. Listing acceptable products by name also minimises the use of the broad term "or equal" which may often be interpreted as "or cheaper".

2. Specifying or allowing additives

Because there are numerous concrete additives on the market,one should take care to understand the properties and possible side effects before use. For example, some additives delay the appearance of bleed water, thus delaying the finishing while others may allow more rapid slab shrinkage, adding to curl problems. Concrete additives can be helpful in achieving certain results (better finishing characteristics, etc.), but they should never be considered a substitute for a good basic mix design, proper placement by qualified contractors and adequate curing.

3. Minimise shrinkage and curl

Excessive (or rapid) shrinkage and slab edge curl can affect even the best designed floors. It is therefore important to have the correct mix design. Many in the industry equate low slump with low shrinkage. This is true to a degree, but aggregate size and water:cement ratio are likely of greater importance. The following are tips that may be considered:

- Use the largest aggregate possible. Coarse aggregate occupies space without shrinking.
- Water and cement both add significantly to shrinkage and curl. A concrete with a low water:cement ratio is a better option.
- Avoid high strength concrete mixes. Concrete strength is measured by compressive strength, and floors seldom, if ever, fail in compression. Higher strength mixes require more cement and this may contribute to shrinkage and curl.



4. Joint spacing: closer, more square

The trend over the past decade has been to make slab panels larger, and thus have fewer joints. The reasons most commonly cited include the costs associated with filling more joints – the costs to the owner in floor maintenance if he has more joints and extending the spacing between columns in turn tends to extend joint spacing.

These reasons are all valid, but we often fail to consider the effect of normal shrinkage on joints. As a rule of thumb, a typical 150mm thick slab may shrink 3mm every 6m. Thus, a 3mm cut every 6m will eventually open to 6mm. This means the joint has opened 100%. Consider what this means to a semi-rigid epoxy joint filler that may be able to accommodate only 5 to 10% expansion. By bringing your joints closer together you minimise the degree of filler-to-concrete separation that will occur.

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Random cracking also has to be taken into consideration. The larger the slab panel, the greater the potential for random cracking. It all comes down to a choice between joints or cracks, and joints are definitely less expensive than cracks. To cut and properly fill a joint is relatively inexpensive and gives an aesthetically pleasing floor. Joints are also relatively easy to maintain. Random cracks, on the other hand, are unsightly and cost more to cut out (chase) and fill. Cracks are much more difficult and expensive to maintain than joints.

Another consideration is the panel shape. Concrete shrinkage causes an even stress build-up across the slab. Thus, a 4,5m x 4,5m panel shrinks equally across all directions while for a 4,5m x 6m panel, the stress will be greater across the 6m dimension. It is quite likely a crack will occur dividing the 6m span into two 3m segments.

In conclusion, one has a choice between joints or cracks. You can reduce the effects of cracking by heavily reinforcing the slab. But reinforcing does not prevent cracks. It merely holds them tight at best. Reinforcing is also expensive. One needs to consider the trade-offs carefully in design.

5. The myth of mesh

There are a number of beliefs about mesh that are not necessarily correct. The first myth about mesh is that it will prevent cracking. This is not true. It merely holds the cracks tight, if properly placed. The second is that mesh adds compressive strength to the slab, if properly placed. This is also incorrect. The third is that the mesh can be properly placed which may not be true in a number of cases. It may end up at the top of the slab where it may add to both the frequency of cracking and the surface width of your cracks. In light of this, a viable and increasingly popular alternative to mesh is steel fibres which are mixed into the concrete prior to placing and offer 3D reinforcing throughout the depth of the slab. This is a simpler, cost-effective and better solution.

6. Dowel the construction joints

The ideal floor is one where all slab panels work together in unison as traffic passes over the joints. Construction joints create a total separation between panels, thus creating the potential for one panel to deflect under load while the adjacent panel stays up, resulting in joint edge spalling. The use of dowels at construction joints can ensure that all panels work together under load. To be effective, dowels must be properly spaced and aligned and sleeved on one end to allow for joint movement.

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7. Construction joints should have an amoured edge

Construction joints have two major disadvantages:

- The edges may be inherently weak because they are finished less densely than the rest of the surface.

- Unlike a saw-cut joint, there is no base to support the eventual joint filler. To counter this, construction joints should have an amoured edge to protect the joint against continued hard wheel traffic, minimise joint damage and high maintenance costs and increase MHV efficiency.

8. Don't over-specify flatness

Some owners and designers specify higher flatness numbers than they really need. A higher flatness number will result in higher costs as more time, skills and effort is required to flatten the floor. Before specifying a flatness number, it is suggested that an acceptable existing floor be tested. Many, if not most, conventional warehouse floors can get by with an FM2 specification.

9. Joints at doorways through walls

Joints where two separate slabs meet at doorways, such as at fire walls or into separate storage rooms (coolers, etc.), are frequently found to be suffering severe spalling. Sometimes the cause is that this was a butted joint and never filled. In other cases, the designer used a pre-moulded filler to isolate the two slabs. Both approaches are wrong and inappropriate. If hard-wheeled vehicles will pass over this junction, an armoured joint should be provided. The most durable armouring is usually a precision engineered flat bar with anchor rods.

10. Properly specifying the floor joint filling

Floor joint fillings should never be treated as an afterthought, something incidental to the actual floor. This thinking fails to recognise that:

- Because joints are an interruption in the surface, joint filling must be considered a vital link in the floor surface.
- Each joint is a potential impact point for the wheels of material handling vehicles.
- Since joints will continue to open for a year or two during the extended shrinkage period of the floor, joints are in effect the most vulnerable part of the floor surface.

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Here are a few critical points on floor joint filling that need consideration:

- Joint fillers should be specified on the surface bed drawing and must make the distinction that floor joints are to be filled, not sealed, where hard wheel traffic is anticipated.

- To be effective as an edge protector, the filler must fill the entire saw cut, taking advantage of the support offered by the base of the saw cut. The design must clearly specify that the filler must be installed full-depth with no compressible backer rod allowed and provide proper details in structural drawings.

NB: The filling of joints with the most expensive product on the market will cost you a fraction of what it costs to repair a joint allowed to spall due to improper filler, not to mention the downtime for repairs. Therefore, joint filling is the last place you want to cut corners.

Problems in the bidding phase:

11. Pre-qualify your main contractors

It is recommended that contractors be pre-qualified as mistakes may be costly.

12. Hold a pre-bid conference

The demands for quality, schedules, job conditions, availability of good aggregate, specs and drawings, etc., should be made upfront to the shortlisted contractors. It is also important to heed to recommendations made and the reasons for these.

Problems in the construction phase:

13. Hold a pre-construction conference

It is important to hold a site conference with all the role players that will be involved in the job at least a week before the job starts as a last opportunity to discuss job conditions, mix design, schedules, pour sequence, light and ventilation, temperature, access, curing, etc. This meeting may include owners, designers, concrete contractors, readymix suppliers, accessory suppliers (additives, joint fillers, etc.), the testing lab and any trades whose work might interfere with or affect the floor placement.

14. Inspect the finish grade

A well-compacted even grade is critical. The base must have no hard or soft spots, and no high or low points. Inconsistencies will cause sub-grade drag which will result in cracking. The best verification of adequate finished grade is to proof-roll it with a heavy vehicle such as a cement truck.

15. Start curing procedures promptly

Once the finishing is complete, the curing process should begin immediately and be for at least seven days. Retention of moisture is critical in ensuring complete cement hydration and yield stronger and more durable concrete. The concrete should be remisted whenever the curing sheet is temporarily removed (for cutting, etc.) or as dictated by conditions.

16. Cutting of contraction (control) joints

The most difficult element in cutting is the timing. This is one prime example of the art/science equation as cutting too early will cause joint edges to ravel while cutting too late may encounter other problems such as an already cracking slab, due to tensile stress brought about by shrinkage. There are three critical things to remember in the cutting operation:

- The timing should be such that the cut is clean, not disturbing the adjacent aggregate.
- The blade should be appropriate for the aggregate through which it must cut.
- The base plate of the saw must be replaced in strict compliance with the saw manufacturer's instructions. Failure to comply can result in micro-fracturing of the joint edges.

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17. Avoid premature loading on slabs

Concrete does not usually reach its optimum compressive strength until 14 to 28 days. It is always wise to avoid or at least minimise heavy loads (rack delivery, etc.) until the slab has reached adequate strength. If access must be granted, insist that material handling vehicles have pneumatic tyres. All vehicles crossing the slab should wear 'nappies'. In the case of tilt-up construction, the push for access is intense. If at all possible, keep readymix trucks and cranes off the floors and especially off panel corners.

18. Proper filling of floor joints

Assuming specs and details have been properly prepared, the next critical issue in joint filling is the timing. Concrete will have significant shrinkage for a period of one to two years. As shrinkage occurs, the joints grow wider. Thus, it is advisable to always delay joint filling until the last possible opportunity. Immediately after cutting, a temporary joint protector that remains in place for three to six months may be used and also serves to minimise the amount of filler-to-concrete separation that occurs.

After timing, the most critical element in filling is the depth of the filler. A filler is most supportive of loads when the filler itself is supported by the bottom of a saw cut. Surveys indicate that more than 70% of all projects suffer cheating in the filler installation.

Another important issue is the finished profile of the filler. Since one goal in filling is to avoid impact points, a filler should be finished flush with the floor surface. This is best achieved by over-filling, allowing the filler to cure into a solid, then shaving the filler off flush with a razor.

19. Provide for correction of filler separation

No matter how long one is able to defer your filler installation, filler-to-concrete separation may still occur. This is because filler that is firm enough to support traffic cannot be flexible enough to accommodate significant joint opening. There are two basic means to provide correction of separation:

- Provide in your specs a call-back top-up provision, obligating us to return to the project six months after occupancy to refill all voids that are credit card width or greater; or

- Have a refilling separation as part of the maintenance contract.

20. Use common sense in crack correction

There are very few slabs placed that do not have cracks. Hairline, occasional cracks need not necessarily be of concern, since aggregate interlock will keep the panel structurally sufficient. If numerous cracks occur, or if cracks are wider than hairline, an evaluation is required.

One problem frequently experienced is the practice of filling cracks with a structural epoxy, with the idea of welding the slab back together. This procedure is often done by pressure injecting epoxy into drilled port holes. The problem is that the crack may still be active. Welding an active crack is likely to cause the development of a new crack adjacent to the repaired one. If it can be avoided, structurally welding any crack (or joint) is not advisable.



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Concrete

Applicable specifications

ASTM C494 / C494M -11: Admixtures
BS EN 1992-1-1 2004: Structural use of concrete
Part 2: Code of practice for special circumstances (replaces BS 8110)
SANS 878:2012: Readymixed concrete
SANS 1083:2006: Aggregates from natural sources – Aggregates for concrete
SANS 1090:2009: Aggregates from natural sources – Fine aggregates for plaster and mortar
SANS 2001-CC1:2012: Construction works
Part CC1: Concrete works (structural)
SANS 10100-1:2000: The structural use of concrete
Part 1: Design
SANS 10100-2:1995: The structural use of concrete
Part 2: Materials and execution of work
SANS 50197:2000: Cement. Part 1: Composition, specifications and conformity criteria for common cements
Part 2: Conformity evaluation
SANS 50450:2011: Fly Ash for concrete
Part 1: Definitions, specifications and conformity criteria
Part 2: Conformity evaluation
SANS 51008:2006: Mixing water for concrete: Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete
SANS 53263:2011: Silica Fume for concrete
Part 1: Definitions, specifications and conformity criteria
Part 2: Conformity evaluation
SANS 55167:2011: Ground granulated blast furnace slag for use in concrete, mortar or grout
Part 1: Definitions, specifications and conformity criteria
Part 2: Conformity evaluation

Test methods

SANS 5860:2006: Concrete tests – Dimensions, tolerances and uses of cast test specimens
SANS 5861:2006: Concrete tests
Part 1: Mixing fresh concrete in the laboratory
Part 2: Sampling of freshly mixed concrete. Part 3: Making and curing of test specimens
SANS 5862:2006: Concrete tests – Consistence of freshly mixed concrete
Part 1: Slump test
Part 2: Flow test
Part 3: Vebe test
Part 4: Compacting factor and compaction index
SANS 5863:2006: Concrete tests – Compressive strength of hardened concrete

For road stabilisation:
Improved CSIR: Developed method: Determination of the Initial Consumption of cement required for road modification
TMH1 Method A1(a): The wet preparation and sieve analysis of gravel, sand and soil samples
TMH1 Method A2, A3 and A4: Determination of the liquid limit, plastic limit, plasticity index and linear shrinkage of soils
TMH1 Method A7: Determination of the maximum dry density and optimum moisture content of gravel, soil and sand
TMH1 Method A8: Determination of the California Bearing Ratio of untreated soils and gravels
TMH1 Method A13T: Determination of the Unconfined Compressive Strength of soils and gravels
TMH1 Method A716T: Determination of the Indirect Tensile Strength of soils and gravels

Hardened Concrete



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Hardened Concrete

Characteristic strength, drying shrinkage, creep, modulus of elasticity, permeability and resistance to chemical attack are hardened and time-dependent properties of concrete that may influence structural performance.

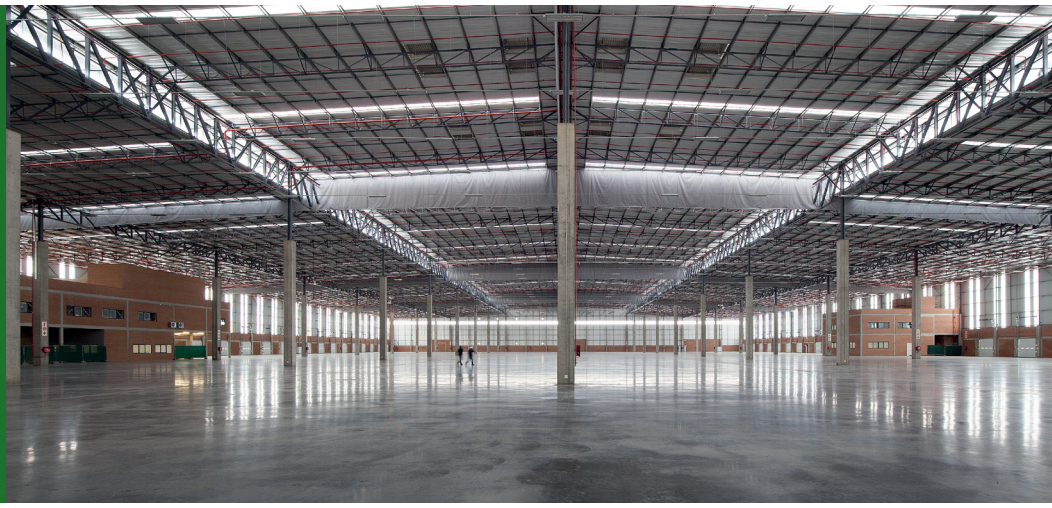
Structural performance may be described in terms of:

- **Strength**
  The ability of the structure to withstand load.

- **Serviceability**
  The ability of the structure to provide a comfortable, aesthetic environment when used for intended functions.

- **Durability**
  The time for which the structure is serviceable, and the maintenance required for it to remain serviceable.

Influencing structural performance and durability.





The ability of a structure to withstand load does not necessarily imply that the structure will fulfill its function.

Therefore, serviceability (quantified in terms of the deformation and displacement of structural elements) and durability are important additional performance criteria.

This section describes how AfriSam cementitious materials and aggregates influence the hardened and time-dependent properties of concrete. Cement chemistry is integral to the processes taking place in concrete during initial hydration and throughout and beyond the initial 28-day hardening period. We define the various factors involved and describe the test methods used to obtain accurate test results. Recommendations are made for estimating these properties for structural design purposes.



Compressive strength

The compressive strength of concrete is the most common measure for judging not only the ability of the concrete to withstand load, but also the quality of the hardened concrete. Test results obtained from compressive strength tests have proved to be sensitive to changing mix materials and mix proportions, as well as to differences in curing and compaction of test specimens.

- Compressive strength is defined as:
  fc, N/mm² or MPa = $\frac{P}{A}$

  where:
  P = load to failure, N
  A = cross-sectional area, mm²

- Characteristic strength (f_{ck}) is defined as the value for the compressive strength of concrete below which not more than 5% of the valid test results obtained on concrete cubes of the same grade should fall.

  For example, a concrete with characteristic strength of 30MPa has a 95% probability of achieving 30MPa and more, and a 5% probability of being less than 30MPa.

- A valid test result is the average result obtained from the testing of three test specimens of concrete in accordance with SANS 5863.

- Specified strength normally refers to the characteristic strength and is indicated on design drawings or project specifications.

- Target strength (f_{ck}) is the compressive strength that is aimed at ensuring that the concrete meets the characteristic strength requirement. It is obtained using the formula:

  $f_{ct} = f_{ck} + 1.64 \times \text{standard deviation (SD)}$

  (SD) is dependent on the degree of control at the concrete production facility.

In South Africa, project specifications refer to characteristic strength, which is derived from statistical analysis of 28-day compressive strength test results. Experience has proved that when a structure is designed for a certain characteristic strength, e.g. 30MPa, and the 28-day characteristic compressive strength test results meet that requirement, the structure will in all probability be able to withstand the appropriate design loads.

Compressive strength test method (SANS 5863)

Test specimens are crushed between two platens in a hydraulic press. The rate of load application influences the compressive strength results and is specified at a uniform rate of 0.3MPa/s ± 0.1MPa/s.

The mode of failure is primarily in tension. Satisfactory (normal) modes of failure are shown in Figure 24.

Note: All four faces are cracked approximately equally, generally with little damage to the faces in contact with the platens.

The shape of the crushed specimen is a good indication of whether the test was conducted in accordance with the specification.

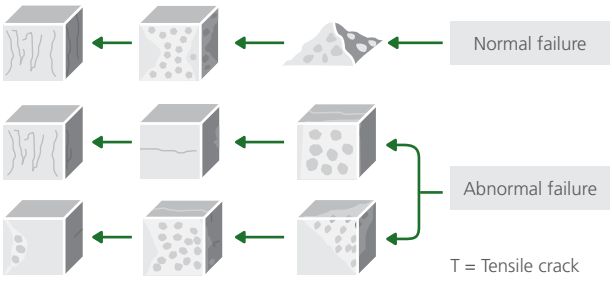


Figure 24: Modes of failure

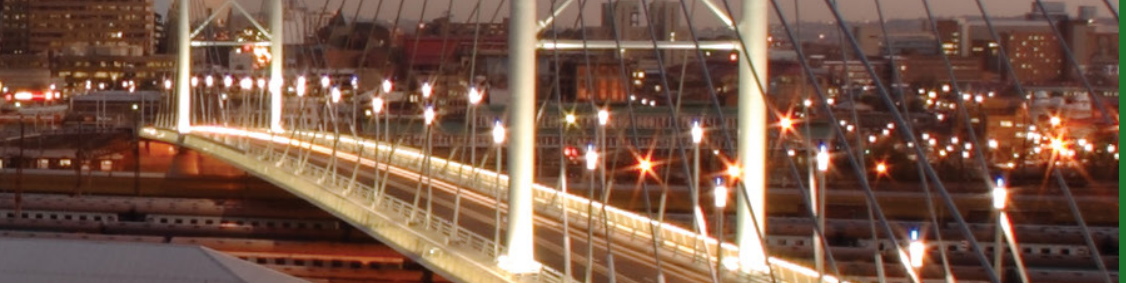
An unsatisfactory (abnormal) failure may indicate that the platens are not parallel, the cube is not square or the faces of the cube are not flat. The concrete areas in contact with the platens must be plane, parallel to each other and at right angles to the y-axis of the specimen.

An unsatisfactory failure may give a suspect result, and indicates a deviation from standard procedure.

An accurate representation of the strength of cast concrete can only be obtained when cubes have been prepared and tested in a controlled manner as prescribed in relevant standard test methods.

See also *Guidelines to preparing cubes or refer to SANS 5861-2 and SANS 5861-3.*

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Hardened Concrete

Factors influencing compressive strength

The most significant factor influencing compressive strength is the amount of cement in the mix, relating to water:cement ratio (W/C). The lower the W/C, the higher the strength for similar other materials.

Other factors include the amount of mineral component in the cement and/or mix influencing the rate of strength gain, and the quality of the aggregate used as well as the use of admixtures.

- **Water:cement ratio (W/C)**
  Mix designs for concrete with different compressive strengths are based on predetermined ratios between water and cement. Most concrete used in practice is designed with a W/C between 0.45 and 0.7.

- **Mineral components**
  Cement containing mineral components is recommended for use in all concretes to enhance durability. Mineral components such as GGBFS and FA are used to enhance the sulphate and chloride resistance of concrete, preventing expansion and reducing attack on reinforcing steel. Mineral components, especially CSF, also improve the impermeability of concrete preventing ingress of aggressive substances into the concrete.

  For more detail, see *The use of GGBFS and CSF in concrete (Concrete)* and *Durability*.

- **Aggregate**
  Aggregate is often not considered in strength prediction. However, the use of inferior aggregate which may be weathered, soft and contain deleterious substances may result in the predicted strength not being achieved.

  The use of good quality concrete aggregate from AfriSam may be beneficial for achieving higher than predicted strength. It has been proved that the use of AfriSam Newcastle dolerite, Zeekoewater felsite, Pietermaritzburg dolerite and Eikenhof andesite has resulted in higher strength when compared to aggregate from other sources at the same W/C.

  For effects of aggregate type on creep, shrinkage and modulus of elasticity, see *Deformation of concrete*.

- **Admixtures**
  Chemical admixtures may change the rate of strength development of concrete, and may influence 28-day compressive strength. It is recommended that the admixture supplier is involved in selection of the appropriate product, and that trial mixes are carried out using the specific admixture/s. See also *The use of admixtures in concrete (Concrete)*.

Compressive strength development with time

Structural design and associated specifications normally refer to 28-day compressive strength. However, early strength, e.g. 7-day compressive strength test results, may be used to predict 28-day strength.

The compressive strength of concrete one to three days after placing is important for structures where early loading is expected, fast-track construction is required or early demoulding or stripping of shutters is necessary. In these cases, not only the 28-day strength, but also the early required strength is a consideration when choosing cement type and W/C.

If the concrete does not comply with specified strength at 28 days, or there are reasons to doubt that it will, e.g. very low ambient temperatures on-site, the engineer may decide to evaluate the concrete strength at a later age, typically 56 days.

Process control

The principle elements in process control include:

- Identifying the properties of suitable raw materials and monitoring these properties.
- Proportioning these materials to give concrete of the required quality in the fresh and hardened states.
- Identifying process variability to allow correct target strengths to be achieved.
- Acceptance control and criteria for compressive strength test results.
- Adequate sampling and testing.
- Statistical evaluation of results.
- Corrective action in the event of non-compliance.



- **Acceptance control and criteria for test results**

  Acceptance control testing is generally carried out on behalf of the customer by an external laboratory to confirm the effectiveness of the readymix producer's quality control system, see *Table 36*.

  When compressive strength test results do not meet the above requirement, the concrete from which the samples were taken may not necessarily be weaker than required. The fault may lie elsewhere, and the steps shown in Figure 25 may be taken to investigate the cause.

See also *Guidelines to preparing cubes (Concrete) or refer to SANS 5861-2 and 5861-3*.

Predicting compressive strength based on raw materials and mix proportions

Prior to concreting, trial mixes are conducted to ensure that the proposed on-site mix proportions and the properties of the raw materials to be used will produce concrete that complies with the requirements of the specification. It is, however, possible to obtain an approximate strength when the relationship between W/C and strength is known for a given set of materials. Figure 26 shows typical 28-day compressive strengths.

Table 36: Sampling frequency and acceptance criteria

Specification	SANS 1200-G	SANS 10100-2	SANS 878
Sampling frequency	One sample per 50m³	One sample per 50m³	N/A
Acceptance criteria • No individual result below characteristic strength by more than:	3MPa	3MPa	3MPa
• Mean of three overlapvping results must exceed characteristic strength by:	2MPa	2MPa	2MPa

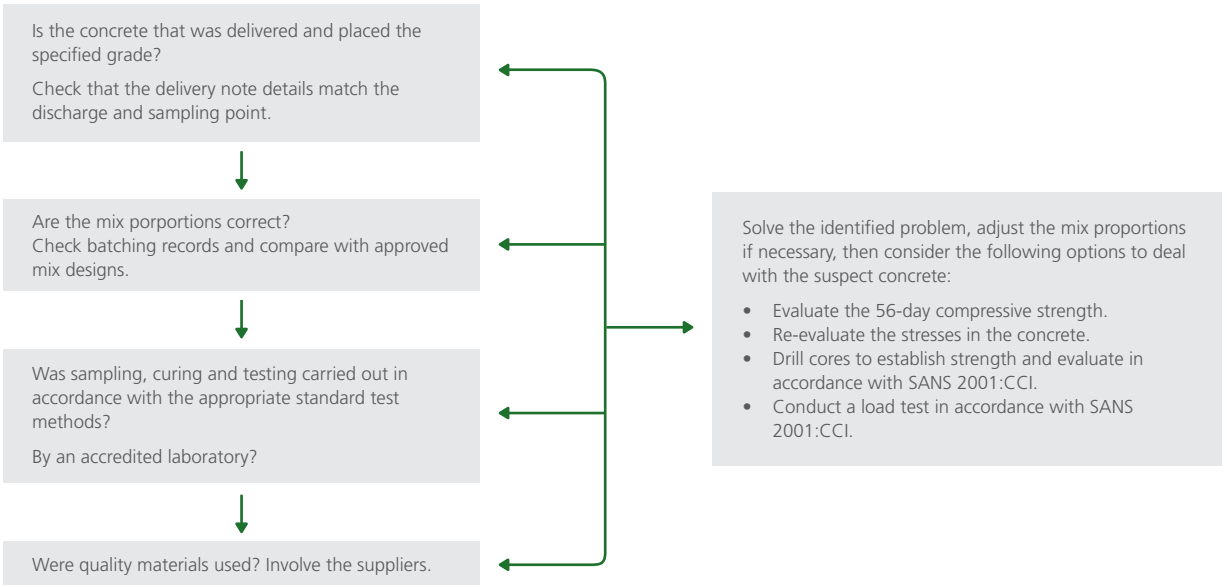


Figure 25: Investigating low compressive strength results

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Monitoring concrete strength

It is common practice to use at least two cementitious materials, two fine and coarse aggregate products and more than one admixture. To control the combined effects imparted to concrete by all these constituents, comprehensive quality control programmes are essential.

The main factors affecting the quality of concrete relate primarily to:

- Control of an increasing number of raw materials.
- The use of different materials with differing concrete-making properties.
- Proportioning materials to provide concrete with different properties in the fresh and hardened state.
- Production processes.
- Sampling and testing: Between batches of concrete made with identical proportions of the same raw materials, there will be some inherent and acceptable variation in quality. Any quality control system employed should be able to quickly detect unacceptable deviations in order to initiate effective corrective action.

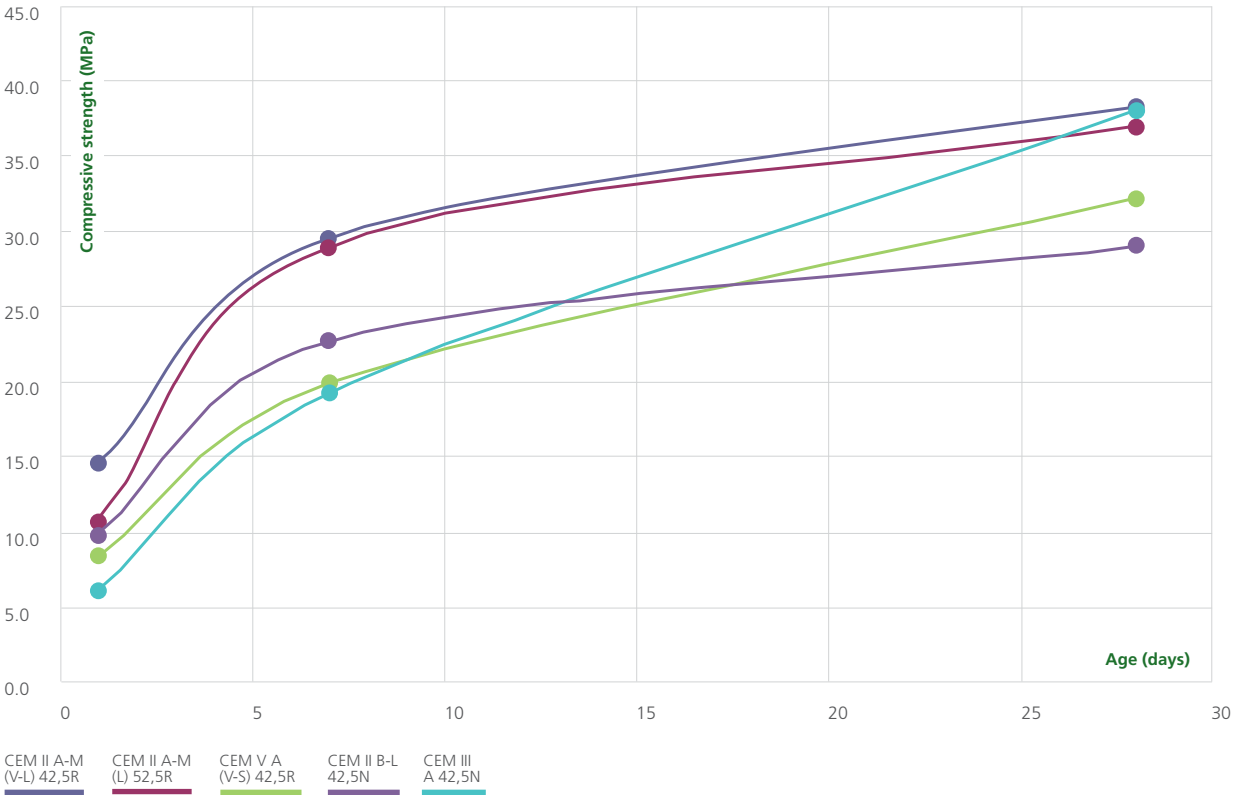


Figure 26: Typical compressive strength of AfriSam cements vs age

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Deformation of concrete

Deformation and structural integrity

Concrete deforms due to elastic, creep, shrinkage and thermal strains. The effect of concrete deformation on the integrity of the structure will depend on the ability of the structure to tolerate deformation occurring over time. In general, deformation may cause excessive deflection, cracking, loss of prestress of structural elements, buckling of long columns and excessive joint movements.

These detrimental effects can be minimised if the structural designer allows for the elastic, creep and shrinkage potential of the concrete.

Components of deformation

Elastic strain occurs instantaneously upon loading and is recoverable when the load is removed.

Creep and shrinkage strains are time-dependent and are not completely reversible.

The components of deformation are illustrated in Figure 27.

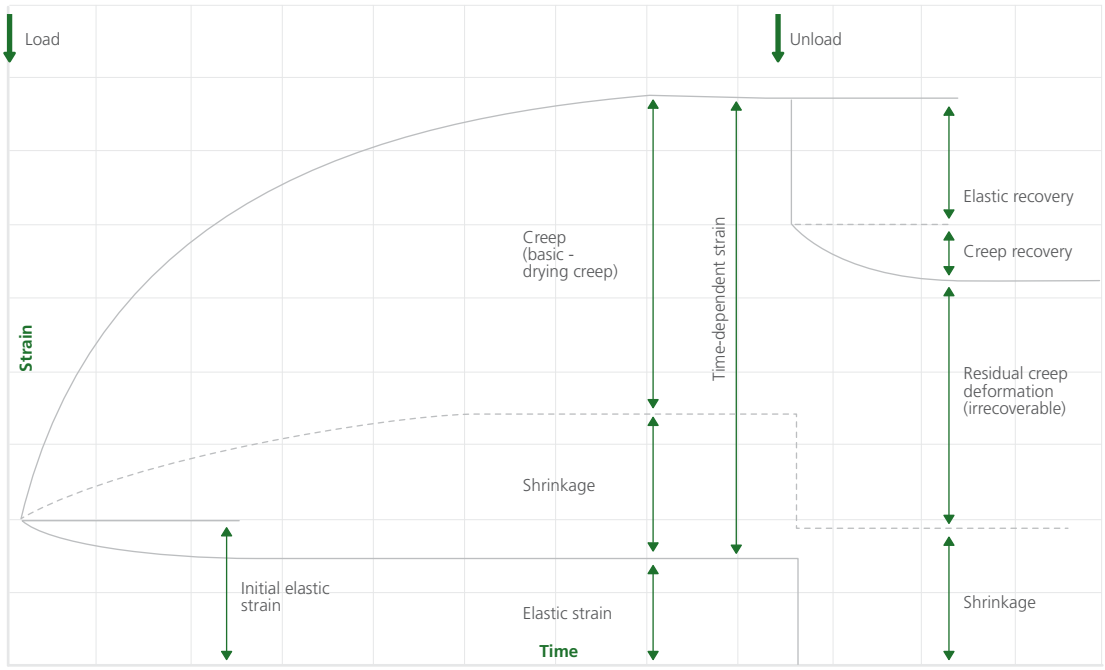


Figure 27: Components of deformation

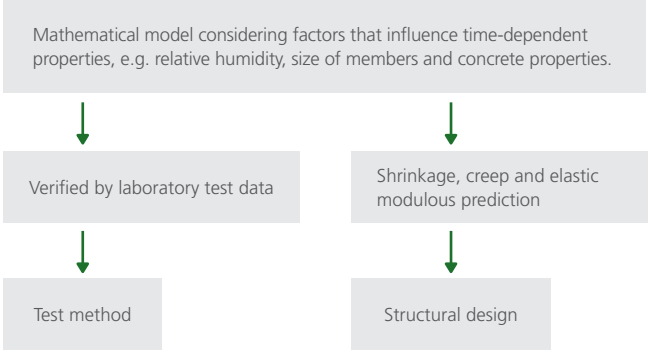
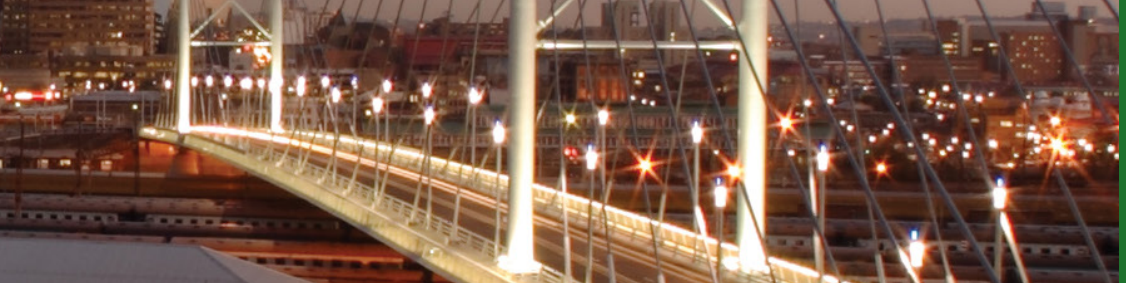


Figure 28: Relevance of laboratory data to structural design

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Factors influencing the deformation of concrete

The magnitude of elastic, creep, shrinkage and thermal strains in concrete is influenced by intrinsic factors relating to raw materials and mix proportions, and extrinsic factors relating to the environment the concrete is exposed to, and the loading the structure has to resist.

Table 37 summarises these factors.

AfriSam has commissioned four research programmes since 1989 to assess the effect of our materials on the deformation of concrete. The relevance of this research is to provide the structural engineer with more appropriate prediction values for local concretes. The process of validating and calibrating is illustrated in Figure 28.

Table 37: Significant factors influencing deformation

Factors	Deformation			
	Elastic	Creep	Shrinkage	Thermal
Intrinsic				
W/C				
Cement type				
Moisture content				
Aggregate properties and content				
Extrinsic				
Level of applied stress				
Duration of load				
Curing				
Age of loading				
RH and temperature				
Rate and time of drying				
Member geomentry and size				
Dependent on	Load	Load and environment	Environment	

Applicable Not Applicable

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Deformation: **Modulus of elasticity**

The modulus of elasticity of a material is defined by the slope of the stress:strain curve. The higher the elastic modulus, the more resistant the material is to deformation. Concrete is not a perfectly elastic material and therefore the stress:strain curve indicates a varying elastic modulus (the slope of the tangent).

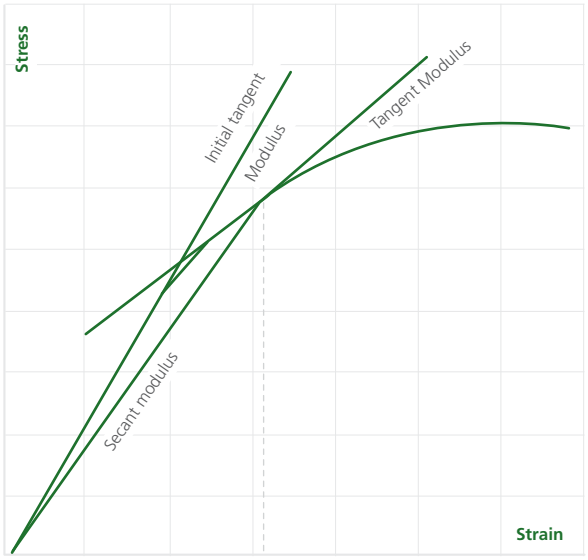


Figure 29: Typical stress:strain curve

- **Young's modulus or initial tangent modulus**
  The initial linear part of the curve.

- **Tangent modulus**
  The slope of the tangent at an arbitrary strain.

- **Secant modulus or static modulus of elasticity**
  The strain corresponding to a given stress. The value is normally determined by testing, where the stress is equal to one-third of the compressive stress. The value depends on the rate of load application.

- **Dynamic modulus**
  The modulus of elasticity determined by electrodynamic testing. This test is more convenient to carry out than static modulus testing.

The dynamic modulus is roughly equal to the initial tangent modulus, and is therefore higher than the static modulus of elasticity. The approximate relationship between static and dynamic modulus are given in BS 8110-2 as:

$$E_c = 1.25E_{cq} - 19$$

Such an estimate for static modulus will generally be correct within ± 4GPa. However the relationship may vary depending on the aggregate type used in the concrete.

Test methods

- **Static modulus**
  There is no SANS standard test method to determine the static elastic modulus of concrete and therefore either BS 1881-121 or ASTM C469-02 methods are used. The tests determine initial tangent modulus (Young's) as well as the secant modulus corresponding to one-third of the compressive failure stress.

  The test involves loading a concrete prism at a constant rate and recording the load (stress) and deformation (strain) of the specimen. Several load cycles to one-third of the compressive strength are carried out to reduce the effects of creep and small shrinkage cracks on the results. A stress:strain curve is obtained from which the modulus of elasticity is determined.

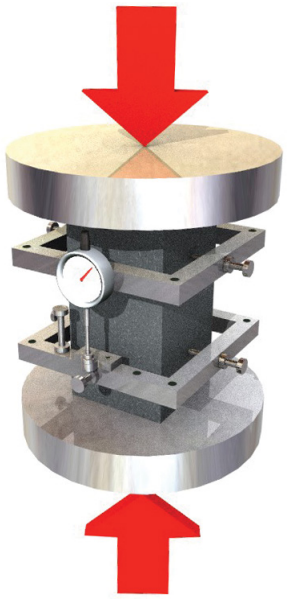
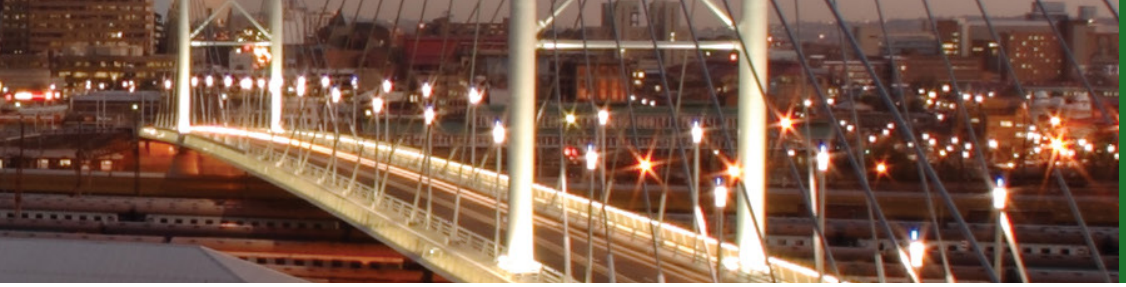


Figure 30: Static modulus test

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- **Dynamic modulus**

  Dynamic modulus refers to the modulus of elasticity determined by an electrodynamic test method described in BS 1881-121 in which the first natural mode frequency of the longitudinal vibration of a standard test beam is measured. The longitudinal vibration subjects the beam to very small stresses and the release is rapid; the effects of creep are therefore negligible.

  The modulus of elasticity is calculated by multiplying the first natural mode frequency by the mass of the specimen and a correction factor for size and shape of the member.

  Ultrasonic pulse velocity (UPV) may also be used to determine dynamic modulus, where the density of the concrete and Poisson's ratio are known. This test method has limited practical value.

Factors influencing modulus of elasticity

- **Aggregate type**

  The modulus of elasticity is mainly influenced by the stiffness of the aggregate and its volume concentration. Strength of the concrete is not per se an influencing factor, and the relationship between modulus of elasticity and compressive strength is determined by the aggregate.

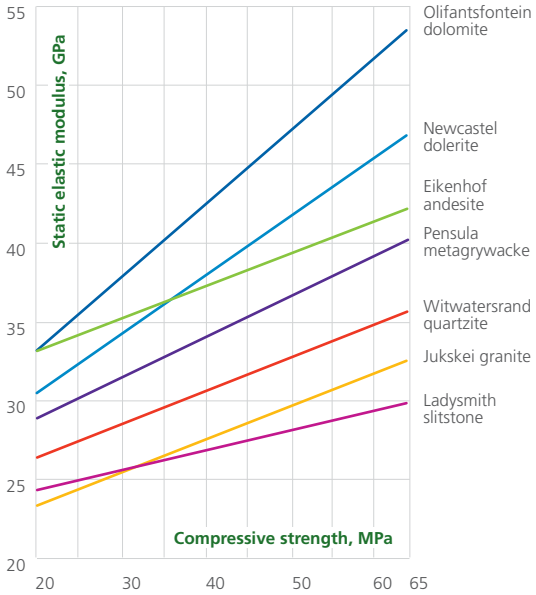


Figure 31: Static elastic modulus vs compressive strength of concrete for 3 to 28 days

Figure 31 indicates this relationship for AfriSam Aggregate, where concretes with similar compressive strengths but with different aggregates have significantly different E-values.

- **Cement types**

  Elastic modulus does not differ greatly in concretes when using mineral components proportioned for the same 28-day strength. Kearsley concluded that GGBFS content does not have a significant effect on the elastic deformation for concrete and that the effect of the aggregate type was more significant. The report was based on an investigation with AfriSam Cement and Aggregate.

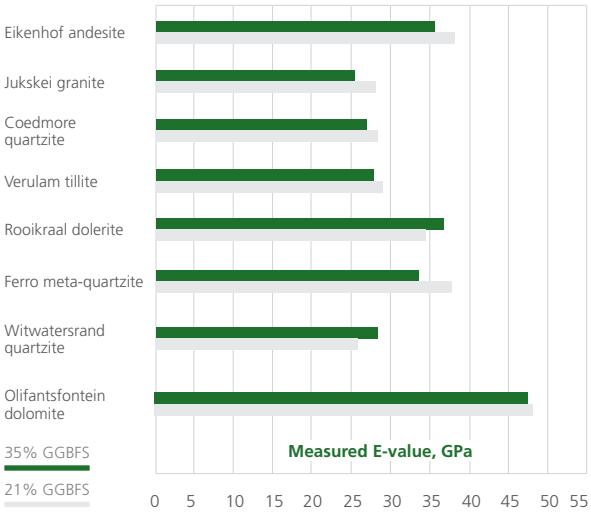


Figure 32: Modulus of elasticity using cements containing 35 and 21% GGBFS

Prediction of modulus of elasticity

Table 1 in SANS 10100 presents the relationship between compressive strength of concrete and modulus of elasticity. The values in the table were derived from:

$$E_{c28} = K_o + 0.2\, f_{cu,\,28}$$

where:

E_{c28} = static modulus of elasticity at 28 days
$f_{cu,\,28}$ = characteristic cube strength, MPa
K_o = a constant closely related to the modulus of elasticity of the aggregate (taken as 20 kN/mm^2 for normal-density concrete)

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This approach was adopted from BS 8110-2. Alexander et al adapted the equation for South African aggregate based on a comprehensive study on AfriSam aggregates and their effects on modulus of elasticity:

$$E = K'_o + \alpha f_{cu}$$

where:

E = static modulus of elasticity at 28 days for particular age being considered, GPa

f_{cu} = characteristic cube strength, MPa, corresponding to the age considered

K'_0 = a constant related to the stiffness of the aggregate, GPa

α = a strength factor, also related to the aggregate characteristics, GPa/MPa

Table 38 shows recommended factors for K'_0 and α suitable for estimating E for design purposes for AfriSam Aggregates.

Kearsley confirmed the validity of the factors for K'_0 and α for concretes containing 21 and 35% GGBFS for most of the aggregate from the earlier mentioned sources. The difference between the modulus of elasticity calculated using the equation on the previous page and the factors recommended in Table 38, and the measured E-values are indicated in Figure 33 for concretes containing 35% GGBFS.

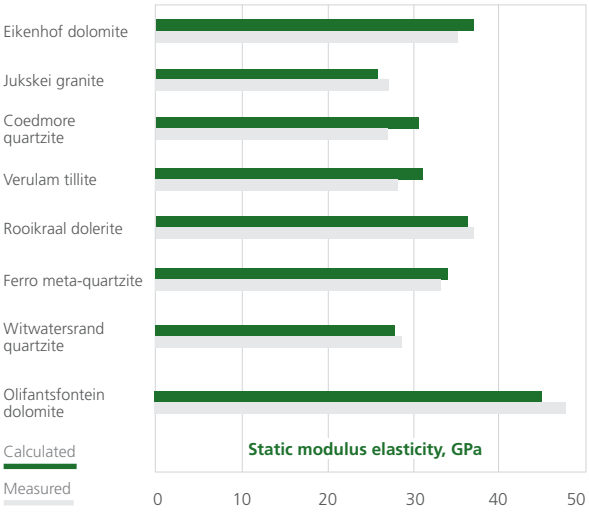


Figure 33: Measured vs calculated E for concretes with 35% GGBFS

Specification of modulus of elasticity

In structural applications where the accurate prediction of modulus of elasticity is critical, the engineer should consider the use of an AfriSam Aggregate with a known prediction factor.

For special design requirements, the engineer must take into account the properties of the aggregate type that is economically obtainable and where necessary verify the E-values of the concrete to be used.

See also *AfriSam Aggregate*.

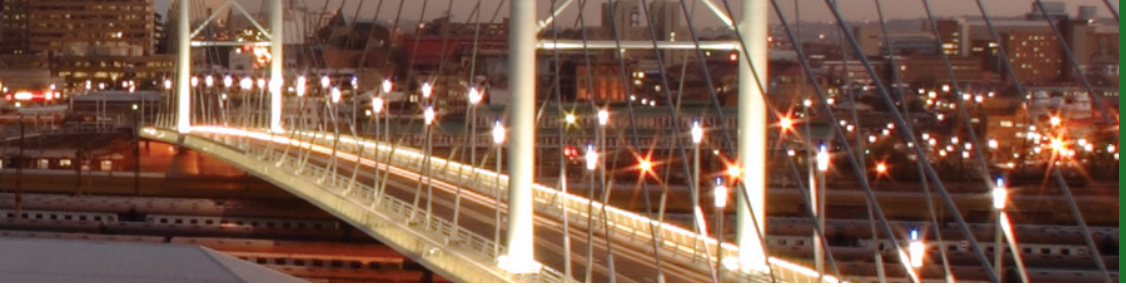


Table 38: Values for estimating E for design purposes

Aggregate source and type	Design value, 3 to 28 days		Design value, 6 months or older	
	K'_0	α	K'_0	α
Coedmore quartzite	19	0.3	30	0.15
Eikenhof dolomite	29	0.2	35	0.2
Ferro meta-quartzite	17	0.4	31	0.2
Jukskei granite	20	0.2	31	0.1
Ladysmith dolerite	20	0.4	37	0.2
Ladysmith siltstone	21	0.5	27	0.1
Newcastle dolerite	22	0.4	38	0.15
Olifantsfontein dolomite	24	0.45	41	0.25
Peninsula meta-greywacke	24	0.25	31	0.2
Pietermaritzburg dolerite	18	0.3	29	0.15
Rheebok granite	21	0.25	34	0.1
Umlaas Road tillite	20	0.35	29	0.2
Witwatersrand quartzite*	18	0.25	33	0.1
Zeekoewater felsite	23	0.3	27	0.25

**Witwatersrand quartzite = Reef quartzite*

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Deformation: **Thermal movement**

Thermal movement may be defined as the expansion or contraction of concrete due to changes in temperature. The coefficient of thermal expansion is the relationship between thermal movement measured in microstrain and change in temperature, measured in °C.

The importance of the thermal properties of concrete depends on the type of structure and on the degree of exposure to which the concrete is subjected. Thermal expansion influences the movements of joints in concrete structures and needs to be considered in joint design. This is of vital importance in structures that are subject to extreme temperatures.

The building of nuclear reactors has greatly increased research into the thermal behaviour of concrete at high temperatures. At the opposite extreme, South Africa has major cryogenic storage facilities with temperatures well below minus 100°C.

Factors influencing thermal movement

Aggregate type and moisture content of the concrete are the main factors affecting the thermal movement of concrete.

- **Aggregate type**
  The thermal performance of concrete is strongly influenced by that of the aggregate from which it is made. The coefficient of thermal expansion concrete using AfriSam Aggregates varies from 7 to 12 microstrain. In general, aggregate with high quartz content has the highest coefficient of thermal expansion and so do concretes made with quartzite. Andesites and dolerites have the lowest coefficients of expansion.

  Table 39 indicates the coefficients of thermal expansion for normal concretes made with AfriSam Aggregate. These values are recommended for design purposes.

  Generally the greater the aggregate volume, the lower the coefficient of thermal expansion. However, for aggregate volumes between 60 and 80% representing the normal range of concretes, aggregate volume is not significant.

Table 39: Coefficients of thermal expansion

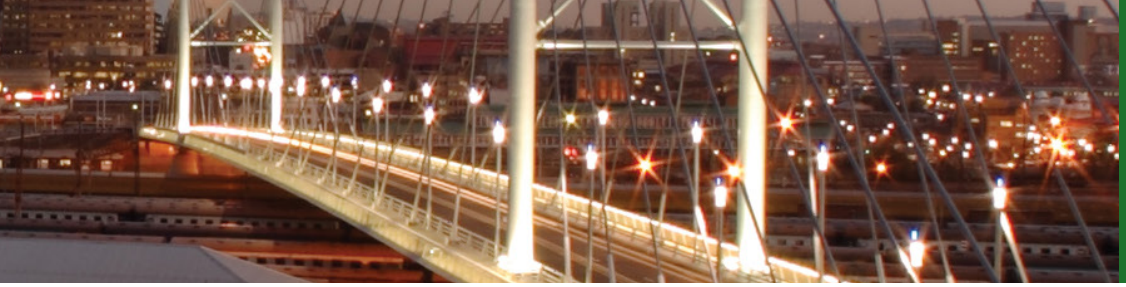
Aggregate source and type	Design value, 3 to 28 days
Coedmore quartzite	9.5
Eikenhof dolomite	9
Ferro meta-quartzite	11.9
Jukskei granite	8
Ladysmith dolerite	8
Ladysmith siltstone	7.5
Newcastle dolerite	7.5
Olifantsfontein dolomite	9
Peninsula meta-greywacke	10
Pietermaritzburg dolerite	7.5
Rheebok granite	9.5
Umlaas Road tillite	9
Witwatersrand quartzite*	11
Zeekoewater felsite	9

**Witwatersrand quartzite = Reef quartzite*

- **Moisture content of the concrete**
  Partially-moist concretes have coefficients of expansion considerably higher than completely dry or saturated concretes. The explanation of this lies in the thermal properties of the cement paste, with a maximum coefficient at some intermediate moisture content, and lower coefficients in both the saturated and the dry state.

  Some failures of concrete have been attributed to continued cycles of temperature changes, wetting, drying and setting up internal stresses between the aggregate and the paste. However, in general, most hardened concrete is able to resist severe exposure conditions to such cyclic variations.

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Deformation: **Drying shrinkage**

Drying shrinkage is the shortening of concrete elements with time due to the evaporation of water from the hardened cement paste.

Shrinkage is measured in terms of strain, which is defined as:

$$\alpha = \frac{\Delta \ell}{\ell}$$

where:

$\frac{\Delta \ell}{\ell}$ = change in length
ℓ = original length

Strain is dimensionless and is expressed in terms of microstrain or percentage: 1 000 microstrain or 0.1% represents a movement of 1mm per linear metre.

Drying shrinkage is a long-term process that typically occurs over a period of up to 30 years. The rate of shrinkage depends on the rate of drying, which is influenced by the volume-to-surface ratio of the concrete element and the drying environment. The potential shrinkage that may occur depends on mix materials and proportions.

Unrestrained shrinkage is generally not problematic. However, in most concrete structures shrinkage is restrained by stiff concrete walls or columns, adjacent concrete elements or by the ground. The concrete will crack to accommodate the movement, and deformation of the element will occur.

Structures must be designed to take into account and accommodate the movement that occurs as a result of shrinkage, creep, elastic and thermal strains.

Test methods

In South Africa, two test methods are used to determine potential drying shrinkage:

1. SANS 6085 initial drying and wetting expansion of concrete is based on drying concrete specimens at 50°C to 55°C, and at 15% to 25% relative humidity. The test takes approximately three weeks to complete and is terminated when two consecutive readings, taken at 48-hour intervals after an initial drying period of seven days, do not differ by more than 2µm per 100mm specimen.
2. An alternative natural drying test is also conducted by research facilities, usually performed in conjunction with creep tests. Concrete specimens are dried in a controlled environment of 65% ± 5% relative humidity and 22°C ± 2°C. The shrinkage movement is measured over a period of 60 days or longer.

This test is similar to shrinkage tests prescribed by the American Society of Testing and Material (ASTM C157/ C157 N–92) and the Australian Standard (AS 1012.13).

The interpretation of test results

SANS 10100-2 states that potential shrinkage may be determined by using SANS 6085.

However, a study initiated by AfriSam proved that this test is unable to account for the effect of different aggregate and cement types in concrete. Concretes made with different aggregate and cement types were tested in accordance with the shrinkage tests described above, and the results were compared. The natural drying test results were used as a basis of comparison because this concept is accepted internationally, both as an indication of structural performance and to calibrate prediction models used for long-term shrinkage prediction.

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The results of the comparison between the two test methods are presented in Figures 34 and 35. The results of SANS 6085 do not correspond to those of the natural drying tests, neither in terms of ranking the shrinkage performance of the concretes nor of relative shrinkage.

It is therefore recommended that the consultant takes care when using SANS 6085 to compare the shrinkage of different concretes or to predict the long-term shrinkage as the interpretation of the result may be problematic.

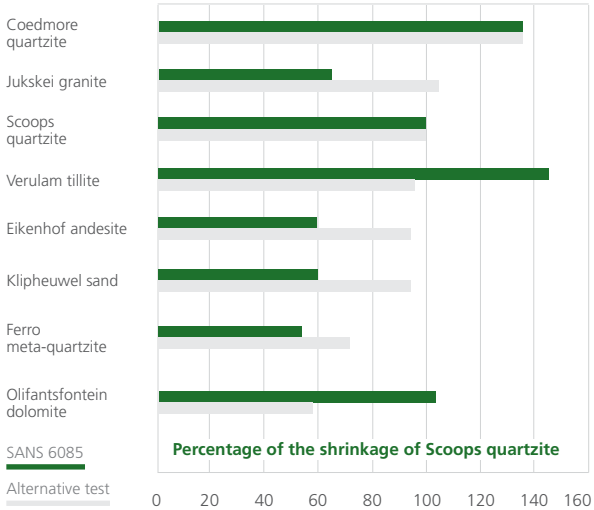


Figure 34: Relative shrinkage of concrete with aggregate from different sources

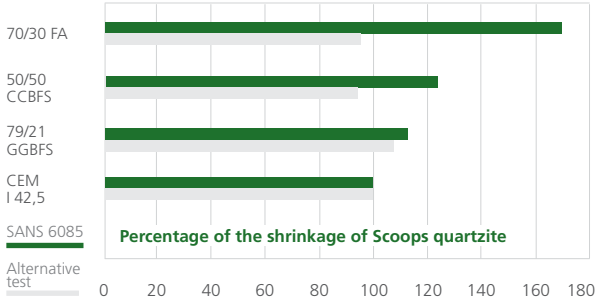


Figure 35: Relative shrinkage of concrete with different cements

Factors influencing shrinkage

Shrinkage is caused by drying, therefore factors that contribute to the drying of concrete such as relative humidity, size and shape of the concrete member will influence shrinkage.

Shrinkage is also influenced by the concrete mix proportions and materials.

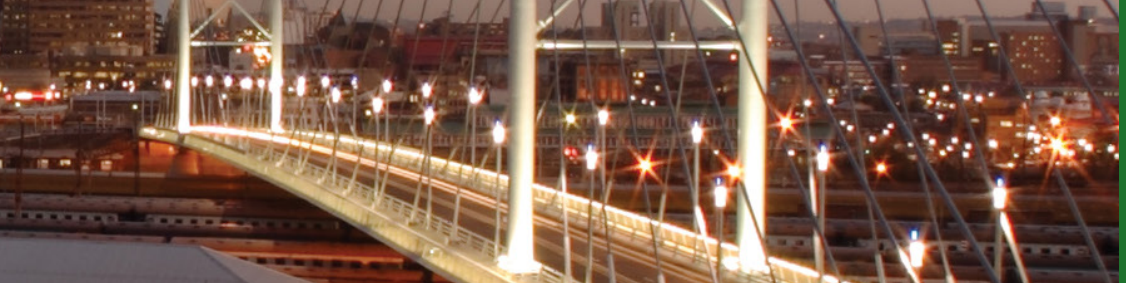
The following relates to the influence of AfriSam materials on potential drying shrinkage.

- **Aggregate type**
  AfriSam commissioned three different studies between 1994 and 2003 to assess the effect of aggregate from different AfriSam operations on concrete drying shrinkage. The results of these investigations are represented in Table 40 and graphically in Figure 36, expressed as a percentage of the shrinkage of Witwatersrand quartzite. This aggregate was chosen as a reference because the aggregate has been used in structural concrete for many years.

Table 40: Effect of aggregate type on drying shrinkage

Range	Aggregate type	Percentage of shrinkage in comparison with that of Witwatersrand quartzite
Lower than average	Ferro meta-quartzite Ladysmith dolerite Olifantsfontein dolomite Rooikraal dolerite	60 – 80
Average	Eikenhof andesite Jukskei granite Klipheuwel sand with meta-greywacke Newcastle dolerite Rheebok granite Verulam tillite Zeekoewater felsite	80 – 100
Higher than average	Coedmore quartzite Ladysmith siltstone Pietermaritzburg dolerite Umlaas Road tillite	100 and more

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Hardened Concrete

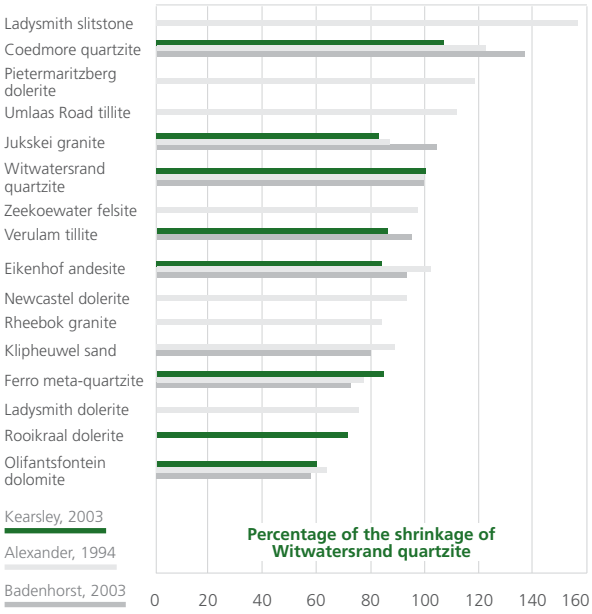


Figure 36: Performance of concrete with aggregate from different sources

> Klipheuwel sand was used as fine aggregate in conjunction with greywacke aggregate from AfriSam Peninsula.

The figure indicates that aggregate type has a significant influence on the shrinkage of concrete and that historical performance may be useful in predicting the potential shrinkage of concrete.

Although Coedmore quartzite and Ladysmith siltstone shrink more than average, concrete using these materials has been used successfully for all types of structures and a range of compressive strengths.

See *AfriSam Aggregate*.

- **Aggregate content**
  The total volume of aggregate in a mix is a significant factor in drying shrinkage. The higher the volume of aggregate, the lower the shrinkage. Figure 37 indicates the relationship between W/C, aggregate content and shrinkage.

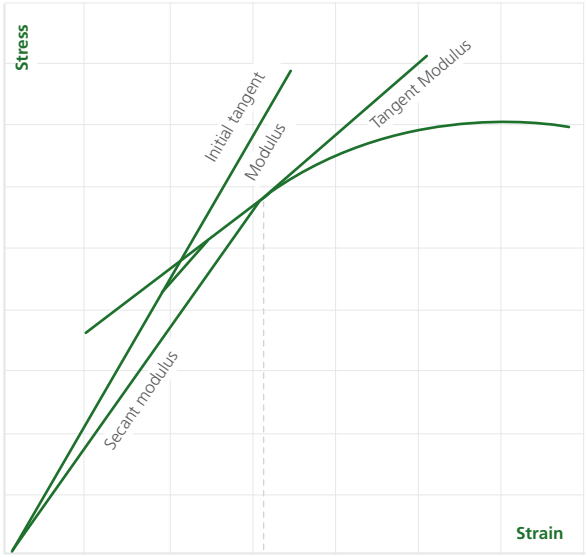


Figure 37: Effect of W/C and aggregate content on shrinkage

- **Cement type**
  Cement has less effect than aggregate type.

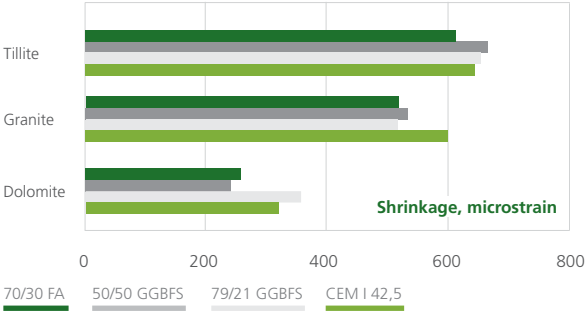


Figure 38: Influence of cement type and aggregate on shrinkage

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- **Water content**
  The effect of water content is illustrated in Figure 39. There is a general trend that an increase in water content results in an increase in shrinkage. However, there is a significant amount of scatter in the results between water contents of 180 litres/m³ to 190 litres/m³. On closer investigation of the aggregate types used in these concretes, it is clear that concretes with similar water contents may have significantly different shrinkage, depending on the aggregate type used.

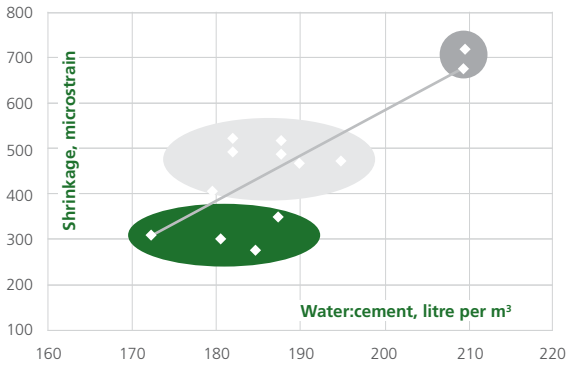


Figure 39: Shrinkage vs water content

Shrinkage prediction

Most South African designers refer to the prediction model described in the concrete design code SANS 10100-1 (adapted from BS 8110-1 design code) to predict long-term shrinkage. The code recommends consulting specialist literature for shrinkage prediction for highly shrinkage-sensitive structures.

The six month and 30-year shrinkages are determined from a nomogram that accounts for the effects of effective section thickness and ambient relative humidity (see *Figure 40*).

Effective section thickness for uniform sections is defined as twice the cross-sectional area divided by the exposed perimeter.

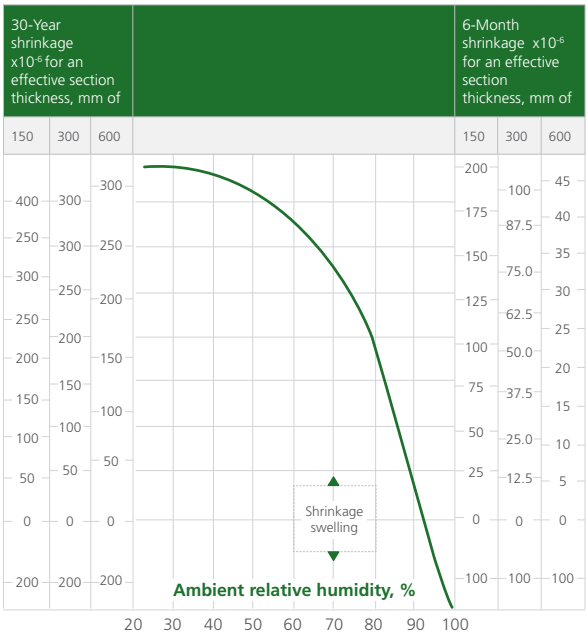


Figure 40: SANS 10100-1 shrinkage prediction

Note: The model is applicable to concrete of normal workability, made without water-reducing admixtures and an original water content of 190 litres/m³. Where concrete is known to have a different water content, shrinkage values are regarded as being proportional to the water content within a range of 150 litres/m³ to 230 litres/m³. The model does not account for the effect of aggregate type.

> SANS 10100 Parts 1 and 2 are currently under review with the intention of adopting EN 13670:2009 Execution of concrete structures (British Standard).

To improve shrinkage prediction, the adjustment factors shown in Table 41 may be used to take into account the effect of aggregate type.

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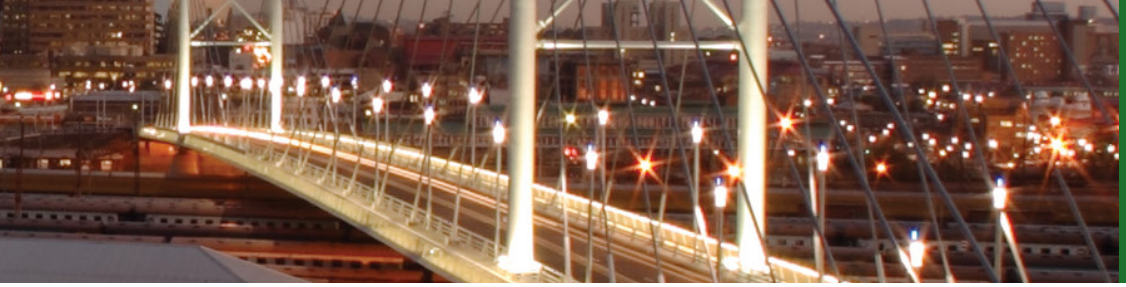


Table 41: Aggregate adjustment factor

Aggregate source	Adjustment factor, a_a
Coedmore quartzite	1.76
Eikenhof andesite	1.28
Ferro meta-quartzite	0.89
Jukskei granite	1.42
Klipheuwel sand; Peninsula meta-greywacke	1.17
Olifantsfontein dolomite	0.91
Verulam tillite	1.28

Adjustment factors were derived from two data sets, from samples dried for a relatively short drying period, i.e. 250 days.

Alternative prediction model

As an alternative to the model described above, the RILEM prediction model has proved to be more accurate than the SANS 10100-1 model, even without an adjustment for aggregate type. It is applicable for:

- Reinforced concrete beams, frames and slabs with spans under 20m.
- Plain concrete footings.
- Retaining walls.
- Prestressed beams or slabs of spans up to 20m.
- High rise frames up to 100m.

The model is restricted to concrete with the following parameters:

- Compressive strength between 17MPa and 70MPa.
- W/C between 0.35 and 0.85.
- Cement content between 160kg/m^3 and 720kg/m^3.

Furthermore, it is valid for concrete that is cured for at least one day. Model parameters were not developed for special concretes containing various admixtures or mineral components. However, if the model is calibrated with experimental data, it may be applied outside the ranges given.

Specification of shrinkage

The effects of excessive shrinkage may be detrimental to structural performance. Shrinkage limits for shrinkage-sensitive structures should be specified.

However, the use of performance-based specifications, where maximum limits of shrinkage in terms of microstrain or percentage are specified, is not recommended as verification in performance is problematic.

To limit the risk of excessive shrinkage for shrinkage-sensitive structures within economic sense, it is recommended that:

1. At concept design stage, the structural designer and the material specialist assess the shrinkage (and creep and modulus of elasticity) characteristics of the materials available in the project area.

2. The material specialist is vigilant in material selection. Aggregate type has a significant influence on the components influencing deformation. A reduction in the water content of a concrete mix or the blending of materials may assist in dealing with an aggregate source with high shrinkage potential.

3. Structural design and specifying engineers utilise the knowledge available relating to the hardened and time-dependent properties of different concretes, and allow for these in their design parameters.

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Deformation: **Creep**

The ability of concrete to creep imparts a degree of ductility to concrete that enables it to tolerate the normal range of structural deformations encountered in practice. Creep provides a structure with the ability to redistribute excessive stresses.

Without the ability to creep, concrete would simply be too brittle for use in the majority of structures. However, creep also may have detrimental effects such as increased deflection resulting in cracking, loss of prestress, and buckling of slender columns.

It is therefore important that the designer takes the necessary steps to allow for creep in the design of concrete structures.

Definition

Creep is defined as the increase in strain (deformation) under a sustained stress (load). When loaded, concrete experiences an instantaneous elastic strain, which is recoverable. In addition, an inelastic creep strain takes place that is only partially recoverable (see *Figure 41*).

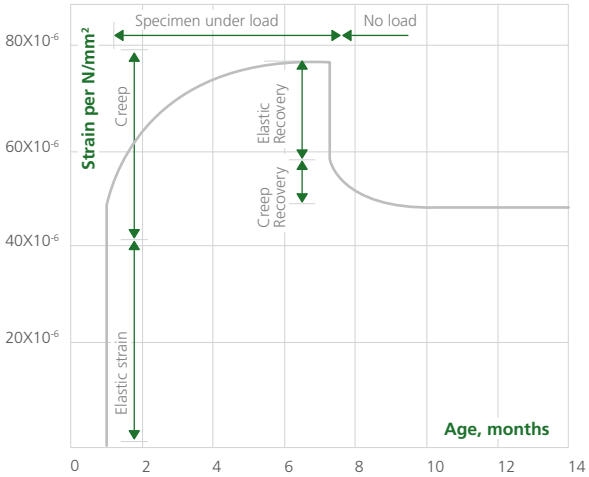


Figure 41: Typical strain vs time curve for concrete subjected to constant load followed by load removal

Creep consists of two components:

- **Basic creep**
  The creep that occurs under conditions where there is no drying.

- **Drying creep**
  The additional creep that occurs when the loaded concrete is drying.

To be able to compare the creep of concretes loaded to different stress levels and for computational purposes, the following expressions have been derived:

- **Specific creep C_c**
  Creep strain per unit ofapplied stress.

$$C_c = \frac{\varepsilon_c}{\alpha}$$

- **Creep factor or creep coefficient F**
  Defined as the creep strain divided by the initial elastic strain.

$$\Phi = \frac{\varepsilon_c}{\varepsilon_e}$$

where:

$$\varepsilon_e = \frac{\sigma}{E_t}$$

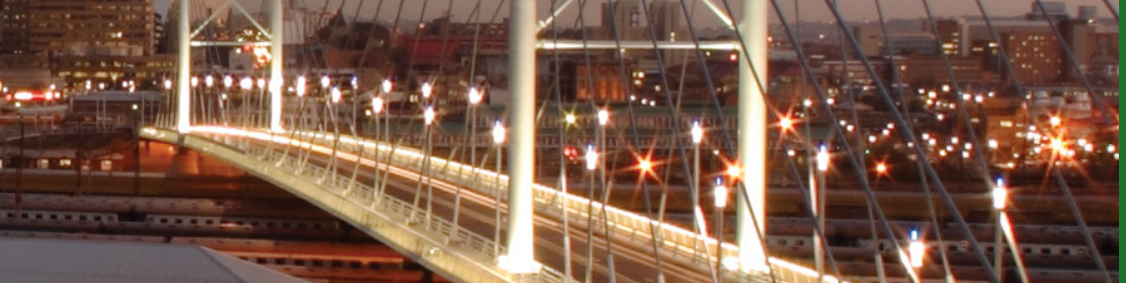
E_t is the elastic modulus of the concrete on loading, therefore:

$$\Phi = C_c E_t$$

Test methods

Creep is usually determined by measuring the change in strain with time of a specimen subjected to a constant stress and stored under appropriate conditions.

There are no South African or British standard test methods for testing creep. As several different forms of creep apparatus have been used by the Universities of Pretoria, Cape Town and the Witwatersrand to test the creep properties of different concretes, it is often difficult to compare the results of studies conducted at different times and at different testing facilities.



Factors influencing creep

Creep of concrete is load induced, and is influenced by factors associated with the application of load and the ability of the concrete to withstand the load.

The potential of the concrete to creep is determined by mix materials and proportions of the concrete. The cement paste creeps, and the role of the aggregate is to:

- Reduce creep by diluting the cement paste.
- Restrain creep by mechanical means.
- Stress:strength ratio.
- Creep is linearly proportional to the stress:strength ratio as shown in Figure 42.

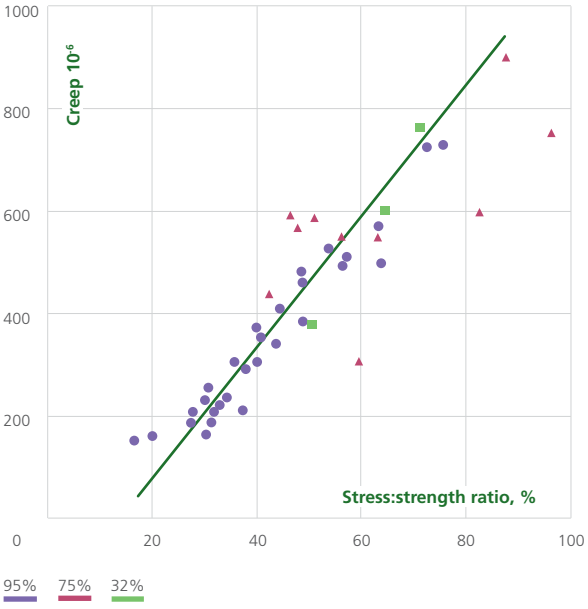


Figure 42: Relationship between applied stress and concrete strength

As an example, 45MPa concrete stressed at 15MPa would have approximately the same creep as 30MPa concrete stressed at 10MPa, provided the concretes have the same cement paste content.

- **Cement paste content**

  A 1% increase in cement paste by volume will result in approximately a 5% increase in creep. This is applicable for concretes with a cement paste volume of 28 to 40%.

  The cement paste volume is influenced by the aggregate content of the mix: the greater the aggregate content, the lower the cement paste content.

- **Cement type**

  The type of cement influences the strength development of concrete. A high stress:strain ratio could potentially result if the concrete is loaded at an early age and the cement has a slow rate of strength development.

  Kearsley characterised the specific creep (creep strain per unit applied stress) of concrete with AfriSam cements containing 21% and 35% GGBFS for different aggregate types, and has concluded that the higher GGBFS content resulted in slightly increased long-term creep (see *Figure 43*).

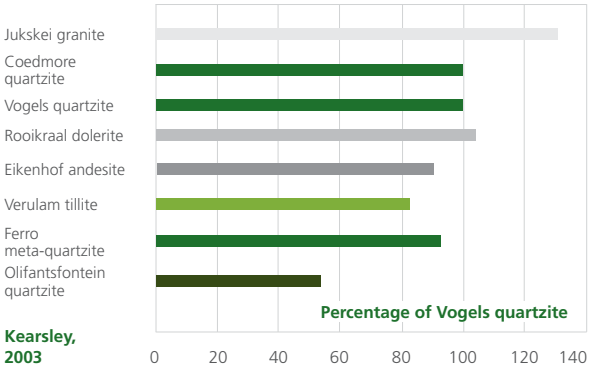


Figure 43: The effect of GGBFS on creep

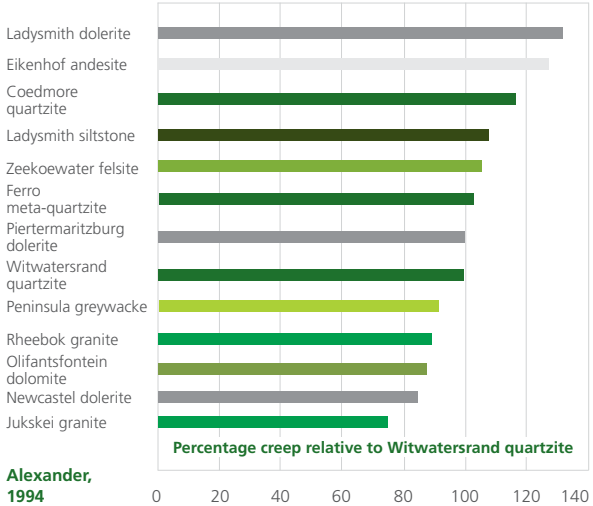
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- **Aggregate type**

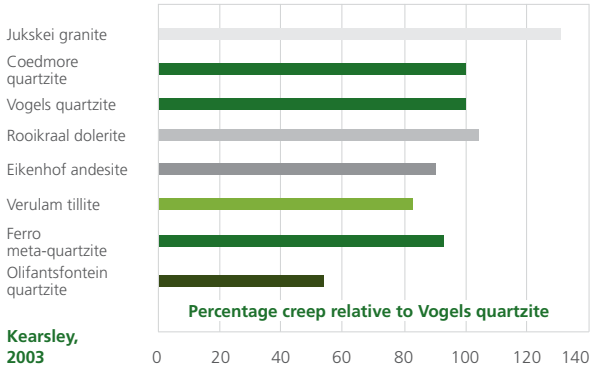
  The influence of AfriSam aggregate on the creep properties of concrete was determined by Alexander and Kearsley in separate studies.

  Both Alexander and Kearsley concluded that aggregate type has a significant effect on creep. However, the relative performance of different aggregate types differed in the two studies. Kearsley found that Olifantsfontein dolomite had the lowest creep and Jukskei granite the highest, whereas in the Alexander study Jukskei granite performed best and Ladysmith dolerite worst. The results are illustrated in Figures 44 and 45.



Alexander, 1994

Figure 44: Effect of aggregate



Kearsley, 2003

Figure 45: Effect of aggregate type on concrete containing 21 and 35% GGBFS (Olifantsfontein dolomite)

The difference in the results of the two studies may be attributed to:

- Differences in stress:strain ratios.
- Different ages at loading.
- Time period under load.
- The use of different cements.

Prediction of creep

Due to the complex nature of factors that influence creep, prediction is at best imperfect. Several different creep prediction models have been developed and are available.

Different types of structures require different levels of accuracy and therefore the designer should establish an appropriate prediction model based on the specific structural problem and the information available at design stage.

To incorporate the mix materials and proportions of concrete, the specific creep vs time curves obtained from long-term testing (conducted by Kearsley) or those shown in Figure 46 could be used to verify the accuracy of the prediction model selected.

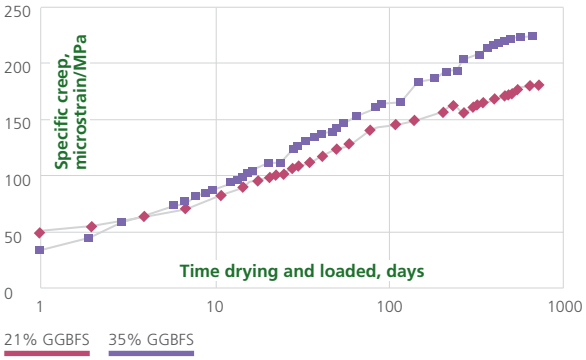


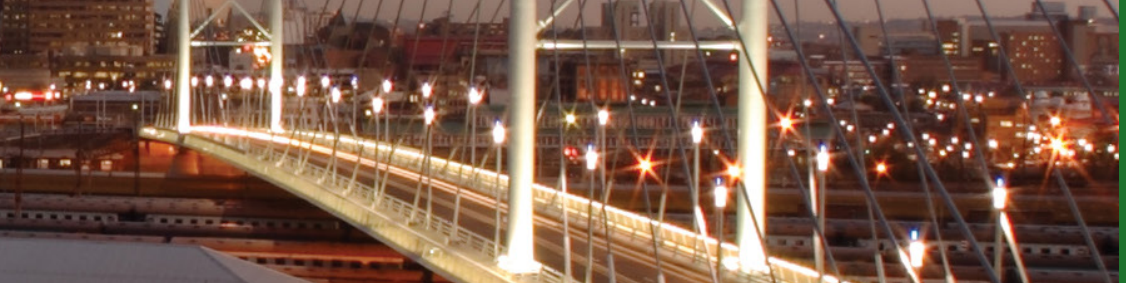
Figure 46: Specific creep vs time curve

Specification for creep

It is impractical to specify maximum limits for creep, as creep testing is a long-term process.

Long-term test results require careful interpretation and it is best to consult an expert in the field.

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Durability

The durability of a structure may be defined as the time period for which the structure can satisfactory fulfill the function for which it was designed and constructed.

Factors influencing durability

The following factors are of equal importance in influencing the durability of a concrete structure:

- Design and detailing of structural elements.
- Construction practices, workmanship and supervision.
- Concrete raw materials and mix proportions.
- The environment to which the concrete is exposed.

The achievement of structural durability requires rigorous attention to detail by the designer, contractor, supervisory engineer and materials engineer. Even if the highest possible grades of concrete are supplied, the structure will only be durable if good practice prevails in all phases of the building project.

To illustrate this point, a concrete structure in a marine environment, built of concrete with the potential to be dense in the hardened state, will only be durable if, at design and detailing stage, attention is paid to the following factors:

- To accurately predict cracking, concrete properties such as shrinkage and creep that are considered in the design relate to the properties of concrete materials available locally.
- Member shapes complicating concrete compaction and thin concrete sections are to be avoided.
- Ponding of water is prevented. Rain- and seawater is to drain away from the structure.
- No ingress of water may occur into joints.
- Correct curing times and methods are specified.
- Detail reinforcement to limit cracks and crack widths.
- Reinforcement is properly and simply detailed with the steel fixer in mind.
- Minimum cover can be achieved by allowing for reinforcement bending and shutter tolerances.
- Practical methods of concrete compaction are taken into account at design stage.
- Inclusions of embedded services, e.g. downpipes in the centre of concrete columns are taken into account.

In addition, concrete mix proportions and raw materials must be selected to ensure that:

- The slump of the concrete and maximum aggregate size is appropriate for the placement method and shutter arrangement.
- Bleeding is limited.
- No segregation occurs between aggregate and cement paste during placement.
- The mix is stable enough to limit grout loss.
- Workability is retained long enough for placement of concrete.
- Strength gain is acceptable for the type of application.
- Specified strength is achieved.
- Drying shrinkage and creep are not excessive.

Finally, during construction ensure that:

- The mixing process results in homogenous concrete.
- Placing and compaction of concrete achieves near-to-complete consolidation.
- Shutters are sealed to prevent grout loss.
- Cover to reinforcement is achieved within allowable tolerances.
- Concrete is adequately cured and protected, which means the loss of moisture from the concrete is prevented at all times while the concrete is hardening in its early life.

See also *Handling concrete on-site (Concrete).*

Concrete is durable when the movement of aggressive chemicals within its structure is minimised, i.e. the concrete must be dense and impervious, with minimal cracking.

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Deterioration of concrete

Concrete deteriorates with time due to one or more of the following factors:

- The ingress of chlorides, oxygen, water and carbon dioxide, resulting in corrosion of reinforcing steel with subsequent loss of load-bearing capacity and unsightly concrete spalling and cracking.
- Disruptive expansions that occur within the concrete due to reactions that take place between the alkalis in the cement and certain minerals in some aggregates.
- Sulphates normally present in ground water may attack the concrete. Depending on the concentration of sulphates and the permeability of concrete, sulphate attack may result in spalling and corrosion of reinforcement, internal cracking and strength reduction.
- Other forms of chemical attack.
- Wearing of the surface of the concrete due to abrasion, erosion or cavitation.

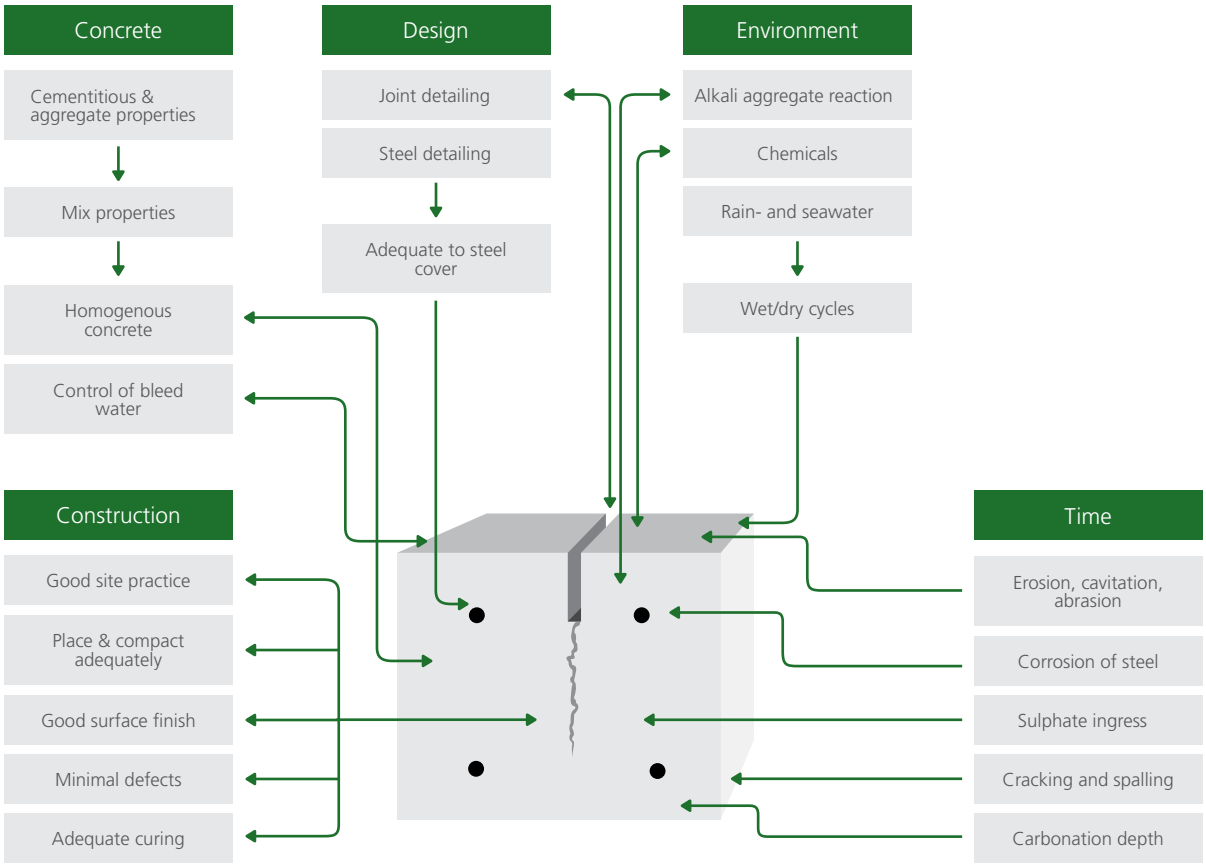
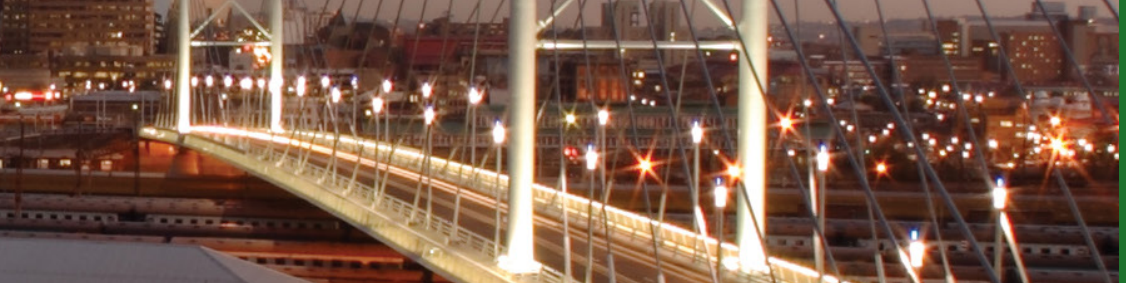


Figure 47: Schematic representation of factors affecting durability of concrete

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Durability: **Minimising the risk of corrosion**

Corrosion of reinforcing steel occurs when the protective layer of ferric oxide, which forms when reinforcing steel embedded in concrete (pH 12.5 to 13.5) is depassivated and sufficient oxygen and moisture are available to cause corrosion. Depassivation of the steel occurs due to:

- Carbonation: loss of alkalinity of the concrete, caused by the ingress of CO_2.
- Migration of ions (usually chloride) towards the surface of the embedded steel.

The risk of corrosion may be reduced by:

- Minimising the ingress of chlorides, carbon dioxide, water and oxygen into the concrete. These ions are transported into the concrete by diffusion, gas permeation or water penetration.
- Increasing the migration distance to the steel, ie providing adequate cover to steel.

Testing potential durability

The resistance of the concrete to ingress and transport of ions and molecules differs for concretes made with different cementitious materials and aggregate, and at different water:cement ratios. Resistance to ingress is improved by adequate compaction and curing.

Test methods have been developed to characterise the transport properties of concrete. In South Africa, three test methods developed by Alexander, Ballim, Mackechnie and Streicher are used to characterise oxygen permeability, water sorptivity and chloride conductivity of the outer (cover) layer of concrete. The results of the tests are expressed as index values.

These test results may be used to:

- Control the quality of site concrete.
- Optimise concrete mixes for durability.
- Specify durability based on performance.
- Predict long-term performance.

However, further research is required. AfriSam is, on an ongoing basis, actively involved in characterising our materials in terms of these tests. For more information contact the AfriSam Centre of Product Excellence.

Oxygen permeability

The D'Arcy coefficient of permeability is determined by placing 70mm diameter by 30mm thick oven-dried concrete samples (representing the cover layer of concrete) in a falling head permeameter (see *Figure 48*). The samples are obtained either from cubes made in the laboratory or cores drilled from structural elements.



Figure 48: Oxygen permeability test

The falling head permeameter applies an initial pressure to the concrete sample and allows the pressure to decay with time. The pressure decay with time is measured and is converted to a linear relationship between the logarithm of the ratio of pressure head vs time, from which the D'Arcy coefficient of permeability (k) is determined.

The coefficient of permeability (k) is a clumsy exponential number and therefore is simplified by defining the oxygen permeability index (OPI):

$$\text{OPI} = -\log_{10} k$$

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Water sorptivity

Through the action of capillary forces, fluid is drawn into porous, unsaturated material. The amount of water drawn into the concrete under capillary suction is determined by carrying out a water sorptivity test.

The test faces of oven-dried concrete samples, 70mm diameter by 30mm thick representing the cover layer of concrete, are placed in a few millimetres of water. The test face represents the side of the sample that would be exposed to wetting and drying cycles.

At regular intervals the specimens are removed from the water and the mass of water absorbed is determined by weighing the sample. Measurements are stopped before saturation is reached, and the concrete is then vacuum saturated in water to determine the effective porosity (see *Figure 49*).

A linear relationship exists between the mass of water absorbed and the square root of time. The sorptivity index is determined from the slope of the straight line produced.



Figure 49: Water sorptivity test apparatus

Chloride conductivity

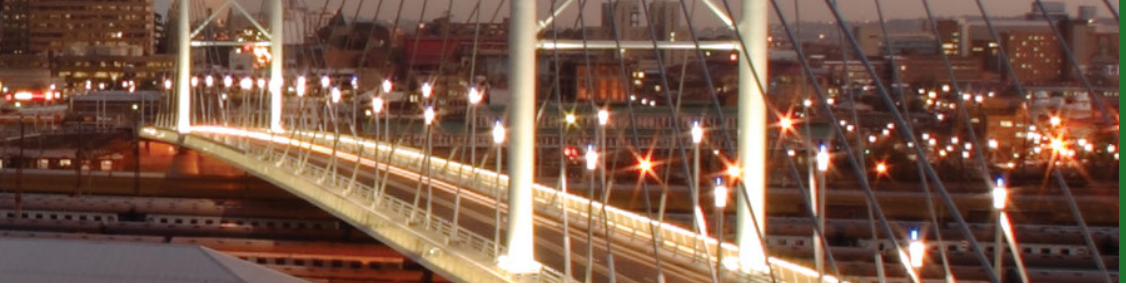
Diffusion is the process during which liquid, gas or ions move through porous material under the action of a concentration gradient. Diffusion occurs in partially or fully-saturated concrete and is an important transport mechanism for most concrete structures exposed to salts.

High surface salt concentrations are initially developed by absorption. This salt subsequently migrates by diffusion towards the low concentrations of the internal material.

The chloride conductivity test (see *Figure 50*) is an accelerated diffusion test using an applied potential difference to accelerate migration of chlorides in concrete to obtain quick results in the laboratory. Normally laboratory samples are tested. The results of the test are related to chloride ingress into the concrete.



Figure 50: Chloride conductivity test apparatus



Selection of materials to minimise corrosion

When specifying, selecting and producing concrete for potentially aggressive environments, the following factors should be taken into consideration:

- The environment to which the concrete is exposed.
- Locally available materials, including water.
- The construction method.
- The type of structure.
- Cement type: based on results of the durability tests described above, cement type has a significant influence on potential durability of concrete.
- Aggregate type, which could have a profound influence on permeability.

The use of composite cement with appropriate compressive strength reduces the probability of penetration of aggressive ions and molecules. Concretes containing Silica Fume (CSF) perform particularly well. CSF increases impermeability and GGBFS improves the chloride resistance of the concrete.

Figures 51 to 53 illustrate the relationship between compressive strength and durability indices for concrete with different mineral components.

Other important concrete properties to consider with regard to reinforcement corrosion are:

- Compressive strength.
- Bleeding.
- Drying shrinkage.

Bleeding channels and drying shrinkage cracks create potential pathways for harmful ions and molecules and may compromise the durability of a structure.

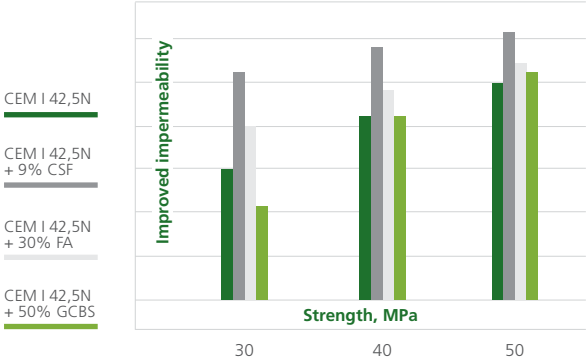


Figure 51: OPI vs strength

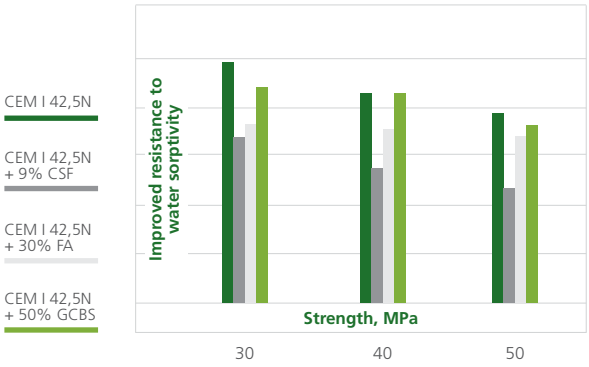


Figure 52: Sorptivity vs strength

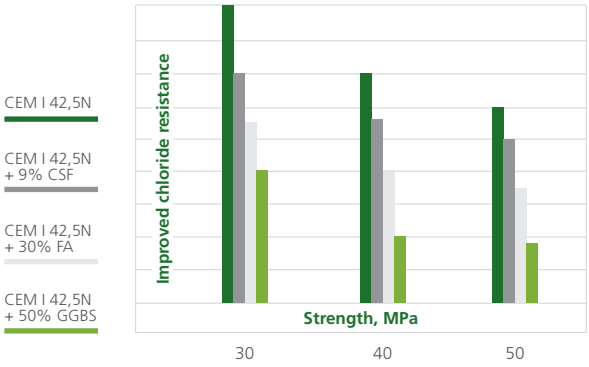


Figure 53: Chloride conductivity vs strength

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Specification of durability indices to minimise the risk of corrosion

Limits for durability index values indicated in Table 42 were suggested by Alexander et al to classify concrete in terms of durability, i.e. minimise corrosion of reinforcing steel. The minimum values were based on controlled laboratory studies and site data.

Table 42: Suggested ranges for durability classification

Durability class	OPI, log scale	Sorptivity, mm/-h	Conductivity, mS/cm
Excellent	>10	<6	<0.75
Good	9.5 - 10	6 -10	0.75 - 1.5
Poor	9 - 9.5	10 -15	1.50 - 2.5
Very poor	>9	>15	>2.5

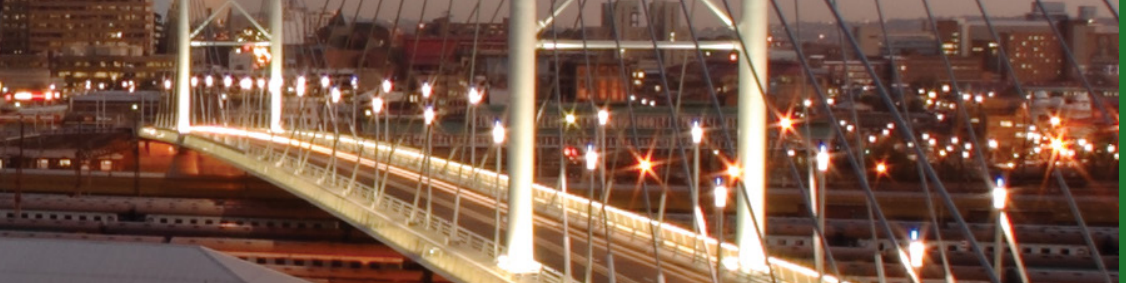
Durability requirements are generally project-specific, with minimum values for compliance given in the project specification.

Durability indices are not the only parameters that have to be considered when writing a specification to ensure durable concrete. Other equally important concrete parameters are drying shrinkage, creep and compressive strength and good construction practice. The optimisation of all these concrete parameters with the materials available in the area of construction is needed to ensure that the potential durability is achieved.

See also *Specialty products (Readymix)*.



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Durability: **Sulphate resistance**

Magnesium, calcium, sodium and potassium sulphates occur naturally in soil, groundwater, seawater, salt deposits, lakes and pans. Sulphates are also found where sulphur, sulphuric acid and sulphates are used and/or produced in industrial processes.

Concrete in contact with sulphate solutions deteriorates, because sulphates enter the concrete by diffusion and chemically alter the hydration products of the cement. New chemical compounds are formed, causing expansion which results in spalling, cracking and deterioration of the concrete.

Testing for sulphate resistance

Testing concrete to assess resistance against sulphate attack is done by submerging concrete prisms in high concentration sulphate solutions and determining the loss in mass with time. This is a long and cumbersome exercise, and the results give only a relative indication of the resistance of different concretes.

Factors influencing sulphate attack

The environment

Environmental factors that influence the severity of sulphate attack on concrete include:

- **The concentration and nature of the sulphate present**
  Magnesium sulphate at a concentration of less than 0.5% is more detrimental than sodium sulphate. However, at a concentration of 5%, the effect of both sulphates is similar.

- **The level of the water table and seasonal variation**
  Concrete permanently submerged in a sulphate solution is less at risk than concrete subjected to wetting and drying cycles.

- **The flow of groundwater and soil porosity**
  The sulphate content of the soil (contained in the soil or draining from it) is important in maintaining or increasing the sulphate content of the groundwater. Groundwater sulphate content can be determined by analytical methods conducted by an accredited laboratory.

The concrete

Where sulphates cannot be prevented from reaching the structure, the actual concrete must withstand sulphate attack.

Based on trials and field experience in the United States and the United Kingdom, the following factors affect the ability of concrete to withstand attack:

- **Cement type**
  Sulphate-resistant cement or cement containing GGBFS and Fly Ash will help give durable structures in conditions of moderate severity, but none of these cements are immune from attack in low-quality concrete.

- **Chemical composition of the cement**
  The C_3A content of the cement influences the resistance of concrete to sulphate attack. Cements with lower C_3A contents are more resistant than cements with high C_3A content, and BS 4027 specifies a maximum C_3A content of 3.5%.

- **Use of composite cement**
  In South Africa, cements containing high-quality FA are used to produce concrete immune to sulphate attack. GGBFS is less effective than FA, and replacement levels must be at least 70% before any significant sulphate resistance is imparted.

- **Cement content**
  The higher the cement content, the more resistant the concrete is to attack. Requirements for specific minimum cement content depend on the concentration of sulphates and the type of cement.

- **Concrete quality**
  To effectively resist sulphate attack, concrete must be fully compacted and properly cured.

See *Concrete*.

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Specification of sulphate-resisting concrete

Once the severity of (potential) exposure has been established, an appropriate prescriptive specification for sulphate-resistant concrete can be put in place.

The specification should refer to five critical components:

1. Cement type.
2. Minimum cementitious contents.
3. Water:cement ratio.
4. Adequate curing of concrete.
5. Adequate monitoring of concrete strength.

Construction in sulphate environments

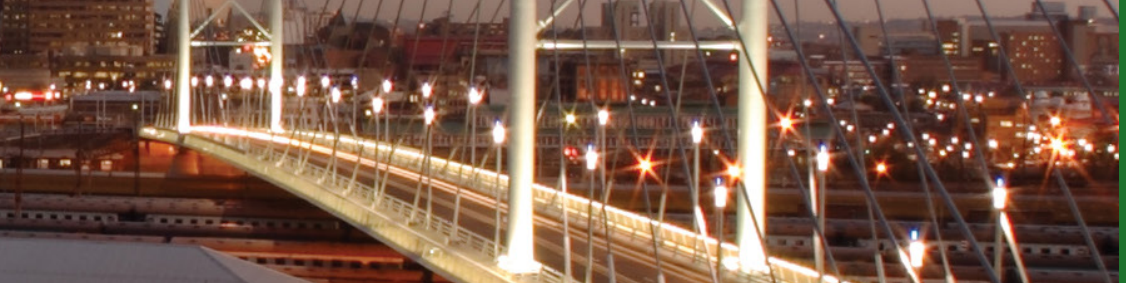
In addition to specifying appropriate parameters for concrete construction in sulphate environments, take the following precautions:

- Drain water away from the structure.
- Avoid thin concrete sections.
- Provide at least 75mm cover to all reinforcing.

Table 43: Specification of cementitious material available in South Africa for sulphate-resistant concrete, based on recommendations of BS EN 1992-2

Class	Concentration of sulphates expressed as SO_3			Type of cement	Requirements for dense fully compacted concretes	
	In soil				Minimum cement content, kg/m³	Maximum free w:c ratio
	Total SO_3	SO_3 in 2:1 water:soil extract, g/L	In groundwater, g/L			
1	<0.2	<0.1	<0.3	CEM I Plain concrete	250	0.7
				CEM I Reinforced concrete	300	0.6
2	0.2 - 0.5	1.0 - 1.9	0.3 - 1.2	CEM II B-V	330	0.5
					310	0.55
3	0.5 - 1	1.9 - 3.1	1.2 - 2.5	Cement combinations containing 70% min or 90% max GGBFS, or 25% min and 40% max FA	380	0.45
4	1 - 2	3.1 - 5.6	2.5 - 5	Cement containing at least 50% FA	330	0.5
					370	0.45
5	>2	>5.6	>5	Cement containing at least 50% FA with a protective coating	370	0.45

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Durability: **Alkali-aggregate reaction**

Alkali-aggregate reaction (AAR) is the disruptive expansion and cracking that may occur in concrete as a result of reaction taking place between alkalis and aggregate.

Deterioration of the concrete takes place only when all three of the following adverse conditions exist:

- Sufficient alkalis are present in the mix.
- The aggregate is potentially deleteriously reactive.
- Environmental conditions promote the reaction, eg water is present.

AAR is also known as Alkali-silica reaction (ASR).

> At a pH of <13, potential for AAR is zero even if all of the above conditions exist.
>
> With the introduction of composite cements containing GGBFS and FA, the risk of AAR is significantly reduced, regardless of the type of aggregate used in concrete.

Diagnosis of AAR

Indications that AAR may have occurred in concrete are:

- **Expansion**
  Closure of expansion joints, spalling, off-setting and warping of structural members and pavements are evidence that expansion has taken place.

- **Cracking**
  The most obvious manifestation of the reaction. Unrestrained concrete typically shows map-pattern cracking. Cracks in columns tend to run vertically, and cracks in retaining walls horizontally.

- **Presence of gel**
  Drops of resinous gel may be observed on concrete surfaces.

- **Discolouration**
  Dark discolouration giving the impression of permanent dampness is commonly observed along the edges of cracks. Light-coloured zones may also border cracks.

- **Dampness**
  Damp patches on the surface are sometimes seen.

If AAR has been confirmed, it is necessary to evaluate both the ability of the structure to withstand load, and the potential serviceability and durability of the structure. Expert advice should be obtained to determine the severity of the problem.

Factors influencing AAR

The following factors may influence the potential for AAR:

- **Alkali content**
  The total amount of alkalis present in concrete will determine the severity of the reaction.

  Cement contains soluble alkali salts that enter the pore solution very early in the hydration process, and these alkali hydroxides are available to participate in AAR. Although cement is the predominant source of alkalis, reactivity of a particular mix is actually dependent on the alkali content of the concrete, rather than just that of the cement component. Studies carried out indicate that expansion does not usually occur, even with a potentially reactive combination and in the presence of moisture, unless the concrete alkali content and the soluble or reactive alkali component of cement exceeds 3kg/m^3.

  Concrete mixes containing more than 350kg/m^3 may be more likely to cause expansion when used in combination with reactive aggregate.

  The alkali content of cementitious materials is indicated in terms of Na_2O equivalent, i.e. % Na_2O + (0.658 x % K_2O). When the Na_2O equivalent is higher than a fairly arbitrary figure of 0.6%, disruptive expansion may occur, provided that the other contributing factors are present.

  Values for alkali content indicated in Table 44 apply to AfriSam cements; the values should not be universally applied to other similar cement types from other sources. Note that these figures are total alkali contents; the soluble or reactive alkali component may be considerably lower.



AfriSam composite cements in the 32,5 and 42,5 strength classes contain mineral components (GGBFS, FA or limestone). These cements have significantly lower reactive alkali content than CEM I cements.

Table 44: AfriSam cements total Na_2O equivalent, averaged over January to December 2012

Cement operation	RHC, %	SHC, %	APC, %	EBC, %
Brakpan	0.43	0.53	0.56	-
Dudfield	0.47	0.48	0.56	-
Roodepoort	0.47	0.51	0.58	0.71
Swaziland	-	0.62	0.59	-
Ulco	-		0.60	-

- **Admixtures**
  Chemical admixtures may also contribute to the total alkali content in concrete. Consult the suppliers to obtain the Na_2O equivalent for their products.

- **Aggregate**
  Most AfriSam Aggregate products are not deleteriously reactive. Aggregate from some operations was assessed by the CSIR National Building Research Institute as only potentially reactive (see *Table 45*). However, even potentially reactive aggregate can safely be used in most circumstances without any special precautions.

  Certain preventive measures may be required only when the cement content of the proposed concrete is high and the environmental conditions are poor.

  Table 45 applies to aggregate from the sources indicated and should not be universally applied.

Concrete that is well-protected and dry, may be used with any aggregate complying with SANS specifications regardless of the alkali content of the mix.

Table 45: Reactivity of AfriSam Aggregate

Aggregate source and type	Reactivity potential
Coedmore quartzite	Not deleteriously reactive
Eikenhof andesite	
Ferro meta-quartzite	
Jukskei granite	
Olifantsfontein dolomite	
Pietermaritzburg dolerite	
Rheebok granite	
Zeekoewater felsite	
Peninsula meta-greywacke	Potentially deleteriously reactive at an alkali content of 2.1kg Na_2O equivalent/m^3 of concrete

The CSIR made the following general recommendations for Na_2O equivalent/m^3 of concrete for potentially reactive aggregate from different sources to ensure a conservative margin of safety:

- Quartzites of the Table Mountain group (Cape Supergroup) in Natal are not all non-reactive. Use a value of 2.8kg Na_2O equivalent/m^3 of concrete.

- All Witwatersrand Supergroup quartzites should be regarded as suspect. Use a value of 2kg Na_2O equivalent/m^3 of concrete.

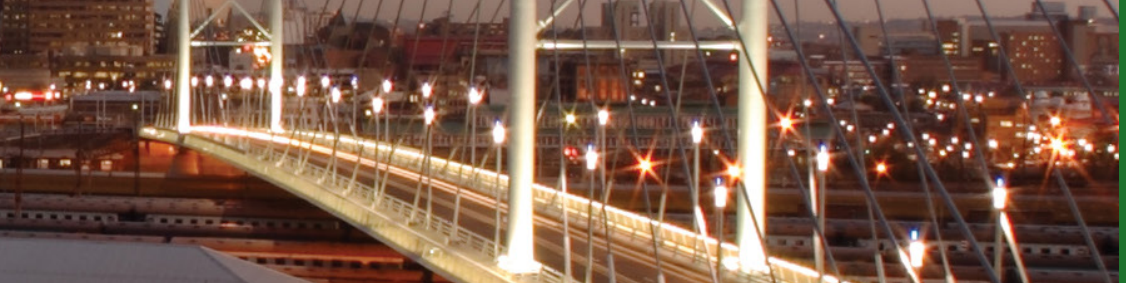
- All Malmesbury Shales/Hornfels/Meta-greywackes in the Western Cape should be regarded as suspect.

- Granites of the Cape Granite Suite are not all non-reactive. Use a value of 4kg Na_2O equivalent/m^3 of concrete.

- **Environment**
  Concrete structures exposed to fluctuating conditions of moisture content and temperature, continual dampness or continuous cycles of wetting and drying over a long period are vulnerable to AAR.

  It has been suggested that the relative humidity of concrete must be in excess of 75% or 85% for deleterious reaction to occur.

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Minimising the risk of AAR

In considering the possibility of alkali aggregate reactivity, see *Figure 54*. The following steps will assist the user in choosing materials for concrete.

- **Calculating alkali content**
  Alkali content/m³ of concrete, contributed by cement =

$$\frac{\text{Cement content of concrete, kg/m}^3 \times \text{Na}_2\text{O equivalent of cement}}{100}$$

Example 1: Calculation of alkalis for concrete with AfriSam All Purpose Cement ex Roodepoort

- The Na_2O equivalent of AfriSam All Purpose Cement ex Roodepoort is 0.58% (see *Table 44*).
- The cement content for normal structural concrete is generally between 270kg/m³ and 380kg/m³, so assume a cement content of 380kg/m³.

Alkali content from above equation =

$$\frac{380 \times 0.58}{100}$$

$= 2.2\text{kg/m}^3$

Assuming that the cement is the only contributor to alkalis in the concrete mix, this cement may be used with aggregate from any AfriSam Aggregate operation as the concrete alkali content is below the 3kg/m³ threshold.

Example 2: Calculation of maximum cement content for concrete with AfriSam High Strength Cement and AfriSam Witwatersrand quartzite

- The Na_2O equivalent of AfriSam High Strength Cement ex Swaziland is 0.51% (see *Table 44*).
- Witwatersrand quartzite is potentially reactive at an alkali content of 2.4 Na_2O equivalent kg/m³.

Therefore:

$$\text{Cement content} = \frac{\text{Alkali content/m}^3 \times 100}{\text{Na}_2\text{O equivalent}}$$

$$= \frac{2.4 \times 100}{0.51}$$

$= 471\text{kg/m}^3$

This cement content is above that normally used in concrete, therefore no deleterious reaction would be expected. If the cement content was higher or the concrete was subjected to moisture, the use of FA would be recommended.

Specifying cement to prevent AAR

To prevent deleterious expansion when using alkali-reactive aggregate, the cementitious binder should contain a minimum of the following materials, by mass:

- 40% GGBFS, or
- 20% FA, or
- 15% CSF.

If the Na_2O equivalent of the CEM I portion of the cement exceeds 1%, the extender content should be increased to 50% GGBFS or 30% FA.

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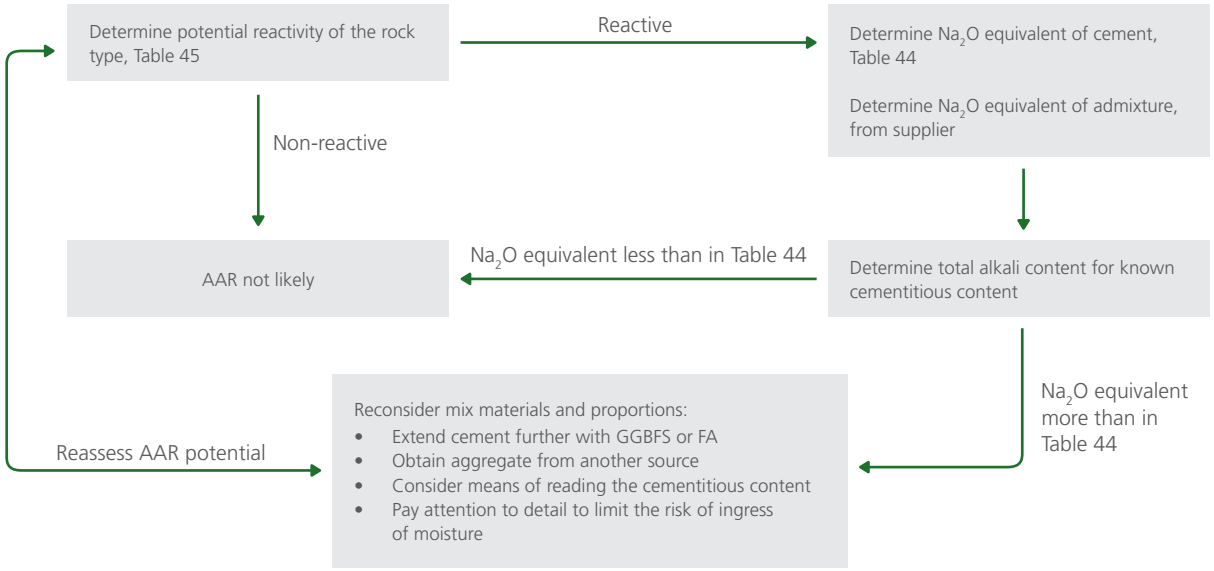


Figure 54: Assessing materials

Durability: **Resistance to acid attack**

All concretes are vulnerable to varying degrees to attack by acids. Acids erode the surface of the concrete by dissolving the cement paste and calcareous aggregates (if these are used). In general, the higher the concentration of acid, the greater the degree of attack.

It is generally recommended that GGBFS- and FA-cements are used in applications where concrete is subject to acid attack. However, in a review of concrete behaviour in acidic soils and groundwater, it was found that the quality of the concrete was more important than the type of cement used.

Specifications for concrete exposed to acid attack refer to minimum cement contents, maximum W/C, adequacy of curing and quality control measures.

See also *Sulphate resistance*.

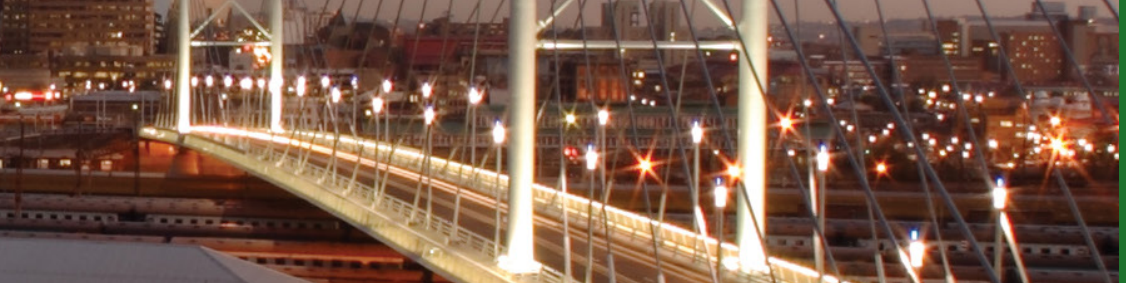
Recommended cement contents are between 320kg/m^3 to 400kg/m^3 and maximum W/C should be 0.4 to 0.5, depending on the aggressiveness of the acid.

However, these measures alone may not ensure the durability of the concrete. Depending on the cost and the required enhancement of service life, other measures may include:

- **Surface protection**
  The surface of the concrete can be protected either by using a coating or by providing a waterproof barrier. Common coatings include rubberised bitumen emulsions and epoxy resins.

- **Sacrificial layer**
  This involves providing an additional layer of concrete that can be attacked by the acids present without sacrificing structural integrity. This layer is in addition to the nominal cover to reinforcement, i.e. additional to the minimum cover plus the margin for site workmanship.

  Sacrificial layers can be up to 50mm in depth, depending on the potential severity of attack and the intended service life.



Applicable specifications

BS EN 1992-1-1 2004: Structural use of concrete
Part 1: Code of practice for design and construction
Part 2: Code of practice for special circumstances
(replaces BS 8110)
BS 4027:1996: Specification for sulfate resisting Portland cement
SANS 2001-CCI:2012: Construction works Part CC1: Concrete works (structural)
SANS 10100-1:2000: The structural use of concrete
Part 1: Design
SANS 10100-2:1995: The structural use of concrete
Part 2: Materials and execution of work

Test methods

AS 1012.13-1992/AMDT 1-1993: Methods of testing concrete – Determination of the drying shrinkage of concrete for samples prepared in the field or in the laboratory
ASTM C157/C157N-92: Standard test method for length change of hardened hydraulic-cement mortar and concrete
ASTM C469/C469-10: Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression
BS 1881-121:1983: Testing concrete. Method for determination of static modulus of elasticity in compression
SANS 6085:2006: Concrete tests – Initial drying shrinkage and wetting expansion of concrete

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References



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Click to return to contents page.

References

Websites

AfriSam (South Africa) (Pty) Ltd
www.afrisam.com

Aggregate and Sand Producers Association of South Africa (ASPASA)
www.aspasa.co.za

American Concrete Institute (ACI)
www.concrete.org

American Concrete Pavement Association (ACPA)
www.acpa.org

Association of Cementitious Materials Producers (ACMP)
www.acmp.co.za

British Cement Association (BCA)
www.concretecentre.com

Building Research Establishment (BRE) UK
www.bre.co.uk

Cement and Concrete Association of New Zealand (CCANZ)
www.cca.org.nz

Committee of Land Transport Officials (COLTO), South African Institution of Civil Engineers
www.civils.org.za

Concrete Manufacturers Association (CMA)
www.cma.org.za

Concrete Society of South Africa
www.concretesociety.co.za

Concrete Society UK
www.concrete.uk

Consulting Engineers of South Africa (CESA)
www.saace.co.za

Council for Scientific and Industrial Research (CSIR)
www.csir.co.za

Engineering Council of SA
www.ecsa.co.za

German Cement Works Association (VDZ)
www.vdz-online.de

Institute of Concrete Technology UK (ICT)
ict.concrete.org.uk

National Home Buildings Registration Council (NHBRC)
www.nhbrc.org.za

Portland Cement Association (PCA)
www.cement.org

SA Institute of Architects (SAIA)
www.saia.org.za

South African Bureau of Standards (SABS)
www.sabs.co.za

South African Post Tensioning Association (SAPTA)
www.sapta.co.za

South African Readymix Association (SARMA)
www.sarma.co.za

South African Reinforced Concrete Engineers Association (SARCEA)
www.sarcea.co.za

The Concrete Centre UK
www.concretecentre.com

The Concrete Institute
www.theconcreteinstitute.org.za

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Abbreviations

A	
AAR	Alkali aggregate reaction
ACF	Asphalt continuously graded fine
ACI	American Cement Institute
ACM	Asphalt continuously graded medium
ACMP	Association of Cementitious Materials Producers
ACV	Aggregate crushing value
AFRs	Alternative fuels and resources
ALD	Average least dimension
APC	All Purpose Cement
ASPASA	Aggregate and Sand Producers Association of South Africa
ASR	Alkali silica reaction
ASTM	American Association for Testing and Materials
B	
B-BBEE	Broad-based Black Economic Empowerment
BRAC	Bitumen rubber asphalt course
BRASO	Bitumen rubber asphalt semi-open
BS	British Standards
BTB	Bitumen treated base
C	
CBD	Compacted bulk density
CBR	California bearing ratio
CEN	European Committee for Standardisation
COLTO	Committee of Land Transport Officials
CO_2	Carbon dioxide
CO_2e	Carbon dioxide emissions

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CPE	Centre of Product Excellence
CSF	Condensed Silica Fume
CSI	Cement Sector Initiative
CSH	Calcium silicate hydrate
CSIR	Council for Scientific and Industrial Research
CSR	Coarse sand ratio
CSR	Corporate social responsibility

D

DCP	Dynamic cone penetration
DI	Durability index
DIY	Do-it-yourself
DME	Department of Minerals and Energy

E

E	Modulus of elasticity
EBC	Eco Building Cement
EC	European Commission
EC	Electrical conductivity

F

FA	Fly Ash
FACT	10% Fines aggregate crushing test
FEL	Front-end loader
FM	Fineness modulus

G

GGBFS	Ground granulated blast furnace slag

H

HSC	High Strength Cement
HR-WR	High range water reducer

I

ISO	International Standards Association

L

LAMBS	Large aggregate mixes for bases and surfaces
LOI	Loss on ignition

M

MDD	Maximum dry density
MPa	Megapascal
MSA	Monosulphoaluminate

N

NBI	National Business Institute
NQF	National qualifications framework

O

OHSAS	Occupational Health and Safety Association
OPI	Oxygen permeability index

P

PBFC	Portland blastfurnace slag
PC	Portland cement
PCB	Polychlorinated Biphenyls
PI	Plasticity index
PSV	Polished stone value

R

RD	Relative density
RHC	Rapid Hard Cement

S

SABS	South African Bureau of Standards
SANAS	South African National Accreditation Service
SANS	South African National Standard
SEM	Scanning electron microscope
SCC	Self-compacting concrete
SD	Standard deviation
SGS	Societe Generale de Surveillance
SP	Superplasticiser

T

TEA	Triethanolamine
TSA	Tri-sulphoaluminate
TSAF	Tri-sulpho-alumino-ferrite
TCI	The Concrete Institute

U

UNISA	University of South Africa
UPV	Ultrasonic pulse velocity

W

W/C	Water:cement ratio
WBCSD	World Business Council for Sustainable Development
WESSA	Wildlife and Environment Society of South Africa
WRI	World Resources Institute
WWF-SA	World Wildlife Foundation of South Africa

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Portland cement

Material Safety Data Sheet (91/155/EEC)

1. Identification of preparation and company

Preparation name:	Portland cement (synonym: Cement)
Normal use:	Hydrating binder for concrete, mortar and plaster
Company registered name:	AfriSam (South Africa) (Pty) Ltd
Address:	Constantia Park, cnr 14th Ave and Hendrik Potgieter Rd, Roodepoort, Gauteng
Telephone:	011 670 5500

The product includes five main types of cement:

- CEM I Portland cement
- CEM II Portland-composite cement
- CEM III Portland blastfurnace cement
- CEM IV Pozzolanic cement
- CEM V Composite cement

2. Information on ingredients

(Chemical formula:) Tri and di-calcium silicate.

3. Hazard identification

UN no.: None
Hazchem code: Awaited
NIOSH no.: W8770000 (RTECS)

4. First-aid measures

Inhalation: Remove person to fresh air.
Contact with eyes: Wash with large volumes of water. Seek medical attention.
Contact with skin: Wash with water and non-sensitising soap.
Ingestion: If ingested, drink plenty of water and consult a doctor immediately. Do not induce vomiting.

5. Fire-fighting measures

Non-flammable.

6. Measures to be taken in the event of accidental spillage

Safety precautions: Consult the safety measures listed under sections 7 and 8.
Environmental safety precautions: Prevent any material entering drains or waterways.

7. Handling and storage

Standard regulations relating to storage premises and to sites where the product is handled and used.

8. Exposure control – personal safety

Personnel shall wear standard PPE, including gloves.

- **Inhalation:** Demarcate dust area with zebra lines. Wear dust masks where TLV is exceeded in line with SANS 1455 and Govt Gazette 1200 of 22/10/89.
- **Eyes:** Wear fully-sealing eye protection. Optional eye and dust shields.
- **Skin:** Wear gloves and long sleeves preventing skin contact with product, and preventing undue perspiration.
- **Ingestion:** Do not eat in area exposed to cement. Ingestion in harmful quantities unlikely to occur.

9. Physical and chemical properties

Appearance	Fine grey powder
Maximum particle size	0,1mm
Density	2.3kg/litre to 3.8kg/litre
Specific gravity and angle of repose	Dependent on amount of air in the material
Mobility	Readily air-entrained
Solubility in water	Negligible, but sticky when wet
Melting point	1 500°C
Molecular weight	Variable
Alkalinity	pH 10 to 12

10. Stability and reactivity

The preparation is unstable. Avoid contamination with other materials which may render the product useless as a binding agent. The surface of cement exposed to air may harden to form a crust. Cement will dissolve slowly in acidic conditions. Store bags off the ground on pallets in weatherproof shed. Shelf-life bags: 3 months. Discard cement with lumps that cannot be broken easily by hand.

Incompatibility with other materials:
Avoid moisture – hardens when wet.
Hazardous decomposition: Nil
Hazardous polymerization: Nil

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11. Toxicological information

OEL total inhalable:10mg/m^3
OEL respiratable dust: 5mg/m^3
Summary of toxicology: Portland cement dust irritates the eyes and causes dermatitis. Prolonged exposure to undefined mixtures of cement and other dusts have led to reports of increased incidence of bronchitis and chest X-ray changes. Exposure to cement can cause chronic conjunctivitis, blepharitis, and skin ulcers of the nose. Repeated and prolonged contact can result in primary irritant dermatitis of hands, forearms and feet, with potential complications.

Recommended medical surveillance for persons exposed to Portland cement at potentially hazardous levels:

- **Initial examination**
  Complete history and physical examination to detect pre-existing conditions for increased risk, and to establish base-line for future health monitoring, with stress on examination of respiratory tract (14 x 17" chest X-rays) and eyes. FVC and FEV (1 sec): Portland cement mixtures may cause signs of respiratory impairment. Persons with impaired pulmonary function may be at increased risk from exposure: periodic surveillance is indicated. Skin: examine for evidence of chronic disorders.

- **Periodic/annual surveillance**
  of lungs for persons with impaired pulmonary function. X-rays are necessary when indicated by results of pulmonary testing, or by signs and symptoms of respiratory disease. Contact the Poison Information Centre at the Johannesburg General Hospital at 011 495 5112 all hours.

12. Ecological information

Aquatic toxicity to Fish daphnia, Algae: Non-toxic in small quantities. Large quantities especially in static water will increase pH to >12, and pH changes may result in death of aquatic life.

13. Disposal considerations

Do not pour into drains or waterways.

14. Transport information

Packaging: 20kg and 25kg paper sacks; mini-bulk silos; road and rail tankers.
No UN no.: Non-hazardous cargo in terms of the IMDC code.
BC code: Appendix C cargo.

15. Statutory information

Inhalation: Exposure over long periods of time to very high concentrations may cause cough with phlegm.
Skin contact: Prolonged exposure could sensitise skin causing mild irritation or dermatitis in extreme cases.
Back strain: As bags are heavy, prevent back and neck injuries by proper bending and lifting.

16. Other information

Since the user's working conditions are not known by us, the information supplied on this material safety data sheet is based on our current level of knowledge and on national and community regulations.

The product must not be used for any purposes other than those specified under section 1 without first obtaining written instructions.

It is at all times the responsibility of the user to take all necessary measures to comply with legal requirements and local regulations.

The information given on this safety data sheet must be regarded as a description of the safety requirements relating to our product and not a guarantee of its properties.

This MSDS supercedes all previous issues prior to:
March 2009.

Ground granulated **blast furnace slag**

Material Safety Data Sheet (91/155/EEC)

1. Identification of preparation and company

Preparation name:	Portland cement (synonym: Cement)
Normal use:	Hydrating binder for concrete, mortar and plaster
Company registered name:	AfriSam (South Africa) (Pty) Ltd
Address:	Constantia Park, cnr 14th Ave and Hendrik Potgieter Rd, Roodepoort, Gauteng
Telephone:	011 670 5500

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References

2. Information on ingredients

Chemical formula: A complex mixtures of oxides and silicates, dependent on the process parameters:

Chemical name	CAS no.	%	EC no.	Classification
Silica, amorphous, fumed	7631-8v6-9	38.5	231-545-4	Xi: R36
Calcium oxide	1305-78=8	0-31.4	215-138-9	Xi: R38, 41
Calcium silicate	1344-95-2	0-31.4	2315-710-8	Xi: R38, 41
Alumina	1344-28-1	12.4	215-691-6	Xi: R36/38
Magnesium oxide	1309-48-4	10.5	215-171-9	Xi: R36/38
Manganese oxide	1344-43-0	1.41	215-695-8	-

3. Hazard identification

The preparation is classified as dangerous according to Directive 1999/45/EC and its amendments.
Classification: Xi; R38, 41.
Additional hazards: None identified.

Effects and symptoms
Inhalation: Hazardous.
Ingestion: Hazardous.
Skin contact: Hazardous (irritant/permeator). Skin inflammation is characterised by itching, scaling, reddening or, occasionally, blistering.
Eye contact: Hazardous (irritant). Inflammation is characterised by redness, watering and itching.
Aggravating conditions: Repeated or prolonged exposure is not known to aggravate medical condition.

4. First-aid measures

Inhalation: Remove person to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Seek medical attention.

Ingestion: DO NOT induce vomiting unless directed to do so by medical personnel. If unconscious, do not give anything by mouth. Loosen tight clothing. Seek medical attention if symptoms appear.

Skin contact: Immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Cover irritated skin with an emollient. Wash clothing, clean shoes thoroughly before reuse. Seek medical attention immediately, and show the container or label.

Eye contact: Remove contact lenses, if any. Flush eyes with plenty of water for at least 15 minutes. Seek medical attention immediately.

5. Fire-fighting measures

Non-flammable.

6. Measures to be taken in the event of accidental spillage

Safety precautions: Consult the safety measures listed under sections 7 and 8.

Environmental precautions and clean-up: Use shovel to move material into a convenient waste disposal container. Clean by spreading water on contaminated area and allow to evacuate through the sanitary system. Prevent any material entering drains or waterways.

7. Handling and storage

Handling: Do not ingest or breathe dust.
Storage: Store in segregated and approved area. Keep away from incompatibles such as acids and moisture.

8. Exposure control – personal safety

PPE: Wear splash goggles, overalls buttoned to the neck and wrist, boots and gloves. In case of insufficient ventilation, wear suitable approved/certified dust respirator when ventilation is inadequate.

Engineering measures: Use process enclosures, local exhaust ventilation or other engineering controls to keep airborne levels below exposure limits. Where dust, fume or mist is generated, use ventilation.

Hygiene: Wash hands after handling and before eating, smoking, using lavatory, and at end of day.

Occupational exposure limits: OHSAS (Act 85 of 1993) Hazardous chemical substances regulations 1995:

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Silica, amorphous, fumed	TWA: 3mg/m^3 (respirable) STEL: 6mg/m^3 (inhalable)
Calcium oxide	TWA: 2mg/m^3
Calcium silicate	TWA: 10.5mg/m^3
Alumina	TWA: 10.5mg/m^3
Magnesium oxide	TWA: 5mg/m^3, STEL:10 mg/m^3
Manganese oxide	TWA: 5mg/m^3

9. Physical and chemical properties

Appearance	Amorphous solid, powder or lumps
Colour	Greyish white
Odour	Odourless
Boiling/melting point	Not known
Solubility	Very slightly soluble in n-octanol. Insoluble in cold/hot water, methanol and diethyl ether.
Octanol/water partition coefficient	More soluble in octanol
Alkalinity	pH 5.76 (acidic)

10. Stability and reactivity

The product is stable.
Incompatibility with other materials: Reactive with acids, moisture. Slightly reactive with oxidising or reducing agents and organic materials.
Hazardous decomposition products: N/A.

11. Toxicological information

Skin and eye irritant. Sensitisation not suspected for humans.
Routes of entry: Inhalation and ingestion.
Target organs: Contains material which causes damage to blood, kidneys, lungs, upper respiratory tract, skin, nervous system (CNC), and eye lens or cornea.
Acute toxicity of silica: (amorphous, fumed): LD50 3 160mg/kg (rat, oral).
Chronic toxicity: Repeated or prolonged exposure is not known to aggravate medical condition.
Specific carcinogenic, mutagenic, developmental or fertility impairment effects: No evidence of risk in humans.

12. Ecological information

Exotoxicity of calcium oxide to trout: LC50: 7 hours, 97ppm.
Exotoxicity of calcium oxide to mosquito fish: LC50: 24 hours, 240ppm.
Not readily biodegradable, not expected to bioaccumulate.

13. Disposal considerations

In a landfill in accordance with regulatory and statutory permission. Non-hazardous.

14. Transport information

Not regulated.

15. Statutory information



Hazard symbol:
Irritant

Risk phrases: R36/37: Irritating to eyes and respiratory system.
Safety phrases: S2: Keep out of reach of children.
S46: If swallowed, seek medical attention and show container or label.

16. Other information

Since the user's working conditions are not known by us, the information supplied on this material safety data sheet is based on our current level of knowledge and on national and community regulations.

The product must not be used for any purposes other than those specified under section 1 without first obtaining written instructions.

It is at all times the responsibility of the user to take all necessary measures to comply with legal requirements and local regulations.

The information given on this safety data sheet must be regarded as a description of the safety requirements relating to our product and not a guarantee of its properties.

This MSDS supercedes all previous issues prior to:
March 2009.

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Reducing our Carbon Footprint

With the planet as one of our core values, we assess the carbon footprint of each and every one of our operations and products while actively striving to drive down our impact on the environment.