Concrete Technology for Concrete Pumps

Putzmeister

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Imprint

Editor
Putzmeister Concrete Pumps GmbH
Max-Eyth-Straße 10, 72631 Aichtal, Germany

Revision of previous edition
Dr.-Ing. Knut Kasten, Putzmeister Engineering GmbH

Specialist support
Dr.-Ing. Dieter Bergemann

Dipl.-Ing. H.-Jürgen Wirsching,
Concrete technologist, V+O Valet u. Ott Transportbeton GmbH & Co. KG, Albstadt

Dipl.-Wirtsch.-Ing. Christian Klafszky,
Director, Betonpumpenunion GmbH & Co. KG, Ulm

Layout and Print
Offizin Scheufele GmbH & Co. KG
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Preliminary comments

"Concrete is an artificial stone which is made from a mixture of cement, aggregates and water – and if necessary also with concrete admixtures and concrete additions (concrete additives) – by the hardening of the cement paste (cement-water mixture)." A highly diverse range of concrete properties can be achieved depending on the composition selected. Before hardening, the freshly-mixed concrete is more or less "fluid" and can be made into almost any shape, and when it has hardened as an artificial stone it retains this shape.

The wide range of possible compositions and applications of concrete as a construction material have resulted in a variety of different distinctions and categories:

- **In terms of reinforcement, a differentiation is made between:**

  - Reinforced concrete:
    - conventionally reinforced concrete
    - pre-stressed concrete
  - Non-reinforced concrete
  - Fibre-reinforced concrete

- **In terms of dry density, a differentiation is made between:**

  - Lightweight concrete lighter than 2.0 t/m^3, but not lighter than 0.8 t/m^3
  - Normal concrete heavier than 2.0 t/m^3, but not heavier than 2.6 t/m^3
  - High density concrete heavier than 2.6 t/m^3

- **In terms of the hardening state, a differentiation is made for**

  - Fresh concrete as long as it can still be processed
    - according to its consistency, fresh concrete is subdivided into
      → stiff (F1), plastic (F2), soft (F3), very soft (F4), free-flowing (F5) and very free-flowing (F6)

  - according to the type of conveying and placing,
    - → cast concrete, pumped concrete, underwater concrete and sprayed concrete.
  - according to the type of compacting, the following types of concrete are classified:
    - → tamped, rod, vibrated, jolted and spun concrete, easily workable concrete, self-compacting concrete

- Green concrete — concrete after initial setting and during hardening; can no longer be placed (it has begun to develop hardness)

- Hardened concrete — after hardening
  - according to the type of surface conditions, hardened concrete is subdivided into:
    - → exposed concrete, washed concrete, smooth concrete, etc.

In terms of the preparation location, a differentiation is made between:

- Construction site concrete — mobile mixer located on-site

- Ready-mixed concrete — a stationary concrete plant makes the concrete and the fresh concrete is delivered by truck mixers to the construction site ready for placing

In terms of the placement location, a differentiation is made between:

- Cast in-situ concrete — placement of freshly-mixed concrete and hardening at the final site

- Concrete products — manufactured at a precasting plant or components that are manufactured on-site and installed once the concrete has hardened (roof elements, supports, etc.)

In terms of the manufacturing and monitoring requirements, the following subdivisions are mad

Object	Monitoring class 1	Monitoring class 2	Monitoring class 3
Property class for normal and High density concrete in accordance with DIN EN 206-1 and DIN 1045-2	≤ C25/30	≥ C30/37 and ≤ C50/60	≥ C55/67
Property class for lightweight concrete in acc. with DIN 1045-2 and EN 206-1 of raw density classes D1,0 to D1,4 D1,6 to D2,0	cannot be used ≤ LC25/28	≤ LC25/28 LC30/33 and LC35/38	≥ LC30/33 ≥ LC40/44
Exposition class acc. to DIN 1045-2	X0, XC, CF1	XS, XD, XA, XM, XF2, XF3, XF4	–
Special properties of concrete		Concrete for watertight buildings (e.g. water-impermeable basements) Underwater concrete Concrete for high working temperatures ≤ 250 °C Radiation protection concrete (apart from nuclear power plant construction) For certain applications (e.g. delayed concrete, concrete construction when handling materials hazardous to water), the relevant DAfStb guidelines must be applied.	

Concrete technology comprises all tasks which especially serve the purpose of guaranteeing the desired construction material properties of concrete with the base materials available. After determining the mix contents, this mainly concerns all freshly-mixed concrete processes from mixing, to transport, placing and compaction, through to any required after-treatment of the green concrete. At the same time, concrete technology is responsible for purposefully influencing the properties of the freshly-mixed concrete for the planned placing stages in a serviceable way, but if possible without any negative impact on the later properties of the hardened concrete.

Nowadays, the pumping of freshly-mixed concrete is a link in the process chain that one can scarcely imagine living without. With the current state of concrete technology, pumpable concrete is no longer classed as a special concrete, instead it is a construction material regulated by the concrete standard DIN EN 206-1 / DIN 1045-2 with a specified composition as required with reinforced concrete for reinforced components (from C16/20, consistency F3).

However, every good pump operator should have a basic knowledge of concrete technology. Pump operators should know which technical pumping consequences are a result of the different properties of the material, while also recognising the potential consequences for the construction material if the fresh concrete is handled incorrectly when pumping. This present document "Concrete Technology For Pumping" aims to fulfil this purpose. Further information can be found in the "Technical Regulations" (see section 6) as well as in more specialised literature (see section 7).

Fig. 1: Putzmeister M 42-5 truck-mounted concrete pump in Bonn

1. Concrete components Base materials and their influences

1.1 Cement

Cement is usually a grey powder which is fabricated by burning and grinding certain rock with lime and clay content. During hardening, a mixture of cement and water, known as the cement paste, firmly combines (binds) the individual aggregates to each other to form artificial stone.

Cement used for general purposes is subdivided into 5 main categories:

- CEM I Portland cement
- CEM II Portland composite cement (main components in addition to PC clinker: granulated cinder, powdered limestone, burnt shale, fly ash, etc.)
- CEM III Blast furnace cement
- CEM IV Pozzolanic cement
- CEM V Composite cement

The different cements are available in different quality levels, classified according to property classes. For example:

- CEM I 32,5 R (Portland cement with property class 32.5 N/mm^2 and quicker – rapid hardening)
- CEM II/B-T 42,5 N (Portland shale cement with property class 42.5 N/mm^2 and normal hardening)

Depending on the chemical composition and fineness of grinding, the cements all develop their hardness at different rates. Portland cements are usually among the cements with higher early strength. Blast furnace cements can considerably improve chemical resistance. The standard norms for cement are as follows:

- In Germany, DIN EN 197-1
- Various country-specific standards

The numerical data of the property classes usually refer to the minimum strength attained by test specimens after 28 days at a certain w/c ratio, measured in the respective country-specific unit (e.g. in Germany: N/mm^2, in Austria: kp/cm^2). The strength development is by no means complete after 28 days; however, this value usually forms the basis for the strength calculation and the granting of permission to use the building.

The setting of the cement (hydration) is a very complicated process where water is bound chemically and physically. When mixing cement and water a cement paste results and here the cement immediately starts to form new microscopic crystal bonds with the water. These fine crystals mat together more and more densely, and this first results in the setting and then the hardening of the cement paste to form cement stone. This has the following special properties:

- It remains solid and volumetrically stable both in air and under water
- The steel components in the concrete (e.g. reinforcement) are protected against corrosion
- When temperatures increase, it expands to the same extent as steel

This fulfils essential prerequisites for the durability of reinforced concrete.

The cement must only be allowed to set at the earliest 90 minutes after the mixture is created. The concrete must therefore be placed within this time period.

For complete hydration, approximately 40 % of the cement mass must be water. Approximately 25 % is chemically bound, while the rest remains in the gel pores as steam, i.e. physically bound. For a water-cement ratio below 0.40, the cement grain cannot hydrate completely even with constant water immersion; whereas for a w/c ratio of over 0.40, even after complete hydration, very fine capillary pores are formed which at first remain full of water, which later evaporates. Fig. 2 illustrates these conditions. The diameter of these capillary pores is approximately 1000 times larger than that of the gel pores.

To fabricate a placeable concrete usually more than just 40 % of the cement mass is required as water. The amount of water required is stipulated in the mixture breakdown.

Caution!
Any unauthorised addition of water on the construction site will lead to drastic quality losses.

With pumping concrete, this significantly impairs hardness (up to 30 %) and hence also the density and durability of the concrete.*

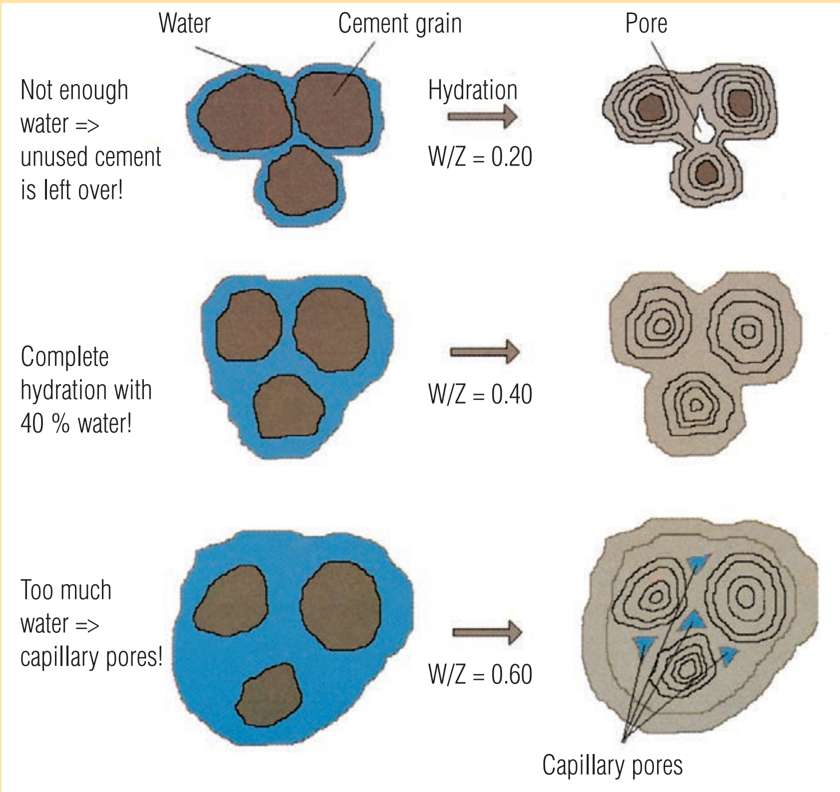

Fig. 2: Diagram showing the reaction of cement and water (hydration)

*refer to section 1.5 und 3

1.2 Addition of water

Suitable water is mixing water in accordance with DIN EN 1008. This standard includes guidelines for limiting the content of harmful substances that have a corrosive action or may impair hardening. In general: drinking water is always suitable as mixing water.

Caution!
The mix of water and cement is greatly alkaline and has a caustic effect on skin and mucous membranes. Always wear appropriate gloves, protective goggles and sturdy shoes. In case of accidental direct contact, rinse immediately with plenty of clean water.

1.3 Aggregates

Aggregates are usually natural rock from gravel pits, rivers (gravel and sand) or quarries (chippings) and they give the concrete certain properties. The quality requirements that are to be monitored are stipulated in the respective standards:

- In Germany, DIN EN 12620
- Various country-specific standards

Along with the designation of the aggregate and the usual grain groups, these standards also contain the requirements regarding:

- Aggregate composition
- Aggregate shape
- Resistance to shattering
- Resistance to burnishing and abrasion
- Alkali-silicic acid reactivity
- Resistance to wear
- Resistance to frost and thawing agent
- Content of substances of organic origin
- Sulphate content
- Compressive strength
- Content of expandable components
- Content of water-soluble chloride

Concrete aggregates are divided into aggregate classes according to particle size: The minimum and maximum particle sizes for each class are specified, e.g. 0/2; 0/4; 2/8; 8/16; 16/32. The aggregate of a type of concrete usually consists of a mix of fine, medium and coarse grain. This composition may be naturally present in a quarrying site. Usually, however, the natural grain mix or the mix that results when rocks are broken is classified immediately on site, i.e. it is separated by large sifting plants according to grain size and then delivered to concrete mixing plants and stored in separate boxes.

When preparing the concrete in the mixer, the portions of the different aggregate sizes are mixed in the composition required. The composition of a grain mix is measured by screening and represented graphically as a grading curve. To do this, a previously measured sample is separated into individual grain size groups in a laboratory by a set of stacked, vibrating screens made up of the prescribed mesh or square hole screens. Fig. 3 illustrates this process. The top screen has the largest mesh width and the lowest screen the smallest. At the very bottom the base is solid to retain the finest components. The sample to be examined is evenly distributed onto this vibrating set of screens. The individual grains drop downwards from screen to screen until the mesh or hole width is too small for the respective particle size.

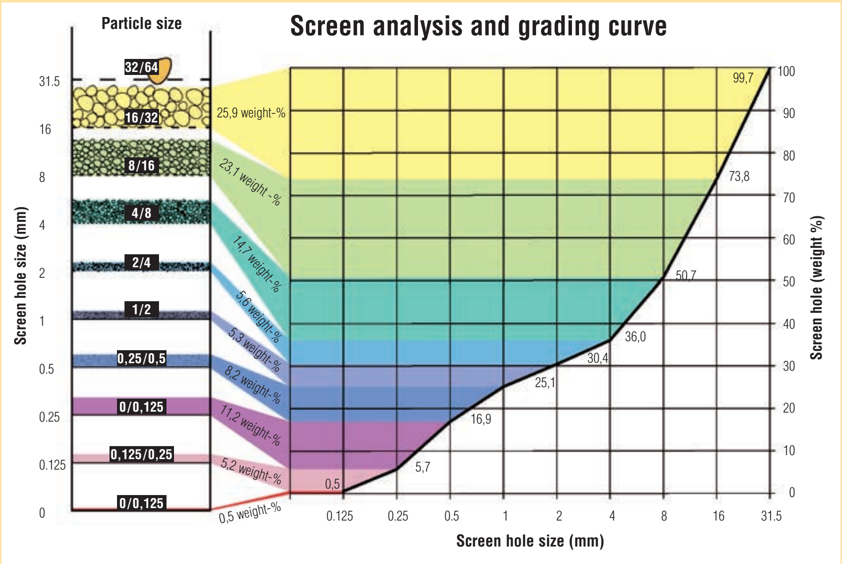

Fig. 3: Sieve analysis and grading curve

The distribution of coarse and fine aggregates in the grain mix influences the specific surface to be wetted, and hence directly affects the requirement for cement paste. The quantities of water and cement paste required for an aggregate mixture also depend on the shape of the granules. Fig. 4 illustrates this with the example of a cube representing a "compact" grain and a plate with the same volume representing a "flat" grain which has a surface 2/3 times greater than that of the "compact" grain. For "broken" grain, this difference is even greater, whereas the surface area of a "round grain" (sphere) with the same volume is 1/5 smaller than that of the cube. In addition, the shape of the grain (see Fig. 5) also directly influences the workability of the concrete. Concrete with round, compact and smooth grain "flows" better and can also be compacted better than concrete with long, plate-like or easily broken aggregates with a rough surface.

Usually the maximum particle size of the aggregate for concrete is restricted to a diameter of 32 mm. For components with a particularly large mass, this value can be raised to 63 mm (the concrete can then only be pumped using special equipment). The maximum particle size for finely structured and densely reinforced components is restricted to a diameter of 16 mm or even 8 mm.

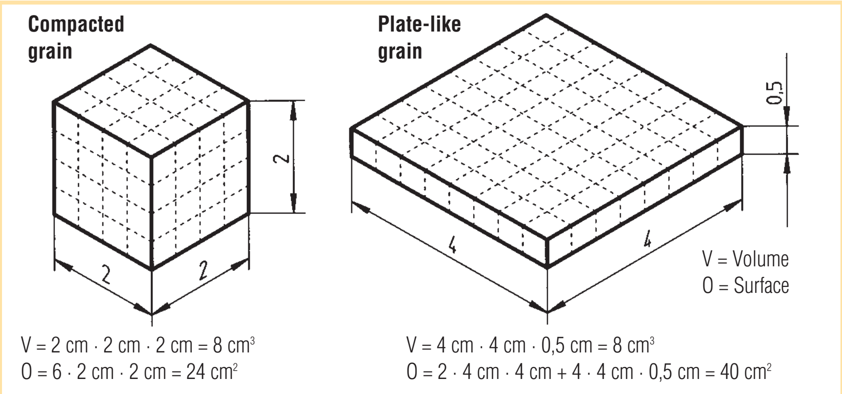

Fig 4: Different geometries result in different surface areas for the same volume

Compacted grain

Multiple broken grain

Plate-like grain

Fig. 5: Influence of the shape of the grain on the surface

1.4 Concrete admixtures

Admixtures influence the properties of fresh or hardened concrete. In Germany, concrete admixtures must either correspond to a standard, possess a test mark from the Deutsches Institut für Bautechnik (German Institute of Construction Technology), or have a CE conformity declaration. Admixtures are usually powdered substances that are added to the concrete. They mainly work physically and usually serve as an aid for better workability, less water repellence (bleeding), higher structural imperviousness or as coloration.

Admixtures are classified into type I and type II.

- Type I admixtures are inert, non-reactive substances that mainly improve workability through a "filler" effect. E.g.: powdered rock, colour pigments.
- Type II admixtures are reactive substances that improve hardness which, in addition to improving workability, also cause changes in physical properties. E.g.: Coal fly ash, microsilica.

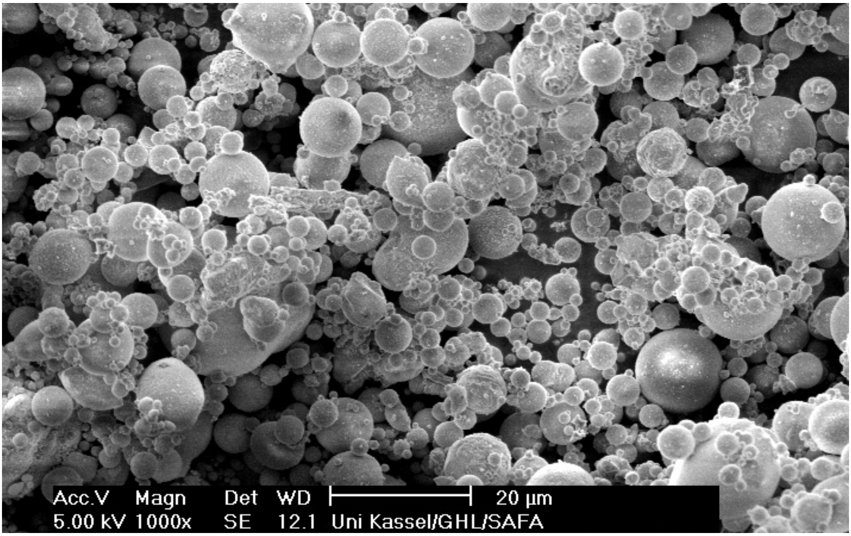

Fig. 6: Fly ash in an electron microscope grid (SAFAMENT)*

**Source: SAFA Baden-Baden*

1.5 Concrete additives

Concrete additives are usually liquid and are only added in very small amounts whilst mixing the concrete. They have a physico-chemical action and are classified into so-called efficiency groups depending on their effect in freshly-mixed or hardened concrete:

- Concrete deflocculants (BV)
  These concrete additives depressurise the water, improving workability while at the same time reducing or maintaining the prescribed water-cement ratio.

- Plasticising admixtures (FM)
  These concrete additives are advanced deflocculants. They have a particularly strong deflocculant action and enable efficient concrete installation with very soft to liquid consistencies. Plasticising admixtures are usually treated as deflocculants and are added in the transport concrete mixer. Plasticising admixtures based on polycarboxylate ether usually have a high consistency and no longer need to be added at the construction site.

Fig. 7: Concrete before and after addition of plasticising admixture

- Air-entraining agents (LP)
  Concrete with high resistance to frost and thawing salt must have a minimum content of micro air voids (smaller than 0.3 mm) which can be obtained by adding air entraining agents. Ice has a larger volume than water. If the expansion of the frozen water is prevented in the concrete then the concrete may burst. The additional air voids offer the necessary space for this extension.

- Water resisting admixtures (DM)
  These are used to improve the water imperviousness of the concrete. Water resisting admixtures are designed in particular to protect the structure from penetrating substances that may be harmful to water.

- Setting retarders (VZ)
  These delay the setting time of the concrete, which may be required for several reasons, e.g. hot weather or jointless components with a large mass (e.g. bridge superstructures, strong base plates, concrete for kerb stones). Over-metering can, however, have the opposite effect and turn the setting retarder into a setting accelerator agent!

- Setting accelerators (BE)
  These chemically accelerate the setting of, for example, shotcrete or sealing mortar up to just a few seconds after spraying or placing. An alternative, without the disadvantage of considerable reduction of the 28 day- and final strength is physically-active micro silica dust.

Caution!
It is not advisable to add admixtures and additions on the construction site, since the concrete purchaser loses all claims to a guarantee.

*Fig. 8: Laboratory research into concrete additives and storage in compliance with regulations in the transport concrete mixer**

1.6 Concrete composition – mix calculation

The composition of fresh concrete is specified by defined limits in the standards DIN EN 206-1/ DIN 1045-2. Depending on the environment, concrete is divided into exposition classes*, which refer to the corrosion of concrete and reinforcements.

		No risk of corrosion or attack	Reinforcement corrosion									
			Corrosion cause by carbonation				Corrosion caused by chloride					
							Chloride except from sea water			Chloride from sea water		
No.	Exposition class	XO[a]	XC1	XC2	XC3	XC4	XD1	XD2	XD3	XS1	XS2	XS3
1	Max. permitted W/Z	–	0,75		0,65	0,60	0,55	0,50	0,45			
2	Min. compress. strength class[b]	C8/10	C16/20		C20/25	C25/30	C30/37[d]	C35/45[de]	C35/45[d]			
3	Min. cement content[c] in kg/m^3	–	240		260	280	300	320	320	see XD1	see XD2	see XD3
4	Min. cement content[c] allowing for additions in kg/m^3	–	240		240	270	270	270	270			
5	Min. air content in %	–	–		–	–	–	–	–			
6	Other requirements	–	–		–	–	–	–	–			

[a] Only for concrete with no reinforcement or embedded metal.

[b] Does not apply for lightweight concrete.

[c] With a maximum aggregate particle size of 63 mm, the cement content can be reduced by 30 kg/m^3.

[d] If using air-entrained concrete, e.g. due to simultaneous requirements from exposition class XF, one property class lower.

[e] For slowly or very slowly hardening concrete (r < 0.30), one property class lower. The compressive strength for classification into the required compressive strength class should also be determined in this case using 28-day old samples.

Limits for the composition and properties of concrete – reinforcement corrosion

**refer to section 3.1 on page 32*

		Concrete corrosion												
		Attack by frost						Aggressive chemical environment			Exposure to wear[h]			
No.	Exposition class	XF1	XF2		XF3		XF4	XA1	XA2	XA3	XM1	XM2		XM3
1	Max. permitted W/C	0,60	0,55[g]	0,50[g]	0,55	0,50	0,50[g]	0,60	0,50	0,45	0,55	0,55	0,45	0,45
2	Min. compressive strength class[b]	C25/30	C25/30	C35/45[e]	C25/30	C35/45[e]	C30/37	C25/30	C35/45[de]	C35/45[d]	C30/37[d]	C30/37[d]	C35/45[d]	C35/45[d]
3	Min. cement content[c] in kg/m^3	280	300	320	300	320	320	280	320	320	300[i]	300[i]	320[i]	320[i]
4	Min. cement content[c] allowing for addition of admixtures in kg/m^3	270	[g]	[g]	270	270	[g]	270	270	270	270	270	270	270
5	Min. Air content in %	–	[f]	–	[f]	–	[fj]	–	–	–	–	–	–	–
6	Other Require-ments	F_4	MS_{25}		F_2		MS_{18}	–	–	[l]	–	Surface treat-ment of the con-krete[k]	–	Hardma-terials acc. to DIN 1100
		Aggregates for the exposition classes XF1 to XF4 (see DIN V 20000-103 and DIN V 20000-104)												

[bcde] See footnotes to the table on page 20.

[f] The average air content in fresh concrete immediately before placing must be as follows: with a maximum aggregate particle size of 8 mm ≥ 5,5 % (volume share), 16 mm ≥ 4,5 % (volume share), 32 mm ≥ 4,0 % (volume share) and 63 mm ≥ 3,5 % (volume share) Individual values are permitted to fall no more than 0.5 % (volume share) below these requirements.

[g] Type II admixtures may be added, but must not be included in the cement content or the W/C.

[h] Only aggregates according to DIN EN 12620 in compliance with the specifications of DIN V 20000-103 must be used.

[i] Maximum cement content 360 kg/m^3, but not for high-strength concrete.

[j] Earth-moist content with W/C ≤ 0.40 may be manufactured without air entrainment.

[k] e.g. vacuuming and power trowelling of the concrete.

[l] Protective measures.

Limits for the composition and properties of concrete – concrete corrosion

The aim of the mix calculation is to determine a composition of the required consistency and the required maximum particle size in accordance with the existing exposition classes. To do this, the substance volume calculation of a construction technology calculation program with corresponding results output is used.

The water-cement ratio as the most important quality parameter

The water-cement ratio is determined by the quantity ratio of total added water to cement content.

With increasing water-cement ratio,

- the strength of the concrete decreases
- the water permeability increases
- the concrete dries more quickly and shrinks more, which results in high shrinkage stress and the risk of crack formation
- the concrete may become more prone to "bleeding" and segregation
- the sealing properties, durability and service life of the concrete decrease

Content of fine matter

Fine matter is the share of solid matter which has a particle size smaller than 0.125 mm, i.e. the fine content is composed of cement, the share of 0/0.125 mm grain contained in the concrete aggregate, and any concrete additive added.

Fine matter improves the workability of the freshly-mixed concrete and leads to a dense texture of the hardened concrete. A sufficient share of fine matter is therefore important for pumped concrete, exposed concrete, concrete for thin-walled, tightly reinforced components and for water-impermeable concrete.

However, if the proportion of fine matter is too great, there is also a greater demand for water and hence the water/cement ratio also increases. The resistance to frost and wear decreases. The standard DIN EN 206-1/DIN 1045-2 therefore limits the content of fine matter for concrete:

Cement content (kg/m³)	Maximum permitted fine matter content (kg/m³)
≤ 300	400
≥ 350	450

Maximum permitted fine matter content for concrete with a maximum aggregate particle size of 16 mm to 63 mm up to and including the concrete property class C50/60 and LC50/55 in the exposition classes XF and XM.

Mortar content

Mortar is defined as the shares of cement, water, air voids, and 0/2 mm aggregate. Its content is given in dm³ per 1 m³ compressed fresh concrete.

The mortar content influences the pumpability and workability of the concrete. The following are standard values for pumpable concrete:

Maximum particle size (mm)	Mortar content (dm³/m³)
32	≥ 450
16	≥ 500

Mix formula calculation

For the final calculation of the mix formula for 1 m³ compacted freshly-mixed concrete, note that the % shares of the individual grain groups from the grading curve not only have very different bulk densities but also a certain, usually individual water content. Due to this, the dry mass, the water contained in the aggregate and the total mass to be weighed when mixing, are to be calculated for every grain group. The amount of water actually added when mixing is a result of the reduced water content of the water contained in the aggregate of all the grain groups.

2. Properties of freshly-mixed concrete (general)

The most important properties of freshly-mixed concrete are:

- bulk density (incl. degree of compaction and pore content)
- workability (incl. consistency, deformation behaviour, homogeneity etc.)

2.1 Bulk density

The bulk density of freshly-mixed concrete refers to the mass in kg per m^3 of fresh concrete compacted in accordance with specifications, including the remaining air voids.

Following careful compaction, for a normal concrete with a 32 mm maximum particle size, the remaining air content in the concrete is still 1 – 2 Vol.-%, i.e. 10 – 20 litres per m^3. In fine-grained concrete, this value can be up to 60 litres per m^3. Too great an air content, no matter what type, would however impair the strength of the concrete.

The freshly-mixed concrete placed in the component contains more or fewer voids depending upon the consistency and the aggregate mix. These voids that are first filled with air must be removed as far as possible by compaction. With the aid of an exterior vibrator on the formwork or a vibrating cylinder that is immersed into the freshly-mixed concrete, the freshly-mixed concrete is made to vibrate so that it seems to become fluid within the vibrator's zone of action and the air from the air voids rises to the surface as a result of natural ascending force. In order to ensure that this path up to the surface does not become insurmountably long, or the duration for compaction and the associated risk of segregation is not increased unnecessarily, the concrete layer to be compacted by vibrating should not be higher than approx. 0.5 m.

However, the compaction of freshly-mixed concrete comprises more than this. The concrete components on the construction component surface formed by a formwork as well as on the surface of the reinforcement rods or mats located in the construction components have to be rearranged in such a way that even these surfaces are completely covered with cement paste. Unsatisfactory compaction is very often the cause for later damage to the structure or for complaints even at the stage of the acceptance test for the structure. The degree of compaction of recently placed and compacted concrete can, however, not be measured.

2.2 Workability

The consistency is a measure for the stiffness and thereby the workability of the concrete. With an otherwise constant concrete quality, it does not depend upon the w/c ratio but upon the amount of cement paste. The consistency is measured and tested by various standardised test methods.

The most common test procedures in Germany are the flow-table test in accordance with DIN EN 12350-5 and, for stiffer concretes, the compaction test in accordance with Walz (DIN EN 12350-4).

Spread classes		
Class	Spread (diameter in mm)	Description of consistency
F1	≤ 340	stiff
F2	350 bis 410	plastic
F3	420 bis 480	soft
F4	490 bis 550	very soft
F5	560 bis 620	free-flowing
F6	≥ 630	very free-flowing

For spreads above 700 mm, the DAfStb "self compacting concrete" guideline or the EFNARC guidelines must be followed.

Compaction classes		
Class	Compaction	Description of consistency
C0	≥ 1,46	very stiff
C1	1,45 bis 1,26	stiff
C2	1,25 bis 1,11	plastic
C3	1,10 bis 1,04	soft
C4*	< 1,04	–
* C4 applies only to lightweight concrete		

The compaction test in accordance with DIN EN 12350-4 is suitable for determining the consistency of stiff, plastic and soft concrete, but not for free-flowing concrete. This method may be more suitable than the slump test for consistency classes F2 and F3 when using chip concrete, concrete with a high fine matter content or lightweight and high-density concrete.

The flow-table test in accordance with DIN EN 12350-5 is applied in Germany as shown in figure 10 under the same test conditions for determining the consistency for consistency ranges F2 to F6. In the US the consistency of the freshly-mixed concrete is usually quoted with the so-called slump test according to Chapman/Abrams (ASTM) according to Fig. 11. This test is also very widespread and well-known in many countries. In Germany, the test has become standardised in accordance with DIN EN 12350-2.

The consistency of the freshly-mixed concrete continuously changes from the time it leaves the mixer to the end of workability – approximately as shown in Fig. 12. This process, generally known as "stiffening" is completely normal and meets the requirements for the later strength development of the concrete and is not to be mistaken for the effect of plasticising admixtures, which is also limited to a certain time.

The temperature of the fresh concrete is important when concreting during extremely cold and extremely warm outside temperatures. This should be between +5° C and +30° C when placing. If the air temperature is below -3 °C, the concrete temperature when placing must be at least +10 °C.

Fig. 9: Compacting the concrete with vibrating cylinder

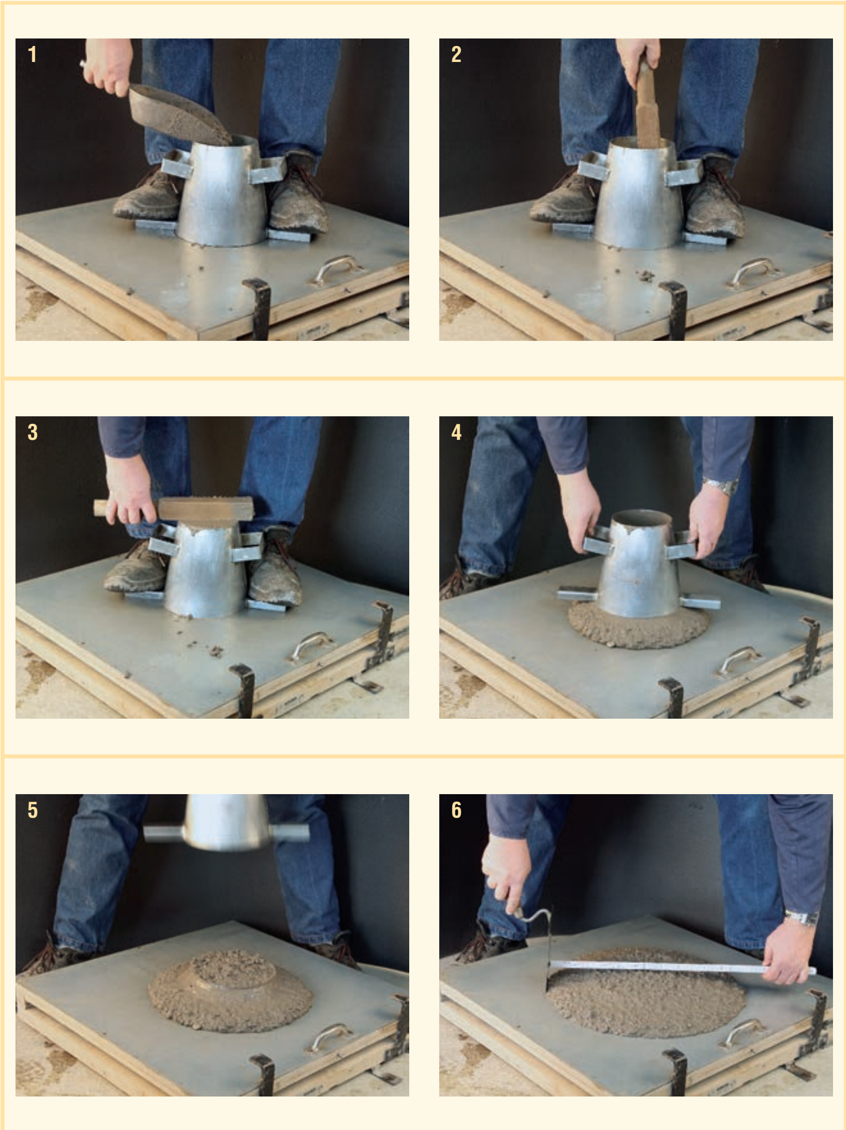

Fig. 10: Measuring spread in accordance with DIN EN 12350-5

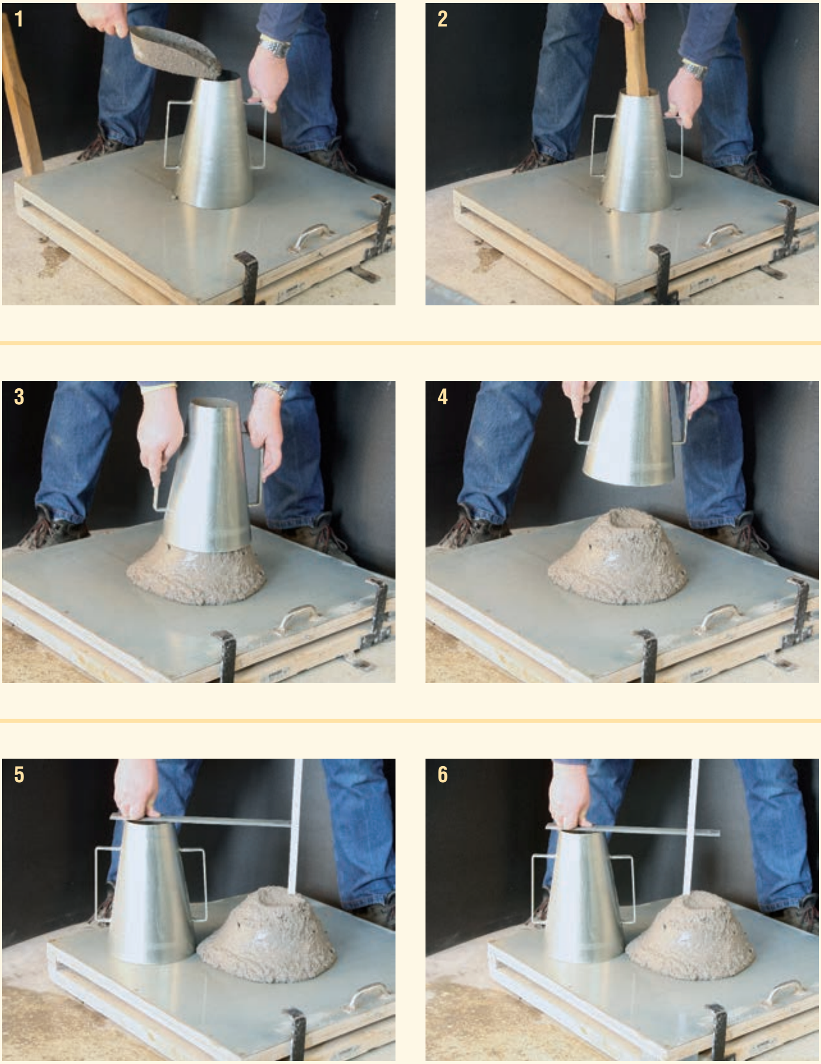

Fig. 11: Measuring slump in accordance with DIN EN 12350-2

Increased temperatures of freshly-mixed concrete (considerably above +20° C) generally accelerate the stiffening. High summer temperatures or artificially increased temperatures of freshly-mixed concrete (warm concrete for winter construction) considerably shorten the length of time between the mixing and the initial setting.

If a longer period of time has to be bridged between the fabrication and placing of concrete, then the stiffening of the concrete must be taken into account accordingly. This means, for example, that ready-mixed concrete must be made soft enough whilst being prepared in the works – and that both the travelling time and the temperature are taken into consideration – so that it has the desired consistency when it arrives on the construction site.

Caution!
Unauthorised addition of water on the construction site for renewed "softening" of the concrete drastically impairs the quality!

However, the different consistency parameters only reflect a part of the qualities of the freshly-mixed concrete with regard to workability. Important here are also the water-retaining capacity, the pump-ability and pump-willingness (refer to section 4.1), the deformation and alternating behaviour during compaction (refer to section 2.1) etc.

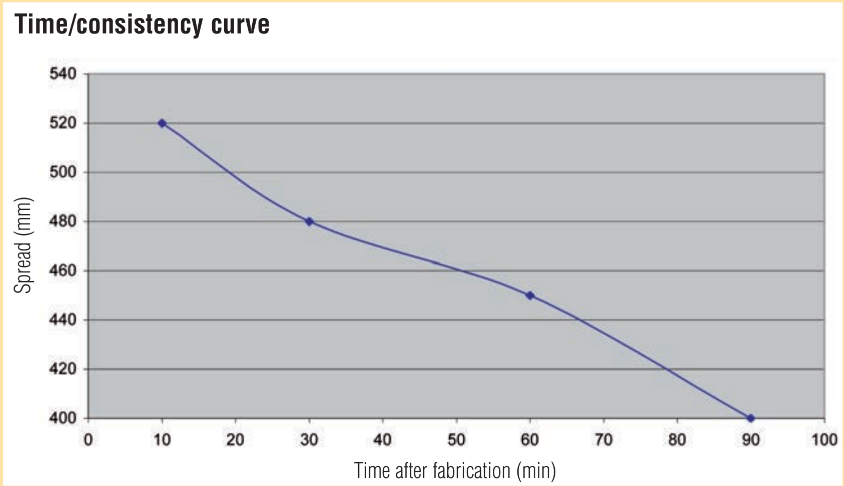

Fig. 12: Time-dependency of consistency

3. Properties of hardened concrete

3.1 Exposition classes

Exposition classes are used to describe chemical and physical environmental conditions to which the concrete may be subjected. To guarantee an intended usage of at least 50 years and a durability for the intended use, the exposition classes are used to define requirements for the concrete composition (see section 1.6).

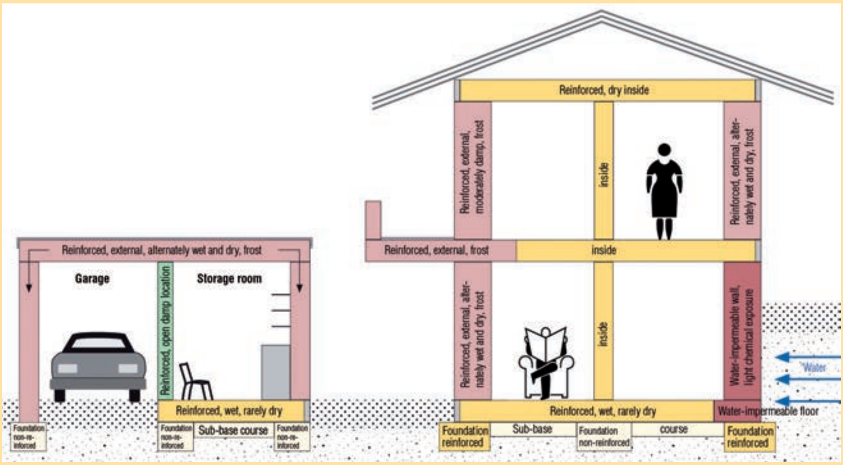

*Fig. 13: Exposition classes in the residential construction**

Exposition Class	Corrosion and Exposure Type
X0	No risk of corrosion or exposure
XC1, XC2	Reinforcement corrosion due to carbonation
XC3	Reinforcement corrosion by carbonation, moderate damp
XC4, XF1 or XC4, XF1, XA1	Reinforcement corrosion by carbonation, concrete exposure by frost without thawing agents, Weak environmental chemical exposure
XC4, XF1, XA1	Concrete with high resistance to water penetration (water-impermeable concrete) in accordance with DIN 1045-2 and German "WU-Richtlinie" - water impermeable concrete guideline

**Source: publication by Holcim (Baden-Württemberg) GmbH*

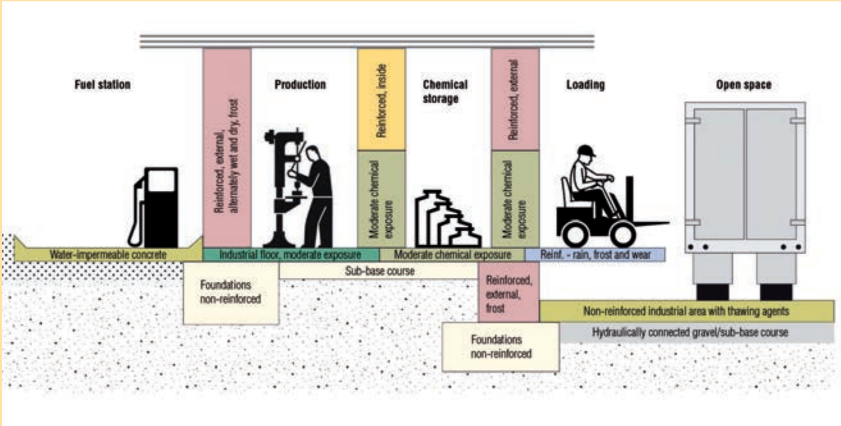

*Fig. 14: Exposition classes in the industrial construction**

Exposition Class	Corrosion and Exposure Type
X0	Reinforcement corrosion due to carbonation
XC1, XC2	Reinforcement corrosion due to carbonation
XC4, XF1 or XC4, XF1, XA1	Reinforcement corrosion by carbonation, concrete exposure by frost without thawing agents, Weak environmental chemical exposure
XC2, XM1 and XM2 XC2, XM2	Reinforcement corrosion due to carbonation, concrete exposure due to moderate to severe Exposure to wear
XC4, XA2, XF3 XM1, XM2	Reinforcement corrosion due to carbonation, concrete exposure through moderate chemical attack Environment, frost, and exposure to wear
XC4, XA2, XF3 XM1, XM2	Reinforcement corrosion due to carbonation, concrete exposure through moderate chemical attack Environment, frost, and moderate to severe exposure to wear
XC4, XF4, XD3, XA2 XM1, XM2	Reinforcement corrosion due to carbonation and chloride, concrete exposure to frost with thawing Agents, moderate environmental chemical exposure and moderate to severe exposure to wear

*Source: publication by Holcim (Baden-Württemberg) GmbH

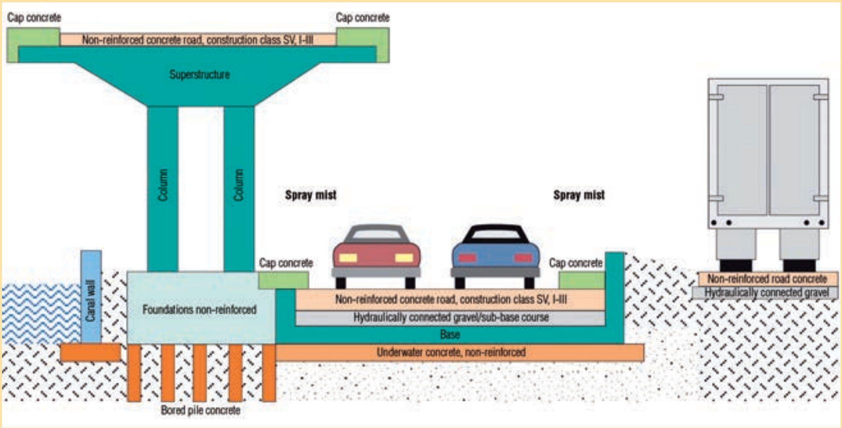

*Fig. 15: Exposition classes in the engineering construction**

Exposition Class	Corrosion and Exposure Type
XC4, XF1, XA1 or XC4, XF1, XA1, XD1 XM1	Reinforcement corrosion by carbonation, concrete exposure by frost and weak chemical Environmental exposure
XC4, XF3, XA1	Reinforcement corrosion by carbonation, concrete exposure by frost and weak environmental chemical exposure
XC4, XD3, XF4	Reinforcement corrosion due to carbonation and chloride, concrete exposure to frost with and without thawing agents
XC4, XD1, XD2, XF2 XF3, XA2, XM1, XM2	Reinforcement corrosion due to carbonation and chloride, concrete exposure to frost with and without thawing agents, moderate environmental chemical exposure and exposure to wear
XF4, XM1 or XF4, XM2	Concrete exposure to frost with and without thawing agents, moderate to severe exposure to wear
XA1 or XA2	Concrete exposure to moderate to severe chemical environment
XC2, XA1 or XC2, XA2	Reinforcement corrosion by carbonation, concrete exposure to moderate to severe chemical environment

**Source: publication by Holcim (Baden-Württemberg) GmbH*

3.2 Compressive strength

The compressive strength is the most important property of concrete. The standard check for determining compressive strength (DIN EN 12390, part 4) is usually performed after 28 days on sample cubes with 15 cm edges. The compressive strength is determined from the maximum load applied in the test press (before breakage) in Newtons, divided by the surface area of the test object that was subjected to the load in mm^2. Depending on the compressive strength, the concrete is assigned to one of the property classes described in chapter 1.6. A certain cube compressive strength may also be necessary at a specified time earlier than after 28 days, e.g. when stripping walls or floors. It can, however, also be arranged for a later date, e.g. when using slowly-hardening cement.

A lower compressive strength than anticipated can be caused by improper handling of the concrete when placing.
This includes in particular:

- unauthorised addition of water on the construction site
- placing of fresh concrete after setting has begun
- insufficient compaction, especially as a result of fill lifts being too great and
- improper subsequent treatment, e.g. insufficient protection against premature drying out

Fig. 16: Compressive strength test

3.3 Corrosion protection

A permanent protection against corrosion of the reinforcement can only be attained by the concrete surrounding it, but only when the hardened cement paste is sufficiently leakproof and the concrete cover thick enough. Unfortunately, when determining the maximum particle size mistakes are often already made in assessing the actual amount of space available for the concrete to "slip through" when placing between the reinforcement rods.

Likewise the "mixing work" necessary for complete covering of the reinforcement must not be underestimated whilst compacting. What makes it more complicated here is that the reinforcement is necessarily concentrated in the areas near the surface where the concrete also still has to be "arranged" so that the surface is enclosed by the concentration of the fine particles.

The necessary concrete cover which is a requirement for sufficient protection against corrosion, must be guaranteed by sufficient spacers. The forces that the falling or flowing fresh concrete exerts on the reinforcement are often very great and the subsequent displacement of a correctly installed reinforcement is covered by concrete. The damage does not come to light until quite a long time afterwards when the reinforcement rusts and the concrete chips.

Fig. 17/18: Spalling of the concrete cover due to reinforcement corrosion (severe exposure to sea salt)

The impermeability of the concrete to water does not just serve to guarantee the corrosion protection for the reinforcement but also prevents the penetration of water that stands under pressure, e.g. for dams or building foundations below the groundwater table. Testing of water impermeability is carried out according to DIN 12390-8 by testing the action of a water pressure of 0.5 N/mm^2 (5 bar) for 3 days. Then the average penetration depth of the water must not be more than 50 mm. Besides the intensive compaction, special attention must be given to avoiding construction joints between the individual concreting sections. It is imperative to ensure that concrete layers are placed "fresh on fresh". Concrete layers of not more than 30 to 50 cm guarantee that, for example, the vibrating cylinder with a normal penetration depth also reaches into the previous layer before this has begun to set.

3.4 Other properties of hardened concrete

Resistance to chemical corrosion is divided into three classes:
Weak, medium, and severely corrosive environments.

When the attacking water is highly charged with sulphate (more than 0.6 g per litre) cement with a high resistance to sulphate (HS-cement) is to be used. However, concrete that is exposed to "very strong" chemical attacks over a long period of time must be protected consistently and in the long-term by a protective cover before the onset of the corrosive substances.

Frost-resistance requires concrete that is impermeable to water with sufficient strength and with aggregates that are resistant to frost. Resistance to frost and thawing salt is improved by the addition of air-entraining additives (LP).

A high **resistance to wear** is required by concrete with a surface that is exposed to a great mechanical load, e.g. lots of traffic, slipping bulk material, the movement of heavy objects or water with a strong current and water that carries solids.

4. Properties and conditions of freshly-mixed concrete when pumping

4.1 Pumpability and willingness to pump

Pumpable concrete is not a special type of concrete, although not every type of concrete fulfils the requirements for pumpability. The question regarding the pumpability of fresh concrete can be asked and answered in two steps:

1. Is the concrete at all pumpable under the given conditions?
2. If yes, how can the concrete be pumped, i.e. at what cost?

A freshly-mixed concrete is deemed pumpable when it is structurally leakproof and remains so throughout the whole pumping process. Structurally leakproof means that all firm components are completely enclosed by liquid (water) and can move against each other. The pressure transmission within the concrete must therefore only take place via the liquid. Therefore, in every cross-section along the route of transmission, the aggregate-cement mixture must at least be saturated with water. The flow resistance within the aggregate-cement mixture must be greater than the friction in the external layer.

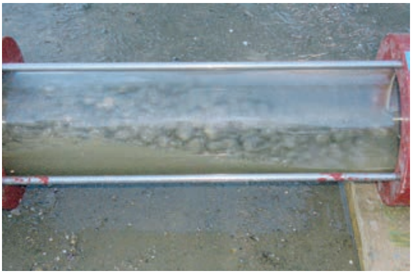

Fig. 19: Typical blockage

Fig. 20: Pumping of high-density concrete in compressive strength class C100/115

The concrete composition in the finest grain range is thus very important. The cement and the other finest grain shares therefore do not just provide the "lubrication" on the pipe wall and thereby a reduction of the wall friction resistance but also provide an almost complete "packing" of the grain structure.

The pumpability and structural density of fresh concrete are not, however, simply a question of composition, but also depend on the pipe diameter and the associated "boundary zone layer".

Experience shows that the following are needed for pumpability:

- a suitable composition to provide a constant grading curve between the limit grading curves A and B according to DIN 1045-2
- a cement content of at least 240 kg/m^3 for concrete with a maximum particle size of 32 mm
- a fine matter and powdered sand content (≤ 0.25 mm) of at least 400 kg/m^3 for concrete with a maximum particle size of 32 mm
- a mortar content of at least 450 dm^3/m^3 for concrete with a maximum particle size of 32 mm
- a pipeline diameter of at least three times the maximum particle size diameter

The willingness to pump when pumpable does not simply imply the specific conveying resistance depending upon the consistency coefficient and flow velocity, but also the internal mobility of the freshly-mixed concrete when sucked into and passing through delivery line bends and other changes in cross-section. The relevant parameter for the willingness to pump is expressed by the consistency coefficient in the so-called "concrete pressure performance diagram" (refer to section 4.4). The consistency coefficient is used to calculate the viscosity of the concrete in relation to the pipeline. The "Bingham" model often associated with concrete in literature also requires a so-called material yield limit for the description in addition to the viscosity. This yield limit represents the minimum resistance that must be overcome for the material to move. The yield limit has not yet been integrated in the nomogram. However, in practice it has emerged that the pipeline resistance of concrete can be calculated accurately using the formula used to create the nomogram.

The number of different ways to describe the consistency and the wide range when comparing measured values that cannot be precisely described physically, demonstrate the complexity of this matter. We will nevertheless try to provide an idea of this property in the following.

4.2 Origination and properties of the "boundary zone layer"

When concrete is conveyed through pipes and tubes, the necessity of applying a "lubricating film" made of cement paste directly on the pipe wall is emphasised at all times. A concentration of fine grain can be clearly seen on the outside of the "concrete sausage" when the concrete emerges out of the pipeline. The causes and effects of this "boundary zone layer" are as yet only little understood.

As has already been mentioned, pumpable fresh concrete is structurally leakproof in every part of the delivery line, i.e. the aggregate mix "swims" freely in the "concrete paste". The spaces between the grains are "saturated" with cement paste. The air voids that are also present and that have a liquefying effect are pressed together by the delivery pressure that is needed for pumping to just a fraction of their natural size and thereby lose their liquefying effect when pumping.

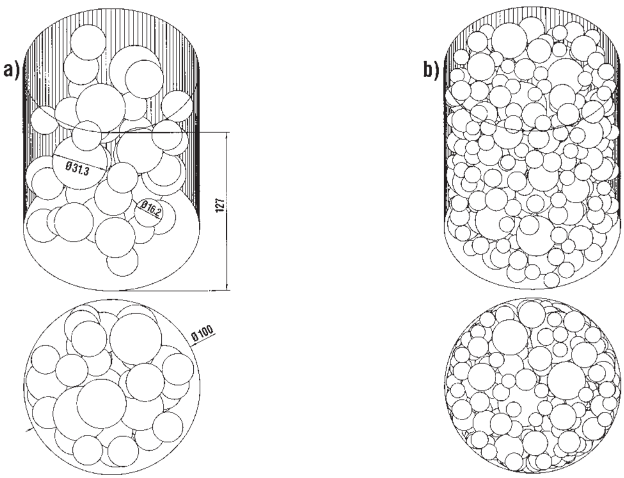

Fig. 21: Space occupation of a pipe section (1 litre) with spherical grains of the example mixture: a) particle size 16/32 b) particle size 8/16 and 16/32

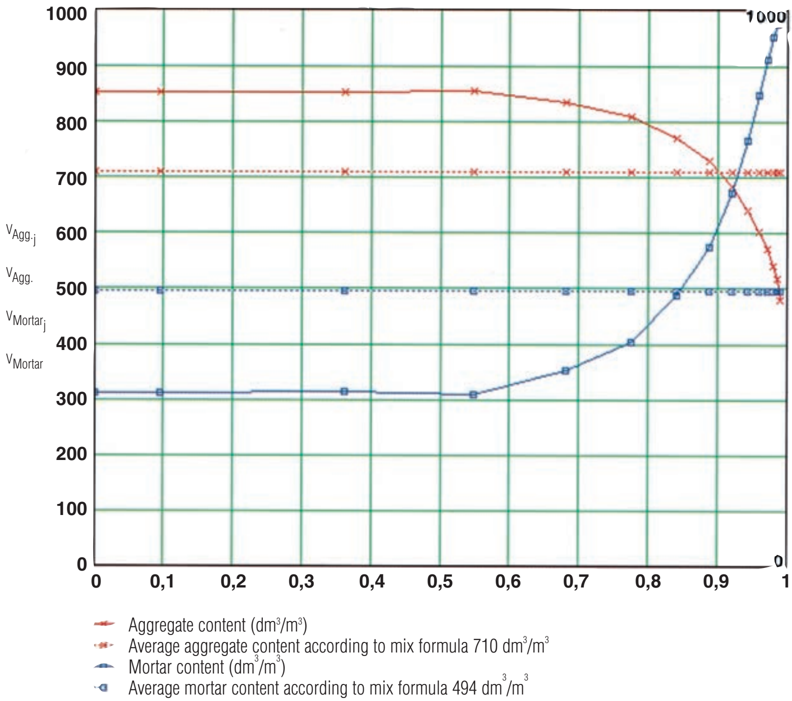

Fig. 22: Boundary zone layer segregation for a delivery pipe diameter of 100 mm for the example concrete (composition dependent upon the relative distance from the central axis of the pipe)

As an example the air void content falls from 10 % in a loose bulk concrete to a residual share of just 0.12 % with a conveying pressure of 85 bar. The additive grains of the concrete occupy the space in accordance with their volume share. To illustrate this better, one can, for example, examine a line section with a diameter of 100 mm, 127 mm long with a volume of 1 litre and all aggregate grains of the grain 8/16 and 16/32 as spheres of different sizes. Fig. 21 shows a possible, random arrangement of these spheres in a pipe section of this type.

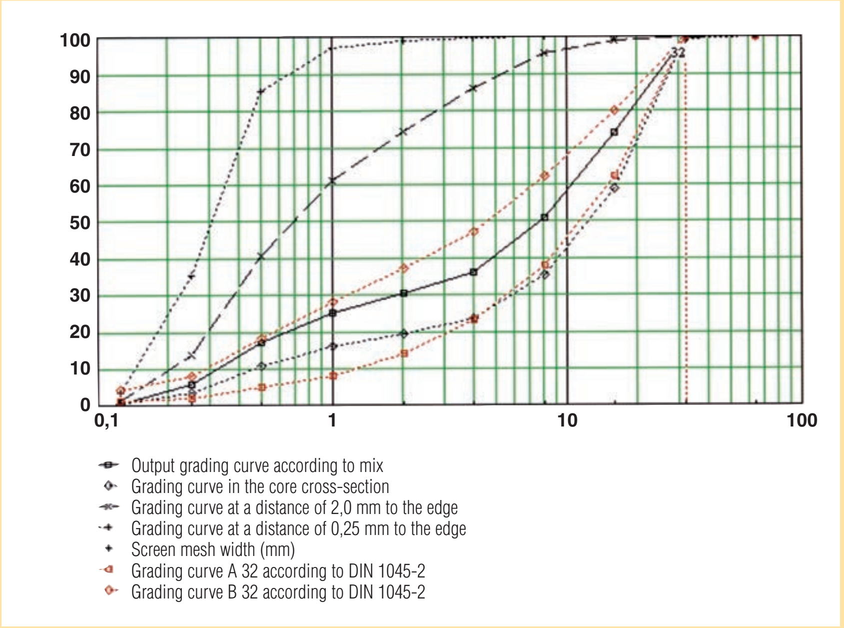

Fig. 23: Changes to grading curve in the core and boundary zone

*Fig. 24: Axial cross-section through the stream of concrete, left = blockage, right = flowing**

*Fig. 25: Radial cross-section through the stream of concrete, left = blockage, right = flowing**

* *Kaplan, D.: Pompage des bèton, Laboratoire Central des Ponts et Chaussees, issue 36, 2001, Paris*

As is generally known, the largest, "bulkiest" grains have a diameter of up to a third of that of the pipe that encloses them. However, each grain can only approach the pipe wall until it makes contact with its surface. If you now "step back" in a layer parallel to the pipe wall, for example, at a distance of 1 mm, you also only come across the external layers of the larger particles, while all particles with a diameter smaller than
1 mm contribute to filling the space with their whole volume, and can compensate for the "lack" of coarse grain. In other words, to fill the pipe cross-section completely with the concrete components, the large grains must be pressed inwards and a suitable share of the smaller grain and water must be pressed outwards – at least in the boundary zone. This process is comparable to flattening the concrete surface with a trowel.

The "boundary zones segregation" is always carried out when a space is filled with concrete, therefore already when filling the delivery cylinders as well as for final placement, e.g. into a wall formwork. A requirement here, however, is the previously mentioned inner mobility of the freshly-mixed concrete.

In the boundary zone, the mixture becomes constantly finer until there is pure cement mortar immediately next to the internal pipe wall. This accordingly results in an accumulation of

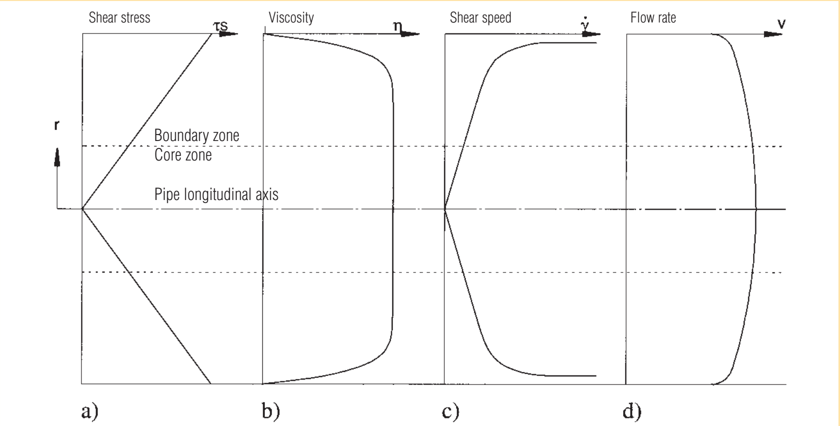

Fig. 26: Flow influences on the pipe conveying of fresh concrete
a) Shear stress b) Viscosity c) Shear speed d) Speed profile

coarse grain in the core zone. A requirement, however, for the pumpability of the concrete, is that the structural impermeability of the cone zone remains despite boundary zone segregation. This explains why concrete is only pumpable up to a certain minimum pipe diameter. Fig. 23 shows the alterations to the grading curve at different distances to the pipe wall.

This radius-dependent concrete composition in the pipe cross-section shows that the freshly-mixed concrete properties are also dependent upon cross-section and radius, and that they alter according to changes during pumping. On the way through the delivery line the freshly-mixed concrete is subject to different stresses and changes in shape which it opposes with a certain resistance. When being conveyed in the straight cylindrical pipe, an exclusive shear stress τ_S increases linearly as a function of the radius, as shown in Fig. 26a.

The concrete opposes this stress with a shear resistance (concrete viscosity) τ_W which is dependent upon the speed but is in no way constant over the course of the cross-section. Rather, the viscosity of the concrete coincides with the "denticulation" of the cement paste with aggregate grain that greatly decreases towards the wall (refer to Fig. 22): The share of aggregate in the core zone is a multiple of the share of cement paste, whereas towards the edge the share of aggregate practically drops to zero. This difference also becomes apparent

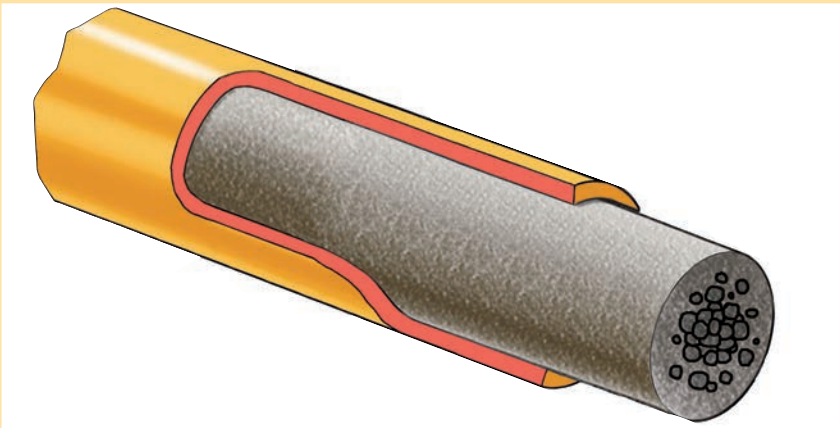

Fig. 27: Schematic representation of boundary zone segregation

when the average particle size of cement (approx. 0.01 mm) is compared with the maximum particle size (e.g. 32 mm), The course in Fig. 26b shows the overall viscosity results: The tenacity on the wall is approximately equivalent to that of the cement paste as known from rheological readings; increasing towards the core zone by a multiple factor..

The significantly greater viscosity of the core zone compared to the boundary zone (see Fig. 26b) and the increase in shear stress with the increasing radius (see Fig. 26a) result in a very rapidly increasing shear stress $\dot{\gamma}$ in accordance with Figure 26c, and a 'plug conveyance' that is very similar to the rate profile for the concrete flow in the pipe in accordance with figure 26d. Laboratory experiments performed by RÖSSIG with normal concrete only showed a total shear deformation of 0.3 to 0.5 m within the core zone after a pumping distance of 10m. This corresponds approximately to a 100 to 200x shear distortion of the whole boundary zone compared to the core zone. It thus follows that the pipe conveying of freshly-mixed concrete has no additional mixing effect. Only in delivery line bends and after leaving the delivery line does a certain remix ensue when placing and packing and in this case, as already mentioned, renewed zone segregation occurs, e.g. on the surfaces of the formwork as well as in the reinforcement.

4.3 The behaviour of freshly-mixed concrete in the concrete pump

The concrete technological task of the pump is to press the freshly-mixed concrete as a closed and continuous conveying current into the delivery line, and then through this to the point of placement and to carry this out as far as possible without any impairment to its given composition and properties. The behaviour of the freshly-mixed concrete in the concrete pump includes on the one hand its passive behaviour as a result of the active reaction of the concrete pump to it, and on the other hand its own reactive effect on the concrete pump and its behaviour. The freshly-mixed concrete and the concrete pump run through different "operating phases" here.

One must distinguish between on the one hand the operating state of the pump (starting up pumping, normal conveying operation, emptying and cleaning the line, malfunctions) and, on the other hand, the operating state of the concrete (transfer and sojourn time in the hopper, suction, filling of the conveying space, passing through the valve system and the tapering after this). The type of concrete pump used (piston pump or squeezed tube pump) and the type of valves used for a piston pump (e.g. trunk of S-pipe valve) can have an influence on the behaviour of the freshly-mixed concrete inside the concrete pump. We will not go into further details here about the characteristic features and characteristics of the two principle types of pump as well as the different valve systems of piston pumps (refer to Fig. 28). The aim of the present document is simply to make the processes within the concrete pump comprehensible from a concrete technology point of view.

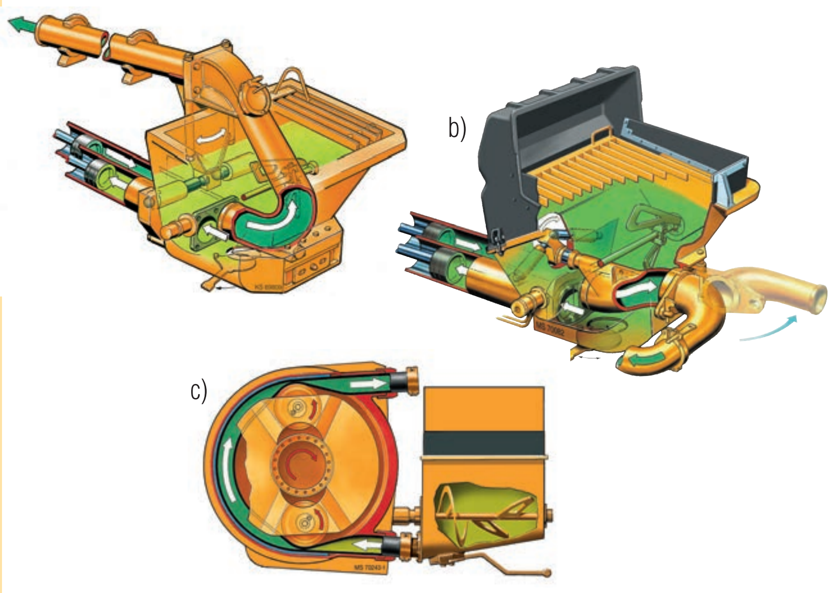

Fig. 28: Concrete pump models:
a) Piston pump with trunk valve b) Piston pump with S-pipe valve c) Squeezed tube pump

Fig. 29: Putzmeister stationary concrete pumps of the 1400 series

Concrete can only be pushed through the delivery line when this has previously been sucked out of an open vessel (hopper) by increasing the volume of the conveying space (piston stroke) of the pump, and the concrete fills the conveying space as much as possible. By decreasing the volume of the conveying space, the concrete is pushed out into the delivery line whilst displacing the whole concrete column in the delivery line. When observed more closely, the suction is also pushing; the volume increase of the conveying space (i.e. movement of the delivery piston in the delivery cylinder away from the inlet aperture) causes a low pressure compared to the atmosphere, which pushes the concrete out of the hopper into the conveying space with max. 1 bar, but only when there is not a continuous "air bridge" between the conveying space and the atmosphere.

The low pressure level for suction and filling requires a low as possible resistance to flow and deformation of the concrete. The agitator of the hopper and its geometrical shape contribute towards this. The agitator does not just serve to keep the concrete free-flowing during the breaks in conveying but also moves and pushes the concrete during suction in such a way that the concrete can flow "from this movement" and flow without congestion into the suction opening that is as large as possible. The filling rate of the conveying space is an essential criterion for the efficiency of a pump.

An increase of the speed of the delivery pistons or the rotor does not lead to the improvement of an insufficient filling rate caused by poorly-flowing concrete, since the atmospheric pressure difference of 1 bar can not be increased. On the contrary, the filling rate and therefore the efficiency of the concrete pump actually tend to deteriorate. For optimum suction conditions the suction openings and the conveying area diameter are kept as constant and as large as possible. This also results in the essential differences between the piston and the squeezed tube pumps: piston pumps suck in the concrete through large cross-sections and reduce the cross-section when pressing out the material; which enables large conveying outputs. Squeezed tube pumps are limited with regard to their delivery pressure to approx. 30 bar, and they therefore suck in the concrete preferably with the same cross-section as that through which the material is conveyed through the line afterwards. Its delivery performance is primarily restricted by the suction performance.

For piston pumps the suction behaviour of the freshly-mixed concrete is determined not only by the size of the suction opening and the efficiency of the agitator hopper but also by the "hindrance" of the suction due to the valve system used.

The filling of the conveying space also comprises the "boundary zone segregation" described in section 4.2 for the complete space-filling and the emergence of the more free-flowing boundary zone layer connected to this. There is only little time available for this as when the delivery pistons reverse direction the conveying space must be tightly filled immediately and the concrete must be pumpable.

When the concrete is pressed out of the delivery cylinders of a piston pump into the delivery line, the concrete current experiences a reduction in cross-section to the diameter of the delivery line (100 mm or 125 mm) both whilst passing through the valve (trunk or S-pipe) and afterwards. For the concrete this does not just mean a considerable deformation but also a great increase in speed as well as a corresponding increase of the boundary zone layer per volume unit of the concrete. To reduce the associated conveying resistance, the cross-section reduction is carried out continuously as far as possible over a sufficiently long section. This reduction of the cross-section inside or immediately after the pump also provides a pumpability test for the concrete. If a difficult concrete passes this "obstacle" without any problems then it really is pumpable and the danger of a blockage over the course of the delivery line due to the result of a wrong concrete composition is very improbable.

Fig. 30: Reduction from DN 150 to DN 65

An essential condition to maintain the pumpability of the concrete inside the pump is the reliable imperviousness of the valve system during the pressing phase. A valve system that is not watertight means a loss of water or cement paste in the boundary zone and thus the danger of the concrete not being watertight any longer and its wall friction no longer being pressure-independent which inevitably leads to blockages. The same is similar for the squeezed tube pump. Here there is the danger that insufficient sealing of the squeeze gap leads to the water or cement paste flowing away and the concrete loosing its pumpability just in front of the squeezing roller.

Under high pressure an effect arises in the concrete at points of leakage which in job-site jargon is called "encrustation". Finest mortar settles along the gaps and a part of the mix water is pushed through this. Under the influence of pressure and time the encrustation increases in the shape of a ring from the outside to the inside. Narrowing of the cross-section by more than 50 % is not rare. The result of this is the tendency to form blockages. As this encrustation hardens during operation it is not possible to remove it by the usual methods when cleaning the concrete pump afterwards. If the concrete encrustation is not noticed by the operator, frequent blocking is caused the next time the pump is used after the preliminary slurry has been pumped.

Fig. 31: Pipe wear in the delivery line bend

It is very important for piston concrete pumps that the delivery space is emptied as thoroughly as possible with every pump stroke, as a so-called dead volume remains in the delivery space, primarily on the delivery piston, at least up to the next time the pump is cleaned. It hardens or sets there and this can lead to the destruction of seals, the delivery piston, and the delivery cylinder inside wall. This danger does not exist for squeezed tube pumps as the concrete only passes through the delivery space (the pump hose) in one direction and is therefore always flushed through with freshly-mixed concrete. The special operating states of the concrete pump described above (starting up pumping, emptying, etc.) have a considerable smaller influence on the behaviour of the concrete inside the pump than on the behaviour inside the delivery line. This is why these problems do not arise until in the following section. Besides the reactions of the concrete behaviour to the concrete pump that have already been mentioned and in addition to the stress resulting from concrete conveying pressure, the wear effect of the concrete on all parts that come into contact with the concrete should be mentioned. The wear effect of the concrete inside the concrete pump as well as later in the delivery line is primarily dependent upon the consistency and speed, as is the delivery resistance. The enormous abrasiveness of the concrete is due to the wear characteristics of the cement mortar and the aggregates embedded in it, especially where the concrete does not flow in parallel with the component surface, but where it moves towards the surface at an angle, i.e. in the hopper, in the agitator, in the valve system, in the reductions and in the elbows (outside). The aggregates have a greater relative speed at which they also scratch the contact surface through the boundary layer zone or the mortar layer. Their irregular shape and the tight toothing of the grain mix also prevents a rolling off of the contact surface which would reduce wear, but rather lead to a twisting effect on neighbouring grains which are thereby additionally turned towards the contact surface.

Fig. 32: Measuring pipe wear: wall thickness measuring units for two-layer lines (le.) and single-layer lines (ri.)

4.4 The behaviour of freshly-mixed concrete in the delivery line

When flowing through a straight, cylindrical pipe this process calms down after a short time by making use of the available ‘toothing play’ between the grains, provided that the pipe sections do not have any indentations and do not leak. The latter leads in extreme cases to the loss of pumpability and therefore to blockages or "merely" to the formation of a firm concrete crown, constricting the cross-section, with increased resistance to conveying. When pumping through high quality delivery pipes to great vertical heights, the wall contact of coarse aggregate is partly reduced and there is therefore both a lower conveying resistance and less wear.
With a horizontal delivery line the effect can only occur to a reduced extent as even a slight setting of the coarse aggregates leads to wall contact and all the previously mentioned consequences, albeit mainly on the lower pipe inside wall.

Flowing through pipe elbows means an additional bending and shearing stress for the freshly-mixed concrete. As a pipe elbow in the ‘outside curve’ has a greater surface than a straight pipe, the boundary zone with more fine grain becomes thinner; whereas in the ‘inner curve’ it becomes thicker. The very thick core zone displaces the softer and weak outside boundary zone and is diverted by hitting the pipe wall due to shearing and bending, which causes intensive wear. This may well lead to some local zone no longer being leakproof and therefore to an even greater conveying resistance and wear. Moreover, the flow of concrete needs a consolidation and quietening phase after a pipe elbow.

The throughput of freshly-mixed concrete through a delivery line is a result of the performance of the concrete pump (engine performance [kW], eff. output [m3/h], eff. delivery pressure [bar]), geometry of the delivery line (diameter [mm], length of line [m], delivery height [m]) and consistency coefficient of the freshly-mixed concrete (also known as tenacity or friction coefficient).The mutual dependence of these diameters is illustrated with the concrete pressure performance nomogram in Fig. 33, which is independent of the concrete pump used.

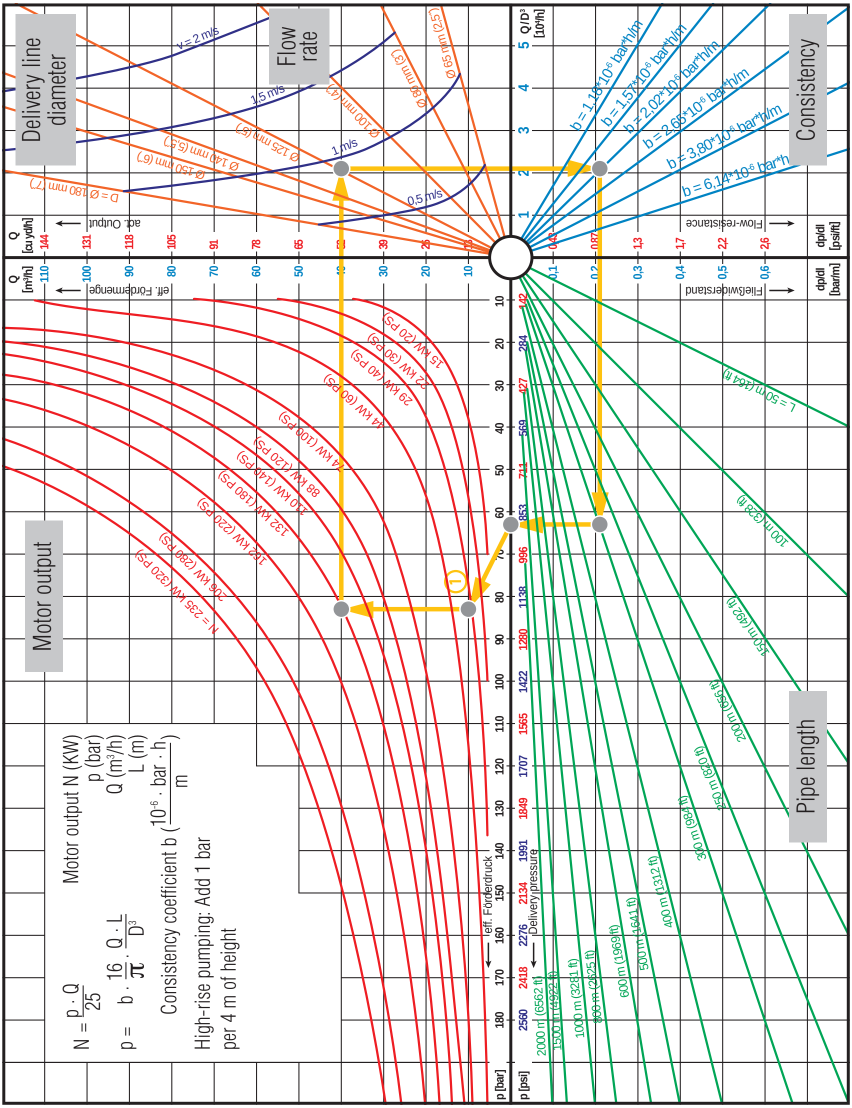

Fig. 33: Concrete pressure performance nomogram

Caution:
The consistency coefficient of the concrete must be determined by performing a pump trial or measuring with the Sliding Pipe Rheometer (see chapter 4.5). Deriving the pump properties from the spread or slump is no longer possible.

The old method is only applicable in individual cases where the concrete is mixed without or with only small quantities of concrete additives. Therefore, the spread or slump should not be considered reliable parameters for calculating the pump willingness. The formula for pressure calculation is still valid.
The example shown here assumes an effective pump output of Q = 40 m3/h. For the assumed conveyor pump diameter of D = 125 mm, we can see an average flow rate of approx. 1 m/s. The relationship of the delivery pressure to the delivery pipe diameter is even greater than the dependency on the flow rate: a reduction of the pipe diameter from 125 mm to 100 mm, for example, is the equivalent of increasing the speed of the concrete in the pipe to almost 1.5 m/s, whereas the necessary delivery pressure is almost doubled. The consistency range represented is in keeping with experience with many concrete mixtures gained over a number of years. If more exact values are necessary for a certain application case, then pump trials must be carried out with the planned concrete mix formula. For the example in Fig. 33 for a plastic concrete with a consistency coefficient of 2 (*10^-6 bar*h/m), the flow resistance is 0.21 bar per metre run. The assumed length of delivery line of L = 300 m results in a delivery pressure of p = 63 bar, which is to be enlarged by the share of 0.25 bar per metre of height resulting from the high-rise conveying, in the example 20 bar for 80 m delivery height. The resistance to flow in the pipe elbows as well as the leaking pipe couplings with encrustation is usually converted to an equivalent pipe length:

	Elbow radius	**Equiv. pipe length**
Large pipe elbow 90°	1000 mm	3 m
Pipe elbow 90°	281 mm	1 m
Leaking coupling	–	1 m

Starting to pump

The pump operator must direct his full attention to the behaviour of fresh concrete in the delivery line when starting to pump. The problem here is the necessary wetting of the inside wall of the pipe with cement paste until starting the stationary pump operation. The quantity required for this per running metre of the delivery line is the same quantity that would remain in a 1 m section if the line was initially completely filled with fresh concrete and this was then allowed to empty. (10 m of a 125 delivery line have an internal surface to be wetted of approx. 4 m^2.) When starting to pump, this quantity of cement paste is "removed" only from the first concrete to flow through the delivery line. For this reason, when starting to pump, a start-up mixture enriched with cement surplus, or even a sand concrete/smooth mixture separately mixed in the hopper of up to 30 m – 1/4 m^3 and from 30 m – 1/2 m^3 should be conveyed before the first concrete (see the operating manual).

A more economical and effective solution to provide a start-up mix is to use a Putzmeister slurry for starting up pumping which is available as powder and only water needs to be added. The substance, which is ready after just a few minutes, is fed in via the cleaning opening. When starting to pump, this substance is pushed in front of the concrete and thereby covers the pipe inside wall.

The method commonly used in the field of covering the delivery pipes with water before pumping is only to be used if no other method is available, and can only be used for short delivery pipe lengths. If nothing is carried out, a blockage can be expected as soon as the machine starts to pump because after a relatively short conveying period an unpumpable, dry concrete plug is formed, which stops the flow of concrete at one of the first elbows or in a long straight line piece.

An important requirement for a trouble-free flow of concrete is also the correct emptying and cleaning of the delivery line during a longer break in conveying so that no old, hardened concrete or cement paste residue remains in the line which would also lead to blockages when starting to pump again.

4.5 Calculating the consistency coefficient of concrete

Due to the increasing complexity of concrete recipes, the spread is no longer a viable way of calculating a realistic consistency coefficient for the concrete. This method was only viable for concrete without additives. Today, the process for determining the pipeline resistance of fresh concrete is therefore rather more complex.
The standard procedure for assuring the pumpability and pump willingness of concrete is a pump trial. When pumping a recently developed concrete recipe through a defined pipe diameter and optionally a shortened pipeline length at the desired delivery rate, the pressure loss can be measured. Together with the nomogram, this value is used to produce the consistency coefficient used to calculate the situation on the construction site.
The consistency coefficient may far exceed the highest value of 6 *10^-6 bar*h/m displayed in the nomogram, even though the slump flow is more than 650 mm, for example. In this case, a high pipe resistance is generated even though the consistence is F6.

Because the pump trial procedure is extremely demanding, Putzmeister has developed laboratory equipment that delivers the same results. A small sample of the concrete is inserted in the Sliding Pipe Rheometer, or SLIPER for short, which simulates the flow characteristics of the pipe on a small scale in order to calculate the consistency coefficient.
The exact function of this robust instrument has already been put to the test in many applications and it can be used both in the laboratory and on the construction site.

The instrument is shown in Figure 34. The measurement instrument is made of a standing piston through which a pipe glides down vertically. During this process, the material in the pipe exercises a dynamic pressure on the sensor inside the piston. The instrument was given the name "Sliding Pipe Rheometer" due to the downward movement of the gliding pipe. The gliding speed varies through the use of different additional weighs. Several aspects of the interdependence between the delivery pressure and output of the Sliding Pipe Rheometer are identified by measuring the pressure and the distance. Consequently, the consistency coefficient can be calculated using a clever software program.

The system is also suitable for other materials such as sewage sludge.

Fig. 34: Measuring the consistency coefficient of freshly-mixed concrete using the Sliding Pipe Rheometer

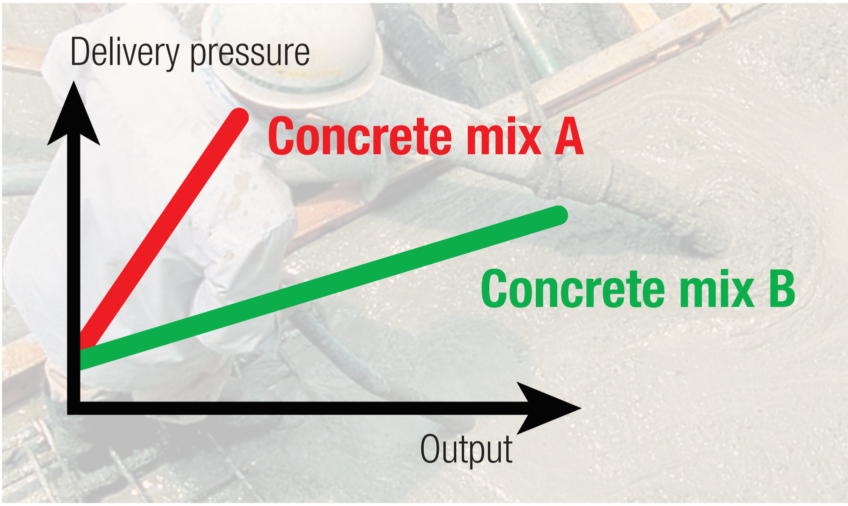

Fig. 35: Effect of different concrete recipes on pumping

The consistency coefficient is a value representing the viscosity of concrete in relation to the pipeline. Figure 35 shows the effects of different concrete recipes. The relationship between the concrete pressure and delivery rate is usually linear, i.e. the performance of the concrete is represented in the diagram by a straight line. The steeper the incline of this straight line, the higher the viscosity or the consistency coefficient of the concrete. At maximum available delivery pressure, a much smaller quantity of recipe A concrete can be pumped than recipe B concrete, for example.

It was noted that among high-strength concrete recipes in particular, the consistency coefficient can change by a factor of two due to tolerance fluctuations in the mixing apparatus. The spread (and slump or slump flow) can be almost identical, which means that small changes in the composition of high-quality concrete recipes can have a significant effect on pumping, even though no major changes are noticed on the flow table.

When attempting to improve the pump willingness of a concrete recipe, all components and the reciprocal actions of these components must be taken into consideration. The consequences of any changes can be tested in the laboratory using the SLIPER. As a general rule, any changes that are made must not affect the mandatory exposure classes.

5. Short guide to avoiding and eliminating faults

5.1 For the delivery of concrete and charging of the concrete pump

Established irregularity	Possible causes	Recommended measures
Gravel and rock noises in the truck mixer drum	Proportion of fine grain is too small	Check the delivery note
Increasing and subsiding noises of concrete in the truck mixer drum	Concrete consistency is too fluid	Check the delivery note or determine the spread
Concrete breaks up with sharp edges when exiting the truck mixer drum	Concrete consistency too stiff	Check the delivery note, when pumping, add a generous quantity of cement paste
Consistency changes during concrete transfer	Segregation	Stop transfer and mix the concrete thoroughly (several minutes)
Frequent blockage of the agitator shaft	Proportion of fine matter too small	Check the delivery note

5.2 When pumping

Established irregularity	Possible causes	Recommended measures
Concrete pressure considerably above the expected value	– Duration of action of deflocculant or setting retarder exceeded or shortened (summer heat, hot delivery line) - Unsuitable concrete recipe	Cover of delivery line Modify concrete recipe to suit lower concrete pressure
Rapid increase in pressure above normal value	Blockage in or directly after the concrete pump	Fill with two truck mixers in parallel, mix in hopper start pumping slowly
Slow increase in pressure beyond normal value	Blockage towards the end of the delivery line	Reverse pump for a few strokes, pump again slowly, if nec. locate the blockage using a hammer handle test and dismantle the delivery line starting from the end
Poor fill level of delivery cylinder	– Consistency too stiff – Hopper fill level too low	Check the delivery note, if necessary determine the spread Hopper fill level until above agitator shaft
Blockage in the delivery cylinder of the pump	– Proportion of fine matter too small – Concrete consistency too stiff – Segregation – Gate valve system not sealed or does not switch	see above see above see above Check settings of gate valves and switching
Blockage in the delivery line	– old concrete residues or foreign bodies in the delivery line – Non-sealed pipe joints or weld cracking – Unfavourable delivery line installation – Kinked final distributor hose or kinks in delivery hoses – Proportion of fine matter too small – Consistency too stiff	Remove the obstacle Check pipe coupling, rectify cracks Alternative installation Straighten out kinks see above see above

6. Specifications and recommendations of technical regulations

Designation	Issued	Title
DIN technical report 100 "Concrete"	03.10	Summary of DIN EN 206-1 and DIN 1045-2
DIN EN 206-1	07.01	Concrete part 1: Specification, performance, production and conformity, German version EN 206-1:2000
DIN EN 206-1/A1	10.04	Concrete part 1: Specification, performance, production and conformity, German version EN 206-1:2000/ A1:2004
DIN EN 206-1/A2	09.05	Concrete part 1: Specification, performance, production and conformity, German version EN 206-1:2000/ A2:2005
DIN EN 206-9	09.10	Concrete part 9: Additional rules for self-compacting concrete (SCC)
DIN 1045-2	08.08	Concrete, reinforced and prestressed concrete structures – Part 2: Concrete – Specification, performance, production and conformity – Application rules for DIN EN 206-1
DIN 1045-3	08.08	Concrete, reinforced and prestressed concrete structures – Part 3: Execution of structures
DIN EN 12350-2	08.09	Testing fresh concrete - Part 2: Slump test
DIN EN 12350-4	08.09	Testing fresh concrete - Part 4: Degree of compactability
DIN EN 12350-5	08.09	Testing fresh concrete - Part 5: Flow table test
DIN EN 197-1	08.04	Cement – Part 1: Composition, specifications and conformity criteria for common cements
DIN EN 197-1/A3	09.07	Cement – Part 1: Composition, specifications and conformity criteria for common cements/ A3:2007
DIN EN 197-4	08.04	Cement – Part 4: Composition, specifications and conformity criteria for blast furnace cements
DIN 1164-10-12	08.04 11.03 06.05	Special cement, part 10, 11, 12

Designation	Issued	Title
DIN EN 450-1	05.08	Fly ash concrete – Part 1: Definition, specifications and conformity criteria;
DIN EN 12620	07.08	Aggregates for concrete; German version EN12620:2002 + A1:2008
DIN EN 1008	10.02	Mixing water for concrete – Specification sampling, testing, and assessing the suitability of water
DAfStb Guideline (German committee for reinforced concrete)	11.03	Water impermeable concrete structures ("WU-Richtlinie")
DAfStb Guideline (German committee for reinforced concrete)	11.06	For concrete with prolonged pot life ("Verzögerter Beton")
DAfStb Guideline (German committee for reinforced concrete)	11.03	Self-compacting concrete ("Selbstverdichtender Beton")
DAfStb Guideline (German committee for reinforced concrete)	04.10	Large concrete components – Part 1: Supplement to DIN 1045-1 Part 2: Amendments and supplements to DIN EN 206-1 and DIN 1045-2 Part 3: Amendments and supplements to DIN 1045-3
FGSV 818 (German Road and Transport Research Association)	2004	Code of practice for the manufacture and processing of air-entrained concrete
ZTV-ING	05.03	Additional Technical Terms of Contract and Guidelines for Civil Engineering Structures
EFNARC	05.05	The European Guidelines for Self-Compacting Concrete – Specification, Production and Use

7. Further literature

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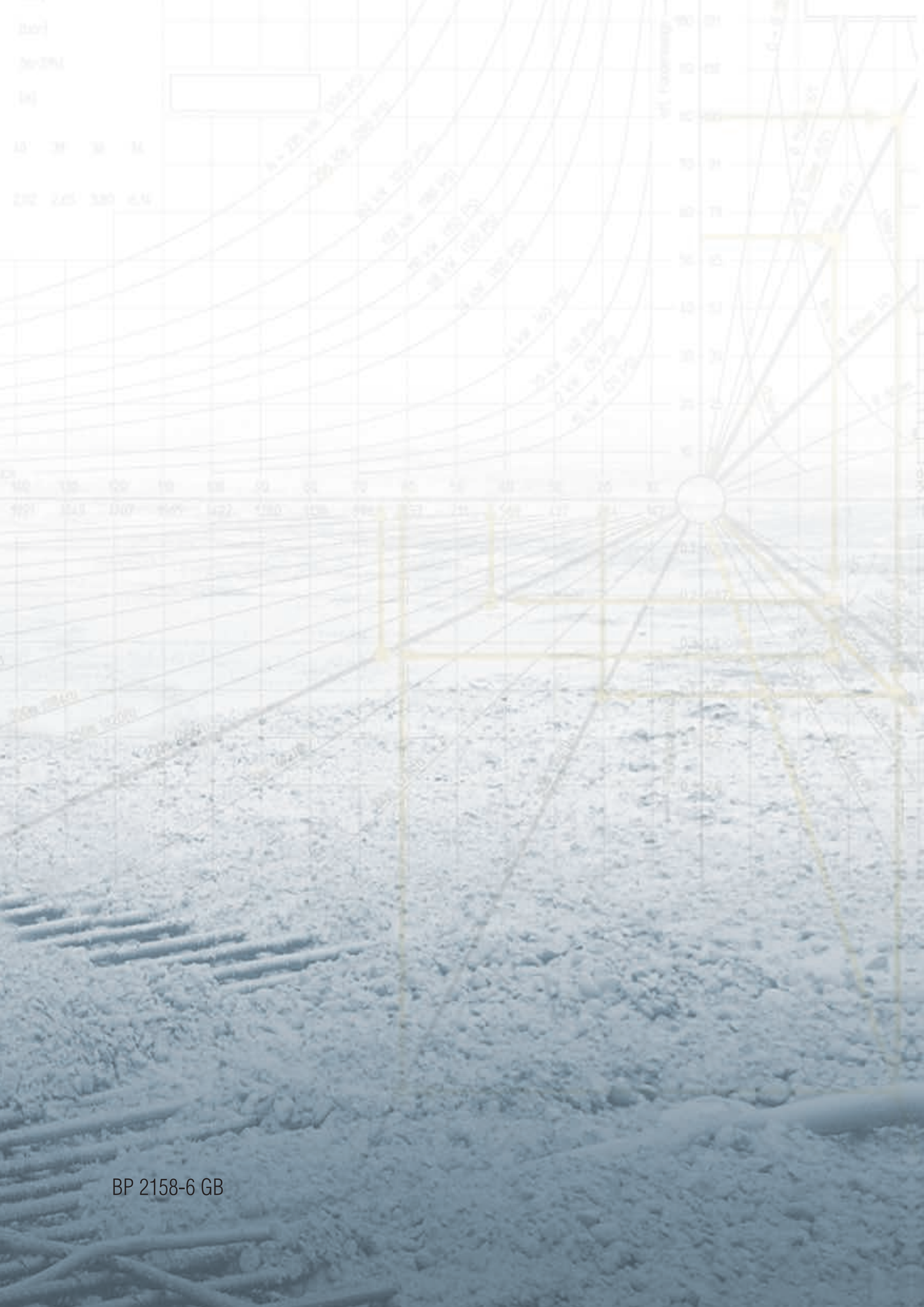

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