TÜRK STANDARDLARI ENSTİTÜSÜ

Türk Standardı

TS EN 14487-1

Aralık 2022

TS EN 14487-1:2006 yerine

ICS 01.040.91; 91.100.30

Püskürtme beton - Bölüm 1: Tarifler, özellikler ve uygunluk

Sprayed concrete -Part 1:Definitons, specifications and conformity

Béton projeté - Partie 1 : Définitions, spécifications et conformité

Spritzbeton - Teil 1: Begriffe, Festlegungen und Konformität

ICS 01.040.91; 91.100.30

TÜRK STANDARDI

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Milli Önsöz

Bu standard, CEN/TC 104 “Concrete and related products - Beton ve ilgili ürünler” Teknik Komitesi tarafından hazırlanmış, CEN tarafından 02.10.2022 tarihinde onaylanmış ve Türk Standardları Enstitüsü Teknik Kurulu'nun 08.12.2022 tarihli toplantısında Türk Standardı olarak kabul edilerek yayımına karar verilmiştir.

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EUROPEAN STANDARD

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EN 14487-1

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ICS 01.040.91; 91.100.30

Supersedes EN 14487-1:2005

English Version

Sprayed concrete - Part 1: Definitions, specifications and conformity

Béton projeté - Partie 1 : Définitions, spécifications et conformité

Spritzbeton - Teil 1: Begriffe, Festlegungen und Konformität

This European Standard was approved by CEN on 2 October 2022.

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European foreword

This document (EN 14487-1:2022) has been prepared by Technical Committee CEN/TC 104 “Concrete and related products”, the secretariat of which is held by SN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2023, and conflicting national standards shall be withdrawn at the latest by May 2023.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 14487-1:2005.

In comparison with the previous edition, the following technical modifications have been made:

— Table 3 has been added;

— Table 13 has been modified;

— Normative references have been updated.

This document has taken EN 206 as a basis. Some clauses which apply to sprayed concrete refer to EN 206 because of their importance. Other clauses have been modified to meet the specific requirements of sprayed concrete.

This document is only operable with product standards for constituent materials (i.e. cement, aggregates, additions, admixtures, fibres and mixing water) and related test methods for sprayed concrete which form the package defined below. For this reason, the latest date of withdrawal of national standards (DOW) conflicting with this document is determined by TC 104 to be DAV + 6 months.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.

Introduction

This document will be applied in Europe under different climatic and geographical conditions, different levels of protection and under different, well-established, regional traditions and experience. Classes for concrete properties have been introduced to cover this situation. Where such general solutions were not possible, the relevant clauses contain permission for the application of EN 206 or other standards valid in the place of use.

This document incorporates rules for the use of constituent materials that are covered by European Standards. Other by-products of industrial processes, recycled materials, etc. are in current use based on local experience. Until European specifications for these materials are available, this document will not provide rules for their use, but instead refers to the recommendations given in EN 206 to apply national standards or provisions valid in the place of use of the concrete.

This document defines tasks for the specifier, producer and user. For example, the specifier is responsible for the specification of concrete, Clauses 5 and 6 and the producer is responsible for conformity and production control, Clause 7. The user is responsible for placing the concrete in the structure. In practice there may be several different parties specifying requirements at various stages of the design and construction process, e.g. the client, the designer, the contractor, the concreting sub-contractor. Each is responsible for passing the specified requirements, together with any additional requirements, to the next party in the chain until they reach the producer. In the terms of this document, this final compilation is known as the “specification”.

Further explanations and guidance on the application of this document are given in Annex A.

1 Scope

This document is applicable to sprayed concrete to be used for repair and upgrading of structures, for new structures and for strengthening of ground.

This document covers:

— classification related to consistence of wet mix;

— environmental exposure classes; young, hardened and fibre reinforced concrete;

— requirements for constituent materials, for concrete composition and for basic mix, for fresh and hardened concrete and all types of fibre reinforced sprayed concrete;

— specification for designed and prescribed mixes;

— conformity.

This document is applicable to wet mix as well as dry mix sprayed concrete. The substrates to which sprayed concrete can be applied include:

— ground (rock and soil);

— sprayed concrete;

— different types of formwork;

— structural components constituted of concrete, masonry and steel;

— drainage materials;

— insulating materials.

Additional or different requirements may be needed for applications not within this document, for instance-refractory uses.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 197-1, *Cement — Part 1: Composition, specifications and conformity criteria for common cements*

EN 206:2013+A2:2021, *Concrete — Specification, performance, production and conformity*

EN 933-1, *Tests for geometrical properties of aggregates — Part 1: Determination of particle size distribution — Sieving method*

EN 934-2, *Admixtures for concrete, mortar and grout — Part 2: Concrete admixtures — Definitions, requirements, conformity, marking and labelling*

EN 934-5:2007, *Admixtures for concrete, mortar and grout — Part 5: Admixtures for sprayed concrete — Definitions, requirements, conformity, marking and labelling*

EN 934-6, *Admixtures for concrete, mortar and grout — Part 6: Sampling, assessment and verification of the constancy of performance*

EN 1008, *Mixing water for concrete — Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete*

EN 1504-3, *Products and systems for the protection and repair of concrete structures — Definitions, requirements, quality control and evaluation of conformity — Part 3: Structural and non-structural repair*

EN 1542, *Products and systems for the protection and repair of concrete structures — Test methods — Measurement of bond strength by pull-off*

EN 12350-2, *Testing fresh concrete — Part 2: Slump test*

EN 12350-5, *Testing fresh concrete — Part 5: Flow table test*

EN 12350-6, *Testing fresh concrete — Part 6: Density*

EN 12390-3, *Testing hardened concrete — Part 3: Compressive strength of test specimens*

EN 12390-5, *Testing hardened concrete — Part 5: Flexural strength of test specimens*

EN 12390-7, *Testing hardened concrete — Part 7: Density of hardened concrete*

EN 12390-8, *Testing hardened concrete — Part 8: Depth of penetration of water under pressure*

EN 12390-13, *Testing hardened concrete — Part 13: Determination of secant modulus of elasticity in compression*

EN 12504-1, *Testing concrete in structures — Part 1: Cored specimens — Taking, examining and testing in compression*

EN 12504-2, *Testing concrete in structures — Part 2: Non-destructive testing — Determination of rebound number*

EN 12620, *Aggregates for concrete*

EN 13412, *Products and systems for the protection and repair of concrete structures — Test methods — Determination of modulus of elasticity in compression*

EN 14487-2, *Sprayed concrete — Part 2: Execution*

EN 14488-1, *Testing sprayed concrete — Sampling fresh and hardened concrete*

EN 14488-2, *Testing sprayed concrete — Part 2: Compressive strength of young sprayed concrete*

EN 14488-3, *Testing sprayed concrete — Part 3: Flexural strengths (first peak, ultimate and residual) of fibre reinforced beam specimens*

EN 14488-4, *Testing sprayed concrete — Part 4: Bond strength of cores by direct tension*

EN 14488-5, *Testing sprayed concrete — Part 5: Determination of energy absorption capacity of fibre reinforced slab specimens*

EN 14488-7, *Testing sprayed concrete — Part 7: Fibre content of fibre reinforced concrete*

EN 14651, *Test method for metallic fibre concrete — Measuring the flexural tensile strength (limit of proportionality (LOP), residual)*

EN 14889-1, *Fibres for concrete — Part 1: Steel fibres — Definitions, specifications and conformity*

EN 14889-2, *Fibres for concrete — Part 2: Polymer fibres — Definitions, specifications and conformity*

ISO 758, *Liquid chemical products for industrial use — Determination of density at 20 degrees C*

ISO 20290-1, *Aggregates for concrete — Test methods for mechanical and physical properties — Part 1: Determination of bulk density, particle density, particle mass-per-volume and water absorption*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Mix component

3.1.1 Admixtures

3.1.1.1
admixtures for basic mix
material added during the mixing process of concrete in a quantity not more than 5 % by mass of the cement content of the concrete, to modify the properties of the mix in the fresh and/or hardened state

[SOURCE: EN 934-2:2009+A1:2012, definition 3.2.1]

3.1.1.2 Admixtures for projection

3.1.1.2.1
sprayed concrete set accelerating admixture
admixture to develop very early setting and very early hardening of the sprayed concrete differing from set accelerating admixtures according to EN 934-2

Note 1 to entry: As defined and specified in EN 934-5:2007.

[SOURCE: EN 934-5:2007, definition 3.2.2]

3.1.1.2.2
non-alkaline sprayed concrete set accelerating admixture
sprayed concrete set accelerating admixture according to 3.1.1.2.1 with an alkali content (given as Na_2O equivalent) not exceeding 1 % by mass of the admixture

Note 1 to entry: Admixture made according to EN 934-5:2007.

[SOURCE: EN 934-5:2007, definition 3.2.3]

3.1.2
additions
finely divided mineral material used in concrete in order to improve certain properties or to achieve special properties

[SOURCE: EN 206:2013+A2:2021, definition 3.1.2.1]

3.1.3
cement
finely ground inorganic material which, when mixed with water, forms a paste that sets and hardens by means of hydration reactions and processes and which, after hardening, retains its strength and stability even under water

[SOURCE: EN 206:2013+A2:2021, definition 3.1.2.8]

3.1.4
aggregate
granular material used in construction, aggregate may be natural, manufactured or re-cycled

[SOURCE: EN 12620:2002+A1:2008, definition 3.1]

3.1.5 Fibres

3.1.5.1
steel fibres
straight or deformed pieces of cold-drawn steel wire, straight or deformed cut sheet fibres, melt extracted fibres, shaved cold drawn wire fibres and fibres milled from steel blocks which are suitable to be homogeneously mixed into concrete or mortar

[SOURCE: EN 14889-1:2006, definition 3.1]

3.1.5.2
polymer fibres
polymer fibres can be straight or deformed pieces of extruded orientated and cut material which are suitable to be homogeneously mixed into concrete or mortar and which are not affected over time by the high pH of concrete

[SOURCE: EN 14889-2:2006, definition 3.2]

3.2 Product

3.2.1 General

3.2.1.1
basic mix
mixture of cement, aggregates and any other constituents as fed into the spraying machine, excluding any component added at the nozzle

Note 1 to entry: The basic mix may be dry or wet.

Note 2 to entry: The basic mix may also contain:

— additions;

— admixtures;

— fibres;

— water.

3.2.1.2 Sprayed concrete with fibres

3.2.1.2.1
fibre reinforced sprayed concrete
sprayed concrete, including reinforcing fibres to improve certain properties of concrete

3.2.1.2.2
sprayed concrete with crack reducing fibres
sprayed concrete with fibres that reduce cracking in young sprayed concrete

3.2.1.2.3
sprayed concrete with fibres for fire resistance
sprayed concrete with fibres for improved fire resistance

3.2.1.3
fresh sprayed concrete
concrete prior to setting

3.2.1.4
rebound
part of material that, having been sprayed through the nozzle, does not adhere to the surface of application

3.2.1.5
reference sprayed concrete
sprayed concrete which does not contain admixtures for projection

Note 1 to entry: This definition cannot be applied to sprayed concrete produced with factory blended dry mix containing admixtures for projection, in this case the admixture compatibility should be controlled according to EN 934-5. The reference sprayed concrete is usually used as reference material for the evaluation of mechanical properties changes with time of sprayed concrete (e.g. strength losses).

3.2.1.6
sprayed concrete
concrete produced with basic mix and projected pneumatically from a nozzle into place to produce a dense homogeneous mass by its own momentum

3.2.1.7
young sprayed concrete
sprayed concrete up to an age of 24 hours

3.2.2 Dry mix

3.2.2.1
factory blended dry mix
basic mix with a minimum moisture content not exceeding 0,5 % by mass for the dry process (excluding any component at the nozzle)

3.2.2.2
site batched dry mix
basic mix with a maximum moisture content of the aggregate not exceeding 6 % by mass for the dry process which need to be used shortly after mixing

3.2.3
wet mix
basic mix to be used in the wet process

3.3 Process

3.3.1 Dry spraying process

3.3.1.1
pre-wetting
adding water to dry mix before the nozzle, in order to reduce dust and improve mix quality

3.3.1.2
dry mix conveying
method of conveying a dry mix with or without pre-wetting where the necessary amount of additional water is added in the nozzle

3.3.2 Wet spraying process

3.3.2.1
dense flow conveying
pump conveying a wet mix to the nozzle, where it is pneumatically projected and compacted by adding high pressure air

3.3.2.2
thin flow conveying
conveying of the basic mix to the nozzle, through hoses or pipes with high pressure air, where the force of the transportation is used to project and compact the mix

3.3.3 General

3.3.3.1
nozzle
general term for the end of the conveying line, through which the mix is discharged

Note 1 to entry: It consists of a mixing unit, into which – depending on the process – water, compressed air and/or admixtures are injected into the flow of the basic mix.

3.3.3.2
hose
flexible tube conveying mix

3.3.3.3
pipe
rigid tube conveying mix

3.3.3.4
curing
measures to reduce harmful evaporation and subsequent drying shrinkage of the sprayed concrete

3.4 Properties

3.4.1
early age strength
strength developed by young sprayed concrete

3.4.2
energy absorption capacity
energy, in Joule, absorbed in loading a fibre reinforced plate

Note 1 to entry: As described in EN 14488-5.

3.4.3
first peak flexural strength
stress at the determined first peak load which fibre reinforced concrete withstands when subjected to a flexural test

Note 1 to entry: As specified in EN 14488-3.

3.4.4
open time
time between mixing and latest possible spraying of the basic mix

Note 1 to entry: It depends on type and quantity of cement, moisture content for the dry mix, type and amount of admixtures and temperature.

3.4.5
residual strength
calculated stress in fibre reinforced concrete corresponding to a load in the load-deflection curve recorded during the flexural test

Note 1 to entry: As defined in EN 14488-3.

3.4.6
ultimate flexural strength
stress corresponding to the maximum load which unreinforced or fibre reinforced concrete can withstand when subjected to a flexural test

Note 1 to entry: As specified in EN 12390-5 and EN 14488-3.

3.5 Execution

3.5.1
free-standing structure
structure formed by spraying concrete against temporary or permanent formwork, which does not act compositely with the ground or an existing structure

3.5.2
repair
replacement of inferior or deteriorated parts of concrete or masonry members

3.5.3
shadow effect
phenomenon of a poorer concrete compaction or voids on the rear side of for example, a reinforcement bar, which is being sprayed on from one side only

3.5.4
strengthening of ground
formation of a temporary or permanent composite structure by spraying concrete against the ground

3.5.5
substrate
surface to which the sprayed concrete is applied

3.5.6
surface improvement
use of layer of sprayed concrete in order to improve the durability or the appearance of the structure

3.5.7
upgrading
placing of additional sprayed concrete, with or without reinforcement, in order to increase the load bearing capacity or the integrity of the structure

3.6 Operative

3.6.1
nozzleman
operator who controls and regulates the application of the sprayed concrete

3.6.1.1
nozzleman – manual spraying
nozzleman with special skills for spraying with hand-held nozzle

3.6.1.2
operator – robot spraying
nozzleman with special skills for robot spraying

3.6.2
certified nozzleman/operator
nozzleman/operator with certified special skills

Note 1 to entry: Skills according to requirements in EN 14487-2.

3.7 Test and inspection

3.7.1
preliminary test for sprayed concrete
test or tests to check how a sprayed concrete is composed in order to meet all the specified requirements in the fresh and hardened state

3.7.2
preconstruction test
test or tests performed with the proposed personnel, materials, equipment and spray method which the contractor will carry out before the start of the spraying work to ensure that the specified properties are met

3.7.3
inspection
activities carried out in order to check that execution is in accordance with the project specification

3.7.4
inspection category
set of properties and their testing frequencies, selected according to the level of risk and the design life of the structure

3.7.5
assessment of conformity
systematic examination of the extent to which a production process and a product are capable of fulfilling special requirements

4 Classification

4.1 Consistence of wet mix

The classification of consistence of fresh concrete in this document is applicable for wet mixed concrete before being sprayed and consistence classes in EN 206 shall be applied.

4.2 Exposure classes

The limiting values for composition of concrete related to the exposure classes given in EN 206, apply for sprayed concrete with the following exceptions:

— recommendation on minimum cement content in the basic mix shall be 300 kg/m^3;

— recommendation on minimum air content is not applicable.

NOTE Current available test methods for the measurement of air content do not give reliable data results for fresh sprayed concrete.

Provisions valid in the place of use of the concrete may establish different limiting values related to the exposure classes as mentioned in EN 206:2013+A2:2021.

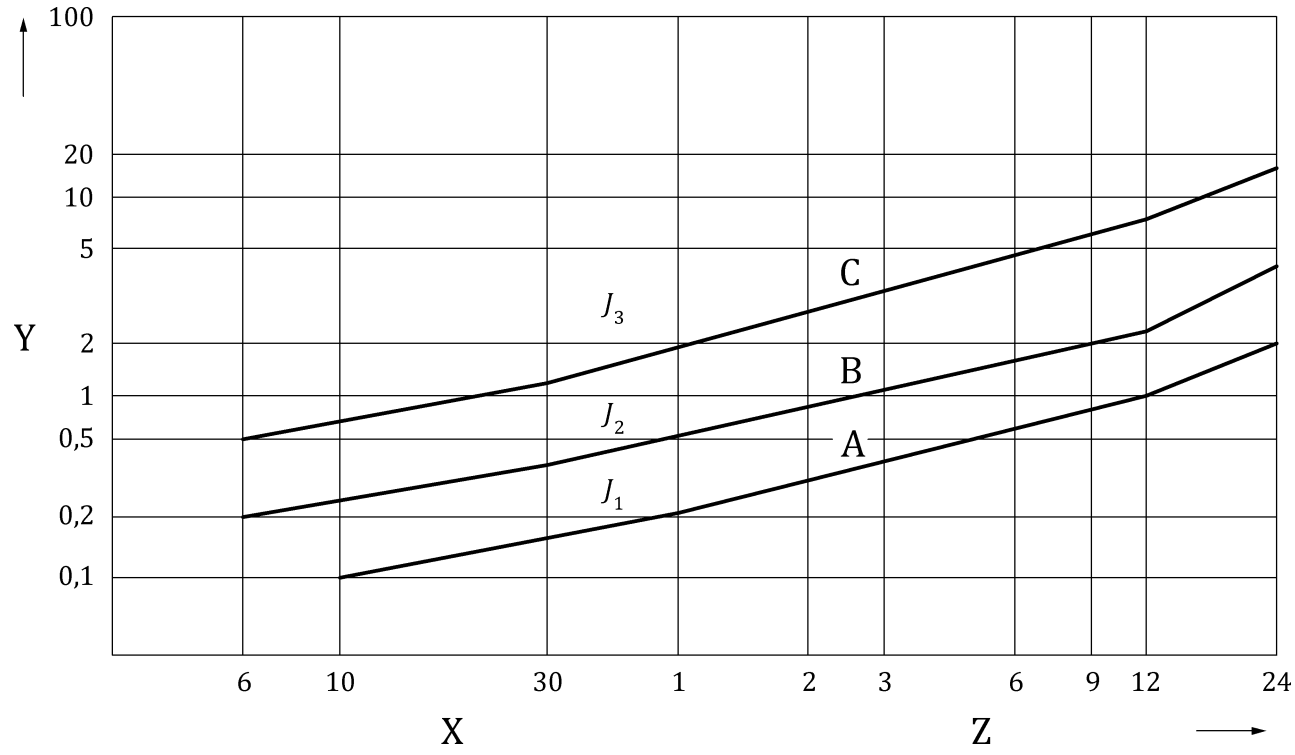
4.3 Young sprayed concrete

Young sprayed concrete may also be classified according to the ranges of its significant early strength development. The classification is based on the average range of the typical hardening rate according to the chosen production process and requirements.

When specified the strength development of the young sprayed concrete shall apply to the early strength classes J1, J2 or J3 according to Figure 1. Early strength class J1 is defined by at least 3 data points (compressive strength vs. time) falling in the area between the lines A and B, class J2 in the area between the lines B and C and class J3 above the line C.

The recommended time intervals in which strength data have to be evaluated are: 0 h to 1 h; 4 h to 6 h; 12 h to 24 h.

Early strength development shall be determined with the penetration needle method according to EN 14488-2 and/or stud driving method according to EN 14488-2, according to the expected strength range (see Table 1).



Key

X minutes

Y compressive strength, f_G in N/mm²

Z hours

Figure 1 — Early strength classes of young sprayed concrete

Table 1 — Range of strength of young concrete determined by different test methods

Method	Range of strength of young concrete (MPa)
EN 14488-2 – Method A	0,2 to 1,2
EN 14488-2 – Method B	2 to 16

NOTE Current available test methods are not able to cover the entire range of expected early strength.

4.4 Compressive strength

The compressive strength of sprayed concrete is classified according to EN 206.

4.5 Fibre reinforced sprayed concrete

4.5.1 General

Fibre reinforced sprayed concrete has additional and/or complementary properties, some of which are related to residual strength and energy absorption capacity. Informative guidance on the classification principles is given in Annex A.

4.5.2 Residual strength classes

4.5.2.1 General

Classification of residual strength shall be made by specification of a strength level at a certain deformation range.

This can be done using the four point bending test (Method A) or using the alternative three point bending test on square panel (Method B), both described in EN 14488-3.

4.5.2.2 Classification according to the four point bending test without a notch (EN 14488-3, method A)

Classification of residual strength shall be made by specification of a strength level at a certain deformation range according to Table 2 and determined in accordance with EN 14488-3 and denoted by combination of the symbols for the specified deformation range and strength level, e.g. Class D2S2 means that the residual strength shall exceed 2 MPa between 0,5 mm and 2 mm deflection.

Table 2 — Definitions of residual strength classes

Deformation range		Strength level (minimum strength, MPa)			
	Deflection mm	S1	S2	S3	S4
D1	0,5 to 1	1	2	3	4
D2	0,5 to 2				
D3	0,5 to 4				

4.5.2.3 Classification according to alternative three point bending test on square panel with a notch (EN 14488-3, method B)

Parameters $f_{R_s,j}$ representing the residual flexural tensile strength, are evaluated from the F-CMOD relationship, as follows:

$$fR_s, j = \frac{3F_s, j \times l}{2bh_{sp}^2}$$

where

$fR_{s,j}$ is the residual flexural strength corresponding to CMOD = $CMOD_j$ in MPa;

$F_{s,j}$ is the load corresponding to CMOD = $CMOD_j$ in N;

l is the span length in mm;

b the specimen width in mm;

h_{sp} the distance between the notch tip and the top of the specimen in mm.

If the three points bending test on square panel with a notch is specified, it shall be determined in accordance to EN 14488-3.

The residual flexural strengths given in Table 3 may be determined according to EN 14488-3, method B or according to EN 14651, depending on the specification.

Table 3 — Definition of class of ductility

Class of ductility	Ductility requirement	Crack control requirement
Class 1	$fR_{s3k}/fR_{s1k} > 0,5$	$fR_{s1k}/f_{Ls}{}_k > 0,4$
Class 2	$fR_{s3k}/fR_{s1k} > 0,7$	$fR_{s1k}/f_{Ls}{}_k > 0,5$
Class 3	$fR_{s3k}/fR_{s1k} > 0,9$	$fR_{s1k}/f_{Ls}{}_k > 0,6$

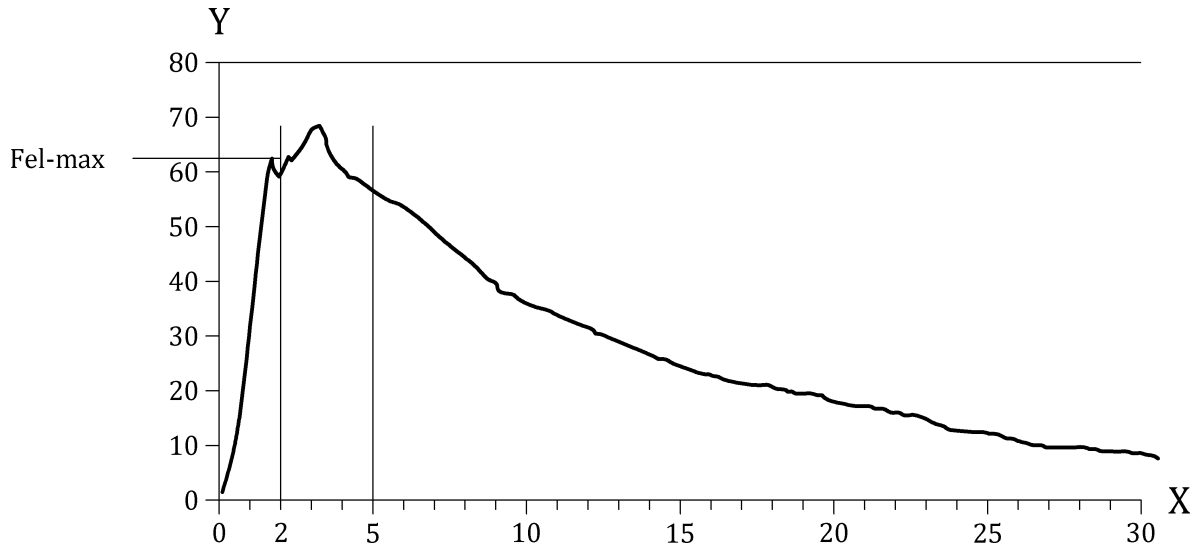
Class 1 for ductility and crack control requirement meets the requirements of the Model Code.

Depending on the application (structural or non-structural), crack control requirement shall be specified accordingly.

The statistical basis on which fL_{sk}, fR_{s1k}, fR_{s2k} and fR_{s3k} are to be determined shall be specified during preconstruction testing (7.3). 7.4.4 applies to production control and 7.5.2.4 applies to proof of conformity.

4.5.3 Energy absorption capacity

If the energy absorption capacity of the material is specified, it shall be determined from a slab specimen tested in accordance to EN 14488-5.



Key

X deflection [mm]

Y load [kN]

Figure 2 — Typical Load-Deflection graph

The definitions of $F_{el\text{-}max}$ and $F_{post\text{-}crack}$ are:

$F_{el\text{-}max}$ is the maximum load value of the elastic part of the load-deflection curve;

$F_{post\text{-}crack}$ is the maximum load value between $F_{el\text{-}max}$ and the load value at 5 mm-deflection.

Each load-deflection curve shall fulfil the following criteria:

$F_{el\text{-}max}$ shall be reached for a deflection lower than 2 mm;

$F_{post\text{-}crack}$ shall be higher than 70 % of $F_{el\text{-}max}$.

Table 4 — Definitions of energy absorption classes

Energy absorption class	Energy absorption in J for deflection up to 25 mm
E500	500
E700	700
E1000	1000

5 Requirements for sprayed concrete

5.1 Requirements for constituent materials

Constituent materials shall not contain harmful ingredients in such quantities as may be detrimental to the durability of the concrete, or cause corrosion of the reinforcement and shall be suitable for the intended use in sprayed concrete.

Where general suitability is established for a constituent material, this does not indicate suitability in every situation and for every sprayed concrete composition.

Only constituents with established suitability for the specified application shall be used in sprayed concrete conforming to this document.

The general suitability of a constituent material is established when it conforms to a European Standard. Requirements for constituent materials are given in Table 5.

Table 5 — Requirements for constituent materials

Constituent material	Requirements
Cement	The suitability shall be established for cement conforming to EN 197-1
Aggregates	The suitability for the specified application shall be established for aggregate referring to EN 12620
Mixing water	Mixing water shall conform to EN 1008
Admixtures	Admixtures shall conform to EN 934-2 and/or EN 934-5
Additions (including mineral fillers and pigments)	Additions shall comply to requirements as specified in EN 206
Polymer modified sprayed concrete	Polymer modified sprayed concrete used for repair shall conform to EN 1504-3
Fibres	Fibres shall meet the requirements in EN 14889-1 and/or EN 14889-2

Alternatively, where either the European Standard does not cover the particular material or its intended performance, or the material deviates from an existing European Standard, the establishment of suitability may result from:

— European Technical Approval which refers specifically to the use of the material in sprayed concrete conforming to this document;

— relevant national standards or provisions valid in the place of use of the sprayed concrete, which refer specifically to the use of the material in sprayed concrete conforming to this document.

5.2 Requirements for sprayed concrete composition

5.2.1 General

The concrete mix proportions shall be selected to satisfy all the performance criteria for fresh and hardened concrete including consistence (wet mix), density, strength, durability, protection of embedded steel against corrosion and taking into account the current process technique and quantity of rebound and dust when executing the spraying works.

The requirements for concrete composition and properties related to exposure classes depend on the intended design life of the sprayed concrete structure and shall be in conformity with EN 206.

Provisions valid in the place of use of the concrete may establish different limiting values related to the exposure classes as mentioned in EN 206:2013+A2:2021.

Values for the composition of the concrete refer to the concrete after spraying and shall take into account the influence of water and accelerator admixtures addition by the spraying process as well as the effect of rebound.

The achievement of the design life depends on:

— the concrete being sprayed and cured in accordance with EN 14487-2;

— the sprayed concrete having an adequate cover over reinforcement or required extra thickness. In case of fibre reinforcement, the cover requirement does not apply to the fibres;

— the sprayed concrete being used in the environment for which the particular limiting values apply;

— the anticipated maintenance without major repair.

5.2.2 Concrete composition

Table 6 — Requirements for concrete composition

Component	Requirements and Test Methods
Use of cement	The type of cement shall be specified, taking into account the influence of current temperature and heat evaluation on required workability time, the requirement on strength development and final strength as well as the current curing conditions. If required, it shall be checked by means of an appropriate method. For permanent structures, the environmental conditions to which the sprayed concrete is exposed shall be in accordance with EN 206, as well as precautions regarding resistance to alkali-silica reactions according to EN 206.
Use of aggregates	Precautions regarding resistance to alkali-silica reactions according to EN 206 shall be applied.
Use of admixtures	Limitations for the use of admixtures set out in EN 934-2 and EN 934-5 shall not be exceeded.
Use of additions	The use of additions for permanent structures shall conform to EN 206.
Chloride content	The chloride content of a sprayed concrete for permanent structure shall not exceed the values given in EN 206 for the specified class. For steel fibre reinforced sprayed concrete, values for steel reinforcement apply.
Water/cement ratio	For permanent structures, the environmental conditions to which the sprayed concrete is exposed shall be in accordance with EN 206. Where water/cement ratio of a wet mix is specified, it shall be calculated according to EN 206.
For fibre reinforced concrete	
Use of fibres	Steel and polymer fibres shall comply to EN 14889-1 and EN 14889-2, other types of fibres shall comply to 5.1. Fibres shall be added in such a way that a homogenous distribution is obtained.

5.3 Requirements on the basic mix

Table 7 — Requirements for wet basic mix

Property	Requirements and Test Method
Consistence of wet basic mix	The consistence of wet basic mix shall be specified according to EN 206.
Temperature	The temperature of the basic mix before applying shall be between 5 °C and 30 °C in order to maintain the workability conditions and avoid adverse set effects.
NOTE The concrete consistency required for spraying depends on the type of conveyance and the application procedure.	

5.4 Requirements for the fresh sprayed concrete

Table 8 — Requirements of the fresh sprayed concrete

Property	Requirements and Test Method
Density	The density shall be determined in accordance with EN 12350-6.
Fibre content	Fibre content shall be determined from a fresh sample according to EN 14488-7. The sample shall be taken from *in situ* material unless otherwise specified.

5.5 Requirements for hardened sprayed concrete

At least, the compressive strength of prescribed mixes shall be specified.

Table 9 — Requirements for hardened concrete

Property	Requirements and Test Method
Early age strength	An estimate of the early compressive strength can be determined in accordance with EN 14488-2.
Compressive strength	The compressive strength of sprayed concrete is expressed and defined according to EN 206. The strength shall be determined from tests carried out at 28 days in accordance with EN 12504-1 on drilled cores or sawn cubes, taken from the sprayed concrete structure according to EN 12504-1, or from sprayed panels according to EN 14488-1. Their minimum diameter shall be 50 mm and the height/diameter ratio shall be either 1,0 or 2,0, specimen shall be tested in accordance with EN 12504-1. NOTE The length/diameter ratio is ideal at: 2,0 if the strength result is to be compared to cylinder strength; 1,0 if the strength result is to be compared to cube strength.
Density	The density of hardened concrete shall be determined in accordance with EN 12390-7.
Modulus of elasticity	The modulus of elasticity in compression shall be determined in accordance with EN 12390-13, except in repair application where EN 13412 shall apply.
Flexural strength	The flexural strength shall be determined in accordance with EN 12390-5 for sprayed concrete without fibres unless it is to be compared to fibre reinforced sprayed concrete when EN 14488-3 or EN 14651 shall be used.
Resistance to water penetration	The resistance to water penetration shall be determined in accordance with EN 12390-8. The depth of an *in situ* sample may be reduced where the layer thickness is less than 150 mm. The depth shall be sufficient to ensure that complete penetration does not occur. In addition, the direction of water penetration and the method of surface preparation shall be specified. The maximum value of penetration shall be 50 mm. The test is normally performed at 28 days.
Freeze/thaw resistance	NOTE A European Standard is presently not available. Until such time, reference is made to national standards or provisions given in a national Annex to this standard.

Property	Requirements and Test Method
Bond strength to substrate	The bond strength shall be determined for repair materials in accordance with EN 1542 with the exception of mould size which shall not be smaller than 500 mm × 500 mm to provide a border of at least 100 mm in order to exclude defective material in the edges of the specimens. Surface finish shall either be trowelled when wet or ground when hardened otherwise it shall be on drilled cores in accordance with EN 14488-4.
For fibre reinforced sprayed concrete	
First peak flexural strength	The first peak flexural strength shall be expressed as the average value of the strength at the moment of first peak determined in accordance with EN 14488-3 or EN 14651. The test shall normally be performed at 28 days.
Ultimate flexural strength	The ultimate flexural strength of fibre reinforced sprayed concrete shall be expressed as f_{fl} when determined according to EN 14488-3 or EN 14651. Unless otherwise required, tests shall normally be performed at 28 days.
Residual strength	The residual strength class of fibre reinforced concrete shall be determined for a specified deformation level. The stress-deflection curve shall be determined in accordance with EN 14488-3 or EN 14651. The test is normally done at 28 days.
Fibre content	The fibre content shall be determined from a hardened sample in accordance with EN 14488-7, when it is not practical to determine it from the fresh sprayed concrete. The sample shall be taken from *in situ* material unless otherwise specified.
Energy absorption capacity	The energy absorption capacity shall be expressed as the average energy capacity, determined in accordance with EN 14488-5. The specified energy absorption for the required class shall meet the requirements in Table 4. The test is normally done at 28 days.

6 Specification for sprayed concrete

6.1 General

Sprayed concrete shall be specified either as a designed concrete referring to classification given in Clause 4 and requirements given in Clause 5, or as prescribed concrete by prescribing the composition on the basis of results of initial tests or information obtained from long term experiences with comparable sprayed concrete. Where inspection categories 2 and 3 (see 7.2) are specified only designed concretes shall be used. Where category 1 applies, prescribed concrete may be used.

Basic data for sprayed concrete shall be indicated in all cases and additional data shall be indicated when required.

6.2 Data for specifying designed mix

6.2.1 Basic data

The designed mix shall be specified by the following basic data:

— consistency (if appropriate);

— compressive strength class;

— exposure class;

— chloride class;

— inspection category;

— nominal maximum aggregate size.

In case of fibre reinforced concrete:

— residual strength and/or

— energy absorption capacity.

6.2.2 Additional data

The concrete specifications may also contain additional requirements such as:

— cement content;

— special requirements for cement properties (e.g. sulphate resistant cement);

— maximum water/cement ratio related to exposure classes;

— early age strength development;

— resistance to water penetration;

— bond to substrate;

— freeze/thaw resistance (with or without de-icing salts);

— modulus of elasticity.

In the case of fibre reinforced concrete:

— first peak flexural strength;

— ultimate flexural strength.

6.3 Data for specifying prescribed mix

6.3.1 Basic data

The prescribed mix shall be specified by the following basic data:

— cement type and class;

— cement content;

— consistence for wet mix (see Table 7);

— water/cement ratio;

— type of aggregate and limitations for grading;

— type and quantity of admixtures;

— type and quantity of additions;

— sources of all concrete constituents;

— inspection category.

In the case of fibre reinforced concrete:

— fibre characteristics (according to EN 14889-1 and EN 14889-2) and fibre content.

6.3.2 Additional data

The concrete specifications may also contain additional requirements such as:

— additional requirements for aggregate;

— special requirements regarding the temperature of the basic mix.

7 Assessment of conformity

7.1 General

Conformity control comprises the combination of actions and decisions to be taken in accordance with conformity rules adopted in advance to check the conformity of the sprayed concrete with the specifications.

Conformity shall be assessed by preconstruction test as well as test during execution and be applied in accordance with the applicable inspection category. Production control includes process control and control of sprayed concrete.

The conformity or non-conformity is judged against the conformity criteria and is valid for preconstruction as well as for production tests. Conformity leads to acceptance while non-conformity shall lead to corrective action.

If the results of conformity tests do not fulfil the requirements, supplementary testing according to EN 12504-1 on cores, taken from the structure, or a combination of tests on cores and non-destructive tests on the structure, e.g. according to EN 12504-2, shall be required.

7.2 Inspection categories

For conformity control of sprayed concrete one of the following inspection categories shall be specified:

— inspection category 1;

— inspection category 2;

— inspection category 3.

The choice of category shall be determined by the designer and the owner, taking into account the characteristics of the project, the degree of risk and required design life.

NOTE Tables A.1 to A.3 give guidance on selection of the inspection category. The inspection regime is subject to national provision valid in the place of use of the sprayed concrete.

7.3 Preconstruction testing

Preconstruction tests shall be performed according to Table 10 unless otherwise specified in production control system (Producer's production control manual). Tests shall be carried out on a sufficient quantity of sprayed concrete in order to reach a uniform flow.

It shall be demonstrated that the requirements can be met before start of execution.

The preconstruction tests shall be performed with the same personnel, materials, equipment and spray method which will be used during production.

When long term experience with similar sprayed concrete equipment and same personnel is available preconstruction testing is not necessary. The concrete design and design relationships shall be re-established when there is a significant change in constituent materials, composition, personal or equipment as indicated below:

— changes to higher water/cement ratio;

— change of aggregate type or supplier;

— change of maximum aggregate size;

— change of admixtures or additions;

— change of cement type, class or source;

— change of fibre type or supplier.

All parameters specified and shaded in Table 10 shall be tested, unshaded parameters shall be tested only if specified.

Table 10 — Preconstruction tests – requirements for the designed sprayed concrete

Type of work	Repair and upgrading			Free standing structures			Strengthening of ground		
Inspection category:	1	2	3	1	2	3	1	2	3
Property:									
Consistence for wet mix	■	■	■	■	■	■	■	■	■
Early age strength development								■	■
Compressive strength	■	■	■	■	■	■	■	■	■
Density of hardened concrete		■	■	■	■	■	■	■	■
Modulus of elasticity			■						
Bond to substrate		■	■						
Ultimate flexural strength						■			■
First peak flexural strength [a]						■			■
Residual strength [a, b]						■		■	■
Energy absorption capacity [a, b]						■		■	■
Freeze/thaw resistance (with or without de-icing salts)									
Resistance to water penetration									
Composition:									
Fibre content [a]	■	■	■	■	■	■	■	■	■
Maximum chloride content									

NOTE For test methods refer to Table 13.

[a] Only for fibre reinforced sprayed concrete.

[b] Residual strength or energy absorption capacity can be specified.

7.4 Production control

7.4.1 General

Production control comprises all measures necessary to maintain and regulate the quality of the sprayed concrete in conformity with specified requirements.

Production control shall be related to the characteristics of the project including the degree of risk and expected design life.

Production control consists of following parts:

— constituent materials control (Table 11);

— control of basic mix (Table 12);

— control of sprayed concrete properties (Table 13).

NOTE Inspection of execution is covered by EN 14487-2.

All relevant data from the process shall be recorded.

7.4.2 Constituent materials control

The control of constituent materials shall be performed according to Table 11.

Table 11 — Constituent materials control

	Material	Inspection/test	Purpose	Minimum sampling frequency		
				Category 1	Category 2	Category 3
1	Cements	Inspection of delivery ticket	To ascertain correct type and source	Each delivery		
2	Aggregates	Inspection of delivery ticket [a]	To ascertain correct type and source	Each delivery		
3		Test by sieve analysis according to EN 933-1 or aggregate supplier information	To assess compliance with standard or other agreed grading	-	first delivery from new source	
4		Test for impurities or aggregate supplier information (according to EN 12620)	To assess the presence and quantity of impurities	-	first delivery from new source	
5	Additional control for light weight concrete	Test according to ISO 20290-1	To measure the bulk density	-	first delivery from new source	
Relevant materials control shall, in case of doubts, be performed independent of inspection category.						
6	Admixtures [b]	Inspection of delivery ticket and label on container according to EN 934-6	To ascertain if the consignment is as ordered and properly marked	Each delivery		
7		Test for density for liquid admixtures according to ISO 758	To ascertain if the consignment is as ordered and from the correct source	In case of doubt		
8	Additions bulk powder	Inspection of delivery ticket	To ascertain if the consignment is as ordered and from the correct source	Each delivery		

	Material	Inspection/test	Purpose	Minimum sampling frequency		
				Category 1	Category 2	Category 3
9	Additions in suspension	Inspection of delivery ticket	To ascertain if the consignment is as ordered and from the correct source	Each delivery		
10		Test for density according to ISO 758	To ascertain uniformity	-	Each delivery	
11	Water	Test according to EN 1008	To ascertain that the water is free from harmful constituents	-	If the water is not potable; when new source is used for first time; and in case of doubt	
12	Fibres	Inspection of length, diameter and shape according to EN 14889-1 and EN 14889-2	To ascertain if the consignment is as ordered and from the correct source	Each delivery		

[a] The delivery ticket or the product data sheet shall also contain information on the maximum chloride content and should identify classification with respect to alkali silica reaction in accordance with the provisions valid in the place of use of the concrete. The delivery ticket shall contain or be accompanied by a declaration or certificate of conformity as required in the relevant standard or specification.

[b] It is recommended that samples are taken at each delivery and stored.

7.4.3 Control of basic mix

The control of the basic mix shall be performed according to Table 12.

Table 12 — Control of basic mix

	Material	Inspection/test	Purpose	Minimum sampling frequency		
				Category 1	Category 2	Category 3
1	Consistence when using wet-mix method	Test according to EN 12350-2 or EN 12350-5	To assess conformity with required class of consistence and to check possible changes of water content	At start of production Every truck		
2	Water/cement ratio of fresh concrete		To check the limiting values related to exposure classes	Every delivery, by control of the batch w/c ratio supplied by the producer		
3	Admixture content except accelerator	Record of the quantity added	To check the content	Optional	Every batch	
4	Additions content	Record of the quantity added	To check the content	Optional	Every batch	
5	Fibre content	Record of the quantity added	To check the content	Every batch		

7.4.4 Control of sprayed concrete properties

If testing is required by the project specification, the sprayed concrete shall be tested according to Table 13.

Other test methods than listed in Table 13 may be applied if their suitability is proven and the application is declared by the producer.

The test frequencies refer to the normal continuous production situation. Four times higher test frequency should be applied in the beginning of a continuous working period or during certain critical parts of a project. However, normally no more than two tests per working day should be necessary.

After four consecutive acceptable results, normal frequency shall be applied.

The minimum rate of sampling and testing for production control of concrete shall be at the rate which gives the highest number of samples.

The minimum sampling frequencies are valid for production volumes or areas as indicated in Table 13. For volumes or areas smaller than those in Table 13, at least one test sample shall be taken.

A sample shall be represented by 5 cores from where at least 3 results have to be considered within the evaluation.

Table 13 — Control of sprayed concrete properties

	Type of test	Inspection/test according to	Minimum sampling frequency								
			Strengthening of ground			Repair and upgrading			Free standing structures		
			Category 1	Category 2	Category 3	Category 1	Category 2	Category 3	Category 1	Category 2	Category 3
Control of fresh concrete											
1	Water/cement ratio of fresh concrete when using wet mix method	See footnote [d]			Daily			Daily			Daily
2	Accelerator	From record of quantity added			Daily			Daily			Daily
3	Fibre content in the fresh concrete	According to EN 14488-7	At least 1 [f]	1/200 m^3 or 1/1 000 m^2	1/100 m^3 or 1/500 m^2	At least 1	1/500 m^2 or at least 2	1/250 m^3 or at least 3	1/200 m^3 or 1/1 000 m^2 or at least 1	1/100 m^3 or 1/500 m^2 or at least 2	1/50 m^3 or 1/250 m^2 or at least 3
Control of hardened concrete											
4	Strength test of young sprayed concrete	EN 14488-2	1/5 000 m^2 or 1/2 months	1/2 500 m^2 or 1/month	1/250 m^2 or 2/month						
5	Compressive strength	EN 12504-1 EN 12390-3	1/1 000 m^3 or 1/5 000 m^2	1/500 m^3 or 1/2 500 m^2	1/250 m^3 or 1/1 250 m^2	1/500 m^3 1/2 500 m^2 or min 1	1/100 m^3 or 1/500 m^2 or min 2	1/50 m^3 or 1/250 m^2 or min 3	1/500 m^3 or 1/2 500 m^2 or min 1	1/100 m^3 or 1/500 m^2 or min 2	1/50 m^3 1/250 m^2 or min 3
6	Density of hardened concrete	EN 12390-7	When testing compressive strength			When testing compressive strength			When testing compressive strength		

	Type of test	Inspection/test according to	Minimum sampling frequency								
			Strengthening of ground			Repair and upgrading			Free standing structures		
			Category 1	Category 2	Category 3	Category 1	Category 2	Category 3	Category 1	Category 2	Category 3
7	Resistance to water penetration	EN 12390-8				1/1 000 m^2 or min 1	1/500 m^2 or min 2	1/250 m^2 or min 3	1/1 000 m^2 or min 1	1/500 m^2 or min 2	1/250 m^2 or min 3
8	Freeze/thaw resistance	See footnote [d]				1/1 000 m^2 or min 1	1/500 m^2 or min 2	1/250 m^2 or min 3	1/1 000 m^2 or min 1	1/500 m^2 or min 2	1/250 m^2 or min 3
9	Bond strength	EN 14488-4 [a] EN 1542 [b]		1/2 500 m^2	1/1 250 m^2	1/1 000 m^2 or min 1	1/500 m^2 or min 2	1/250 m^2 or min 3			
Control of fibre reinforced sprayed concrete											
10	Fibre content of hardened concrete [c]	EN 14488-7	When testing residual strength or energy absorption capacity			When testing residual strength			When testing residual strength		
11[e]	Energy absorption capacity	EN 14488-5	1/2 000 m^3 or 1/10 000 m^2	1/400 m^3 or 1/2 000 m^2	1/100 m^3 or 1/500 m^2	min 1	1/2 000 m^2 or min 2	1/500 m^2 or min 3		1/2 000 m^2 or min 2	1/500 m^2 or min 3
12	Flexural strengths (First peak, ultimate and residual)	EN 14488-3 or EN 14651	1/2 000 m^3 or 1/10 000 m^2	1/400 m^3 or 1/2 000 m^2	1/100 m^3 or 1/500 m^2	min 1	1/2 000 m^2 or min 2	1/500 m^2 or min 3		1/2 000 m^2 or min 2	1/500 m^2 or min 3

[a] For ground strengthening.

[b] For repair.

[c] This test is alternative to the one in line 4 when it is not practical to determine the fibre content from the fresh sprayed concrete.

[d] No European Standard on this issue is available during the publication of this standard. Until the publication of the respective European Standard national standards or provisions apply.

[e] The frequency of testing of energy absorption capacity can be dived by 2 after 6 good results for Category 3.

[f] When a single number is mentioned, it refers to the number of times the test shall be performed. The required number of specimens for each test is specified in the test method standard.

7.5 Conformity criteria

7.5.1 General

7.5.1.1 Early strength development

Conformity of young sprayed concrete early strength development, tested according to EN 14488-2, is obtained if the data points of compressive strength f_c [MPa] vs. time fall in the area of early strength classes as defined in 4.3.

7.5.1.2 Compressive strength

Conformity of sprayed concrete compressive strength is assessed according to Table 14 for:

— groups of "*n*" consecutive individual test results f_{cm} (criterion 1);

— each individual test result f_{ci} (criterion 2);

where each individual test result is the average compressive strength of 5 cores taken from a single test panel or *in situ* location. If the value of one or two cores is more than ±20 % than the average, the result(s) shall be disregarded from the calculation, provided that the average is obtained from at least three cores.

Table 14 — Conformity criteria for compressive strength test results

Production	Number n of test results for compressive strength in the group	Criterion 1	Criterion 2
		Mean of "*n*" results f_{cm} in MPa	**Any individual test result f_{ci} in MPa**
Initial	3	$\geq f_{ck} + 4$	$\geq f_{ck} - 4$
Continuous	15	$\geq f_{ck} + 1{,}48\ \delta$	$\geq f_{ck} - 4$

where

f_{ck} is the characteristic compressive strength;

δ is the standard deviation from at least 6 samples.

Conformity of compressive strength is obtained when both criteria in Table 14 are fulfilled.

7.5.1.3 Resistance to water penetration

Conformity is obtained if mean value of a set of specimens (at least 3 specimens) satisfy the specified limit value.

The value of 50 mm should be considered the maximum value for water resistant concrete.

7.5.1.4 Freeze/thaw resistance

Conformity is obtained if test results satisfy the specified limit value.

NOTE A European Standard is presently not available. Until such time, reference is made to national standards or provisions given in a national Annex to this standard.

7.5.1.5 Bond strength

Conformity of sprayed concrete bond strength is obtained if the mean value of a set of specimens (at least 3 specimens) is not lower than the specified value.

7.5.1.6 Consistence

Conformity of sprayed concrete consistence is obtained if the test results satisfy the limits of the specified class.

7.5.2 Additional for fibre reinforced sprayed concrete

7.5.2.1 Fibre content

Conformity is obtained if the mean value of measured fibre content in fresh concrete from a set of at least 6 samples is not lower than V_f – 10 % by mass, where V_f is the target value for the fibre content specified according to preconstruction testing.

Conformity of steel fibre content in hardened concrete is obtained if the mean value from a set of at least 6 samples is not lower than V_f – 15 % by mass, where V_f is the value obtained from preconstruction tests of sprayed concrete.

NOTE The value of fibre content in fresh and hardened concrete is different due to the application.

7.5.2.2 First peak flexural strength

Conformity of first peak flexural strength is obtained when:

— the mean value of test results obtained from 3 test specimens fulfils the requirement on the first peak strength;

— no individual test result deviates more than ±25 % from the mean value.

7.5.2.3 Ultimate flexural strength

Conformity of ultimate flexural strength is obtained when:

— the mean value of test results obtained from 3 test specimens fulfils the requirement on the ultimate flexural strength;

— no individual test result deviates more than ±25 % from the mean value.

7.5.2.4 Residual strength

Conformity of residual strength is obtained when:

— the characteristic value of test results obtained from 12 test specimens fulfils the requirement for the specified residual strength boundary given in Table 2 or Table 3 up to the deflection limit appropriate to the specified deformation level;

— the mean value of test results obtained from 3 test specimens fulfils the requirement for the specified residual strength boundary given in Table 2 or Table 3 up to the deflection limit appropriate to the specified deformation level;

— no individual test result shall in any point (corresponding to the specified deformation level) show a residual stress that is lower than 10 % of the stress corresponding to the boundary of the specified strength class.

NOTE In this case, the test result is the whole load-displacement curve.

7.5.2.5 Energy absorption capacity

Conformity for energy absorption capacity is obtained on specimens defined in EN 14488-5. Mean value shall have an energy absorption capacity not lower than the specified energy absorption capacity according to the specified class given in Table 4. $F_{el\text{-}max}$ and $F_{post\text{-}crack}$ shall be in conformity with definitions exposed in paragraph 4.5.3.

Annex A
(informative)

Guidelines for definitions, specification and conformity for sprayed concrete

A.1 Introduction

This annex provides guidance and background information on the normative text.

A.2 Scope

The application of sprayed concrete covers the entire field of civil engineering, mining and building construction. It is particularly adapted for work under the following special condition:

— no formwork;

— application in thin layers;

— early strength;

— special construction methods.

A.3 Classification

A.3.1 Guidance related to exposure classes

Exposure classes are determined in accordance with EN 206.

A.3.2 Fibre reinforced sprayed concrete

A.3.2.1 General

The different ways of specifying the ductility of fibre reinforced sprayed concrete in terms of residual strength and energy absorption capacity are not directly comparable.

The residual strength can be prescribed when the concrete characteristics are used in a structural design model.

The energy absorption value measured on a panel can be prescribed when in the case of rock-bolting emphasis is laid on energy which has to be absorbed during the deformation on the rock.

A.3.2.2 Residual strength classes

The specification regarding residual strength is related to the deformation conditions of the rock mass. A higher deformation of the rock will demand higher deflection capabilities of the concrete lining.

The purpose of the different deformation levels (Method A) or ductility requirement (Method B) is to give flexibility to the designers in the choice of deformation required or ductility requirement of the sprayed concrete under service conditions.

The purpose of the different deformation levels is to give flexibility to the designers in the choice of deformation required of the sprayed concrete under service conditions. For the purpose of design, the

deflection limit for deformation level can be considered as equivalent to the one of beam cracked at midspan (e.g. for a beam of 450 mm × 125 mm × 75 mm test according to EN 14488-3).

Three typical rock deformation ranges have been identified:

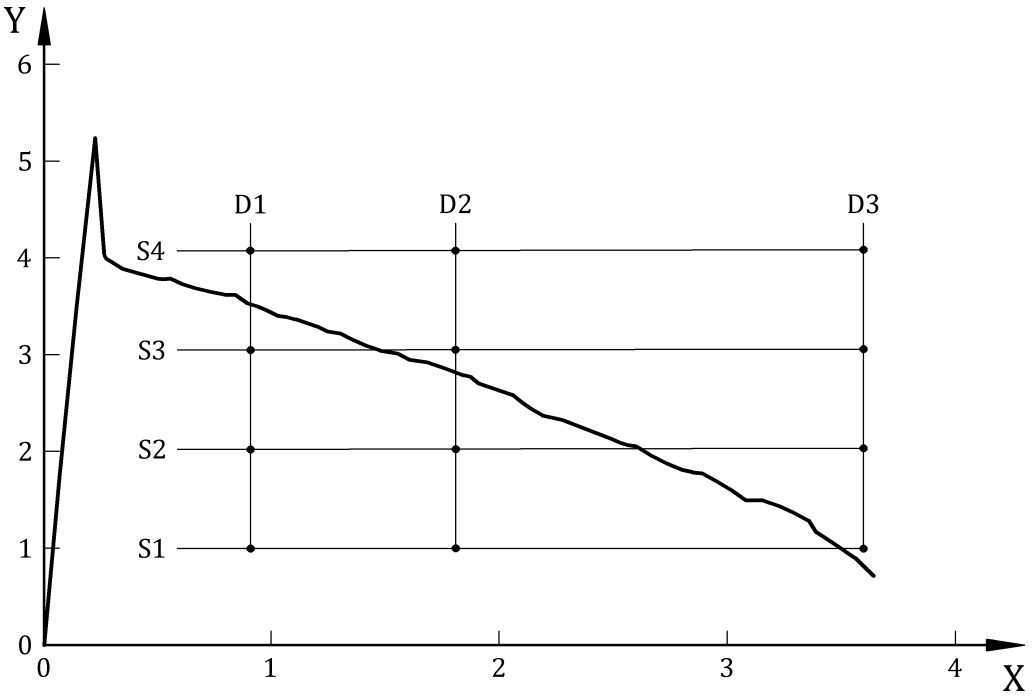
— D1 corresponding with a deflection = l/250 = 0,9 mm;

— D2 corresponding with a deflection = l/125 = 1,8 mm;

— D3 corresponding with a deflection = l/62,5 = 3,6 mm.

Correspondingly four residual strength levels, S1 to S4, are defined which in combination with applicable deformation range, can be specified in terms of residual strength class.

An illustrative example is given in Figure A.1 for a typical fibre reinforced sprayed concrete beam, this beam fulfils the requirement for residual strength class D1S3 and D2S2.



Key

X beam deflection [mm]

Y residual stress [MPa]

Figure A.1 — Typical stress-deflection curve for a beam of reinforced concrete

A.3.2.3 Energy absorption capacity

The plate test is designed to determine the absorbed energy from the load/deformation curve as a measure of toughness. The test is designed to model more realistically the biaxial bending that can occur in some applications, particularly rock support. The central point load can also be considered to replicate a rock bolt anchorage. This test has proved to be of considerable benefit.

The plate test is appropriate in the pre-construction test-program to check all the parameters affecting the fibres reinforced sprayed concrete quality requirements as specified in the project documents. For routine quality control, cube tests to determine strength and wash out tests to check the steel fibre content in-place should be carried out. The plate test is also appropriate for a comparison of different fibre types and dosages and it allows a comparison between mesh-reinforcement and fibre-reinforced concretes, provided that the failure mode is the same.

A.4 Guidance for sprayed concrete

A.4.1 Constituent materials

Cement

It is of particular importance for sprayed concrete to use cements of consistent properties, especially with respect to its chemical composition, fineness and setting behaviour.

If characteristic values as well as requirements to the homogeneity should be defined, the cement supplier and the contractor should agree prior to the start of deliveries.

A.4.2 Guidance for the sprayed concrete composition

A.4.2.1 General

Determination of the basic-mix proportions should consider the fact that the quantity of rebound during application will result in a different proportioning of the applied concrete. The composition, especially the content of the cementitious paste and the water/cement ratio in the basic mix should, therefore, be so designed that the sprayed concrete on site has the quantity of binder necessary to obtain the required characteristics and strength. A high rebound may produce an excessive binder content in the sprayed concrete adhering to substrate. This may result in an excessive shrinkage.

A.4.2.2 Use of cement

The cement temperature should not exceed +80 °C when the cement is delivered from the cement mill and +70 °C when it is filled into the silos of the mixing plant. A higher temperature of the cement delivered from the cement mill is only admissible if precautions to cool the cement before use are taken.

A.4.2.3 Use of aggregates

The use of a properly balanced grading curve is necessary in order to have enough fine material to ensure a good pumpability of the basic mix (wet process) and a balanced amount of coarse aggregate to achieve the compaction, strength and permeability requirements, keeping at a minimum the binder/aggregate ratio (less shrinkage) and to help to reduce the rebound rate.

The use of large coarse aggregates (especially over 10 mm) may result in a higher rebound. The excess of fines in the mix leads to a higher water demand.

A.4.2.4 Use of admixtures

Sprayed concrete accelerating admixtures

Special attention should be given to the compatibility of the sprayed concrete accelerating admixture with the binder with regard to the setting, early and final strength.

With liquid sprayed concrete accelerating admixtures, special attention should be paid to the storage stability and temperature, the working temperature and the compatibility to water added in accordance with the instructions given by the producer.

A.4.2.5 Use of fibres

Because of the possible increased proportion of fibres in the rebound, this needs to be taken into account when choosing the concrete composition.

It is common practice to use steel and polymer fibres up to 30 mm for the dry process and up to 40 mm for the wet process. The length of the fibres should not exceed 75 % of the internal diameter of the pipes or hoses used unless it has been proven that longer fibres can be used without blockage. If the fibres are added in the form of endless wire directly at the nozzle, even longer fibres may be used.

The values for a minimum overlap between fibres may be estimated as:

$$s = \sqrt[3]{\frac{\pi \times d_f^2 \times l_f}{4 \rho_f}} \quad \text{(A.1)}$$

where

d_f is the equivalent diameter of fibre;

l_f is the length of fibre;

ρ_f is the fibre percentage.

s should be lower than 0,45 l_f to ensure a minimum overlap.

NOTE Formula (A.1) and s limit are taken from the thesis of D. C. McKee, University of Louisiana, "The properties of an expansive cement mortar reinforced with random wire fibers".

A.4.2.6 Water/cement ratio

For dry mix sprayed concrete, the water/cement ratio should be assessed by the continuous monitoring of consistence during spraying. In the case of correctly applied sprayed concrete, the water/cement ratio can be expected to be below 0,5. *In situ* water/cement ratios are usually in the range 0,35 to 0,50.

A.5 Specification of sprayed concrete

General

It is common practice to use the designed concrete approach instead of the prescribed concrete.

A.6 Assessment of conformity

Inspection categories

Examples of inspection categories are given in Tables A.1, A.2, A.3 and A.4.

Table A.1 — Categories related to repair and upgrading of non-load-bearing structures and components

Category	Examples of inspection categories
1	Structures with low durability requirements and without risk for users and local residents, such as: construction in un-urbanized zones and far-off traffic ways; temporary repairs in low risk situation.
2	Structures and components with moderate durability requirements and with moderate risks for users and local residents, such as: small buildings, houses; sewers in medium-sized urban areas.
3	Structures and components with high durability requirements and with high risks for users and local residents, such as: rail or road tunnels with heavy traffic; factories classified as high risk, hospitals, schools.

Table A.2 — Categories related to repair and upgrading of load-bearing structures and components

Category	Examples of inspection categories
2	Structures and components with normal design complexity regarding risk of instability or functional safety and with low risks for users and local residents such as: sewers in small urban zones; tunnels, bridges and other structural light traffic circulation; permanent stabilization of slopes.
3	Structures and components with special design complexity regarding risk of structural instability or functional safety as well as high durability requirements and with medium to high level of risk for users and local residents, such as: rail or road tunnels with medium traffic; aqueducts for drinking water; small dams, sewers in medium-sized urban areas, canals; hospitals, schools and high occupancy buildings.

Table A.3 — Categories related to strengthening of ground

Category	Examples of inspection categories
1	Constructions with minor degree of risk in design and structural instability as well as low durability requirements, usually constructions with short design life and low risk of structural instability, such as: small permanent constructions; stabilization for small or temporary slopes or pits.
2	Constructions with normal design complexity regarding risk of structural instability or functional safety as well as constructions with moderate durability requirements/design life, such as: permanent stabilization of slopes; temporary sprayed concrete for tunnels and caverns in poor ground.
3	Constructions with special design complexity regarding risk of structural instability or functional safety as well as constructions with high durability requirements/long design life, such as: caverns in very poor ground; tunnels for traffic.

Table A.4 — Categories related to free-standing structures

Category	Examples of inspection categories
1	Constructions with minor degree of risk in design and structural instability as well as low durability requirements, usually constructions with short design life and low risk of structural instability, such as: decorative imitation rock; surrounding walls.
2	Constructions with normal design complexity regarding risk of structural instability or functional safety as well as constructions with moderate durability requirements and low risks for users and local residents, such as: open-top aqueducts or canals; small swimming pools; decorative imitation rock or sculpture.
3	Constructions with special design complexity regarding risk of structural instability or functional safety as well as constructions with high durability requirements and high risks for users and local residents, such as: small buildings, houses; domes and shells; fire protection for steel structures; large swimming pools; security structures; high imitation rocks receiving public; high climbing walls.

Bibliography

[1] EN 450-1, *Fly ash for concrete — Part 1: Definition, specifications and conformity criteria*

[2] EN 12504-3, *Testing concrete in structures — Part 3: Determination of pull-out force*

[3] EN 12350-3, *Testing fresh concrete — Part 3: Vebe test*