



EUROPEAN SPECIFICATION FOR SPRAYED CONCRETE

EXECUTION OF SPRAYING

(revised version of Section 8)

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In each product area it operates through specialist Technical Committees which have been responsible for producing Specifications and Guidelines which have become recognised as essential reference documents by specifiers, contractors and material suppliers throughout Europe and beyond.

Acknowledgements

EFNARC wishes to acknowledge gratefully the extensive work undertaken by members of its Sprayed Concrete Technical Committee.

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Foreword

The “European Specification for Sprayed Concrete” was published in 1996 following a draft that had been produced three years earlier. During the intervening period, over 1000 copies of the draft version had been circulated and the comments received were taken into account in the final published specification. The Specification has since been used widely and has rapidly become a standard reference document in the industry around the world.

As its use has developed, EFNARC has received requests for the Specification clauses relating to the Spraying operation to be expanded, in order to allow a greater degree of assurance of the quality of the sprayed work. This additional Specification replaces the whole of section 8 in the Specification, but must be read in conjunction with all the other requirements of that Specification.

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8 Execution of Spraying

8.1 Preparatory work

Preparatory works and any additional measures necessary to secure proper functioning and quality of the sprayed concrete shall be completed prior to the application of sprayed concrete. Prior to the beginning of the Works, the nozzleman shall receive the method statement necessary to carry out the sprayed concrete application correctly.

8.1.1 Substrate

Sprayed concrete shall not be placed on substrates having temperatures below +2°C or on substrates exposed to strong winds or heavy rainfall without special precautions being taken.

The substrate for sprayed concrete can be any load-bearing structure capable of withstanding the impact of the sprayed concrete jet, e.g. rock, ground, earth, masonry, concrete, wood, metal, plastic, formwork or insulation. If the sprayed concrete is to be applied properly and bond well to the substrate, the latter shall be sufficiently robust and not deflect or vibrate.

Surface structure, strength and cleanliness of the substrate are all essential for effective adhesion of the sprayed concrete. The surface shall be damp, but without free water prior to the application of sprayed concrete.

8.1.2 For rock support

Rock shall be freshly broken, solid and clean.

Before the application of sprayed concrete, rock surfaces and/or existing sprayed concrete shall be cleaned, as far as the local conditions permit, with an air-water mixture as necessary to remove all material which may prevent proper adhesion to the surface.

No pressurised water shall be coming through the substrate at the time of spraying.

Action shall be taken to control groundwater and prevent it adversely affecting the sprayed concrete lining. Measures adopted shall be to the approval of the Engineer and remain effective for at least 28 days after spraying. Water inflows which might cause deterioration of the sprayed concrete, or prevent adherence, shall be diverted or controlled.

8.1.3 For concrete repair

Removal of concrete

All loose, defective and condemned concrete shall be removed as follows:

- In the event of carbonation the concrete shall be removed to a depth of at least 20 mm behind the rebars to allow complete re-encasement, and 50 mm into non-carbonated concrete at the edge boundaries.

- In the case of the chloride content being above the critical limit (see 6.2), the concrete shall be removed to a depth of at least 30 mm behind rebars, and 100 mm into concrete with a chloride content below the critical value at the edge boundaries.
- In the case of concrete that has been exposed to fire, all concrete subjected to temperatures above +300°C shall be removed. If the resulting exposed concrete contains chlorides, the above section on chloride contaminated concrete shall apply.

All poorly compacted concrete and accumulations of coarse aggregates shall be removed. Should defects exceed the limitations given in the Specification or for heavily corroded rebars, the Engineer shall be notified immediately.

The edges of a cut out section shall form an inward sloping angle of approximately 45° from the adjoining external surface.

If the rebar perimeter is exposed by more than 50% or if it is debonded, the concrete shall be removed to a minimum depth of 20 mm behind the rebars.

Following mechanical break-out the concrete surface shall be cleaned by air blasting.

Removal of the concrete shall be performed without damage to the reinforcement or the remaining concrete. The method of demolition shall be approved by the Engineer.

Only hand operated pneumatic hammers shall be permitted.

Robotic hydrodemolition equipment shall only be used with the approval of the Engineer.

Hand operated hydrodemolition equipment shall be of the non-recoil type equipped with a 'fail-safe' handle.

Rebars

Unless otherwise stated, exposed rebars shall be cleaned to Swedish Standard Sa 2.

Formwork

The formwork system shall be capable of withstanding the load imposed by the concrete and shall be designed to avoid entrapment of rebound.

8.1.4 Quantities

Prior to the application of sprayed concrete, the rock quality and area shall be assessed and recorded, in order to establish the required volume of concrete.

8.1.5 Approvals

Sprayed concrete shall not be applied to any substrate without the prior approval of the Engineer. The Contractor shall give to the Engineer, in writing, an agreed period of notice in writing of his intention to spray, except for reasons of safety of the Works in which case the circumstances shall be reported to the Engineer without delay.

8.2 Spraying operations

8.2.1 Spraying technique

Each layer of sprayed concrete shall be built up by making several passes of the nozzle over the working area using good working practices and nozzle manipulation. The sprayed concrete shall emerge from the nozzle in a steady and uninterrupted flow, at right angles to and at the correct distance from the substrate. Should the flow become intermittent for any cause the nozzleman shall direct it away from the work until it again becomes constant.

For vertical and near vertical surfaces application shall commence at the bottom. Where thick layers are applied, the top surface shall be maintained at a slope of approximately 45 degrees. For curved overhead surfaces sprayed concrete shall preferably be applied from the shoulder to the crown.

Each layer shall be given sufficient time to set before the next is applied (refer to Appendix 1, table 2 and to 8.2.6). Loose material and rebound shall be removed. The surface shall be checked for soundness as well as cleaned and wetted using a blast of air and water. In the absence of compelling reasons to the contrary, such as the rapid application of the thickest possible layers for support in tunnel headings, it is advisable to build up the prescribed concrete thickness from as few thin layers as possible.

The following requirements also apply:

- the substrate to be sprayed shall be free from dust, cement slurry, oil or free water.
- if necessary, wetting of the substrate shall be performed to control suction.
- prior to spraying, the equipment and the operator shall be approved by the Engineer.
- when starting the spraying operation, the nozzle shall be directed away from the Works until the mix is correctly adjusted.
- normally, the nozzle shall be kept at a distance of 0.5 to 1m from the receiving substrate and directed perpendicularly to it.
- on vertical or sloping surfaces spraying shall start at the lower point.
- adjoining areas shall be adequately protected against overspray.

8.2.2 Treating of defects

Pockets, sags or other defects shall be cut out and re-sprayed. The area of re-spraying shall be not less than 300 mm x 300 mm.

8.2.3 Finishing

Unless otherwise specified, finishing actions, such as trowelling or screeding, should be avoided. Where the contract requires treatment (trowelling), this shall be carried out only by using a flash-coat technique. No surface treatment may take place until the previous layer has reached an adequate strength. Immediately after finishing the final layer, a curing agent or other approved curing method shall be applied to protect the surface from drying out. Where a subsequent surface coating is required, curing membranes shall be removed prior to its application.

8.2.4 Disposal of rebound

No rebound material shall be covered with sprayed concrete. All rebound material shall be removed from the working area and shall not be used in the Works. Disposal of rebound shall be in accordance with the Contract and with proper regard to the risks of environmental pollution.

8.2.5 Embedment of reinforcement for rock support

Where no other thickness is specified, lattice girders and/or embedded steelwork shall be covered by at least 30 mm of sprayed concrete.

8.2.6 Spraying for repair works

For concrete repair works both wet and dry concrete spraying can be used. For wet spraying, the general requirements given in other sections apply. For repair work spraying the following requirements also apply:

- prior to commencement of the actual repair works, a test area shall be completed to verify proper embedding of rebars and surface quality.
- dry spraying: The equipment shall be of a type to allow continuous regulation of the output with proportional adjustment of water and dry material in order to obtain proper embedment of the rebars.
- when spraying behind rebars, the nozzle shall be held closer to the substrate and at an angle to ensure total encapsulation of the reinforcement and to avoid any entrapment of rebound.
- concrete shall be applied to the level of the surrounding concrete or until the specified cover is obtained. If necessary, formwork shall be used to restore the original shape.
- if the clearance between rebars is less than 50 mm, special measures shall be taken (only for dry spraying), such as increasing the w/c ratio, lowering the output and reducing the distance between the nozzle and the substrate.

For finishing, refer to 8.2.3.

8.2.7 Proficiency of operators

Nozzlemen shall be competent and shall have had previous documented experience in the application of sprayed concrete, or shall work under the immediate supervision of the foreman or instructor with such experience. Production sprayed concrete shall be applied only by nozzlemen who have successfully demonstrated their competence and their ability to produce either plain sprayed concrete or steel fibre reinforced sprayed concrete complying in all respects with this Specification.

8.2.8 Site trials

8.2.8.1 General

Site trials shall normally be required. An exception may be made when an approved proprietary bagged material with a proven track record is to be used.

8.2.8.2 Timing

Site trials shall be started sufficiently early to ensure that the required sprayed concrete mixes are developed and all trials completed satisfactorily by the time spraying of each sprayed concrete type commences in the Works. Spraying of any sprayed concrete type shall not commence until the relevant trials and results of laboratory tests have been completed to the satisfaction of the Engineer.

8.2.8.3 Equipment and materials

The Site Trials shall employ the equipment that is to be used in the Works and the constituent materials should be fully representative of those to be used in the Works.

8.2.8.4 Production of test panels

For each type of sprayed concrete to be used a trial mix may be designed by the Contractor and prepared with the constituent materials in the proportions proposed for use in the Works. Sampling and testing procedures shall be in accordance with Section 10.1 of this Specification. A clean dry mixer shall be used and the first batch discarded.

From the trial mix, an experienced nozzleman shall prepare sufficient test panels. Each panel shall be at least 1000 x 1000 mm in size for robot spraying and at least 600 x 600 mm for hand spraying and shall have a thickness of at least 100 mm. The panels shall be prepared by spraying into vertical moulds. Moulds shall be as detailed in Section 10.1 of this specification. The sprayed concrete in the panels shall adhere well to the backform, be properly compacted and exhibit no sagging.

The panels shall not be moved for 18 hours after spraying and shall be stored without disturbance at a temperature of $20\pm 5^{\circ}\text{C}$ and be covered by polythene sheet until the time of coring.

8.3 Equipment

8.3.1 General

All equipment used for batching and mixing of materials and the application of all types of sprayed concrete shall be of designs approved by the Engineer and shall be maintained in proper working order for the duration of excavation and lining works. Full details of all equipment to be used shall be provided to the Engineer prior to commencement of site trials. The spraying machine and ancillary equipment shall be of an adequate capacity for the volumes to be applied. Equipment shall be leak-proof with respect to all materials.

Spraying equipment shall be capable of feeding materials at a regular rate and ejecting sprayed concrete mixes from the nozzle at velocities that will allow adherence of the materials to the surface being sprayed with a minimum of rebound and maximum adhesion and density.

Equipment shall be thoroughly cleaned at least once per shift, or at other appropriate intervals if hydration control admixtures are used, to prevent accumulations of residual deposits.

Transport pipes consisting of hoses or pipes shall be laid straight or in gentle curves. They shall have a uniform diameter appropriate to the mix and fibre characteristics determined by site trials, and shall be free of any dents or kinks.

Working areas for spraying shall be well illuminated to the approval of the Engineer. Caplamps attached to safety helmets are not acceptable as sufficient illumination.

8.3.2 For the wet-mix process

Equipment for the wet-mix process shall be set up according to the recommendations of the manufacturer.

The nozzle should be designed for the addition of

- Necessary liquid admixtures (sprayed concrete set accelerators or activators)
- Pressurised air to obtain speed and high compaction of the concrete.

Liquid admixtures should be mixed with the compressed air within the nozzle prior to being mixed with the concrete. The nozzle should be sufficiently long to utilise the compressed air energy and should be secured against fluttering and vibrations.

Air for the equipment has to be clean, dry and oil free and to be continuously provided at the equipment at not less than the operating pressure and volume rates specified by the manufacturer.

8.3.3 For the dry-mix process

Equipment for the dry-mix process shall be set up according to the recommendations of the manufacturer and be designed so that dust is kept at the lowest possible level.

The nozzle shall be capable of allowing full and continuous control of the quantity of water to be added as well as ensuring effective mixing of all sprayed concrete ingredients. It shall be designed to transform the flow of dry materials into a mouldable concrete without reducing the velocity and to spray the concrete against the substrate to compaction. The nozzle shall be equipped with at least one ring for injecting water perpendicularly into the material flow.

In addition, the nozzle shall allow addition and accurate mixing of additives/admixtures. It shall be equipped with a throttle valve to allow adjustment of the water and a shut-off valve.

Air for the equipment has to be clean, dry and oil free and to be continuously provided at the equipment at not less than the operating pressure and volume rates specified by the manufacturer.

8.3.4 Dosing of sprayed concrete set accelerating admixtures

A set accelerating admixture shall be dispensed through a proportioning pump. Dosing of admixtures by hand is not permitted.

Each machine provided for the wet-mix process shall incorporate an integrated proportioning unit to dispense admixtures at the required dosages.

When an admixture is being used, dry-mix process equipment shall incorporate an integrated proportioning pump to dispense liquid admixtures into the water supply to an accuracy of $\pm 5\%$ of the required dosage and this shall be calibrated and operated in accordance with the manufacturer's instructions.

Accelerators should be stored such that exposure to frost and contamination is prevented.

8.4 Application of wet-mix sprayed concrete used for rock support

- Prior to spraying, the rock surface shall be inspected and mapped and the types of rock support be determined.
- The surface shall be cleaned by compressed air and water through the nozzle.
- In the surface cleaning procedure, cleaning shall start at the uppermost section and work downwards. The surface shall be monitored during the cleaning operation to ensure that it is thorough.

8.5 Means of access

All access equipment, including scaffolding and lifting platforms, shall meet local safety requirements.

8.6 Curing

All sprayed concrete shall be properly cured using methods and materials to the approval of the Engineer in order to limit cracking due to plastic shrinkage, early thermal contraction and long term drying shrinkage and to ensure effective bond between layers of sprayed concrete by preventing premature surface dehydration. The use of internal curing compounds shall be subject to the requirements of Appendix 1: 3.6, 4.1, 4.2, table 5.

If sprayed curing agents are proposed where a further layer of sprayed concrete is to be applied, site trials of the bond between layers as agreed with the Engineer shall be carried out using the approved mixes and methods of working before such agents should be used in the Works.

Curing shall commence within 20 minutes of completion of each spraying operation if sprayed concrete set accelerating admixtures are used and within 1 hour when sprayed concrete set accelerating admixtures are not used. Curing shall be continuous and for a minimum period of 7 days.

8.7 Protection against frost

Sprayed concrete shall be protected against frost until it has reached a compressive strength of at least 5 MPa.