Sika – Your Local Partner with a Global Presence

Sika is a globally active company in the speciality and construction chemicals business. It has subsidiary manufacturing, sales and technical support facilities in over 70 countries around the world.

Sika is THE global market and technology leader in waterproofing, sealing, bonding, dampening, strengthening and protection of buildings and civil engineering structures. Sika has more than 9,200 employees worldwide and is therefore ideally positioned to support the success of its customers.

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Our most current General Sales Conditions shall apply. Please consult the Product Data Sheet prior to any use and processing.
Sika – with Long Experience

Sika began developing the first admixtures for cementitious mixes in 1910, the year in which it was founded. At that time the main aims were to shorten the setting time of mortar mixes, make them watertight or increase their strength. Some of these early, successful Sika products are still in use today.

Water is necessary in concrete for consistence and hydration of the cement, but too much water in the hardened concrete is a disadvantage, so Sika products were also developed to reduce the water content while maintaining or even improving the consistence (workability):

<table>
<thead>
<tr>
<th>Date</th>
<th>Product base</th>
<th>Typical Sika Product</th>
<th>Main effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>1930</td>
<td>Lignosulphonate</td>
<td>Plastocrete®</td>
<td>Water reduction up to 10%</td>
</tr>
<tr>
<td>1940</td>
<td>Gluconate</td>
<td>Plastiment®</td>
<td>Water reduction up to 10% plus retardation</td>
</tr>
<tr>
<td>1960</td>
<td>Sika Retarder®, Fro-V</td>
<td></td>
<td>Retardation and air entrainment</td>
</tr>
<tr>
<td>1970</td>
<td>Naphthalene</td>
<td>Sikament®-NN</td>
<td>Water reduction up to 20%</td>
</tr>
<tr>
<td>1980</td>
<td>Melamine</td>
<td>Sikament®-300/-320</td>
<td>Water reduction up to 20%, reduced air content</td>
</tr>
<tr>
<td>1990</td>
<td>Vinyl copolymers</td>
<td>Sikament®-10/-12</td>
<td>Water reduction up to 25%</td>
</tr>
<tr>
<td>2000</td>
<td>Modified polycarboxylates</td>
<td>Sikar® ViscoCrete®</td>
<td>Water reduction up to 40%, SCC concrete technology for self-compaction</td>
</tr>
</tbody>
</table>

Ever since the company was formed, Sika has always been involved where cement, aggregates, sand and water are made into mortar or concrete – the reliable partner for economic construction of durable structures.

Sika – with a Global Presence

Sika AG in Baar is a globally active, integrated speciality chemicals company. Sika is a leader in the technology and production of materials used to seal, bond, insulate, strengthen and protect load bearing structures in buildings and in industry.

Sika’s product range includes high performance concrete admixtures, speciality mortars, sealants and adhesives, insulating and strengthening materials, systems for structural strengthening, industrial flooring and waterproofing membranes.

Sika team of authors:
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1. Concrete Constituents

1.1 Terms

Three main constituents are actually enough to produce concrete:
- Binder (cement)
- Aggregate
- Water

Due to continually increasing demands for the concrete quality (mainly durability) and huge advances in admixture and concrete technology, it is now possible to produce many different kinds of concrete.

<table>
<thead>
<tr>
<th>Type</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard concrete</td>
<td>Concrete with a maximum particle diameter &gt; 8 mm</td>
</tr>
<tr>
<td></td>
<td>Density (kiln dried) &gt; 2000 kg/m³, maximum 2600 kg/m³</td>
</tr>
<tr>
<td>Heavyweight concrete</td>
<td>Density (kiln dried) &gt; 2600 kg/m³</td>
</tr>
<tr>
<td>Lightweight concrete</td>
<td>Density (kiln dried) &gt; 800 kg/m³ and &lt; 2000 kg/m³</td>
</tr>
<tr>
<td>Fresh concrete</td>
<td>Concrete, mixed, while it can still be worked and compacted</td>
</tr>
<tr>
<td>Hardened concrete</td>
<td>Concrete when set, with measurable strength</td>
</tr>
<tr>
<td>“Green” concrete</td>
<td>Newly placed and compacted, stable, before the start of detectable setting</td>
</tr>
<tr>
<td></td>
<td>(green concrete is a pre-casting industry term)</td>
</tr>
</tbody>
</table>
Other terms in use are shotcrete, pumped concrete, craned concrete etc. They define the placement into the formwork, working and/or handling to the point of installation (see next chapter).

1.2 Binders

**Cement** is the hydraulic binder (hydraulic = hardening when combined with water) which is used to produce concrete. Cement paste (cement mixed with water) sets and hardens by hydration, both in air and under water. The main base materials, e.g. for *Portland cement*, are limestone, marl and clay, which are mixed in defined proportions. This raw mix is burned at about 1450 °C to form *clinker* which is later ground to the well-known fineness of cement.

**Cement to the standard**
In Europe, cements are covered by the standard EN 197-1 (composition, specifications and conformity criteria). The standard divides the common cements into 5 main types, as follows:

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I</td>
<td>Portland cement</td>
</tr>
<tr>
<td>CEM II</td>
<td>Composite cements (mainly consisting of Portland cement)</td>
</tr>
<tr>
<td>CEM III</td>
<td>Blast furnace cement</td>
</tr>
<tr>
<td>CEM IV</td>
<td>Pozzolan cement</td>
</tr>
<tr>
<td>CEM V</td>
<td>Composite cement</td>
</tr>
</tbody>
</table>

Under the above table, the various types of cement may contain other components as well as Portland cement clinker (K):

**Major components**
- Granulated slag (S)
- Silica dust (D)
- Natural and industrial pozzolans (P or Q)
- High silica and limestone fly ashes (V or W)
- Burnt shales (e.g. oil shale) (T)
- Limestone (L or LL)

**Minor components**
These are mainly selected inorganic natural mineral materials originating from clinker production, or components as described (unless they are already contained in the cement as a major constituent). See table on page 7.
## Types of cement and their composition according to EN 197-1

| Main cement type | Designation | Cement type | Composition (parts by weight in %)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Portland cement clinker</td>
<td>[K]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CEM I</strong></td>
<td>Portland cement</td>
<td>CEM I</td>
<td>95–100</td>
</tr>
<tr>
<td><strong>CEM II</strong></td>
<td>Portland slag cement</td>
<td>CEM II/A-S</td>
<td>80–94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-S</td>
<td>65–79</td>
</tr>
<tr>
<td></td>
<td>Portland silica dust cement</td>
<td>CEM II/A-D</td>
<td>90–94</td>
</tr>
<tr>
<td></td>
<td>Portland pozzolan cement</td>
<td>CEM II/A-P</td>
<td>80–94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-P</td>
<td>65–79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/A-Q</td>
<td>80–94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-Q</td>
<td>65–79</td>
</tr>
<tr>
<td></td>
<td>Portland fly ash cement</td>
<td>CEM II/A-V</td>
<td>80–94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-V</td>
<td>65–79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/A-W</td>
<td>80–94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-W</td>
<td>65–79</td>
</tr>
<tr>
<td></td>
<td>Portland shale cement</td>
<td>CEM II/A-T</td>
<td>80–94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-T</td>
<td>65–79</td>
</tr>
<tr>
<td></td>
<td>Portland limestone cement</td>
<td>CEM II/A-L</td>
<td>80–94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-L</td>
<td>65–79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/A-LL</td>
<td>80–94</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM II/B-LL</td>
<td>65–79</td>
</tr>
<tr>
<td><strong>CEM III</strong></td>
<td>Blast furnace cement</td>
<td>CEM III/A</td>
<td>35–64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/B</td>
<td>20–34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM III/C</td>
<td>5–19</td>
</tr>
<tr>
<td><strong>CEM IV</strong></td>
<td>Pozzolan cement</td>
<td>CEM IV/A</td>
<td>65–89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM IV/B</td>
<td>45–64</td>
</tr>
<tr>
<td><strong>CEM V</strong></td>
<td>Composite cement</td>
<td>CEM V/A</td>
<td>40–64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CEM V/B</td>
<td>20–39</td>
</tr>
</tbody>
</table>

1. The numbers in the table refer to the total major and minor components.
2. The silica dust content is limited to 10%.
3. In the Portland composite cements CEM II/A-M and CEM II/B-M, the pozzolan cements CEM IV/A and CEM IV/B and the composite cements CEM V/A and CEM V/B, the major component type must be specified by the cement designation.
4. Total organic carbon (TOC) must not exceed 0.2% by weight.
5. Total organic carbon (TOC) must not exceed 0.5% by weight.
Strengths
Cements are divided into 3 strength classes according to the standard mortar compressive strength after 28 days. The levels represent the required minimum compressive strengths of 32.5/42.5/52.5 N/mm². Cements with a high 2-day compressive strength have the additional designation “R”.

Detailed information on the individual constituents is given in EN 197-1: Chapter 5: Constituents
5.1 General
5.2 Major Constituents
5.3 Minor Constituents

1.3 Concrete Aggregates

Gravels, stone and sands form the granular structure, which must have its voids filled as completely as possible by the binder glue. They make up approximately 80% of the weight and 70–75% of the volume. Optimum use of the aggregate size and quality improves the concrete quality. Aggregates can occur naturally (fluvial or glacial); for high-quality concrete they are cleaned and graded in industrial facilities by mechanical processes such as mixing together, crushing, screening and washing (mechanical preparation).

Suitable as concrete aggregates are materials which do not interfere with the cement hardening, have a strong enough bond with the hardened cement paste and do not put the resistance of the concrete at risk.

Standard and special aggregates

<table>
<thead>
<tr>
<th>Standard aggregates</th>
<th>Density 2.2–3 kg/dm³</th>
<th>From natural deposits, e.g. river gravel, moraine gravel etc. Material rounded or crushed (e.g. excavated tunnel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavyweight aggregates</td>
<td>Density &gt; 3.0 kg/dm³</td>
<td>Such as barytes, iron ore, steel granulate. For the production of heavy concrete (e.g. radiation shielding concrete)</td>
</tr>
<tr>
<td>Lightweight aggregates</td>
<td>Density &lt; 2.0 kg/dm³</td>
<td>Such as expanded clay, pumice, polystyrene. For lightweight concrete, insulating concretes</td>
</tr>
<tr>
<td>Hard aggregates</td>
<td>Density &gt; 2.0 kg/dm³</td>
<td>Such as quartz, carborundum; e.g. for the production of granolithic concrete surfacing</td>
</tr>
<tr>
<td>Recycled granulates</td>
<td>Density approx. 2.4 kg/dm³</td>
<td>From crushed old concrete etc.</td>
</tr>
</tbody>
</table>
Standard aggregates
In Europe aggregates are defined in standard EN 12620. This standard is very comprehensive and to give more details than in the list below would be outside the scope of this document. Further references to the standard are given in chapter 2 (page 20).

Important terms from the standard (with additional notes):

- **Natural aggregate**
  Comes from mineral deposits; it only undergoes mechanical preparation and/or washing.

- **Aggregate mix**
  Aggregate consisting of a mixture of coarse and fine aggregates (sand). An aggregate mix can be produced without prior separation into coarse and fine aggregates or by combining coarse and fine aggregates (sand).

- **Recycled aggregate**
  Aggregate made from mechanically processed inorganic material previously used as a building material (i.e. concrete).

- **Filler (rock flour)**
  Aggregate predominantly passing the 0.063 mm sieve, which is added to obtain specific properties.

- **Particle size group**
  Designation of an aggregate by lower (d) and upper (D) sieve size, expressed as d/D.

- **Fine aggregate (sand)**
  Designation for smaller size fractions with D not greater than 4 mm. Fine aggregates can be produced by natural breakdown of rock or gravel and/or crushing of rock or gravel, or by the processing of industrially produced minerals.

- **Coarse aggregate**
  Designation for larger size fractions with D not less than 4 mm and d not less than 2 mm.

- **Naturally formed aggregate 0/8 mm**
  Designation for natural aggregate of glacial or fluvial origin with D not greater than 8 mm (can also be produced by mixing processed aggregates).

- **Fines**
  Proportion of an aggregate passing the 0.063 sieve.

- **Granulometric composition**
  Particle size distribution, expressed as the passing fraction in percent by weight through a defined number of sieves.

**Passing fraction, particle size distribution curves**
The particle size is expressed by the hole size of the test sieves just passed by the particle concerned.
According to EN 933-2, sieves with square holes must be used.

**Sieve type specified**

<table>
<thead>
<tr>
<th>Hole size</th>
<th>Type of sieve</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 4 mm</td>
<td>Metal wire mesh</td>
</tr>
<tr>
<td>≥ 4 mm</td>
<td>Perforated metal plate</td>
</tr>
</tbody>
</table>

The hole sizes of the individual sieves (sieve sizes) are described in ISO 3310-1 & 2. A standard section from the main series R20 can be taken as an example. The following sieve sizes are required (hole sizes in mm):

Aggregate mix 0–32 mm:
0.063 / 0.125 / 0.25 / 0.50 / 1.0 / 2.0 / 4.0 / 8.0 / 16.0 / 31.5

In this case the sands and gravels are washed, therefore filler is added to improve consistence.
**Practical information**

- **Optimum grain shape, crushed/round**
  Cubic/spherical shapes have proved more suitable than linear forms, which can affect the consistence. Crushed aggregate has a slightly higher water requirement for the same consistence because of its larger specific surface area, but higher concrete compressive and particularly tensile strengths can be obtained due to better interlocking.

- **Predominantly crushed aggregates**
  The surface of crushed materials from rock, large blocks etc. consists only of broken surfaces, while the surface of crushed round material also includes natural rounded areas.
  Crushed rock material is now mainly used in tunnelling, the motto being: “Extraction point = installation point”.

- **Quarry sands**
  These are angular and also longish or flattish depending on the rock. They are not conducive to a good consistence and their water requirement is generally higher.

- **Harmful contaminants**
  Loam, humus, marl, clay, gypsum and aggregates containing sulphates, chlorides and alkalis are all potentially harmful and their presence and possible consequences must be clarified.

**Physical requirements for aggregates**
Standard EN 12620 divides coarse aggregates into categories covering:

- Resistance to splitting
- Resistance to wear
- Resistance to polishing and abrasion
- Particle density and water absorption
- Bulk density
- Durability

**Durability**
This is mainly associated with the frost and freeze/thaw resistance of coarse aggregates, which must be adequate for the specified purpose and must be verified if necessary.

**Alternative aggregates (recycled material)**
Large natural gravel and sand deposits are often valuable, non-renewable resources. It is becoming increasingly impossible to obtain and use gravel from these natural areas.

Possible substitutes are:

- Crushing and processing of old concrete to form concrete granules
- Reuse of microfines from concrete wash water installations

The suitability of recycled material should preferably be checked in every case.
Concrete admixtures are liquids or powders which are added to the concrete during mixing in small quantities, normally based on the cement content. They influence the properties of the fresh and/or hardened concrete chemically and/or physically.

According to EN 206-1, concrete admixtures are defined and the requirements are described in EN 934-2. The standard includes the following under “Special Terms” (slightly abbreviated):

**Admixtures – definitions and effects**

- **Water reducer**
  Enables the water content of a given concrete mix to be reduced without affecting the consistence, or increases the workability without changing the water content, or achieves both effects.

- **Superplasticizer**
  Enables the water content of a given concrete mix to be greatly reduced without affecting the consistence, or greatly increases the workability without changing the water content, or achieves both effects.

- **Stabilizer**
  Reduces mixing water bleeding in the fresh concrete.

- **Air entrainer**
  Introduces a specific quantity of small, evenly distributed air voids during the mixing process which remain in the concrete after it hardens.

- **Set accelerator**
  Reduces the time to initial set, with an increase in initial strength.

- **Hardening accelerator**
  Accelerates the initial strength with or without an effect on the setting time.

- **Retarder**
  Retards the time to initial set and prolongs the consistence.

- **Waterproofer**
  Reduces the capillary water absorption of the hardened concrete.

- **Retarder/water reducer**
  Has the combined effects of a water reducer (main effect) and a retarder (additional effect).

- **Retarder/superplasticizer**
  Has the combined effects of a superplasticizer (main effect) and a retarder (additional effect).

- **Set accelerator/water reducer**
  Has the combined effects of a water reducer (main effect) and a set accelerator (additional effect).

Other product groups such as shrinkage reducers and corrosion inhibitors etc. are not (yet) covered by EN 934-2.
Dosage of admixtures to EN 206-1:

| Permitted dosage                   | \( \leq 5\% \) by weight of the cement  
|                                   | (The effect of a higher dosage on the performance and durability of the concrete must be verified.) |
| Low dosages                        | Admixture quantities < 0.2 % of the cement are only allowed if they are dissolved in part of the mixing water. |

If the total quantity of liquid admixture is > 3 l/m\(^3\) of concrete, the water quantity contained in it must be included in the water/cement ratio calculation.
If more than one admixture is added, their compatibility must be verified by specific testing.
The effects and uses of the admixtures listed above (and others) are discussed in detail in the following chapters.

1.5 Concrete Additives

Concrete additives are fine materials which are generally added to concrete in significant proportions (around 5–20 %). They are used to improve or obtain specific fresh and/or hardened concrete properties.
EN 206-1 lists 2 types of inorganic concrete additive:

Type I

- Virtually inactive materials such as lime fillers, quartz dust and colour pigments.
- **Pigments**
Pigmented metal oxides (mainly iron oxides) are used to colour concrete. They are added at levels of 0.5–5 % of the cement weight; they must remain colour-fast and stable in the alkaline cement environment. With some types of pigment the water requirement of the mix can increase.
- **Rock flours (quartz dust, powdered limestone)**
Low fines mixes can be improved by adding rock flours. These inert materials are used to improve the grading curve. The water requirement is higher, particularly with powdered limestone.
Technical data for rock flours (to DIN 4226-1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rock flours</td>
</tr>
<tr>
<td></td>
<td>Quartz flour</td>
</tr>
<tr>
<td>Density (specific gravity)(^1)</td>
<td>2650</td>
</tr>
<tr>
<td>Specific surface</td>
<td>≥ 1000</td>
</tr>
<tr>
<td>Bulk density, loose*(^1)</td>
<td>1300–1500</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>0.2</td>
</tr>
</tbody>
</table>

* This factor has to be taken into account for the filling capacity of silos, etc.

\(^1\) Current experience

Type II
Pozzolanic or latent hydraulic materials such as natural pozzolans (trass), fly ash and silica dust.

Fly ash is a fine ash from coal-fired power stations which is used as an additive for both cement and concrete. Its composition depends mainly on the type of coal and its origin and the burning conditions.

Silica dust (Silicafume) consists of mainly spherical particles of amorphous silicon dioxide from the production of silicon and silicon alloys. It has a specific surface of 18–25 m\(^2\) per gram and is a highly reactive pozzolan.

Standard dosages of silica dust are 5% to 10% max. of the cement weight.

Cement/pozzolans comparison table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cements</td>
</tr>
<tr>
<td></td>
<td>CEM I 42.5*</td>
</tr>
<tr>
<td>Density (specific gravity)(^1)</td>
<td>~ 3100</td>
</tr>
<tr>
<td>Specific surface</td>
<td>~ 3000</td>
</tr>
<tr>
<td>Bulk density, loose*(^1)</td>
<td>~ 1200</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>2.4</td>
</tr>
<tr>
<td>SiO(_2) content</td>
<td></td>
</tr>
</tbody>
</table>

* Data from randomly selected common cements to EN 197-1

** This factor has to be taken into account for the filling capacity of silos, etc.

\(^1\) Current experience for pozzolans
1.6 Finest Grain

The finest grain content consists of:
- the cement
- the 0 to 0.125 mm granulometric percentage of the aggregate
- and any concrete additive(s)

The finest grain acts as a lubricant in the fresh concrete to improve the workability and water retentivity. The risk of mixture separation during installation is reduced and compaction is made easier. However, finest grain contents which are too high produce doughy, tacky concrete. There can also be a greater shrinkage and creep tendency (higher water content).

The following quantities have proved best:

<table>
<thead>
<tr>
<th>Round aggregate</th>
<th>Crushed aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>For concrete with a maximum particle size of 32 mm</td>
<td>Finest grain content between 350 and 400 kg/m³</td>
</tr>
<tr>
<td>For concrete with a maximum particle size of 16 mm</td>
<td>Finest grain content between 400 and 450 kg/m³</td>
</tr>
</tbody>
</table>

Higher finest grain contents are usual for self-compacting concretes (SCC).
1.7 Mixing Water

The suitability of water for concrete production depends on its origin. EN 1008 lists the following types:

- **Drinking water**
  Suitable for concrete. Does not need to be tested.

- **Water recovered from processes in the concrete industry (e.g. wash water)**
  Generally suitable for concrete but the requirements in annex A of the standard must be met (e.g. that the additional weight of solids in the concrete occurring when water recovered from processes in the concrete industry is used must be less than 1 % of the total weight of the aggregate contained in the mix).

- **Ground water**
  May be suitable for concrete but must be checked.

- **Natural surface water and industrial process water**
  May be suitable for concrete but must be checked.

- **Sea water or brackish water**
  May be used for non-reinforced concrete but is not suitable for reinforced or prestressed concrete.
  The maximum permitted chloride content in the concrete must be observed for concrete with steel reinforcement or embedded metal parts.

- **Waste water**
  Not suitable for concrete.

Combined water is a mixture of water recovered from processes in the concrete industry and water from a different source. The requirements for the combined water types apply.

**Preliminary tests (EN 1008, Table 1)**

The water must first be analysed for traces of oil and grease, foaming (detergents!!), suspended substances, odour (e.g. no odour of hydrogen sulphide after adding hydrochloric acid), acid content ($\text{pH } \geq 4$) and humic substances.

Water which does not meet one or more of the requirements in Table 1 may only be used if it meets the following chemical specifications and its use does not have negative consequences for the setting time and strength development (see EN 1008 for test methods).
### Chemical properties

- **Chlorides**
  The chloride content of the water must not exceed the levels in the table below:

<table>
<thead>
<tr>
<th>End use</th>
<th>Maximum chloride content in mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prestressed concrete or grouting mortar</td>
<td>500</td>
</tr>
<tr>
<td>Concrete with reinforcement or embedded metal parts</td>
<td>1000</td>
</tr>
<tr>
<td>Concrete without reinforcement or embedded metal parts</td>
<td>4500</td>
</tr>
</tbody>
</table>

- **Sulphur**
  The sulphur content of the water must not be more than 2000 mg/l.

- **Alkalis**
  If alkali-sensitive aggregates are used in the concrete, the alkali content of the water must be tested. The alkali content (Na₂O equivalent) must normally not exceed 1500 mg/l. If this level is exceeded, the water may only be used if it can be proved that measures have been taken to prevent harmful alkali-silicate reactions.

- **Harmful pollutants**
  Quality tests for sugars, phosphates, nitrates, lead and zinc must first be carried out. If the results are positive, either the content of the material concerned must be determined or setting time and compressive strength tests must be carried out.

### Chemical analyses limits:

<table>
<thead>
<tr>
<th>Material</th>
<th>Maximum content in mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugars</td>
<td>100</td>
</tr>
<tr>
<td>Phosphates, expressed as P₂O₅</td>
<td>100</td>
</tr>
<tr>
<td>Nitrates, expressed as NO₃</td>
<td>500</td>
</tr>
<tr>
<td>Lead, expressed as Pb²⁺</td>
<td>100</td>
</tr>
<tr>
<td>Zinc, expressed as Zn²⁺</td>
<td>100</td>
</tr>
</tbody>
</table>

- **Setting time and strength**
  The initial set, tested on specimens with the water, must not be less than 1 h and must not differ by more than 25 % from the initial set obtained on specimens with distilled or deionized water. The completion of setting must not be more than 12 h and must not differ by more than 25 % from the completion of setting obtained on specimens with distilled or deionized water.

The average compressive strength after 7 days of specimens produced with the water must reach at least 90 % of the compressive strength of the corresponding specimens produced with distilled or deionized water.
1.8 Material Volume Calculation

The purpose of the material volume calculation is to determine the concrete volume from the volume of the raw materials by calculation. The material volume means the volume of the individual concrete components. The calculation assumes that the designed quantities of cement, water, aggregate, admixtures and additives mixed for 1 m³ of fresh concrete, plus the voids after compaction, just add up to a volume of 1 m³.

*Calculation volumes and mass for 1 m³ of concrete*

<table>
<thead>
<tr>
<th>Raw material used for designed concrete</th>
<th>Dosage in %</th>
<th>Needs kg for 1 m³ (according to mix design)</th>
<th>Spec. density in kg/l</th>
<th>Yields litre for 1 m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>kg</td>
<td>3.15 (check locally)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional binder</td>
<td>kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additive Silcafume (additional binder)</td>
<td>kg</td>
<td>2.2 (check locally)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Admixture 1</td>
<td>kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Admixture 2</td>
<td>kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air expected or planned 1 % = 10 l in 1 m³</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixing water w/c (or w/b) = (including water content aggregates)</td>
<td>kg</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Total volume in litres without aggregates and sand**

<table>
<thead>
<tr>
<th>Aggregates and sand (in dry state)</th>
<th>kg</th>
<th>2.65 (check locally)</th>
<th>(= Δ for 1000 l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total concrete</td>
<td>kg (for 1 m³)</td>
<td>kg/l (spec. density of fresh concrete)</td>
<td>1000 l (= 1 m³)</td>
</tr>
</tbody>
</table>

→ = way of calculation

**Remark:** If total amount of admixture(s) exceeds 3 litres/m³ of concrete, water content of admixture(s) has to be included in calculation of water/cement ratio.
<table>
<thead>
<tr>
<th>Raw material used for designed concrete</th>
<th>Dosage in %</th>
<th>Needs kg for 1 m³ (according to mix design)</th>
<th>Spec. density in kg/l</th>
<th>Yields litre for 1 m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>kg</td>
<td>325</td>
<td>3.15 (check locally)</td>
<td>103</td>
</tr>
<tr>
<td>Kind: CEM I</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional binder</td>
<td>kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kind:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additive Silicafume (additional binder)</td>
<td>6%</td>
<td>19.5</td>
<td>2.2 (check locally)</td>
<td>9</td>
</tr>
<tr>
<td>(additional binder)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Admixture 1</td>
<td>1.2%</td>
<td>4.13</td>
<td>(incl. in water)</td>
<td></td>
</tr>
<tr>
<td>Kind: ViscoCrete® (calc. on cement + Silicafume)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Admixture 2</td>
<td>kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kind:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air expected or planned</td>
<td>%</td>
<td>3.0</td>
<td>–</td>
<td>30</td>
</tr>
<tr>
<td>1 % = 10 l in 1 m³</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixing water</td>
<td>kg</td>
<td>155</td>
<td>1.0</td>
<td>155*</td>
</tr>
<tr>
<td>w/c (or w/b) = 0.45 (w/b) (including water content aggregates)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total volume in litres without aggregates and sand</th>
<th>297</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregates and sand (in dry state)</td>
<td>kg 1863</td>
</tr>
<tr>
<td>Total concrete</td>
<td>kg 2362 (for 1 m³)</td>
</tr>
</tbody>
</table>

* approx. 1 litre of water has theoretically to be added (replacing approx. dry content admixture)

The European Concrete Standard EN 206-1:2000 was introduced in Europe with transition periods varying country by country. The name is abbreviated for simplicity to EN 206:1 below.

It applies to concrete for structures cast in situ, precast elements and structures, and structural precast products for buildings and civil engineering structures.

*It applies to*
- normalweight concrete
- heavyweight concrete
- lightweight concrete
- prestressed concrete

*European Standards are under preparation for the following types of concrete:*
- sprayed concrete
- concrete to be used in roads and other traffic areas

*It does not apply to:*
- aerated concrete
- foamed concrete
- concrete with open structure (“no-fines” concrete)
- mortar with maximum particle ⌀ ≤ 4 mm
- concrete with density less than 800 kg/m³
- refractory concrete

Concrete is specified either as *designed concrete* (consideration of the exposure classification and requirements) or as *prescribed concrete* (by specifying the concrete composition).

2.1 Definitions from the Standard

**Concrete properties, exposure**

- *Designed concrete*
  Concrete for which the required properties and additional characteristics are specified to the producer who is responsible for providing a concrete conforming to the required properties and additional characteristics.

- *Prescribed concrete*
  Concrete for which the composition of the concrete and the constituent materials to be used are specified to the producer who is responsible for providing a concrete with the specified composition.
Environmental actions (→ exposure classes)
Those chemical and physical actions to which the concrete is exposed and which result in effects on the concrete or reinforcement or embedded metal that are not considered as loads in structural design.

Specification
Final compilation of documented technical requirements given to the producer in terms of performance or composition.

Standardized prescribed concrete
Prescribed concrete for which the composition is given in a standard valid in the place of use of the concrete.

Specifier
Person or body establishing the specification for the fresh and hardened concrete.

Producer
Person or body producing fresh concrete.

User
Person or body using fresh concrete in the execution of a construction or a component.

Water balance of the concrete

Total water content
Added water plus water already contained in the aggregates and on the surface of the aggregates plus water in the admixtures and in additions used in the form of a slurry and water resulting from any added ice or steam heating.

Effective water content
Difference between the total water present in the fresh concrete and the water absorbed by the aggregates.

Water/cement ratio
Ratio of the effective water content to cement content by mass in the fresh concrete.

Load, delivery, place of use

Site-mixed concrete
Concrete produced on the construction site by the user of the concrete for his own use.

Ready-mixed concrete
Concrete delivered in a fresh state by a person or body who is not the user. Ready-mixed concrete in the sense of this standard is also
– concrete produced off site by the user
– concrete produced on site, but not by the user

Quantity of concrete transported in a vehicle comprising one or more batches.

**Batch**
Quantity of fresh concrete produced in one cycle of operations of a mixer or the quantity discharged during 1 min from a continuous mixer.

2.2 Exposure Classes related to environmental Actions

The environmental actions are classified as exposure classes. The exposure classes to be selected depend on the provisions valid in the place of use of the concrete. This exposure classification does not exclude consideration of special conditions existing in the place of use of the concrete or the application of protective measures such as the use of stainless steel or other corrosion resistant metal and the use of protective coatings for the concrete or the reinforcement.

The concrete may be subject to more than one of the actions described. The environmental conditions to which it is subjected may thus need to be expressed as a combination of exposure classes.

Table 2.2.1

<table>
<thead>
<tr>
<th>Class designation</th>
<th>Description of the environment</th>
<th>Informative examples where exposure classes may occur</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No risk of corrosion or attack</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X 0</td>
<td>For concrete without reinforcement or embedded metal: all exposures, except where there is freeze/thaw, abrasion or chemical attack</td>
<td>Concrete inside buildings with low air humidity</td>
</tr>
<tr>
<td></td>
<td>For concrete with reinforcement or embedded metal: very dry</td>
<td></td>
</tr>
<tr>
<td><strong>Corrosion induced by carbonation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X C 1</td>
<td>Dry or permanently wet</td>
<td>Concrete inside buildings with low air humidity. Concrete permanently submerged in water</td>
</tr>
<tr>
<td>X C 2</td>
<td>Wet, rarely dry</td>
<td>Concrete surfaces subject to long-term water contact; many foundations</td>
</tr>
<tr>
<td>X C 3</td>
<td>Moderate humidity</td>
<td>Concrete inside buildings with moderate or high air humidity; external concrete sheltered from rain</td>
</tr>
<tr>
<td>Class designation</td>
<td>Description of the environment</td>
<td>Informative examples where exposure classes may occur</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td>X C 4</td>
<td>Cyclic wet and dry</td>
<td>Concrete surfaces subject to water contact, not within exposure Class X C 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Corrosion induced by chlorides other than from sea water</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X D 1</td>
<td>Moderate humidity</td>
<td>Concrete surfaces exposed to airborne chlorides</td>
</tr>
<tr>
<td>X D 2</td>
<td>Wet, rarely dry</td>
<td>Swimming pools; concrete exposed to industrial waters containing chlorides</td>
</tr>
<tr>
<td>X D 3</td>
<td>Cyclic wet and dry</td>
<td>Parts of bridges exposed to spray containing chlorides; pavements; car park slabs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Corrosion induced by chlorides from sea water</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X S 1</td>
<td>Exposed to airborne salt but not in direct contact with sea water</td>
<td>Structures near to or on the coast</td>
</tr>
<tr>
<td>X S 2</td>
<td>Permanently submerged</td>
<td>Parts of marine structures</td>
</tr>
<tr>
<td>X S 3</td>
<td>Tidal, splash and spray zones</td>
<td>Parts of marine structures</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Freeze/thaw attack with or without de-icing agents</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X F 1</td>
<td>Moderate water saturation, without de-icing agent</td>
<td>Vertical concrete surfaces exposed to rain and freezing</td>
</tr>
<tr>
<td>X F 2</td>
<td>Moderate water saturation, with de-icing agent</td>
<td>Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents</td>
</tr>
<tr>
<td>X F 3</td>
<td>High water saturation, without de-icing agent</td>
<td>Horizontal concrete surfaces exposed to rain and freezing</td>
</tr>
<tr>
<td>X F 4</td>
<td>High water saturation, with de-icing agent</td>
<td>Road and bridge decks exposed to de-icing agents; concrete surfaces exposed to direct spray containing de-icing agents and freezing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chemical attack</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X A 1</td>
<td>Slightly aggressive chemical environment according to Table 2.2.2</td>
<td>Concrete in treatment plants; slurry containers</td>
</tr>
<tr>
<td>X A 2</td>
<td>Moderately aggressive chemical environment according to Table 2.2.2</td>
<td>Concrete components in contact with sea water; components in soil corrosive to concrete</td>
</tr>
<tr>
<td>X A 3</td>
<td>Highly aggressive chemical environment according to Table 2.2.2</td>
<td>Industrial effluent plants with effluent corrosive to concrete; silage tanks; concrete structures for discharge of flue gases</td>
</tr>
</tbody>
</table>
Limiting values for exposure classes for chemical attack from natural soil and ground water

Table 2.2.2

<table>
<thead>
<tr>
<th>Common name</th>
<th>Chemical characteristic</th>
<th>X A 1 (slightly aggressive)</th>
<th>X A 2 (moderately aggressive)</th>
<th>X A 3 (highly aggressive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphate</td>
<td>SO$_4^{2-}$ mg/l</td>
<td>(\geq 200) and (\leq 600)</td>
<td>(&gt; 600) and (\leq 3000)</td>
<td>(&gt; 3000) and (\leq 6000)</td>
</tr>
<tr>
<td>pH</td>
<td>mg/l</td>
<td>(\leq 6.5) and (\geq 5.5)</td>
<td>(&lt; 5.5) and (\geq 4.5)</td>
<td>(&lt; 4.5) and (\geq 4.0)</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO$_2$ mg/l</td>
<td>(\geq 15) and (\leq 40)</td>
<td>(&gt; 40) and (\leq 100)</td>
<td>(&gt; 100) up to saturation</td>
</tr>
<tr>
<td>Ammonium</td>
<td>NH$_4^+$ mg/l</td>
<td>(\geq 15) and (\leq 30)</td>
<td>(\geq 30) and (\leq 60)</td>
<td>(&gt; 60) and (\leq 100)</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg$^{2+}$ mg/l</td>
<td>(\geq 300) and (\leq 1000)</td>
<td>(&gt; 1000) and (\leq 3000)</td>
<td>(&gt; 3000) up to saturation</td>
</tr>
<tr>
<td>Soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphate</td>
<td>SO$_4^{2-}$ mg/kg</td>
<td>(\geq 2000) and (\leq 3000)</td>
<td>(\geq 3000) and (\leq 12000)</td>
<td>(&gt; 12000) and (\leq 24000)</td>
</tr>
</tbody>
</table>

A list of the exposure classes and associated minimum cement contents is given at the end of chapter 2 (page 30).
2.3 Classification by Consistence

The classes of consistence in the tables below are not directly related. For moist concrete, i.e. concrete with low water content, the consistence is not classified.

### Compaction classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Degree of compactability</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0¹</td>
<td>≥ 1.46</td>
</tr>
<tr>
<td>C1</td>
<td>1.45 to 1.26</td>
</tr>
<tr>
<td>C2</td>
<td>1.25 to 1.11</td>
</tr>
<tr>
<td>C3</td>
<td>1.10 to 1.04</td>
</tr>
</tbody>
</table>

### Flow classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Flow diameter in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1¹</td>
<td>≤ 340</td>
</tr>
<tr>
<td>F2</td>
<td>350 to 410</td>
</tr>
<tr>
<td>F3</td>
<td>420 to 480</td>
</tr>
<tr>
<td>F4</td>
<td>490 to 550</td>
</tr>
<tr>
<td>F5</td>
<td>560 to 620</td>
</tr>
<tr>
<td>F6¹</td>
<td>≥ 630</td>
</tr>
</tbody>
</table>

### Slump classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Slump in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>10 to 40</td>
</tr>
<tr>
<td>S2</td>
<td>50 to 90</td>
</tr>
<tr>
<td>S3</td>
<td>100 to 150</td>
</tr>
<tr>
<td>S4</td>
<td>160 to 210</td>
</tr>
<tr>
<td>S5¹</td>
<td>≥ 220</td>
</tr>
</tbody>
</table>

### Vebe classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Vebe time in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>V0¹</td>
<td>≥ 31</td>
</tr>
<tr>
<td>V1</td>
<td>30 to 21</td>
</tr>
<tr>
<td>V2</td>
<td>20 to 11</td>
</tr>
<tr>
<td>V3</td>
<td>10 to 6</td>
</tr>
<tr>
<td>V4²</td>
<td>up to 3</td>
</tr>
</tbody>
</table>

¹ Not in the recommended area of application  
² Not in the recommended area of application (but common for self-compacting concrete)
2.4 Compressive Strength Classes

The characteristic compressive strength of either 150 mm diameter by 300 mm cylinders or of 150 mm cubes may be used for classification.

**Compressive strength classes for normalweight and heavyweight concrete:**

<table>
<thead>
<tr>
<th>Compressive strength class</th>
<th>Minimum characteristic cylinder strength $f_{ck,\text{cyl}}$ N/mm²</th>
<th>Minimum characteristic cube strength $f_{ck,\text{cube}}$ N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 8 / 10</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>C 12 / 15</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>C 16 / 20</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>C 20 / 25</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>C 25 / 30</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>C 30 / 37</td>
<td>30</td>
<td>37</td>
</tr>
<tr>
<td>C 35 / 45</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td>C 40 / 50</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>C 45 / 55</td>
<td>45</td>
<td>55</td>
</tr>
<tr>
<td>C 50 / 60</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>C 55 / 67</td>
<td>55</td>
<td>67</td>
</tr>
<tr>
<td>C 60 / 75</td>
<td>60</td>
<td>75</td>
</tr>
<tr>
<td>C 70 / 85</td>
<td>70</td>
<td>85</td>
</tr>
<tr>
<td>C 80 / 95</td>
<td>80</td>
<td>95</td>
</tr>
<tr>
<td>C 90 / 105</td>
<td>90</td>
<td>105</td>
</tr>
<tr>
<td>C 100 / 115</td>
<td>100</td>
<td>115</td>
</tr>
</tbody>
</table>

**Compressive strength classes for lightweight concrete:**

<table>
<thead>
<tr>
<th>Compressive strength class</th>
<th>Minimum characteristic cylinder strength $f_{ck,\text{cyl}}$ N/mm²</th>
<th>Minimum characteristic cube strength $f_{ck,\text{cube}}$ N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC 8 / 9</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>LC 12 / 13</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>LC 16 / 18</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>LC 20 / 22</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>LC 25 / 28</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>LC 30 / 33</td>
<td>30</td>
<td>33</td>
</tr>
</tbody>
</table>
2.5 The \( k \)-Value (Extract from EN 206-1)

If type II additions are used (fly ash and Silicafume, see chapter 1, page 14), the \( k \)-value permits them to be taken into account in the calculation of the water in the fresh concrete. (The \( k \)-value concept may differ from country to country.)

Use of:

<table>
<thead>
<tr>
<th>Cement</th>
<th>“Water/cement ratio”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement and type II addition</td>
<td>“Water/(cement + ( k \times ) addition) ratio”</td>
</tr>
</tbody>
</table>

The actual value of \( k \) depends on the specific addition.

**\( k \)-value concept for fly ash conforming to EN 450**

The maximum amount of fly ash to be taken into account for the \( k \)-value concept shall meet the requirement:

\[
\text{Fly ash/cement} \leq 0.33 \text{ by mass}
\]

If a greater amount of fly ash is used, the excess shall not be taken into account for the calculation of the water/(cement + \( k \times \) fly ash) ratio and the minimum cement content.
The following $k$-values are permitted for concrete containing cement type CEM I conforming to EN 197-1:

<table>
<thead>
<tr>
<th>Cement Type</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I 32.5</td>
<td>0.2</td>
</tr>
<tr>
<td>CEM I 42.5 and higher</td>
<td>0.4</td>
</tr>
</tbody>
</table>

**Minimum cement content** for relevant exposure class (see page 30):

This may be reduced by a maximum amount of $k \times (\text{minimum cement content} - 200) \text{ kg/m}^3$.

Additionally, the amount of (cement + fly ash) shall not be less than the minimum cement content required.

The $k$-value concept is not recommended for concrete containing a combination of fly ash and sulphate resisting CEM I cement in the case of exposure classes XA2 and XA3 when the aggressive substance is sulphate.

**$k$-value concept for Silicafume conforming to prEN 13263:1998**

The maximum amount of Silicafume to be taken into account for the water/cement ratio and the cement content shall meet the requirement

Silicafume/cement $\leq 0.11$ by mass

If a greater amount of Silicafume is used, the excess shall not be taken into account for the $k$-value concept.

$k$-values permitted to be applied for concrete containing cement type CEM I conforming to EN 197-1:

<table>
<thead>
<tr>
<th>Water/Cement Ratio</th>
<th>$k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\leq 0.45$</td>
<td>2.0</td>
</tr>
<tr>
<td>$&gt; 0.45$</td>
<td>2.0</td>
</tr>
</tbody>
</table>
|                    | except for exposure Classes XC and XF where $k = 1.0$

**Minimum cement content** for relevant exposure class (see page 30):

This shall not be reduced by more than 30 kg/m$^3$ in concrete for use in exposure classes for which the minimum cement content is $\leq 300$ kg/m$^3$.

Additionally, the amount of (cement + $k \times$ Silicafume) shall be not less than the minimum cement content required for the relevant exposure class.
**Combined use of fly ash conforming to EN 450 and Silicafume conforming to prEN 13263**

To ensure sufficient alkalinity of the pore solution in reinforced and prestressed concrete, the following requirements shall be met for the maximum amount of fly ash and Silicafume:

- Fly ash $\leq (0.66 \times \text{cement} – 3 \times \text{Silicafume})$ by mass
- Silicafume/cement $\leq 0.11$ by mass

**2.6 Chloride Content (Extract from EN 206-1)**

The chloride content of a concrete, expressed as the percentage of chloride ions by mass of cement, shall not exceed the value for the selected class given in the table below.

<table>
<thead>
<tr>
<th>Concrete use</th>
<th>Chloride content class $^a$</th>
<th>Maximum chloride content by mass of cement $^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not containing steel reinforcement or other embedded metal with the exception of corrosion-resistant lifting devices</td>
<td>Cl 1.0</td>
<td>1.0 %</td>
</tr>
<tr>
<td>Containing steel reinforcement or other embedded metal</td>
<td>Cl 0.20</td>
<td>0.20 %</td>
</tr>
<tr>
<td></td>
<td>Cl 0.40</td>
<td>0.40 %</td>
</tr>
<tr>
<td>Containing prestressing steel reinforcement</td>
<td>Cl 0.10</td>
<td>0.10 %</td>
</tr>
<tr>
<td></td>
<td>Cl 0.20</td>
<td>0.20 %</td>
</tr>
</tbody>
</table>

$^a$ For a specific concrete use, the class to be applied depends upon the provisions valid in the place of use of the concrete.

$^b$ Where type II additions are used and are taken into account for the cement content, the chloride content is expressed as the percentage chloride ion by mass of cement plus total mass of additions that are taken into account.
Extract from EN 206-1: Annex F: Recommended limiting values for composition and properties of concrete

<table>
<thead>
<tr>
<th>Exposure classes</th>
<th>Carbonation-induced corrosion</th>
<th>Chloride-induced corrosion</th>
<th>Freeze/thaw attack</th>
<th>Aggressive chemical environments</th>
</tr>
</thead>
<tbody>
<tr>
<td>No risk of corrosion or attack</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum w/c</td>
<td>0.65</td>
<td>0.60</td>
<td>0.55</td>
<td>0.50</td>
</tr>
<tr>
<td>Minimum strength class</td>
<td>C12/15</td>
<td>C20/</td>
<td>C25/</td>
<td>C30/</td>
</tr>
<tr>
<td>Minimum cement content (kg/m³)</td>
<td>–</td>
<td>260</td>
<td>280</td>
<td>280</td>
</tr>
<tr>
<td>Minimum air content (%)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Other requirements</td>
<td>Aggregate in accordance with EN 12620 with sufficient freeze/thaw resistance</td>
<td>Sulphate resisting cement</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where the concrete is not air entrained, the performance of concrete should be tested according to an appropriate test method in comparison with a concrete for which freeze/thaw resistance for the relevant exposure class is proven.

Moderate or high sulphate resisting cement in exposure Class XA2 (and in exposure Class XA1 when applicable) and high sulphate resisting cement in exposure Class XA3.
2.7 Specification of Concrete

The concrete grade designations have changed due to the introduction of EN 206-1 (e.g. for a tender).

Example: Pumped concrete for ground slab in ground water area

**Specification conforming to EN 206-1 (designed concrete)**

Concrete conforming to EN 206-1
C 30/37
XC 4
Cl 0.20
Dmax 32 (max. particle Ø)
C3 (degree of compactability)
Pumpable

2.8 Conformity Control

This comprises the combination of actions and decisions to be taken in accordance with conformity rules adopted in advance to check the conformity of the concrete with the specification.

The conformity control distinguishes between designed concrete and prescribed concrete. Other variable controls are also involved depending on the type of concrete.

The conformity control may be performed either on individual concretes and/or concrete families.

**Minimum rate of sampling for assessing compressive strength**
(to EN 206-1)

<table>
<thead>
<tr>
<th>Up to 50 m³</th>
<th>More than 50 m³&lt;sup&gt;a&lt;/sup&gt;</th>
<th>More than 50 m³&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete with production control certification</td>
<td>Concrete without production control certification</td>
<td></td>
</tr>
<tr>
<td>Initial (until at least 35 test results are obtained)</td>
<td>3 samples</td>
<td>1/200 m³ or 2/production week</td>
</tr>
<tr>
<td>Continuous&lt;sup&gt;b&lt;/sup&gt; (when at least 35 test results are available)</td>
<td>1/400 m³ or 1/production week</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Sampling shall be distributed throughout the production and should not be more than 1 sample within each 25 m³.

<sup>b</sup> Where the standard deviation of the last 15 test results exceeds 1.37 σ, the sampling rate shall be increased to that required for initial production for the next 35 test results.

Conformity criteria for compressive strength: see EN 206-1.
2.9 Proof of other Concrete Properties

Certificates of conformity according to EN 206-1 must be provided for other fresh and hardened concrete properties in addition to compressive strength.

A sampling and testing plan and conformity criteria are specified for tensile splitting strength, consistence (workability), density, cement content, air content, chloride content and w/c ratio (see the relevant sections in EN 206-1).

Details of individual test methods are given in chapter 4 (page 83) and chapter 5 (page 105).
3. Concrete

3.1 Main Uses of Concrete

It makes sense to classify the uses of concrete on the basis of where and how it is produced, together with its method of application, since these have different requirements and properties. The sales of cement in two European countries in 2002 are given as an example of how the percentages vary for the different distribution and usage channels for the overall methods of use:

<table>
<thead>
<tr>
<th>Switzerland</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approx. 72 % to ready-mix plants</td>
<td>Approx. 55 % to ready-mix plants</td>
</tr>
<tr>
<td>Approx. 17 % to builders’ merchants</td>
<td>Approx. 20 % to concrete product manufacturers</td>
</tr>
<tr>
<td>Approx. 7 % to precasting</td>
<td>Approx. 11 % to precast component producers</td>
</tr>
<tr>
<td>Approx. 4 % to other outlets</td>
<td>Approx. 14 % to other outlets</td>
</tr>
</tbody>
</table>
Concrete cast in situ is site-mixed or ready-mixed concrete which remains in its final position in the structure after being placed in the formwork.

The ready-mix plant facilities from which the concrete is delivered have now become so widespread in many markets that the contractor can be supplied quickly and reliably.

A facility on site still offers economic and logistic advantages on large construction sites where concrete is required continuously.

Concrete cast in situ can be produced in different variations and must conform with a variety of specifications. Its application can be divided into the following stages:

**Preparation of concrete design**

When preparing the design, the concrete performance must be defined by the specific project requirements. The following parameters should be defined:

- Strength requirements
- Durability requirements
- Aesthetic requirements
- Maximum particle diameter
- Method of placement
- Placing rate
- Concrete consistence
- General boundary conditions (temperature etc.)
- Delivery method and time
- Curing/waiting time
- Definition of test requirements
- Mix design and specification
- Preliminary testing
- Mix design adjustment if necessary

The concretes obtained from these parameters are detailed in section 3.2 (page 37). The fresh concrete properties are discussed in detail in chapter 4 (page 72) and the hardened concrete properties in chapter 5 (page 91).

The testing of fresh concrete is discussed in chapter 4 (page 83) and of hardened concrete in chapter 5 (page 105).

**Production**

Production is a critical factor for the resulting concrete and consists basically of dosing and mixing the raw materials. The following parameters can affect the concrete properties during mixing:

- Type of mixer
- Size of mixer
- Mixing intensity
- Mixing time
- Addition of raw materials
- Plant quality control
- Concrete mixer operator
- Cleaning/maintenance of mixer
Superplasticizers should generally be mixed with the mixing water or added to the mix with it (at the earliest). Further information can be found in the relevant Sika Product Data Sheets.

**Preparation on site**
The preparation on site includes the following:
– Installation of the concrete handling/placing systems
– Preparation of the formwork (including release agent application)
– Reinforcement check
– Formwork check (fixing, integrity, form pressure)
– Supply of tools for compacting (vibrators etc.) and finishing (beams and trowels etc.)

**Delivery**
If the concrete is supplied by ready mix trucks, the following additional criteria must be considered:
– Delivery time (traffic conditions, potential hold-ups etc.)
– Define the necessary drum revolutions during the journey
– Do not leave the ready mix truck standing in the sun during waiting periods
– For a fluid consistence (SCC), define the maximum capacity to be carried
– Do not add water or extra doses of admixture (unless specified)
– Mix again thoroughly before unloading (1 minute per m³)

**Placing the concrete**
The concrete is generally placed within a limited and defined time period. The following factors contribute to the success of this operation, which is critical for the concrete quality:
– Delivery note check
– Use of the right equipment (vibrators etc.)
– Avoid overhandling the concrete
– Continuous placing and compacting
– Re-compaction on large pours
– Take the appropriate holding measures during interruptions
– Carry out the necessary finishing (final inspection)

**Curing**
To achieve constant and consistent concrete quality, appropriate and correct curing is essential. The following curing measures contribute to this:
– Generally protect from adverse climatic influences (direct sun, wind, rain, frost etc.)
– Prevent vibration (after finishing)
– Use a curing agent
– Cover with sheets or frost blankets
– Keep damp/mist or spray if necessary
– Maintain the curing time relevant to the temperature
Detailed information on curing is given in chapter 8 (page 134).
3.1.2 Concrete for Precast Structures

Precast concrete is used to form structures which are delivered after hardening. Long journeys in the fresh concrete state disappear, which changes the whole production sequence. Concrete used for the production of precast structures requires an industrialized production process, and a good concrete mix design with continuous optimization is essential. The following points are important through the different stages of the process:

- **Preparation of concrete design**
  When preparing the design, the concrete requirements must be defined according to the specific elements, their intended use and exposure conditions. The following parameters should normally be defined:
  - Strength requirements
  - Durability requirements
  - Aesthetic requirements
  - Maximum particle diameter
  - Method of placement
  - Placing rate
  - Concrete consistence
  - General boundary conditions (temperature etc.)
  - Handling of the concrete and its placing
  - Definition of test requirements
  - Consideration of the specific concrete element parameters
  - Curing definition
  - Mix design and specification
  - Preliminary testing
  - Mix design adjustment if necessary

The concretes obtained from these parameters are detailed in section 3.2 (page 37). The fresh concrete properties are discussed in detail in chapter 4 (page 72) and the hardened concrete properties in chapter 5 (page 91). The testing of fresh concrete is discussed in section 4.2 (page 83) and of hardened concrete in section 5.2 (page 105).

- **Production**
  Production is a critical factor for the resulting concrete and consists basically of dosing and mixing the raw materials. The following parameters can affect the concrete properties during mixing:
  - Type of mixer
  - Size of mixer
  - Mixing intensity
  - Mixing time
  - Addition of raw materials
  - Plant quality control
  - Concrete mixer operator
  - Cleaning/maintenance of mixer
Superplasticizers should generally be mixed with the mixing water or added to the mix with it (at the earliest). Further information can be found in the relevant Sika Product Data Sheets.

**Preparation**
The preparations at the precast plant include the following:
- Supply of the formwork and handling equipment
- Preparation of the formwork (including release agent application)
- Reinforcement check
- Formwork check (fixing, integrity)
- Supply of tools for concrete placing and finishing

**Placing the concrete**
The concrete is generally placed within a defined short time span. The following factors contribute to the success of this operation, which is critical for the concrete quality:
- Inspection of the concrete to be placed
- Use of the right equipment (vibrators)
- Avoid overhandling the concrete
- Continuous placing and compacting
- Very careful finishing
- Final check

**Curing**
Since precasting generally involves continuous production, short intervals are required in all of the production phases, curing is therefore particularly important because of its time constraints:
- Include the curing in the concrete design
- Use steam curing if necessary
- Prevent vibration (after finishing)
- Use a curing agent
- Cover with sheets or frost blankets
- Keep damp/mist or spray if necessary
- Maintain the curing time relevant to the temperature
Detailed information on curing is given in chapter 8 (page 134).

### 3.2 Special Concretes

#### 3.2.1 Pumped Concrete

Pumped concrete is used for many different requirements and applications nowadays. A suitable concrete mix design is essential so that the concrete can be pumped without segregation and blocking of the lines.

**Composition**

- **Aggregate**
  - Max. particle $\varnothing < 1/3$ of pipe bore
  - The fine mortar in the pumped mix must have good cohesion to prevent the concrete segregating during pumping.
Standard values for finest grain content (content $\leq 0.125$ mm)
according to EN 206-1:2000

<table>
<thead>
<tr>
<th>Particle Ø 8 mm</th>
<th>Particle Ø 16 mm</th>
<th>Particle Ø 32 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 kg/m³</td>
<td>400 kg/m³</td>
<td>350 kg/m³</td>
</tr>
</tbody>
</table>

Sika recommendation:

<table>
<thead>
<tr>
<th>Max. particle Ø</th>
<th>Round aggregate</th>
<th>Crushed aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 mm</td>
<td>500 kg/m³</td>
<td>525 kg/m³</td>
</tr>
<tr>
<td>16 mm</td>
<td>425 kg/m³</td>
<td>450 kg/m³</td>
</tr>
<tr>
<td>32 mm</td>
<td>375 kg/m³</td>
<td>400 kg/m³</td>
</tr>
</tbody>
</table>

Particle size distribution curve: Pumped concrete should be composed of different individual constituents if possible. A continuously graded particle-size distribution curve is important. The 4–8 mm content should be kept low, but there should be no discontinuous gradation.

Cement

Recommended minimum cement content

<table>
<thead>
<tr>
<th>Max. particle Ø</th>
<th>Round aggregate</th>
<th>Crushed aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 mm</td>
<td>380 kg/m³</td>
<td>420 kg/m³</td>
</tr>
<tr>
<td>16 mm</td>
<td>330 kg/m³</td>
<td>360 kg/m³</td>
</tr>
<tr>
<td>32 mm</td>
<td>300 kg/m³</td>
<td>330 kg/m³</td>
</tr>
</tbody>
</table>
**Water/binder ratio**

If the water content is too high, segregation and bleeding occurs during pumping and this can lead to blockages. The water content should always be reduced by using superplasticizers.

**Workability**

The fresh concrete should have a soft consistence with good internal cohesion. Ideally the pumped concrete consistence should be determined by the degree of compactability.

**Fresh concrete consistence**

<table>
<thead>
<tr>
<th>Test method</th>
<th>Consistence class</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of compactability</td>
<td>C2–C3</td>
<td>1.04–1.25</td>
</tr>
<tr>
<td>Flow diameter</td>
<td>F3–F4</td>
<td>42–55 cm</td>
</tr>
</tbody>
</table>

**Pumping agents**

Difficult aggregates, variable raw materials, long delivery distances or high volume installation rates require a pumping agent. This reduces friction and resistance in the pipe, reduces the wear on the pump and the pipes and increases the volume output.

**Pump lines**

- ∅ 80 to 200 mm (normally ∅ 100, 125 mm)
- The smaller the ∅, the more complex the pumping (surface/cross-section)
- The couplings must fit tightly to prevent loss of pressure and fines
- The first few metres should be as horizontal as possible and without bends. (This is particularly important ahead of risers.)
- Protect the lines from very strong sunlight in summer

**Lubricant mixes**

The lubricant mix is intended to coat the internal walls of the pipe with a high-fines layer to allow easy pumping from the start.

- Conventional mix: Mortar 0–4 mm, cement content as for the following concrete quality or slightly higher. Quantity dependent on ∅ and line length

**Effect of air content on pumped concrete**

Freeze/thaw resistant concrete containing micropores can be pumped if the air content remains < 5 %, as increased resilience can be generated with a higher air content.
Concrete for traffic areas has many applications and is often installed as an alternative to blacktop because of its durability and other advantages. The uses of concrete for traffic areas:

- Conventional road building
- Concrete roundabouts
- Runways
- Industrial floors

When concrete is used for these applications, the concrete layer acts as both a load bearing and a wearing course. To meet the requirements for both courses, the concrete must have the following properties:

- High flexural strength
- Freeze/thaw resistance
- Good skid resistance
- Low abrasion

The composition is a vital factor in achieving the desired requirements. The criteria for selection of the various constituents are as follows:

- **Aggregate**
  - Use of low fines mixes
  - Use of a balanced particle size distribution curve
  - Crushed or partly crushed aggregate increases the skid resistance and flexural strength

- **Cement**
  - Dosage 300–350 kg/m², usually CEM I 42.5

### Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sikament®</td>
<td>Superplasticizer</td>
<td>Water reduction. Increased strength and impermeability with guaranteed consistence (workability) and pumpability</td>
</tr>
<tr>
<td>Sika® ViscoCrete®</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SikaFume®</td>
<td>Silicafume</td>
<td>High strength, increased impermeability, improved pumpability</td>
</tr>
<tr>
<td>SikaPump®</td>
<td>Pumping agent</td>
<td>Supports the pumping of difficult aggregates and protects the equipment from excessive wear</td>
</tr>
<tr>
<td>Sika® Stabilizer</td>
<td>Stabilizer</td>
<td>Maintains internal cohesion. Supports the pumping of difficult aggregates and protects the equipment from excessive wear</td>
</tr>
</tbody>
</table>

---

### 3.2.2 Concrete for Traffic Areas

Concrete for traffic areas has many applications and is often installed as an alternative to blacktop because of its durability and other advantages.

The uses of concrete for traffic areas:

- Conventional road building
- Concrete roundabouts
- Runways
- Industrial floors

When concrete is used for these applications, the concrete layer acts as both a load bearing and a wearing course. To meet the requirements for both courses, the concrete must have the following properties:

- High flexural strength
- Freeze/thaw resistance
- Good skid resistance
- Low abrasion

The composition is a vital factor in achieving the desired requirements. The criteria for selection of the various constituents are as follows:

- **Aggregate**
  - Use of low fines mixes
  - Use of a balanced particle size distribution curve
  - Crushed or partly crushed aggregate increases the skid resistance and flexural strength

- **Cement**
  - Dosage 300–350 kg/m², usually CEM I 42.5
Additives
- Silicafume for use in heavily traffic areas or to increase the durability generally
- Increase in the skid resistance by spreading silicon carbide or chippings into the surface

Concrete for traffic areas is a special concrete and the following points require special attention:
- Large areas are often installed using paving machines. The consistence must be suitable for the type of machine
- Improvement in skid resistance by cut grooves or brush finishing
- Thorough curing is essential

Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sikament®</td>
<td>Superplasticizer</td>
<td>Water reduction. Improved compressive and flexural strength. Improved consistence</td>
</tr>
<tr>
<td>Sika® ViscoCrete®</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SikaFume®</td>
<td>Silicafume</td>
<td>High strength, increased impermeability</td>
</tr>
<tr>
<td>SikaAer®</td>
<td>Air entrainer</td>
<td>Air entrainment to increase freeze/thaw resistance</td>
</tr>
<tr>
<td>SikaRapid®</td>
<td>Hardening accelerator</td>
<td>Faster strength development</td>
</tr>
<tr>
<td>Sika Retarder®</td>
<td>Set retarder</td>
<td>Retarded initial set</td>
</tr>
<tr>
<td>Sika® Antisol®-E20</td>
<td>Curing agent</td>
<td>Protection from premature drying</td>
</tr>
</tbody>
</table>

3.2.3 Self-compacting Concrete (SCC)

Self-compacting concrete (SCC) has a higher fines content than conventional concrete due to a higher binder content and a different particle size distribution curve. These adjustments, combined with specially adapted superplasticizers, produce unique fluidity and inherent compactability. Self-compacting concrete opens up new potential beyond conventional concrete applications:
- Use with close meshed reinforcement
- For complex geometric shapes
- For slender components
- Generally where compaction of the concrete is difficult
- For specifications requiring a homogeneous concrete structure
- For fast installation rates
- To reduce noise (eliminate or reduce vibration)
- To reduce damage to health (“white knuckle” syndrome)
Composition

Aggregate
Smaller maximum particle sizes of approx. 12 to 20 mm are preferable, but all aggregates are possible in principle.

Example of aggregate grading

<table>
<thead>
<tr>
<th>Particle size fraction</th>
<th>SCC 0/8 mm</th>
<th>SCC 0/16 mm</th>
<th>SCC 0/32 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/ 4 mm</td>
<td>60 %</td>
<td>53 %</td>
<td>45 %</td>
</tr>
<tr>
<td>4/ 8 mm</td>
<td>40 %</td>
<td>15 %</td>
<td>15 %</td>
</tr>
<tr>
<td>8/16 mm</td>
<td>–</td>
<td>32 %</td>
<td>15 %</td>
</tr>
<tr>
<td>16/32 mm</td>
<td>–</td>
<td>–</td>
<td>30 %</td>
</tr>
</tbody>
</table>

Fines content $\leq 0.125$ mm (cement, additives and fines)

| SCC 0/4 mm | ≥ 650 kg/m$^3$ |
| SCC 0/8 mm | ≥ 550 kg/m$^3$ |
| SCC 0/16 mm | ≥ 500 kg/m$^3$ |
| SCC 0/32 mm | ≥ 475 kg/m$^3$ |

Binder content

Based on the fines content, the following cement and aggregate contents can be determined, dependent on the concrete quality required and the sands used:

Cement and additives content (total)

| SCC 0/4 mm | 550–600 kg/m$^3$ |
| SCC 0/8 mm | 450–500 kg/m$^3$ |
| SCC 0/16 mm | 400–450 kg/m$^3$ |
| SCC 0/32 mm | 375–425 kg/m$^3$ |

Water content

The water content in SCC depends on the concrete quality requirements and can be defined as follows:

<table>
<thead>
<tr>
<th>Water content</th>
<th>Concrete quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 200 l/m$^3$</td>
<td>Low concrete quality</td>
</tr>
<tr>
<td>180 to 200 l/m$^3$</td>
<td>Standard concrete quality</td>
</tr>
<tr>
<td>&lt; 180 l/m$^3$</td>
<td>High concrete quality</td>
</tr>
</tbody>
</table>

Concrete admixtures

To adjust these water contents and ensure the homogeneity and the viscosity adjustment, 3$^{rd}$ generation superplasticizers of the Sika® ViscoCrete® type should be specified.
Installation of SCC

Formwork facing
The forms for SCC must be clean and tight. The form pressures can be higher than for normal vibrated concrete. The form pressure is dependent on the viscosity of the concrete, the installation rate and the filling point. The full hydrostatic pressure potential of the concrete should be used for the general formwork design.

Placing method
Self-compacting concrete is installed in the same way as conventional concrete. SCC must not be freely discharged from a great height. The optimum flow potential and surface appearance are obtained by filling the form from below. This can be achieved by using tremie pipes etc.

Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sika® ViscoCrete®-1</td>
<td>SCC superplasticizer (summer product)</td>
<td>Increased strength and impermeability</td>
</tr>
<tr>
<td>Sika® ViscoCrete®-2</td>
<td>SCC superplasticizer (winter product)</td>
<td>High water reduction Helps self-compacting properties</td>
</tr>
<tr>
<td>Sika® ViscoCrete®-20 HE</td>
<td>SCC superplasticizer (precasting)</td>
<td>Boosts internal cohesion</td>
</tr>
<tr>
<td>SikaFume®</td>
<td>Silicafume</td>
<td>High strength, increased impermeability Supports the stability of the entrained air</td>
</tr>
<tr>
<td>Sika® Stabilizer</td>
<td>Stabilizer</td>
<td>Boosts cohesion Finest grain substitute</td>
</tr>
<tr>
<td>SikaAer®</td>
<td>Air entrainer</td>
<td>Air entrainment for the production of freeze/thaw resistant SCC</td>
</tr>
<tr>
<td>SikaRapid®</td>
<td>Hardening accelerator</td>
<td>Control of the setting and hardening process of SCC</td>
</tr>
<tr>
<td>Sika Retarder®</td>
<td>Set retarder</td>
<td></td>
</tr>
</tbody>
</table>

3.2.4 Frost and Freeze/Thaw resistant Concrete

Frost and freeze/thaw resistant concrete must always be used when concrete surfaces are exposed to weather (wet) and the surface temperature can fall below freezing.

- Fair-faced concrete façades
- Bridge structures
- Tunnel portal areas
- Traffic areas
- Retaining walls
By adding air entrainers, small, spherical, closed air voids are generated during the mixing process in the ultra-fine mortar area (cement, finest grain, water) of the concrete. The aim is to ensure that the hardened concrete is frost and freeze/thaw resistant (by creating room for expansion of any water during freezing conditions).

**Type, size and distribution of air voids**

Air voids contained in a standard concrete are generally too large (> 0.3 mm) to increase the frost and freeze/thaw resistance. **Effective air voids** are introduced through special air entrainers. The air voids are generated physically during the mixing period. To develop their full effect, they must not be too far from each other. The “effective spacing” is defined by the so-called **spacing factor SF**.

**Production/mixing time**

To ensure high frost and freeze/thaw resistance, the wet mixing time must be longer than for a standard concrete and continue after the air entrainer is added. Increasing the mixing time from 60 to 90 seconds improves the content of the air voids by up to 100 %.

**Quantity of air voids required**

To obtain high frost resistance, the cement matrix must contain about 15 % of suitable air voids. Long experience confirms that there are enough effective air voids in a concrete if the results of the test (air pot) show the following air contents:
- Concrete with 32 mm maximum particle size 3 % to 5 %
- Concrete with 16 mm maximum particle size 4 % to 6 %

Fresh concrete with an air void content of 7 % or over should only be installed after detailed investigation and testing.

**The factors influencing air entrainment**

■ **Granulometry**

The air voids are mainly formed around the 0.25–0.5 mm sand fraction. Larger particles have no effect on the air entrainment. Ultrafines from the sand constituents or the cements and some admixtures can inhibit air entrainment.

■ **Consistence**

Optimum air entrainment is achieved in the plastic to soft plastic range. A concrete that is softened by the addition of extra water might not retain the air voids as well or as long as the original concrete.

■ **Temperature**

The air entrainment capability decreases as fresh concrete temperatures rise and vice versa.
Delivery
A change in the air content can be expected during delivery. Dependent on the method of delivery and the vibration during the journey, mixing or demixing processes take place in the concrete. Air-entrained concrete must be mixed again before installation and the critical air content is only then determined.

Compaction of air-entrained concrete
Correct vibration mainly removes the air “entrapped” during placing, including the coarse voids in the concrete. Pronounced overvibration can also reduce the “entrained” air by 10 to 30%. Concrete susceptible to segregation can then lose almost all of the air voids or exhibit foaming on the surface.

Finest grain replacement
1% of entrained air can replace approximately 10 kg of ultra-fine material (< 0.2 mm) per m³ of concrete. Air voids can improve the workability of rough, low-fines mixes.

Design of air-entrained concrete
Detailed specifications for strength, air content and test methods must be given. For major projects, preliminary tests should be carried out under actual conditions. During the concreting works check the air content at the concrete plant and before placing.

<table>
<thead>
<tr>
<th>Characteristics of air voids</th>
<th>Shape: spherical and closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size: 0.02 to 0.30 mm</td>
<td>Spacing factors:</td>
</tr>
<tr>
<td></td>
<td>≤ 0.20 mm frost resistant</td>
</tr>
<tr>
<td></td>
<td>≤ 0.15 mm freeze/thaw resistant</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Positive secondary effects</th>
<th>Improvement in workability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Blocking of capillary pores</td>
</tr>
<tr>
<td></td>
<td>(water resistance)</td>
</tr>
<tr>
<td></td>
<td>Better cohesion of the fresh concrete</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Negative effects</th>
<th>Reduction in mechanical strengths</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(compressive strength)</td>
</tr>
</tbody>
</table>

Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sika ViscoCrete®</td>
<td>Superplasticizer</td>
<td>To reduce the capillary porosity and therefore introduce less water</td>
</tr>
<tr>
<td>SikaAer®</td>
<td>Air entrainer</td>
<td>Air entrainment to ensure freeze/thaw resistance</td>
</tr>
<tr>
<td>SikaFume® Sikacrete®</td>
<td>Silicafume</td>
<td>For further compaction of the hardened cement paste and improvement of the bond between aggregate and hardened cement paste</td>
</tr>
</tbody>
</table>
3.2.5 High Strength Concrete

**High compressive strength**
Concretes with high compressive strengths (> 60 MPa) are classified in the high performance concretes group and are used in many different structures. They are often used in the construction of high load bearing columns and for many products in precast plants.

**Conventional high strength concrete mixes**
In conventional high strength concrete production, the mix and the constituents require particular care, as does the placing.
- High strength aggregates with a suitable particle surface (angular) and reduced particle size (< 32 mm)
- A highly impermeable and therefore high strength cement matrix due to a substantial reduction in the water content
- Special binders with high strength development and good adhesion to the aggregates (Silicafume)
- Use of a soft concrete consistence using concrete admixtures to ensure maximum de-aeration

*Sample mix:*

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I 52.5</td>
<td>450 kg/m³</td>
</tr>
<tr>
<td>Silicafume</td>
<td>45 kg/m³</td>
</tr>
<tr>
<td>Aggregates</td>
<td>Crushed siliceous limestone 0–16 mm</td>
</tr>
<tr>
<td>Eq. w/c ratio</td>
<td>0.28</td>
</tr>
<tr>
<td>Strength after 7 days</td>
<td>95 MPa</td>
</tr>
<tr>
<td>Strength after 28 days</td>
<td>110 MPa</td>
</tr>
<tr>
<td>Strength after 90 days</td>
<td>115 MPa</td>
</tr>
</tbody>
</table>

**Innovative high strength concrete mixes**
Many different alternative mixes for high strength concrete (and mortars) are being developed alongside conventional concrete mixes. The search for high strength constituents and a minimum water content is common to them all. Special aggregate particles and gradings with superplasticizers are used to achieve this. Strength development is also boosted by new drying and hardening techniques (such as compression hardening). Concretes produced in this way, which are more usually mortars, can reach strengths of 150 MPa to 200 MPa plus.

Note in particular that:
- High strength concrete is always highly impermeable
- Therefore the curing of high strength concrete is even more important than usual (inadequate supply of moisture from inside the concrete)
High strength concrete is also brittle because of its strength and increased stiffness (impact on shear properties)

- By reducing the water content to below 0.38 some cement grains act as aggregate grains because not all of the cement can be hydrated
- Apart from Portland cement, high strength concrete uses large quantities of latent hydraulic and pozzolanic materials which have excellent long term strength development properties

### Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sika® ViscoCrete®</strong></td>
<td>Superplasticizer</td>
<td>For maximum reduction of the water content and therefore strengthening of the hardened cement paste</td>
</tr>
<tr>
<td><strong>SikaFume®</strong></td>
<td>Silicafume</td>
<td>For further compaction and strengthening of the hardened cement paste and to improve the bond between aggregate and hardened cement paste</td>
</tr>
</tbody>
</table>

### 3.2.6 Slipformed Concrete

In the slipforming method, the formwork is moved continuously in sync with the concreting process in a 24-hour operation. The formwork, including the working platform and the hanging scaffold mounted internally or on both sides, is fixed to the jacking rods in the centre of the wall. The hydraulic oil operated lifting jack raises the formwork by 15 to 30 cm per hour depending on the temperature. The jacking rods are located in pipe sleeves at the top and are supported by the concrete that has already hardened. The rods and sleeves are also raised continuously. These works are carried out almost entirely by specialist contractors.

Slipforming is quick and efficient. The method is particularly suitable for simple, consistent ground plans and high structures such as:

- High bay warehouses, silos
- Tower and chimney structures
- Shaft structures

Because the height of the formwork is usually only around 1.20 m and the hourly production rate is 20 to 30 cm, the concrete underneath is 4–6 hours old and must be stiff enough to bear its own weight (green strength). However, it must not have set enough for some of it to stick to the rising formwork (“plucking”). The main requirement for slipforming without problems is concreting all areas at the same level at the same time, and then the simultaneous setting of these layers. Therefore the temperature has a major influence, along with the requirement for the consistently optimum w/c ratio.
**Composition**

- **Aggregate**
  - 0–32 mm, or 0–16 mm for close reinforcement
  - Although slipformed concrete is mainly crane handled concrete, the fines content should be as for pumped concrete

- **Cement**
  - Min. 300 kg/m³
  - CEM I 42.5 for close reinforcement and large dimensions, CEM I 52.5 for smaller dimensions (towers, chimneys)

**Workability**

The best workability has proved to be a stiff plastic concrete having a flow diameter of 35–40 cm and a low water content.

**Note in particular that**

a wall thickness of less than 14 cm can be a problem (plucking, anchorage of jacking rods etc.).

The newly struck surfaces should be protected as much as possible from wind, sunlight etc.

**Sika product use**

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sikament®</strong></td>
<td>Superplasticizer (higher temperatures)</td>
<td>Increased strength and impermeability</td>
</tr>
<tr>
<td><strong>Sika® ViscoCrete®-20 HE</strong></td>
<td>Superplasticizer (with increased flow capabilities)</td>
<td>Substantial water reduction Good initial strength development</td>
</tr>
<tr>
<td><strong>SikaFume®</strong></td>
<td>Silicafume</td>
<td>High strength, increased impermeability Fines enrichment</td>
</tr>
<tr>
<td><strong>Sika® Stabilizer</strong></td>
<td>Stabilizer</td>
<td>Boosts cohesion Fines replacement</td>
</tr>
<tr>
<td><strong>SikaAer®</strong></td>
<td>Air entrainer</td>
<td>Introduction of air voids Production of frost and freeze/thaw resistant slipformed concrete</td>
</tr>
<tr>
<td><strong>SikaRapid®</strong></td>
<td>Hardening accelerator Retarder</td>
<td>Control of the setting and hardening processes of slipformed concrete</td>
</tr>
</tbody>
</table>
3.2.7 Waterproof Concrete

Waterproof concrete is normally an impermeable concrete. To obtain an impermeable concrete, a suitable particle-size distribution curve must be generated and the capillary porosity should be reduced. The water resistance testing is discussed in section 5.1.3 (page 95).

Measures to reduce the capillary porosity are as follows:

- Reduction in w/c ratio
- Additional sealing of the voids with pozzolanic reactive material

The concrete curing process is another parameter affecting the water resistance.

**Composition**

- **Aggregate**
  - Well graded particle-size distribution curve
  - Fines content of the aggregate kept low
  - Adjustment to the binder content is usually necessary to obtain a satisfactory fines content

- **Cement**
  Conformity with the minimum cement content according to EN-206

- **Additions**
  Use of pozzolanic or latent hydraulic additions

- **w/c ratio**
  Low w/c ratio to reduce the capillary porosity

**Placing**

- A plastic to soft concrete is recommended to produce waterproof concrete
- Careful and correct compaction of the concrete is important

**Curing**

- Immediate and thorough curing is essential; see chapter 8 (page 134).

**Sika product use**

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sikament®</td>
<td>Superplasticizer</td>
<td>Increased strength and impermeability</td>
</tr>
<tr>
<td>Sika® ViscoCrete®</td>
<td></td>
<td>Substantial water reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction in capillary porosity</td>
</tr>
<tr>
<td>SikaFume®</td>
<td>Silicafume</td>
<td>High strength, increased impermeability</td>
</tr>
<tr>
<td>Sika®-1</td>
<td>Pore blocker</td>
<td>Reduction in capillary porosity</td>
</tr>
<tr>
<td>SikaAer®</td>
<td>Air entrainer</td>
<td>Air entrainment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interruption of capillary voids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction in water absorption</td>
</tr>
</tbody>
</table>
3.2.8 Fair-faced Concrete

In modern architecture concrete is increasingly used as a design feature as well as for its mechanical properties. This means higher specifications for the finish (exposed surfaces). There are many ways to produce special effects on these exposed surfaces:

- Select a suitable concrete mix
- Specify the formwork material and type (the formwork must be absolutely impervious!)
- Use the right quantity of a suitable release agent
- Select a suitable placement method
- Use form liners if necessary
- Consider any necessary retouching
- Colour using pigments
- Install correctly (compaction, placing etc.)
- Thorough curing

In addition to all of these factors listed, the following are important for the concrete mix:

- **Aggregate**
  - Use high fines mixes
  - Minimum fines content as for pumped concrete
  - Select a balanced particle-size distribution curve
  - Use rounded material if possible
  - Allow for any colour differences in the aggregate

- **Cement**
  - Any grade of cement can be used
  - Allow for the effect of the cement on the colour of the exposed surface
  - Generally > 300 kg/m³

- **Additions**
  - Use specific additions for systematic improvement of the concrete properties as required

- **Water**
  - The water content in a fair-faced concrete requires great care and consistency (avoid fluctuations)
  - Prevent bleeding
**Placing**
- Place the concrete in even layers of 300 to 500 mm. Each layer should be vibrated into the one below (mark the vibrator).
- Use a suitable size of vibrator:
  - Wall thickness up to 20 cm: Poker $\odot \leq 40$ mm
  - Wall thickness 20–40 cm: Poker $\odot 60$ mm
  - Wall thickness over 50 cm: Poker $\odot 80$ mm

- Plastic to soft installation consistence
- For greater quality control: Consider a solution with self-compacting concrete (SCC)
- Select an appropriate filling method and rate

**Curing**
- Specify thorough curing (as described in chapter 8, page 134).
- Allow for the climatic conditions

**Precautions**
- Considerable retardation can occur with new, untreated timber formwork due to the pressure of wood “sugar” on the surface → leading to discolouration and dusting
- If the concrete is too “wet” when placed, water pores with a thin or non-existent cement laitance skin can occur (blowholes)
- Inadequate concrete vibration can result in vibration pores with a hard, thick cement laitance skin
- If the concreting layers are too thick, there is a danger of insufficient air removal during vibration
- Excessive release agent application prevents the air bubbles (created by vibration) from escaping

**Sika product use**

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sikament®</strong></td>
<td>Superplasticizer</td>
<td>Improves the consistence</td>
</tr>
<tr>
<td>Sika® ViscoCrete®</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sika® Separol®</strong></td>
<td>Formwork release agent</td>
<td>Easier striking and cleaning</td>
</tr>
<tr>
<td><strong>Sika® Rugasol®</strong></td>
<td>Surface retarder</td>
<td>Production of exposed aggregate concrete surfaces</td>
</tr>
</tbody>
</table>
3.2.9 Mass Concrete

Mass concrete refers to very thick structures (> 80 cm). These structures often have a large volume, which generally means that large volumes of concrete have to be installed in a short time. This requires extremely good planning and efficient processes.

**Mass concrete is used for:**
- Foundations for large loads
- Foundations for buoyancy control
- Solid walls (e.g. radiation protection)
- Infill concrete

**These massive structures create the following main problems:**
- High internal and external temperature variations during setting and hardening
- Very high maximum temperatures
- High internal and external temperature variations and therefore forced shrinkage
- Secondary consolidation (settling) of the concrete and therefore cracking over the top reinforcement layers and also settlement under the reinforcement bars

**Risks**
All of these problems can cause cracks and cement matrix defects:
So-called “skin or surface cracks” can occur if the external/internal temperature difference is more than 15 °C or the outer layers can contract due to their drying out first. Skin cracks are generally only a few centimetres deep and can close again later.

**Measures to be taken**
- Use cements with low heat development
- Low water content (reduction in w/c ratio)
- Largest possible maximum particle size (e.g. 0–50 instead of 0–32)
- If necessary, cool the aggregates to obtain a low initial fresh concrete temperature
- Place the concrete in layers (layer thickness < 80 cm)
- Retard the bottom layers to ensure that the whole section can be re-compacted after placing of the top layer
- Use curing with thermal insulation methods
- Ensure the correct design and distribution of joints and concreting sections, to allow heat dissipation and to accommodate the temperature developments and differences
Measurement of hydration heat in a 160 cm thick ground slab in three levels

Temperature development in mass concrete

<table>
<thead>
<tr>
<th>Temperature in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>61 2 1 8 2 4 6 1 2 1 8 2 4 6 1 2 1 8 2 4 6 1 2 1 8 2 4 6 1 2 1 8 2 4 6 1 2 1 8 2 4 6 1 2 1 8 2 4 6 1 2 1 8 2 4 6 1 2 1 8 2 4 6 1 2 1 8 2 4 6</td>
</tr>
</tbody>
</table>

Measurement period in days (time data)

Thursday, 9 May
Friday, 10 May
Saturday, 11 May
Sunday, 12 May
Monday, 13 May
Tuesday, 14 May

Product name         | Product type          | Product use                  |
----------------------|-----------------------|------------------------------|
Sikament®            | Superplasticizer      | Substantial water reduction  |
Sika® ViscoCrete®    |                       |                              |
Sika Retarder®       | Retarder              | Control of the setting process|
3.2.10 Fiber reinforced Concrete

Many different properties of the fresh and hardened concrete can be effectively influenced by adding fibers. There are innumerable different types of fiber with different material characteristics and shapes. Correct selection for different uses is important. As well as the actual material, the shape of the fibers is also a critical factor.

**Fiber reinforced concrete is used for**
- Industrial flooring
- Sprayed concrete
- Slender structures (usually in precast plants)
- Fire resistant structures

**Properties of fiber reinforced concretes**
- To improve the durability of the structure
- To increase the tensile and flexural strength
- To obtain resistance to later cracking
- To improve crack distribution
- To reduce shrinkage in the early age concrete
- To increase the fire resistance of concrete
- To influence the workability

**Concrete production**
The fiber manufacturers’ instructions must be followed when producing fiber reinforced concretes. Adding the fiber at the wrong time or mixing incorrectly can cause great problems and even make the fibers useless.
- Comply with the manufacturer’s adding time and method (i.e. at the concrete plant or in the ready mix truck)
- Comply with the mixing times (balling/destruction of fibers)
- Do not exceed the maximum recommended fiber content (considerable reduction in workability)
- Fibers generally increase the water requirement of the mix (compensate for this with superplasticizer)

**Fiber types**
- Steel fiber
- Plastic fiber
- Glass fiber
- Carbon fiber
- Natural fibers
3.2.11 Heavyweight Concrete

Heavyweight concrete is mainly used for radiation protection. The critical properties of a heavyweight concrete are:

- Homogeneous density and spatial closeness of the concrete
- Free from cracks and honeycombing
- Compressive strength is often only a secondary criterion due to the large size of the structure
- As free from air voids as possible
- Keep shrinkage low

**Composition**

- **Aggregate**
  - Use of barytes, iron ore, heavy metal slags, ferrosilicon, steel granules or shot

- **Cement**
  - Allow for hydration heat development when selecting the cement type and content

- **Water content**
  - Aim for a low water/cement ratio

**Workability**

To ensure a fully closed concrete matrix, careful consideration should be given to the placing (compaction).

**Curing**

Allowance must be made in the curing method for the high heat development due to the likely large mass of the structure. Otherwise curing is as described in chapter 8 (page 134).

**Sika product use**

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sikament®</strong></td>
<td>Superplasticizer</td>
<td>Substantial water reduction</td>
</tr>
<tr>
<td><strong>Sika® ViscoCrete®</strong></td>
<td></td>
<td>Improvement in placing (workability and compaction)</td>
</tr>
<tr>
<td><strong>SikaFume®</strong></td>
<td>Silicafume</td>
<td>Reduced permeability</td>
</tr>
<tr>
<td><strong>Sika® Control®-40</strong></td>
<td>Superplasticizer</td>
<td>Substantial water reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Improvement in placing (workability and compaction)</td>
</tr>
</tbody>
</table>
3.2.12 Underwater Concrete

As the name suggests, underwater concrete is installed below the water line, e.g. for:
- Port and harbour installations
- Bridge piers in rivers
- Water industry structures
- Metro systems
- Deep shafts in unstable ground, where an internal fall in the water level could lead to hydraulic ground heave, etc.

**Composition (⌀ 0–32 mm)**

- **Aggregate**
  - Use an aggregate suitable for pumped mixes
  - Fines including cement > 400 kg/m³
- **Cement**
  - Min. cement content 350 kg/m³

**Special requirements**

A reliable method of placing underwater concrete with minimum loss is the tremie process (Contractor method). The concrete is placed directly through a 20–40 cm ⌀ pipe into and through the concrete already installed. The pipe is raised continuously, but the bottom end must always remain sufficiently submerged in the concrete to prevent the water going back into the pipe.

Another method also used today is pumping a suitably modified mix through a standard concrete pump. Here again, the end of the delivery pipe must be kept deep enough in the fresh concrete.

Other important considerations:
- As the flow rate of water increases, more leaching can occur. Minimum flow conditions are best
- Avoid pressure differences on the pipe (such as water level differences in shafts)

**Special underwater concrete**

Previously installed rough stone bags or “gabions” can be infilled later with modified cement slurries (the bag method).
3. Concrete 57

Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sikament®</td>
<td>Superplasticizer</td>
<td>Improves the consistence</td>
</tr>
<tr>
<td>Sikament®</td>
<td></td>
<td>Reduces the water content</td>
</tr>
<tr>
<td>Sika® ViscoCrete®</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sika® Stabilizer</td>
<td>Stabilizer</td>
<td>Improves the cohesion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prevents the fines from leaching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For use in still and especially flowing conditions</td>
</tr>
<tr>
<td>Sika® UCS-01</td>
<td>Underwater stabilizer</td>
<td>Improves the cohesion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prevents the fines from leaching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>For use in strongly flowing water (tidal situations)</td>
</tr>
</tbody>
</table>

3.2.13 Lightweight Concrete

Lightweight means concrete and mortar with a low density. Either aggregates with a lower density are used or artificial voids are created to reduce the weight. The method used depends mainly on the lightweight concrete application and its desired properties.

**Lightweight concrete is used for**

- Thermal insulation
- Lightweight construction (ceilings, walls, bridge decks, slabs)
- Precast products
- Levelling concrete
- Infill concretes

**Characteristics of lightweight concretes**

- Reduction in fresh concrete density
- Reduction in hardened concrete density
- If lightweight concrete is used as an infill concrete with low load bearing requirements i.e. for dimensional stability, highly porous concretes and mortars are generally produced (aerated lightweight concrete)
- If lightweight concrete with good mechanical properties (i.e. compressive strength) is required, special aggregates are used (naturally very porous but also dimensionally stable)

**Production of lightweight concrete**

- Porous lightweight materials such as expanded clays must be prewetted to prevent too much water being drawn out of the concrete during mixing
- Do not use too fluid a consistence due to the risk of segregation
- Lightweight concrete with a specific gravity < 1600 kg/m³ can be difficult to pump
- Correct handling of vibrators is particularly important (quick immersion, slow lifting) to prevent air entrapment
- Cure immediately and thoroughly. Suitable methods are misting treatment and covering with sheets or spraying with curing agents. Without
proper curing there is a high risk of cracking due to excessive drying differences.

- Foamed concretes often shrink considerably and have low dimensional stability

**Constituents for the production of lightweight concretes**
- Expanded clays
- Expanded polystyrene balls
- Wood shavings, sawdust
- Special void producing admixtures to generate large quantities of defined stable air voids
- Foaming agents

**Density**
Based on the mix and the constituents used, the following density classes and properties are obtainable:

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Density Range</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate</td>
<td>Density over 1800 kg/m³</td>
<td>High mechanical properties</td>
</tr>
<tr>
<td>Expanded clays</td>
<td>Density over 1500 kg/m³</td>
<td>Limited mechanical properties</td>
</tr>
<tr>
<td>Void producers</td>
<td>Density over 1200 kg/m³</td>
<td>No mechanical properties (easy to produce porous lightweight concrete)</td>
</tr>
<tr>
<td></td>
<td>Density over 1500 kg/m³</td>
<td>Porous lightweight concrete with low mechanical properties</td>
</tr>
<tr>
<td>Foaming agents</td>
<td>Density over 800 kg/m³</td>
<td>No mechanical properties such as infill mortar</td>
</tr>
<tr>
<td>Expanded polystyrene</td>
<td>Density over 800 kg/m³</td>
<td>Low mechanical properties</td>
</tr>
</tbody>
</table>

**Porous concrete**
Expansion causing additives (e.g. powdered aluminium) are mixed with the mortar for porous concrete. Porous concrete is generally produced industrially. Porous concrete is not really a concrete, it is really a porous mortar.

**Sika product use**

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>SikaLightcrete®</td>
<td>Void producer</td>
<td>To produce porous lightweight concrete with a void content of up to 40%</td>
</tr>
<tr>
<td>SikaPump®</td>
<td>Stabilizer</td>
<td>To improve the pumpability and cohesion of lightweight concrete</td>
</tr>
<tr>
<td>Sikament®</td>
<td>Superplasticizer</td>
<td>To reduce the permeability and improve the workability of lightweight concrete</td>
</tr>
</tbody>
</table>
3.2.14 Rolled Concrete

Rolled concrete is concrete which is placed with standard (asphalt) road pavers and is then levelled and compacted with smooth coated vibrating rollers. Rolled concrete is used mainly in the USA (but also in Germany) for the construction of hard standing, large surfaces (car parks) and road surfaces. The concrete composition is similar to standard concrete. Semi-dry consistence: Crushed material is preferable for good green strength.

The coarse material, sand, binder (standard cement) and water content must be coordinated. In particular, the water content must be kept constant and precise to allow the voids to be filled as fully as possible by rolling.

3.2.15 Coloured Concrete

Coloured concrete is produced by adding pigmented metal oxides (mainly iron oxide). The pigments are in the form of powder, low dust fine granulates or liquid.

The dosage is normally 0.5–5 % of the cement weight. Higher dosages do not deepen the colour but may adversely affect the concrete quality.

**Typical colours are**
- Iron oxide yellow
- Iron oxide red/brown
- Chromium oxide green
- White (titanium dioxide; general brightener)
- Black (iron oxide black; note: carbon black may adversely affect the creation of air voids)

**The colouring can be heightened**
- By using light coloured aggregate
- By using white cement

The colour of a “coloured” concrete can only be reliably assessed in the dry hardened state and depends on the following factors:
- Type, quantity and fineness of the colorant
- Cement type
- Aggregates
- Concrete mix composition

Further information on the use of coloured concrete is given in section 3.2.8 Fair-faced Concrete (page 50).
### Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sikament®</strong></td>
<td>Superplasticizer</td>
<td>Increased strength and impermeability</td>
</tr>
<tr>
<td><strong>Sika® ViscoCrete®</strong></td>
<td></td>
<td>Substantial water reduction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Optimized pigment distribution (particularly at the surfaces)</td>
</tr>
<tr>
<td><strong>Sika® ColorCrete®</strong></td>
<td>Pigment slurry with integral</td>
<td>Colouring of fair-faced concrete</td>
</tr>
<tr>
<td></td>
<td>superplasticizer</td>
<td>Improvement in workability</td>
</tr>
</tbody>
</table>

#### 3.2.16 Semi-dry Concrete for Precast Manufacture of Concrete Products

**General**

Semi-dry concrete is used for the manufacture of small precast concrete products.
- Concrete paving stones
- Kerbs
- Flags and paving slabs
- Garden products
- Pipes

The main application is now concrete paving stones.

The special characteristics of semi-dry concrete are
- Instantly demouldable
- Stability of unhydrated concrete
- Dimensional accuracy immediately after compaction (green strength)

The advantages of this process are
- Only one form per product shape (low capital investment)
- A compacting installation for all the products
- Production flexibility due to rapid changing over of the formwork for a new product type

**Semi-dry concrete technology**

How are these different fresh concrete characteristics obtained technologically?
- Fine particle size distribution curve (max. particle size 8 mm, high water requirement)
- Low w/c ratio (0.35 to 0.40)
- Low binder content
- High strength cement (42.5 R)
- Cement substitutes (fly ash, powdered limestone)
This gives a low adhesive matrix content and therefore a granular consistence in the fresh state. The results:
- Difficult to compact
- Low air entrainment
- Susceptible to early water removal drying

The strength develops according to the general laws of concrete technology and is then similar to high strength concretes.

**Comparison with high strength standard concrete**

<table>
<thead>
<tr>
<th>Material/m²</th>
<th>C 45/55</th>
<th>Semi-dry core concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consistence (not compacted)</td>
<td>Fluid (a: 56 cm)</td>
<td>Granular, pourable</td>
</tr>
<tr>
<td>Aggregate</td>
<td>1860 kg</td>
<td>1920 kg</td>
</tr>
<tr>
<td>Sand 0/2</td>
<td>38 %</td>
<td>55 %</td>
</tr>
<tr>
<td>Gravel 2/8</td>
<td>18 %</td>
<td>45 %</td>
</tr>
<tr>
<td>Gravel 8/16</td>
<td>44 %</td>
<td>—</td>
</tr>
<tr>
<td>k-value</td>
<td>4.14</td>
<td>3.10</td>
</tr>
<tr>
<td>Total binder (cement and substitutes)</td>
<td>360 kg</td>
<td>320 kg</td>
</tr>
<tr>
<td>Cement</td>
<td>100 %</td>
<td>75 %</td>
</tr>
<tr>
<td>Fly ash</td>
<td>—</td>
<td>25 %</td>
</tr>
<tr>
<td>Water</td>
<td>162 kg</td>
<td>120 kg</td>
</tr>
<tr>
<td>w/b ratio</td>
<td>0.45</td>
<td>0.38</td>
</tr>
<tr>
<td>Concrete admixture</td>
<td>1.5 % of cement (SP)</td>
<td>0.4 % of cement (WR)</td>
</tr>
<tr>
<td>Pore volume</td>
<td>1.5 %</td>
<td>3.9 %</td>
</tr>
<tr>
<td>Fresh concrete density</td>
<td>2.38 kg/dm³</td>
<td>2.36 kg/dm³</td>
</tr>
<tr>
<td>Compressive strength 1 day</td>
<td>~ 33 N/mm²</td>
<td>~ 33 N/mm²</td>
</tr>
<tr>
<td>Compressive strength 28 days</td>
<td>~ 68 N/mm²</td>
<td>~ 68 N/mm²</td>
</tr>
</tbody>
</table>

The comparison with standard concrete indicates the reason for the semi-dry consistence:
- More viscous due to lower w/c ratio (stiff)
- Approx. 40–50 % less wetting of the cement paste on the aggregate surface due to less binder, lower w/c ratio and finer aggregate.

**Production process for concrete paving stones and small concrete products**

**Concrete products**

This granular concrete cannot be compacted with standard vibration systems. It requires special machines which operate by the vibration compression process: vibration of the concrete under superimposed load.
Concrete

Egg-layer production (compaction is made directly on the factory floor)

Multilayer finisher (former mass production, freshly made products are stacked directly on top of each other (risk of collapse of total pallet)

Static board machine (modern mass production, static machines with continuous process, products are compacted, handled and stored on wood or steelboards)

Paving stones are often produced in two layers:

- Base concrete = bulk concrete which has to support the static load
- Face concrete = fine concrete which gives the block an attractive appearance and is mainly responsible for the durability (wear, frost etc.)

In some areas blocks are also produced in monolithic concrete, in which case a slightly finer concrete is used.

Concrete product quality

Concrete product requirements

- Economy
- Closed surfaces and sharp edges
- Adequate green strength
- High impermeability
- High initial and final strengths
- Adequate frost and freeze/thaw resistance
- Minimal tendency to efflorescence or discoulouration
- Homogeneous and uniform colouring

Factors influencing concrete product quality

The quality of the semi-dry concrete depends largely on the concrete design and its production. Compaction is vitally important and depends on production process and the concrete mix design.

Process factors

- Condition of the forms
- Condition of the compaction base
- Filling method
- Compaction time and intensity
- Climate during storage of the fresh concrete products
- Climate and duration of outdoor storage

Concrete technology factors

- Type, quantity and particle size distribution curve of aggregates
- Type, quantity and fineness of cement
- Water content of fresh concrete
- Dosage of additives
- Dosage of admixtures
- Mixing sequence

To obtain a consistent quality, all the factors must be kept constant.
Compaction
The quality of the compaction depends on the above mentioned factors. The compactability generally increases with
- increasing compaction energy (duration, frequency etc.)
- rising water content
- higher binder content
- addition of admixtures (compaction aids)
About 3.5 to 5.0 % by volume of remaining pores should be assumed in the mix calculation.

Admixtures allow more rapid and intensive compaction. It is therefore possible to save compacting time and produce a more homogeneous concrete.

Green strength
Semi-dry concretes can be de-moulded immediately after compaction. The newly formed concrete products have good green strength and therefore retain their shape. In standard paving stones this green strength is in the range approx. 0.5–1.5 N/mm².

At this time cement has not generally begun to hydrate (development of strength). This effect can be deduced from the laws of soil mechanics (apparent cohesion).
**Edge quality**
Poor compaction causes honeycombing and rough edges. Admixtures improve the compactability. Intensive compaction pushes the aggregates closer together. The cement paste is then forced onto the surface and is further distributed vertically over the edges during striking (lifting of the form) and this helps to produce smooth edges. Special admixtures also cause more slurry to form and assist this.

This lubricating film also reduces the friction between the compacted concrete and the form, prolonging the life of the formwork.

**Strength**
Semi-dry concrete paving stones are stored after production for about 24 hours on racks in a curing chamber. After that, they need to withstand the stress of the palleting units. Therefore, early strength is the crucial point.
In general the strength improves as the density increases.

![Compressive strength after 28 days in N/mm²](chart)

However if the optimum water content is exceeded, the strength falls despite increasing density. This occurs due to the strength-reducing capillary voids which form as a result of the excess water and cancel out the small increase in density. The more cement substitutes are used and the lower the cement content, the more often and sooner this effect occurs – even with a relatively low w/c ratio.

Therefore it is very important to find and maintain the best water content for the actual raw materials and mix design being used.
With SikaPaver® technology admixtures, the range of variation in the results can be minimized while still increasing the strength. The concrete mixes are more robust, enabling the end product specifications to be met despite unavoidable variations in the base materials, e.g. in the water content. The concrete mixes can then be optimized.

![Graph showing 28d compressive strength in N/mm² vs w/b ratio with different admixtures](image)

**Coloured concrete**

Today approximately 80% of precast concrete products are coloured. It is important to consider the fact that the cement matrix itself varies in brightness dependent on the w/c ratio. A change in the water content as small as w/c 0.02 is clearly visible to the naked eye. The colour intensifies as the cement matrix lightens.

![Images of coloured concrete with varying w/c ratios](images)

**Efflorescence**

The problem of efflorescence is well known; these white “salt” deposits spoil the look of dark coloured products in particular. The worst cases occur when the efflorescence varies in intensity, which is generally the case. Even now there is no cost effective way of absolutely preventing this. What are the causes of efflorescence?

- Free calcium hydroxide Ca(OH)₂
- Water-filled capillary voids (up to the concrete surface)
- Water lying on the concrete surface
- Low evaporation rates (particularily when cooler, autumn – winter)
- Incomplete hydration

i.e. efflorescence generally occurs during the outdoor storage of products in stacks!
Calcium hydroxide is transported to the concrete surface due to the concentration gradient of calcium ions in the moisture. Water is the primary conveyor. The more water can infiltrate the hardened concrete, the greater the likelihood of a supply of excess calcium ions, which will result in a higher tendency to efflorescence.

The following precautions can be taken to prevent/reduce efflorescence:

- Low evaporation rate during storage (no draughts)
- Unrestricted air circulation (carbon dioxide) during initial hardening
- Use of CEM III cement
- Dense concrete structure (cement matrix content + compaction)
- Protect from rain and condensation and maintain air circulation through ventilation

**Water repellent admixtures in both the face and base concrete**

With the SikaPaver® water repellent admixture technology, the greatly reduced capillary water absorption of the paving stones is clearly obvious, resulting in a reduced potential for efflorescence.

![Capillary water absorption graph](image)

**Standards/regulations**

- EN 1338 Concrete paving stones
- EN 1339 Concrete paving flags (slabs)
- EN 1440 Concrete kerbs
- DIN 1115 Concrete roof tiles
- DIN 4032 Concrete pipes and fittings
- DIN 4034 Manhole and well segments
- DIN 4035 Reinforced concrete pipes and pressure pipes
- Regulation for the production and quality monitoring of waterproof paving blocks in no-fines concrete
Concrete with enhanced or high fire resistance means concrete which is improved so that it can withstand the defined high heat conditions. Concrete itself cannot burn, but above certain temperatures it loses first its mechanical properties and then its form. Without special measures concrete is normally heat resistant in service up to a temperature of about 80 °C.

Concrete with high fire resistance is used for
- Emergency areas in enclosed structures (tunnel emergency exits)
- General improved fire resistance for infrastructure
- Fire resistant cladding for structural members
Properties of concrete with high fire resistance
- As a rule the fresh concrete behaves like standard concrete during placing
- The hardened concrete has a somewhat slower strength development than normal, but again the properties are similar

Production of concrete with high fire resistance
- The concrete production does not differ from standard concrete
- The mixing process must be monitored due to the fibers normally included
- It is beneficial to the future fire resistance of this concrete if it can dry out as much as possible

Constituents for the production of concrete with high fire resistance
- Achievement of maximum fire resistance is based on the composition of the aggregates used
- The resistance can be greatly increased by using special aggregates
- The use of special plastic fibers (PP) increases the resistance considerably
- The use of selected sands improves the resistance of the cement matrix

Mechanisms of behaviour in fire
The capillary and interstitial water begins to evaporate at temperatures around the boiling point of water (100 °C). Steam needs more space and therefore exerts expansion pressure on the concrete structure. The cement matrix begins to change at temperatures of about 700 °C. The effect of the aggregates is mainly dependent on their origin and begins at about 600 °C. Concrete starts to “melt” at about 1200 °C.

Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sikament®</td>
<td>Superplasticizer</td>
<td>Due to the substantial water reduction, there is less excess water in the concrete</td>
</tr>
<tr>
<td>Sika® ViscoCrete®</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2.18 Tunnel Segment Concrete
Modern tunnelling methods in unstable rock use concrete segments which are immediately load bearing as linings to the fully excavated tunnel section.
Precast concrete units called tunnel segments perform this function.

Production
Due to the large numbers required and heavy weight (up to several tonnes each), tunnel segments are almost always produced near the tunnel portal in specially installed precasting facilities. They have to meet high accuracy specifications. Heavy steel formwork is therefore the norm.
Because striking takes place after only 5–6 hours and the concrete must already have a compressive strength of >15 N/mm², accelerated strength development is essential.

There are several methods for this. In the autoclave (heat backflow) process, the concrete is heated to 28–30 °C during mixing (with hot water or steam), placed in the form and finished. It is then heated for about 5 hours in an autoclave at 50–60 °C to obtain the necessary demoulding strength.

**Composition**

- **Aggregate**
  - Normally 0–32 mm in the grading range according to EN 480-1

- **Cement**
  - Cement content 325 or 350 kg/m³
  - CEM I 42.5 or 52.5

**Placing**

- The fresh concrete mix tends to stiffen rapidly due to the high temperature, making correct compaction and finishing of the surface difficult.

- Due to the rapid industrialized process, a plastic fresh concrete consistence can be used. The desired initial strength can only be obtained by a low water/cement ratio, which should therefore always be < 0.48.

**Special requirements**

The newly demoulded segments must be cured by covering or spraying with a curing agent such as Sika® Antisol®.

However, to obtain a combination of maximum durability in variable ground conditions and optimum curing, the segment surfaces are treated more often with a special Sikagard® protective coating immediately after striking. With this additional protection against chemical attack, extremely durable concrete surfaces are achieved for these segments.

**Sika product use**

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sika® ViscoCrete®-20 HE</td>
<td>Superplasticizer</td>
<td>Increased initial strength and impermeability Improvement in consistence</td>
</tr>
<tr>
<td>SikaFume®</td>
<td>Silicafume</td>
<td>High strength, increased impermeability Improved sulphate resistance</td>
</tr>
<tr>
<td>SikaAer®</td>
<td>Air entrainer</td>
<td>Air entrainment Production of frost and freeze/thaw resistant concrete</td>
</tr>
</tbody>
</table>
3.2.19 Monolithic Concrete

Wear resistant, level concrete floors or decks ready for use quickly. Monolithic concrete has the same high quality throughout and these floor designs are extremely economic.

Composition
The concrete mix must be adapted to any special requirements (waterproof concrete, frost resistant concrete etc.)

Placing
Standard placing and compaction with immersion vibrators. Smooth off with vibrating beam. After the stiffening process begins, the surface is finished with power floats.

Curing
Start as early as possible, by spraying with Sika® Antisol® (Attention! What coating is to follow?) and cover with sheeting.

Notes
- Check the potential for the use of steel fibers when forming monolithic concrete slabs
- To improve the finished surface, we recommend the use of Sikafloor®-Top Dry Shakes, which are spread into the surface during the finishing operation
- Concrete admixtures for extended workability are not generally suitable for monolithic concrete

Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
</table>
| Sikament®             | Superplasticizer                           | Increased strength and impermeability
                                                                      Good workability
                                                                      Good green strength
|                       |                                             |                                                                             |
| SikaRapid®            | Hardening accelerator                       | Control of the hardening process at low temperatures                       |
| Sikafloor®-Top Dry Shakes | Mineral, synthetic and metallic grades | Improved abrasion
                                                                      Option of colouring |
| Sikafloor®-ProSeal    | Curing and hardening surface sealer         | Reduced water loss
                                                                      Supports hardening and curing,
                                                                      seals the surface |
| Sika® Antisol®        | Curing agent                               | Reduced water loss                                                          |
Granolithic concrete pavements are highly abrasion resistant, cementitious industrial floors and traffic areas with a minimum thickness of 20 mm. They are laid over a cementitious substrate (e.g. old concrete) with a bonding layer and have a density of > 2100 kg/m³. If the layer thickness exceeds 50 mm, a light reinforcement mesh (minimum 100 × 100 × 4 × 4) is normally installed.

### Composition
- **Aggregate**
  - 0–4 mm for a layer thickness of up to 30 mm
  - 0–8 mm for a layer thickness of 30–100 mm
- **Cement**
  - 400–500 kg/m³

### Substrate/adhesion
Before placing a bond coat is brushed into the slightly damp (prewetted) substrate. The granolithic concrete is placed “wet on wet” onto the bond coat and carefully compacted, smoothed off and then finished with power floats. The abrasion resistance is further improved by applying dry shakes during the floating operation. Polypropylene fibers included in the mix can also counteract shrinkage cracking.

### Curing
Always apply a curing agent (which must be mechanically removed if a coating is to be applied at a later date), and/or cover with sheeting, preferably for several days.

### Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sikament®</strong></td>
<td>Superplasticizer</td>
<td>Increased strength and impermeability</td>
</tr>
<tr>
<td><strong>Sika® ViscoCrete®</strong></td>
<td></td>
<td>Good workability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good green strength</td>
</tr>
<tr>
<td><strong>SikaRapid®</strong></td>
<td>Hardening accelerator</td>
<td>Control of the hardening process at low temperatures</td>
</tr>
<tr>
<td><strong>Sikafloor®-Top Dry Shakes</strong></td>
<td>Mineral, synthetic and metallic grades</td>
<td>Reduced abrasion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Option of colouring</td>
</tr>
<tr>
<td><strong>Sikafloor®-ProSeal</strong></td>
<td>Curing and hardening surface sealer</td>
<td>Reduced water loss</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supports hardening and curing, seals the surface</td>
</tr>
<tr>
<td><strong>Sika® Antisol®</strong></td>
<td>Curing agent</td>
<td>Reduced water loss</td>
</tr>
</tbody>
</table>
4. Fresh Concrete

4.1 Fresh Concrete Properties

4.1.1 Workability

The consistence defines the behaviour of the fresh concrete during mixing, handling, delivery and placing on site and also during compaction and surface smoothing. Workability is therefore a relative parameter and is basically defined by the consistence.

**Workability requirements**

- Cost effective handling, delivery/placement and placing of the fresh concrete
- Maximum plasticity (“flowability”), with the use of superplasticizers
- Good cohesion
- Low risk of segregation, good surface smoothening (“finishing properties”)
- Extended workability → Retardation/hot weather concrete
- Accelerated set and hardening process → Set and hardening acceleration/cold weather concrete
4.1.2 Retardation/Hot Weather Concrete

The concrete should be protected from drying out during handling.

Concreting is only possible at high temperatures if special protective measures are provided. These must be in place from the start of concrete production to the end of curing. They are dependent on the outside temperature, air humidity, wind conditions, fresh concrete temperature, heat development and dissipation and the dimensions of the pour. The fresh concrete must not be hotter than +30 °C during placement and installation without these protective measures.

Possible problems
Working with non-retarded concrete can become a problem at air temperatures over 25 °C.

- Hydration is the chemical reaction of the cement with the water. It begins immediately on contact, continues through stiffening to setting (initial set) and finally to hardening of the cement paste.
- Each chemical reaction is accelerated at a higher temperature.

This can mean that correct and complete compaction is no longer possible.
The normal counter measures are the use of retarded superplasticizers or superplasticizers combined with a set retarder.

Retardation terms and dosing tables

*Purpose of retardation:* To extend the working time at a specific temperature.

*Working time:* The time after mixing during which the concrete can be correctly vibrated.

*Free retardation:* The initial set is certain to start only after a specific time.

*Targeted retardation:* The initial set is started at a specific time.

**Certainty comes only from specific preliminary testing!**

<table>
<thead>
<tr>
<th>Structural element and retardation</th>
<th>Critical temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium concrete cross sections</td>
<td>Fresh concrete temperature</td>
</tr>
<tr>
<td>Small concrete cross sections</td>
<td>Air temperature at placement point</td>
</tr>
</tbody>
</table>

The higher temperature (fresh concrete or air temperature) is the critical one for medium concrete cross sections with long retardation, and for small concrete cross sections with short retardation.

**Dosing table for concrete with free retardation**
The retardation depends largely on the type of cement.
Dosage of Sika Retarder® in % of cement mass

<table>
<thead>
<tr>
<th>Retardation time in hours</th>
<th>Critical temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 °C</td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td>6</td>
<td>0.2</td>
</tr>
<tr>
<td>8</td>
<td>0.3</td>
</tr>
<tr>
<td>10</td>
<td>0.4</td>
</tr>
<tr>
<td>12</td>
<td>0.4</td>
</tr>
<tr>
<td>14</td>
<td>0.5</td>
</tr>
<tr>
<td>16</td>
<td>0.5</td>
</tr>
<tr>
<td>18</td>
<td>0.6</td>
</tr>
<tr>
<td>20</td>
<td>0.7</td>
</tr>
<tr>
<td>24</td>
<td>0.8</td>
</tr>
<tr>
<td>28</td>
<td>1.0</td>
</tr>
<tr>
<td>32</td>
<td>1.2</td>
</tr>
<tr>
<td>36</td>
<td>1.5</td>
</tr>
<tr>
<td>40</td>
<td>1.8</td>
</tr>
</tbody>
</table>

The dosages relate to concrete with 300 kg CEM I 42.5 N and w/c = 0.50. The dosage should be increased by about 20 % for semi-dry concrete. The figures in this table are laboratory results and relate to one special formulation of retarder which might not be available everywhere. Preliminary suitability tests are always necessary.

Influencing factors
Various factors affect the retardation:

**Influence of temperature** (see “Critical temperature”)
- Temperature increases shorten, and temperature reductions extend the retardation

The rough rule of thumb:
- Each degree under 20 °C extends the retardation time by about 1 hour.
- Each degree over 20 °C shortens the retardation time by 0.5 hours.

For safety: **Preliminary testing!**

**Influence of water/cement ratio**
A cement content of 300 kg/m³ and a Sika Retarder® dosage of 1 % shows that:
- An increase in the w/c ratio of 0.01 causes additional retardation of about half an hour
Combination of Sikament®/Sika® ViscoCrete®
- With a non-retarded superplasticizer, Sika Retarder® extends the retardation slightly.
- With a retarded superplasticizer, Sika Retarder® further extends (cumulative) the retardation.

Preliminary testing should always be carried out on major projects.

Influence of cement
The hydration process of different cements can vary due to the different raw materials and grinding fineness. The retardation effect is also susceptible to these variations, which can be considerable at dosages of over 1%.
The tendency:
- Pure, fine Portland cements: retardation effect reduced
- Coarser cements and some mixed cements: retardation effect extended

For safety
- Preliminary tests!
- Always preliminary test at dosages over 1%

Influence of concrete volume
If the whole of a concrete pour is retarded, the volume has no influence on the retardation effect.
During the initial set of an adjacent pour (e.g. night retardation in a deck slab), the “critical temperature” changes in the contact zone with the retarded next section (it increases), and this will cause the retardation effect to decrease.

Characteristics of the retarded concrete
- Hardening
If hardening is initiated after the retardation has stopped, it is quicker than in non-retarded concrete.
- Shrinkage/creep
The final shrinkage or creep is less than in non-retarded concrete.
- Early shrinkage
Contraction cracks resulting from early shrinkage can form due to dehydration during the retardation period (surface evaporation). Protection from dehydration is extremely important for retarded concrete! Correct curing is essential!
Examples of concreting stages with retardation

1. Night retardation
- Foundation slabs
- Decks, beams etc.

Towards the end of the normal day’s concreting, 3 strips about 1.20 m wide with increasing retardation are installed.
- 1st strip: 1/3 of main dosage
- 2nd strip: 2/3 of main dosage
- 3rd strip: main dosage from table or preliminary testing results

Suspension of the works overnight.

Resumption of the works next morning:
- 1st strip (adjacent to the 3rd from the previous day) is retarded at 1/3 of the main dosage

2. Retardation with simultaneous initial set
This happens with large bridge spans, ground slabs etc.

Important preparations are:
- Define a precise concreting programme with the engineer and contractor
- On that basis, divide into spans and produce a time schedule
- Target: all the spans set together
- When the times are determined, the dosages for the individual spans can be specified on the basis of preliminary tests and the precise temperature information.

Preliminary tests

Preliminary tests relate only to the concrete composition specified for the retarded stage:
- i.e. with the same w/c ratio and the same cement with the same dosage

The limits of vibration capability should be tested on site with several concrete samples per dosage (in minimum 20 litre vessels), in temperature conditions as similar as possible to the conditions during placing.

Procedure:
- Determine the retarder dosage from the table
- Fill at least 5 vessels with that concrete mix
- Vibrate the contents of the first vessel 2 hours before the assumed initial set
- Vibrate the next vessel after a further hour in each case (the contents of each vessel are only vibrated once)
- When the contents of the next vessel cannot be further vibrated, the concrete has begun to set
- Note the times obtained and check whether they agree with the predictions (in the table)
- If the differences are too great, repeat the tests with an adjusted dosage.
Measures for retarded concrete

The formwork
Timber formwork used for the first time can cause unsightly staining, surface dusting etc., particularly around knots, due to wood sugars on the surface.
Timber formwork which is highly absorbent, insufficiently wetted and not properly treated with release agent, draws far too much water from the concrete surface. Loose or friable particles and dusting are the result. This damage is greater in retarded concrete because the negative effects continue for longer.
Timber formwork which is properly prepared and correctly treated with Sika® Separol® will produce good, clean surfaces on retarded concrete.

Compaction and curing
Retarded concrete must be compacted. The following stage (e.g. next morning) is vibrated together with the “old layer”. Retarded areas are compacted and finished together.
Curing is enormously important, so that the retarded, compacted and then the hardening concrete loses as little moisture as possible.
The best methods for retarded surfaces (floors etc.) are:
- Cover with plastic sheeting or insulating blankets.
On retarded areas to be vibrated again later:
- Full covering with plastic sheets or damp hessian. Protect from draughts. Additional surface watering [i.e. misting] can cause washout with retarded concrete.

4.1.3 Set Acceleration/Cold Weather Concrete

The concrete should be protected from rain and frost during handling.
Concreting is only possible in freezing temperatures if special protective measures are taken. They must be in place from the start of concrete production to the end of curing.
They depend on the outside temperature, air humidity, wind conditions, fresh concrete temperature, heat development and dissipation and the dimensions of the concrete pour.
The fresh concrete must not be colder than +5 °C during placement and installation without additional protective measures. The mixing water and aggregates should be preheated if necessary.

Problem
Low temperatures retard the cement setting. At temperatures below –10 °C the chemical processes of the cement stop (but continue after warming). Dangerous situations arise if concrete freezes during setting, i.e. without having a certain minimum strength. Structural loosening occurs, with a corresponding loss of strength and quality. The minimum
strength at which concrete can survive one freezing process without damage is the so-called freezing strength of 10 N/mm². The main objective must be to reach this freezing strength as quickly as possible.

The temperature \( t \) of fresh concrete can be estimated by the following equation:

\[
t_{\text{concrete}} = 0.7 \times t_{\text{aggregate}} + 0.2 \times t_{\text{water}} + 0.1 \times t_{\text{cement}}
\]

**Measures**

1. **Minimum temperature**
   According to EN 206-1, the fresh concrete temperature on delivery must not be below +5 °C. (For thin, fine structured elements and ambient temperatures of −3 °C or below, EN requires a fresh concrete temperature of +10 °C, which must be maintained for 3 days!) These minimum temperatures are important for setting to take place at all. The concrete should be protected from heat loss during handling and after placing (see Protective measures).

2. **Reduction in w/c ratio**
   The lowest possible water content gives a rapid increase in initial strength. Generally there is also less moisture available to freeze. Superplasticizers allow a low w/c ratio while retaining good workability.

3. **Hardening acceleration**
   The use of SikaRapid®-1 gives maximum hardening acceleration when there are high initial strength requirements.

**Time to reach 10 N/mm² at 0 °C in days (d)**

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Control mix</th>
<th>With 1 % SikaRapid®-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEM I 300 kg/m³</td>
<td>4 d</td>
<td>1 d</td>
</tr>
<tr>
<td>w/c = 0.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEM I 300 kg/m³</td>
<td>8 d</td>
<td>2 d</td>
</tr>
<tr>
<td>w/c = 0.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Sika MPL)

4. **Use of CEM I 52.5**
   The more finely ground, top grade cements are known to produce a more rapid increase in initial strength. Superplasticizers guarantee the best workability with a low w/c ratio.

**Protective measures on site**

1. No concreting against or on frozen existing concrete.
2. The steel reinforcement temperature must be more than 0 °C.
3. Install the concrete quickly and immediately protect it from heat loss and evaporation (as important as in summer!). Thermal insulation blankets are best for this.
Example
for an outside temperature of –5 °C and a fresh concrete temperature of
11 °C

4. For decks: Heat the formwork from below if necessary.
5. Check the air and concrete temperatures and the strength progression
regularly (e.g. with a rebound hammer).
6. Extend the formwork dismantling and striking times!

Conclusion: Winter measures must be planned and organized at an early
stage by all of the parties.

Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Fresh concrete property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sikament®</td>
<td>Superplasticizer</td>
<td>Freezing strength reached rapidly due to water reduction</td>
</tr>
<tr>
<td>Sika® ViscoCrete®</td>
<td>Superplasticizer</td>
<td></td>
</tr>
<tr>
<td>Sikament®-HE/</td>
<td>Superplasticizer/hardening</td>
<td>Very high initial strength in a very short time</td>
</tr>
<tr>
<td>Sika® ViscoCrete®-HE</td>
<td>accelerator</td>
<td></td>
</tr>
<tr>
<td>SikaRapid®-1</td>
<td>Hardening accelerator</td>
<td>Very high initial strength in a very short time</td>
</tr>
</tbody>
</table>

4.1.4 Consistence

Unlike “workability”, the consistence – or deformability – of the fresh
concrete can be measured. Standard EN 206-1:2000 differentiates be-
tween 4 and 6 consistence classes dependent on the test method and de-
fines fresh concretes from stiff to fluid (see section 2.3, Classification by
Consistence, page 25).

Tolerances for target consistence values according to EN 206-1

<table>
<thead>
<tr>
<th>Test method</th>
<th>Degree of compactability</th>
<th>Flow diameter</th>
<th>Slump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target value</td>
<td>1.26</td>
<td>1.25 … 1.11</td>
<td>≤ 1.10</td>
</tr>
<tr>
<td>ranges</td>
<td></td>
<td></td>
<td>All values</td>
</tr>
<tr>
<td>Tolerance</td>
<td>± 0.10</td>
<td>± 0.08</td>
<td>± 0.05</td>
</tr>
</tbody>
</table>

The consistence tests are generally among the concrete control param-
eters which are established in preliminary tests for the applications in-
olved.
Factors influencing consistence
- Particle form/composition
- Cement content/type
- Water content
- Use of additives
- Use of concrete admixtures
- Temperature conditions
- Mixing time/intensity
- Measurement time

Time and place of tests
The consistence of the concrete should be determined at the time of delivery, i.e. on site before installation (monitoring of workability).
If the consistence is recorded both after the mixing process (production consistency check) and before installation on site, a direct comparison of the change in consistence as a factor of the fresh concrete age is possible.

If the concrete is delivered in a readymix truck, the consistence may be measured on a random sample taken after about 0.3 m³ of material has been discharged.

4.1.5 Bleeding
Emergence of water on the surface caused by separation of the concrete. Bleeding often occurs as a result of defects in fines in the aggregate and in low cement or high water containing mixes.

Consequences
- Irregular, dusting, porous surfaces
- The concrete surface has inadequate resistance to environmental actions and mechanical wear
- “Blooming” or efflorescence on the surface

To reduce bleeding
- Reduce the water content
- Monitor the fines content
- Use a mix stabilizer, Sika® Stabilizer
- Optimize the particle size distribution curve

4.1.6 Finishing
During installation make sure that the concrete is not compacted for too long, to prevent too much water and slurry coming to the surface.
The surface should not be finished (smoothened) too early. Wait until the surface is only slightly damp.
The wear resistance of the surface can generally be improved if the surface smoothening by float is repeated for a second or even third time.
4.1.7 Fresh Concrete Density

Fresh concrete density means the mass in kg per m³ of fresh, normally compacted concrete, including its remaining voids. Given the same quantity of cement and aggregate, a lower fresh concrete density indicates a lower concrete strength because the density falls as the water and void content increases.

The fresh concrete density falls
- as the water content increases
- as the void content increases

The fresh concrete density increases
- as the cement content rises
- as the water/cement ratio decreases
- as the void content decreases

Determination of the fresh concrete density according to EN 12350-6, see section 4.2.6 (page 88).

4.1.8 Air Void Content

All concretes contain voids. Even after careful compaction, the remaining air content, e.g. at a maximum particle size of 32 mm, is 1–2 % by volume, and this typical residual air content can rise to 4 % by volume in fine aggregate concrete.

Different types of void
- Compaction voids
- Open and closed capillary voids
- Gel voids
- Artificially entrained air voids to improve the frost and freeze/thaw resistance

The air void content in the concrete or mortar can be artificially improved with air entraining admixtures. Products for artificial air entrainment:
- SikaAer®
- Artificially created air voids for the production of lightweight concrete: SikaLightcrete®-02

Determination of the air void content according to EN 12350-7, see section 4.2.7 (page 88).
4.1.9 Pumpability

The pumpability of concrete depends basically on the composition of the mix, the aggregates used and the method of delivery. As far as the delivery and installation of pumped concrete is concerned, a significant reduction in the pump pressures and an increase in the output can be obtained by the systematic addition of pumping agents, particularly for use with crushed aggregates, secondary raw materials, highly absorbent aggregates etc. Adjustments to the mix design (section 3.2.1, page 37) and use of a pumping agent such as SikaPump® can reduce the frictional resistance on the pipe walls, giving lower pump pressures combined with a higher output and reduced wear.

4.1.10 Cohesion

The cohesion of a mix means the consistent homogeneity of a fresh concrete mix during placing. Absence of cohesion leads to segregation, separation and placing problems.

Ways to improve cohesion

- Increase the fines (powder + fine sand)
- Reduce the water content → use of a superplasticizer → Sikament® / Sika® ViscoCrete®
- Use a stabilizer → Sika® Stabilizer
- Use an air entrainer → SikaAer®

4.1.11 Fresh Concrete Temperature

The fresh concrete temperature should not be too low, so that the concrete gains sufficient strength fast enough and does not suffer damage from frost at an early age.

- The fresh concrete temperature should not drop below +5 °C during placement and installation.
- The freshly placed concrete should be protected from frost. Freezing resistance is reached at a compressive strength of approximately 10 N/mm².
- On the other hand too high concrete temperatures can result in (cause) placement problems and decline of certain hardened concrete properties. To avoid this, the fresh concrete temperature should not go above 30 °C during placement and installation.

Precautions at low temperatures

→ see Low Temperature Concrete (section 4.1.3, page 77)

Precautions at high temperatures

→ see High Temperature Concrete (under section 4.1.2, page 73)
4.1.12 Water/Cement Ratio

The water/cement ratio (w/c) is the water : cement weight ratio in the fresh concrete.
It is calculated by dividing the weight of the total water \( W \) by the weight of the added cement \( C \).

The equation for the water/cement ratio is therefore:

\[
\frac{W}{C} \quad \text{or} \quad \frac{W}{C_{eq}} = \frac{W}{C + (K \times \text{type II addition})}
\]

The effective water content of a mix is calculated from the difference between the total water quantity \( W_0 \) in the fresh concrete and the water quantity absorbed in the aggregate \( W_G \), determined according to EN 1097-6).

The equation for the water/cement ratio is therefore

\[
\frac{W_0 - W_G}{C}
\]

The w/c ratio required is mainly influenced by the aggregates used, round or crushed materials and their composition.
The choice of the w/c ratio is determined principally by the environmental actions (new exposure classes) according to EN 206-1:2000.

4.2 Fresh Concrete Tests

4.2.1 Workability

“Workability” means the behaviour of the fresh concrete during mixing, handling, delivery and placement at the point of placing and then during compaction and finishing of the surface. It is a measure of the deformability of the fresh concrete. It is defined by measurable numbers.

Standard EN 206-1 divides consistence into 4–6 classes according to the test method. They can be used to specify and test a stiff to almost liquid consistence (see section 2.3, Classification by consistence, page 25).
Consistence tests are used for regular monitoring of the fresh concrete. The test frequency should be based on the importance of the structure and arranged so that a given concrete quality can be obtained consistently.

Chapters 8–10 of EN 206-1 give detailed information on these conformity controls.

### 4.2.2 Sampling

Sampling for subsequent fresh concrete tests is covered by:

**Standard EN 12350-1 for composite and random samples.**

- **Composite samples:**
  Concrete quantities which consist of a number of individual samples which are taken uniformly around a mixer or a concrete mass and are then thoroughly mixed.

- **Random samples:**
  Individual samples which originate from just one part of a mixer or concrete mass and are then thoroughly mixed.

- **Individual samples:**
  Samples taken at a single suitable point and then thoroughly mixed.

The decision on whether to take random or composite samples depends on their purpose. The total sample quantity must represent at least **1.5 times** the concrete quantity required for the testing (a 60 litre capacity wheelbarrow full is normally enough).

### 4.2.3 Testing the Consistence by the Slump Test

**Principle:**

*The fresh concrete is placed in a hollow cone-shaped form and compacted. When the form is raised, the slump gives a measure of the concrete consistence. The slump is the difference in mm between the height of the form and the height of the fresh concrete cone out of the form.*

**Standard: EN 12350-2**

The whole process from the start of pouring to raising of the form must be carried out within 150 seconds. The test is only valid if it gives a residual slump in which the concrete remains largely intact and symmetrical after removal of the form, i.e. the concrete remains standing in the form of a cone (or body resembling a cone). If the concrete collapses (see «Forms of slump», page 85), another sample must be taken. If the specimens collapse in two consecutive tests, the concrete does not have the plasticity and cohesion required for the slump test.
4.2.4 Testing the Consistence by Degree of Compactability

**Principle:**
The fresh concrete is placed carefully in the steel test container. Compaction must be avoided. When the container is full to overflowing, the concrete is smoothed flush with the edge without vibration. The concrete is then compacted, e.g. with a poker vibrator (max. bottle diameter 50 mm). After compaction the distance between the concrete surface and the top of the container is measured at the centre of all 4 sides. The mean figure (s) measured is used to calculate the degree of compactability.
4.2.5 Testing the Consistence by Flow Diameter

*Principle:*

This test determines the consistence of fresh concrete by measuring the flow of concrete on a horizontal flat plate. The fresh concrete is first poured into a cone-shaped form (in 2 layers), compacted and smoothed flush with the top of the form. The form is then carefully removed vertically upwards. At the end of any concrete collapse, the plate is raised manually or mechanically 15 times up to the top stop and then dropped to the bottom stop. The concrete flow is measured parallel to the side edges, through the central cross.
**Standard EN 12350-5**

Flow diameter classes: see section 2.3, Classification of consistence, page 25.

1. Metal plate
2. Lift height (limited to $40 \pm 1$ mm)
3. Top stop
4. Impact plate
5. Hinges (outside)
6. Marking
7. Frame
8. Handle
9. Bottom stop
10. Foot rest

Steel form, sheet thickness min. 1.5 mm

Dimensions in millimetres:
- 130 $\pm 2$
- 200 $\pm 2$
4.2.6 Determination of Fresh Concrete Density

**Principle:**
The fresh concrete is compacted in a rigid, watertight container and then weighed.

**Standard EN 12360-6**
The minimum dimensions of the container must be at least four times the maximum nominal size of the coarse aggregate in the concrete, but must not be less than 150 mm. The capacity of the container must be at least 5 litres. The top edge and base must be parallel.

(Air void test pots with a capacity of 8 litres have also proved very suitable.)

The concrete is compacted mechanically with a poker or table vibrator or manually with a bar or tamper.

4.2.7 Determination of Air Void Content

There are two test methods using equipment operating on the same principle (Boyle-Mariotte’s Law): these are the water column method, and the pressure equalization method. The description below is for the pressure equalization method, as this is more commonly used.

**Principle:**
A known volume of air at a known pressure is equalized with the unknown volume of air in the concrete sample in a tightly sealed chamber. The scale graduation of the pressure gauge for the resultant pressure is calibrated to the percentage of air content in the concrete sample.

**Standard EN 12360-7**
Diagram of a test device for the pressure equalization method

1. Pump
2. Valve B
3. Valve A
4. Expansion tubes for checks during calibration
5. Main air valve
6. Pressure gauge
7. Air outlet valve
8. Air space
9. Clamp seal
10. Container
Air void test containers for standard concrete normally have a capacity of 8 litres. Compaction can be carried out with a poker or table vibrator. If using poker vibrators, ensure that entrained air is not expelled by excessive vibration.

Neither method is suitable for concrete produced with lightweight aggregates, air-cooled blast furnace slags or highly porous aggregates.

### 4.2.8 Other Fresh Concrete Consistence Test Methods

Test methods other than those described above have been developed in recent years, particularly for self-compacting concrete. They are not yet covered by standards but have proved effective in practice. Test methods in common use are listed below.

**The slump flow method**
Actual a combination of slump (the same form is used) and flow diameter. The slump cone is filled with concrete on the flow plate, levelled and then slowly lifted. The usual measurement is the time in seconds to reach a flow diameter normally of 50 cm, and then the maximum flow diameter at the end of its motion.

![Slump Flow Method](image)

An alternative method which can be found sometimes is to invert the slump cone. This makes the work easier, as the form does not have to be held while pouring.

This method is suitable for both site and laboratory use.

Further obstacles can be added by placing a ring of steel with serrated steel in the centre, to simulate the flow behaviour around a reinforcement.

**The L-box**
The L-box is suitable for analysis of the flow behaviour from the vertical to the horizontal. Here again, the usual measurement is the time taken to reach the first 50 cm horizontally and also to reach the opposite side of the channel and the depth of the concrete at the outlet and on the opposite side. The flow velocity at 2 different measuring points can also be measured electronically, for example.
The discharge channels often have reinforcing steel at the outlet. This method is suitable for both laboratory and site.

**The V-channel**

The concrete is poured in with the base flap closed, then the flap is opened and the outflow time is measured, e.g. until the first break in the flow.

More suitable for the laboratory than for site, as the cone is normally fixed to a stand.
5. Hardened Concrete

5.1 Hardened Concrete Properties

5.1.1 Compressive Strength

Compressive strength classes according to EN 206-1
See section 2.4 (page 26)
An important property of hardened concrete is the compressive strength. It is determined by a compression test on specially produced specimens (cubes or cylinders) or cores from the structure.
The main factors influencing compressive strength are the type of cement, the water/cement ratio and the degree of hydration, which is affected mainly by the curing time and method.
The concrete strength therefore results from the strength of the hydrated cement, the strength of the aggregate, the bond between the two components and the curing. Guide values for the development of compressive strength are given in the table below.

<table>
<thead>
<tr>
<th>Cement strength class</th>
<th>Continuous storage at</th>
<th>3 days N/mm²</th>
<th>7 days N/mm²</th>
<th>28 days N/mm²</th>
<th>90 days N/mm²</th>
<th>180 days N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>32.5 N</td>
<td>+20 °C</td>
<td>30…40</td>
<td>50…65</td>
<td>100</td>
<td>110…125</td>
<td>115…130</td>
</tr>
<tr>
<td></td>
<td>+ 5 °C</td>
<td>10…20</td>
<td>20…40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32.5 R; 42.5 N</td>
<td>+20 °C</td>
<td>50…60</td>
<td>65…80</td>
<td>100</td>
<td>105…115</td>
<td>110…120</td>
</tr>
<tr>
<td></td>
<td>+ 5 °C</td>
<td>20…40</td>
<td>40…60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42.5 R; 52.5 N</td>
<td>+20 °C</td>
<td>70…80</td>
<td>80…90</td>
<td>100</td>
<td>100…105</td>
<td>105…110</td>
</tr>
<tr>
<td>52.5 R</td>
<td>+ 5 °C</td>
<td>40…60</td>
<td>60…80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ The 28-day compressive strength at continuous 20 °C storage corresponds to 100 %.
Correlation between concrete compressive strength, standard strength of the cement and water/cement ratio (according to Cement Handbook 2000, p. 274)

Effects of the curing on compressive strength, see chapter 8 (page 134).

Notes on the diagram:

$f_{c,dry,cube}$:
- Average 28-day concrete compressive strength of 150 mm sample cubes.
- Storage according to DIN 1048: 7 days in water, 21 days in air.
5.1.2 High Early Strength Concrete

High early strength means the compressive strength of the concrete in the first 24 hours after production.

**High early strength concrete for precast structures**

High early strength is often very important for precast structures. Higher early strength means
- Earlier striking
- Faster turnaround of the formwork
- Earlier handling of the precast structures
- More economic use of cement
- Less heat energy, etc.

**High early strength ready mixed concrete**

Diametrically opposed requirements are often involved here. On the one hand, a long working time is often required (for handling/installation), but on the other hand, early strength after 6 hours is required. These requirements can only be met by using modern superplasticizers, hardening accelerators and specially adapted mixes.

**Uses of high early strength ready mixed concrete**

For all ready mixed concrete applications where high initial strength is required, including:
- Short striking times, especially in winter
- Early load bearing situations (traffic areas/tunnel invert concrete)
- Slipforming
- Early finishing (e.g. granolithic concrete during the winter)
- Reduced winter protection measures

**Parameters influencing high early strength concrete**

The strength development and consistence depend on the following parameters:
- Cement type and content
- Concrete, ambient and substrate temperatures
- Water/cement ratio
- Element dimensions
- Curing
- Aggregate composition
- Concrete admixtures
Sika product use

**Products**

<table>
<thead>
<tr>
<th>Products</th>
<th>5 °C</th>
<th>10 °C</th>
<th>20 °C</th>
<th>30 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>h : N/mm²</td>
<td>h : N/mm²</td>
<td>h : N/mm²</td>
<td>h : N/mm²</td>
</tr>
<tr>
<td>Base concrete</td>
<td>CEM: 350</td>
<td>CEM: 350</td>
<td>CEM: 325</td>
<td>CEM: 325</td>
</tr>
<tr>
<td></td>
<td>18 h: 0</td>
<td>12 h: 0</td>
<td>9 h: 2</td>
<td>6 h: 5</td>
</tr>
<tr>
<td></td>
<td>24 h: 2</td>
<td>18 h: 3</td>
<td>12 h: 5</td>
<td>9 h: 9</td>
</tr>
<tr>
<td></td>
<td>48 h: 10</td>
<td>24 h: 14</td>
<td>18 h: 17</td>
<td>12 h: 13</td>
</tr>
<tr>
<td><strong>Sika® Antifreeze</strong></td>
<td>CEM: 350</td>
<td>CEM: 325</td>
<td>CEM: 325</td>
<td></td>
</tr>
<tr>
<td>Antifreeze admixture</td>
<td>Dos: 1 %</td>
<td>Dos: 1 %</td>
<td>Dos: 1 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18 h: 1</td>
<td>12 h: 2</td>
<td>9 h: 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24 h: 3</td>
<td>18 h: 5</td>
<td>12 h: 6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48 h: 12</td>
<td>24 h: 16</td>
<td>18 h: 18</td>
<td></td>
</tr>
<tr>
<td><strong>SikaRapid®-1</strong></td>
<td>CEM: 350</td>
<td>CEM: 325</td>
<td>CEM: 325</td>
<td>CEM: 300</td>
</tr>
<tr>
<td>Hardening accelerator</td>
<td>Dos: 1 %</td>
<td>Dos: 1 %</td>
<td>Dos: 1 %</td>
<td>Dos: 1 %</td>
</tr>
<tr>
<td></td>
<td>18 h: 1</td>
<td>12 h: 3</td>
<td>9 h: 4</td>
<td>6 h: 12</td>
</tr>
<tr>
<td></td>
<td>24 h: 4</td>
<td>18 h: 7</td>
<td>12 h: 10</td>
<td>9 h: 16</td>
</tr>
<tr>
<td></td>
<td>48 h: 16</td>
<td>24 h: 15</td>
<td>18 h: 23</td>
<td>12 h: 20</td>
</tr>
<tr>
<td><strong>Sika® ViscoCrete®-20 HE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superplasticizer with</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>high early strength</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Strength tests**
To obtain reliable data on the early strength development in the structure, the specimens must be produced with great care. The following are suitable:

- Preferably, production of specimens with dimensions matched to the structure and cores taken from them shortly before the test
- Or production of specimens with the same storage conditions. It is important to realize that the early strengths are much lower due to the small dimensions.
- Special pendulum impact test machines can also be used for testing on the structure. It is not appropriate to test early strength with a concrete test hammer.

**Concrete composition**
It is only possible to give general information, as the precise mix depends mainly on the specific requirements.

- **Cement type:** Use a CEM I 52.5 instead of CEM I 42.5. Silicafume accelerates the strength development, but fly ash tends to retard it.
- **Cement content:** For 32 mm max. particle size, increase the binder content from 300 to 325–350 kg/m³.
- **Concrete temperatures:** If possible increase the temperatures for high specifications.
5. Hardened Concrete

- **Particle-size distribution curve:** Select curves with a low fines content, normally by reducing the sand content, in order to reduce the water requirement.
- **W/C ratio:** Greatly reduce the water content with a superplasticizer.
- **Acceleration:** Speed up the strength development with a hardening accelerator (SikaRapid®), without reducing the final strengths.
- **Curing:** Contain the hydration heat in the concrete by protection from heat loss and drying.

5.1.3 Watertightness

The watertightness defines the resistance of the concrete structure to the penetration of water. The watertightness of concrete is determined by the impermeability (capillary porosity) of the hydrated cement.

**Definition of watertightness according to EN 12390-8**

- Max. penetration of water into the concrete $\leq 50$ mm
- Requirement: Good concrete quality and the right solution for joint construction!

**Diagram:**

- **Stress**
  - Water pressure
- **Test**
  - Measurement of maximum depth of penetration (EN 12390-8)
Definition of water impermeability

- Water conductivity $q_w <$ evaporable water volume $q_d$

![Diagram showing water and air flow through a concrete wall.](image)

The higher $d$ is, the better the watertightness.

- Recommended range for watertight structures: $q_w \leq 10 \text{ g/m}^2 \times \text{h}$

![Graph showing air temperature vs. relative air humidity with qw range.](image)

- Stress
  Variable saturation due to sustained water contact

- Test
  Measurement of water conductivity $q_w$
Reduction of capillary voids and cavities by water reduction

High w/c ratio > 0.60
Large voids due to absence of fine sand and fines

Low w/c ratio > 0.40
Very impermeable cement matrix

Water reduction in % with Sikament®/Sika® ViscoCrete®

Proper hydration is of primary importance for watertight concrete. Therefore correct curing of the concrete is essential (chapter 8, page 134).
5.1.4 Frost and Freeze/Thaw Resistance

**Frost stress**
Damage to concrete structures due to frost can generally be expected when they have been penetrated by moisture and are exposed to frequent freeze/thaw cycles in that condition. The damage to the concrete occurs due to the cyclic freezing and thawing of the water which has been absorbed due to capillary suction. Destruction follows due to the increase in volume of the water [ice] in the outer concrete layers.

**Essentials for high frost resistance**
- Frostproof aggregates
- Impermeable concrete structure and/or
- Concrete enriched with micropores
- Thorough and careful curing
- Degree of hydration of the concrete as high as possible (i.e. it is not a good idea to place concrete immediately before periods of frost)

**Test methods**
- Frost resistance
  This can be estimated by comparing the fillable and non-fillable voids.

**Freeze/thaw resistance**
Given the extensive use of de-icing salts (generally sodium chloride NaCl, intended to lower the freezing point of the water on roads and prevent ice formation etc.), the concrete surface cools abruptly due to heat extraction from the concrete. These interactions between frozen and unfrozen layers cause structural breakdown in the concrete.

**Conditions for freeze/thaw resistance**
- Frostproof aggregates
- Concrete with an impermeable structure enriched with micropores
- Thorough and careful curing
- Avoid too much fine mortar enrichment of the surface area
- Concreting as long as possible before the first freeze/thaw stress so that the concrete can dry out.

**Test methods e.g. according to**
- prEN 12390-9 (Weathering)

5.1.5 Concrete Surface

The impermeability and appearance requirements for concrete surfaces vary widely. Detailed planning and execution of the structure are required to meet these requirements.

Maximum surface impermeability is essential for all durability requirements. The attack always comes from outside to inside. Overvibration or inadequate curing weakens these zones. High quality appearance requirements have led to the production of so-called “fair-faced” concrete.
Appearance of concrete surfaces
Fair-faced concrete → section 3.2.8 (page 50).

Exposed aggregate concrete
Exposed aggregate concrete is a popular surface design feature, e.g. for retaining walls, façade panels, garden features etc.
The aggregate structure is exposed on the surface by washing off and out. This requires surface retardation, which must be effective down to several mm.
In correctly designed exposed aggregate concrete, 2/3 of any single coarse aggregate is still within the hardened cement matrix.

Sika product use

<table>
<thead>
<tr>
<th>Product name</th>
<th>Product type</th>
<th>Product use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sika® Rugasol® Range</td>
<td>Surface retarder</td>
<td>For exposed aggregate surfaces and construction joints</td>
</tr>
</tbody>
</table>

Notes
- The maximum particle size should be adapted to the element dimensions, and for design appearance reasons (e.g. 0–16 mm for slender units)
- Cement content 300–450 kg/m³ dependent on the composition of the aggregate (fine aggregate → more cement)
- Water/cement ratio 0.40–0.45
  (→ add Sikament®/Sika® ViscoCrete®)
- Generally increase the reinforcement cover by 1 cm
According to the Sika Waterproof Concrete Concept, the surface profile and the water circulation path are considerably increased, and watertightness improved, for construction joints with an exposed aggregate concrete surface structure.

5.1.6 Shrinkage

Shrinkage means the contraction or decrease in volume of the concrete. The time sequence and shrinkage deformation level are influenced mainly by the start of drying, ambient conditions and the concrete composition.

The time sequence breaks down as follows:
- Chemical shrinkage of the new concrete is due only to the difference in volume between the reaction products and the base materials. Shrinkage affects only the cement matrix, not the aggregate.
- Plastic shrinkage of the new concrete in the initial stage of setting and hardening. Water is drawn out of the concrete after the initial set by evaporation, which reduces the volume and results in contraction of the concrete in every direction. The deformation usually stops when the concrete reaches a compressive strength of 1 N/mm².
Drying shrinkage → shrinkage caused by the slow drying of the hardened concrete, i.e. the quicker the quantity of free water in the structure decreases, the more the concrete shrinks.

**Influences on the degree of shrinkage**

- Planning and detailed specification of construction joints and concreting stages
- Optimized mix design
- Lowest possible total water content → use of **Sikament®/Sika® ViscoCrete®**
- Shrinkage reduction admixture → **Sika® Control®-40** → reduction in shrinkage after the start of hydration
- Prevention of water extraction by prewetting the formwork and substrate
- Thorough curing: by covering with plastic sheets or insulating blankets, water-retaining covers (hessian, geotextile matting) or spraying with a liquid curing agent → **Sika® Antisol®**

<table>
<thead>
<tr>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical shrinkage</td>
<td>Plastic shrinkage</td>
<td>Drying shrinkage</td>
</tr>
<tr>
<td>Recom- paction</td>
<td>Prevent water loss</td>
<td>Curing Shrinkage reduction</td>
</tr>
<tr>
<td>approx. 4–6 hours</td>
<td>approx. 1 N/mm²</td>
<td></td>
</tr>
</tbody>
</table>

### 5.1.7 Sulphate Resistance

Water containing sulphate sometimes occurs in soil or is dissolved in ground water and can attack the hardened concrete.

**Process**

Water containing sulphate combines with the tricalcium aluminate (C₃Al) in the cement to form ettringite (also thaumasite under certain conditions), which leads to increases in volume and to high internal pressure in the concrete structure and therefore cracking and spalling occurs.

**Measures**

- Concrete structure as impermeable as possible
  - i.e. low porosity → use of the Sika Silicafume technology
    → **SikaFume®/Sikacrete®**
- Low water/cement ratio → **Sikament®/Sika® ViscoCrete®**, aim for ≤ 0.45
- Use cement with a minimum tricalcium aluminate (C₃Al) content
- Curing suited to the structure
Note: Clarification of specific requirements is essential for every project. Limiting values for exposure classification of chemical attack from natural soil and ground water:
See Table 2.2.1 (page 22) in section 2.2 Environmental actions.

Test methods e.g.
ASTM C 1012

5.1.8 Chemical Resistance

Concrete can be attacked by contaminants in water, soil or gases (e.g. air). Hazards also occur in service (i.e. in tanks, industrial floors etc.).

- Surface and ground water, harmful soil contaminants, air pollutants and vegetable and animal substances can attack the concrete chemically.
- Chemical attack can be divided into two types:
  - Solvent attack: caused by the action of soft water, acids, salts, bases, oils and greases etc
  - Swelling attack: caused mainly by the action of water soluble sulphates (sulphate swelling), see section 5.1.7 (page 100).

See table on page 22 in section 2.2, Environmental actions

Measures
- Concrete structure as impermeable as possible,
  i.e. low porosity → use of the Sika Silicafume technology
  → SikaFume®/Sikacrete®
- Low water/cement ratio → Sikament®/Sika® ViscoCrete®,
  aim for \( \leq 0.45 \)
- Increase the concrete cover by 10 mm minimum
Concrete only has adequate resistance against very weak acids. Medium strength acids degrade the concrete. Therefore extra protection of the concrete with a coating must always be specified for moderate to highly aggressive acid attack.

5.1.9 Abrasion Resistance

Abrasion stress
Concrete surfaces are exposed to rolling stress (wheels/traffic), grinding stress (skids/tyres) and/or impact stress (heavyweight/dropped materials). The cement matrix, aggregates and their bond are all stressed together. This attack is therefore primarily mechanical.

Conditions for better abrasion resistance
The abrasion resistance of the hydrated cement is lower than that of the aggregate, particularly with a porous cement matrix (high water content). However, as the w/c ratio falls, the porosity of the hydrated cement also falls and the bond with the aggregate improves.
w/c $\leq 0.45$ ideal
- Improvement in the impermeability of the hydrated cement matrix, the aggregate and the hydrated cement bond (SikaFume®/Sikacrete®)
- Selection of a good particle-size distribution curve, using special sizes if necessary, thorough curing
- To increase the abrasion resistance still further, special aggregates should also be used.

Composition for abrasion-resistant concrete/granolithic concrete

<table>
<thead>
<tr>
<th>Standard mortar-sand mixes</th>
<th>Particle size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer thickness</td>
<td>30 mm</td>
</tr>
<tr>
<td>Layer thickness</td>
<td>30–100 mm</td>
</tr>
<tr>
<td>Cement content</td>
<td>400–500 kg/m³</td>
</tr>
</tbody>
</table>

If the layer thickness exceeds 50 mm, a light reinforcement mesh should normally be incorporated (min. $100 \times 100 \times 4 \times 4$ mm).

Adhesion to the substrate and finishing
- Before installation, a “bond coat” is brushed into the slightly damp substrate (also prewetted!).

Curing
- With Sika® Antisol® (remove mechanically afterwards, i.e. by wire brushing or blastcleaning if a coating is to follow), cover with sheeting to cure, preferably for several days.

5.1.10 Flexural Strength

Concrete is basically used under compressive stress and the tensile forces are absorbed by reinforcement bars. Concrete itself has some tensile and flexural strength, which is strongly dependent on the mix. The critical factor is the bond between aggregate and hydrated cement. Concrete has a flexural strength of approximately 2 N/mm² to 7 N/mm².

Influences on flexural strength

- Flexural strength increases
  - As the standard cement compressive strength increases (CEM 32.5; CEM 42.5; CEM 52.5)
  - As the water/cement ratio falls
  - By the use of angular and broken aggregate

Applications
- Steel reinforced fiber concrete
- Runway concrete
- Shell structure concrete

Test methods
- EN 12390-5, see section 5.2.5 (page 109)
5.1.11 Development of Hydration Heat

When mixed with water, cement begins to react chemically. This is called hydration of the cement.

The chemical process of hardening is the foundation for the formation of the hardened cement paste and therefore of the concrete. The chemical reaction with the mixing water produces new compounds from the clinker materials → hydration.

Viewing under an electron microscope shows three distinct phases of the hydration process, which is strongly exothermal, i.e. energy is released in the form of heat.

**Hydration phase 1**

**Generally up to 4 to 6 hours after production**

The gypsum in the plastic cement paste binds the tricalcium aluminate (C$_3$Al) to form trisulphate (ettringite), a water-insoluble layer which initially inhibits the conversion process of the other components. The gypsum addition of 2–5 % therefore has a retarding effect.

The longer “needles” which are created in this phase bind the separate cement particles together, causing the concrete to stiffen.

**Hydration phase 2**

**Generally between 4 to 6 hours after production and up to one day**

After a few hours comes the start of vigorous hydration of the clinker materials, particularly the tricalcium silicate (Ca$_3$Si), with the formation of intertwined long-fiber calcium silicate hydrate crystals which further consolidate the structure.

**Hydration phase 3**

**From about one day**

The structure and microstructure of the cement matrix are initially still open. As hydration progresses, the interstices are filled with other hydration products and the strength is further increased.

**Hydration stages**

Illustration of the “hydrate” phases and structural development during hydration of the cement.
5.1.12 Alkali-Aggregate Reaction

Alkali-Aggregate Reaction (AAR) means reactions of the pore solution of the concrete with the aggregates. They produce a silica gel which swells due to water absorption and causes cracking or spalling in the concrete.

The form and rate of the reaction varies according to the type of aggregate.

- Alkali-Silica Reaction (ASR) in volcanic aggregates
- Alkali-Carbonate Reaction (ACR) in limestone aggregates
- Alkali-Silicate reaction in crystalline aggregates

Alkali-Aggregate Reaction

There is a risk of this reaction when using alkali-sensitive aggregates. The problem can obviously be overcome by not using these aggregates – but this is often impractical for economic and ecological reasons. By using suitable cements and high performance concrete technology, this reaction can be prevented or at least reduced.

The precise mechanisms involved continue to be intensively analyzed in great detail. Roughly speaking, alkali ions penetrate the aggregates with water absorption, and generate an internal pressure which causes cracks and bursting in the aggregate, and later the cement matrix, destroying the concrete. This can be described in simple terms as a pressure or explosive effect. Its duration and intensity depend on the reactivity of the cement, type and porosity of the aggregate, the porosity of the concrete and the preventative measures adopted.

The measures are:

- Partial replacement of the Portland cement by slag sands or other additions (Silicafume/fly ash) with low equivalent Na$_2$O
- Analysis of the AAR/ASR potential of the aggregate and its classification (petrographic analyses/microbar test/performance testing etc.)
- Replacement or partial replacement of the aggregates (blending of available aggregates)
- Keep moisture access to the concrete low or prevent it (seal/divert)
- Reinforcement design for good crack distribution in the concrete (i.e. very fine cracks only)
- Impermeable concrete design to minimize the penetration of moisture
5.2 Hardened Concrete Tests

The hardened concrete tests are regulated in the EN 12390 standards.

5.2.1 Requirements for Specimens and Moulds

Standard: EN 12390-1

Terms from this standard:
- Nominal size:
  The common specimen size.
- Specified size:
  The specimen size in mm selected from the permitted range of nominal sizes in the standard and used as the basis for the analysis.

Permitted nominal sizes available for use (in mm)

<table>
<thead>
<tr>
<th></th>
<th>Edge length</th>
<th>100</th>
<th>150</th>
<th>200</th>
<th>250</th>
<th>300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubes(^1)</td>
<td>Edge length</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>Cylinders(^2)</td>
<td>Diameter</td>
<td>100</td>
<td>113(^3)</td>
<td>150</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td>Prisms(^1,,^4)</td>
<td>Edge length of face</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>250</td>
<td>300</td>
</tr>
</tbody>
</table>

---

1. The specified sizes must not differ from the nominal sizes.
2. The specified sizes must be within 10 % of the nominal size.
3. This gives a load transfer area of 10 000 mm\(^2\).
4. The length of the prisms must be \(L \geq 3.5 \, d\).
Permitted tolerances for specimens

<table>
<thead>
<tr>
<th>Permitted tolerances</th>
<th>Cubes</th>
<th>Cylinders</th>
<th>Prisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specified size</td>
<td>± 0.5 %</td>
<td>± 0.5 %</td>
<td>± 0.5 %</td>
</tr>
<tr>
<td>Specified size between top area and bottom area</td>
<td>± 1.0 %</td>
<td></td>
<td>± 1.0 %</td>
</tr>
<tr>
<td>Evenness of load transfer areas</td>
<td>± 0.0006 d, in mm</td>
<td>± 0.0005 d, in mm</td>
<td></td>
</tr>
<tr>
<td>Squareness of sides in relation to the base area</td>
<td>± 0.5 mm</td>
<td>± 0.5 mm</td>
<td>± 0.5 mm</td>
</tr>
<tr>
<td>Height</td>
<td></td>
<td>± 5 %</td>
<td></td>
</tr>
<tr>
<td>Permitted straightness tolerance for the barrel line of cylinders used for splitting tests</td>
<td>± 0.2 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straightness of the area on the supports, for flexural tests</td>
<td></td>
<td>± 0.2 mm</td>
<td></td>
</tr>
<tr>
<td>Straightness of load transfer area, for tensile splitting strength tests</td>
<td>± 0.2 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Moulds**
Moulds must be waterproof and non-absorbent. Joints may be sealed with suitable material.

**Calibrated moulds**
These should be made of steel or cast iron as the reference material. If other materials are used, their long term comparability with steel or cast iron moulds must be proven.
The permitted dimensional tolerances for calibrated moulds are stricter than as defined above for standard moulds.

### 5.2.2 Making and curing Specimens*

* **Note:** It is recommended that this standard should also be applied to all comparative concrete tests other than just the strength tests.

**Standard EN 12390-2**

**Notes on making specimens**

- **Stacking frame**
  Pouring into the moulds can be easier with an extension frame, *but its use is optional.*

- **Compaction**
  Poker vibrator with a minimum frequency of 120 Hz (7200 oscillations per minute).
  *(Bottle diameter ≤ ¼ of the smallest dimension of the specimen.)*
5. Hardened Concrete

Table vibrator with a minimum frequency of 40 Hz (2400 oscillations per minute).

Circular steel tamper \( \Theta \) 16 mm, length approx. 600 mm, with rounded corners.

Steel compacting rod, square or circular, approx. 25 \( \times \) 25 mm, length approx. 380 mm.

Release agents
These should be used to prevent the concrete from sticking to the mould.

Notes on pouring
The specimens should be poured and compacted in at least 2 layers, but layers should be no thicker than 100 mm.

Notes on compaction
When compacting by vibration, full compaction is achieved if no more large air bubbles appear on the surface and the surface has a shiny and quite smooth appearance. Avoid excessive vibration (release of air voids!). Manual compaction with a rod or tamper: The number of impacts per layer depends on the consistence, but there should be at least 25 impacts per layer.

Identification of specimens
Clear and durable labelling of the demoulded specimens is important, particularly if they will then be conditioned for some time.

Conditioning of specimens
The specimens must remain in the mould at a temperature of 20 \( (\pm 2) \) °C, or at 25 \( (\pm 5) \) °C in countries with a hot climate, for at least 16 hours but no longer than 3 days. They must be protected from physical and climatic shock and drying.
After demoulding, the specimens should be conditioned until the test begins at a temperature of 20 \( (\pm 2) \) °C, either in water or in a moisture chamber, at relative air humidity \( \geq 95 \% \).
(In the event of dispute, water conditioning is the reference method.)

5.2.3 Compressive Strength of Test Specimens

Standard EN 12390-3
Test equipment: Compressive testing machine according to EN 12390-4.

Specimen requirements
The specimens must be cubes or prisms. They must meet the dimensional accuracy requirements in EN 12390-1. If the tolerances are exceeded, the samples must be separated out, adapted or screened accord-
ing to Annex B (normative). Annex B gives details of how to determine the geometric dimensions.

One of the methods described in Annex A (normative) is used for adaptation (cutting, grinding or applying a filler material).

Cube samples should be tested perpendicular to the direction of pouring (when the cubes were made).

At the end of the test, the type of break should be assessed. If it is unusual, it must be recorded with the type number.

**Standard break patterns (illustrations from the standard)**

![Standard break patterns](image1)

**Unusual break patterns on cubes (illustrations from the standard)**

![Unusual break patterns](image2)

\[ T = \text{Tension crack} \]
5.2.4 Specifications for Testing Machines

*Standard EN 12390-4*
This standard consists mainly of mechanical data: Pressure plates/force measurement/force regulation/force transmission. For detailed information see the standard.

**Principle**
The test specimen is placed between an upper movable pressure plate (spherical) and a lower pressure plate and an axial compressive force is applied until break occurs.

**Important notes**
The test specimens must be correctly aligned in relation to the stress plane. The lower pressure plate must therefore be equipped with centering grooves, for example.
The compression testing machine should be *calibrated* after initial assembly (or after dismantling and reassembly), as part of the test equipment monitoring (under the quality assurance system) or at least once a year. It may also be necessary after replacement of a machine part which affects the testing characteristics.

5.2.5 Flexural Strength of Test Specimens

*Standard EN 12390-5*

**Principle**
A bending moment is exerted on prism test specimens by load transmission through upper and lower rollers.

- Prism dimensions:
  Width = height = d
  Length ≥ 3.5 d

Two test methods are used:
- 2-point load application
  Load transfer *above through 2 rollers* at a distance d (each one ½ d from centre of prism).
  The reference method is 2-point load application.
- 1-point load application (central)
  Load transfer *above through 1 roller*, in centre of prism.

In both methods the lower rollers are at a distance of 3 d (each one 1½ d from centre of prism).
Analyses have shown that 1-point load transfer gives results about 13% higher than 2-point load transfer. The load must be applied perpendicular to the pouring direction (when the prisms were made).
5.2.6 Tensile Splitting Strength of Test Specimens

*Standard EN 12390-6*

**Principle**
A cylindrical test specimen is subjected to a compressive force applied immediately adjacent along its longitudinal axis. The resultant tensile force causes the test specimen to break under tensile stress.

**Test specimens**
Cylinders according to EN 12390-1, but a diameter to length ratio of 1 is permissible.
If the tests are carried out on cube or prism specimens, convex steel spacers may be used for load application (instead of conventional flat plates).
The broken specimen should be examined and the concrete appearance and type of break recorded if they are unusual.

5.2.7 Density of hardened Concrete

*Standard EN 12390-7*

**Principle**
The standard describes a method to determine the density of hardened concrete.
The density is calculated from the mass (weight) and volume, which are obtained from a hardened concrete test specimen.

**Test specimens**
Test specimens with a minimum volume of 1 litre are required. If the nominal size of the maximum aggregate particle is over 25 mm, the minimum volume of the specimen must be over 50 \(D^3\), when \(D\) is the maximum aggregate particle size.
(Example: Maximum particle size of 32 mm requires a minimum volume of 1.64 litres.)

**Determining the mass**
The standard specifies 3 conditions under which the mass of the specimen can be determined:
- As a delivered sample
- Water saturated sample
- Sample dried in warming cupboard (to constant mass)

**Determining the volume**
The standard specifies 3 methods to determine the volume of a specimen:
- By displacement of water (reference method)
- By calculation from the actual measured masses
- By calculation from checked specified masses (for cubes)

Determining the volume by displacement of water is the most accurate method and the only one suitable for specimens of irregular design.
### Test result
The density is calculated from the specimen mass obtained and its volume:

\[ D = \frac{m}{V} \]

- **D** = density in kg/m³
- **m** = mass of specimen at time of test in kg
- **V** = volume determined by the relevant method in m³

The result should be given to the nearest 10 kg/m³.

---

### 5.2.8 Depth of Penetration of Water under Pressure

**Standard EN 12390-8**

#### Principle
Water is applied under pressure to the surface of hardened concrete. At the end of the test period the test specimen is split and the maximum depth of penetration of water is measured.

#### Test specimens
The specimens are cubes, cylinders or prisms with a minimum edge length or diameter of 150 mm.

The test area on the specimen is a circle with a 75 mm diameter (the water pressure may be applied from above or below).

#### Conditions during the test
- The water pressure must not be applied on a smoothed/finished surface of the specimen (preferably take a formed lateral area for the test). The report must specify the direction of the water pressure in relation to the pouring direction when the specimens were made (at right angles or parallel).
- The concrete surface exposed to the water pressure must be roughened with a wire brush (preferably immediately after striking of the specimen).
- The specimens must be at least 28 days old at the time of the test.

#### Test
During 72 hours, a constant water pressure of 500 (± 50) kPa (5 bar) must be applied.

The specimens must be regularly inspected for damp areas and measurable water loss.

After the test the specimens must be immediately removed and split in the direction of pressure. When splitting, the area exposed to the water pressure must be underneath.

If the split faces are slightly dry, the directional path of penetration of water should be marked on the specimen.

The maximum penetration under the test area should be measured and stated to the nearest 1 mm.
5.2.9 Frost and Freeze/Thaw Resistance

Standard EN 12390-9 (2005: Draft state)
The standard describes how to test the frost resistance of concrete with water and the freeze/thaw resistance with NaCl solution ("salt water"). The amount of concrete which has separated from the surface after a defined number and frequency of freeze/thaw cycles is measured.

Principle
Specimens are repeatedly cooled to temperatures partly below –20 °C and reheated to +20 °C or over (in water or a common salt solution). The resultant amount of material separation indicates the available frost or freeze/thaw resistance of the concrete.

Three methods are described:
- Slab test method
- Cube test method
- CD/CDF test method
The slab test method is the reference method.

Terms from the prestandard
- Frost resistance:
  Resistance to repeated freeze/thaw cycles in contact with water
- Freeze/thaw resistance:
  Resistance to repeated freeze/thaw cycles in contact with de-icing agents
- Weathering:
  Material loss on the concrete surface due to the action of freeze/thaw cycles
- Internal structure breakdown:
  Cracks within the concrete which are not visible on the surface but which produce a change in the concrete characteristics such as a reduction in the dynamic E-modulus.
6. Sprayed Concrete

6.1 Definition

Sprayed concrete is a concrete which is delivered to the point of installation in a sealed, pressure-resistant hose or pipe, applied by “spraying” and this method of application also compacts it simultaneously.

Uses

Sprayed concrete is mainly used in the following applications:

- Heading consolidation in tunnelling
- Rock and slope consolidation
- High performance linings
- Repair and refurbishment works
### 6.2 Quality Sprayed Concrete Requirements

- High economy due to rebound reduction
- Increase in compressive strength
- Thicker sprayed layers due to increased cohesion
- Better waterproofing
- High frost and freeze/thaw resistance
- Good adhesion and tensile bond strength

**How these requirements can be achieved:**

<table>
<thead>
<tr>
<th>WHAT</th>
<th>HOW</th>
<th>Sika Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early strength</td>
<td>Accelerator</td>
<td>Sigunit®-L50 AFS/-L53 AFS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sigunit®-L20/-L62</td>
</tr>
<tr>
<td>Final strength</td>
<td>Water reducer/SiO₂/alkali-free accelerator</td>
<td>SikaTard®-203</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sika® ViscoCrete® SC-305</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SikaFume®-TU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sigunit®-L53 AFS</td>
</tr>
<tr>
<td>Resistance</td>
<td>Sulphate</td>
<td>Water reducer + SiO₂</td>
</tr>
<tr>
<td></td>
<td>Chemical</td>
<td>SikaTard®/Sika® ViscoCrete®/SikaFume®</td>
</tr>
<tr>
<td></td>
<td>Abrasion</td>
<td>SikaCrete®-PP1</td>
</tr>
<tr>
<td>Watertightness</td>
<td>Water reducer for low w/c</td>
<td>SikaTard®/Sika® ViscoCrete®</td>
</tr>
<tr>
<td>Low rebound</td>
<td>SiO₂/pumping agent</td>
<td>SikaFume®/SikaPump®</td>
</tr>
<tr>
<td>Long working time</td>
<td>Set retarder</td>
<td>SikaTard®</td>
</tr>
<tr>
<td>High application output</td>
<td>Water reducer/pumping agent (wet spray)</td>
<td>SikaTard®/Sika® ViscoCrete®/SikaPump®</td>
</tr>
<tr>
<td>High flexibility and delays/hold-ups in use</td>
<td>Set retarder</td>
<td>SikaTard®</td>
</tr>
</tbody>
</table>
6.3 Early Strength Development

The quality of sprayed concrete is best defined by its properties. Standard SN EN 206-1 should be used for the sprayed concrete where appropriate.

The early strength classes J1, J2 and J3 from the Austrian Concrete Society: Code of Practice for Sprayed Concrete, are also often used in Europe to define the early strength.

**Early strength class J1**
Application in thin layers on a dry substrate with no structural requirements.

**Early strength class J2**
Application in thicker layers, including overhead, at a high output, with low water pressure and with load on the newly sprayed concrete from subsequent works.

**Early strength class J3**
Application for consolidation works or under high water pressure. Should only be used for special situations due to increased dust formation.

Source: Code of Practice for Sprayed Concrete, Austrian Concrete Society
6.4 The Spraying Process

Dry spray process
In the low build dry spray process (blown delivery), the semi-dry (earth moist) base mix is pumped using compressed air, then water is added at the nozzle together with an accelerator (as required) and this mixture is spray applied.

The inherent moisture content of the aggregates in the base mix should not exceed 6 %, as the effective flow rate is greatly reduced by clogging and the risk of blockages is increased.

Particle size distribution curve calculation with individual aggregate fractions

<table>
<thead>
<tr>
<th>Content</th>
<th>Component</th>
<th>0.125</th>
<th>0.25</th>
<th>0.5</th>
<th>1.0</th>
<th>2.0</th>
<th>4.0</th>
<th>8.0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grading range A</td>
<td>7</td>
<td>10.4</td>
<td>15.6</td>
<td>23.9</td>
<td>37.5</td>
<td>60.4</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Grading range B</td>
<td>12.5</td>
<td>17.7</td>
<td>25</td>
<td>35.4</td>
<td>50</td>
<td>70.7</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Grading range C</td>
<td>12.5</td>
<td>17.7</td>
<td>30</td>
<td>40.4</td>
<td>55</td>
<td>75.7</td>
<td>100</td>
</tr>
<tr>
<td>100 %</td>
<td>0–8 mm</td>
<td>5.8</td>
<td>12.5</td>
<td>19.0</td>
<td>28.0</td>
<td>40.5</td>
<td>62.2</td>
<td>100</td>
</tr>
</tbody>
</table>

Cement content
For 100 litres dry mix
28 kg of cement is added to 80 litres of aggregate.
For 1250 litres dry mix
350 kg of cement is added to 1000 litres of aggregate.
Example of mix design for 1 m³ dry mix
Dry sprayed concrete 0–8, sprayed concrete class C 30/37, CEM I 42.5, 350 kg for 1000 litres of aggregate, Silicafume 20 kg

<table>
<thead>
<tr>
<th>Materi</th>
<th>Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>280 kg</td>
</tr>
<tr>
<td>SikaFume®-TU</td>
<td>20 kg</td>
</tr>
<tr>
<td>0–4 mm with 4 % inherent moisture (55 %)</td>
<td>~ 680 kg</td>
</tr>
<tr>
<td>4–8 mm with 2 % inherent moisture (45 %)</td>
<td>~ 560 kg</td>
</tr>
<tr>
<td>Moist dry mix m³</td>
<td>~ 1540 kg*</td>
</tr>
</tbody>
</table>

* Must be checked by a consumption test

Admixtures
Water reducer/retarder: SikaTard®-930, dosage 0.2–2.0 %
Accelerator (alkali-free and non-toxic): Sigunit®-L50 AFS, dosage 3–6 %
Alternative, alkaline: Sigunit®-L62, dosage 3.5–5.5 %

Sprayed concrete from 1 m³ dry mix gives solid material on the wall of:

<table>
<thead>
<tr>
<th>Accelerated with</th>
<th>Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sigunit®-L50 AFS (Rebound 16–20 %)</td>
<td>0.58–0.61 m³</td>
</tr>
<tr>
<td>Sigunit®-L62 (Rebound 20–25 %)</td>
<td>0.55–0.58 m³</td>
</tr>
</tbody>
</table>

Cement content in the sprayed concrete on the wall ~ 450–460 kg/m³

Wet spray process
There are two different wet spray processes, namely “thin” and “dense” stream pumping. In the thin stream process, the base concrete is pumped in a dense stream to the nozzle with a concrete pump, then dispersed by compressed air in a transformer and changed to a thin stream. The accelerator is normally added into the compressed air just before the transformer. This ensures that the sprayed concrete is uniformly treated with the accelerator.
With thin stream pumping, the same base mix is pumped through a rotor machine, as with dry spraying, with compressed air (blown delivery). The accelerator is added through a separate attachment to the nozzle with more compressed air.
Assuming that the same requirements are specified for the applied sprayed concrete, both processes – dense and thin stream application – require the same base mix in terms of granulometry, w/c, admixtures, additives and cement content.
Particle size distribution curve calculation with individual aggregate fractions

<table>
<thead>
<tr>
<th>Component</th>
<th>0.125</th>
<th>0.25</th>
<th>0.5</th>
<th>1.0</th>
<th>2.0</th>
<th>4.0</th>
<th>8.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIA-A</td>
<td>7</td>
<td>10.4</td>
<td>15.6</td>
<td>23.9</td>
<td>37.5</td>
<td>60.4</td>
<td>100</td>
</tr>
<tr>
<td>SIA-B</td>
<td>12.5</td>
<td>17.7</td>
<td>25</td>
<td>35.4</td>
<td>50</td>
<td>70.7</td>
<td>100</td>
</tr>
<tr>
<td>SIA-C</td>
<td>12.5</td>
<td>17.7</td>
<td>30</td>
<td>40.4</td>
<td>55</td>
<td>75.7</td>
<td>100</td>
</tr>
<tr>
<td>100 % 0–8 mm</td>
<td>5.8</td>
<td>12.5</td>
<td>19.0</td>
<td>28.0</td>
<td>40.5</td>
<td>62.2</td>
<td>100</td>
</tr>
</tbody>
</table>

Example of mix design for 1 m³ wet sprayed concrete
Wet sprayed concrete 0–8, sprayed concrete class C 30/37, CEM I 42.5, 425 kg, Silicafume 20 kg, steel fibers 40 kg

Cement 425 kg 135 l
SikaFume®-TU 20 kg 9 l

Aggregates:
0–4 mm with 4 % inherent moisture (55 %) 967 kg 358 l
4–8 mm with 2 % inherent moisture (45 %) 791 kg 293 l
Mixing water (w/b = 0.48) 155 kg 155 l
Air voids (4.5 %) 45 l
Steel fibers 40 kg 5 l

Sprayed concrete 1000 l
Unit weight per m³ 2398 kg

Admixtures
Water reducer/retarder: Sika® ViscoCrete®/SikaTard®
Alkali-free accelerator: Sigunit®-L53 AFS, Sigunit®-49 AFS, dosage 3–8 %
Alternative, alkaline: Sigunit®-L62, dosage 3.5–5.5 %

1 m³ applied sprayed concrete gives solid material on the wall of:

Accelerated with Sigunit®-L53 AFS 0.90–0.94 m³
Accelerated with Sigunit®-L20 (Rebound 10–15 %) 0.85–0.90 m³
Cement content in sprayed concrete on the wall 450–470 kg/m³
Steel fiber content in sprayed concrete on the wall 30–36 kg/m³
Sprayed Concrete

**Dry spraying**

- **Compressed air**
- **Concrete spraying machine**
- **Water**
- **Liquid accelerator**
- **Pneumatic delivery (thin stream)**
- **80–120 cm**

**Steps:**
1. **Dry mix**
2. **Sigunit, alkaline**
3. **Sigunit, alkali-free**
4. **Accelerator + water**
Wet spraying by the dense stream process

- Wet mix
- Concrete pump
- Liquid accelerator
- Compressed air
- Air for transformer
- Accelerator + air
- Hydraulic delivery (dense stream)
- Pneumatic delivery (thin stream)
- Sigunit, alkali-free
- Sigunit, alkaline
- 80–120 cm
Wet spraying by the thin stream process

- Wet mix
- Pneumatic delivery (thin stream)
- 80–120 cm
- Compressed air
- Concrete spraying machine
- Sigunit, alkaline
- Sigunit, alkali-free
- Accelerator + air
- Liquid accelerator
6.5 Test Methods/Measurement Methods

**Determination of early strengths**

To determine the very early strengths (in the range 0 to 1 N/mm²), the Proctor or Penetrating needle is used.

The following methods are well established for compressive strength testing between 2 and 10 N/mm²:

- **Kaindl/Meyco**: Determination by the pull-out force of bolts.
- **HILTI (Dr. Kusterle)**: Determination of the impression depth (I) and pull-out force (P) of nails shot with a HILTI DX 450L shot bolt machine (load and nail size are standard).
- **Simplified HILTI method (Dr. G. Bracher, Sika)**: Determination of the impression depth (I) of nails shot with a HILTI DX 450L shot bolt machine (load and nail size are standard). Determining the required early strength by this method should be accurate to ± 2 N/mm².

![Graph showing early strength testing methods](image)

- Penetrating needle up to 1 N/mm²
- HILTI method from 2 to max. 15 N/mm²
- Above 10 N/mm² cores can be made and then tested
**Strength development from 1 to x days**

Above 10 N/mm² cores can be taken from a test specimen. The Ø and height of the cores is 50 mm. The average is calculated from a series of 5 cores.

According to Dr. G. Bracher, Sika
### 6.6 The Sika Wet Spray System

<table>
<thead>
<tr>
<th>Water reducer with stabilizer</th>
<th>SikaTard®</th>
<th>Sika® ViscoCrete®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended average dosing range</td>
<td>0.8 %–1.6 %</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alkali-free and non-toxic accelerator</th>
<th>Sigunit®-L50 AFS</th>
<th>Sigunit®-L53 AFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended average dosing range</td>
<td>4 %–8.0 %</td>
<td>3.0 %–6.0 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Silicafume</th>
<th>SikaFume®</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended average dosing range</td>
<td>4 %–10 %</td>
</tr>
</tbody>
</table>

**Water reducer with stabilizer**
Set retarded and stabilized sprayed concrete with optimum workability due to SikaTard®.

**Water reducer**
- SikaTard®
- Sika® ViscoCrete®

Water reducers for sprayed concrete differ from traditional water reducers. They are subject to the following additional requirements:
- Good pumpability with low w/c ratio
- Extended workability/open time
- Combining well with the selected accelerator to support the strength development.

**Set accelerator**

<table>
<thead>
<tr>
<th>Sigunit®-L50 AFS</th>
<th>The alkali-free accelerator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sigunit®-L53 AFS</td>
<td>The alkali-free accelerator for maximum early strength</td>
</tr>
<tr>
<td>Sigunit®-L20</td>
<td>The alkaline accelerator</td>
</tr>
</tbody>
</table>

**Silicafume**
The SiO₂ in Silicafume reacts with calcium hydroxide to form additional calcium silicate hydrate. This makes the cement matrix denser, harder and more resistant. Today’s requirements for sprayed concrete, such as watertightness and sulphate resistance, are not easily met without the addition of Silicafume.
### 6.7 Steel Fiber reinforced Sprayed Concrete

**Definition**

Steel fiber reinforced sprayed concrete, like conventionally reinforced sprayed concrete, consists of cement, aggregates, water and steel. By using and adding steel fibers, the sprayed concrete is homogeneously reinforced.

**Reasons for using steel fiber reinforced sprayed concrete:**
- Saving on the costs for installation of steel mesh reinforcement
- Reduction in slump due to higher early strengths
- Elimination of “spray shadow” when spraying onto reinforcing mesh
- Due to its homogeneity, steel fiber reinforced sprayed concrete can withstand forces of various kinds in various directions at any point on its cross-section.

**Recommended Sika mix design for wet sprayed, steel fiber reinforced concrete:**

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granulometry</td>
<td>0–8 mm</td>
</tr>
<tr>
<td>Cement content</td>
<td>425–450 kg/m³</td>
</tr>
<tr>
<td>SikaFume®</td>
<td>min. 15 kg/m³</td>
</tr>
<tr>
<td>SikaTard®</td>
<td>1.2 %</td>
</tr>
<tr>
<td>Sika® ViscoCrete®</td>
<td>1 %</td>
</tr>
<tr>
<td>SikaPump®</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Sigunit®-L53 AFS</td>
<td>3–6 %</td>
</tr>
<tr>
<td>Steel fiber</td>
<td>40–50 kg/m³</td>
</tr>
</tbody>
</table>

**Additional notes:**
- The cement content may have to be increased because the fines content of steel fiber reinforced sprayed concrete must be higher than in standard wet sprayed concrete, to anchor the fibers.
- Adding Silicafume helps to achieve the target values of the sprayed concrete because it also improves anchorage of the fibers.
- SikaPump® improves the pumpability considerably.
- The minimum diameter of the pump line should be at least double the maximum fiber length.
- Recommended pump hose diameter min. 65 mm.
- The fiber loss in wet sprayed concrete is 10–20 %.
- In dry spraying, up to 50 % fiber loss must be assumed. The filling capacity of the pumping machine may also be less good, resulting in a lower application output and higher accelerator consumption.
- Test specimens for the workability of steel fiber reinforced sprayed concrete are slabs 10 cm thick with 60 × 60 cm sides.
6.8 Sulphate resistant Sprayed Concrete

A sprayed concrete with a standard cement content of 400–450 kg/m³ has high sulphate resistance when it uses:
- an HS cement combined with water reducer and SikaPump® or
- a standard Portland cement combined with water reducer and SikaFume® added at > 5 % or
- a CEM III-S.

Requirement: w/c < 0.50

Recommended Sika mix design for wet sprayed concrete:

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granulometry</td>
<td>0–8 mm</td>
</tr>
<tr>
<td>Cement content</td>
<td>425 kg/m³</td>
</tr>
<tr>
<td>SikaFume®</td>
<td>30 kg/m³</td>
</tr>
<tr>
<td>SikaTard®</td>
<td>1.6 %</td>
</tr>
<tr>
<td>Sika® ViscoCrete®</td>
<td>1.2 %</td>
</tr>
<tr>
<td>SikaPump®</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Sigunit®-L53 AFS</td>
<td>3–5 %</td>
</tr>
</tbody>
</table>

6.9 Sprayed Concrete with increased Fire Resistance

A sprayed concrete has increased fire resistance if it is improved with polypropylene fibers. In the event of fire, the PP fibers melt and leave pathways free for the incipient vapour diffusion, preventing destruction of the cement matrix due to the internal vapour pressure. Suitable aggregates are essential for increased fire resistance. Their suitability must be verified by preliminary tests.

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granulometry</td>
<td>0–8 mm</td>
</tr>
<tr>
<td>Cement type</td>
<td>CEM III / A-S</td>
</tr>
<tr>
<td>Cement content</td>
<td>425 kg/m³</td>
</tr>
<tr>
<td>SikaTard®</td>
<td>1.5 %</td>
</tr>
<tr>
<td>Sika® ViscoCrete®</td>
<td>1.2 %</td>
</tr>
<tr>
<td>SikaPump®</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Sigunit®-L53 AFS</td>
<td>3–6 %</td>
</tr>
<tr>
<td>Polypropylene fibers</td>
<td>2.7 kg/m³, according to type</td>
</tr>
</tbody>
</table>
The finish quality of the concrete is influenced by many factors. They include the concrete composition, the concrete raw materials, the formwork used, the concrete compaction, the temperature, the curing and the release agent used. The effect of the release agent is described below and advice on the right choice and correct use of release agents follows.

7.1 Structure of Release Agents

Release agents can be formulated from up to three different material groups:

**Release film formers**

These are the materials which are the base substances mainly responsible for the release effect, e.g. various natural and synthetic oils and also paraffin waxes are used.

**Additives**

Additional or intensified effects are obtained with these materials. They include release boosters, “wetting” agents, anti-corrosion additives, preservatives and the emulsifiers which are necessary for water-borne oil formulations. Most of the release agents in use today also contain other additives, some of which react chemically with the concrete, causing targeted disruption of setting. It is then much easier to release the concrete from the forms and the result is a more general purpose product.
7. Release Agents

**Thinners**
These products act as viscosity reducers for the release film formers and additives. Their purpose is to adjust the workability, layer thickness, drying time etc. Thinners are basically organic solvents or water for emulsions.

### 7.2 Release Agent Requirements

The following requirements are specified for the action of release agents, both in situ/cast in place situations, and for precasting:

- Easy and clean release of the concrete from the form (no concrete adhesion, no damage to the form)
- Visually perfect concrete surfaces (impermeable surface skin, uniform colour, suppression of void formation)
- No adverse effect on the concrete quality on the surface (no excessive disruption of setting, no problems with subsequent application of coatings or paints – or clear instructions for additional preparation are required)
- Protection of the form from corrosion and premature ageing
- Easy application

Another important requirement specifically for precast work is high temperature resistance when heated formwork or warm concrete is used. Unpleasant odour development is also undesirable, particularly in a precast factory. For site use, another important requirement is adequate rain resistance, and possibly traffickability after the release agent has been applied.

### 7.3 Selection of suitable Release Agents

The type of form is the main criterion for selection of the most suitable release agent. A list of different types is given in the table on page 130.

### 7.3.1 Release Agents for absorbent Formwork

In previously unused new timber formwork, the absorbency of the timber is very high. If the form is not correctly prepared, the water will be drawn out of the concrete surface from the cement paste. The results seen will be concrete adhesion to the form, and future dusting of the hardened concrete surface due to a lack of cement hydration. The concrete layer near the surface can also be damaged by constituents in the formwork (e.g. wood sugars). This manifests itself as powdering, reduced strength or discolouration, and occurred particularly when timber forms had been stored unprotected outdoors and were for some time exposed to direct sunlight. The effects described can all be quite pronounced when formwork is used for the first time but gradually they decrease with each additional use.
A simple way of counteracting these problems with new formwork has been developed and it has proved effective in practice. Before being used for the first time, the timber form is treated with release agent and then coated with a cement paste or thick slurry. The hardened cement paste is then brushed off. After this artificial aging, a release agent with some sealing effect should be applied initially for a few concreting operations. A low solvent or solvent-free, weak chemically reactive release oil should generally be used for this.

When timber formwork has been used a few times, its absorbency gradually decreases due to increased surface sealing as the voids and interstices of the surface fill with cement paste and release agent residues. Therefore older timber formwork only needs a thin coat of release agent. It is also possible to use release agents containing solvents or release agent emulsions on this older formwork.

### 7.3.2 Release Agents for non-absorbent Formwork

Forms made from synthetic resin modified timber, plastic or steel are non-absorbent and therefore cannot absorb release agent, water or cement paste. With all these materials it is extremely important to apply the release agent sparingly, evenly and thinly. “Puddles” should be avoided. They do not only result in increased void formation but can also cause discolouration and/or dusting of the concrete surface.

To obtain a thin and even release agent film on the form surface, low-viscosity oils with release additives are generally used, often also with solvents for fair-faced concrete. The release additives give improved release (e.g. with fatty acids or specific “wetting” agents) and also better adhesion of the release film to smooth, vertical form surfaces. This is particularly important where there are high formwork walls, considerable concrete pouring heights causing mechanical abrasion of the form surface, or the effects of weather and long waiting times between release agent application and concrete placing.
Heated steel forms represent a special application. The release film formed on the form must not evaporate due to heat and the release agent must be formulated so that a stronger chemical reaction (lime soap formation or saponification) cannot occur between the concrete and the release agent constituents during the heat treatment.

Textured forms made from special rubber or silicone rubber do not always require release agent, at least when new, because concrete does not stick to the smooth, hydrophobic form surface. If there is a need for release agent due to the form texture or increasing age, products containing solvents or special emulsions should be used dependent on the texture profile. A thin coat is necessary to prevent surplus release agent accumulating in lower lying parts of the form. A suitability test must be carried out to ensure that the release agents used do not cause the form to swell or partly dissolve.

7.4 Directions for Use

There are a few general directions for use in addition to the specific release agent product information.

7.4.1 Application of Release Agent

The most important rule is to apply the absolute minimum quantity as evenly as possible. The method of application for a release agent depends mainly on the consistence of the product. Low viscosity (liquid) products should preferably be applied by low pressure spray (pressure of 4–5 bar). Use a flat nozzle, the fineness of which depends on the solvent content of the release agent – possibly combined with a control valve or filter to prevent excess application with runs and drips etc.
Checking the correct release agent application rate

On smooth formwork, the correct, uniform release agent thickness can be checked by the “finger test”. No visible finger marks or release agent accumulations should be formed. Surplus release agent must be removed from horizontal formwork with a rubber or foam squeegee and the surface must be rubbed over. If too much material is applied on vertical or sloping formwork, runs on the surface or release agent accumulations at the base of the form will be visible. They must be removed with a cloth or sponge.

Very high viscosity release agents (e.g. wax pastes) are applied with a cloth, sponge, rubber squeegee, brush etc. Here again, only apply the absolute minimum quantity and as evenly as possible.
The weather conditions play an important part in the use of release agents. It is not appropriate to apply a release agent in the rain due to potential inadequate adhesion and water on the form. Absorbent forms may have a higher release agent requirement in strong sunlight and drought. Release agent emulsions are at risk in frosty weather as the emulsion may break up when it thaws before placing of the concrete.

7.4.2 Waiting Time before Concreting

A specific minimum waiting time between applying the release agent and concreting cannot generally be given, as it depends on many factors such as form type, temperature, weather and release agent type. The correct drying time of products containing solvents and water-based emulsions must always be maintained, otherwise the required release effect is not achieved. The quality of the concrete finish can also suffer because entrapped solvent residues can cause increased void formation.

The evaporation rate varies according to the type of solvent. The waiting times for each product should be taken from the Product Data Sheets.

Exposure or stress (foot traffic, weather etc.) on the release agent film and too long a time delay between application and concreting can reduce the release effect in some circumstances. With absorbent formwork this can happen after a period of a few days. Non-absorbent formwork is less critical and the effect of the release agent is generally maintained for a few weeks, dependent on the ambient conditions.

7.4.3 Concreting Operation

In general, when concreting it is important to ensure that the release agent suffers as little mechanical stress as possible. If possible the concrete should not be poured diagonally against vertical formwork to prevent localized abrasion of the release film. The pour should be kept away from the form as much as possible by using tremies/pipes etc. When compacting, make sure that the poker vibrators do not come too close to the formwork skin or touch it. If they do, they exert high mechanical stress on the form surface, which can result in abrasion of the release agent and later to localized adhesion (non-release) of the concrete.

Summary

The concrete industry cannot do without release agents. When correctly selected and used with the right formwork and concrete quality, they contribute to visually uniform and durable concrete surfaces. Inappropriate or wrongly selected release agents, like unsuitable concrete raw materials and compositions, can cause defects and faults in and on the concrete surface.

The Sika® Separol® range offers ideal solutions for most form release requirements.
8. Curing

8.1 General

For high durability, concrete must not only be “strong” but also impermeable, especially in the areas near the surface. The lower the porosity and the denser the hardened cement paste, the higher the resistance to external influences, stresses and attack. To achieve this in the hardened concrete, measures have to be taken to protect the fresh concrete, particularly from

- premature drying due to wind, sun, low humidity etc.
- extreme temperatures (cold, heat) and damaging rapid temperature changes
- rain
- thermal and physical shock
- chemical attack
- mechanical stress

Protection from premature drying is necessary so that the strength development of the concrete is not affected by water removal. The consequences of too early water loss are:

- Low strength in the parts near the surface
- Tendency to dusting
- Higher water permeability
- Reduced weather resistance
- Low resistance to chemical attack
- Occurrence of early age shrinkage cracks
- Increased risk of all forms of shrinkage cracking
The diagram below gives an illustration of the amount of water evaporation per m² of concrete surface under different conditions. As can be seen from the figure (arrow marking), at air and concrete temperatures of 20 °C, relative air humidity of 50 % and an average wind speed of 20 km/h, 0.6 litres of water per hour can evaporate from 1 m² of concrete surface. At concrete temperatures higher than air temperature and with widening temperature differences, the rate of water evaporation increases significantly. In the same conditions, a concrete temperature of 25 °C would result in 50 % more evaporation, i.e. 0.9 litres per m² per hour.

Effect on evaporation of relative air humidity, air and concrete temperature as well as wind speed (according to VDZ [German Cement Manufacturers’ Association])

An example to illustrate these figures:
Fresh concrete with a water content of 180 litres per m³ contains 1.8 litres of water per m² in a 1 cm thick layer. The evaporation rate of 0.6 litres per m per hour means that the concrete loses an amount of water equivalent to the total water content of concrete layers 1 cm thick within 3 hours and 3 cm thick after 9 hours. This thickness exceeds the minimum concrete cover required for external structures according to DIN 1045. A “resupply” of the evaporated water from the deeper areas of the concrete only
occurs to a limited extent. The negative impact on the strength, wear resistance and impermeability of the layers near the surface is considerable.

*Extreme temperature effects* cause the concrete to deform; it expands in heat and contracts in cold. This deformation causes stresses which can lead to cracks, as with shrinkage due to constraint. It is therefore important to prevent wide temperature differences (>15 K) between the core and the surface in fresh and new concrete and exposure to abrupt temperature changes in partially hardened concrete.

*Mechanical stress* such as violent oscillations and powerful shocks during setting and in the initial hardening phase can damage the concrete if its structure is loosened. Rainwater and running water often cause permanent damage to fresh or new concrete. Damage during subsequent works should be prevented by edge protection and protective covers for “unformed” concrete surfaces and by leaving formed concrete surfaces for longer before striking.

*Chemical attack* by substances in ground water, soil or air can damage concrete or even make it unfit for its purpose, even given a suitable mix formulation and correct installation, if this stress occurs too early. These substances should be kept away from the concrete for as long as possible, e.g. by shielding, drainage or covering.

### 8.2 Curing Methods

Protective measures against premature drying are:
- Applying liquid curing agents (e.g. *Sika® Antisol®-E20*)
- Leaving in the forms
- Covering with sheets
- Laying water-retaining covers
- Spraying or “misting” continuously with water, keeping it effectively submerged and
- A combination of all of these methods

Liquid curing agents such as *Sika® Antisol®-E20* can be sprayed onto the concrete surface with simple tools (e.g. low pressure, garden type sprayers). They must be applied over the whole surface as early as possible: on exposed concrete faces immediately when the initial “shiny” surface of the fresh concrete becomes “matt”, and on formed faces immediately after striking. It is always important to form a dense membrane and to apply the correct quantity (in g/m²) as specified, and in accordance with the directions for use. Several applications may be necessary on vertical concrete faces.

*Sika® Antisol®-E20* is milky white in colour when fresh, making application defects or irregularities easy to detect. When it dries, it forms a transparent protective membrane.
Leaving in the form means that absorbent timber formwork must be kept moist and steel formwork must be protected from heating (i.e. by direct sunlight) and from rapid or over-cooling in low temperatures.

Careful covering with impervious plastic sheets is the most usual method for unformed surfaces and after striking of formwork components. The sheets must be laid together overlapping on the damp concrete and fixed at their joints (e.g. by weighing down with boards or stones) to prevent water evaporating from the concrete.

The use of plastic sheets is particularly recommended for fair-faced concrete, as they will largely prevent undesirable efflorescence. The sheets should not lie directly in the fresh concrete. A “chimney effect” must also be avoided.

When enclosing concrete surfaces in water-retaining materials such as hessian, straw mats etc., the cover must be kept continuously moist or if necessary must also be given additional protection against rapid moisture loss with plastic sheets.

Premature drying can be prevented by keeping the surface continuously damp by continuously wetting the concrete surfaces. Alternate wetting and drying can lead to stresses and therefore to cracks in the new concrete. Avoid direct spraying on the concrete surface with a water jet, as cracks can occur if the concrete surface cools due to the lower water temperature and the latent heat development of the concrete, particularly on mass concrete structures. Suitable equipment types are nozzles or perforated hoses of the type used for garden lawn sprinklers. Horizontal surfaces can be left to cure under water where possible.
### 8.3 Curing Measures for Concrete

<table>
<thead>
<tr>
<th>Method</th>
<th>Measures</th>
<th>Outside temperature in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Below -3 °C</td>
</tr>
<tr>
<td>Sheet/curing membrane</td>
<td>Cover and/or spray with curing membrane and dampen. Wet timber formwork; protect steel formwork from sunlight</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Cover and/or spray with curing membrane</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>Cover and/or spray with curing membrane and heat insulation; advisable to use heat insulating formwork – e.g. timber</td>
<td>X*</td>
</tr>
<tr>
<td></td>
<td>Cover and heat insulation; enclose the working area (tent) or heat (e.g. radiant heater); also keep concrete temperature at +10 °C for at least 3 days</td>
<td>X*</td>
</tr>
<tr>
<td>Water</td>
<td>Keep moist by uninterrupted wetting</td>
<td></td>
</tr>
</tbody>
</table>

* Curing and striking periods are extended by the number of frosty days; protect concrete from precipitation for at least 7 days

At low temperatures it is not enough just to prevent water loss on the concrete surface. To prevent excessive cooling, additional protective heat insulation measures must be prepared and applied in good time. These depend mainly on the weather conditions, the type of components, their dimensions and the formwork.

Curing with water is not allowed in freezing temperatures. Thermal covers such as boards, dry straw and reed mats, lightweight building board and plastic mats are all suitable protection for brief periods of frost. The cover should preferably be protected on both sides from moisture with sheets. Foil-backed plastic mats are the most suitable and are easy to handle. In heavy frosts or long periods of freezing temperatures, the air surrounding the fresh concrete must be heated and the concrete surfaces must stay damp. Good sealing is important (e.g. by closing window and door openings and using enclosed working tents).
8.4 Curing Period

The curing period must be designed so that the areas near the surface achieve the structural strength and impermeability required for durability of the concrete, and corrosion protection of the reinforcement. Strength development is closely connected to the concrete composition, fresh concrete temperature, ambient conditions, concrete dimensions and the curing period required is influenced by the same factors.

As part of the European standardization process, standardized European rules are being prepared for concrete curing. The principle of the European draft is incorporated in E DIN 1045-3. Its basis is that curing must continue until 50 % of the characteristic strength $f_{ck}$ is obtained in the concrete component. To define the necessary curing period, the concrete producer is required to give information on the strength development of the concrete. The information is based on the ratio of the 2 to 28 day average compressive strength at 20 °C and leads to classification in the rapid, average, slow or very slow strength development range. The minimum curing period prescribed according to E DIN 1045-3 is based on these strength development ranges. The table below shows the minimum curing period as a factor of the strength development of the concrete and the surface temperature.

**Curing according to DIN 1045-3 July 2001**

**Curing methods**

<table>
<thead>
<tr>
<th>DIN 1045-3</th>
</tr>
</thead>
</table>
| – Relative air humidity $\geq 85\%$  
| – Leaving in the form  
| – Covering with waterproof sheets  
| – Laying water-retaining covers  
| – Maintaining a film of water on the concrete surface  
| – Curing agent |
Curing period
Exposure classes: see section 2.2 (page 22)

<table>
<thead>
<tr>
<th>Regulation</th>
<th>DIN 1045-3</th>
<th>ZTV-ING Part 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure classes (according to DIN 1045-2)</td>
<td>X0</td>
<td>XC2–XC4</td>
</tr>
<tr>
<td></td>
<td>XS</td>
<td>XM</td>
</tr>
<tr>
<td></td>
<td>XD</td>
<td>X0</td>
</tr>
<tr>
<td></td>
<td>XF</td>
<td>XA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minimum curing period requirements</th>
<th>12 h</th>
<th>Until strength of concrete near the surface reaches min. 50 % 70%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>50 % 70%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 % 70%</td>
</tr>
</tbody>
</table>

| Simplified definition of minimum curing period | If the periods specified in Table 2 DIN 1045-3 are maintained for single double single double time, the necessary strength is considered to be achieved |

Table 2 DIN 1045-3

<table>
<thead>
<tr>
<th>Surface and/or air temperature</th>
<th>Minimum curing period in days as a factor of the strength development $r^1$ of the concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r \geq 0.50$</td>
</tr>
<tr>
<td>$T \geq 25^\circ C$</td>
<td>1</td>
</tr>
<tr>
<td>$25 &gt; T \geq 15^\circ C$</td>
<td>1</td>
</tr>
<tr>
<td>$15 &gt; T \geq 10^\circ C$</td>
<td>2</td>
</tr>
<tr>
<td>$10 &gt; T \geq 5^\circ C$</td>
<td>3</td>
</tr>
</tbody>
</table>

$^1$ Interim values may be interpolated.

The value $r = \frac{f_{CM \, 2}}{f_{CM \, 28}}$ (ratio of average concrete compressive strength after 2 and 28 d) defines the strength development of the concrete and shall be determined by suitability tests.

Precise definition of minimum curing period | Precise evidence of sufficient strength development on the structure is permissible (e.g. by maturity)

Generally applicable requirements | Consistence over 5 h → An appropriate extension to the curing period is to be specified
Temperature below 5 °C → Periods at $T < 5^\circ C$ cannot be deducted from the specified curing times
Temperature below 0 °C (ZTV-ING) → frost protection measures are to be provided while the concrete has not reached a minimum compressive strength of 10 N/mm²
Concrete Admixtures and the Environment

Concrete admixtures are liquid or powder additives. They are added to the concrete mix in small quantities to meet specific requirements:

- To increase the durability
- To improve the workability
- To change the setting or hardening reaction of the cement

The effect of admixtures is always to improve the concrete. In quantity terms, superplasticizers (high range water reducers) and plasticizers (water reducers) as a group make up about 80% of all of the admixtures used today.

How much do concrete admixtures leach, biodegrade or release fumes?

Superplasticizers should be non-toxic, water-soluble and biodegradable.

Tests on pulverized concrete specimens show that small quantities of superplasticizers and their decomposition products are leachable in principle. However, the materials degrade well and do not cause any relevant ground water pollution. Even under the most extreme conditions, only small quantities of organic carbon leaches into the water.

- Conclusion of test: The air is not polluted by superplasticizers.

To summarize: How environment-friendly are superplasticizers?

Concrete admixtures are appropriate for their application and when correctly used are harmless to man, animals and the environment.

The technical benefits of superplasticizers for clients and construction professionals outweigh the occurrence of low, controllable emissions during use. Concrete admixtures merit being rated environment-friendly because they create negligible air, soil or ground water pollution.

See the following publications:

- “Environmental Compatibility of Concrete Admixtures”
  Report by the Association of Swiss Concrete Admixtures Manufacturers (FSHBZ)
  July 1995

- EU Project ANACAD
  Analysis and Results of Concrete Admixtures in Wastewater
  Final report BMG Engineering AG Zürich
  February 2000
Sika is a member of EFCA, the European Federation of Concrete Admixtures Associations.

Sika Admixtures conform to the EFCA environmental quality standard.
# Index

## A

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
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Sika – with Long Experience

Sika began developing the first admixtures for cementitious mixes in 1910, the year in which it was founded. At that time the main aims were to shorten the setting time of mortar mixes, make them watertight or increase their strength. Some of these early, successful Sika products are still in use today.

Water is necessary in concrete for consistence and hydration of the cement, but too much water in the hardened concrete is a disadvantage, so Sika products were also developed to reduce the water content while maintaining or even improving the consistence (workability):

<table>
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<th>Date</th>
<th>Product base</th>
<th>Sika Product</th>
<th>Main effects</th>
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<tr>
<td>1930</td>
<td>Lignosulphonate</td>
<td>Plastocrete®</td>
<td>Water reduction up to 10 %</td>
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<td>1940</td>
<td>Gluconate</td>
<td>Plastiment®</td>
<td>Water reduction up to 10 % plus retardation</td>
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<td>1960</td>
<td>Naphthalene</td>
<td>Sika Retarder®, Fro-V</td>
<td>Retardation and air entrainment</td>
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<td>1970</td>
<td>Melamine</td>
<td>Sikament®-NN</td>
<td>Water reduction up to 20 %</td>
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<tr>
<td>1980</td>
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<td>Sikament®-300/-320</td>
<td>Water reduction up to 20 %, reduced air content</td>
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<td>1990</td>
<td>Vinyl copolymers</td>
<td>Sikament®-10/-12</td>
<td>Water reduction up to 25 %</td>
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<tr>
<td>2000</td>
<td>Modified polycarboxylates</td>
<td>Sika® ViscoCrete®</td>
<td>Water reduction up to 40 %, SCC concrete technology for self-compaction</td>
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</table>

Ever since the company was formed, Sika has always been involved where cement, aggregates, sand and water are made into mortar or concrete – the reliable partner for economic construction of durable structures.

Sika – with a Global Presence

Sika AG in Baar is a globally active, integrated speciality chemicals company. Sika is a leader in the technology and production of materials used to seal, bond, insulate, strengthen and protect load bearing structures in buildings and in industry.

Sika’s product range includes high performance concrete admixtures, speciality mortars, sealants and adhesives, insulating and strengthening materials, systems for structural strengthening, industrial flooring and waterproofing membranes.

Sika team of authors:

Sika, the right System Solutions

Concrete and mortar production
Waterproofing
Concrete repair, protection and strengthening
Bonding and sealing
Flooring
Steel corrosion protection and fire protection
Synthetic sheet membrane waterproofing of roofs and containment
Tunneling
Associated machinery and equipment

Sika concrete admixtures
Sika sprayed concrete machines and support systems
Sika waterproofing systems
Sika – Your Local Partner with a Global Presence

Sika is a globally active company in the speciality and construction chemicals business. It has subsidiary manufacturing, sales and technical support facilities in over 70 countries around the world.

Sika is THE global market and technology leader in waterproofing, sealing, bonding, dampening, strengthening and protection of buildings and civil engineering structures. Sika has more than 9’200 employees worldwide and is therefore ideally positioned to support the success of its customers.