
The new Italian standard on sprayed concrete

DIE NEUE ITALIENISCHE SPRITZBETONNORM

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In der vorliegenden Arbeit wird die neue italienische Norm für Spritzbeton (UNI 10834) vorgestellt. Die italienische Norm wurde erarbeitet, um der auf mehreren Seiten aufgetretenen Erfordernis zu entsprechen, eine Lücke im nationalen Regelwerk für Beton zu stopfen. Die UNI 10834 nimmt weitestgehend die jüngsten, internationalen Richtlinien und Leitsätze auf und stellt ein Dokument dar, das, obwohl es nicht den Anspruch erhebt, enzyklopädischen Charakters zu sein, ein Bezugsdokument bei der Erstellung von Ausschreibungsunterlagen zum Tunnelbau darstellen kann. Darüber hinaus stellt es einen nützlichen Beitrag im Rahmen der Ausarbeitung der entsprechenden, europäischen Richtlinie dar, die zur Zeit aufgesetzt wird.

The new Italian standard on sprayed concrete (UNI 10834) is presented in this paper. The Italian standard was drawn up to satisfy the need, which has arisen from various sources, to fill a gap in the national standard framework on concretes. UNI 10834 mostly deals with the most recent international standards and guidelines. This document, though not purporting to be encyclopaedic, can serve as a reference document when laying down specifications relative to underground works and be a valid contribution to the production of the European standard presently being drawn up.

1. Introduction

As is well known, spraying is a special technique used to apply mortars and concretes that is normally used in Civil Engineering works in particular conditions such as, for example, in the absence of formworks.

The technique for the spraying of the cementitious mixes is usually considered to have originated in 1907 [1], however, it was only with the beginning of

the Sixties that it began to be widely used as a temporary protection system for excavation surfaces. At present, with the development of ever more refined design methods, sprayed concrete can be used not only for temporary works but also for permanent ones and with structural functions.

Faced with the growing use of sprayed concrete, the necessity has risen in several countries to define guidelines and/or summarize the state of the art in standard documents so as to establish a reference

framework for the various professional and entrepreneurial figures, (from the designer to the customer), involved in the building process.

ACI (the American Concrete Institute) set up the first commission on sprayed concrete in 1942 [2]; it was again set up in 1960 as Commission 506, with the purpose of drawing up the recommendation "Recommended Practice for Shotcreting". At present ACI recommendations are available concerning sprayed concrete guidelines [3], the state of the art concerning fibre-reinforced spraying [4], the specifications on the materials [5]; in addition particular ASTM regulations have been drawn up concerning concrete spraying [6-10]. In recent years standards and recommendations on sprayed concrete have been issued in different European countries [11--23]; the EFNARC (European Federation of National Associations of Producers and Applicators of Special Products for Structures) document [24] is also of particular importance in the role of support that this Association performs in the ambit of European standards.

As far as Italy is concerned, already back in 1975 the Società Geotecnica Italiana (Italian Geotechnical Society) published a wide and detailed technical report [25] on the spread of the knowledge of the specific characteristics of sprayed concrete and of the relative application techniques; this document however did not result in the desired evolution of the drawing up of a specific Italian standard. In the absence of a national standard document, a first proposal of an Italian standard was published [26] in which the particular importance of the preliminary conformity control of the mix before the start of execution works was underlined; the duties and responsibilities of the designer, the company and the work management were all defined in this proposal. In the middle of the Nineties, on the suggestion of the SIG (Società Italiana Gallerie) work group "The Use of Sprayed Concrete", UNICEMENTO included concrete spraying as one of its themes; the competent work group, in the absence of a specific CEN standard on the subject, considered it opportune to draw up a national document. The work of the Italian Work Group finished at the end of 1997 and the standard on sprayed concrete (UNI 10834) was published in October 1999.

In the meantime, the CEN/TC 104/WG10 Work Group was set up and its work is still under way. The objectives and most important points of UNI 10834 "Sprayed concrete" are illustrated in this report.

2. The objectives and the structure of UNI 10834

UNI 10834 is a product standard and, as such, it has the objective of defining and classifying the material, establishing the requirements and the controls before and after spraying and setting down the acceptance criteria; UNI 10834 is also a production standard in that it sets forth provisions and supplies basic indications on the production methods and the application of sprayed concrete.

The standard is sub-divided into the following sections:

- introduction;
- scope and field of application;
- definitions;
- classification;
- characteristics of the constituents;
- requirements, controls on the concrete before and after spraying;
- production;
- test methods;
- acceptance criteria;
- recommendations on and safety of the work environment;
- Appendixes (standards):
 - A. Tests on hardened sprayed concrete - determination of the absorption of the deformation energy;
 - B. Sampling and control plan during execution works;
 - C. Tests on fresh sprayed concrete;
 - D. Dosage of the metallic fibre in fibre-reinforced sprayed concrete;
 - E. Dosage of the polymeric fibres in sprayed concrete.

3. Definitions

In UNI 10834 sprayed concrete is defined in relation to its composition, specifying that, apart from the well known constituents of ordinary concrete (cement, aggregates, water and possible additions and/or additives according to UNI EN 206), either metallic or polymer fibres can be present. In the section on the definitions it is also particularly specified that the application has to be made through spraying, with a nozzle, onto the application surfaces in order to obtain a compact and homogeneous mass.

One of the peculiar characteristics of sprayed concrete is its capacity to bear, even in a very short term, not only its own weight but also external loads that derive, for example, from slope or rock mass deformations. As a consequence, UNI 10834 has defined fresh sprayed concrete (with an age up to

24 hours after spraying) distinguishing it from hardened sprayed concrete which is characterised by an age greater than 24 hours after spraying. The requirements and the controls before spraying refer to the basic mix whose definition therefore proved necessary in terms of mix made up of cement and aggregates; it can be at the dry state or mixed with water, and can contain fibres, additions and/or admixtures. The basic mix does not contain any spraying admixtures, unless we are dealing with dry pre-mixed products.

4. Classification

As already mentioned, one of the essential characteristics of sprayed concrete is that of developing mechanical strength even at early ages. The classification of fresh sprayed concrete in relation to the development of its mechanical strength, shown in table 1, therefore appears to be of fundamental importance.

Age [hours]	Normal development [MPa]	Quick development [MPa]
1	≥ 0.2	≥ 0.5
6	≥ 0.7	≥ 1.5
24	≥ 2.0	≥ 5.0

Tab. 1: Classification of fresh sprayed concrete in relation to the development of strength up to 24 hours after spraying

The classification shown in table 1 basically acknowledge the classification of fresh sprayed concrete as indicated in the Austrian guidelines[19]. It should be pointed out that UNI 10834, having defined the ages at which mechanical strength should be estimated, results to be more stringent than the previously mentioned guidelines, in which a higher class is nevertheless foreseen. In UNI 10834 further requirements about strength development rate is left to the design specifications.

As far as hardened sprayed concrete is concerned, UNI 10834 foresees, in analogy with UNI EN 206, its classification on the basis of the cubic characteristic compressive strength.

In comparison to what is indicated in the standards for ordinary concrete, UNI 10834 is substantially different in that the reference strengths are not evaluated on laboratory specimens but on cored specimens taken in situ or from panels. In this respect, relation (1), which is given in UNI 10834, allows the estimation of the cubic strength R_c [MPa], once the compressive strength f_l [MPa] of the cored specimens and their slenderness ratio ($l = h/d$, where h = height, d = diameter) are known; in or-

der to take into account the effect of the disturbance caused by the coring operations and specimen preparation, the cubic strength R_c is increased by 20%.

$$R_c = \frac{2.5}{1.5 + 1/\lambda} \times f_l \tag{1}$$

It is hardly worth mentioning that structural sprayed concrete should satisfy the provisions set for reinforced concretes, as defined by current legislation [27].

Sprayed concrete is classified by UNI 10834, according to the indications in table 2, in relation to the final uses. This classification is particularly important as the sampling and control plan (Appendix B of UNI 10834) of sprayed concrete is defined as a function of the class of final use; the exposure class according to UNI EN 206 can also be defined in relation to the final use.

A requirement that is frequently posed to sprayed concrete is the ability to absorb deformation energy following the displacement imposed by ground or rock masses. This characteristic, which can be defined as toughness, is imparted to the material through a fibre reinforcement that is homogeneously distributed across its mass. In the UNI 10834 report, it was therefore considered opportune to also classify the material under this important aspect.

	Final Use	Code	Typical uses
Temporary	Non structural	TN	- Foundations - Embankments - Temporary slope protection - Surface protection - Protection of excavation surface in tunnels
	Structural	TS	- Bypass tunnels - Side walls - Surface protection - Protection of excavation surface in tunnels
Permanent	Non structural	PN	- Embankments - Slope protection - Waterproofing
	Structural	PS	- Single-shell structures - Repairs, restructuring and linings in general

Tab. 2: Classification of sprayed concrete as a function of its final use

The determination of the deformation energy is made through the well known plate method [24]. The test is carried out by applying a load on a sprayed concrete plate, according to the scheme that is illustrated in figure 1.

The curve relative to the cumulative energy, calculated by integration of the load-displacement curve, absorbed by the plate up to a displacement value of 25 mm (figure 2) may be then plotted. The classifi-

cation of sprayed concrete, in relation to the absorption of the deformation energy, is shown in table 3.

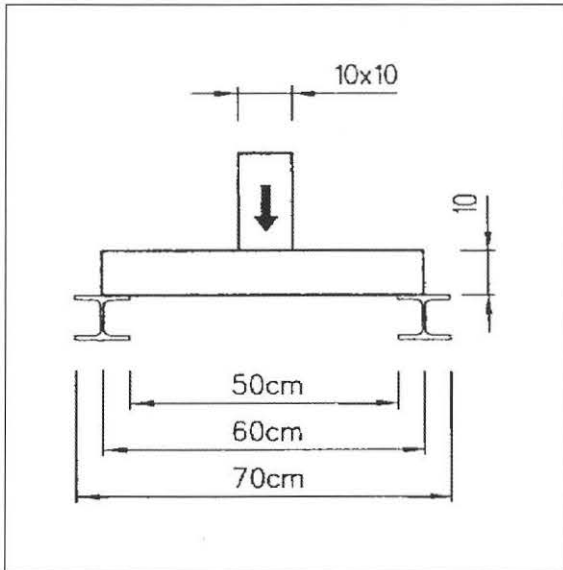


Fig. 1: Test loading scheme.

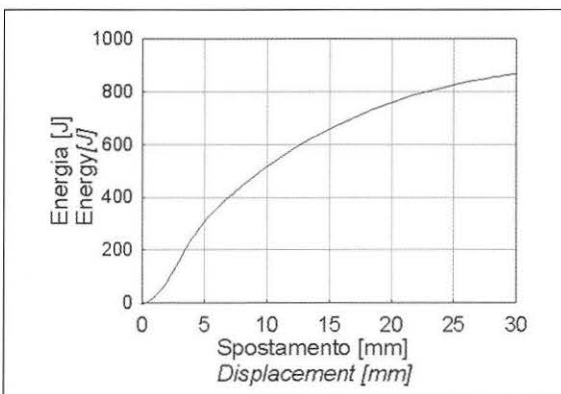


Fig. 2: Absorbed energy - displacement curve

The absorbed energy determination method should, in the near future, be integrated with the method established by the UNI E07001292 standard project "Concrete reinforced with steel fibres - Part II - Test method for the determination of the first cracking strength and of the ductility indexes". The characterisation of the material is dealt with in the latter method, working on prismatic samples (beams) on which are determined quantities that are useful for classifying the material and performing structural calculations [28].

5. Characteristics of the constituents

UNI 10834 defines the characteristics of the sprayed concrete constituents and provides some indications on the composition of the mixture; the most important provisions concern:

Class	Deformation energy [J] absorbed up to a displacement of 25 mm
A	< 500
B	≥ 500
C	≥ 700
D	≥ 1 000

Tab. 3: Classification of hardened sprayed concrete in relation to the absorption of the deformation energy

Cement: should conform to UNI EN 197-1, if used for sprayed concrete for structural uses; the use of special cements or binders not included in UNI EN 197-1 is allowed, on condition that their suitability has been verified through preliminary tests.

Aggregates: their maximum dimensions should be chosen in relation to the type of application; in the case in which the maximum diameter is greater than 8 mm, the supply should be constituted by at least two granulometric classes.

Water: should respond to the requirements contained in prEN 1008

Admixtures for the basic mix: are basically plasticising admixtures and should conform to the provisions of the following regulations UNI EN 934-1, UNI 709, UNI 7120 and UNI 10765.

Additions for the basic mix: in order to improve some characteristics of concrete at the fresh and hardened state, such as cohesivity or resistance to aggressive chemical agents, mineral additions can be added (usually fly-ash and silica fume) as long as they conform to UNI EN 206 and UNI 8981-2.

Pigments: are permitted as long as they do not cause harmful reactions.

Fibres (polymeric and/or metallic): as is well known the fibres are basically added to the cement pastes to improve characteristics at the fresh state (resistance to shrinkage-induced micro-cracking) and at the hardened state (toughness - deformation energy); in the absence of specific standards on fibres, it has not been possible to indicate the requirements that they should satisfy UNI 10834. However it should be pointed out that at the moment the UNI standard on steel fibres is being published (E16.11.442.0 - Steel fibres to be used in the manufacturing of reinforced concrete").

Spraying admixtures: should conform to prEN 934-5. Setting and hardening accelerating admixtures have the purpose of thickening the fresh mix and

causing a rapid development of strength. The dosage of the spraying admixtures should never be greater than 12% of the cement mass; 28 day-strength should not be reduced by more than 75% of that found in the samples obtained from panels prepared with the reference sprayed concrete (sprayed basic mix). Alkali-free admixtures can be used for technical and environmental reasons. Alkali-free admixtures should have an equivalent alkali content ($\text{Na}_2\text{O} + 0.64 \text{K}_2\text{O}$) that is lower than 1% by mass.

6. Requirements before and after spraying

Taking into account the analogies with ordinary concrete, the design of the basic mix should be carried out in consideration of the required performances and of the environmental working conditions. The basic mix, apart from satisfying the provisions of UNI EN 206, should also respect the following provisions:

- in the case of dry mix process, the aggregate/cement ratio in mass should be lower than 6;
- in the case of wet mix process, the cement content should be $\geq 300 \text{ kg/m}^3$.

As far as hardened sprayed concrete is concerned, the essential performance requirements, which should be indicated in the design specifications, are:

- strength class and development;
- deformation energy absorption class (toughness).

7. Controls before, during and after casting

Checks are foreseen on the basic mix and on the hardened sprayed concrete according to the sampling frequency (Appendix B of UNI 10834) which depend on the class of final use given in table 2.

7.1 Controls before projection

The controls concern:

- basic mix for the dry mix - process;
- basic mix for the wet - mix process.

7.2 Controls during the projection:

The controls concern:

- the dosage of the spraying admixtures;
- the assessment of rebound losses.

7.3 Controls after projection:

According to UNI 10834, the controls should be carried out both on fresh and hardened sprayed concrete.

Fresh sprayed concrete: for expected strength values not exceeding 15 MPa, indirect methods are used that allow an estimation of the compressive strength through penetration measurements with a modified penetrometer and/or measurements related to shot/extraction of bolts (studs).

Modified penetrometer method: for estimated strength values of the sprayed concrete ranging between 0.2 MPa and 1.2 MPa, a penetrometer, made up as described in UNI 7123, is used which is supplied with a needle point of (3 ± 1) mm in diameter with an opening of (60 ± 1) mm or of cylindrical probes with flat ends with surfaces of about 65 mm^2 . The procedure consists in measuring the force necessary to introduce the needle point or the cylindrical probe to a pre-set depth value (15 ± 2) mm. The estimation of the compressive strength, with reference to a cylindrical concrete specimen, should be made through suitable experimental calibration curves. In their absence, strength can be estimated using the correlation lines shown in figures 3 (a) and (b) which refer, respectively, to concrete with

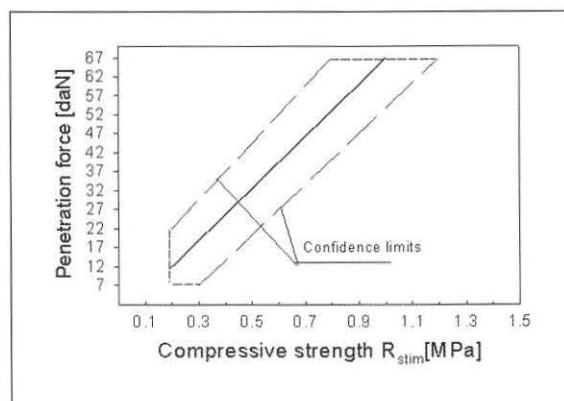


Fig. 3-a: Calibration line for the needle penetrometer for concretes with having aggregates with Φ_{\max} 8 mm.

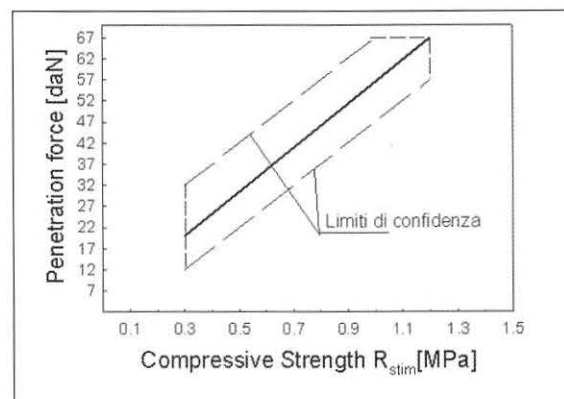


Fig. 3-b: Calibration line for the needle penetrometer for concretes with having aggregates with $\Phi_{\max} \leq 16$ mm.

aggregates with a maximum diameter of 8 mm and concrete with aggregates with a maximum diameter of ≤ 16 mm.

Shooting and extraction of studs: if the estimated strength value of the sprayed concrete falls between 2 MPa and 15 MPa, a safety stud driving gun, equipped with explosive cartridges that are able to push the stud at an initial velocity of between 50 m/s and 70 m/s (power code 0.2), is used; the studs should have a pre-fixed length of 52 mm or 72 mm. The test consists in shooting at least 8 studs in sequence; if, after the shooting, the longest available stud completely penetrates the concrete, the test should be suspended and it is necessary to wait sufficient time before continuing the test. If the stem of the stud protrudes from the surface too much, it is necessary to use the shorter stud. The following shooting should be at a distance greater than or the same as (100 ± 10) mm from the adjacent one. After shooting, knowing the length of the stem of the stud, the part of the stud that protrudes should be measured so as to calculate - by difference - the extraction depth value equal to l . The studs are then extracted using a suitable extractor. The extraction device should be provided by a calibration curve that is able to supply the correct value of the extraction load (E_{cor}) with the read loading value. The value of E_{cor} is determined for each stud and the mean value is calculated. In the case where no experimentally determined calibration curve for the compressive strength (R_{stim}) of the sprayed concrete is available, the expressions given in table 4, which compare the (E_{cor}/l) ratio with the estimated strength R_{stim} , can be used.

for calcareous aggregates		for siliceous aggregates
with $\Phi_{max} \leq 8mm$	with $\Phi_{max} \leq 16mm$	with $\Phi_{max} \leq 8mm$
$R_{stim} = \frac{E_{cor}}{l} + 2.7$	$R_{stim} = \frac{E_{cor}}{l} + 0.02$	$R_{stim} = \frac{E_{cor}}{l} - 3.32$
$R_{stim} = \frac{E_{cor}}{7.67}$	$R_{stim} = \frac{E_{cor}}{6.69}$	$R_{stim} = \frac{E_{cor}}{5.13}$

Tab. 4: Relations for the calculation of the compressive strength (R_{stim}) in function of the (E_{cor}/l) ratio

As far as hardened sprayed concrete is concerned: UNI 10834 foresees the characterisation of sprayed concrete at the hardened stage through the following controls:

Compressive strength

the compressive strength should be determined according to EN 12390-3 on specimens obtained according to EN 12504-1 in situ or from test panels;

the specimens that have to be tested at an age of 1 day should not be extracted earlier than 20 hours from concrete spraying and, however, not before a compressive strength equal to 10 MPa has been reached, while those destined to subsequent testing ages should be extracted at least 48 hours after concrete spraying.

Absorption of deformation energy:

the tests should be performed on plates with (600 ± 5) mm sides, as previously described.

Secant compressive elastic modulus:

the tests should be performed on samples according to UNI 6556.

Resistance to freezing/thawing cycles:

the tests should be performed according to UNI 7087.

Fibre content:

the dosage of the metallic and polymer-based fibres is determined both on fresh sprayed concrete, through the separation of fibres, and on hardened sprayed concrete, where it is only possible to determine the metallic fibres through the thermal disintegration of the concrete itself.

Thickness:

Controls can be carried out by inserting gauges (thickness templates) into the support at pre-fixed distances or through direct measurement on samples obtained in situ.

8. Production

As far as the manufacturing of sprayed concrete is concerned, UNI 10834 supplies provisions concerning the moisture content of the aggregates, which should not be greater than 6% in the case of dry mixes, and concerning the mixing and working temperature, which should be between $(5 \pm 2)^\circ\text{C}$ and $(35 \pm 2)^\circ\text{C}$.

The indications and the provisions concerning the equipment for the concrete spraying basically concern:

- the pump;
- the nozzle;
- the batcher of the admixture for the concrete spraying.

Finally, useful indications are given on concrete spraying procedures (distance between the nozzle and surfaces to be treated, orienting of the nozzle with respect to the support, etc.).

9. Conclusive remarks

The Italian Standard on Sprayed Concrete (UNI 10834) has been drawn up to satisfy the requirement, that has emerged from different sources, to fill the gap that exists in the national standard framework on concretes.

Though not purporting to be exhaustive, UNI 10834 deals with the essential indications of the most recent international standards and guidelines; it also constitutes a reference document, which has already been checked, for the laying down of the building specifications that are concern in particular underground and tunnel works.

The availability of a national document allows one to make a constructive contribution to the drawing up of the relative CEN standard.

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