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.

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

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.

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 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. And, 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 re-usability 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.cnci.org 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 re-use, see the C&CI’s series of booklets on Sustainable Concrete.
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 210litres/m³ 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/m³, 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 workability.

- **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 consistence

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 and 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.
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 wider 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.
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 55197-1.
  - **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: Design 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 3 minutes from arrival on site.

### Table 32: Slump tolerances.

<table>
<thead>
<tr>
<th>Specified slump, mm</th>
<th>Tolerance, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 and less</td>
<td>-15 to +25</td>
</tr>
<tr>
<td>More than 50, up to 100</td>
<td>± 25</td>
</tr>
<tr>
<td>More than 100</td>
<td>± 40</td>
</tr>
<tr>
<td>Where applicable, air content tolerance: ±1.5%</td>
<td></td>
</tr>
</tbody>
</table>

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.
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 program, 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 12: Accepting concrete on-site.
Sampling and testing guidelines

Sampling 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 and tolerances of cubes (SANS 5860)
• The tolerance on the basic dimension between each face of a specimen is 1.0%.
• The basic dimension \(d\) should be at least four times the maximum aggregate size.
• Load-bearing surfaces to be flat to within 0.0005\(d\).

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 to 25ºC.
• During transporting 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 covermeter: 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 covermeter reading.
• The minimum core diameter is ideally at least four times the size of the aggregate in the concrete, ie 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 rawbolt 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 (ie 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 13.

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, eg 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.

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Figure 13: Producing concrete.
Concrete

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.

Figure 14: Production equipment.
**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.

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**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.
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 15 gives examples using APC, 19mm stone and crusher sand.

Figure 15: Mix adjustment.
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, eg first load at 10:00 am, with subsequent loads every hour thereafter.

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, ie 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, eg 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.

### Handling concrete on-site

### Table 33: Pre-concreting check list.

<table>
<thead>
<tr>
<th>Item checked</th>
<th>Area to be concreted</th>
<th>Date:</th>
<th>YES</th>
<th>NO</th>
<th>ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formwork restrained against movement in all directions?</td>
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<tr>
<td>Formwork correctly aligned and levelled?</td>
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<td>Props plumb and at right spacing?</td>
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<tr>
<td>All inserts and cast-in fixings in right position and secure?</td>
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<td>Void formers firmly fixed or tied down?</td>
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<tr>
<td>All stop ends properly secured?</td>
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<tr>
<td>All joints sealed to avoid grout loss, especially against kicker?</td>
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<tr>
<td>Forms clean and free of rubbish (tie-wire cuttings, bits of timber or metal)?</td>
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<tr>
<td>Release agent applied?</td>
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<tr>
<td>Correct release agent?</td>
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<tr>
<td>Correct reinforcement?</td>
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<td>Enough spacers?</td>
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<td>Correct depth of cover?</td>
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<tr>
<td>All kicker bars straight and correctly positioned?</td>
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<tr>
<td>Sufficient access for placing concrete?</td>
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<tr>
<td>Adequate access for compaction?</td>
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<td>All toe-boards provided?</td>
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<td>Guard rails provided?</td>
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<tr>
<td>Curing materials available?</td>
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</table>
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 ready-mixed 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, ie 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, eg 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.
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, eg 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 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.

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 in discarded. Pumping commences within 15 minutes of discharge of the readymix concrete into the pump hopper.
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.

**Compaction**

After placing, compact and finish the surface of the concrete prior to initial hardening. Entrapped air reduces the concrete strength, eg 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, eg for industrial floors, parking garages, etc.
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.

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 matt 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.
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.
• Improved dispersion of the high amount of fines in the mix.

On arrival on-site, check workability retention.

Self-levelling concrete (eg 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 (eg 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.
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 17).

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

- **Resistance to chemical attack or attack by aggressive 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, resistance to sulphate and soft water attack is improved due to reduction of the calcium hydroxide content.

- **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.
Concrete

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, eg 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.**
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 mixing water at a given cement content and workability, to reduce the and therefore to 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 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 18: Fluidity effect of adding SPs.

Figure 19: Potential effect plasticisers on concrete.
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, ie has not set. They occur when the rate of evaporation of moisture from the surface exceeds the rate at which moisture is being supplied, ie via bleeding. Concretes with low bleed potential (eg 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 20.

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 21). 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.

Figure 20: Effect of concrete and air temperatures, relative humidity and wind speed on the evaporation of surface moisture from concrete.

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.
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, eg erect windbreaks.
- Commence curing regime promptly after finishing and continue for the specified period.

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

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 22). 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, eg lower slump, better cohesiveness.
- Increase the ratio of cover to reinforcing bar diameter, ie 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.

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

- Use higher extender contents.
- Use suitable retarding admixture.
- Aggregate should be kept cool, eg 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:

$$T = \frac{0.22 (TaWa + TcWc) + TwWw}{0.22 (Wa + Wc) + Ww}$$

where:

- $T$ = temperature of material, °C
- $W$ = mass of material, kg
- $a$, $c$ and $w$ = aggregate, cement and water

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.

This formula is applicable to estimating concrete temperature in hot and cold conditions.
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, eg 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.
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, ie prevention of ravelling and/or plucking during cutting. The harder the aggregate, the higher the early strength requirement.

Table 34: Strength requirement for early joint cutting for different aggregate types.

<table>
<thead>
<tr>
<th>Aggregate type</th>
<th>Early strength required before sawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite or quartzite</td>
<td>3MPa - 5MPa</td>
</tr>
<tr>
<td>Dolerite or andesite</td>
<td>4MPa - 6MPa</td>
</tr>
<tr>
<td>Felsite</td>
<td>&gt; 8MPa</td>
</tr>
</tbody>
</table>

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.
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 is 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, see also 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 C&CI.

What is effective curing?

Preventing the loss of moisture from the concrete from the time of placing for at least seven days after casting.
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 100m³, 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 ready mixed concrete, as concrete can be delivered from several batching plants and scheduled to arrive on-site at a rate that ensures continuous pouring.
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, eg 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 limestone lower 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 pre-determined 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 subbase lower layers can also result in cost savings in surfacing layers.

This section only refers to stabilisation with cement eg 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 23). 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 23: Reduction of pH of in-situ material using different cement.
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 24).
• 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.

Cement with extended setting times, eg 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.

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 25. The engineer may then decide on an acceptable working time to limit the risk of strength loss.

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.
Applicable specifications

ASTM C494 / C494M -11: Admixtures
SANS 878:2012: Ready mixed 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)
Part 2: Conformity evaluation
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
Part 2: Conformity evaluation

Test methods

SANS 5860:2006: Concrete tests – Dimensions, tolerances and uses of cast test specimens
Part 2: Sampling of freshly mixed concrete. Part 3: Making and curing of test specimens
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