Österreichische Vereinigung
für Beton- und Bautechnik

GUIDELINE

Sprayed Concrete

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UND VIELES MEHR ......

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Guideline

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Edition August 2006

Herausgeber: Österreichische Vereinigung
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PREFACE

The 2004 edition of the Sprayed Concrete Guideline is the second revision of the Sprayed Concrete Guideline first published by the Austrian Concrete Society in 1989 (Part I – Application) and 1992 (Part 2 – Testing).

The revision was necessary in order to define the new terms and requirements contained in the European Concrete Standard EN 206 also for sprayed concrete. At the same time, experience gained with the 1998 edition of the Sprayed Concrete Guideline as well as new developments in research and practice have been incorporated.

The 2004 edition of the Sprayed Concrete Guideline, continuing a fifteen-year tradition, is intended as a basis for the production of sprayed concrete of adequate quality under objective contractual conditions.

Vienna, July 2006 Baurat h.c. Dr. Helmut Huber

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Summary

Annex

0. PRELIMINARY REMARKS

In order to eliminate barriers to trade within the European Economic Area, the following principles have to be observed:

- Products from member states of the European Union as well as goods originating from EFTA countries belonging to the European Economic Area (EEA), which are not in conformity with this Guideline, but have passed the tests and inspections performed and recognised in the member state concerned, are regarded as equivalent, including these tests and inspections, provided the level of protection required in Austria in terms of safety, health and fitness for use is reached and maintained on a permanent basis.
- The inspection bodies concerned must provide adequate and satisfactory guarantees of their technological and technical qualifications as well as their independence according to ÖVE/ÖNORM EN ISO/IEC 17025.
- The body inviting tenders may demand the submission of documents on the tests and inspections performed as well as standards, technical guidelines and regulations governing products and/or materials in German.

1. SCOPE

This Guideline applies to the production of structural components made of plain and reinforced concrete as well as close-textured reinforced concrete placed by the method of shotcreting.

Sprayed concrete is to be mixed from the constituent materials of concrete (cement, additions, spray cement, mineral aggregates, water and admixtures) in such a way as to permit proper placing under the conditions to be expected at the building site and to ensure achievement of the required properties.

Sprayed concrete is used in all fields of civil engineering and building construction. In particular, sprayed concrete is suited for use under special conditions, such as:

- absence of formwork
- application in thin layers
- early strength requirements
- special construction methods.

For the purposes of construction planning and execution, sprayed concrete can be classified as follows:

- Sprayed concrete without structural functions (**SpC I**), e.g. for surface improvement, short-term support during construction.
- Sprayed concrete with structural functions (**SpC II**), e.g. rock support in tunnelling, excavation support, open caisson foundations.
- Sprayed concrete with special structural functions (**SpC III**) e.g. for use in single-shell tunnel construction and for inner linings.

Preference is given to sprayed concrete with non-alkaline acceleration (spray cement or non-alkaline acceleration), which offers special advantages in terms of occupational health and safety and is preferable for ecological and technological reasons. Sprayed concrete with non-alkaline accelerators does not experience a loss of strength or, if such loss occurs, it never exceeds 15%; it reaches a high level of final compressive strength and is dense-textured (less segregation in tunnel drainage systems).

Non-alkaline acceleration is to be used for sprayed concrete with structural functions (SpC II, SpC III). The use of alkaline accelerators is only permitted in sprayed concrete without structural functions (SpC I).

In dry-mix shotcreting, the use of mix with dry mineral aggregates (dry mix - TM) or spray cement mixed in situ with naturally moist mineral aggregates (moist mix - FM-S) enables building sites to be supplied with fresh mix at any time and thus ensures of a continuously high level of quality.

At present,

- the dry-mix sprayed concrete method uses spray cement or tunnel cement with powder or liquid accelerators;
- the wet-mix sprayed concrete method uses powder or liquid accelerators.

Sprayed concrete can be applied to the following types of substrate:

- rock and soil
- sprayed concrete
- formwork of different types
- structural components made of concrete, masonry and steel (casings)
- frozen rock or soil, ice.
- insulating layers, nap sheeting, geotextiles.

Further applications of sprayed concrete:

- sprayed concrete for repair, reinforcement and casings
- fibre-reinforced sprayed concrete
- sprayed concrete under compressed air
- sprayed concrete with light-weight mineral aggregates.

2. DEFINITIONS, ABBREVIATIONS

2.1 Definitions

Accelerator (EB)	Admixture in powder or liquid form to accelerate the reaction of cement in placed sprayed concrete.
Additives	Finely dispersed substance used in concrete and added to the concrete during mixing in order to obtain or improve certain properties of the concrete.
Admixture	Substance added during production of the concrete mix in small quantities, relative to the cement content, in order to modify the properties of fresh or hardened concrete.
Aerosols	Multi-phase systems of air and other gases with finely dispersed solids or liquids.
Reference concrete	Sprayed concrete without accelerator used for reference to evaluate changes in technological properties (e.g. loss of strength).
Binder	Cement to which a hydraulically effective addition can be added and which meets the requirements of the application concerned.
Cement	Finely ground inorganic substance; when mixed with water, it forms cement paste, which hardens and sets through hydration and retains its volume stability also under water.
Degree of utilisation	Ratio of maximum stress level on the sprayed concrete and its strength at a given age.
Dense-stream concrete conveyance	A method of conveying the wet mix in which the concrete is pumped through the delivery line without compressed air.
Double-shell construction method	Tunnel lining consisting of two or several shell elements designed to meet different static and structural requirements (not forming a composite structure), placed in separate operations and by different methods (e.g. outer sprayed concrete shell, in-situ concrete arch).
Drop-off	Mixture of sprayed concrete and substrate dropping off due to lack of adhesive strength of the substrate.
Dry mix (TM)	Mix for dry-mix shotcreting consisting of dry mineral aggregates, binder, additions, water (process-related) and, possibly, fibres.
Dry-mix sprayed concrete	Sprayed concrete made from dry mix or moist mix as base mixture.
Leachate	Liquid enriched through elution.
Leaching	Extraction of soluble components of a solid in contact with a liquid.
External inspection	Periodic inspection of a building material and its production by an accredited inspection body.
Young sprayed concrete	Sprayed concrete up to an age of 24 hours (J_1, J_2, J_3, depending on early strength class).

Identity test Test performed to identify whether a batch or lot of concrete comes from a compliant total quantity of concrete.

Preconstruction test (qualification test)

Test or tests performed prior to the beginning of sprayed concrete production to establish the composition required for new sprayed concrete to meet the specifications in fresh and hardened condition.

Loss of strength Diminished strength of sprayed concrete with accelerator in comparison with reference concrete without accelerator.

Mix Mixture prepared for the respective shotcreting procedure.

Moist mix (FM-L, FM-S) Mix for dry-mix shotcreting with naturally moist mineral aggregates, binder, admixtures, water (process-related) and, possibly, fibres.

Multi-shell construction method

See double-shell construction method.

Non-alkaline acceleration of setting

The required strength of fresh sprayed concrete (J_1 - J_3) is achieved without addition of alkalis. For this purpose, spray cement with an alkali content not higher than that of normal cement or non-alkaline accelerator is used.

Non-alkaline accelerator Accelerator with a pH value within a certain range (3.0 - 8.0) and an alkali content below a certain limit (Na_2O equivalent $\leq$ 1.0 wt.%).

Ready-mix concrete plant Plant in accordance with the requirements of ÖNORM B 4710-1 with micro-processor control, in which the constituents required for concrete production are batched, as a rule, by weight (in case of liquids by weight or volume) and mixed into concrete ready for use.

Rebound Proportion of the mix rebounding from the substrate during placing of the sprayed concrete. Rebound consists mainly of mineral aggregate and, to a lesser extent - binder and water.

Single-shell construction method

All static and structural requirements to be met by the tunnel lining are fulfilled by a single-shell lining consisting of one or several layers forming a composite structure.

Spray cement (SBM) General term used to designate fast-setting binders which ensure the required rate of setting and fast strength development in young sprayed concrete without addition of admixtures (EB).

Overspray Proportion of fines in the sprayed concrete which deposit on the substrate and the reinforcing bars and diminish the adhesion of subsequent layers.

Sprayed concrete (SpC) Concrete projected into place at high velocity and compacted by its own momentum.

Sprayed concrete layer Two-dimensional structural component of a defined minimum thickness consisting of one or several spraying layers (e.g. sealing layer).

Sprayed concrete shell Three-dimensional structural component consisting of one or several layers of sprayed concrete with a temporary or permanent supporting and/or load-bearing function (e.g. outer sprayed concrete shell, arch).

Spraying layer Sprayed concrete placed in a single operation without interruption.

Spraying mix The mixture discharged through the (spraying) nozzle.

(Spraying) nozzle A pipe with a mixing unit for the addition of liquid and/or air through which the mix is discharged from the delivery line. In dry-mix shotcreting, water and - if required - powder or liquid admixtures and additions are added; in wet-mix shotcreting by the dense-stream method, air and, possibly, admixtures are added.

Standard sprayed concrete (prescribed sprayed concrete)

Sprayed concrete without special properties (maximum strength class SpC 12/15) of predetermined composition, not subject to preconstruction testing (according to It. 5.2).

Substrate Surface onto which sprayed concrete is sprayed.

Thin-stream concrete conveyance

A method of pneumatic conveyance of the base mix to the location of placement; the loosened dry or wet mix is conveyed from the spraying machine to the nozzle by compressed air.

Water-binder ratio Mass ratio of effective water to cement content (eligible binder content) in fresh concrete.

Wet mix (NM) Mix for wet-mix shotcreting (usually pumped concrete) prepared from mineral aggregates, binders, water and, possibly, admixtures and fibres.

Wet-mix sprayed concrete Sprayed concrete made from wet mix (in dense-stream processes: usually pumped concrete) as base mixture.

Workability time Time between the first contact of naturally moist aggregate with cement and/or production of wet mix and application of sprayed concrete, or time between the first contact of naturally moist mineral aggregates with spray cement (SBM) and discharge from the nozzle.

2.2 Abbreviations used

AAR	alkali-aggregate reaction
AHWZ	prepared hydraulically effective additions
AM	spread for determination of fresh concrete consistency
ASTM	American Society for Testing Materials
BV	plasticiser
CEM	cement type according to standard series EN 197-1
CEN	European Committee for Standardisation
D	density of accelerator
D_1	compressive strength of cement at the age of one day
DAfStb	German Reinforced Concrete Committee
DBV	German Concrete and Structural Engineering Association
DIN	German Industrial Standard
EB	accelerator
EB-AF	non-alkaline accelerator
EB-AH	alkaline accelerator
EFNARC	European Federation of National Associations of Specialist Contractors and Material Suppliers for the Construction Industry
EN	European Standard
F	category of resistance to frost and thaw cycles of mineral aggregates
f	category of fines content of mineral aggregates
FGSV	Road and Transport Research Society
FM	plasticiser
FM-L	moist mix, storable
FM-S	moist mix, for immediate application
FRSpC	fibre-reinforced sprayed concrete
GK	maximum grain size of the mineral aggregate
HK	frequency class
HZ	tensile adhesive strength
ISO	International Standards Organisation
J	young sprayed concrete strength class
K	factor for consideration of additive type II effect
LP	air-entraining agent
LPV	combined plasticiser and air-entraining agent
LV	bill of quantities
MAK	maximum permissible concentration at the workplace
MS	silica fume
NAD	national application document

NM	wet mix
ON	Austrian Standard
PB	pumped concrete
ÖVBB	Austrian Association for Concrete and Structural Engineering
R	correlation coefficient
RVS	Guideline for Transport and Road Engineering
SBM	spray cement for sprayed concrete
SI	shape index, category of grain shape parameter
SIA	Swiss Association of Engineers and Architects
SN	Swiss Standard
SpC	sprayed concrete
SpC-XF4	sprayed concrete resistant to frost and thaw cycles
TM	dry mix
W	water content
WA	water segregation through bleeding of cement
XAL	exposure class: solvent chemical attack
XM	exposure class: wear and tear
XAT	exposure class: expansive chemical attack
XC 1 and XC 2	exposure classes: corrosion caused by carbonation
XC 3 and XC 4	exposure classes: water impermeability
XD	exposure class: corrosion caused by chlorides, except sea water
XF	exposure class: risk of frost attack, with or without thawing agent

3. ENVIRONMENTAL COMPATIBILITY OF SPRAYED CONCRETE

To assess the environmental compatibility of sprayed concrete, its influence on ambient air, water and soil needs to be considered. Past experience with alkali accelerators suggests that the environmental impact is of minor importance. However, health effects on the building-site crew applying the sprayed concrete are possible.

A reduction of the environmental impact and improved occupational health and safety have been among the priority objectives in the further development of sprayed concrete technology. Sprayed concrete with non-alkaline acceleration has no negative influence on the environment and offers considerable advantages in terms of occupational health and safety.

The following environmental influences have to be considered:

- *Impact on air quality*

  In general, shotcreting operations do not have a negative impact on air quality. The presence of aerosols has to be assessed in terms of occupational health and safety.

- *Impact on soil*

  As a matter of principle, a reduction of the rebound ratio is desirable (to less than 25.0 wt.% in conventional traffic tunnels requiring large amounts of sprayed concrete).

  Experience available to date does not suggest that the use of non-alkaline acceleration in sprayed concrete has any negative influence on the leaching behaviour of excavated material, provided the rate of rebound in the excavated material is less than 5.0 wt.%.

- *Impact on water*

  When used in tunnelling, sprayed concrete may be exposed to rock and ground water. Increased leachability of sprayed concrete may therefore lead to segregation and a long-term impact on draining water [1, 2, 3].

  The leachability of concrete being very low even after a short period of hardening, a negative impact on water quality has not been observed. Thus, concrete qualifies as an environmentally safe construction material. The same applies to sprayed concrete with non-alkaline acceleration.

  Besides the use of non-alkaline accelerators, careful working and a low water-binder ratio (< 0.6) also contribute towards ensuring a leaching behaviour in sprayed concrete similar to that of in-situ concrete. The admixture of silica fume may also have a favourable influence on leaching. For sprayed concrete leachate, the limits according to Table 3/1 apply:

Table 3/1 Limits for leachate concentrations from sprayed concrete aged 28 days according to It. 12.4.12.

Parameter	**Unit**	**Limit**
pH		≤ 12
Electric conductivity	mS/m	≤ 100
Calcium	mg/l	≤ 25
Potassium	mg/l	≤ 40
Sodium	mg/l	≤ 10
Aluminium	mg/l	≤ 1.0

- *Impact on occupational health and safety*

  During sprayed concrete production, the building-site crew is at risk due to dust formation and the alkalinity of suspended particles in the air. The amount of aerosols has to be minimised through suitable measures. Dust as well as smoke and mist are classified as aerosols.

Depending on the location and the time, the concentration of dust during the placing of sprayed concrete is subject to major fluctuations, which have to be considered in the interpretation of the results obtained. The fine dust concentration is assessed on the basis of the maximum permissible concentration of contaminants at the workplace measured according to It. 12.5.3 [4, 5]. Fine dust is defined as dust likely to penetrate into the alveoli of the lungs. Fine dust is deemed to be quartzitic, if its quartz content is 1.0 wt.% or more.

The maximum permissible contaminant concentration at the workplace according to Table 3/2 is equal to the maximum permissible concentration of dust which, in general, does not adversely affect the health of workers in the case of repeated and long-term exposure, usually for eight hours, but for no more than 40 hours a week, without use of personal protective equipment (fine-dust masks).

Table 3/2 Permissible dust concentration based on maximum permissible contaminant concentration at the workplace according to [4, 5]

C[mg/m³]	Type of dust	Assessment period	Pollutant load
15	total dust	annual average	inert
30	total dust	hourly average	inert
6	fine dust	annual average	inert
12	fine dust	hourly average	inert
4	quartzitic fine dust		silicogenic
0.15	fine quartz dust		silicogenic

Given the fact that a range of activities are performed during tunnelling which produce varying amounts of dust, the assessment has to be based on the entire working cycle. The hourly average may be reached twice per working day, but not consecutively, provided the daily average of 15 mg/m³ (total dust) and 6 mg/m³ (fine dust) is not exceeded. If personal protective equipment is used, higher limits are permissible, depending on the protective effect of the equipment (ÖNORM EN 149).

To diminish the dust load over the entire working cycle, the following measures are recommended:

- dry-mix shotcreting: use of moist mineral aggregates or pre-moistering of the dry mix, machine enclosure, favourable nozzle design, nozzle distance, water content
- wet-mix shotcreting with non-alkaline accelerators
- use of spraying arms (manipulators)
- sufficient ventilation.

The impact of spraying mist on the building-site crew has not yet been clearly established. In subjective terms, workers report that non-alkaline accelerators, compared with alkaline accelerators, are considerably less irritating.

Health hazards for building-site personnel, above all the risk of skin and eye lesions, can be prevented through the elimination of highly alkaline and strongly irritating admixtures.

4. CONSTITUENT MATERIALS FOR SPRAYED CONCRETE

The required strength of fresh sprayed concrete according to It. 7.3 is achieved without addition of alkalis (non-alkaline acceleration [6, 7]) either through spray cement according to It. 4.1.2 or cement according to It. 4.1.1. and non-alkaline accelerators (EB-AF) according to It. 4.5.1.1 (see Table 4/1) In special cases (e.g. strong ingress of water), the combined use of spray cement and non-alkaline accelerators is possible.

Alkaline accelerators (EB-AH) according to It. 4.5.1.2 are only permissible for SpC I. The use of water glass is not permitted.

Additions may be added according to It. 4.2.

4.1 Binders

4.1.1 Cement

Cement grades bearing a CE or ÜA mark and standard-compliant according to ÖNORM B 3327-1 and EN 197-1 are to be used. Cement grades not subject to external inspection according to ÖNORM B 3327-1 (e.g. CEM 152.5) have to meet the requirements of Table 4/2. Compliance with these requirements is to be demonstrated on the basis of samples taken at the construction site (mixing plant) at the frequency specified in ÖNORM B 3327-1[1), 2)]:

Table 4/1 Non-alkaline acceleration of setting

	Dry-mix shotcreting Wet-mix shotcreting	**Dry-mix shotcreting**
Acceleration	non-alkaline accelerators	spray cement (SBM)
Binders	cement grades meeting additional requirements according to ÖNORM B 3327-1, possibly with additions	SBM
Aggregates	dry or moist	dry[3)] or moist[4)]

3) Water content < 0.2 % or according to manufacturer's specifications

4) Water content as a rule between 2.0 wt.% and 4.0 wt.%

1) If necessary, the supply of information on test results has to be agreed upon.

2) To test compliance with these requirements, the values provided by a tesing body agreed upon before the beginning of delivery have to be used. Agreement between the results obtained by these testing bodies and those of the manufacturing plant has to be established by comparative testing before delivery is begun. The necessary samples have to be obtained from different consecutive deliveries and delivery days.

Table 4/2 Permissible parameters of cement grades according to ÖNORM B 3327-1 for sprayed concrete

Requirement	**Sprayed concrete**	**Sprayed concrete Sulfate attack**
C_3A content	-	0 % according to Bogue
Initial setting	90 min [1)]	90 min [1)]
Compressive strength after 1 day	D_1 8 (D_1 11 for requirements of fresh SpC)	D_1 8 (D_1 11 for requirements of fresh SpC)
Fineness according to Blaine	Deviation < 5 %	Deviation < 5 %
Bleeding after 120 minutes	WA 20	WA 20
Cement temperature	max. 80 °C	max. 80 °C
Additional: alkali content (Na_2O equivalent)	< 1.5 wt.% for non-alkaline acceleration according to ÖNORM EN 196-21	< 1.5 wt.% for non-alkaline acceleration according to ÖNORM EN 196-21

[1)] If high early strength, e.g. J3, is required, this value may be lower.

4.1.2 Spray cement (SBM)

Use of spray cement permits the production of dry-mix sprayed concrete with specified fresh sprayed concrete characteristics without addition of an accelerator. Both dry and moist mineral aggregates can be used. Spray cement reacts very fast upon contact with water and has a permissible workability time of a few minutes. If moist mineral aggregates are used, the processing technology has to be adjusted accordingly on account of the limited workability time. The spray cement is mixed with the moist aggregate in a suitable in-situ plant for immediate placing.

Spray cement for the production of sprayed concrete according to prEN 14487-1 can be used as a constituent material primarily for dry-mix shotcreting, provided it meets the following requirements in addition to or other than those specified in ÖNORM EN 197-1:

Table 4/3 For spray cement the following parameters and/or requirements have to be established on the basis of the results of preconstruction testing [1]:

Requirement	Spray cement	Additional requirement in case of sulfate attack
Initial setting (Test see It 12.1.3)	≥ 60″	
Constancy of volume (ÖNORM EN 196-3)	passed	
SO_3 (ÖNORM EN 196-2)	≤ 4.5 wt.% ≤ 7.5 wt.% [3]	in the presence of water with SO_4^{-2} content above 600 mg/l ≤ 3.5 wt.%
Cl (ÖNORM EN 196-2)	max. 0.1 wt.%	
MgO in clinker (ÖNORM EN 196-2)	max. 5.0 wt.%	
C_3A		C_3A-free (C_3A content of clinker 0 wt.-%, C_3A content of cement ≤ 1.0 wt.%. If C_3A content is higher, test according to It. 12.4.7 required.)
Al_2O_3 (ÖNORM EN 196-2)	≤ 6.5 wt.% ≤ 9.0 wt.% [3]	≤ 5.0 wt.%
Strength [2]	1 h ≥ 0.5 N/mm² 6 h ≥ 1.5 N/mm² and ≥ 70 % of preconstr. test 24 h ≥ 12 N/mm² and ≥ 70 % of preconstr. test 28 d ≥ 32.5 N/mm² and ≥ 80 % of preconstr. test	
Specific surface according to Blaine	Coefficient of variation ≤ 5 %	
Alkali content (ÖNORM EN 196-2)	Na_2O equivalent ≤ 1.5 wt.%	
Spray cement temperature on discharge from plant	≤ 70 °C	

1) Agreement between the test results of the inspection body and those reported by the manufacturer has to be established through comparative testing before the commencement of delivery.

2) For method of determination, see It. 12.1.5. The water/binder ratio to be used for test purposes is determined on the basis of preconstruction testing (as a rule 0.35 – 0.45).

3) Only applies to binder containing $C_{12}A_7$. Presence of $C_{12}A_7$ in the binder to be demonstrated by XRD.

A data sheet containing information on permissible reaction times, aggregate moisture, aggregate temperature, working temperature (air, mix) and the requirements regarding air humidity during pneumatic conveyance from the mill has to be provided for each spray cement grade.

Preconstruction testing and external inspection of the spray cement are to be performed by an accredited testing and inspection body on the basis of an inspection agreement. External inspection includes an audit of the contractor's system of self-inspection. Major changes in the nature of the spray cement, e.g. changes of the constituent materials, are to be notified to the inspection body and another preconstruction test, if necessary, is to be agreed upon.

4.2 Additions

The addition of hydraulically active substances serves to improve the properties of the sprayed concrete, such as workability, stickiness, dust formation, rebound, strength and density of the sprayed concrete texture, and to diminish heat build-up.

Prepared hydraulically active additions according to ÖNORM B 3309 have proved to be suited as additions, although other substances (e.g. silica dust, slag sand, hydraulic lime) can also be used. A qualification test has to be performed to establish the most favourable cement/additive ratio. The total amount of additions must not exceed 35 % (8% in case of silica dust) of the amount of binder used.

- Prepared hydraulically active additions must meet the requirements of ÖNORM B 3309.
- Silica dust must meet the requirements of ÖNORM EN 13263. Silica can be added as slurry or in powder form (but not as precompacted powder for dry-mix shotcreting) in dosages of between 2 wt.% and 8 wt.% of the solid components of the binder mass.

  Combinations of silica dust and plastifier, added to the sprayed concrete by means of suitable metering devices, have proved their value.

  In the case of dry-mix sprayed concrete, compatibility of the suspension with liquid accelerators has to be checked (preferably, the suspension should be added to the material flow at the spray nozzle). As regards storage of the suspension, the specifications for liquid accelerators apply.
- Stone dust (filler) according to ÖNORM EN 12620

In the case of cement grades with more than 20 % of additives (e.g. CEM II/B, CEM III), the use of additives is not to be recommended. In case of using spray cement specific compatibility tests have to be made.

The additions have to be metered as individual components and mixed homogeneously with the other constituent materials.

The k-value approach for additions is governed by ÖNORM B 4710-1, It. 5.2.5.2.

In case of sulfate attack, the additive used must have been tested for sulfate resistance according to ÖNORM B 3309.

4.3 Mineral aggregates

Following the withdrawal of ÖNORM B 3304, the mineral aggregates used must at least meet the national requirements (SI_{40}, F_2) of ÖNORM B 3131 according to ÖNORM EN 12620. Currently, the basic requirements are also laid down in ÖNORM B 4710-1, It. 5.2.3.

For sprayed concrete grades SpC II and SpC III, at least F_2 aggregates according to ÖNORM EN 12620, supplied in separate grain fractions from an on-site preparation plant or a plant conforming to the CE marking requirements, are used. For sprayed concrete of exposure classes XF2 or XF4, F_1 is required.

The grain size distribution has to be such as to ensure compliance with the standard range of the aggregate grading line according to Table 4/4 (with maximum deviations of grading line class SK2 from the value established in the preconstruction test) and/or the category required in ÖNORM B 3131. As a rule, segregation by grain size should be in 4 mm fractions.

Table 4/4 Favourable range of the aggregate grading line for grain sizes 0/8 and 0/11

Maximum grain size (mm)	Passing the screen in wt.%
11	95 – 100
8	85 – 95
4	65 – 75
2	45 – 55
1	30 – 40
0.5	18 – 25
0.25	8 – 15
0.063	2 – 6 (f_3 or f_{11})

Depending on the application, the maximum grain size should be between 4 mm and 16 mm. For SpC II and SpC III, a maximum grain size ≤ 11 mm is to be used. In the case of wet-mix sprayed concrete, pumpability of the concrete is an important consideration as far as the grading of the mineral aggregates is concerned.

In crushed mineral aggregates, the maximum permissible percentage of settleable solids or fines (grain size < 0.063 mm) may exceed the figure given in Table 4/4 by 5 wt.%, if the aggregate is purely carbonate and the fraction smaller than 0.02 mm (determined by sedimentation test) does not exceed 3.0 wt.%. (According to ÖNORM B 3131 category f3 or f11, if footnote 2 of ÖNORM B 3131 applies.)

If de-mixing during storage and transport is negligible, plant-mixed grain mixtures (prepared grain mixture) with a maximum grain size of up to 11 mm can also be used for the production of sprayed concrete mix. In pre-mixed dry mix, special attention has to be paid to the strong de-mixing tendency (special bin design, storage and transport units, limitation of maximum grain size).

An important factor to be considered in the selection of mineral aggregates is their ability (petrographic characteristics, grain adhesion, grain shape, grain mixture) to contribute towards compliance with the specified sprayed concrete strength requirements. If spray cement is used, the water content of the mineral aggregates should be between 2 wt.% and 4 wt.% so as to guarantee correct mixing and working of the dry mix.

In the case of unfavourable petrographic characteristics and, in particular, if alkali accelerators according to It. 4.5.1.2. are used, the contribution of the mineral aggregates to sprayed concrete strength has to be established in "reference concrete" (see It. 12.1.10.) or F2 according to ÖNORM EN 12620 must be demonstrated.

If experience from earlier use is insufficient, mineral aggregates may have to be tested for possible chemical reactions with cement, additions, admixtures and/or spray cement (e.g. alkali-aggregate reactions according to It. 12.1.13).

4.4 Water

As regards water, ÖNORM B 4710-1 applies. The characteristics of the water added must be within the limits of ÖNORM EN 1008.

4.5 Admixtures

Admixtures for sprayed concrete must comply with ÖNORM EN 934-2, ÖNORM EN 934-5 or an ÖVBB Guideline.

4.5.1 Accelerators (EB)

Accelerators (EB) are used in combination with suitable cements and, possibly, additions according to It. 4.1.1. and It. 4.2. At present, non-alkaline accelerators according to It. 4.5.1.1., or alkali accelerators according to It. 4.5.1.2. for applications of minor importance, are used. In special cases (e.g. strong ingress of water at the substrate) the addition of non-alkaline accelerator may be necessary even to spray cement. For accelerators an initial test certificate by an accredited testing body not older than three years has to be produced. The maximum permissible accelerator dose for the application in question has to be established in the preconstruction test.

In due time before the beginning of shotcreting, the admixtures used have to be specifically adjusted to the cement as regards acceleration, early setting, late development of strength and sulfate resistance (if necessary). Laboratory testing methods are to be employed for this purpose (see It. 12).

The values for the beginning and end of setting established in identity tests of accelerators must not deviate from the values established in the preconstruction test by more than ± 20 seconds and ± 60 seconds, respectively. The laboratory tests, although providing a good indication of building-site behaviour, are not able to consider all possible on-site influences and therefore are no substitute for preconstruction tests performed with the actual building-site equipment.

The manufacturer has to indicate the accelerator parameters, as established during preconstruction testing, for the purposes of identity testing according to It. 12.1.8.

4.5.1.1 Non-alkaline accelerators (EB-AF)

The requirements according to table 4/5 apply. For reasons of occupational health and safety, the pH value of the accelerator solution or suspension has to be within a range of 3.0 to 8.0. As a rule, the dosage should be between 4.0 and 8.0 wt.% (in liquid accelerators a solid content ≤ 5.0 % of the binder mass is recommended).

4.5.1.2 Alkali accelerators

The requirements of table 4/5 apply, except for the pH value (≤ 12.0), the loss of strength (≤ 30 %), and the Na_2O content (no limit).

Table 4/5 Requirements to be met by admixtures and accelerators according to ÖNORM EN 934-5 (Table 1) for sprayed concrete (including additional requirements)

Properties	**Test method**	**Requirements**
Homogeneity	Visual inspection	No segregation
Colour	Visual inspection	Uniform and according to manufacturer's description
Composition (active constituents)	ÖNORM EN 480-6	No difference found in comparison of infrared spectra with manufacturer's specifications
Relative density	ISO 758	D ± 0.03 at D > 1.10 D ± 0.02 at D < 1.10 D = density as indicated by manufacturer
Solid content	ÖNORM EN 480-8	0.95 T < X < 1.05 T, if T > 20 wt.% 0.90 T < X < 1.10 T, if T < 20 wt.% T = solid content according to manufacturer, X = test result
pH value	ISO 4316	Manufacturer's indication ± 0.2, additionally 3.0 < pH <8.0
Chloride	ISO 1158	< 0.1 wt.%
Water-soluble chloride	ÖNORM EN 480-10	< 0.1 wt.%
Na_2O equivalent	ÖNORM EN 480-12	< 1.0 wt.%
Corrosion behaviour	not yet regulated	No initiation of corrosion in reinforcement steel
Additional requirements to be met by accelerators:		
Setting times	according to It. 12.1.3 as reference procedure or based on ÖNORM EN 480-2	Initial setting < 10 min Completion of setting < 60 min
Loss of strength	based on ÖNORM EN 196-1 according to It. 12.1.5 (mix temperature 20±2°C)	≤ 15.0 %
Requirements to be met in addition to ÖNORM EN 934-5:		
Sulfate content as SO_3:	based on ÖNORM EN 196-2	≤ 4.8 wt.% as sum total of cement and accelerator
Al_2O_3 (water soluble) for sulfate-resistant sprayed concrete (water with SO_4^{2-} content of more than 600 mg/l):	According to It. 12.1.9 or proof of sulfate resistance in reference sprayed concrete or sprayed-concrete structure according to It. 12.4.7	Al_2O_3 in wt.% x accelerator dose in wt.% of binder ≤ 115

4.5.2 Other admixtures

The effectiveness of concrete admixtures and their mutual compatibility (if several admixtures are used) has to be established through preconstruction and conformity testing of the sprayed concrete.

For the admixtures listed in Table 4/6, approval documents, test reports and test certificates, as required in the technical regulations and not older than three years, must be available. For all other admixtures (retarders, stabilisers, etc.), the supplier has to provide evidence of the permissible chloride content of ≤ 0.1 wt.% at intervals of two years.

Long-term retarders prevent the hydration reaction of cement for a certain period of time, usually between a few hours and a maximum of three days. Thus, FM-L moist mix and NM wet mix (fresh concrete) can be stored without loss of quality and without change in consistence. The effect of long-term retarders has to be compensated for through the addition of a modified accelerator. Possible influences on the further setting process and the properties of the hardened concrete (e.g. loss of strength) have to be taken into consideration. The additional requirements specified in Table 4/7 have to be met.

Admixtures intended to diminish dust formation and rebound serve to improve working conditions on the building site, particularly in the case of dry mix. The quantities to be added have to be established through preconstruction testing. The other sprayed concrete properties must not be negatively affected. The method by which admixtures are added has to be adjusted to the shotcreting method used.

Table 4/6 Other admixtures

Admixture	Abbreviation	Standard
Plasticiser	BV	ÖNORM EN 934-2
Superplasticiser	FM	ÖNORM EN 934-2
Air entraining water reducer	LPV	Guidelines ÖVBB[1)]
Air entraining agent	LP	ÖNORM EN 934-2

1) ÖVBB Guideline "Herstellung und Prüfung von Beton mit LPV-Zusatzmittel"

Table 4/7 Additional requirements to be met by long-term retarders (consistence regulators) according to ÖNORM EN 934-5

Property	Reference concrete	Test method	Requirement
Maintenance of consistency	ÖNORM EN 934-5 Annex B	ÖNORM EN 12350-5	Spread after mixing 55-60 cm, after 6 hours 80 %
Compressive strength	ÖNORM EN 934-5 Annex B	ÖNORM EN 12390-3	After 28 days equal to or higher than reference mix

4.6 Fibres

Steel fibres have to meet the requirements of Table 10/1 and plastic fibres those of Table 10/2 of the ÖVBB Guideline on fibre-reinforced concrete. The production of fibres is subject to external inspection.

5. MIX

5.1 Mix composition and production

Based on current technology, mix as a base product for dry-mix sprayed concrete and wet-mix sprayed concrete is classified according to Table 5/1. For indicative values of mix composition, see Table 5/2.

Table 5/1: Mix classification

	Dry-mix sprayed concrete			**Wet-mix sprayed concrete**
Water content of mineral aggregates	W < 0.2 wt.%	Standard W = 2.0 - 4.0 wt.% Scatter W = 1.5 - 5.0 wt.%		W ≤ 8.0 wt.%
Designation	dry mix	moist mix storable	moist mix for immediate placing	wet mix
Designation	TM	FM-L	FM-S	NM
Binder	Cement and additions or SBM	Cement and additions	SBM	Cement and additions
Addition of EB	in mixing plant, if necessary	during working	during working, if necessary	during working
Production	plant or site mixing	plant or site mixing	continuous mixing during working	plant or site mixing
Storage	closed (e.g. bin, bag)	sheltered	-	sheltered
Availability	unlimited	limited	unlimited	limited
Storage time (without long-term retarder)	storage according to requirements	Produced in advance, to be used within storage time (max. 1.5 h)	Produced for immediate use	Produced in advance, to be used within storage time (max. 1.5 h)

Table 5/2: Indicative values for mix composition for SpC II and SpC III

	Dry-mix sprayed concrete	**Wet-mix sprayed concrete**
Cement, SBM additions (e.g. fly ash)	310 - 360 kg/m^3 30 - 50 kg/m^3	360 - 420 kg/m^3 0 - 70 kg/m^3
Binder dose (cement, SMB and additions)	340 - 380 kg/m^3 [1)]	400 - 450 kg/m^3
Water-binder ratio	≤ 0.50 for strength requirements J_2 and/or J_3	
Consistency (spread)	-	Favourable range: Dense stream: 55 – 60 cm [2)] Thin stream: 65 ± 5 cm [2)]
Mineral aggregates: standard ranges see Tab. 4/4	GK 8, GK 11	GK 8, max. GK 11

1) With binder doses of less than 340 kg/m^3 adhesion of the sprayed concrete to the substrate is noticeably diminished.

2) See It. 7.2.

5.1.1 Dry mix - TM (dry-aggregate mix)

- *Production*

  Dry mix can be plant-mixed or site-mixed from dry mineral aggregates with cement, with a combination of cement and accelerators, if necessary either with additions or with spray cement (SBM).

  The mixing plant has to meet the following requirements:

  - Facilities for dry storage of cement or spray cement and additions as well as facilities for clean storage of mineral aggregates of the required grain sizes.
  - Weighing equipment for all concrete constituent materials with a weighing accuracy of ± 3.0 wt.%.
  - Metering equipment with a batching accuracy (target-actual deviations) for the concrete constituent materials according to ÖNORM B 4710-1 Table NAD 15.
  - Mixing plant of sufficient mixing efficiency to guarantee a homogeneous mix. Mixing plant with microprocessor control meeting the requirements of ÖNORM B 4710-1, It. 9.6.2.3.1. Extent of documentation according to It. 12.7 of this Guideline.

- *Working temperature*

  The temperatures indicated in Table 5/3 have to be observed.

Table 5/3: Temperature of dry and moist mix during working

	TM	**FM-L FM-S**	**TM**	**FM-L FM-S**
Working temperature	max. °C		min. °C	
Spray cement	+ 60	+ 50	no requirement	
Mineral aggregate	+ 40		+ 5	+ 10
Water	+ 60		no requirement	
Mix	+ 40	+ 30	+ 5	+ 10

The most favourable temperature range for the mix is between 13 °C and 25 °C. Temperatures below 13 °C impair early strength, whereas temperatures above 25 °C shorten the workability time. Frozen mineral aggregates must not be used.

- *Natural moisture*

  Maximum natural moisture: 0.2 wt.% or according to specifications of spray cement manufacturer.

- *Storage and transport*

  Dry mix has to be stored under cover and must not deteriorate during transport. Measures have to be taken to avoid segregation (e.g. central pipe in the bin, bin never completely empty, discharge by means of vibrating floor). Air humidity in the conveyor line may lead to early setting reactions in spray cement.

  Mix spilled during handling or ejected from the spraying machine must not be re-used without prior treatment.

- *Storability of the mix*

  Dry mix can be stored for a period of up to several months according to the manufacturer's specifications.

5.1.2 Moist mix (moist-aggregate mix) FM-L, FM-S

- *Production*

  FM-L moist mix can be ready-mixed or site-mixed from moist mineral aggregates, cement and additions and transported to the placing site. The accuracy of constituent material metering and the mixing plant have to be in accordance with It. 5.1.1. The mixing plant is to be set up in the vicinity of the placing site, so that the maximum permissible workability time of 1.5 hours is not exceeded without additional measures.

  If SMB is used, the short reaction time of a few minutes necessitates continuous (steady) mixing of the FM-S moist mix in a special mixing plant set up next to the sprayed concrete delivery machine. Use of a mixing plant for continuous mixing is permitted. Batching and mixing of the constituent materials has to be such as to guarantee the placing of homogeneous sprayed concrete on the substrate. Metering may be performed by rotary vane batchers on a volumetric basis or, preferably, by weighing conveyors. The batching process (metering) has to be adjusted so as to achieve the required mixing ratio according to Table NAD 15 ÖNORM B 4710-1 (calibration according to It. 12.5.1), which has to be documented accordingly. For dry-mix shotcreting a tolerance range of ±5% for all constituent materials is permissible, since the final composition of the mix is obtained during placing.

- *Working temperature*

  The temperatures according to Table 5/3 have to be observed.

  Measures to reach a favourable working temperature:

  - at low ambient temperatures: heating (direct steaming is to be avoided), covered and/or enclosed storage of mineral aggregates, heating of water added for mixing;
  - at high ambient temperatures: sprinkling of grain size fractions 4/8 and/or 4/11, covered and/or enclosed storage of mineral aggregates, cooling of constituent materials in special cases.

- *Natural moisture of mineral aggregates*

  The natural moisture of the total quantity of mineral aggregates has to be between 1.5 wt.% and 5 wt.% (standard range; 2 wt.% - 4 wt.%).

  If SBM is used, a moisture content within the standard range is essential to ensure correct mixing and working of the mix. As a rule, the mix has to be covered for protection against climatic influences during both transport and storage. If the natural moisture is insufficient, the mix has to be moistened immediately before further use.

- *Storage and transport*

  Prior to placing, the FM-L mix has to be protected against external influences during transport and storage. Any mix spilled during handling or ejected from the spraying machine must not be re-used without prior treatment.

- *Workability time*

  The length of time for which FM-L mix remains workable depends largely on external influences, the type and dosage of the binder, the water content of the mineral aggregate and the temperatures.

  To guarantee first-rate quality of the sprayed concrete, the time taken to spray a mix made from cement according to It. 4.1.1 must not exceed 1.5 hours. Long-term retarders can be used to keep the mix workable for a longer time.

  If SBM is used, the workability time of the FM-S mix is product-specific (workability time of a few minutes).

5.1.3 Wet mix - NM

- *Production of pumped concrete and wet mix for thin-stream conveying*

  The mixing equipment has to be in accordance with ÖNORM B 4710-1 It. 9.6.2.3. The use of microprocessor-controlled equipment is required. Ready-mixed concrete may be used.

- *Working temperature*

  Mineral aggregates and fresh concrete should have a temperature of more than 15° C.

  If the fresh concrete temperature is above 20 °C, pre-hydration of the binder may lead to excessive stiffening of the pumped concrete, which results in an unfavourable setting behaviour.

- *Workability time*

  As a rule, working must not take more than 1.5 hours. The workability time can be prolonged through the addition of retarders or long-term retarders.

5.2 Mix for prescribed sprayed concrete (standard sprayed concrete)

Sprayed concrete without special requirements up to strength class SpC 12/15 and for exposure classes X0 and XC1 can be produced without preconstruction testing according to Table 5/4 with the following mix composition:

Table 5/4: Prescribed sprayed concrete (standard sprayed concrete)

FM-L	Mineral aggregates GK 8 to GK 16 Grading line range AC	5 parts by weight
	Cement CEM I, CEM II Strength class 42.5 (350 kg corresponding to 1 m³ of sprayed concrete)	1 part by weight
NM	C 15/20/XC1/PB/GK 8 and/or GK 11/F66, site-mixed	

6. SPRAYING PROCEDURES

6.1 Placing of sprayed concrete

When placing the sprayed concrete, care has to be taken to produce a homogeneous, dense sprayed concrete texture and a closed, even surface.

For thick sprayed concrete linings, sprayed concrete is to be applied in two or more layers to prevent separation. This applies, in particular, to sprayed concrete placed overhead. Rebound has to removed and not incorporated into the lining.

If the individual layers required to achieve the ultimate sprayed concrete thickness are placed at longer intervals, the previous sprayed concrete layer has be to cleaned and/or wetted by means of a mixture of compressed air and water.

The distance between the nozzle and the substrate should be adjusted to the rate of delivery and the speed at which sprayed concrete is placed. Depending on the operating air volume, it is between 0.5 m and 2.0 m. The spraying angle, i.e. the angle between the nozzle and the wall to be shotcreted, should be as close to 90° as possible. Nozzle distances and angles other than those recommended diminish the sprayed concrete quality and result in increased rebound.

The reference spray cement and/or accelerator dose determined during preconstruction testing may be modified slightly according to local conditions. Such modifications may be required due to the location and condition of the substrate, seasonal temperature fluctuations, moisture, water ingress and geological conditions.

If conditions turn out to be particularly unfavourable for a limited period of time, i.e. strong water ingress, the admixture of additional accelerator, adjusted to the overall system, or an increase of the spray cement dose may be necessary.

The amount of rebound is strongly influenced not only by the nozzle angle, but also by the composition of the mix, the amount of water, the spraying velocity, as well as the thickness of the sprayed concrete layer and the surface of the wall. Rebound and sprayed concrete residues must not be reused for shotcreting without prior treatment [8].

Reinforcements and steel components have to be adequately secured. Loose rock behind the reinforcement (wire mesh) have to be removed before shotcreting. In the presence of steel components, such as steel arches, steel girders, laggings, pipes, etc., small cavities in the lining cannot be excluded, but the effect can be diminished through proper positioning and control of the nozzle. Core samples should not be taken from such places. If a two-layer reinforcement is provided for, the second layer wire mesh (facing the tunnel clearance) should not be placed before the first one (facing the rock) is covered with sprayed concrete.

If sprayed concrete is to be placed consecutively on sections of the substrate and/or joined to existing sprayed concrete structures or protruding steel reinforcements, proper jointing to the existing sprayed concrete surface is essential. Tapering sprayed concrete edges and dirty jointing surfaces in the case of overlapping reinforcements are to be avoided.

If the substrate temperature is low, particularly in the case of frozen rock and soil or ice, the thickness of the sprayed concrete layer has to be increased by 2 – 3 cm.

If sprayed concrete is to be worked at air and underground temperatures of less than +5 °C, additional measures have to be taken. A minimum mix temperature of +13 °C is recommended.

After-treatment of sprayed concrete in tunnels is only required if special properties are to be guaranteed (e.g. SpC III) or under special circumstances (e.g. excessive drying or cooling). In such cases, the sprayed concrete surfaces are to be kept moist for seven days or sprayed with sufficient quantities of post-treatment agent according to RVS 11.064, Part II. For other applications

ÖNORM B 4710-1, NAD 17, applies. Thin layers of sprayed mortar for the rehabilitation of concrete structures require twice the time indicated in Table NAD 17.

6.2 Dry-mix shotcreting

6.2.1 Delivery of the dry mix

The mix is delivered to the nozzle in a pressurized airstream by means of compressed air, wetted with water in the nozzle ring and sprayed onto the substrate.

- *Mix*

  For dry-mix sprayed concrete, dry mix (TM) or moist mix (FM-L, FM-S) according to It. 5 can be used.

- *Mix conveyor, shotcrete gun, shotcreting machine*

  Mix for dry-mix sprayed concrete is delivered into the air stream by means of a rotary spraying machine, a double-chamber spraying machine or other equipment (batching screw). The mix conveyor has to ensure a uniform flow of material at the nozzle. The mechanical equipment has to be absolutely tight (dust formation, sprayed concrete quality).

  Unused mix residues and deposits have to be removed continuously.

- *Conveyor pipework, material delivery hoses*

  The conveyor hoses or pipelines should be installed in straight lines or wide bends. Couplings have to be absolutely tight.

- *Spraying nozzle*

  The spraying nozzle has to be designed in such a way as to ensure thorough mixing of the mix, water and, if necessary, the accelerator and the additions (e.g. micro-silica slurry).

- *Addition of water*

  Water has to be conveyed to the nozzle under sufficient pressure through hoses or pipelines. The temperatures indicated in table 5/3 should be observed.

  If sprayed concrete is delivered at a constant rate, the amount of water required for optimum workability of the sprayed concrete varies within narrow limits. Observance of these limits ensures a water-binder ratio of the sprayed concrete of ≤ 0.5. As a rule, measurements are not required.

6.2.2 Metering of the accelerator

The metering device has to ensure constant batching of the accelerator at a quantity specified relative to the cement mass and/or proportional to the conveyor output. The amount of accelerator to be added to the stream can be adjusted at the metering device. The set values have to be recorded in a calibration certificate (calibration curves, with due consideration given to water pressure in the case of liquid accelerator). To ensure delivery of a constant dose throughout the period of operation at the building site, the metering device has to be maintained, cleaned and calibrated at regular intervals. The accelerator has to be kept at a temperature of above 10° C.

The accelerator dose has to be accurate to less than 1.0 % of the binder dose (e.g. 6.0 % ± 1 % of binder).

- *Metering devices for liquid accelerators*

  As a rule, liquid accelerator is added continuously to the water by means of metering pumps. Addition to and mixing with water in batches in large containers is also possible.

During aspiration of the accelerator from the storage tank, care has to be taken to avoid air bubbles and contamination. During storage, the liquid accelerator has to be stirred and maintained in stable condition (no flocculation or changes in viscosity, e.g. under extreme weather conditions).

- *Metering devices for powder accelerators*

  During dry-mix shotcreting, accelerator in powder form is usually added by means of metering devices immediately upstream of the shotcreting machine.

  - Manual metering into the spraying hopper is permitted in special cases only.
  - Batching screws and rotary vane batchers have to be installed above the conveyor belt according to the supplier's instructions. The accelerator quantity to be added has to be accurately adjusted to the conveyor belt rate in a pre-operational test.

6.3 Wet-mix shotcreting

6.3.1 Delivery of the wet mix

- *Wet-mix shotcreting equipment*

  Piston pumps are used to convey wet mix in a dense stream (piston pumps are suited for use in concrete repair work only). To minimise the interruption of delivery during switching, a long stroke, fast switch control and an accelerated piston speed in the unfilled piston range are recommended.

  Modified dry-mix shotcreting machines or pressure vessels with screw discharge are used for thin-stream conveying.

- *Delivery pipework*

  The delivery pipework is similar to that used for normal pumped concrete. The lines should be as straight as possible. The number of couplings is to be minimised.

- *Spray nozzle*

  In thin-stream conveying, the nozzle only has a guiding function and therefore consists of a single steel pipe, possibly cone-shaped.

  In dense-stream conveying, the dense stream has to be loosened and accelerated through the injection of air.

  Special care must be taken to allow the continuous addition of accelerator to the concrete stream.

6.3.2 Metering of the accelerator

The accelerator has to be added continuously to the concrete stream. Positioning of the batching device a few metres before the end of the pipe and subdivision of the total accelerator dose into smaller quantities have proved successful.

- *Metering device for liquid accelerators*

  The provisions for dry-mix sprayed concrete apply (see It. 6.2.2.). For slurry accelerators, valveless pumps (e.g. squeezecrete pumps) are to be preferred. Pumps integrated into the hydraulic stream of the concrete pump also proved to be useful. During switch-over of the concrete pump, the metering pump must also be stopped.

- *Metering device for powder accelerators*

  Powder accelerators are batched via a compressed-air flow.

  - *Rotary batchers*

    Rotary batchers are based on the principle of the dry-mix shotcreting machine, which delivers the powder accelerator via a rotor into the thin stream in the sprayed concrete hose. The accelerator dose can be adjusted to the shotcreting machine by selection of rotor speed or rotor size.

  - *Pressure pot or pressure silo*

    Instead of a rotor, a pressure pot or pressure silo can also be used to deliver the required accelerator dose. The air pressure required for delivery of the accelerator has to be adjusted to the air pressure for sprayed concrete delivery to prevent the formation of residues. The accelerator dose can be adjusted through selection of the nozzle geometry and control of the air flow. Addition to the sprayed concrete stream is based on the same principle as with rotary batchers.

Powder accelerators can be blown into the dense stream via special nozzles at 3 – 5 m from the end of the hose, which also serve to convert the sprayed concrete stream from dense flow to thin flow. Sufficient mixing of the accelerator with the pumped concrete can also be achieved by simpler means, if the accelerator is batched directly into the thin stream. The design details always depend on the shotcreting system used. The accelerator has to be kept at temperatures of more than 10 °C.

6.3.3. Placing of wet-mix sprayed concrete

As a rule, wet-mix sprayed concrete is placed by remote-controlled spraying arms (spraying robots), manual handling of the nozzle being impossible on account of the weight of the dense stream of fresh concrete and the spraying equipment. If large-diameter pipes and high-rated machines are used, mechanical spraying arms ensure a higher placing output, provided sprayed concrete is applied continuously on large areas of substrate.

The nozzle distance, the nozzle orientation and the delivery rate can be optimised by the nozzle man according to individual requirements. The nozzle man is positioned at a certain distance from the substrate outside the direct rebound and dust range. Depending on the type of equipment, he may be positioned in a control booth on the lower part of the spraying arm, a control booth on the base machine, or on the ground with a remote-control module. Thus, better visibility and greater occupational health and safety can be ensured for the nozzle man.

However, owing to the distance from the substrate and the high delivery rate, production of a sprayed concrete layer of uniform surface and thickness is difficult. At any rate, shotcreting under hazardous conditions is facilitated through low-risk manipulation of the nozzle close to the substrate.

7. REQUIREMENTS TO BE MET BY SPRAYED CONCRETE

The properties of sprayed concrete - sprayed concrete classes, early strength classes, strength classes and exposure classes – are defined in terms of sprayed concrete grades according to It. 7.5.

The properties have to be indicated in the schedule of specifications and/or implementation schedules through reference to the corresponding short designations (sprayed concrete grades according to It. 7.5).

7.1 Sprayed concrete classes

Sprayed concrete is classified according to its application and the structural functions to be fulfilled. The individual sprayed concrete classes have different requirements in terms of early strength, density of the sprayed concrete structure, (e.g. XC4, XAT), uniformity and leaching behaviour; the test requirements to be met differ accordingly.

To reduce the alkalinity of sprayed concrete and, thus, ensure a higher level of occupational health and safety, an improved leaching behaviour and less segregation, the use of non-alkaline accelerators is recommended for sprayed concrete class SpC I; use of non-alkaline accelerators is obligatory for SpC II and SpC III.

If no particular test frequency class (sprayed concrete inspection class) is specified, the sprayed concrete classes correspond to the test frequency classes indicated in Tables 11/1 and 11/2.

7.1.1 Sprayed concrete without structural functions (sprayed concrete class SpC I)

As a rule, the level of quality required (strength class, durability) is relatively low.

7.1.2 Sprayed concrete with structural functions (sprayed concrete class SpC II)

In general, SpC II sprayed concrete is used to fulfil "securing and supporting functions". It is used, inter alia, for outer linings, to support the working face during tunnelling, and for slope, shoulder and trench support. Care should be taken to obtain a close texture.

Special requirements have to be specified as regards the development of early strength according to It. 7.3. When determining the range of strength required ($\mathbf{J_1}$, $\mathbf{J_2}$ or $\mathbf{J_3}$), the degree of utilisation at the respective age has to be considered. The addition of accelerator is not required for certain applications.

7.1.3 Sprayed concrete with special structural functions (sprayed concrete class SpC III)

This class of sprayed concrete is suited for all structural functions according to ÖNORM B 4700, e.g. for outer linings of excavations under built-up areas and a low overburden, single-shell tunnel linings, support elements for slopes and excavated surfaces, and sprayed concrete walls for water tanks.

Sprayed concrete for the repair of structures made of concrete, reinforced concrete and masonry is also understood to fulfil special structural functions. Special care has to be taken to obtain a homogenous and dense texture. Therefore, exposure class XC 4 is generally required for SpC III. Moreover, SpC III is required for applications subject to sulfate attack with SO^{2-}_4 > 600 mg/l.

As in the case of SpC II sprayed concrete, special requirements have to be specified with regard to early strength according to It. 7.3. When determining the range of strength required (**J_1** or **J_2**, **J_3** in special cases only), the degree of utilisation at the respective age has to be considered. The strength requirements have to be adjusted to the development of loading over time.

SpC III sprayed concrete should not be placed directly on surfaces with a strong water ingress without prior precautionary measures (e.g. pre-spraying, drainage).

7.2. Consistency

Maintaining the required consistency is essential to ensure the pumpability of wet-mix sprayed concrete <u>and</u> to guarantee correct metering of the accelerator. Any change in consistency must be taken into account when determining the accelerator dose.

The consistency classes according to ÖNORM B 4710-1 do not apply.

When placing wet-mix sprayed concrete in a dense stream, a spread of AM = 550 mm to 600 mm is favourable. As a rule, an allowance of 80 mm should be made for a workability time of 2 hours. A minimum slump of 500 mm is required.

When placing wet-mix concrete in a thin stream, a spread of AM = 650 ± 50 mm is desirable. As a rule, an allowance of 8 cm should be made for a workability time of 2 hours.

If a longer workability time (VV) is agreed according to ÖNORM B 4710-1, It. 4.2.6 and It. 5.4.9., maintenance of the required consistency is checked 15 minutes before the end of placing.

Consistency classes are of no relevance for dry-mix sprayed concrete.

7.3. Strength of young sprayed concrete (early strength classes)

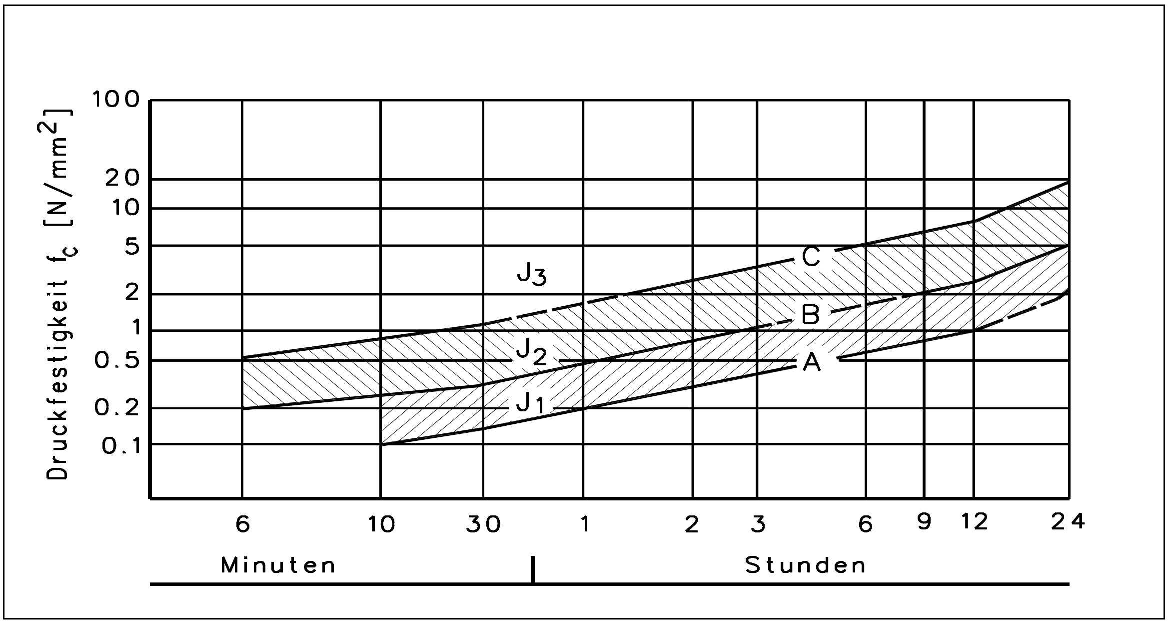
Fresh sprayed concrete is defined as sprayed concrete not older than 24 hours.

If the fresh concrete has to meet certain requirements in terms of strength development, these are specified according to early strength classes **J_1**, **J_2**, **J_3** (see Fig. 7/1).

An adequate development of strength during the first few minutes is a precondition for overhead placing (strength after 2 minutes 0.1 – 0.2 MPa). Test according to It. 12.3.1.

The development of strength during the first few minutes also has a major influence on the extent of dust formation and rebound. If strength builds up too fast, the sprayed concrete will harden instantly after being jetted onto the application wall, which prevents proper embedding of the coarse-grained particles of the subsequent shot. Hence, to keep dust formation and rebound within acceptable limits, the strength measured after 2 minutes under normal conditions should not exceed 0.2 MPa.

In the presence of strong water ingress or on a unfavourable substrate, a higher strength should be reached after a few minutes, which, however, implies a greater amount of dust and rebound.



between A and B	class J_1
between B and C	class J_2
above C	class J_3

Fig. 7/1: Early strength requirements to be met by fresh sprayed concrete

The development of strength in fresh sprayed concrete is determined by the test method specified under It. 12.3. Testing and measuring have to be timed in accordance with the build-up of strength in the sprayed concrete so as to obtain as continuous a picture of strength development as possible (the timing shown in the diagram serving as a guideline). It should be noted, though, that strength values of between 1.0 and 2.0 N/mm² cannot be measured on account of the test methods required according to Fig. 12/3. In all cases the development of sprayed concrete strength has to be demonstrated over the period from 6 minutes to 3 hours; moreover, at least one strength value has to be obtained for the period between 5 and 9 hours (in the measuring range of Procedure B) and 24 hours after placing.

Evidence of strength development after 9 and 12 hours is required in special cases only (e.g. low overburden, built-up areas), but may be specified in greater detail within the strength class (e.g. J_2 and after 12 h: 5.0 n/mm², after 24 h: 10.0 N/mm²).

J_1 sprayed concrete is suited for the placing of thin layers on a dry base without special load-bearing requirements and offers the advantage of low dust formation and rebound.

If sprayed concrete is to be placed in thick layers (including overhead) at a high delivery rate, strength development according to **J_2** is required. The same applies to locations with water seepage and applications involving immediate loading due to subsequent operations (e.g. drilling of anchor holes, driving of steel lagging, vibrations due to blasting).

J_2 requirements also have to be met in the case of rapid load build-up due to rock pressure, earth pressure or gravity loads. The specification of the range required also depends on the degree of utilisation of the fresh sprayed concrete. Examinations have shown that a linear creep behaviour is to be expected in fresh sprayed concrete with a degree of utilisation of up to 40 %, whereas a strongly progressive creep behaviour with a disruptive effect on the concrete texture is to be expected at a degree of utilisation of more than 80 % [9].

For reasons of increased dust formation and rebound, **J_3** sprayed concrete should only be specified under special circumstances (e.g. strong ingress of water, load-bearing requirements, fast rate of advance).

7.4. Strength classes

Compressive strength is specified according to ÖNORM B 4710-1. Strength testing is performed after not more than 28 days (or later at an agreed point in time, e.g. after 56 or 90 days, to be indicated in brackets after the strength class) on drilled cores from load-bearing sprayed concrete structures according to ÖNORM EN 12504-1 or, subject to special agreement and for preconstruction testing, from test panels according to prEN 14488-1.

Table 7/1: Sprayed concrete strength classes – Test age according to specifications

Sprayed concrete strength classes	Characteristic minimum compressive strength of cores with h/d = 1 in MPa
SpC 8/10	10
SpC 12/15	15
SpC 16/20	20
SpC 20/25	25
SpC 25/30	30
SpC 30/37	40
SpC 35/40	45

Preferably, strength testing is performed in cores with a height-to-diameter ratio of 1, if the result is to be compared with cube compressive strength (cores with a height-to-diameter ratio of 2 are used for comparison of the result with cylinder compressive strength). Cores have to be obtained according to ÖNORM B 3303, It. 5.2., and stored according to Table 12/2.

Equivalence of the compressive strength of sprayed concrete is determined according to Table 7/2 for:

- groups of n consecutive test results x_n (criterion 1)
- each individual test result x_i (criterion 2)

Table 7/2 Equivalence criteria for results of compressive strength testing in cores from load-bearing structures or test panels

	Criterion 1	Criterion 2
Number „n“ results in group	Mean value „n“ results x_n in MPa	each individual test result x_i in MPa
at least 15	$\geq f_{ck} + 1,48\ \sigma$	$\geq f_{ck} - 4$
3	$\geq f_{ck} + 4$	$\geq f_{ck} - 4$

with: f_{ck} ...... being the characteristic compressive strength
σ ...... being the standard deviation of at least six samples

In addition to the strength class according to Table 7/1, strength requirements may be specified for certain points in time, e.g. strength after 24 hours or after 3 days.

Instead of conformity testing of core samples according to It. 12.4.2., conformity testing of sprayed concrete by the bolt-driving method according to It. 12.3.2 may be contractually agreed upon in the case of large strength allowances (+ 10 N(mm² in Table 7/2). However, calibration of the method in the course of preconstruction testing is indispensable.

7.5. Sprayed concrete with special properties (sprayed concrete grades)

The special requirements refer to the material properties of the concrete, but not to the properties of the structure. The special properties only have to be demonstrated in the sprayed concrete texture.

For sprayed concrete with special properties, only F2 mineral aggregates according to ÖNORM 12620 may be used. To ensure the required density of the concrete texture, the use of alkaline accelerators is not permitted. The sprayed concrete must correspond at least to strength class SpC 20/25.

As regards the permissible limits for the constituent materials of sprayed concrete according to Table NAD 10 of ÖNORM B 4710-1, the following exceptions apply:

- conformity and identity tests for exposure classes XC3, XC4, XF3, XF4, XD3, XAL and XAT are to be performed in hardened concrete,
- a W/B value of 0.50 is assumed for dry shotcrete without testing,
- use of binders specified under It. 4.1 of this Guideline is permitted,
- the composition is determined in the mix delivered to the construction site, the air content normally assumed to be 3%.

7.5.1. Water-impermeable sprayed concrete (XC 3/XC 4)

Classification as exposure class XC3 with a penetration depth of < 50 mm or XC4 with a penetration depth of < 30 mm has to be performed in hardened concrete (drilled core) according to It. 12.4.4. of ÖNORM B 3303.

7.5.2 Frost-resistant sprayed concrete (frost attack without de-icing salts – XF 3)

Testing for frost resistance is performed in hardened concrete (drilled cores) according to It. 12.4.5. Contrary to the provisions of ÖNORM B 3303, frost resistance is to be demonstrated on the basis of the reduction of the static modulus of elasticity, which must nor exceed 25% after 56 frost-thaw cycles.

7.5.3 Sprayed concrete resistant to frost and thaw cycles (frost attack in combination with de-icing salts – XF 2 and XF 4)

As a rule, this type of sprayed concrete can only be produced by wet-mix or by dry-mix processes from ready-made products filled in bags. The requirements of the ÖVBB Guideline “Maintenance and Repair of Concrete and Reinforced-Concrete structures”. In the case of thawing agents other than salt, the possibility of a sulfate attack may have to be taken into consideration.

7.5.4 Sprayed concrete with high resistance against expansive chemical attack (XAT)

Given the fact that sprayed concrete placed in contact with the substrate cannot be protected against expansive attack from mountain water through subsequent measures, preventive measures must be taken if such attack is suspected. As the sulfate concentration in mountain water may vary strongly, the risk of sulfate attack must be assessed in at least three samples obtained at different points in time.

Sprayed concrete for applications subject to sulfate attack must have a durable and dense texture, i.e. meeting the requirements of SpC III and XC4 (penetration depth < 30 mm). In the case of sulfate contents of SO42- > 600 mg/l, suitable constituent materials according to It. 4, in particular a C3A-free binder, must be used. Testing for sulfate resistance is performed according to It. 12.4.7. Testing on the basis of the W/B value is not permitted.

7.5.5. Sprayed concrete with high resistance against solvent chemical attack (XAL)

For applications subject to mild solvent attack (XA1L), a durable and dense texture must be ensured through class XC 4 (penetration depth < 30 mm).

For applications subject to moderate solvent attack (XA2L), non-carbonated mineral aggregates with a CO_2 content < 15% must be used for the grain size fraction ≤ 4 mm (except in cases of solvent attack in which renewal of the attacking liquid is insignificant to nil; mineral aggregates containing limestone or dolomite have to be used in such cases to neutralise the attacking liquid). Testing for class XA2L is to be performed according to ÖNORM B 3303. Sprayed concrete is to be produced according to SpC III.

Applications subject to strong solvent attack (XA3L) require special measures. As a rule, sprayed concrete must not be used as a permanent support measure for such applications.

7.5.6 Sprayed concrete to be tested for bond strength (HZ)

For special procedures, a tensile adhesive strength value, e.g. HZ 1.5 (tolerance in initial testing: 0.5 N/mm²) has to be specified by the design engineer on a project-specific basis. For concrete repair measures and/or the placing of sprayed concrete layers of up to 80 mm, the ÖVBB Guideline “Maintenance and Repair of Concrete and Reinforced-Concrete structures”. Testing is to be performed on drilled cores or on the structure (in case of thin layers) according to It. 12.4.11.

As a rule, preparation of the substrate is required. To demonstrate the sufficiency of substrate preparation, the adhesive strength and the surface roughness of the substrate are established.

7.5.7 Fibre-reinforced sprayed concrete

The assessment of fibre-reinforced sprayed concrete (FRSpC) is performed in accordance with the ÖVBB Guideline on fibre-reinforced concrete. Fibre-reinforced concrete is classified according to its specific properties.

For sprayed concrete used for tunnel support, classification is based on the indicative toughness values established in the panel loading test, i.e. E1 (500-700J); E2 (700-1000J) and E3 (800-1200J). In Table 9/1 of the Guideline on fibre-reinforced concrete these classes are allocated to different tunnelling conditions.

For applications subject to bending forces (e.g. normal force), fibre-reinforced concrete is classified T1–T5, TS in terms of ultimate strength or TG1-TG5, TGS in terms of service state. The classes are based on the mean equivalent flexural tensile strength measured at the bending test beam. Fibre-reinforced concrete classes higher than T3 or TG5 can only be obtained through special measures.

Fibre-reinforced concrete classes BB 1 and BB 2 are required for applications demanding increased fire resistance through reduced spalling near the surface of the structure; concrete classes BB 1G and BB 2G are required for arches.

Fibre-reinforced concrete classes FS 1 and FS 2 are used to characterise the reduction of early shrinkage cracking through the addition of fibres.

7.6. Designation of sprayed concrete grades

The properties required in sprayed concrete, to be demonstrated through testing, are specified by reference to sprayed concrete grades according to Table 7/3. To indicate the sprayed concrete grades, the abbreviations given in It. 7.1 are to be used. The concrete grades to be used must be indicated in the construction specifications and/or planning and tender documents (for examples of sprayed concrete grades, see Table 7/3).

Table 7/3 Examples of sprayed concrete grades

Application and requirements	**Concrete grade**
Sprayed concrete for outer lining of traffic tunnel	SpC20/25(56)/II/J_2 /XC1/GK8
Water-impermeable sprayed concrete for outer lining of traffic tunnel (moderate water pressure)	SpC20/25(56)/II/J_2 /XC3/GK8
Fibre-reinforced sprayed concrete for initial support	FRSpC20/25/II/J_2 /XC1/E3/GK8
Sprayed concrete for permanent penstock lining	SpC20/25(56)/III/J_1 /XC4/GK8
Fibre-reinforced concrete for permanent lining of cross passages in traffic tunnels	FRSpC25/30/III/J_1/XC4/T3/BB2/ GK8
Sprayed concrete for outer lining exposed to sulfate attack	SpC25/30(56)/III/J_2/XC4/XAT/ GK8
Sprayed concrete as base layer for sealing material	SpC 12/15/I/GK 8
Sprayed concrete for bridge repair work, reprofiling mortar according to ÖVBB Guideline [1)]	SpC25/30/III/XC4/XF4/HZ1.5/ GK4
Sprayed concrete for temporary slope support	SpC20/25/II/J_1/XF3/GK8

1) ÖVBB Guideline "Maintenance and Repair of Concrete and Reinforced-Concrete Structures"

Additional properties established through quality testing as properties of fresh sprayed concrete and hardened sprayed concrete are not defined in this Guideline, but may be of relevance under special conditions, e.g. compressive strength of sprayed concrete between 1 and 28 days after placing, tensile splitting strength, shear strength, creep behaviour, modulus of elasticity (development over time), and adhesion of sprayed concrete to the substrate as well as the procedures indicated in the Guideline “Maintenance and Repair of Concrete and Reinforced-Concrete structures".

8. STRUCTURAL REQUIREMENTS

Given the method by which sprayed concrete is worked and placed, special requirements have to be met in terms of structural design to ensure the required quality of execution.

8.1. Fundamental requirements

- In terms of structural design, preference should be given - as far as possible - to increased sprayed concrete thickness instead of additional reinforcement.
- Joints in the sprayed concrete lining should be reduced to the absolute minimum and, if possible, located outside areas of flexural loading.
- Sprayed concrete with structural functions should be designed to a minimum thickness of 10 cm (except for structural reinforcement and repair works).
- In the case of longitudinal construction joints, the use of formwork is recommended, with due consideration given to the possible transmission of shear forces.
- In the case of double-layer reinforcements, the second layer (facing the tunnel clearance) must not be placed before the first layer (facing the rock) has been embedded with sprayed concrete.

8.2. Reinforcement

- Reinforcing steel mesh with a mesh width of ≥ 100 mm and a diameter of no more than 10 mm is to be used.
- Secondary reinforcing bars required for static reasons are to be placed, if possible, in every other field of the steel mesh only (e.g. mesh width 150/150 mm - min. distance = 30 cm).
- As a rule, the diameter of secondary reinforcing bars should not exceed 14 mm.
- Concrete cover: the minimum thickness of the concrete cover is to be observed throughout the structure. For planning purposes, the minimum design thickness is to be increased by the tolerance (see RVS 9.35); in the case of exposure to frost and thawing agents and/or a requirement for increased fire protection, the corresponding values have to be specified for each individual case.

Table 8/1 Concrete covers required

	Minimum thickness	Tolerance	Minimum design thickness
SpC I	15 mm	15 mm	30 mm
SpC II	20 mm	15 mm	35 mm
SpC III	30 mm	15 mm	45 mm

- Cross-shaped joints of reinforcing steel mesh are to be avoided, if possible (longitudinal and transverse direction). Overlap of additional reinforcing bars should also be avoided. If reinforcement overlaps circumferentially, no longitudinal overlap is required.
- Lap reinforcements to be bent backwards on site must not be more than 12 mm in diameter. The total cross-sectional area of the steel reinforcement may be utilised up to 80 % in the finished structure.

9. SINGLE-SHELL CONSTRUCTION METHOD

9.1 Definition, prerequisites, execution variants

The single-shell construction method is characterised by the fact that all static and structural requirements are fulfilled by a single shell structure. This shell can be produced in one or several operations.

The shell structure has to be designed not only to meet the need for support during tunnel driving, but also to fulfil the requirements of the finished structure. If the sprayed concrete shell fulfils a support function during tunnel driving and is to be subsequently strengthened by another sprayed concrete layer or shuttered in-situ concrete, the structural effectiveness of the composite structure has to be guaranteed through shear bonding.

If single-shell structures are made exclusively from sprayed concrete, local water penetration due to cracks, construction joints and defects cannot be excluded; hence, this method is preferably used in areas with little or no water ingress and the possibility of sufficient drainage.

If there is an ingress of water, the amount of water leakage permissible should be established before deciding in favour of or against a single-shell structure. Possible measures of water drainage and, if necessary, subsequent sealing, should also be considered.

In order to minimise crack formation and to keep the amount of reinforcement low throughout the structure, the bending stress on the tunnel shell should be as low as possible. Under appropriate geological conditions, this can be achieved through an adequate geometry of the tunnel cross section and in case of structurally favourable loading behaviour (symmetrical loading).

Form of execution

Basically , there are two variants based on the exclusive use of sprayed concrete.

- Single-layer sprayed concrete

  The sprayed concrete tunnel shell is placed in the course of tunnel driving, its thickness and reinforcement being sufficient to meet the requirements of both tunnelling and the finished state of the structure.

  Example: *25 cm sprayed concrete shell applied in the course of tunnel driving, with an outer (facing the rock) and inner (facing the tunnel clearance) layer of reinforcement.*

- Sprayed concrete shell formed by a composite multi-layered structure

  The outer sprayed concrete layer is applied during tunnel driving as a support for tunnelling. In a subsequent operation, one or several additional sprayed concrete layers are applied to achieve the shell thickness required for the finished state in static and structural terms, with shear bonding between the sprayed concrete layers being ensured by adequate measures (see It. 9.3).

  The use of fibre-reinforced sprayed concrete is preferable for the inner layer, as the higher density of the concrete eliminates the need for reinforcement by steel mesh or re-bars.

  Application of a sprayable sealing coat, capable of bridging cracks to a limited extent, is also possible.

  Example: *Outer layer of sprayed concrete shell, min. 15 cm, applied on a reinforcement mesh, with due consideration given to rock support by means of anchors, arches, etc., in the course of tunnel driving. After tunnelling, the second sprayed concrete layer is applied to and bonded with the existing outer layer with as few construction joints as possible, 15 cm thick, either with another reinforcement mesh or made from fibre-reinforced sprayed concrete.*

9.2 Sprayed concrete grade, design

Sprayed concrete grade

Considering the requirements to be met by fresh sprayed concrete, the minimum strength class required is SpC 25/30. As special properties, water permeability and a sufficient resistance against chemical attacks are essential.

Example of outer shell: *SpC 25/30(56)/III/XC4/GK8/J_1 or J_2.*

Example of inner shell: *SpC 25/30(56)/III/XC4/XF3/HZ1.0/GK8* .

Design, structural considerations

In addition to Item 8 of this Guideline, the following applies:

The stability of the sprayed concrete shell under all load conditions during construction is established for single-shell structures in the same manner as for double-shell structures.

In the case of multi-layer execution, the stability of the structure in its final state is established for the composite structure, with due consideration given to load transfers. Testing for stability of the structure under construction, in its final state and in borderline cases (in soil or soft ground) can be performed, for instance, in analogy to the Guidelines for Traffic and Road Engineering, RVS 9.32, Items 3.4 and 3.5.

Bonding (shear bonding) between the sprayed concrete layers, if properly executed, is ensured by their surface roughness. Shear strength and bond strength at joints have to be established through preconstruction testing.

In view of the desired avoidance of inhomogeneities and/or defects in the sprayed concrete, the amount of reinforcement used it to be kept at its minimum; the reinforcement should be easy to place and evenly distributed.

In order to avoid additional inhomogeneities in the inner sprayed concrete layer, shear reinforcement should not be used. Reinforcement bars (mandrels, etc.) must not be allowed to penetrate the sprayed concrete shell to avoid the entrance of water.

9.3 Notes on execution

To ensure bonding of the sprayed concrete layers, the outer sprayed concrete layer has to be cleaned with a mixture of compressed air and water, or preferably by means of a high-pressure water jet, before the inner sprayed concrete layer is placed.

The reinforcement is to be kept in the required position through adequate measures, with overlaps of reinforcing mats being arranged in such a way as to avoid the superposition of four mat layers.

Breaking of construction joints in the individual sprayed concrete layers is essential.

After completion of the sprayed concrete shell, a thin levelling layer may be required in view of the use of the tunnel and/or as an additional seal against the ingress of water.

Single-layer sprayed concrete shells have to be executed with special care. Hence, appropriate instruction of the building-site staff and intensive construction supervision and quality control are essential.

10. SPECIAL PROCEDURES

10.1. Sprayed concrete under compressed air

Sprayed concrete under compressed air [10] differs from sprayed concrete under atmospheric conditions for a number of reasons:

- *Increased air humidity*

  Owing to increased air humidity and - in most cases - higher air temperature, the sprayed concrete is permeated by air immediately after placing as a result of above-atmospheric pressure.

- *Impact on quality*

  The equipment set-up and the organisation of mix delivery under compressed air from the lock to the nozzle has to be such as to keep the exposure of the dry mix to compressed air as short as possible, since the high humidity under compressed air leads to a fast reaction of the binder.

  The more permeable the subjacent rock and the higher the pressure above atmospheric, the more easily will the sprayed concrete be permeated by compressed air.

  As a result of air permeation, the sprayed concrete loses moisture immediately after placing, which in turn leads to rapid drying and early shrinkage. Therefore, if sprayed concrete is to be placed on highly air-permeable soil or soft ground, the quality of the sprayed concrete (e.g. strength) will presumably be lower than that of sprayed concrete placed under atmospheric conditions as a result of fast drying and removal of fines. This is true, above all, of fresh sprayed concrete.

  If the substrate is largely impermeable, compressed air has a favourable influence on sprayed concrete quality.

- *Additional measures*
  - Repeated moistening of the fresh sprayed concrete (spraying with water from a nozzle).
  - Use of suitable additions to increase the density of the sprayed concrete texture.
  - Application of a sealing coat (sealing mortar) on the sprayed concrete surface as soon as possible after placing.

  The latter measures also help to diminish the total loss of air in the pressurised section.

- *Air pressure fluctuations*

  Air pressure fluctuations (due to normal tunnel driving or special incidents) have no particular influence on the build-up of strength in fresh sprayed concrete and subsequent strength development, provided the pressure does not drop below 0.6 bar.

10.2 Fibre-reinforced sprayed concrete

Besides steel fibres, glass, polymer, textile and carbon fibres can be used for the production of fibre sprayed concrete according to It. 7.5.7. It is important to note, however, that use of such fibres requires a different working method.

Steel-fibre reinforced sprayed concrete

- *Applications and functions*

  Steel-fibre reinforced sprayed concrete contains at least 30 kg of steel fibres per m³ of placed sprayed concrete; fibres are added to obtain special properties in both fresh and hardened concrete. The fibre component in the rebound has to be taken into consideration. The maximum grain size of the mineral aggregate should not exceed 8 mm.

  The following sprayed concrete properties can be influenced through the addition of steel fibres:

  - increased toughness, particularly under flexural loading
  - limitation of crack width
  - no need for reinforcement for thin and/or irregular sprayed concrete layers
  - improved homogeneity through the avoidance of voids due to the ommitance of reinforcement (e.g. single-shell construction).

  The amount of fibres contained in the placed sprayed concrete is lower than in the base mix. Therefore, the fibre content has to be checked at regular intervals (see It. 12.6).

- *Working procedure*

  Steady addition of the steel fibres is essential for the quality of the placed steel-fibre concrete. The steel fibres need to be straightened out before being added to the mix. Collated fibres require contact with moisture to dissolve the bonding.

  Steel fibres can be added to the moist mix in the mixing plant, the truck mixer or on the conveyor belt upstream of the shotcreting gun. By means of a suitable batching device, steels fibres can be fed into the shotcreting machine or directly into the delivery stream in a well-targeted and controlled manner.

- *Requirements to be met by steel-fibre reinforced sprayed concrete*

  To ensure the necessary bonding of the fibres to the matrix, the strength class must not be less than SpC 20/25. A water-binder ratio of under 0.5 is desirable.

  An essential property of steel-fibre reinforced sprayed concrete is its increased toughness. Toughness is determined through classification according to flexural tensile strength and post-cracking behaviour into the levels T1 to T5, TS and/or TG1 – TG5, TGS (service state), tested on the bending test beam, or according to stress and strain performance levels E1 to E3 of the energy absorption equivalent, tested by loading plate-specimens.

Structural considerations

An "overlap" of fibres at construction joints is not possible. It is therefore necessary to determine the location of construction joints already in the planning stage and to provide for additional overlapping reinforcement.

11. SPECIFICATIONS AND TESTING

The specifications for sprayed concrete production refer either to concrete properties (specification of properties by the author, e.g. design engineer, as a rule), to concrete composition (inspection class I only), or to standard concrete (prescribed concrete, in exceptional cases only).

The specifications and tests applicable to sprayed concrete include the following:

- Specification of properties and inspection classes
- Preconstruction test
- Production control, including conformity tests (constituent materials, mix)
- Additional conformity tests of the mix to be performed by the sprayed concrete user, if not identical with concrete manufacturer
- Identity test
- „Certification“ of production control
- Measures to be taken in the event of non-compliance with criteria

For the purposes of production control, the constituent materials, the mix, the sprayed concrete, and the equipment for the production and intermediate storage of the mix and/or the sprayed concrete have to be tested. The constituent materials have to be subjected to both self-inspection and external inspection. Conformity testing of the mix and the shotcrete comprises preconstruction testing and continuous self inspection.

The frequency of conformity testing depends on the frequency classes to be specified in the tender documents. As a rule, frequency classes I - III correspond to sprayed concrete classes SpC I - III according to It. 7.1.

The identity test is performed on behalf of the owner/client by an accredited inspection body; testing for sprayed concrete thickness and early strength is performed by an experienced representative of the owner/client.

The scope of testing according to Tables 11 is to be observed. The manufacturer and the user have to agree in unmistakable terms on who is to perform which tests. If the manufacturer and the user are identical, double testing is not required.

Sprayed concrete properties and tests to be performed "according to requirements" and/or for special procedures, e.g. steel-fibre reinforced sprayed concrete, are to be specified in the tender documents.

11.1. Testing of constituent materials

The constituent materials for sprayed concrete production (cement, spray cement, additions, mineral aggregates, admixtures) have to be tested according to Table 11/1/1 and Table 11/1/2. As a rule, products subject to external inspection have to be used. In special cases, i.e. if no external inspection is performed, regular submission of evidence of performance of the tests required according to It. 4 by other means may be agreed upon.

11.2 Testing of the mix

The mix is to be subjected to conformity testing in the course of application at the building site. The frequency of testing depends on the type of mix, the frequency class and the presence or absence of certification of mix production, see Table 11/2/1 to Table 11/2/5.

With regard to mix production, the composition of the mix is to be recorded and submitted to the inspection body upon request.

11.3. Testing of sprayed concrete

11.3.1 Preconstruction testing

The composition of the sprayed concrete is to be determined through preconstruction testing, which serves to demonstrate that both fresh sprayed concrete and hardened sprayed concrete meet the requirements specified for the structure in question (Table 11/2). The preconstruction test is to be performed under construction-site conditions, using the concrete components intended for execution of the construction job. The evaluation is made on a step by step basis as the individual test results become available.

If accelerators are used, at least two mixtures with different binder percentages and the corresponding admixture doses are to be tested to establish the required sprayed concrete composition (binder and accelerator doses required)[1)]. To establish the loss of strength, concrete made from the same constituents but without accelerator (base concrete) is to be tested. Base concrete should also be used to test the mix under building-site conditions.

In the event of significant changes regarding the constituent materials used for sprayed concrete production (change of manufacturer, binder, admixtures, additions, binder quantity of more than + 20 kg/m³, etc.), repeat preconstruction testing is required.

For sprayed concrete of a specified strength class, a sufficient allowance has to be made (indicative value: 25 % of characteristic strength of the corresponding strength class, but not less than 6 N/mm²). The allowance is higher than provided for in ÖNORM B 4710-1, which is due to the unavoidable scatter of quality. As regards the allowances for the other test parameters, Annex A of ÖNORM B 4710-1 applies. If new admixture-binder combinations are used, preconstruction testing according to It. 12.1.12 is recommended. For prescribed sprayed concrete up to strength class SpC 12/15, preconstruction testing is not obligatory.

11.3.2. Conformity testing

Conformity testing in the course of execution of the structure serves to demonstrate that the sprayed concrete composition is such as to guarantee the required properties at the specified age of 28 (56 or 90) days, assuming proper production, post-treatment and storage according to It. 12.4.1. The specified testing age may be exceeded by a maximum of 10 %. If wet mix is delivered by a ready-mix plant, the properties of hardened concrete also have to be demonstrated within the framework of conformity testing. The testing frequency is specified in Tables 11/2/1 to 11/2/5.

If the results of conformity testing are inadequate, performance of a second test on twice the original number of samples from the same test batch and/or a theoretical calculation according to Annex 5 is permissible. The conformity criteria for compressive strength are summarised in Table 7/2, and for other properties in Table 11/3.

[1)] If cement according to It. 4.1.1 and non-alkaline accelerator and/or spray cement are used, preconstruction testing with a single binder dose (min. 340 kg/m²) is sufficient.

Tab. 11/1/1 Testing of base materials in the course of conformity testing

Base material and requirements to be met	**Base material testing to be performed by the manufacturer**	**User of base materials**				
		Preconstr. test	Conformity test Frequency class (HK)			
				HK I	HK II	HK III
CEMENT						
Delivery note checked and reference samples taken	Plant inspection according to ÖNORM EN 197-1 and ÖNORM B 3327-1 incl. items listed in Tab. 4/2	x	x	every consignment, weekly testing of reference samples		
Delivery temperature	according to Tab. 4/2	x	x			
SPRAY CEMENT SBM						
Delivery note checked and reference samples taken	Plant inspection according to Tab. 4/3 twice a year	x	x	every consignment, weekly testing of reference samples		
Delivery temperature		x	x	every consignment		
ADDITIVES TYPE II ACCORDING TO ÖN B 4710-1						
Fly ash, slag sand	Inspection according to ÖNORM B 3309 or EN 450					
Silica dust	Inspection according to ÖNORM EN 13263					
Delivery note checked and reference samples taken		x	x	every consignment		
WATER						
Chemical composition		x		Check according to ÖNORM B 4710-1		

x to be tested
(x) to be tested, if necessary

Tab. 11/1/2 Testing of Base Materials in the Course of Conformity Testing

Base material and requirements to be met	Base material testing to be performed by the manufacturer	User of base materials				
		Preconstr. test	Conformity test Frequency class (HK)			
				HK I	HK II	HK III
MINERAL AGGREGATES						
Delivery note checked, visual inspection, reference sample	Preconstruction test and plant inspection according to ÖNORM B 3131/ ÖNORM EN 12620	x	x	every consignment, reference samples to be tested weekly		
Grain size distribution (grading line)		x	x	1 x month	2 x month	4 x month
Water content		x	x	1 x week	2 x week	
Fines and/or settleable solids		(x)	-	-	-	-
chem. reaction (e.g.: alkali-silica reaction)		(x)	-	-	-	-
ACCELERATOR						
Delivery note checked, visual inspection, reference sample taken	Preconstruction test and plant inspection according to ÖNORM EN 934-5 and Tab. 4/5 Preconstruction test by accredited inspection body	x	x	every consignment		
Density, solid content		x	x	every 2 months	every 2 months	monthly
pH value		x	x			
Setting behaviour		x	x	every EB consignment		
OTHER ADMIXTURES						
Delivery note checked, visual inspection, reference sample taken	Preconstruction test and plant inspection according to ÖNORM EN 934-2 and Tab. 4/5 Preconstr. test by accredited inspection body	x	x	every consignment		
FIBRES						
Delivery note checked, visual inspection, reference sample taken	Preconstruction test and plant inspection according to Guideline on fibre-reinforced concrete	x	x	every consignment		
Fibre dimensions		x	x			
Fibre-reinforced concrete class BB and/or BBG	(x)	-	-			
Fibre-reinforced concrete class FS	(x)	-	-			

x to be tested
(x) to be tested, if necessary

Tab. 11/2/1 Testing of Mix and Sprayed Concrete

Performance of test		Manufacturer of mix				User of sprayed concrete					Identity test	
		Preconstr. test	Self-inspection		External inspection	Preconstruction test	Conformity test					
							Frequency class (HK)					
								HK I	HK II	HK III		
SPRAYED CONCRETE MADE FROM DRY MIX (TM) SUBJECT TO EXTERNAL INSPECTION[1)]												
Temperature	Mix	x	x	continuous-ly upon delivery	Plant inspection twice a year	no test required	x	continuously (min. once daily)			(x)	for sur-faces over 100 m^2 every 20,000 m^2
Uniformity (de-mixing)		x	x				x				x	
Moisture		x	x	2 x monthly			x	every 4 months and/or every 10,000 m^2	every 2 months and/or every 5,000 m^2	monthly and or every 2,500 m^2		
Apparent density		x	x				x				(x)	
Grain size distribution		x	x			x	x				x	
Binder content		x	x	continuous-ly		-	-				(x)	
Early strength class	Sprayed concrete	x	x	every 1,000 to, max. once a month[2)]		x	x				x	
Compressive strength 7 d, 28 d		x	x			no test required	x				x	
Sprayed concrete thickness		-	-				x	every 500 m^2			x	
Water impermeability XC3/XC4		x	x	once a year[2)]			(x)	1 x	12 months		(x)	
Frost resistance XF3		(x)	(x)				(x)				(x)	
Resistance to frost and thaw cycles XF4		(x)	(x)				(x)				(x)	
Modulus of elasticity 28 d		(x)	(x)				(x)					
Elution behaviour		(x)	(x)				(x)	-				
Tensile adhesive strength		(x)	(x)				(x)	-	every 500 m^3		(x)	
Sulfate resistance XAT		(x)	(x)	every 2 years								
Solvent attack XAL		(x)	(x)									

1) For sprayed concrete for repair works an agreement has to be made with the external inspection body in accordance with the ÖVBB Guideline on "Maintenance and Inspection of Concrete and Reinforced Concrete Structures".
2) May be included in the conformity test to be performed by the user
x to be tested
(x) to be tested, if necessary
If the user is also the manufacturer of the mix, double testing (manufacturer – user) is not required
Tests for XF1 and XF2 are to be performed in fresh concrete according to ÖNORM B 4710-1

Tab. 11/2/2 Testing of Mix and Sprayed Concrete

Performance of test		Manufacturer of mix				User of sprayed concrete					Identity test	
		Preconstr. test	Self-inspection		External inspection	Preconstruction test	Conformity test					
								Frequency class (HK)				
								HK I	HK II	HK III		
SPRAYED CONCRETE MADE FROM DRY MIX (TM) NOT SUBJECT TO EXTERNAL INSPECTION												
Temperature	Mix	x	x	continuously upon delivery		x	x	continuously (min. 1 x daily)			(x)	for sur-faces over 100 m² every 20,000 m²
Uniformity (de-mixing)		x	x			x	x				x	
Grain size distribution		x	x	1x weekly		x	x	1 x weekly			x	
Apparent density		x	x	1x monthly		x	x	every 2 months and/or every 5,000 m²	monthly and/or every 2,500 m²	2 x monthly and/or every 1,250 m²	(x)	
Moisture		x	x	1x monthly		x	x				x	
Binder content		x	x	continuously		x	x				(x)	
Early strength class	Sprayed concrete	Mixing plant according to It. 5.1.1 or ready-mix plant according to ÖNORM B 4710-1 with microprocessor control				x	x				x	
Compressive strength 7 d, 28 d						x	x				x	
Sprayed concrete thickness						-	x	every 500 m²			x	
Water impermeability XC3 / XC4						x	(x)	1x	every 6 months		(x)	
Frost resistance XF3						(x)	(x)				(x)	
Modulus of elasticity 28 d						(x)	(x)					
Elution behaviour						(x)	(x)	-	every 12 months			
Tensile adhesive strength						(x)	(x)		every 500 m²		(x)	
Sulfate resistance XAT						(x)						
Solvent attack XAL						(x)						

x to be tested
(x) to be test, if necessary
If the user is also the manufacturer of the mix, double testing (manufacturer – user) is not required
Tests for XF1 and XF2 are to be performed in fresh concrete according to ÖNORM B 4710-1

Tab. 11/2/3 Testing of Mix and Sprayed Concrete

Performance of test		**Manufacturer of mix**				**User of sprayed concrete**					**Identity test**	
		Preconstr. test	Self-inspection		External inspection	Preconstr. test	Conformity test – Frequency class (HK)					
								HK I	HK II	HK III		
SPRAYED CONCRETE MADE FROM MOIST MIX FM-L AND FM-S												
Temperature	Mix	x	x	continuously		x	x	continuously (min. 1 x daily)			(x)	for sur-faces over 100 m² every 20,000 m²
Uniformity (de-mixing)		x	x	continuously		x	x				x	
Mix ratio, batch protocols		x	x	daily							x	
Moisture of mineral aggregates		x	x	daily							(x)	
Grain size distribution		x	x	weekly		x	x	every 2 months and/or every 5,000m²	monthly and/or every 2,500m²	monthly and/or every 1,250m²	x	
Workability time (FM-L only)		x	x	2 x monthly		X (FM-L only)	x				(x)	
Base concrete (FM-L only)		x	-	-		x (FM-L only)	x					
Early strength class	Sprayed concrete	Mixing plant according to It.5.1.2 or ready-mix plant according to ÖNORM B 4710-1 with microprocessor control				x	x				x	
Compressive strength 7 d, 28 d						x	x				x	
Sprayed concrete thickness						-	x	every 500 m²			x	
Accelerator dosage						x	x	2x weekly			x	
Water impermeability XC3/XC4						x	(x)	1 x	every 6 months		(x)	
Frost resistance XF3						(x)	(x)				(x)	
Modulus of elasticity 28 d						(x)	(x)					
Elution behaviour						(x)	(x)	-	every 12 months			
Tensile adhesive strength						(x)	(x)		every 500 m²		(x)	
Sulfate resistance XAT						(x)						
Solvent attack XAL						(x)						

x to be tested
(x) to be tested, if necessary
If the user is also the manufacturer of the mix, double testing (manufacturer – user) is not required
Tests for XF1 and XF2 are to be performed in fresh concrete according to ÖNORM B 4710-1

Tab. 11/2/4 Testing of Mix and Sprayed Concrete

Performance of test		Manufacturer of mix				User of sprayed concrete					Identity test	
		Preconstr. test	Self-inspection		External inspection	Preconstr. test	Conformity test Frequency class (HK)	HK I	HK II	HK III		
SPRAYED CONCRETE MADE FROM WET MIX (WET-MIX SPRAYED CONCRETE, DENSE STREAM OR THIN STREAM)												
Fresh concrete temperature	Mix	x	x	continuously		x	x	continuously (min.1 x daily)			x	for sur-faces of more than 100 m^2 every 20,000 m^2
Moisture of mineral aggregates		x	x	according to B 4710-1		-	-				-	
Slump		x	x			x	x				x	
Workability time		x	x			(x)						
LP		x	x			(x)	(x)				x	
Mix ratio, batch protocols		x	x			x	x				x	
Compressive strength 28 d Base concrete not sprayed		x	x	every 400 m^3		x	-	if user is not identical with manufacturer			x	
Accelerator dosage	Spayed concrete	Mixing plant according to It. 5.1.3 or ready-mix plant according to ÖNORM B 4710-1 with microprocessor control				x	x	2 x weekly			x	
W/B ratio						x	x	every 2 months and/or every 5,000 m^2	monthly and/or every 2,500 m^2	monthly and/or every 1,250 m^2	x	
Base concrete sprayed						x	x				(x)	
Early strength class						x	x				x	
Compressive strength 7 d, 28 d						x	x				x	
Sprayed concrete thickness						-	x	every 500 m^2			x	
Water impermeability XC3/XC 4						x	(x)	1 x	every 6 months		(x)	
Frost resistance XF 3						(x)	(x)				(x)	
Frost resistance XF 4						(x)	(x)				(x)	
Modulus of elasticity 28 d						(x)	(x)					
Elution behaviour						(x)	(x)	-	every 12 months			
Tensile adhesive strength						(x)	(x)		every 500 m^2		(x)	
Sulfate resistance XAT						(x)						
Solvent attack XAL						(x)						

x to be tested
(x) to be tested, if necessary
If the user is also the manufacturer of the mix, double testing (manufacturer – user) is not required
Tests for XF1 and XF2 are to be performed in fresh concrete according to ÖNORM B 4710-1

Tab. 11/2/5 Additional Tests for Fibre-Reinforced Sprayed Concrete

Performance of test		**Manufacturer of mix**			**Manufacturer of mix and user of sprayed concrete**					**Identity test**	
		Preconstr. test	Conformity test	External inspection	Preconstr. test	Conformity test					
						Frequency class (HK)					
							HK I	HK II	HK III		
Fibre content	Mix	x	x	x	x	x	if necessary	1 x every 200 to 1,000 m^3	1 x every 100 to 500 m^3		for sur-faces of more than $100 m^2$ every 20,000 m^2
Fibre-reinforced concrete class BZ	Sprayed concrete				(x)	(x)	every 6 months			(x)	
Fibre-reinforced concrete class T					(x)	(x)	-	every 6 months		(x)	
Fibre-reinforced concrete class TG					(x)	(x)	-			(x)	
Fibre-reinforced concrete class E					(x)	(x)	-			(x)	
Fibre content					x	x	-			x	

x to be tested
(x) to be tested, if necessary
If the user is also the manufacturer of the mix, double testing (manufacturer – user) is not required

Table 11/3 Conformity and identity criteria for other properties

Property	**Test method**	**Maximum permissible deviation of individual test results from limits or tolerances**
Moisture of mineral aggregates	Weighing and drying test or equivalent method	± 20 %
Bleeding	ÖNORM B 3303	according to ÖNORM B 4710-1: < 1 kg/m³
Spread	ÖNORM B 3303	according to It. 7.2: -30 mm/+30 mm upon delivery, after working time –30 mm
Density	ÖNORM B 3303	according to ÖNORM B 4710-1: -30 kg/m³
W/B ratio	according to ÖNORM B 4710-1, It. 5.4.2	± 0.02 for wet mix
Fresh concrete temperature	ÖNORM B 3303	< +1°
Binder content	according to ÖNORM B 4710-1, It. 5.4.2	-10 kg/m³
Bulk density	ÖNORM EN 459-2	± 0.05 kg/dm³
Early strength class	It. 12.3	Compliance with required J class over entire period
XC3/XC4	It. 12.4.4 according to ÖNORM B 3303	according to ÖNORM B 4710-1: < 5 mm
XF 3	It. 12.4.5 according to ÖNORM B 3303	Drop of static modulus of elasticity < 25 % after 56 frost-thaw cycles
Leaching?? behaviour	It. 12.4.12	Compliance with values of Table Tab. 3/1
Modulus of elasticity	It. 12.4.6	± 15 %
Bond strength	It. 12.4.11	according to ÖNORM B 4710-1: < -0.3 N/mm²
Thickness of sprayed concrete layer	It. 12.5.4	± 1 cm or Annex 5
Fibre dosage	ÖVBB Guideline „Fibre-Reinforced Concrete“	-15 %, mean -5 %
Fibre-reinforced concrete class BZ	ÖVBB Guideline „Fibre-Reinforced Concrete“	-10 %
Fibre-reinforced concrete class T	ÖVBB Guideline „Fibre-Reinforced Concrete“	-10 %
Fibre-reinforced concrete class TG	ÖVBB Guideline „Fibre-Reinforced Concrete“	-10 %
Fibre-reinforced concrete class E	ÖVBB Guideline „Fibre-Reinforced Concrete“	-10 %
Sulfate resistance	It. 12.4.7.2	to be specified by expert

The minimum number of samples is specified in Table 11/2.

11.3.3 Identity testing

The identity test serves to verify compliance of a lot or batch with a compliant total population. Sprayed concrete of a given strength class is deemed to originate from a compliant total population, if it meets the two criteria of Table 11/4 for "n" results of strength testing of samples obtained from the defined concrete volume. Sprayed concrete is deemed to originate from a compliant total population, if the properties specified are met within the permissible maximum deviations of Table 11/3.

Table 11/4 Identity criteria for the results of compressive strength testing on the load-bearing structure or, if specifically agreed, in test panels

	Criterion 1	**Criterion 2**
Number „n" results for compressive strength of defined concrete volume	Mean value of „n" results f_{cm} in MPa	Each of the individual test results f_{ci} in MPa
5 - 6	$\geq f_{ck} + 2$	$\geq f_{ck} - 4$
2 - 4	$\geq f_{ck} + 1$	$\geq f_{ck} - 4$
1	not applicable	$\geq f_{ck} - 4$

in which: f_{ck} …. characteristic compressive strength

11.3.4. Hardening/structural test

The hardening test serves to establish the structural strength and the special properties of the sprayed concrete in the finished structure at a specified point in time. Hardening tests (except for tests of the young sprayed concrete) are performed to establish matters of principle only and do not form part of the normal conformity testing procedure. For this purpose, tests are to be performed on young sprayed concrete (see It. 7.3) or on core samples (It. 12.4.1).

11.4. Inspection of mixing and metering equipment

In the course of commissioning, mixing plants have to be inspected by an accredited inspection body to establish compliance with the requirements according to It. 5 of this Guideline at the frequency indicated in Table 11/5. The same applies to metering equipment for liquid and powder accelerators. The results have to be recorded in an inspection protocol.

Table 11/5: Inspection of mixing and metering equipment

	Mix	**Type of test**	**Preconstruction test**	**Self-inspection**
Mixing equipment	Dry mix TM with external inspection[1] without external inspection Moist mix FM-L and FM-S[2] Wet mix NM	Inspection of weighing equipment	x	monthly during the first three months of operation, subsequently every three months
		Batching accuracy of metering devices	x	
		Mixing efficiency	x	
		Bin[3] (segregation)	x	
Metering device for accelerator (powder, liquid)	-	Batching accuracy	x	Maintenance and inspection at least once a month

[1] Inspections as part of external inspection
[2] Inspection of other equipment, if any
[3] for dry mix (TM) only

12. TESTING PROCEDURES

The testing methods outlined below are laboratory and building-site tests which provide an indication of the behaviour of spray cement and the interaction of binders and accelerators in sprayed concrete production. To ensure due consideration of building-site influences, adjustments have to be made to local conditions (e.g. temperature, effectiveness of mixing, material flow, type and condition of substrate). The use of special testing methods, optimised for certain procedures or products, may be agreed upon between the parties concerned.

12.1 Testing of constituent materials for concrete production

The constituent materials to be used for concrete production have to be subjected to a preconstruction test to establish the properties essential for sprayed concrete production, such as acceleration of setting, early strength development, strength development, durability and leaching behaviour, well before the beginning of building-site operation. This applies, in particular, to binders (cement, spray cement) and materials to be added (additions, admixtures), possibly also to mineral aggregates and water.

12.1.1. Sampling of constituent materials and dry mix (TM)

Samples of constituent materials and dry mix (TM) are taken for the verification of material properties. Depending on individual arrangements, these tests are either carried out continuously for identification or at a later point in time on the basis of retained samples.

Availability of samples in sufficient quantities and of a quality as delivered and/or used for working has to be ensured. To meet this requirement, extreme care has to be taken during sampling and storage of samples.

Sample quantities:	Cement or spray cement: at least 5 kg Additions (fly ash, silica materials, etc.) and/or admixtures (accelerator): 1 kg or 1 litre Mineral aggregates 10 kg Dry mix: at least 10 kg
Sampling:	The equipment used for sampling and storage of samples must be clean and dry and, if possible, should serve for no other purpose. In the case of silo deliveries, representative samples are to be taken either through the lid of the silo truck or from newly filled containers. Samples must under no circumstances be taken from concrete residues left in the filling hose or the filling flange.
Filling and packaging:	Liquid products and powders have to be filled into clean, dry, and tight-shutting containers. Powders are first filled into PE bags, which then have to be closed tight without air cushions (shrink-wrapped, if possible) and stored in sheet-metal or plastic boxes.
Labelling:	All samples have to be labelled as follows (see enclosed specimen sheet "Sample Labelling"): - type and designation of the product - manufacturer (and/or supplier) - delivery day and, if possible, day of manufacturing - quantity delivered - mode of delivery (silo, bag, barrel, etc.) - place and date of sampling

- name of person taking the sample

Storage: Samples to be retained for later testing are to be stored in a cool and dry place. Samples for subsequent testing on the building site are to be stored until the required sprayed concrete properties have been demonstrated.

In addition, ÖNORM EN 932-1 applies to mineral aggregates and dry mix; ÖNORM EN 196-7 applies to cement, binders and additions.

12.1.2. Bleeding of cement and/or binder pastes

Test to be performed according to ÖNORM B 3303, It. 9.4.

12.1.3. Laboratory testing of binder/accelerator combinations and spray cement (SBM) for acceleration of setting

The testing methods used to assess the acceleration of setting are based on the principle of penetration. The Vicat needle apparatus (test performed on binder paste) or the Proctor penetrometer (test performed on reference sprayed concrete) can be used for this purpose. The manual Vicat needle method described below basically serves to test and assess the suitability of spray cement and binder/accelerator combinations as regards the acceleration of setting. The Proctor penetrometer is used primarily to assess the effect of binder/accelerator combinations on the acceleration of setting and the development of early strength in wet-mix sprayed concrete.

- *Manual testing by means of the Vicat needle apparatus*

  This method of establishing the setting time of the binder/accelerator combination or the spray cement is modelled on the test provided for in ÖNORM EN 196-3. At a given water-binder ratio, the beginning and end of setting are established for a given binder/accelerator combination or spray cement.

- *Instructions for testing*

  a. Temperature of binder (spray cement) and water: +20 °C ± 2 °C, in special cases +8 °C ± 1 °C.

  b. Prepare 250 g binder (spray cement) and water according to preconstruction test[1)].

  c. Add liquid accelerator to water (dry-mix shotcreting), normally at a rate of 3 – 5 wt.% of binder. The moisture content of the accelerator is counted to the water quantity.

     When testing for wet-mix shotcreting, first prepare the binder paste and add the liquid accelerator quickly after 15 minutes (see e,f,g).

  d. When using powder accelerators, pre-mix thoroughly with binder.

  e. Fill the dry components into a conical hard-rubber ring (h = 40 mm, d_{ui} = 65 mm, d_{oi} = 74 mm) placed on a glass or plastic plate and topped with a cylindrical structure (ring) (h = 62 mm). A cylindrical vessel according to It. 12.1.4.1., h = 60 mm, can also be used.

  f. Form a dent in the binder.

  g. Quickly add the liquid components and mix the binder/accelerator paste or spray cement paste thoroughly within 15 seconds by means of a spatula or, preferably, an automatic stirring device (see Fig. 12/1) adapted to the shape of the vessel. After mixing, compact the paste by repeated jolting. Remove the ring and level the paste by means of the spatula. These operations have to be completed within 25 seconds after the initial addition of water or - in the case of wet-mix shotcreting - the addition of accelerator. If the binder paste is not easily workable, repeat the trial with a lower dose.

1) Water/binder ratio normally between 0.35 and 0.45.

h. Use Vicat needle apparatus to determine the beginning and end of setting. Calculate the times from the first addition of water or - in the case of wet-mix shotcreting - the completed addition of accelerator. The beginning of setting is defined as the point in time when the needle remains stuck in the paste at 3 to 5 mm above the plate (glass or plastic plate); the end of setting is defined as the point in time when the needle penetrates no more than 1 mm into the paste.

Alternatively, the needle method according to ÖNORM EN 934-5 (modelled on EN 480-1 with W/B < 0.5 and Vicat needle apparatus 300 g) can be used.

12.1.4. Preparation of samples for the testing of binder/accelerator combinations and spray cement

12.1.4.1 Preparation of cylindrical samples from binder paste

The method is suited for spray cement or binder/accelerator combinations with a setting time ≥ 15 seconds for tests of early strength and volume stability (soundness test). The samples are prepared according to the following instructions:

- *Materials and equipment required:*
  - metal cylinder with an inner diameter of 60 ± 1 mm, 60 ± mm high (cut up longitudinally). For volume stability and sulfate resistance testing, a suitable insert for the required height of 10 mm has to be used.
  - ring top
  - base and cover plate
  - basket stirrer (see Fig. 12/1)
  - hand-drill (1200 rev/min)
  - water tank
  - stop watch
  - weighing device, 0.1 g accuracy
  - amount of binder used: 320 g
  - amount of water - depending on the water-cement ratio established for setting between 15 seconds and 3 minutes (water-cement ratio 0.35 - 0.45)

The temperature of the water and the binder must be 20 °C ± 2 °C.

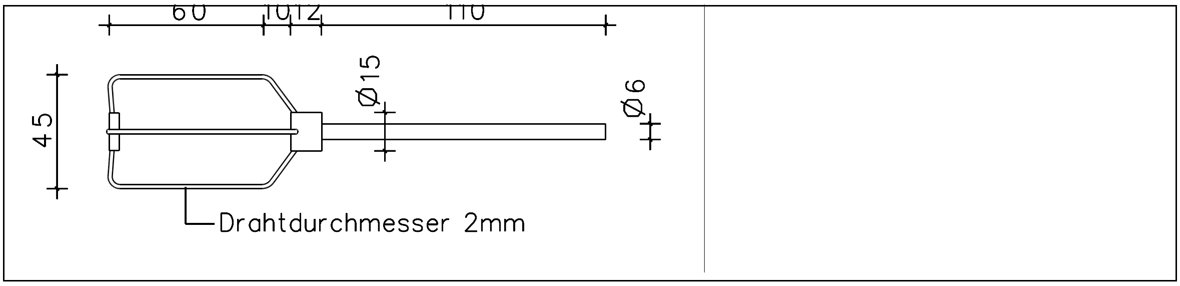


Fig. 12/1: Suitable basket stirrers (dimensions in mm)

- *Sample preparation:*
  - Place the cut cylinder (with top) on the base plate.
  - Pour the binder into the cylinder.
  - Pour water quickly into the cylinder and start the stop watch.
  - Use hand-drill with attached basket stirrer to mix the binder with water for 10 seconds by circular and vertical movements.
  - Remove the cylinder top and press the cover plate onto the cylinder.

    Operations 4 to 5 have to be completed within 15 seconds after the start of the stop watch. The glass plate may have to be turned to remove the binder paste from between the plate and the cylinder rim.
  - Remove the cover and base plates after approx. 10 minutes.
  - Insert a screwdriver into the longitudinal gap of the mould and turn it to strip the sample.
  - If the surface of the sample is not smooth, use fine-grained sand (e.g. standard sand, fine) and water to rework it on a glass plate.
  - Keep the sample moist for one day after stripping, then store it in a water bath at 20 °C ± 2 °C until testing.

12.1.4.2 Preparation of samples 4 cm x 4 cm – 16 cm, in analogy to ÖNORM EN 196 – 1, at water-binder ratio = 0.75[1)], for tests of compressive strength and loss of strength

Preferably, a water-binder ratio of 0.75 is to be observed. Test mortar (with accelerator) and reference mortar (without accelerator) must have the same water-binder ratio. If the loss of strength due to the addition of accelerator can be determined in the sprayed concrete (e.g. during building-site operation), the test according to It. 12.2.4. is to be preferred.

Test method based on the use of cylinders is being investigated – MVA Strass.

- *Mortar consisting of binder/accelerator combinations (M) and mortar without accelerator (0)*
  - Temperature (cement, standard sand and water): +20 °C ± 2 °C.
  - Mix cement and admixtures thoroughly before removal from container.
  - Mix 450 g cement with the dose of powder accelerator established in the setting-time test in dry state by hand with a spoon for two minutes in a dish. Liquid accelerators are added to the mixing water, the rest of the procedure being the same.
  - Pour 315 ml water into the dry mortar mixing dish (in analogy to ÖNORM B 3310).
  - Pour 1350 g ISO standard sand into the mixing dish of the slow-moving mixer.
  - Transfer the binder/accelerator mixture into the mixing dish within five seconds and immediately, i.e. without interruption, switch the mortar mixer to high speed for 15 seconds.
  - Place the mortar in the 4 cm x 4 cm x 16 cm prism moulds as quickly as possible and compact well.
  - Level the mortar in the mould immediately after compacting. This operation has to be completed before stiffening begins.
  - Determine the bulk density of the mortar to verify proper compacting (maximum permissible deviation of prisms prepared with and without additions: ± 5 %.

[1)] A water-binder ratio of 0.75, higher than that provided for in ÖNORM EN 196 - 1, is due to practical conditions. Comparative tests have shown that the loss of strength in this laboratory test largely corresponds to that of sprayed concrete in practice. If sample preparation is not possible, the test can be performed on sprayed concrete.

- After storage in a moist atmosphere for one day, the prisms are stripped and subsequently stored in a water bath at 20 °C ± 2 °C until testing.

- *Mortar made from spray cement*
  - The water-binder ratio depends on the product and has to be specified during preconstruction testing. The samples are produced in analogy to the above procedure, with the quantities being modified in accordance with the water-binder ratio.

12.1.4.3 Preparation of samples from reference sprayed concrete

Samples from reference sprayed concrete are used to test spray cement or binder/accelerator combinations for strength development, frost resistance, modulus of elasticity, water impermeability, sulfate resistance and leaching.

Table 12/1: Composition of reference sprayed concrete

	Dry-mix sprayed concrete	**Wet-mix sprayed concrete**
Mineral aggregates	calcite-dolomite aggregate	
Maximum grain size	8 mm	8 mm
Grain size distribution	grading line according to Table 4/4	
Spray cement[1], binder	380 kg/m³	430 kg/m³
Plastifier	-	according to requirements
Mean water-binder ratio	0.45 ± 0.03	0.50 ± 0.03
Accelerator[2]	corresponding to J_2	
Consistency	-	dense-stream process: a = 55 – 60 cm thin-stream process: a = 65 ± 5 cm

1) Minimum requirements to be met by fresh sprayed concrete J_2

2) Tests for sulfate resistance and elution are to be performed with the maximum permissible accelerator dose (according to manufacturer's specification).

- The following information has to be provided for reference sprayed concrete:
  - binder (designation, plant, place and date of delivery) and mineral aggregates (grading line)
  - mix composition
  - water-cement ratio (in case of dry-mix sprayed concrete through flow measurement)
  - consistency (wet-mix sprayed concrete)
  - spraying method
  - spraying machine and machine parameters, diameter and length of delivery hose, nozzle, water pressure, air pressure at the shotcreting machine or at the nozzle (wet-mix sprayed concrete)
  - spraying output
  - device for dosage and dosage level
  - ambient, fresh-concrete, water and storage temperatures
- Reference sprayed concrete is sprayed into sampling boxes according to It. 12.4.1. and stored.

- Testing of fresh sprayed concrete is performed according to It. 12.3. For all other tests, cores are drilled in the dimensions specified in the individual test procedures.

12.1.5. Laboratory testing of binder/accelerator combinations and spray cement for strength development and loss of strength

The addition of accelerator (above all of alkaline accelerator) may result in a diminished build-up of strength in older sprayed concrete and, thus, lead to a loss of strength relative to accelerator-free sprayed concrete (base sprayed concrete).

Strength development and the loss of strength (binder/accelerator combinations) can be established by means of the test methods described below. The most suitable method has to be chosen on the basis of the spray cement characteristics and/or the binder/accelerator combination used. A combination of different methods is possible.

- *Laboratory testing for compressive strength development on cylindrical samples according to It. 12.1.4.1.*

  The strength development of spray cement as well as binder/accelerator combinations is established through tests performed on cylindrical samples, 60 mm in diameter, 60 mm high, prepared and stored in accordance with It. 12.1.4.1.

  At least class II test presses according to DIN 51302 are permissible for compressive strength testing. Class III presses are permissible for the measuring range from 1 to 4 kN (determination of one-hour strength).

  Compressive strength testing is performed on 3 samples each after 1, 6 and 24 hours (evaluation of spray cement with regard to early strength) and after 28 days. Compressive strength is expressed as a mean value to an accuracy of 0.1 N/mm². Individual values deviating from the mean by more than 15 % are not considered for averaging. At least two useful samples are required for averaging. At least 2 useful samples are required for averaging.

- *Laboratory testing for compressive strength development and loss of strength in 4 x 4 x 16 cm test samples according to It. 12.1.4.2.*

  Testing for compressive strength is performed after 7 days and/or 28 days, or earlier.

- *Laboratory testing for compressive strength development in samples obtained from reference sprayed concrete according to It. 12.1.4.3.*

  Fresh sprayed concrete is evaluated according to It. 12.3.

  Testing for compressive strength after 7 days and/or 28 days is performed on 3 cores, 50 mm in diameter and 50 mm high.

  The loss of strength is calculated on the basis of the mean compressive strength of samples aged 28 days without accelerator (0) and with accelerator (M) according to the following equation:

$$\text{Loss of strength (\%)} \quad \frac{EB(0) - EB(M)}{EB(0)} \times 100$$

12.1.6. Volume stability testing of spray cement

The test is performed according to the Le Chatelier procedure in analogy to ÖNORM EN 196 – 3.

12.1.7 Determination of alkali content (Na2O equivalent) of spray cement and accelerators

12.1.7.1 Determination of alkali content (Na_2O equivalent) in spray cement

Test according to ÖNORM EN 196-21

12.1.7. Determination of alkali content (Na_2O equivalent) in accelerators

Test according to ÖNORM EN 480-12

12.1.8 Identity testing of accelerators

Identity testing of accelerators according to ÖNORM EN 934-5 serves to establish the uniformity of accelerators selected through preconstruction testing and delivered to the building site. A plant certificate has to be produced by the admixture manufacturer at the time of preconstruction testing and at least every other month as long as building-site deliveries are made:

- pH value (ISO 4316)
- density (bulk density, if required, proof of homogeneity, ISO 758)
- infrared analysis (ÖNORM EN 480-6)
- solids content (infrared drying or hot cabinet, 105°C)
- Al_2O_3 content according to It. 12.1.9.2
- SO_3 content (by analogy to ÖNORM EN 196-2)
- content of alkalis (Na_2O equivalent according to It. 12.1.7.2)
- Cl content (according to ÖNORM EN 480-10)
- acceleration of setting with a cement grade agreed upon before delivery (according to It. 12.1.3.)
- loss of strength (with accelerators) according to It. 12.1.5.
- proof of sulfate resistance (to be produced upon preconstruction testing, if required) according to It. 12.4.7.1

12.1.9 Determination of the Al2O3 content of accelerators (EB) and spray cement (SBM)

12.1.9.1 Total Al_2O_3 content of spray cement

Test according to ÖNORM EN 196-2

12.1.9.2 Content of water-soluble Al_2O_3 of accelerator

As a rule, this is determined by complexometric titration by means of Titriplex III and xylene orange as an indicator.

Instructions for testing

Use twice distilled water to dilute a 1 ml sample[1] to 100 ml. Boil up briefly with 50 ml 0.1 m (molar) Titriplex III solution and 2 ml 1 n (normal) hydrochloric acid and keep it on the boiling water bath for 10 minutes. After cooling, adjust to a pH value of 5 to 6 with sodium acetate, and after addition of triturated xylene orange indicator use 0.1 m zinc sulfate solution to titrate until the colour changes abruptly from yellow to red.

Triturated xylene orange indicator:	1 g	xylene orange
	99 g	potassium nitrate

To control the titrating solution, titrate a reference sample in the same manner.

[1]) Powder accelerator has to be dissolved (1:1).

Calculation:

1. $(50 - V) \times 5.098 = mg\ [Al_2O_3]$

   V = consumption in ml 0.1 zinc sulfate solution

2. $\frac{mg\ [Al_2O_3]}{\rho \times 10} = \%\ [Al_2O_3]$

   ρ = density at + 20 °C in g/cm²

12.1.10 Testing of mineral aggregate contribution to sprayed concrete strength

If mineral aggregates other than those corresponding to class I according to ÖNORM B 3304 and/or F2 according to ÖNORM EN 12620 are used, the following concrete without accelerator has to be tested at the age of 7 days:

- Specified mineral aggregates for sprayed concrete

  (aggregate grading line - according to Table 4/4, maximum grain size - depending on application - between 8 mm and 16 mm, for structural tasks 11 mm).
- CEM I 42.5 R/WT 38/C_3A-free, dose 400 kg/m³
- Water-binder ratio 0.50 ± 0.05:

  The water-binder ratio is to be chosen within the range specified for C2 concrete consistency. If this is not the case or if another consistency is more appropriate for the working method in question (wet-mix shotcreting), this has to be indicated separately.
- Sample preparation and testing according to ÖNORM B 3303. Compressive strength is to be indicated as the mean value of 3 cube tests.

  The compressive strength to be reached by this concrete has to be at least 1.3 times the strength of the required sprayed concrete strength class with non-alkaline accelerator and at least 1.6 times the strength of the required sprayed concrete strength class with alkaline accelerator.

12.1.11 Testing of grain size distribution of mineral aggregates

Test according to ÖNORM EN 933-1

12.1.12 Advance qualification testing

In view of the fact that sprayed concrete can only be produced and subjected to preconstruction testing under practical conditions by means of the actual building-site equipment when construction work has begun, a quality forecast should be made in time on the basis of the following tests:

- Testing of cement or spray cement according to It. 4.1.1. and/or 4.1.2
- Testing of the cement/accelerator combination according to It. 12.1.3 and 12.1.5. (for spray cement the results of self-inspection and external inspection are available).
- Testing of mineral aggregates: grain size distribution according to It. 12.1.11

  evaluation of strength contribution according to It. 12.1.10 (not obligatory if the same mineral aggregates have been used before)

On the basis of these tests, an evaluation of the sprayed concrete composition with regard to the binder/accelerator combination and the development of strength can be anticipated before the results of preconstruction testing are available. Ready-mix concrete plants, which only supply a sub-product for the dry-mix shotcreting procedure, should also use these tests for advance assessment. Tests of this type are of particular importance for minor construction projects, where they may fulfil the function of preconstruction testing.

Example: Reference concrete f_{cm} with sprayed concrete formula 42.0 MPa

- Loss of strength due to accelerator, e.g. 15%	-	6.3 MPa
		35.7 MPa
- Influence of compacting 10 %	-	3.6 MPa
- Allowance (6 N/mm³)	-	6.0 MPa
		26.1 MPa
required f_{ck} for SpC 2725		25

12.1.13 Testing for possible alkali - aggregate reaction (AAR) with spray cement or binder/accelerator combination

If the mineral aggregate contains alkali-sensitive constituents, an expansive reaction likely to damage the sprayed concrete may occur under certain circumstances.

In case of doubt, the reactive potential can be established through instant testing according to ASTM C 289-97. If the test results indicate a possible risk, the extent of the potential reaction has to be established in analogy to ASTM C 227-81. Risk assessment can also be based on the Alkali Guideline of the DAfStb.

12.1.14 Testing for extended workability time through use of long-term retarder for wet mix

Test of long-term retardation under ÖNORM EN 934-5 according to ÖNORM EN 12350-5

12.2 Mix, base concrete (without accelerator)

12.2.1 Testing of fresh concrete parameters of wet mix

The fresh concrete parameters (slump, void content, water-binder ratio and fresh-concrete temperature) are tested according to ÖNORM B 3303, sampling is performed according to prEN 14488-1.

12.2.2 Assessment of workability time of moist mix (FM)

The workability time of moist mix depends on the cement grade, the temperature and the natural moisture of the mineral aggregates. To assess the workability time, the temperature development of a cement-sand mixture is measured in analogy to ÖNORM B 3303, It. 9.3..

Evaluation

The time elapsed between the preparation of the cement-sand mix and the point in time by which the temperature has risen by +2 °C over the initial temperature provides the basis for the assessment of workability time. At any rate, the permissible workability time is limited to a maximum of 3 hours. Building-site influences (temperature, natural moisture of mineral aggregates, cement temperature) have to considered when assessing the actual workability time.

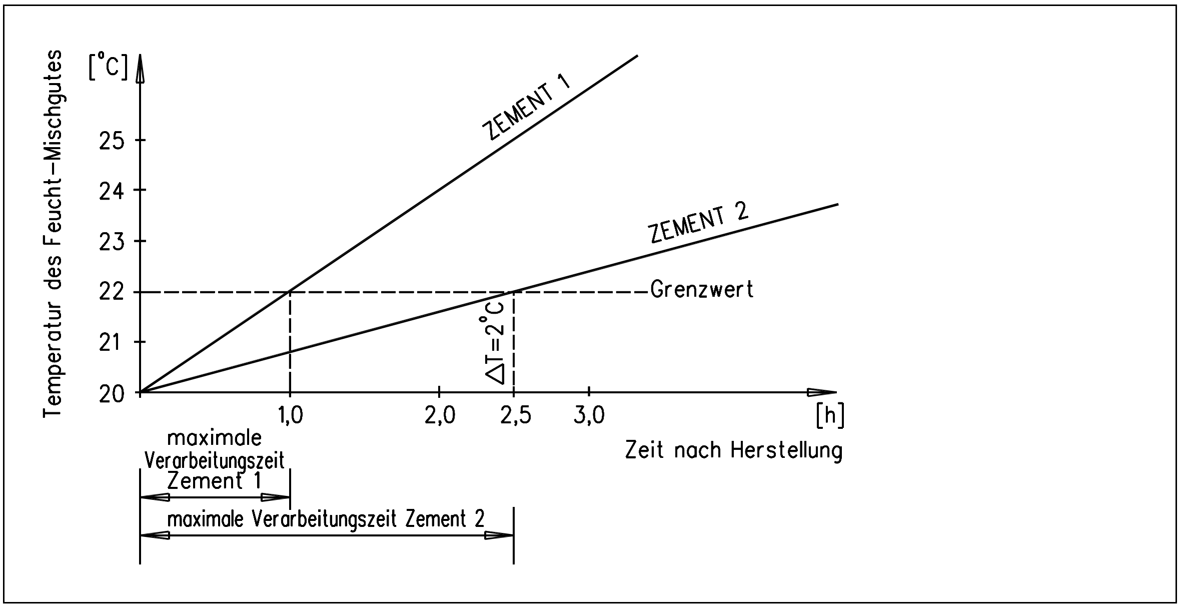


Fig. 12/2: Assessment of workability time of moist mix

12.2.3. Testing of extended workability time of wet mix

The extended workability time (VV) of wet mix is to be determined in terms of maintenance of consistency 15 minutes before the end of working according to ÖNORM B 3303 on the basis of spread table test.

12.2.4. Testing of base concrete (sprayed concrete without accelerator)

The base mix without accelerator is sprayed into test panels by means of the installed shotcreting equipment with the amount of water used for sprayed concrete production. Production of test panels, sampling and compressive strength testing according to It. 12.4.1 and 12.4.2.

The compressive strength determined after 28 days serves as:

- baseline value for the determination of the loss of strength due to the use of accelerators:

Loss of strength (%) : $\frac{EB(0) - EB(M)}{EB(0)} \times 100$

EB (0) = compressive strength of concrete without accelerator

EB (M) = compressive strength of sprayed concrete with accelerator

- evidence of the correct mix design of the concrete without accelerator.

If the user and the manufacturer are not identical, testing of the base concrete is obligatory.

To simplify subsequent conformity testing of wet mix, the compressive strength of sprayed concrete without accelerator tested on drilled cores can be compared with the cube compressive strength of the wet mix. The cubes are to be produced according to ÖNORM B 3303, It. 5.

This test is recommended, in particular, if moist mix is supplied from a ready-mix plant. In addition, the overall amount of water needs to be determined, e.g. through kiln-drying.

The strength of accelerator-free concrete established in the conformity test must at least be equal to the required strength class plus the accelerator-related loss of strength.

To assess the loss of strength due to the use accelerator, base concrete is also sprayed with the amount of water required for sprayed concrete production. If complete compacting is not possible, a suitable concrete plasticiser has to be used.

A comparison of sprayed concrete made with spray cement or plant-mixed dry mix with base concrete is not possible.

12.2.5 Testing for early shrinkage cracking

Fibre-reinforced concrete is tested according to the ÖVBB Guideline on fibre-reinforced concrete, It. 10.4.

12.2.6 Testing of dry mix (TM)

To assess the uniformity of the dry mix (e.g. ready-mixed products), the following parameters can be used:

- bulk density (ÖNORM EN 1097-3)
- grain size distribution up to 0.25 mm
- binder content in dry mix

The method used to determine these parameters needs to be specified (e.g. chemical determination through tracers).

The binder content can, at best, be determined to an accuracy of ± 10 kg/tonne of dry mix.

12.3 Testing of young sprayed concrete (early strength class)

Depending on the measuring range, procedures (see Fig. 12/3) according to It. 12.3.1 and 12.3.2 can be used for strength testing [12].

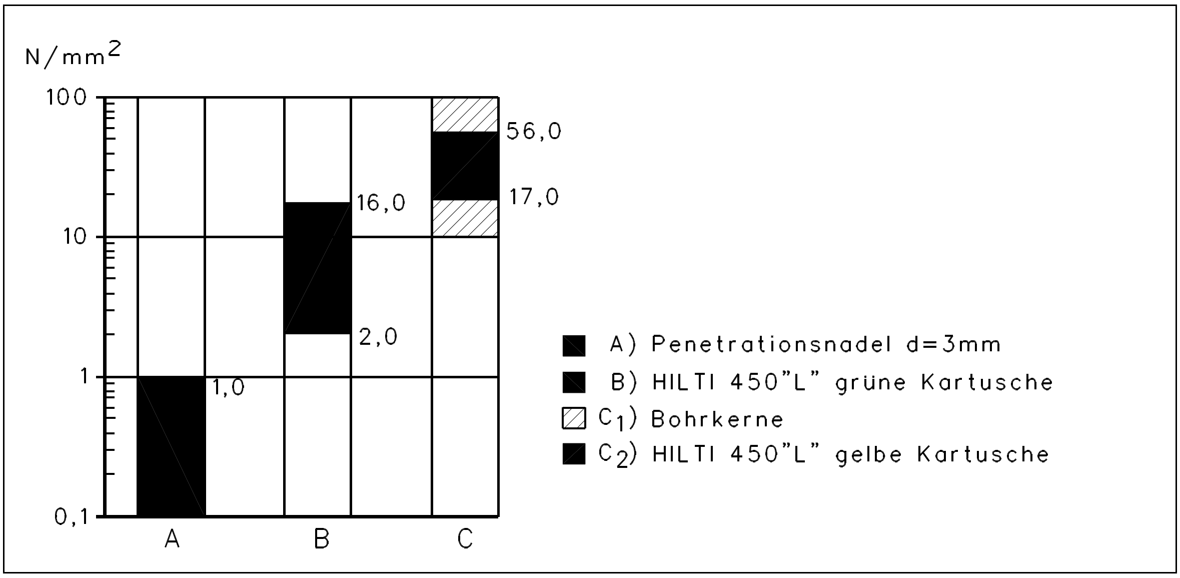


Fig. 12/3: Measuring procedures for the testing of fresh sprayed concrete

12.3.1 Penetration needle method (measuring range 0 to 1.0 MPa)

This method is used to measure the force required for a needle of specified dimensions to penetrate into sprayed concrete to a depth of 1.5 cm. A Proctor penetrometer[1)] according to ASTM C 403-95 is used for this purpose. The device indicates the resisting force through compression of a calibrated spring [12].

Description of equipment and test procedure:

a) Needle with a diameter of 3 mm and a tip with a taper angle of 60° for compressive strength determination up to 1.0 N/mm².

   The procedure has been calibrated for commonly used sprayed concrete grades according to this Guideline (see Fig. 12/4).

   In case of deviations, special calibration curves have to be established as follows:

   20 cm x 20 cm x 20 cm test specimens and 30 cm x 30 cm x 10 cm plates are produced for calibration. Simultaneous strength measurements have to be performed on the test specimens and the plates. The evaluation is made according to the rules of regression analysis.

b) *Instructions for testing and evaluation (Annex 3, Sheets 1 and 2):*

   - Apply device and impress to a depth of 15 mm in one go.
   - Read scale and record resisting force.
   - Perform at least 10 individual tests for each test sequence - take care not to impress the needle on a large aggregate grain.
   - Record testing time and location.

   Use the average of the measurements performed according to b) to derive the cube compressive strength from the calibration curve (Fig. 12/4). Extrapolations are not permissible.

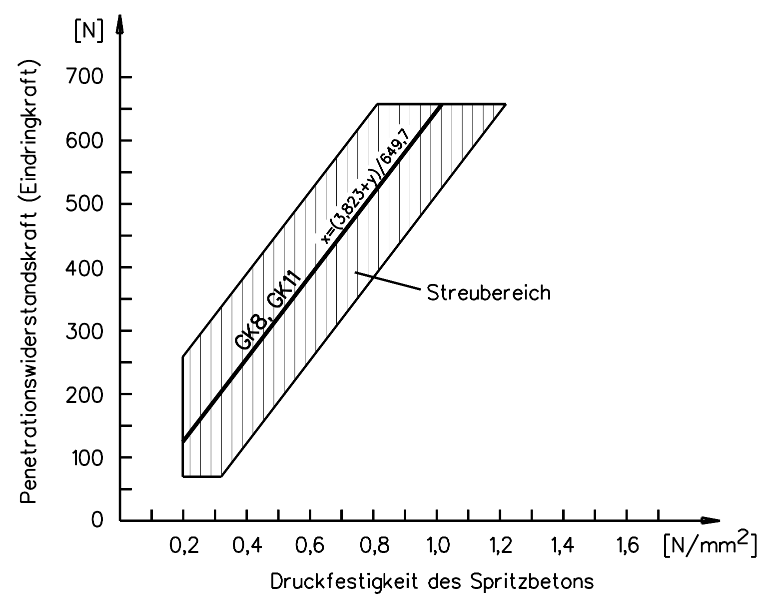


Fig. 12/4: Calibration curve for penetration needle device (needle diameter 3 mm)

1) List of suppliers available from ÖVBB

12.3.2 Bolt-driving method

12.3.2.1 Measuring range 2 to 16 N/mm² [13]

Stud-bolts are driven into the concrete and the depth of penetration is determined. Then the bolt screws are removed and the pull-out force is measured. The ratio of pull-out force to penetration depth is the parameter used to determine the compressive strength. A HILTI DX 450 L piston tool equipment unit with green cartridges is used to shoot the stud-bolts into the concrete (see Annex 3, Sheets 1 and 2).

The pull-out force is determined by means of a pull-out device (e.g. HILTI or ETIRIP). The procedure has been calibrated for commonly used sprayed concrete grades (Fig. 12/5a and 12/5b). In case of deviations - particularly as regards Mohs' hardness of aggregates - calibration has to be performed according to It. 12.3.1.

Instructions for testing and evaluation

- Load bolt screw and set the unit to power-setting position 1, Annex 3, Sheet 1.
- Apply the unit and shoot the bolts into the concrete, 10 individual tests for each test sequence.
- Measure and record the length of stud-bolts that did not penetrate into concrete.
- Determine penetration depth.
- Fasten nut and pull out the stud-bolts in the same order as shot.
- Record pull-out force, time and place of testing, correct force by means of calibration curve.
- Determine the ratio of pull-out force (P) to penetration depth (L).
- Establish individual P/L values.
- Establish cube compressive strength on the basis of the mean derived from the calibration curve according to Fig. 12/5a or 12/5b. Extrapolations are not permissible.

The procedure can be used for measurements at any location without advance preparations. Hence, the method is well suited for quality control measurements. With measuring points distributed over larger surfaces, fluctuations in concrete strength can be detected.

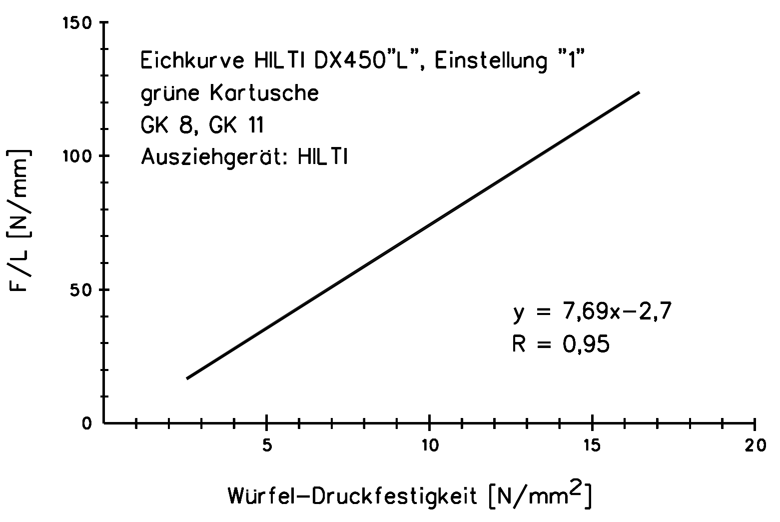


Fig. 12/5a: Calibration curve for bolt-driving method – measuring range 2 N/mm² to 16 N/mm², HILTI unit

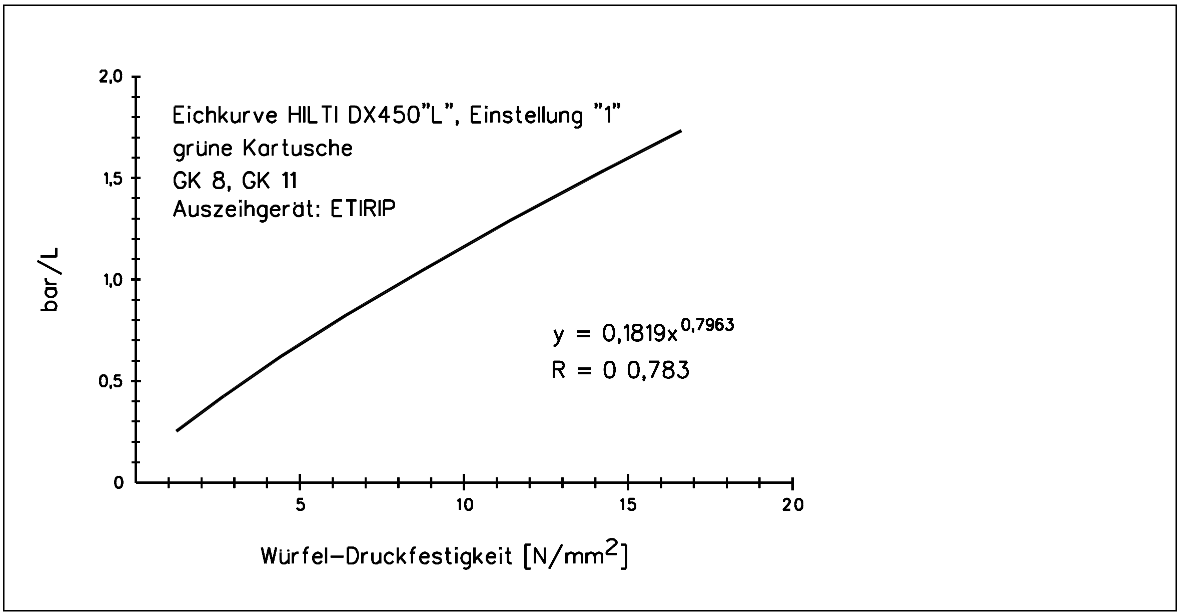


Fig. 12/5b: Calibration curve for bolt-driving method – measuring range 2 N/mm² - 16 N/mm², ETIRIP unit

12.3.2.2 Measuring range 17 to 56 N/mm² [14]

HILTI stud-bolts, type M6-8-52 D12 (60 mm) are shot into the concrete and the depth of penetration is determined. Then the stud-bolts are removed and the pull-out force is measured.

The ratio of pull-out force to penetration depth is the parameter used to determine the compressive strength. A HILTI DX 450 L piston tool equipment unit, set to position 2, with yellow cartridges is used to drive the bolt screws into the concrete (see Annex 3, Sheets 1 and 2). The pull-out force is determined by means of a pull-out tester (e.g. HILTI Tester 4). The procedure has been calibrated for commonly used sprayed concrete grades (Fig. 12/6); a multi-variant evaluation y = 44.297 + 0.057 x F/L – 1.546 x L improves the correlation to R = 8.24. In case of major deviations - particularly as regards Mohs' hardness of aggregates – a new reference line according to It. 12.3.1 has to be determined.

During preconstruction testing of the sprayed concrete, a reference test by means of the bolt-driving method is to be performed simultaneously with core testing (7, 28 or 56 days – at least two measurements). The ratio of mean compressive strength of core samples to the mean value of 10 F/L measurements is to be entered into the diagram with the reference line. The reference line is to be displaced in parallel until the relation between core compressive strength and the measured F/L values is established (calibration curve). In case of major deviations between the reference line and the averaging line, recalibration is necessary.

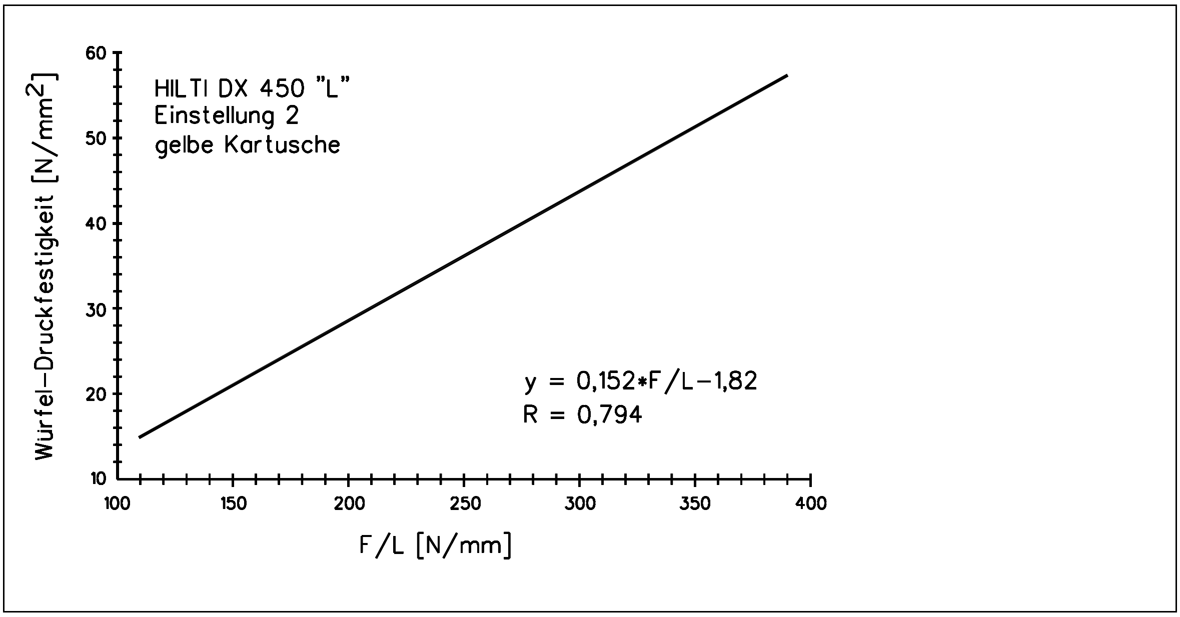


Fig. 12/6: Reference line for bolt-driving method, measuring range 17 N/mm² - 56 N/mm²

Instructions for testing and evaluation

- Load stud-bolts and set the unit to position 2, yellow cartridges.
- Apply the unit and place stud-bolts into the concrete, 10 individual tests for each test sequence.
- Measure and record the length of stud-bolts that did not penetrate into concrete and determine penetration depth.
- Fasten nut and pull out stud-bolts in the same order.
- Record pull-out force.
- Determine the ratio of pull-out force (F) to penetration depth (L).
- Establish averages and read core compressive strength from averaging line (instead of reference line).

12.4 Testing of sprayed concrete

12.4.1 Dimensions of test specimens and storage conditions

Cores of suitable dimensions (see Table 12/2) obtained either from placed sprayed concrete (sampling areas, structure) or from test panels are used as test specimens for sprayed concrete testing. Preference should be given to samples from placed sprayed concrete.

The tolerances must in accordance with ÖNORM B 3303, It. 5.2.

Table 12/2: Sample dimensions and storage conditions

	Core samples		**Storage conditions**
	Diameter	Height	see ÖNORM B 3303 It. 5.1.3
Compressive strength up to 20 days	100 mm	100 mm	Storage in water, air drying for 24 hours before testing
Compressive strength from 21 days onwards	100 mm	100 mm	Storage in water for 7 days, air drying until testing
Tensile splitting strength	100 mm	50 mm	Storage in water after drilling until testing
Water impermeability	150 mm	min. 120 mm	
Frost resistance	100 mm	250 mm	
Modulus of elasticity	100 mm	250 mm	
Adhesive tensile strength	50 mm	100 mm	
Leaching	50 mm	100 mm	Dry storage after drilling until testing
	Prisms		
Sulfate resistance	20 x 20 x 160 mm prisms		Storage in water after cutting until testing
Fibre-reinforced concrete class T or TG	150 x 150 x 500 mm prisms		
Fibre-reinforced concrete class E	600 x 600 x 100 mm plate		

Depending on the method of preparation and storage, the cores can be used for preconstruction, conformity, identity or hardening tests.

Samples taken from placed sprayed concrete with steel reinforcements may be unsuitable for testing (e.g. too high a percentage of reinforcing mesh, shading). Therefore, samples should be taken from different locations in the testing lot.

For sprayed concrete testing, sprayed concrete is produced in firmly secured panels in analogy to prEN 144888-1 (ca. 40 cm x 60 cm, 15 - 20 cm deep, open at the side facing downward). Cores can be taken from these boxes, though not from near the bottom edge (rebound), provided the strength of the concrete is sufficient for core drilling (at least 10 N/mm²). Prior to sampling, the boxes should remain undisturbed in a humid atmosphere at a temperature of between +5°C and +25°C.

Test cores for preconstruction and conformity testing have to be drilled not later than 5 days after shotcreting. Cores have to be drilled in time and as close to the intended time of testing as possible. As a rule, the direction of drilling is the same as the direction of spraying.

Testing for water impermeability (XC3/XC4) and frost resistance (XF3) is performed after 56 days.

12.4.2 Testing for compressive strength

Compressive strength testing is performed according to ÖNORM B 3303, It. 7.2. Contrary to the provisions of the standard, five samples have to be tested and aggregated. For sprayed concrete testing, individual values deviating from the mean by more than 20 % are not considered for averaging. At least three useful samples are required for averaging.

In the case of sprayed concrete made from ready-mix mortar with a maximum grain size of ≤ 4 mm, cores with a diameter of 50 mm can also be used.

12.4.3 Testing for tensile splitting strength

Testing for tensile splitting strength is performed on 5 cores according to ÖNORM B 3303, It. 7.2.

12.4.4 Testing for water impermeability

Testing for water impermeability is performed according to ÖNORM B 3303, It. 7.8. Five core samples have to be taken. Samples with obvious spraying defects have to be excluded. At least three samples must be subjected to testing.

12.4.5 Testing for frost resistance

Three cores, stored under the conditions specified in ÖNORM B 3303, It. 7.10, are tested for frost resistance. Prior to frost storage and after 25 and 56 frost-thaw cycles, the modulus of elasticity is determined according to ÖNORM B 3303, It. 7.7, under the following conditions other than those specified in the standard: $\sigma_u = 0.5$ MPa, σ_o at 0.2 ± 0.03 ‰ compressive strain.

12.4.6 Testing for modulus of elasticity

Modulus of elasticity testing is performed on 3 cores according to ÖNORM B 3303, It. 7.7.

12.4.7 Testing for sulfate resistance

12.4.7.1 Determination of sulfate resistance based on the constituent materials

Sprayed concrete may be considered sulfate-resistant, if it is produced according to class III as XC4 (maximum depth of penetration 30 mm) and if the constituent materials meet the following conditions:

Spray cement	C_3A of SBM (ÖNORM EN 196-2) < 1 wt.% according to Bogue SO_3 (ÖNORM EN 196-2) ≤ 4.8 wt.% Al_2O_3 (ÖNORM EN 196-21) < 4 wt.%
Cement	C_3A of clinker (ÖNORM EN 196-2) 0 wt.% according to Bogue C_3A of cement (ÖNORM EN 196-2) < 1 wt.% according to Bogue
Accelerator	Sulfate content as SO_3 in analogy to ÖNORM EN 196-2 ≤ 4.8 wt.% in total together with the cement and/or SBM used Al_2O_3 (water-soluble) according to It. 12.1.9 in wt.% x accelerator dose in wt.% of binder ≤ 115

12.4.7.2 Sulfate resistance testing of prisms

Spray cement, binder-accelerator combinations and sprayed concrete are tested for sulfate resistance in analogy to ÖNORM B 3309 according to the Graf-Kaufmann method through measurements of changes in length and through visual inspection of sprayed concrete samples stored in saturated gypsum solution.

Resistance to sea water is assessed through storage in synthetic sea water.

- *Preparation of samples*

  Samples can be taken from sprayed concrete test panels produced for this purpose or from structures. Prism-shaped test specimens, 20 mm x 20 mm x 160 mm, are to be cut from the samples obtained. A total of five samples are required.

- *Preparations for measurement*

  At sprayed concrete age 25 days:

  - Drill dia. 6 mm holes, centrally located in front faces of the prism.
  - Insert measuring cones and fasten them by means of suitable bonding agent.
  - Optionally, bonding of measuring cones to the surface is possible.
  - Store samples with measuring cones until age 28 days in water at 20 ± 2 °C.

- *Measurement*

  Principle: Measurement of change in length of prisms due to sulfate or sea-water attack according to Graf-Kaufmann.

  Depending on requirements, the change in length is determined after storage in:

  - saturated gypsum solution (Ca SO_4 x 2 H_2O) with sediment
  - synthetic sea water

  The zero-reading measurement of the prisms is performed after appropriate preparation of samples and storage in water for at least 24 hours.

  During sulfate attack, measurements are made after 4, 8, 12, 16, 20, 28, 40 and 52 weeks of storage. A preliminary assessment can be made after 12 weeks of storage. An interim result can be obtained after 28 weeks of storage.

  Changes in length are measured; moreover, the prisms are inspected for cracks, spalling, warping, segregation of aggregate, etc.

- *Storage in testing media*

  Storage at 20 ± 2°C

  Volumetric ratio of storage medium to test specimen ≥ 4/1.

  Three or five prisms are stored in each medium.

  Change of medium: once a month.

- *Preparation of testing media*

  a) Saturated gypsum solution:

  - Dissolve 2 g/l powdered $CaSO_4$. 2 H_2O through stirring in tap water at +30°C to +40 °C.
  - Allow to cool to +20° C.
  - Add 20g/l CaSO4 . 2 H_2O as sediment.
  - Place prisms in the medium after sedimentation.

  b) Synthetic sea water:

Composition:	solution in 1000 g water	
	NACl	30.0 g
	$MgCl_2 . 6H_2O$	6.0 g
	$MgSO_4 . H_2O$	5.0 g
	$CaSO_4 . 2H_2O$	1.5 g
	$KHCO_3$	0.2 g

- *Evaluation*

  Sulfate resistance is evaluated through visual inspection of the changes in surface quality of the specimen. Cracks, spalling, warping, segregation of aggregates, etc. must not be present. Currently, the change in length is determined for information only, but does not serve as a criterion for evaluation.

12.4.8 Determination of equivalent flexural strength and toughness

The special properties of fibre-reinforced sprayed concrete - high impact resistance, increased energy absorption capacity - are characterised through their performance in the bending test, in particular after the maximum flexural strength has been exceeded.

The test is performed in accordance with the ÖVBB Guideline on fibre-reinforced concrete, It. 10.5.

12.4.9 Panel test

- *Purpose*

  The "plate-bending" test serves to determine the energy absorption capacity, i.e. a function of ductility and concrete quality, of steel-fibre reinforced sprayed concrete. As a comparative test, it does not permit an accurate determination of material parameters, but adequately considers the three-dimensional effect of fibre-reinforcement.

- *Instructions for testing*

  - Preparation of test specimens and dimensions

    Prepare a sprayed concrete sample in a test panel, 60 cm x 70 cm x 10 cm, with side walls open at the bottom allowing the rebound to fall down.

    Number of test specimens required for each test: 3

  - Storage

    Store the test specimens according to It. 12.4.1 of this Guideline in the same manner as specimens for determination of the modulus of elasticity.

  - Preparation of test specimens for testing

    The test specimens are cut plane-parallel to the rough sprayed concrete face to a size of 60 cm x 60 cm x 10 cm and subsequently polished.

  - Performance of the test

    The test specimens are fully supported on a metal frame (UPB 140) and loaded at the centre on an area of 10 cm x 10 cm (see Fig. 12/7). The load is applied to the face which was originally rough from shotcreting.

  As a rule, the test is performed on test specimens aged 28 days.

  The load is applied by a deformation-controlled testing press at a deformation rate of 1.5 mm/min to a deflection of 25 mm.

  The force required for deformation is recorded continuously as a function of deflection with a measuring accuracy of ± 0.01 mm and/or ± 0.01 KN. The data are represented as a load-deformation curve. On the basis of this diagram, the energy-deformation curve is calculated and represented as the area between the X axis and the load-deformation curve (see Fig. 12/8).

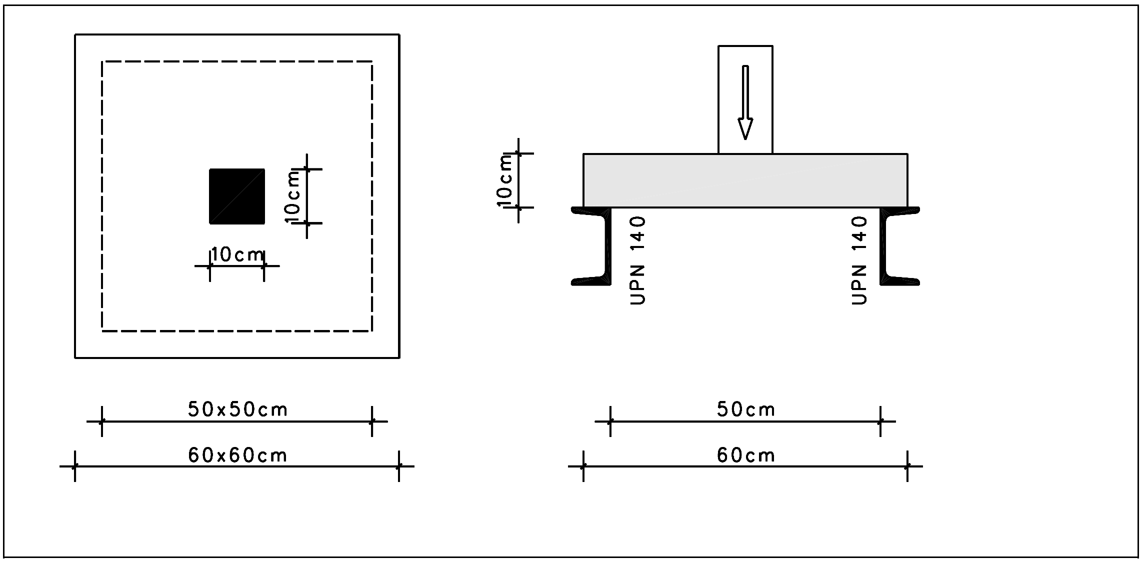


Fig. 12/7: Test specimens and test set-up for panel test

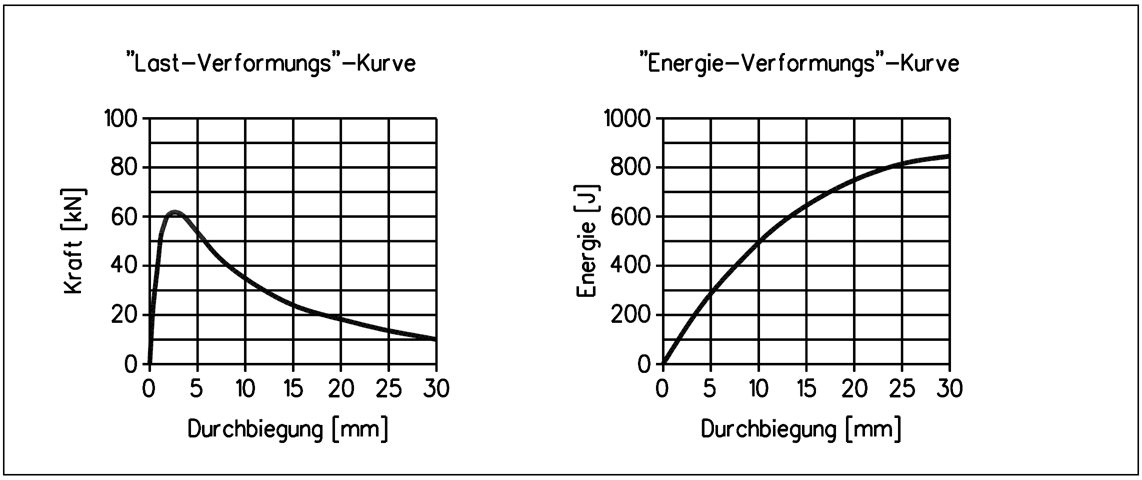


Fig. 12/8: Diagram of load-deformation and energy-deformation curves

12.4.10 Testing for increased fire resistance

Testing is performed according to the ÖVBB Guideline on sprayed concrete for inner linings, Annex 5. Sprayed concrete is placed on the substrate panel, aged 1 month, in the area to be exposed to fire. Further storage of one plate in wet condition and the second plate in dry condition for another month. In the contact layer 3 additional sensors are to be distributed over the surface exposed to fire.

12.4.11 Testing for tensile adhesive strength

Testing for tensile adhesive strength is performed according to ÖNORM EN 1542 for layers of newly placed sprayed concrete of up to 50 mm in thickness, and according to prEN 14488-4 for layers more of than 50 mm in thickness. The quality of the substrate prior to placing of sprayed concrete can be assessed on the basis of its adhesive strength according to ÖNORM B 3303, It. 7.5.

12.4.12 Leaching of sprayed concrete

Elution of sprayed concrete is to be performed on cores aged 28 days, 50 mm in diameter and 100 mm high [1, 2, 3]. The cores have to be obtained from sprayed concrete aged 7 to 14 days through wet drilling. The cores thus obtained are to be stored dry and at room temperature until testing.

The test specimen is to be placed in a leaching vessel and eluted in a leaching agent, which is continuously agitated by a magnetic stirrer (rate of agitation = 200 to 300 rev/min), for 24 hours. The eluant used is de-ionised water, the mass ratio of test specimen to eluant being 1 : 10, with the test specimen completely wetted. The leachate is to be examined for the following parameters: pH value, electric conductivity, calcium, potassium, sodium and aluminium.

12.5 Checks to be performed during sprayed concrete production

12.5.1 Verification of dosages of powder and liquid accelerator and spray cement

The dosage of the accelerator and/or the spray cement has a decisive influence on the early and final strength of the sprayed concrete. Compliance with the dosages determined through preconstruction testing has to be verified continuously during shotcreting. Regular maintenance of the metering equipment has to be performed and recorded in a protocol. In addition, the spraying output has to be determined according to It. 12.5.2.

- *Inspection of the metering equipment for powder accelerators*

  Basically, the correct dosages are verified through weighing. Attention has to be paid to continuous, steady conveyance and, possibly, wear and tear of the metering equipment. Bridge formation in the storage bin and strong fluctuations of filling levels are to be avoided. The calibration intervals according to Table 11/5 have to be observed.

- *Inspection of metering equipment for liquid accelerators*

  Dosage accuracy is checked through weighing of the accelerator bin before and after shotcreting. If a flow meter is connected, accelerator consumption can be recorded continuously over time. The values set at the metering pump have to be checked each time before shotcreting is begun. The calibration intervals according to Table 11/5 have to be observed.

- *Inspection of metering equipment for spray cement SBM-FT (continuous mixing)*

  Calibration of dosages is performed through back-weighing over defined time intervals. Speed and/or weighing protocols are kept to supplement the calibration test. The calibration intervals according to Table 11/5 have to be observed.

- *Inspection of metering equipment for mineral aggregates (continuous mixing)*

  A high degree of measuring accuracy is also required for moist mineral aggregates. Metering can be gravity-based or volume-based. In the case of volume-based metering, possible changes in bulk volume due to different degrees of aggregate moisture should be taken into consideration. Hence, calibration is absolutely necessary. Any change of conditions requires renewed determination of the moisture content. Back-weighing at regular intervals is to be performed according to Table 11/5.

12.5.2 Determination of spraying output and rebound

Before the test is carried out, the spraying output needs to be accurately established, as it affects the accuracy of rebound determination. The quantity of rebound is to be determined separately.

- *Determination of spraying output*

  The total amount of sprayed concrete discharged from the nozzle during a certain period of time (spraying time) is determined through weighing.

  $$\text{Spraying output (kg/h)} = \frac{\text{mass}_{\text{shotcrete}}\ [\text{kg}]}{\text{spraying time [h]}}$$

  It is also possible to spray a weighed amount of mix and to record the time taken for spraying. The amount of water consumed at the nozzle has to be added to the mass of the mix.

- *Determination of rebound*

  A time-consuming, but accurate method consists in collecting the rebound on a tarp spread out before shotcreting, storing it in a suitable container and weighing it. If the spraying time and the rebound mass (converted into kg/h) are known, the percentage of rebound relative to the initial mass can be calculated as follows:

  $$\text{Rebound [\%]} = \frac{\text{Mass}_{\text{rebound}}\ [\text{kg / h}]}{\text{sprayingoutput [kg / h]}}$$

  For rebound measurements to be performed on a laboratory scale, sprayed concrete is applied to wooden formwork prepared with a layer of sealing sprayed concrete (size of formwork depending on weighing unit); the rebound is collected on a tarp and weighed. The concrete mass is calculated by deducting the formwork mass from the (sprayed concrete + formwork) mass. The rebound is obtained as

  $$\text{Rebound [\%]} = \frac{\text{Mass}_{\text{rebound}}[\text{kg}]}{\text{Mass}_{\text{shotcrete}}[\text{kg}] + \text{mass}_{\text{rebound}}\ [\text{kg}]} \times 100$$

- *Process parameters*

  The following factors have to be considered for rebound determination:

  - spraying output
  - process technology
  - conveying pressure
  - spraying angle and distance from substrate
  - sprayed concrete thickness
  - fresh concrete temperature
  - spraying time
  - fluctuations of water flow and pressure at the nozzle
  - water-binder ratio
  - spraying nozzle cross section
  - location of substrate (benches, roof, entire round)
  - building-site or laboratory measurement

12.5.3 Measurement of fine dust concentration

Gravity-based dust measuring devices as well as light-scattering instruments are best suited to determine the concentration of fine dust. For practical purposes, a simple and safe method (preferably with direct display of results without time lag) is recommended. Light-scattering instruments[1)] meet these requirements. Conversion of the values displayed into fine-dust concentrations obtained by gravity-based methods (e.g. PM 4F, VC 25, PAS, etc.) is possible by approximation through $c/l_{\text{reading TM}}$ = 1.1 for sprayed concrete and 1.5 for other activities (especially in the case of a diesel-fuelled vehicle fleet). (Accurate measurements by the Austrian Dust Control Body [4, 5], see Annex 5, sheet 1 and 2).

12.5.4 Sprayed concrete thickness

The sprayed concrete thickness is defined by the average thickness to be obtained (mean value of five measurements) and a minimum thickness for each structural component.

The average thickness derived from five drillings has to be reached. Sprayed concrete thickness must not be below the minimum thickness at any place.

The sprayed concrete thickness has to be determined five times each over 500 m² (at defined randomly distributed points) either during shotcreting on defined structural components or through drilling.

12.6 Fibre content of steel-fibre sprayed concrete

The fibre content in sprayed concrete can be determined immediately after placing or through core sampling according to the ÖVBB Guideline on fibre-reinforced concrete, It. 10.3.

- *Sampling immediately after placing:*
  - Quick drying of sample (minimum sample quantity 10 kg) by means of spirit method
  - Crushing of coherent sprayed concrete particles
  - Removal of fibres by means of hand magnet
  - Weighing
- *Core drilling*
- Drilling of 5 cores, dia. 100 mm, height ca. 100 mm
- Weighing of cores
  - "Crushing" of sample by means of test machine
  - Further manual and mechanical comminution
  - Removal of fibres by means of hand magnet
  - Weighing (errors due to "cut-off" fibre particles)

The fibre content (st) in wt. % is as follows:

$$\text{St (wt. \%)} = \frac{\text{Mass}_{\text{steel fibre}}\,[\text{g}]}{(\text{Mass}_{\text{shotcrete}} - \text{Mass}_{\text{steel fibre}})\,[\text{g}]}$$

The fibre content is to be indicated to an accuracy of 0.1 wt.%. As a rule, the fibre content of the placed sprayed concrete equals roughly 70 % of the fibre content of the initial mix.

1) List of suppliers available from ÖVBB

12.7 Documentation of mix production

As a rule, concreting statistics and batch protocols have to be printed out daily for each sprayed concrete grade. Access to other batch protocols, by numbers of delivery notes, must be possible for up to 3 years after production. (Usually, batch protocols are not available online.)

13. QUALITY MANAGEMENT

Quality Management scheme for sprayed concrete production

Over and above the general, site-specific quality-management schedule, the following measures, as listed in Table 13/1 and Table 13/2, are recommended for sprayed concrete production in the course of production control.

Table 13/1: Quality management for sprayed concrete production

QM measures before shotcreting	
Activity	Relevant documentation
Establish requirements to be met by sprayed concrete	Conformity according to contract
Determine spraying method and type of mix	see Table 5/1
Constituent material and preconstruction testing	see Tables 11/1/1 and 11/1/2
Decide on responsibility for execution	Organisation chart – mailing list for documents and records Agreement on division of responsibilities between producer and user
Maintenance	Establish maintenance schedule
Test schedule	see Tables 11/2/1 to 11/2/5
Select test equipment and decide on test methods	Test instructions Test records

Table 13/2: Quality management for sprayed concrete production

QM measures during shotcreting	
Activity	Relevant documentation
Machine and nozzle operation	Suitable staff
Ensure occupational health and safety	Process instructions by health and safety officer
Execution and acceptance testing	Comparison of actual conditions with contract specifications
Non-compliance with parameters specified	Catalogue of measures according to contract

14. RECOMMENDATIONS FOR TENDERING

The relevant Austrian Standards, in particular ÖNORM B 2203 and/or ÖNORM B 2203-2 and prior art, apply.

14.1 General requirements

The following requirements have to be included, among others, in the invitation to tender and taken into consideration under the corresponding items of the specifications.

- Filling of unavoidable (process-related) overbreak with sprayed concrete and operational impairment due to shotcreting of system-related steel inserts (reinforcing mesh, steel arches, lagging plates, anchor heads, etc.).
- Sprayed concrete to fill up overbreak due to specifications or geological conditions.
- Repair of defects in sprayed concrete with structural functions (SpC III), except for system-related local deficiencies and inhomogeneities in SpC II.

As a matter of principle, it is up to the contractor (user of sprayed concrete) to decide whether to use the dry-mix or wet-mix shotcreting method.

14.2 Contractual provisions

Among others, the following items have to be included in the contract:

- Early strength classes
- Requirements to be met by the sprayed concrete (sprayed concrete grade, with specification of exposure classes)
- Agreement on testing frequency classes and/or exceptions
- Assumption of costs of preconstruction, conformity, identity and structural testing
- Sprayed concrete thickness has to be specified through indication of average thickness and minimum thickness, see It. 12.5.4.
- Minimum thickness has to be specified with due consideration of the surface structure to be expected (e.g. projecting edges of solid rock)
- Provisions regarding possible quality defects and inadequate thickness
- Specification of requirements regarding the smoothness of the sprayed concrete surface
- Definition of surfaces and cubatures to be used as a basis for payment
- Indications regarding the location of shotcreting and possible operating conditions (e.g. working face, roof, floor, slope support, water ingress)
- Specification of unit of measurement (m^2 or m^3)
- Special testing procedures
- Tests according to Tables 11/2/1 to 11/2/5 "according to requirements"
- Specification of test methods for the determination of strength classes within the framework of quality testing (e.g. admissibility of test procedure according to It. 7.4)

15. STANDARDS, GUIDELINES, BIBLIOGRAPHY

15.1 Standards referred to in the text

ÖNORM B 2203-1	Untertagebauarbeiten – Werkvertragsnorm – Teil 1: Zyklischer Vortrieb; Ausgabe 12/01.
ÖNORM B 2203-2	Untertagebauarbeiten – Werkvertragsnorm – Teil 2: Kontinuierlicher Vortrieb; (in Vorbereitung).
ÖNORM B 3131	Gesteinskörnungen für Beton – Regeln zur Umsetzung von EN 12620; Ausgabe 06/03.
ÖNORM B 3303	Betonprüfung; Ausgabe 09/02.
ÖNORM B 3309	Aufbereitete hydraulisch wirksamer Zusatzstoffe für die Betonherstellung; Ausgabe 09/99.
ÖNORM B 3310	Zement für Bauzwecke; Ausgabe 09/95.
ÖNORM B 3327-1	Zemente gemäß ÖNORM EN 197-1 für besondere Verwendungen - Teil 1: Zusätzliche Anforderungen; Ausgabe 01/02.
ÖNORM B 4700	Stahlbetontragwerke – EUROCODE-nahe Berechnung, Bemessung und konstruktive Durchbildung; Ausgabe 06/01.
ÖNORM B 4710-1	Beton; Teil 1: Festlegung, Herstellung, Verwendung und Konformitätsnachweis (Regeln zur Umsetzung der ÖNORM EN 206-1); Ausgabe 04/04.
ÖNORM EN 149	Atemschutzgeräte – Filtrierende Halbmasken zum Schutz gegen Partikeln – Anforderungen, Prüfung, Kennzeichnung; Ausgabe 12/91.
ÖNORM EN 196-1	Prüfverfahren für Zement – Bestimmung der Festigkeit; Ausgabe 07/95.
ÖNORM EN 196-2	Prüfverfahren für Zement – Chemische Analyse von Zement; Ausgabe 07/95.
ÖNORM EN 196-3	Prüfverfahren für Zement – Bestimmung der Erstarrungszeiten und der Raumbeständigkeit; Ausgabe 07/95.
ÖNORM EN 196-7	Prüfverfahren für Zement – Verfahren für die Probenahme und Probeauswahl von Zement; Ausgabe 05/92.
ÖNORM EN 196-21	Prüfverfahren für Zement – Bestimmung des Chlorid-, Kohlenstoff-, Dioxid- und Alkalianteils von Zement; Ausgabe 05/92.
ÖNORM EN 197-1	Zement – Teil 1: Zusammensetzung, Anforderungen und Konformitätskriterien von Normalzement; Ausgabe 12/00.
ÖNORM EN 450	Flugasche für Beton – Definitionen, Anforderungen und Güteüberwachung; Ausgabe 09/95.
ÖNORM EN 459-2	Baukalk – Teil 2: Prüfverfahren; Ausgabe 02/03.
ÖNORM EN 480-1	Zusatzmittel für Beton, Mörtel und Einpressmörtel – Prüfverfahren – Teil 1: Referenzbeton und Referenzmörtel für Prüfungen; Ausgabe 01/98.
ÖNORM EN 480-2	Zusatzmittel für Beton, Mörtel und Einpressmörtel – Prüfverfahren – Teil 2: Bestimmung der Erstarrungszeit; Ausgabe 12/96.
ÖNORM EN 480-6	Zusatzmittel für Beton, Mörtel und Einpressmörtel – Prüfverfahren –Teil 6: Infrarot-Untersuchung; Ausgabe 12/96.
ÖNORM EN 480-8	Zusatzmittel für Beton, Mörtel und Einpressmörtel – Prüfverfahren - Teil 8: Bestimmung des Feststoffgehaltes; Ausgabe 12/96.

ÖNORM EN 480-10	Zusatzmittel für Beton, Mörtel und Einpressmörtel –Prüfverfahren - Teil 10: Bestimmung des wasserlöslichen Chloridgehaltes; Ausgabe 12/96.
ÖNORM EN 480-12	Zusatzmittel für Beton, Mörtel und Einpressmörtel – Prüfverfahren – Teil 12: Bestimmung des Alkaligehaltes von Zusatzstoffen; Ausgabe 01/98.
ÖNORM EN 932-1	Prüfverfahren für allgemeine Eigenschaften von Gesteinskörnungen – Teil 1: Probenahmeverfahren; Ausgabe 01/97.
ÖNORM EN 933-1	Prüfverfahren für geometrische Eigenschaften von Gesteinskörnungen – Teil1: Bestimmung der Korngrößenverteilung – Siebverfahren; Ausgabe 12/97.
ÖNORM EN 934-2	Zusatzmittel für Beton, Mörtel und Einpressmörtel – Teil 2:Betozusatzmittel – Definitionen und Anforderungen; Ausgabe 02/02.
ÖNORM EN 934-5	Zusatzmittel für Beton, Mörtel und Einpressmörtel – Teil5: Zusatzmittel für Spritzbeton – Definitionen, Anforderungen und Konformitätskriterien; Entwurf 09/03.
ÖNORM EN 1008	Zugabewasser für Beton – Anforderungen und Prüfung; Ausgabe 05/93.
ÖNORM EN 1097-3	Prüfverfahren für mechanische und physikalische Eigenschaften von Gesteinskörnungen – Teil 3: Bestimmung von Schüttdichte und Hohlraumgehalt; Ausgabe 08/98.
ÖNORM EN 1542	Produkte und Systeme für den Schutz und die Instandsetzung von Betontragwerken – Messung der Haftfestigkeit im Abreißversuch; Ausgabe 09/99.
ÖNORM EN 12350-5	Prüfung von Frischbeton – Teil 5: Ausbreitmaß; Ausgabe 04/00.
ÖNORM EN 12390-3	Prüfung von Festbeton – Teil 3: Druckfestigkeit von Probekörpern; Ausgabe 05/02.
ÖNORM EN 12504-1	Prüfung von Beton in Bauwerken –Teil 1: Bohrkernproben – Herstellung, Untersuchung und Prüfung der Druckfestigkeit; Ausgabe 09/90.
ÖNORM EN 12620	Gesteinskörnungen für Beton; Ausgabe 03/03.
ÖNORM EN 13263	Silikatstaub für Beton – Definitionen, Anforderungen und Konformitätsnachweis; Ausgabe 08/98.
prEN 14487-1	Spitzbeton – Teil 1: Definitionen, Anforderungen und Konformität; Ausgabe 09/02.
prEN 14488-1	Prüfung von Spritzbeton: Probenahmen Ausgabe 06/02.
ASTM C 227-81	Prüfung der potentiellen Alkaliempfindlichkeit von Zementzuschlagsgemischen an Mörtelprobekörpern; Ausgabe 1990.
ASTM C 289-97	Standard Test Method for Pontential Reactivity of Aggregates (Chemical Method); Ausgabe 1997.
ASTM C 403-95	Ermittlung der Erstarrungsgeschwindigkeit von Betonmischen durch Prüfung des Eindringwiderstandes; Ausgabe 1995.
DIN 51302-1	Werkstoffprüfmaschinen - Teil 1: Prüfung von Zug-, Druck- und Biegeprüfmaschinen – Grundsätzliche Prüfbedingungen; Ausgabe 03/85.
ISO 758	Liquid chemical products for industrial use. Determination of densitiy at 20 °C.
ISO 1158	Plastics – Vinyl chloride homopolymers and copolymers – Determination of chloride.
ISO 4316	Surface active agents – Determination of pH of aqueous solutions – Potentiometric method.

15.2 Guidelines and regulations

Austrian Association for Concrete and Structural Engineering

ÖVBB – Richtlinie	Herstellung und Verarbeitung von Fließbeton; Ausgabe 1977.
ÖVBB – Richtlinie	Herstellung und Prüfung von Beton mit LPV-Zusatzmittel; Ausgabe 1988.
ÖVBB – Richtlinie	Frost-Tausalz-beständiger Beton; Ausgabe 1989.
ÖVBB – Richtlinie	Innenschalenbeton; Ausgabe 10/03.
ÖVBB – Richtlinie	Faserbeton; Ausgabe 03/02
ÖVBB – Richtlinie	Erhaltung und Instandsetzung von Bauten aus Beton und Stahlbeton; Ausgabe 12/03.

Austrian Standards Institute

ÖN – NP 10	ON Handbuch: Zusammenstellung der Prüfverfahren (PVB) gemäß ÖNORM B 3303; Ausgabe 10/02.

Austrian Road and Transport Research Society

RVS 7 TU	Leistungsbeschreibung Tunnelbau.
RVS 8 TU	Technische Vertragsbedingungen für Tunnelbau.
RVS 8.01.71	Betonzusätze - Luftporenbildende Betonzusatzmittel; Ausgabe 05/89.
RVS 9.32	Statisch konstruktive Richtlinien - Geschlossene Bauweise im Lockergestein unter Bebauung; Ausgabe 05/04.
RVS 9.35	Merkblatt - Betondeckung der Stahleinlagen; Ausgabe 06/02.
RVS 11.064	Prüfverfahren – Beton Teil I bis III; Ausgabe 09/84 bis 12/85.
RVS 12.241	Bauprodukte und Bauleistungen; Beton; Qualitätssicherung gemäß ÖNORM B 4710-1; Ausgabe 12/01.

German Reinforced Concrete Comittee

DAfStb-Richtlinie	Vorbeugende Maßnahmen gegen schädliche Alkalireaktion im Beton (Alkali-Richtlinie); Ausgabe 05/01.
DAfStb-Richtlinie	Richtlinie für hochfesten Beton; Ausgabe 95.

German Association of Concrete and Structural Engineering

DBV-Merkblatt	Bemessungsgrundlage für Stahlfaserbeton im Tunnelbau; Ausgabe 96.
DBV-Merkblatt	Technologie des Stahlfaserbetons und Stahlfaserspritzbetons; Ausgabe 96.
DBV-Merkblatt	Stahlfaserbeton; Ausgabe 10/02.
DBV-Merkblatt	Kunststoffmodifizierter Spritzbeton/Spritzmörtel; Ausgabe 96.
DBV-Merkblatt	Technische Lieferbedingungen für Kunststoffe für Spritzbeton/Spritzmörtel; Ausgabe 96.

Other publications

EFNARC	European Specification for Sprayed Concrete. Europäischer Verband der Hersteller und Anwender von Spezialprodukten im Bauwesen. Hampshire 1996.
JSCE-SF4	Method of Test for Flexural Strength and Flexural Toughness of Steel Fibre Reinfored Concrete. Concrete Library of JSCE, Japan Society of Civil Engineers, 3, 58-61. 1984.

15.3 Additional standards, guidelines and reports to be taken into consideration

ÖNORM B 3324-1	Baukalk – Einteilung, Anforderungen und Gütesicherung; Ausgabe 04/95.
ÖNORM B 3327-2	Zemente gemäß ÖNORM EN 197-1 für besondere Verwendungen – Erhöht sulfatbeständige Zemente; Ausgabe 04/01.
ÖNORM B 5017	Hochleistungsbeton im Siedlungswasserbau (HL-SW-Beton) Herstellung, Verwendung und Gütenachweis; Ausgabe 10/00.
ÖNORM EN 196-61	Prüfverfahren für Zement – Bestimmung der Mahlfeinheit; Ausgabe 05/92.
ÖNORM EN 197-2	Zement – Teil2: Konformitätsbewertung, Ausgabe 12/00.
ÖNORM EN 206-1	Beton – Teil 1: Festlegung, Eigenschaften, Herstellung und Konformität; Ausgabe 05/01.
ÖNORM EN 933-2	Prüfverfahren für geometrische Eigenschaften von Gesteinskörnungen – Teil 2: Bestimmung der Korngrößenverteilung – Analysen - Siebe; Ausgabe 03/96.
ÖNORM EN 933-4	Prüfverfahren für geometrische Eigenschaften von Gesteinskörnungen – Teil 4: Bestimmung der Kornform – Kornformkennzahl; Ausgabe 04/00.
ÖNORM EN 934-3	Zusatzmittel für Beton, Mörtel und Einpressmörtel – Teil 3: Zusatmittel für Mauermittel – Definitionen, Anforderungen und Konformität; Ausgabe 10/98.
ÖNORM EN 934-4	Zusatzmittel für Beton, Mörtel und Einpressmörtel – Teil 4: Zusatmittel für Einpressmörtel für Spannglieder – Definitionen, Anforderungen und Konformität; Ausgabe 07/00.
ÖNORM EN 934-6	Zusatzmittel für Beton, Mörtel und Einpressmörtel – Teil 6: Probenahme, Konformitätskontrolle, Bewertung der Konformität, Kennzeichnung und Beschriftung; Ausgabe 07/00.
ÖNORM EN 1367-1	Prüfverfahren für thermische Eigenschaften und Verwitterungsbeständigkeit von Gesteinskörnungen – Teil 1: Bestimmung des Widerstandes gegen Frost-Tau-Wechsel; Ausgabe 05/00.
ÖNORM EN 12350-1	Frischbeton – Teil 1: Probenahme; Ausgabe 04/00.
ÖNORM EN 12350-6	Prüfung von Frischbeton – Teil 6: Frischbeton-Rohdichte; Ausgabe 04/00.
ÖNORM EN 12350-7	Prüfung von Frischbeton – Teil 7: Luftgehalte – Druckverfahren; Ausgabe 10/00.
ÖNORM EN 12390-1	Prüfung von Festbeton – Teil 1: Form, Maße und andere Anforderungen für Probekörper und Formen; Ausgabe 05/01.
ÖNORM EN 12390-2	Prüfung von Festbeton – Teil 2: Herstellung und Lagerung von Probekörpern für Festigkeitsprüfungen; Ausgabe 05/01.
ÖNORM EN 12390-7	Prüfung von Festbeton – Teil 7: Dichte von Festbeton; Ausgabe 05/01.
ÖNORM EN 12636	Produkte für den Schutz und die Instandsetzung von Betontragwerken – Prüfverfahren – Bestimmung der Verbundwirkung - Beton-Beton; Ausgabe 09/99.

ÖNORM EN 12620	Gesteinskörnungen für Beton; Ausgabe 03/03
ÖNORM EN 13501-1	Klassifizierung von Bauprodukten und Bauarten zu ihrem Brandverhalten – Teil 1: Klassifizierung mit den Ergebnissen aus den Prüfungen zum Brandverhalten von Bauprodukten; Ausgabe 06/02.
ÖNORM EN 13501-2	Klassifizierung von Bauprodukten und Bauarten zu ihrem Brandverhalten – Teil 2: Klassifizierung mit den Ergebnissen aus den Feuerwiderstandsprüfungen, mit Ausnahme von Lüftungsanlagen; Ausgabe 01/04.
prEN 14487-2	Spritzbeton (Ausführung) Arbeitspapier N 85; Ausgabe 02/00.
prEN 14651	Precast concrete products-Test method for metallic fibre concrete – Measuring the flexural tensile strength; Ausgabe 03/03.
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prEN 12488-3	Prüfung von Spritzbeton: Biegefestigkeit.
prEN 14488-4	Prüfung von Spritzbeton: Verbundfestigkeit.
prEN 12488-5	Prüfung von Spritzbeton: Determination of energy absorptioncapacity of fibre reinforced slab; Ausgabe 11/02.
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ÖNORM/ÖVE-EN 45002	Allgemeine Kriterien zum Begutachten von Prüflaboratorien; Ausgabe 06/90.
ÖNORM/ÖVE EN 45003	Akkreditierungssysteme für Kalibrier- und Prüflaboratorien - Allgemeine Anforderungen für Betrieb und Anerkennung; Ausgabe 09/95.
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LIST OF ANNEXES

ANNEX 1

Standard form "Designation of samples"

Baustelle: ....
Probenbezeichnung: ....
Produktbezeichnung:
Produktbezeichnung: .... Chargennr.: .... Lieferscheinnr.: .... Hersteller bzw. Lieferant: ....
Datum der Produktlieferung: .... Entnahmedatum: .... Entnahmezeit: .... Entnahmeort: .... Art der Probenentnahme: .... Aufzubewahren bis ....
Angelieferte Menge: ....
Art der Anlieferung: ❍ Silo ❍ Sack ❍ Tank ❍ Fass
Entnommen von: ....
Datum: .... Unterschrift Probennehmer: .... Unterschrift Werks- oder Baustellenvertreter: ....

ANNEX 2

Penetration needle test – Test protocol

Penetrationsnadelverfahren

Nr.:	Datum:	Stollen/Tunnel:
	T-Luft:	Station:
	T-Mischgut:	Lage:
	Bindemittel:	Gesteinskörnung:
	EB:	Bearbeitet:
	SBM:	

☐ Ende der Spritzarbeit

Nadel ∅ 3 mm, Spitze unter 60° geneigt

Zeit	SpC-Alter	Eindringkraft	Mittelwert	fc [N/mm²]
		10 Messungen		aus Eichkurve

ANNEX 3 / SHEET 1

Bolt-driving method – Test protocol

Bolzensetzverfahren: HILTI DX 450 "L" , Einstellung "1", grüne Kartuschen

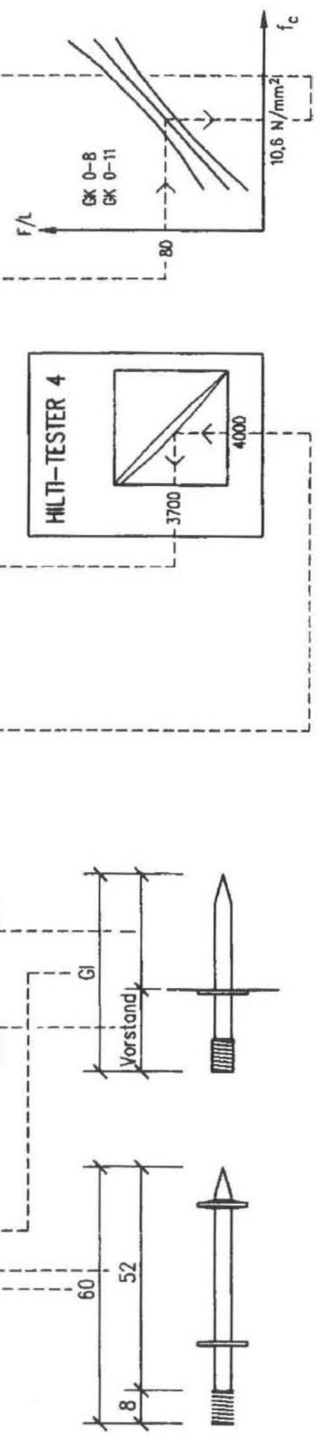
Nr.: 1 | Stollen/Tunnel: *Beispiel* | Lage: *Strosse* | Zement: *TZ 2* | EB: *Typ 1*

Datum: *19.2.* | Station: *km 3.24* | Bearbeitet: | Zuschlag: *0–11* | Temp.: *16 °C*

1	2	3	4	5	6	7	8	9	10
Zeit t [h]	SpB Alter [h, min]	Bolzen Typ/GL	Vorstand [mm]	Eindringtiefe L [mm]	Ausziehkraft F [N]	korr. F [N]	F/L [N/mm]	$\overline{x}$ [N/mm]	f_c [N/mm²]
	$1 - t_0$			3 – 4		aus Eichkurve	7 / 5	$\frac{\Sigma 8}{n}$	mit 9 aus Eichkurve
11:30	0	*Feld 25*	*fertig*	*gleiche Reihenfolge einhalten!*					
am 20.2. um 4:30	17 Std.	M6 – 8 – 52 Gl = 60	25 18 23 18 20 20 17 12	35 42 37 42 40 40 43 48	3400 3700 3100 3900 3800 3500 3100 4000	3100 3400 2800 3600 3500 3200 2800 3700	$\frac{3100}{35}$ = 88,57 80,95 75,68 85,71 87,50 80,00 65,12 77,08	80,08	10,6

$\boxed{60}$ abzüglich $\boxed{12}$ ergibt $\boxed{48}$

$\frac{88{,}57+80{,}95+\ldots\ldots}{8} = \boxed{80}$



ANNEX 3/SHEET 2

Bolt-driving method – Test protocol

Bolzensetzverfahren: HILTI DX 450 "L" mit Kolben 45/NKL

Kolbenführung 45/KFL, Bolzenführung 45/FL1 und Standplatte 45/SL1, Einstellung "1", grüne Kartusche 6.8/11 MGR.

Nr.:	Stollen/Tunnel:	Lage:	Bindemittel:	EB:
Datum:	Station:	Bearbeitet:	Gesteinskörnung:	Temp.:

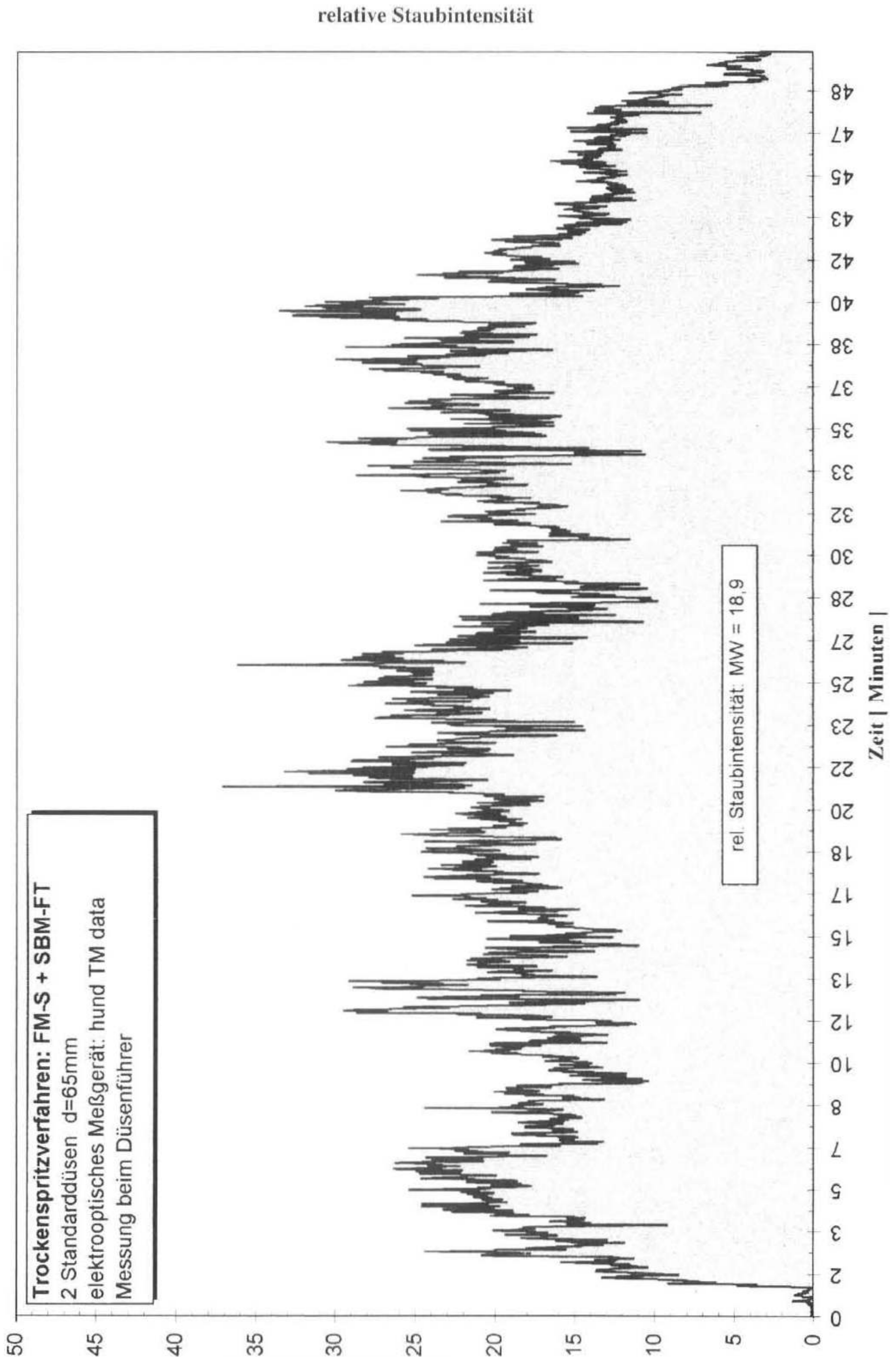
1	2	3	4	5	6	7	8	9	10
Zeit t [h]	SpC-Alter [h, min]	Bolzen Typ/GL	Vorstand [mm]	Eindringtiefe L [mm]	Ausziehkraft F [N]	korr. F [N]	F/L [N/mm]	x [N/mm]	f_c [N/mm²]
	1 – t_0			3 – 4		aus Eichkurve	7 / 5	$\frac{\Sigma 8}{n}$	mit 9 aus Eichkurve

ANNEX 3/SHEET 2

Example: electro-optical dust meter: hund TM data

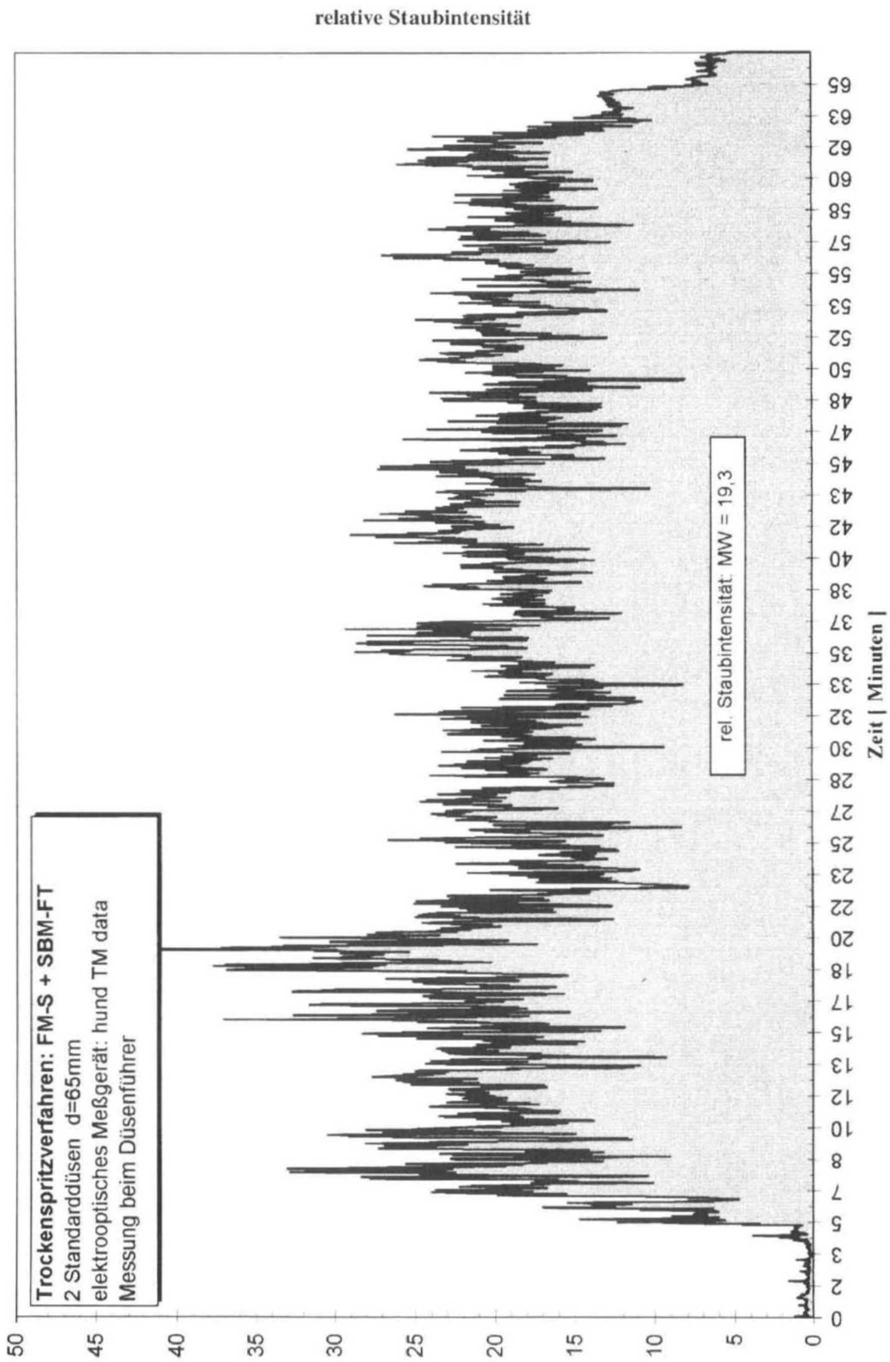
Dry shotcreting method (FM-S + SBM-FT), 3.3 % moist aggregate, 2 standard nozzles ∅ 65 mm, ejection pressure 2.5 bar, output 2 x 4.21 m³/h, excavated cross section 55 m², crown heading, blowing ventilation.

Nozzle operator applying first layer of sprayed concrete: 0.8 hours



ANNEX 4/SHEET 2

Nozzle operators performing other activities:	4.8 hours measured relative dust intensity 1.41[-]
Nozzle operator applying second layer of sprayed concrete:	1.0 hour



ANNEX 3/ SHEET 2

Evaluation:

Activity	measured rel. dust intensity [-]	conversion factor	fine dust concentration [mg/m³]
1st sprayed concrete layer	18.9	1.1	20.79
other activity	1.41	1.5	2.11
2nd sprayed concrete layer	19.3	1.1	21.23

Daily average of fine dust: (20.79 x 0.80 + 2.11 x 4.8 + 21.23 x 1.00) / 8 = 5.99 < 6 mg/m³

Hourly average of fine dust: 1st sprayed concrete layer: 20.79 > 12 mg/m³
2nd sprayer concrete layer: 21.23 > 12 mg/m³

The maximum permissible concentration of fine dust is allowed to be reached twice a day (for one hour each), but not consecutively, provided the daily average of 6 mg/m³ is not exceeded.

Result of evaluation based on the above example:
The criteria according to Table 3/2 are not met and protective measures therefore have to be taken!

Quality Test – Establishment of design sprayed concrete thickness

If the required sprayed concrete strength class is not reached in the quality test, the strength class requirements may be changed accordingly, provided the sprayed concrete is of adequate thickness.

Therefore, in areas in which the required sprayed concrete strength class is not reached, the design thickness ("d") of the sprayed concrete may be increased by "d_1" - clearance permitting - according to the following equation:

$$d_1 = \left(\frac{F}{M} - 1\right) \cdot d$$

F required sprayed concrete strength class in N/mm²

M measured sprayed concrete strength in N/mm²

d design sprayed concrete thickness in cm

d_1 additional sprayed concrete thickness in cm

If the sprayed concrete thickness cannot be increased for reasons of insufficient clearance, the sprayed concrete found to be inadequate has to be removed upon the principal's request and replaced at the contractor's expense.

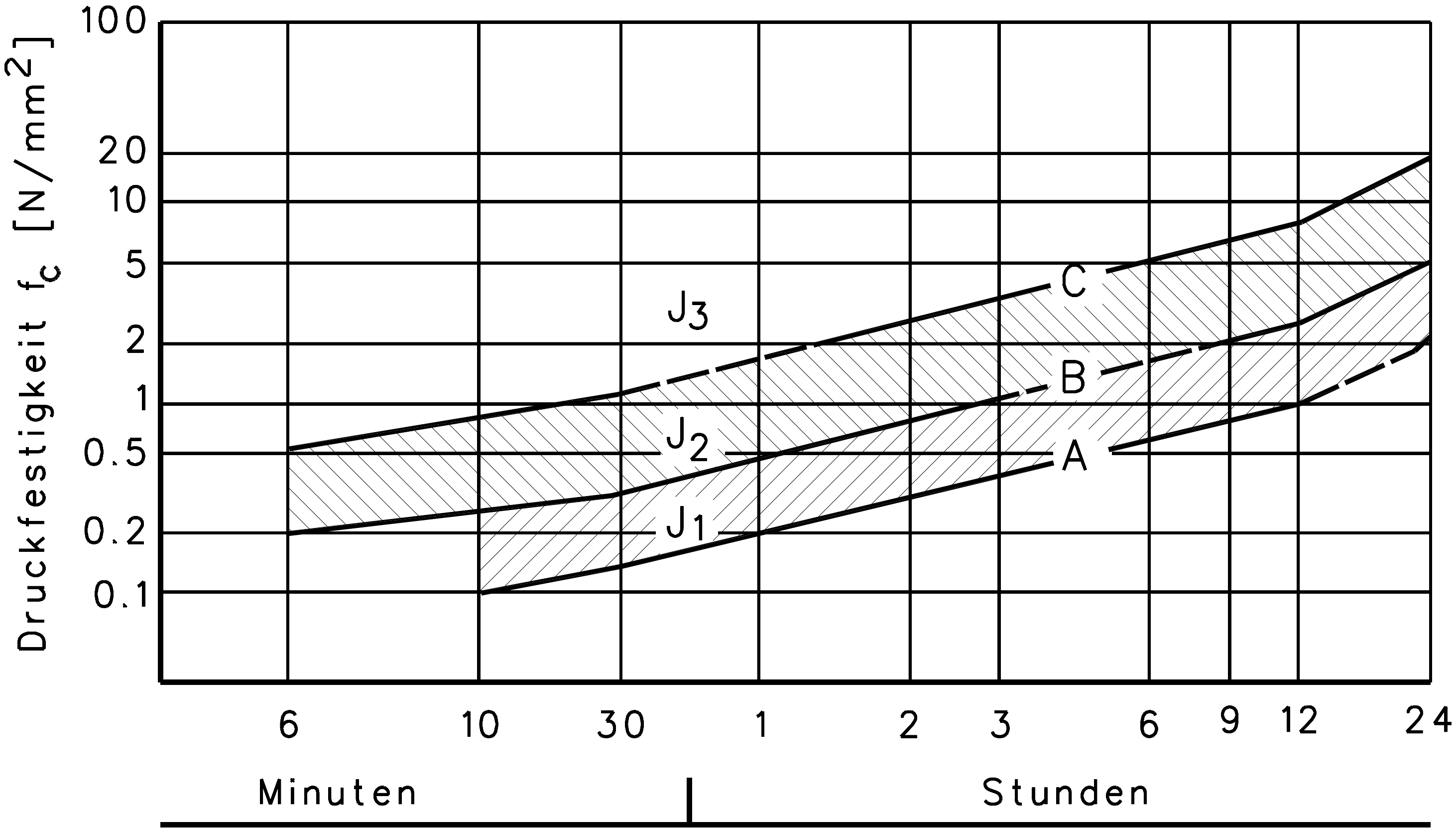
If the design strength is not reached, the principal is entitled to claim a discount instead of demanding an increase of the sprayed concrete thickness, with the unit price being reduced by 2% for each percentage point by which the actual sprayed concrete strength falls short of the design strength. The surface from which the drill core has been obtained is used as a basis for calculation of the price reduction.

ANNEX 6

Musterblatt „Frühfestigkeitsklassen des Jungen Spritzbetons“

Bauvorhaben: .... Bauteil, Station [m]: ....

Prüfer: .... Prüfdatum, Uhrzeit: ....



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