Cementitious materials for concrete standards, selection and properties

1. Introduction

Cementitious materials for concrete are fine mineral powders. When these materials are mixed with water, they react chemically to form a strong rigid mass that binds aggregate particles together to make concrete.

The cementitious materials dealt with in this leaflet are all based on portland cement and many contain a “cement extender.”

This publication gives information on the standards that apply in South Africa to cementitious materials for concrete; discusses, briefly, the manufacture and properties of cementitious materials and fillers; and provides guidance on the selection of cementitious materials for various applications.

The effect of cementitious materials on dimensional stability of hardened concrete is outside the scope of this publication.

> Note: Masonry cements that comply with SANS 50413 are not included in this leaflet because they are not intended for use in concrete. The national foreword of this standard reads: “This part of SANS 50413 gives the definition and composition of masonry cements as commonly used in Europe for bricklaying, block laying, for rendering and plastering only, and not for concrete. Users are therefore cautioned to use the cements only for their intended purpose.”

2. Standards applicable to cement

Cementitious materials for concrete, available in South Africa, include common cements and portland cement extenders.

All cement sold in South Africa must meet the requirements of SANS 50197 for Common cement or SANS 50413 for Masonry cement and the National Regulator for Compulsory Standards (NRCS) requirements as detailed in NRCS VC9085. Bags should be clearly marked with the strength class, notation indicating composition and a Letter of Authority (LOA) number issued by the NRCS. An LOA is issued for each cement type from each source. To verify valid LOA numbers contact the NRCS on 012 428 5199 or www.nrcs.org.za.

Applicable standards are:

Common cements

- **SANS 50197-1** - Cement - Part 1: Composition, specifications and conformity criteria for common cements.
- **SANS 50197-2** - Cement - Part 2: Conformity evaluation.

2.1 SANS 50197-1

The standard specifies a number of properties and performance criteria. Composition and strength are required to be displayed by the manufacturer on the packaging of each cement produced.

2.1.1 Composition

The standard specifies composition of cements according to the proportion of main constituents, and minor additional constituents (overleaf).

As can be seen from Table 2 and 3, the standard permits many different combinations of composition. In practice, however, manufacturers are constrained by what is technically and economically feasible. The number of combinations that are currently being produced in South Africa is fewer than the number permitted by the standard.

For the performance of a particular cement users should consult the relevant producer for these details. Helpline numbers are given in section 6.

2.1.2 Compressive strength requirements

The standard specifies strengths which are determined in accordance with SANS 50196-1 Methods of testing cement. Part 1: Determination of strength; using a water:cement ratio of 0,5. (The method is not the same as the cube test used for concrete.) Strength classes are shown in Table 1. Note that test strengths must clear an early-age (2 or 7 days) “hurdle”; and for strength classes 32,5 and 42,5 must fall within a “window” at 28 days.

2.1.3 Other requirements

SANS 50197-1 lists other physical and chemical requirements with which cements must comply. These are monitored by the manufacturer and compliance is confirmed by external audit control sample testing. Details can be found in SANS 50197-2.

Table 1: Compressive strength requirements of SANS 50197-1

Strength class	Compressive strength, MPa				Initial setting time
	Early strength		Standard strength		
	2 days	7 days	28 days		min
32,5L[a]	-	≥12,0	≥32,5	≤52,5	≥75
32,5N	-	≥16,0			
32,5R	≥10,0	-			
42,5L[a]	-	≥16,0	≥42,5	≤62,5	≥60
42,5N	≥10,0	-			
42,5R	≥20,0	-			
52,5L[a]	≥10,0	-	≥52,5	-	≥45
52,5N	≥20,0	-			
52,5R	≥30,0	-			
[a] Strength class only defined for CEM III cements					

Table 2: Common cements: SANS 50197-1

Main types	Notation of the 27 products (types of common cement)		Composition (percentage by mass [a])										
			Main constituents										Minor additional Cons-tituents
			Clinker	Blast-furnace slag	Silica fume	Pozzolana		Fly ash		Burnt shale	Limestone		
						Natural	Natural calcined	Sili-ceous	Calca-reous				
			K	S	D[(b)]	P	Q	V	W	T	L	LL	
CEM I	Portland cement	CEM I	95 - 100	-	-	-	-	-	-	-	-	-	0 - 5
CEM II	Portland-slag cement	CEM II/A-S	80 - 94	6 - 20	-	-	-	-	-	-	-	-	0 - 5
		CEM II/B-S	65 - 79	21 - 35	-	-	-	-	-	-	-	-	0 - 5
	Portland-silica fume cement	CEM II/A-D	90 - 94	-	6 - 10	-	-	-	-	-	-	-	0 - 5
	Portland-pozzolana cement	CEM II/A-P	80 - 94	-	-	6 - 20	-	-	-	-	-	-	0 - 5
		CEM II/B-P	65 - 79	-	-	21 - 35	-	-	-	-	-	-	0 - 5
		CEM II/A-Q	80 - 94	-	-	-	6 - 20	-	-	-	-	-	0 - 5
		CEM II/B-Q	65 - 79	-	-	-	21 - 35	-	-	-	-	-	0 - 5
	Portland-fly ash cement	CEM II/A-V	80 - 94	-	-	-	-	6 - 20	-	-	-	-	0 - 5
		CEM II/B-V	65 - 79	-	-	-	-	21 - 35	-	-	-	-	0 - 5
		CEM II/A-W	80 - 94	-	-	-	-	-	6 - 20	-	-	-	0 - 5
		CEM II/B-W	65 - 79	-	-	-	-	-	21 - 35	-	-	-	0 - 5
	Portland-burnt shale cement	CEM II/A-T	80 - 94	-	-	-	-	-	-	6 - 20	-	-	0 - 5
		CEM II/B-T	65 - 79	-	-	-	-	-	-	21 - 35	-	-	0 - 5
	Portland-limestone cement	CEM II/A-L	80 - 94	-	-	-	-	-	-	-	6 - 20	-	0 - 5
		CEM II/B-L	65 - 79	-	-	-	-	-	-	-	21 - 35	-	0 - 5
		CEM II/A-LL	80 - 94	-	-	-	-	-	-	-	-	6 - 20	0 - 5
		CEM II/B-LL	65 - 79	-	-	-	-	-	-	-	-	21 - 35	0 - 5
	Portland-composite cement [(c)]	CEM II/A-M	80 - 88	←				12 - 20				→	0 - 5
		CEM II/B-M	65 - 79	←				21 - 35				→	0 - 5
CEM III	Blast furnace cement	CEM III/A	35 - 64	36 - 65	-	-	-	-	-	-	-	-	0 - 5
		CEM III/B	20 - 34	66 - 80	-	-	-	-	-	-	-	-	0 - 5
		CEM III/C	5 - 19	81 - 95	-	-	-	-	-	-	-	-	0 - 5
CEM IV	Pozzolanic cement [(c)]	CEM IV/A	65 - 89	-	←		11 - 35		→	-	-	-	0 - 5
		CEM IV/B	45 - 64	-	←		36 - 55		→	-	-	-	0 - 5
CEM V	Composite cement [(c)]	CEM V/A	40 - 64	18 - 30	-	←	18 - 30	→	-	-	-	-	0 - 5
		CEM V/B	20 - 38	31 - 49	-	←	31 - 49	→	-	-	-	-	0 - 5

Notes

(a) The values in the table refer to the sum of the main and minor additional constituents.
(b) The proportion of silica fume is limited to 10%.
(c) In portland-composite cements CEM II A-M and CEM II B-M, in pozzolanic cements CEM IV A and CEM IV B, and in composite cements CEM V/A and CEM V/B the main constituents other than clinker shall be declared by designation of the cement.

Table 3: Sulfate resisting common cements: SANS 50197-1

Main types	Notation of the seven products (types of sulfate resisting common cement)		Composition (percentage by mass[a])				
			Main constituents				Minor additional constituents
			Clinker K	Blast furnace slag S	Pozzolana natural P	Siliceous fly ash V	
CEM I	Sulfate resisting portland cement	CEM I-SR 0	95 - 100	-	-	-	0 - 5
		CEM I-SR 3					
		CEM I-SR 5					
CEM III	Sulfate resisting blast furnace cement	CEM III/B-SR	20 - 34	66 – 80	-	-	0 - 5
		CEM III/C-SR	5 - 19	81 - 95	-	-	0 - 5
CEM IV	Sulfate resisting pozzolanic cement	CEM IV/A-SR	65 - 79	-	21 - 35		0 - 5
		CEM IV/B-SR	45 - 64	-	36 - 55		0 - 5

[a] The values refer to the sum of main and minor constituents

Where:

CEM I-SR 0	C_3A content of the clinker	= 0%
CEM I-SR 3	C_3A content of the clinker	≤ 3%
CEM I-SR 5	C_3A content of the clinker	≤ 5%
CEM III/B-SR	C_3A content of the clinker	= no requirement
CEM III/C-SR	C_3A content of the clinker	= no requirement
CEM IV/A-SR	C_3A content of the clinker	≤ 9%
CEM IV/B-SR	C_3A content of the clinker	≤ 9%

3. Standards applicable to cement extenders

Portland cement extenders

The following is a list of SANS standards for ground granulated blast furnace slag, fly ash and silica fume.

- **SANS 55167:** Parts 1 and 2. Ground granulated blast furnace slag for use in concrete, mortar and grout.
- **SANS 50450:** Parts 1 and 2. Fly ash for concrete.
- **SANS 53263:** Parts 1 and 2. Silica fume for concrete.

These standards do not apply to extenders used in the production of cements complying with SANS 50197 but to their use in site blends with cement complying with SANS 50197. SANS 50197-1 does however specify various limits as to the chemical composition and performance of extenders used.

4. Manufacture and properties

In this section, only materials available in South Africa are discussed.

4.1 Portland cement

Portland cement is the basis of all common cements covered by SANS 50197-1 (see Tables 2 and 3) and of site blends that include a cement extender. The main raw materials used in the manufacture of portland cement are limestone and shale which are blended in specific proportions and fired at high temperatures to form cement clinker. A small quantity of gypsum is added to the cooled clinker which is then ground to a fine powder - portland cement.

When portland cement is mixed with water to form a paste, a reaction called hydration takes place. As a result, the paste gradually changes from a plastic state into a strong rigid solid. The hardened cement paste acts as a binder in concrete and mortar.

Hydration is an exothermic reaction, i.e. it produces heat. The hydration of portland cement (PC) produces two main compounds:

calcium silicate hydrate (CSH) and
calcium hydroxide (lime).

CSH provides most of the strength and impermeability of the hardened cement paste. Lime does not contribute to strength but its presence helps to maintain, in the pore water, a pH of about 12,5, which helps to protect the reinforcing steel against corrosion.

4.2 Portland cement extenders and fillers

Portland cement extenders and fillers are materials used with portland cement, and must never be used on their own.

The main reasons for the widespread use of portland cement extenders are:

- Cost saving – extenders are generally cheaper than portland cement.
- Technical benefits – extenders can improve impermeability and durability of the hardened concrete; some extenders improve the properties of concrete in the fresh state.

Portland cement extenders affect the rate of early-age strength gain, and the rate of heat development due to cementing reactions.

Extremely fine extender particles can act as nuclei for the formation of calcium silicate hydrate which would otherwise form only on the cement grains. This fine-filler effect brings about a denser and more homogeneous microstructure of the hardened cement paste and the aggregate-paste interfacial zones, resulting in improved strength and impermeability. The performance of the fine-filler effect depends on the content of extremely fine particles in the extender.

The effects of extenders on the properties of concrete are summarised in Table 4. Effects tend to increase with increased level of substitution.

Improvements to the properties of hardened concrete, brought about by the use of extenders, can be realised only if the concrete is properly compacted and cured.

4.2.1 Ground granulated blast-furnace slag

Ground granulated blast-furnace slag (GGBS) is a by-product of the iron-making process. The hot slag is rapidly chilled or quenched (causing it to become glassy) and ground to a fine powder.

When mixed with water, GGBS hydrates to form cementing compounds consisting of calcium silicate hydrate. The rate of this hydration process is however too slow for practical construction work unless activated by an alkaline (high pH) environment. When portland cement and water are mixed, the pH of the water rapidly increases to about 12,5 which is sufficient to activate the hydration of GGBS. Even when activated by PC, GGBS hydrates more slowly than PC.

The effect of GGBS on the properties of concrete depends on the properties of the portland cement, the GGBS content of the cementitious material and the fineness of the GGBS.

4.2.2 Fly ash

Fly ash (FA) is collected from the exhaust flow of furnaces burning finely ground coal. The finer fractions are used as a portland cement extender.

Ultra-fine FA is sold as a separate product. FA reacts with calcium hydroxide, in the presence of water, to form cementing compounds consisting of calcium silicate hydrate. This reaction is called pozzolanic and FA may be described as an industrial pozzolan.

The hydration of portland cement produces significant amounts of calcium hydroxide, which does not contribute to the strength of the hardened cement paste (see section 4.1). By extending PC with FA the calcium hydroxide can be used to form additional calcium silica hydrate.

4.2.3 Silica fume

Silica fume (SF) is the condensed vapour by-product of the ferro-silicon smelting process.

SF reacts with calcium hydroxide, in the presence of water, to form cementing compounds consisting of calcium silicate hydrate. This reaction is called pozzolanic and SF may be described as an industrial pozzolan. Because the hydration of PC produces calcium hydroxide (see section 4.1), the combination of SF and PC is a practical means of using SF and improving the cementing efficiency of PC.

In addition to the chemical role of SF, it is also an effective "fine-filler." The extremely small SF particles in the mixing water act as nuclei for the formation of calcium silicate hydrate which would otherwise form only on the cement grains. SF will also change the microstructure of the interfacial zone. The result is a more homogeneous microstructure that has greater strength and lower permeability. (To ensure thorough dispersion and effective use of the SF, the use of plasticising admixtures is recommended.).

4.2.4 Limestone filler

This is limestone, finely ground but not chemically processed. When mixed with portland cement and water, finely ground limestone is chemically virtually inert (although there may be some minor reactions). Depending on its fineness, limestone may however act as a "fine filler" in fresh paste.

Limestone may be used as a filler in common cement or as a workability improver in masonry cement.

The effect of limestone on the properties of concrete or mortar depends on the specific limestone, whether a grinding aid is used in production, and the fineness of the limestone.

Limestone complying with the requirements of SANS 50197-1 can be designated as follows:

L if its total organic content does not exceed 0.50% by mass
LL if its total organic content does not exceed 0.20% by mass

Note: The limestone ($CaCO_3$) used in cements complying with SANS 50197-1 is not to be confused with:

- building lime (hydrated or slaked lime $Ca(OH)_2$) which is used in mortars and plasters.
- road lime (also hydrated or slaked lime $Ca(OH)_2$) which is used in road material stabilisation or modification.
- quick lime (CaO) which is highly aggressive and is used in the metallurgical industry.
- agricultural lime which, although chemically similar to the limestone used for cement, has less stringent compositional requirements.

There is no $Ca(OH)_2$ or CaO used in cements complying with SANS 50197-1.

Table 4: Effects of extenders on the properties of concrete

		GGBS	FA	SF
Fresh concrete	**Bleeding**	-	-	Significant reduction
	Setting time	Slight retardation		
	Cohesiveness	-	Ultra-fine FA increases cohesiveness	Increases
	Workability	Slight improvement with some aggregates	Improves: lower water requirement for given slump	Reduces: higher water requirement for a given slump
Hardened concrete	**Rate of early-age strength gain**	Reduces, especially at lower temperatures	Slight reduction, especially at lower temperatures	Marginal reduction of 1-day strength
	Response to steam curing	Improves		-
	Strength gain after 28 days	Increases		-
	Rate of heat generation	Reduces		-
	Pore structure of paste	Improves		
	Density of aggregate paste interfacial zones	Improvement	Improvement, especially with ultra-fine FA	Significant improvement
	Impermeability of concrete	Improves		
	Sulphate resistance	Improves	Improves	-
	Rate of chloride diffusion	Reduces: improves protection of embedded steel against corrosion		
	Alkali aggregate reaction	Prevents or retards if content is sufficient (See Table 5)		

5. Selection

Cementitious materials used for concrete may be:

- A common cement complying with SANS 50197 (see Tables 2 and 3) on its own.

- A site blend of a common cement complying with SANS 50197 and a cement extender complying with the relevant SANS standard, combined in the concrete mixer while the concrete is being mixed. Extenders must not be used without portland cement.

Note: As discussed in section 2.1.1, not all the cements shown in Tables 2 and 3 are necessarily available in South Africa. It should also be noted that generally as the extender content of a cement increases, the rate of compressive strength development at early ages is reduced. The extent of this reduction can be assessed by testing the cement in accordance to SANS 50196-1.

Table 5 gives guidelines for selecting cement type for various applications. Unless stated otherwise, the strength class of the common cement may be 32,5N or higher.

6. Strength performance

For accurate and current details of the performance of a particular branded product, consult the technical representatives of the manufacturer. You will find these details on the “Cement grid”.

Table 5: Guidelines for selecting cements for concrete

Application	Comments
Conventional structural concrete in a non-aggressive environment	The cement is normally selected for economy. Any of the SANS 50197-1 common cements should be suitable. Site blends of CEM I cement with 50% GGBS or 30% FA have been extensively and successfully used in South Africa. A site blend of CEM I cement and about 8% SF is technically feasible but there is relatively little local experience of its use.
Large placements where temperature rise, due to heat of hydration, is to be kept as low as possible	Best results are likely to be achieved with cements with extender contents in excess of 50% GGBS or 30% FA.
Structural precast	Choice of cement will depend mainly on strength requirements at early ages. High early strengths, without steam curing, will be achieved most economically with cements of strength grade 42,5R and higher and with low extender content. Cements with higher extender content are better suited to steam curing. Where there is no requirement for rapid strength gain, the choice of cement should be based on economy.
Precast bricks, blocks and pavers	Provided the elements have sufficient strength to allow handling at an early age, typically the day after casting, the choice of cement should be based on economy.
High-strength concrete	Strength class should be 42,5N or higher. The inclusion of about 8% SF is common practice in this application. Other cement extenders may also be used for technical or economic benefits. Superplasticizer is an essential ingredient in high-strength concrete: the compatibility of the specific cementitious material and the superplasticizer is important.
Floors, roads and pavements with sawn joints	Concrete for these applications must develop strength rapidly enough to permit joint sawing before the concrete cracks due to restrained drying shrinkage. The mature concrete must have good abrasion resistance. These properties are likely to be achieved most economically with cements with extender content not greater than 30%, and of strength grade 42,5N or higher.
Reinforced concrete in marine environment	Research done with South African materials has shown that best results are achieved with extender contents of either 50% GGBS, 10% SF, 40% GGBS + 10% SF, or 30% FA.
Concrete made with alkali-reactive aggregate	The cement should contain not less than 40% GGBS, or 20% FA, or 15% SF. However, the use of SF at this high replacement level usually results in sticky concrete requiring the use of a superplasticizer.
Concrete exposed to sulphate attack	Fortunately, this type of attack is rare in South Africa. A CEM I cement's resistance to sulphate attack depends largely on its C_3A content. CEM I cements with C_3A contents below about 9 to 10% give markedly higher sulphate resistance than those with C_3A contents above South African CEM I cements mostly have C_3A contents below 10% and therefore give relatively high sulphate resistance. International experience suggests that using high levels of GGBS in concrete will improve sulphate resistance. There are no South African data on which to base guidance to local users. The sulphate-resisting properties of concrete, made with specific materials, should therefore be investigated before a GGBS blend is specified. The inclusion of a minimum of 30% FA should improve the sulphate resistance of concrete. There are no South African data on which to base guidance on the use of SF for sulphate resistance. Consider the use of sulphate resisting cements as listed in *Table 3*.

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