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FOREWORD

This Introduction to Sprayed Concrete is issued by the Sprayed Concrete Association based in the United Kingdom.

It is intended to be used by industry professionals who may require practical knowledge of the techniques of sprayed concrete for the first time. It is not intended to be a comprehensive Specification or Standard. (Those documents are available and listed on pages 29-31.)

This publication covers the broad range of processes that are commonly used together with descriptions of the more commonly used materials available in the marketplace. It will refer the user to the best ways of carrying out these processes safely and with the expectation of a high quality end product.

It will encourage the use of a member of the Association for advice, design, supply and application of the sprayed concrete.

THE ASSOCIATION

In 1976 a small group of the United Kingdom's leading sprayed concrete contractors came together to form the Association of Gunite Contractors. This group of skilled and like minded experts were all committed to a common set of aims:

- to encourage and promote the use of sprayed concrete
- to develop and maintain codes of practice and specifications
- to develop, encourage and maintain links with other interested bodies both nationally and internationally
- to encourage and promote, through regular meetings, publications, conferences and exchange of views advances in the technology of sprayed concrete.

In 1986 the Association changed its name to the Sprayed Concrete Association.

Since 1976 the Association has worked hard to achieve its aims. It has fostered a much better understanding of the benefits of sprayed concrete. Initially contractor led, the Association now includes a comprehensive list of Associate Members including major industrial companies involved in the manufacture of materials and the supply of specialist plant.

The Association also includes a number of Consultant Members, many of whom have spent much of their working careers involved in the specification, design and execution of sprayed concrete.

Links are closely maintained with overseas contracting members thereby enabling the Association to call upon a full range of expertise and experience.

The full list of members is published as a directory and updated every two years. This book details each Members' area of expertise and their areas of operation.

Working within a very busy industry with ever tighter deadlines demands a high degree of professionalism and commitment from contractors. Common sense requires, and legislation demands, that works are carried out safely and to the highest quality.

The Sprayed Concrete Association supports and promotes training especially for safety and the use of new products. It recognises that the processes it promotes are some of the most operator sensitive in the construction industry. It therefore encourages all its members to establish and maintain the highest standards of workmanship.

HISTORY

Concrete is probably the most versatile material used in the construction industry. In compression it is strong enough to form the basic material for the most massive structures. Before it has set its fluidity allows it to assume the most complex shapes. Indeed, and with addition of steel reinforcement, there are virtually no elements of a structure that cannot be formed from concrete.

If there is a drawback to the use of concrete it is the need for formwork or shutters necessary to create a mould for the concrete whilst in its fluid state.

In 1895 at the Field Museum of Natural Science in Chicago USA, the curator, Dr Carlton Akeley was searching for a way to create models of prehistoric animals. A skeleton frame had been manufactured but the body shapes could not be formed by the application of conventional trowelled mortars.

Dr Akeley needed to develop a device to enable the mortar mixture to be sprayed. After experimentation he developed a single chamber pressure vessel which contained a mixture of cement and sand. When pressurised with compressed air the mixture was forced through an opening and along a delivery hose. At the end of the hose was a nozzle which was fitted with a water spray. When passing through this spray the mixture was hydrated.

This equipment was known as the "Cement Gun" and the sprayed material named "Gunite". The methods were patented in 1911 and taken over by the Cement Gun Company. After moving from the USA to Germany in 1921 it eventually became a British owned company in 1953.

The early machines placed the dry mix of sand and cement into the pressurised chamber from where it was projected to a nozzle where water was added. This system was therefore termed the "dry process".

As the dry process was being developed the "True Gun" method was also being developed. This required the sand and cement mixture to be fully mixed with water before being pumped through a fundamentally different machine. Because of its different mixing the system became known as the "wet process". The wet process was not fully developed commercially until well into the 1970's, much of its experimentation being carried out in the USA.

It is at this point that a few moments should be spent considering terminology.

The original name for the sprayed mixture of sand and cement was "Gunite". Other terms have been, and are still used including "Sprayed Concrete" "Shot Concrete" and "Shotcrete". The term "Shotcrete" is often used when describing a mix whose maximum aggregate size is more than 10mm.

However, the current acceptance is that "Shotcrete" is used in the USA and "Sprayed Concrete" is the more widely used term in Europe.

The acceptance and use of sprayed concrete is now world-wide. The processes allow complex shapes and structures to be formed without the high costs associated with formwork.

Early applications of sprayed concrete were for reinforced concrete repair work. Soon its advantages were adopted for new construction.

During the Second World War free standing hangers for Spitfire fighters were constructed, some of which still exist today. The Mersey Tunnel in Liverpool is another example of a major engineering structure lined with sprayed concrete.

Today it is a common procedure to use sprayed concrete for structural repair, for fire protection to steel framed structures, for tunnel and refractory linings and for other structures such as swimming pools, river walls, domes and shell structures.

Installed properly by experienced applicators, sprayed concrete provides designers with a cost effective and adaptable method to create and repair concrete structures.

PROPERTIES AND ADVANTAGES

Sprayed concrete exhibits certain properties that in some respects makes it superior to poured concrete. However, it must be remembered that these properties are largely as a result of the different methods of mixing, transporting and placing rather than fundamental differences in component materials.

Low Water/Cement Ratio

Sprayed concretes generally have a lower water/cement ratio than poured concrete. This is particularly true in the dry process where a low slump mix capable of supporting itself without sagging is quite normal. Wet process mixes achieve a similar result using a plasticiser.

High Strengths with Rapid Strength Gain

Sprayed concretes can be expected to attain high compressive strengths particularly with a low water/cement ratio and the dense compaction achieved by the high velocity of application. Rapid strength gain is also achieved, especially when using factory batched materials. Compressive strengths 30% higher than conventionally placed concretes can be expected.

High Density/Low Permeability

The high velocity of placement ensures good compaction and high density coupled with low permeability and water absorption. This results in a durable homogeneous material with excellent freeze/thaw resistance, low surface cracking and a high degree of abrasion resistance. These properties may be further enhanced by the use of fibre reinforcement in the mix.

Enhanced Adhesion and Bond Strength

As with so many operations in construction, good surface preparation is vital. Assuming that the substrate is properly prepared then the bond strength with sprayed concrete is generally excellent. Furthermore, the use of bonding agents and coatings is usually unnecessary and, under certain conditions, damaging to the bond.

High Speed High Output

Sprayed concrete can deliver high volumes quickly and economically. Free formed tunnel linings or retaining walls can be sprayed immediately after excavation. Walls up to 1m thick have been constructed in the USA using the wet process even with very high reinforcement densities. Multiple layer application can reduce the generation of thermal stresses in construction.

PROPERTIES AND ADVANTAGES

Reduction in Formwork Costs

In comparison with conventionally poured concrete, sprayed concrete requires far less formwork. This is especially so if curved or organic shapes are favoured by the designer which may be impossible to achieve using conventional formwork. Virtually any shape can be formed especially thin shells and linings.

Ease of Access

The ease of application of sprayed concrete means that material can be applied in restricted areas, often considerable distances from the point of access. Without the need to transport and erect bulky formwork only the operator and delivery hoses need to be able to visit the workface. The cement and sand mixture can be transported over long distances from the production plant.

TYPICAL APPLICATIONS AND USES

The following examples demonstrate the unique adaptability of sprayed concrete.

New Construction

- Shell roofs and domes
- Retaining walls
- Piled wall facings
- Silo structures
- Barrel vaulting
- Diaphragm walls
- Caissons
- Blast proof structures
- Bank vaults

Underground Construction

- Tunnel linings
- New Austrian tunnelling method
- Storage reservoirs

Water Retaining Structures

- Sea and river walls
- Reservoirs and dams
- Aqueducts
- Swimming pools
- Water towers
- Canal linings
- Irrigation and drainage channels

TYPICAL APPLICATIONS AND USES

Protective Coatings

- Fire protection to structural steelwork
- Refractory linings
- Pipeline encasement
- Rock and soil stabilisation

Strengthening and Repair

- Concrete damaged by reinforcement corrosion
- Fire damaged structures
- Housing
- Cooling towers
- Bridges
- Jetties and wharves
- Brick arches and tunnels
- Tunnel linings
- Cathodic Protection overlays

Free Formed Structures

- Swimming pools
- Landscaping
- Climbing walls
- Theme parks
- Sculpture
- Water sports slalom courses
- Bobsleigh runs
- Zoological structures

THE DRY PROCESS

General Information

In dry process sprayed concrete a predetermined ratio of cement and aggregate is batched and mixed without added water. The mixture is fed into a purpose-designed machine, pressurised and introduced into a high velocity air stream and conveyed through flexible hoses to the spraying nozzle. At this nozzle a finely atomised spray of clean water is added to the stream of materials to hydrate the cement and provide the right mix consistency so that the uninterrupted stream of materials can be projected at high velocity into place, where the impact compacts the material. Because water or admixtures are not necessarily required to give workability during transportation or to achieve compaction, dry process sprayed concrete with suitable aggregates and aggregate/cement ratios can be placed at low water/cement ratios, with no slump characteristics. This enables it to be placed without admixtures to limited thicknesses on vertical and overhead surfaces.

Admixtures can be introduced in powder form into the dry pre-mix, in liquid form with the added water at the spraying nozzle or as a separate injection at the nozzle. Steel or other fibres can be incorporated in the pre-mix.

Equipment offering a wide range of throughputs is available, allowing accurately controlled low rates of application for thin layers or on awkward or intricate structures. High rates of application for tunnel construction slope stabilisation and larger areas are also possible.

The application nozzle is generally hand held and the stream of materials is directed by the nozzleman, who also adjusts the amount of water added. The water can only be varied within a limited range, as too little water will prevent the mixture compacting into a homogenous mass, while an excess will make it too workable, causing slumping. Remotely controlled robotic spraying arms are often used in tunnelling work where they enable the sprayed concrete to be placed in situations that could be hazardous for a nozzleman. They also avoid the need for temporary access in order to place the material at high level.

The technique is very flexible, capable of wide variation in throughput, able to handle virtually all types of cement and a wide range of conventional and lightweight aggregates. Aggregate sizes up to 20mm can be used but there is normally no advantage in using material over 10mm.

The range of aggregate/cement ratio mixes that can be sprayed is limited and the range used is typically 3.5/1 to 4.0/1 by weight. Because the rebound is mainly aggregate, the placed mix will be richer in cement than the batched pre-mix. The performance characteristics of dry process sprayed concrete are good density, high strength (typically 40 to 50 N/mm^2) and very good bond to a suitable substrate. The intrinsic properties tend to be more variable than conventional concrete or wet process sprayed concrete.

Dry Process Equipment

Sprayed concreting has been carried out using the dry process for many years, traditionally using twin chamber machines such as the Boulder Gun and many copies. This type of machine was very good using refractory materials or very dry sand/cement mixes. Problems arose however when the material to be sprayed had a moisture content of more than about 3%, causing the machine to block up with material.

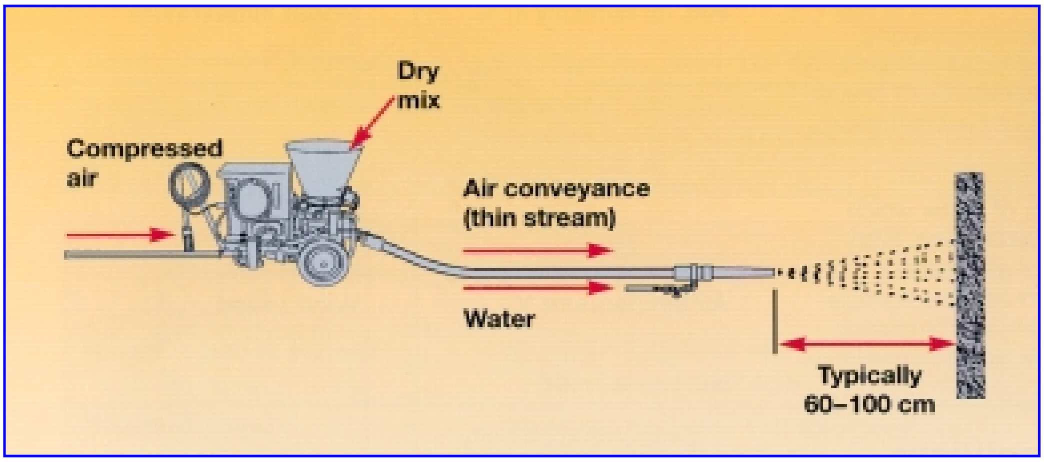
Other versions of the Boulder type gun have also been made, still using the sealed chamber principle but allowing a constant feed by using a rotary valve to feed material into the chamber.

Most dry mix machines today are the rotor type, a design whereby the dry mix is fed into an open hopper, dropping by gravity into a revolving barrel and is blown by compressed air into the spraying hose and to the water injection nozzle where the water is applied by the nozzleman's judgement. The nozzle can be a great distance from the machine (up to 600 metres).

The newer machines available from many manufacturers today are capable of handling moisture contents of up to 10% with outputs up to $10m^3/h$. This is achieved by the use of liners in the rotor and air chamber, normally the places associated with blockages in rotor type machines.

Machines are also manufactured specifically for the application of pre-bagged dry materials. By the use of lubricated sealing plates and oversize motors, the rotor can be clamped to a much greater tension than previously, stopping dust escaping from the rotor/ sealing plates to a great degree. All types of dry spray machine are only a method of feeding an amount of sand/cement/ aggregate mixture into an air stream at a steady rate. If the feed rate is not constant the nozzleman will experience great difficulty in maintaining the correct water/cement ratio.

Dry spray machines have been used for applications ranging from structural repairs due to fire damage, cooling tower and bridge strengthening to new construction in housing, tunnelling, mining, swimming pools and zoo enclosures.



the "dry spray" processs (typical)

THE WET PROCESS

General Information

Wet process sprayed concrete consists of a mixture of cement and aggregate, weight or volume batched and mixed with water prior to being pumped through a hose or pipe to a discharge nozzle. High velocity air is used to propel the mix into position and this supply of high pressure air is introduced at the nozzle and the resultant velocity propels the concrete into position where it is compacted by its own momentum.

Wet mix sprayed concrete can be supplied by ready mix or site batching facilities, or may be supplied as a dry, pre-blended material in bags. Bagged material is favoured for small operations of low volume, such as repairs, where site access may prohibit large wet-mix concrete deliveries.

With the wet process the water cement ratio can be accurately controlled and with water reducing plasticisers, water cement ratios below 0.45 can be easily achieved.

Concrete strength requirements can be specified in a similar manner to conventional concrete although in the wet process high strengths are usually achieved due to the cement rich characteristic. It is usual for wet mix designs to use cement contents in the range of 350kg to 450kg per cubic metre. The resulting cube strengths will normally be between 30N/mm^2 and 60N/mm^2 at 28 days.

With the use of hydration control admixtures, the working life of wet mix concrete can be extended up to 72hours allowing the system great flexibility, and preventing the need to clean out the system after each application.

The Specialist Contractor should be free to design the mix to achieve the required strength and durability, and to take into consideration the balance of fine and coarse aggregates to ensure optimum pumping performance and reduction of rebound.

Where the Specifier considers that a water bar or joint sealing system is necessary, the Contractor's advice should be sought prior to the commencement of work to establish the appropriate design detail and sequence of work.

The designer should consider buildability of the structure, reflecting the construction processes employed in spraying concrete. Particular care is required for joints and reinforcement details. The emphasis should be to reduce the quantity of steel reinforcement wherever possible. The option of fibre reinforcement should be considered where appropriate.

Spraying techniques are varied according to the nature of the work but usually concrete is built up in layers of up to 150mm thick. Further layers may be applied to achieve greater thicknesses once the underlying layer has achieved a final set. Care should be taken that the surface to receive the new sprayed concrete layer should be free from deleterious substances by jet washing with air-water, starting at the top of the structure and working downwards. This is normally achieved with the sprayed concrete nozzle.

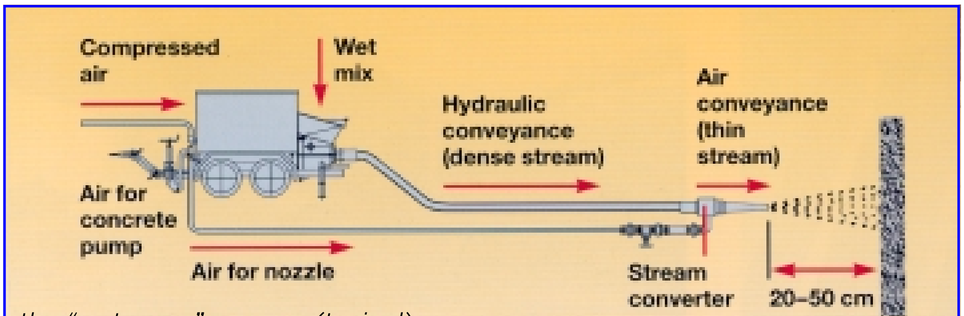
Whereas tolerances of ± 10 millimetres over a 3 metre length are attainable on plain flat surfaces, special provisions will be required in respect of more complicated shapes or difficult locations.

Wet mix sprayed concrete can be a structural material and provide a decorative finish depending on the selection of the appropriate system. Sharp returns and fine details are not advisable but where they are specifically required they should be clearly defined by the Engineer in the specification as they will require careful attention during placing.

Wet mix sprayed concrete can be pigmented for architectural purposes.

Wet Process Equipment

Wet process sprayed concrete pumps include machines with piston and worm pumps where the concrete is delivered to the nozzle as a dense stream. At the nozzle, air and accelerator (if required) are added to project and compact the material to the substrate.



the "wet spray" process (typical)

Worm pump machines can deliver concrete with maximum aggregate sizes of 4mm, and are typically used for repair and surface finishing projects. The output is typically up to $4m^3/h$.

Double piston pump based machines also supply a dense stream of concrete to the nozzle, and should be virtually pulse free when spraying. This type of machine can produce high outputs from $4m^3/h$ to $25m^3/h$, lending itself to tunnel construction or where large structural volumes are required. Accelerator dosing units are usually fitted to these pumps allowing synchronised dosing with the concrete output. These wet process sprayed concrete pumps may take mixes with up to 20mm aggregate.

Rotor chamber pumps normally used for the dry process have been adapted to spray wet mix concrete. These pumps can deliver between 4 and15m^3/h with up to 20mm aggregate. The material is conveyed by compressed air to the nozzle in a thin stream, where accelerator (if required) is added.

Spraying equipment should be capable of delivering concrete to the substrate at a regular rate and be free from pulsation effects that can cause mix segragation and over dosing with additives.

All concrete delivery lines should be sealed and lubricated prior to pumping concrete using a grout mix.

Transport lines consisting of flexible hoses and steel pipes should be laid as straight as possible or in gentle curves. The transport pipes should have a uniform diameter appropriate to the mix and fibre characteristics determined by site trials, and be free from any lips, dents and kinks between the spraying machine and nozzle.

All equipment should be cleaned and maintained at regular intervals to prevent the build-up of concrete in the hopper and delivery system.

SURFACE FINISHES

In both the wet or dry processes

It is usual for the concrete to be placed slightly proud of the required alignment and screeded to the required profile with a timber or steel derby.

On thin coatings (less then 25mm) trowelling is undesirable as it can disturb the impaction bond, unless a specifically designed mix (eg including polymers) is used.

Generally, it is preferable that the finished surface should also be left as sprayed as any finishing of the surface other than very light trowelling, can cause plastic cracking which may be detrimental to the end product.

If required this surface can be finished, preferably with a wooden trowel or, if absolutely necessary, a steel float. No additional water should be used to aid finishing. A very thin flash coat is preferable. Typically, the finer the aggregate, the easier it will be to float and the better the end product.

Pre-Bagged Materials

Material for both dry and wet processes can be supplied ready mixed and factory pre-proportioned. These quality controlled products are available from the Association's Manufacturer Members. They are suitable for both small and large volume work and may be batched to comply with the specification.

Site Batching

Should site-batching be required the mix shall be carefully designed using a number of constituents and additives.

Cements

Traditional Portland cements are used for most sprayed concrete applications and should comply with the requirements of BS12 and EN 197. In general, Class 42.5N or Class 52.5R cements are recommended for sprayed concrete. Other cements shall comply with the national standards or regulations valid in the place of use.

Alternative cements, include such as sulphate resisting cements (to resist sulphate attack), calcium aluminate cements (for high temperature and special requirements) and natural cements (for low heat, fast setting requirements). Reference should be made to the supplier prior to using these products.

As a general rule the higher the C_3A content and the higher the specific surface (Blaine) and the class, the higher the reactivity in terms of setting time and early strength gain, particularly in combination with set accelerators.

Additions

Pulverised fuel ash (PFA) is a finely divided inorganic pozzolanic material which can be added to concrete during wet or dry batching to improve or achieve certain properties in the plastic and/or hardened state. Fly ash used in sprayed concrete should comply with EN 450 and BS 4328.

Ground Granulated Blastfurnace Slag (GGBS) is a fine granular latent hydraulic binding material which can be added to concrete in order to improve or achieve certain properties in the plastic and/or hardened state. GGBS should meet the requirements of BS6699:1992.

Condensed Silica Fume is an extremely finely divided, highly active inorganic pozzolanic material which can be added to concrete during wet or dry batching to improve pumpability, cohesiveness and adhesion. Improvements in some

Table 1: Maximum level of additions (by weight)

CEMENTITIOUS MATERIAL	MAXIMUM ADDITION
Silica fume	15% of Portland Cement
Fly ash	30% of Portland Cement 15% of Portland/Fly ash cement 20% of Portland blastfurnace slag cement
GGBS	30% of Portland cement

Source: EFNARC 1996

hardening properties are also achieved.

Pigments should be used in accordance with the requirements of EN 206 and the supplier's recommendations.

Cement additions may also be specified as a cement replacement, but should not exceed the relative proportions given in Table 1.

Aggregates

Aggregates in general should comply with the requirements of BS 882, and should be checked for their susceptibility to alkali-silica reaction.

The aggregate gradation curve for the wet and dry mix processes should normally lie in the respective envelopes defined in Figure 1.

It is the responsibility of the contractor to choose the most suitable grading for the process and materials available.

For dry mixes the natural moisture content in the aggregate should be as constant as possible and a maximum of 6%.

Proprietary lightweight aggregates may be used but should not be specified without reference to a specialist supplier/ contractor.

Mixing water

Potable water is suitable for sprayed concrete. Other sources should be

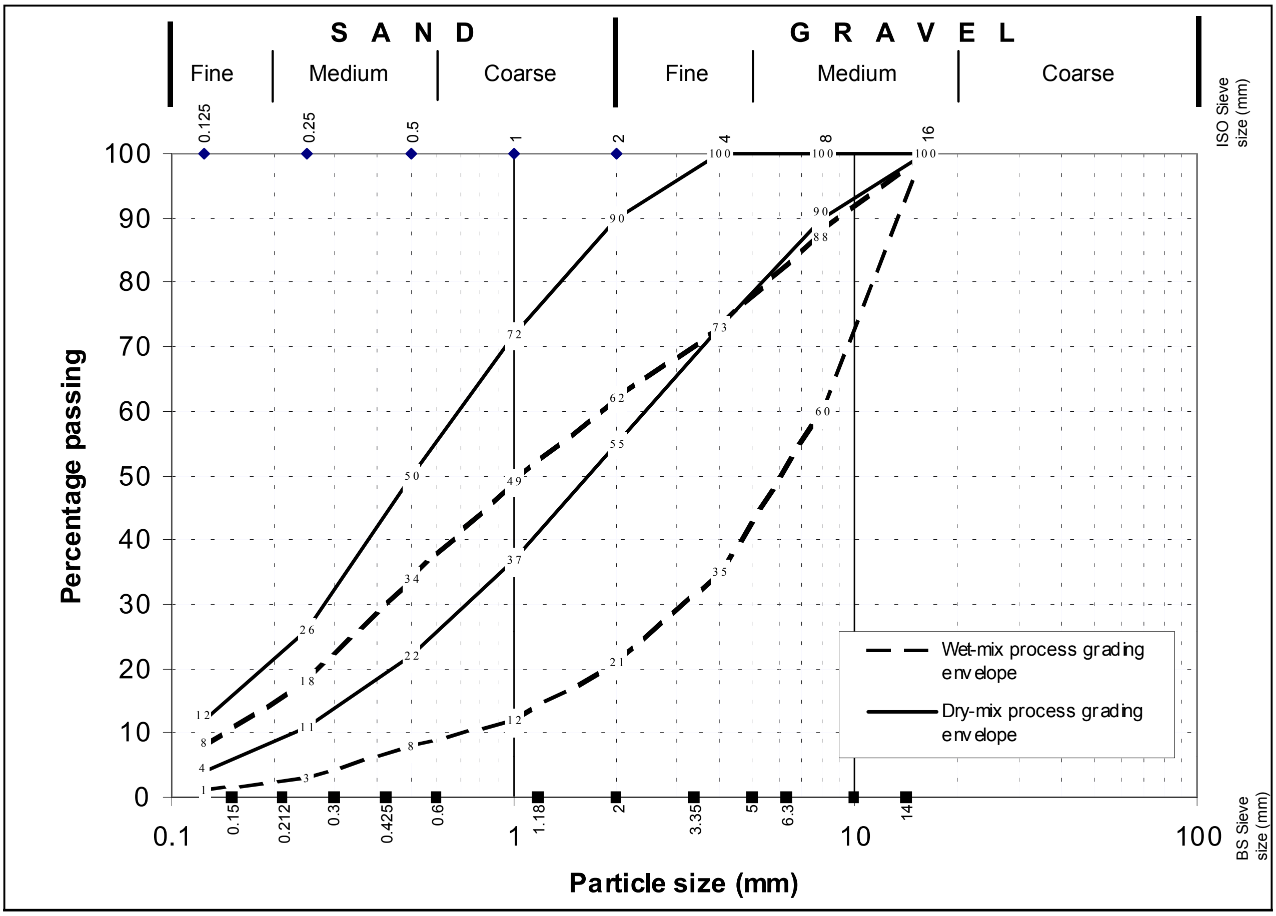


Figure 1: Aggregate grading curves for the wet and dry-mix sprayed concrete process

checked in accordance with BS 3148 for suitability. It should be noted that the mixing water temperature influences the final mix temperature.

Admixtures

A sprayed concrete mix may include admixtures to improve the properties of the fresh mix and the hardened concrete.

The following list of admixtures are commonly included in sprayed concrete systems:

Accelerators increase the stiffening rate, to produce a fast set and provide early strength development. A fast setting concrete may be necessary to build up the required thickness and to ensure overhead stability. The dosage should be optimised to ensure good cohesion between individual passes thus producing a single layer and minimising any adverse effects on long term strength.

Different accelerator types are available for different applications. Guidance should be sought from the manufacturer.

Superplasticisers and Plasticisers are used in sprayed concrete to minimise the amount of water in the mix, thereby improving the final quality. Superplasticisers offer greater water reduction than plasticisers, without retardation of the mix.

Hydration control admixtures are added to sprayed concrete in order to maintain workability and extend the open time during transportation and application without reducing concrete quality.

Retarders are added to retard the setting of the concrete. With the use of retarders, preconstruction tests on site with the actual materials and mix design should be conducted prior to commencement of the work, in order to verify the dosage rate of the product.

Fibres

Fibres are added to sprayed concrete to impart one or all of the following material properties:

- Control of plastic shrinkage cracking
- Control of thermal cracking
- Improved abrasion and impact resistance
- Improved fire resistance
- Improved ductility and toughness
- Enhanced tensile and flexural strength

Further technical information is provided by the Sprayed Concrete Association's Technical Data Sheet No.1.

Steel reinforcement

Steel reinforcement increases the flexural strength and controls cracks. Steel reinforcement is normally in the form of fabric and is recommended for thick layers (≥ 50 mm). For most uses, reinforcing steel fabric with a mesh of 50 to 150 mm and a wire diameter of no more than 10 mm is widely accepted.

Curing agents

Liquid curing agents should be specified to maximise hydration of the cement by reducing water evaporation.

There are two types of curing agent: *Externally spray applied curing agents* and *internal curing admixtures added to the concrete*. Both types should be used in accordance with the manufacturer's technical instructions.

HEALTH AND SAFETY

Whilst inherently safe, like all activities in construction, spraying concrete needs to be planned and executed with due regard to Health and Safety.

It is advisable only to employ the services of competent designers, suppliers and contractors (members of the Sprayed Concrete Association) to carry out these works. Since the Health and Safety at Work Act of 1974 and subsequent legislation such as COSHH (Control of Substances Hazardous to Health) and CDM (Construction Design Management) it is vital that due consideration is given to safety issues.

Construction Design and Management Regulations

From the design stage onwards all parties to the contract are expected to have due regard of the Health and Safety implications of their proposals. Via the site safety plan and the Risk Assessment all parties are now expected to plan and create a safe working environment where risk is, at best, eliminated or certainly reduced.

A safe work site must be maintained. This will include security to prevent unauthorised visitors, especially children, a safe means of access to the works (scaffolding etc) and the elimination of risk to passers-by.

After due consideration at the design stage the construction team will work together to maintain this safe environment.

The site safety plan will accompany the works and form an "as built" record for the future. This is especially relevant where services or structures may be hidden by the spraying operation.

Control of Substances Hazardous to Health – COSHH

The material components of sprayed concrete contain cementitious products and possibly other additives and chemicals.

Material manufacturers and contractors are duty bound to issue a COSHH assessment for the handling and use of the materials. This assessment will highlight the hazards that may exist and the measures required to eliminate risk to the user.

Particular consideration should be given to special circumstances e.g. high buildings, confined spaces etc. All materials should be used in accordance with the manufacturers' instructions.

Personal Protective Equipment (PPE)

The risk assessment and COSHH assessments will inform the user that spraying concrete is going to be a noisy and dirty process.

The nozzleman, mixing gang and those adjacent to them must be issued with appropriate PPE. This will include overalls, gloves and safety helmet with full face visor or specialised helmet with breathing apparatus and safety boots. This equipment must be maintained and replaced when damaged or worn out.

Working Environment

A safe working environment should be created and maintained. This will include levelled ground and proper access to the work area.

Proper lighting should be provided and, if necessary, ventilation, especially for dust extraction or when working in a confined space. Protection against overspray and airborne dust should be provided where necessary.

The workforce must enjoy proper welfare facilities. These will include accommodation where they can change and dry clothes, washing facilities, WC facilities, and a separate clean area for taking breaks and eating.

Plant

Sprayed concrete plant is essentially fairly simple. A large air compressor feeds the wet or dry spray plant via a series of valves and hoses. A mixer may also be used for the dry process.

Plant must be maintained and serviced properly and used in accordance with the manufacturers' instructions. Protective guards should be checked and used. Unsafe or improperly maintained plant should never be used until it is repaired and checked by competent persons.

Plant should never be used in circumstances that exceed the manufacturers' specification.

Disposal of Waste

Sprayed concrete operations usually generate significant quantities of waste material. This will include overspray and rebound material together with packaging from the delivered materials and additives.

This waste must be properly disposed of to licensed tips by licensed contractors. Wherever possible the material selection should minimise the disposal of waste and the impact on the environment.

QUALITY CONTROL AND TESTING

General

Tests should be carried out on a routine basis on cores or other samples taken from sprayed concrete applied in the Works. Only for certain specific tests as indicated in the following clauses should panels or beams be prepared for test purposes.

The Site Trials should be repeated if the source or quality of any of the materials or the mix proportions are required to be changed during the course of the Works.

An agreed testing regime should be carried out on a routine basis.

Specimens should be tested in accordance with the EFNARC Specification: 10.

Preconstruction tests

The frequency of carrying out each test for mix control should be in accordance with the EFNARC Specification: 11.2

Composition of the sprayed concrete is determined in the course of preconstruction tests in which the required properties are checked. Examples of properties to be checked are:

Fresh concrete:

- water demand, workability, pumpability,
- sprayability/rebound
- slump, density
- accelerator dosage and compatibility with cement type

Hardened concrete:

- compressive strength and density at 7 and 28 days
- flexural strength
- residual strength
- fibre content
- bond
- permeability

The need for such tests is dependent on the type of project and the utilisation of the sprayed concrete, but should always be done in control class 3.

Quality control

The production of sprayed concrete shall be subject to quality control procedures. Different levels of control can be exercised dependent upon the complexity of the project.

There are 3 classes of control:

1. Minor control
2. Normal control
3. Extended control

The choice of control class is the decision of the designer, based on type of project and consequence of failure.

There are no special requirements for the organisation of the work in control classes 1 and 2. In control class 3 there should be an organogram for each project with a quality assurance engineer, dedicated to quality control.

The frequency of the tests is decided by the designer, bearing in mind the function of the sprayed concrete (including structural integrity), its design life, the difficulty of installation, the environmental classification and the consequences of a failure. The values

Table 2: Frequency of control testing

TYPE OF CONTROL	MINOR m^2 between tests	NORMAL m^2 between tests	EXTENDED m^2 between tests
Compressive strength	500	250	100
Flexural strength		500	250
Residual strength value		1000	500
Energy absorption		1000	500
Bond		500	250
Fibre content		250	100
Thickness	50	25	10

Source: EFNARC

given in Table 2 may be used as a guide.

Location of test specimens

The location of specimens to be taken from the Works should be proposed by the Contractor and approved by the Engineer. For repair works it is recommended to only measure the compressive strength on cores taken from representative test panels. In the event of a failure the Engineer may require verification from cores taken from the permanent works.

Marking of test specimens

Each core or beam should be marked with an appropriate reference mark and the date and time of spraying.

Test Methods

The tests should be carried out using the methods listed in Table 3.

Test panels and samples

Moulds should be made of steel or other non-water-absorbing rigid material. The minimum plan dimensions are 600 x 600 mm for hand spraying and 1000 x 1000 mm for robot spraying. The thickness should be appropriate to the size of test specimens to be cut from the panel, but should not be less than 100 mm. Appropriate measures should be taken to avoid entrapment of rebound in the mould (such as using chamfered or slotted sides).

The moulds are positioned vertically and sprayed with the same operator, equipment, technique, layer thickness per pass, spraying distance, etc. as the actual work. The panel should be protected immediately against moisture loss using the same method to be used in construction. The samples are marked for later identification (Mix, location, date, operator).

The panel should not be moved within 18 hrs of being sprayed. Curing should continue thereafter for 7 days or until samples are to be extracted.

The test samples should be cored in accordance with EN 7034 or sawn from

Table 3: Test methods	
TEST	**EFNARC TEST METHOD**
Compressive strength	see below (from EFNARC Specification 10.2)
Flexural stength	EFNARC Specification 10.3
Residual strength value	EFNARC Specification 10.3
Bond strength	EFNARC Specification 10.6
Durability/permeability	EFNARC Guidelines to the Specification: 10.7
Setting time	EFNARC Specification Appendix 1: 6.3
Fibre content	EFNARC Guidelines to the Specification: 10.9.3

the panel, but should not include material within 125 mm of the edge (with the exception of the ends of beams for flexural/toughness testing).

During transportation to the testing laboratory the panel or sawn samples are packed to protect against mechanical damage and moisture loss.

Compressive strength and density

The required minimum compressive strength should in accordance with the EFNARC Guideline to the Specification: 9.1, tables 9.1.1 and 9.1.2 as shown in the example below:

40 MPa x 0.8 x 0.85 = 27 MPa

where:

40 = Characteristic cast cube requirement
0.8 = conversion for cube/cylinder specimen
0.85 = conversion factor for in situ sampling

Compressive strength tests should be performed in accordance with EN 4012 on drilled cores taken from the sprayed concrete structure or from sprayed test panels. Their minimum diameter shall be 50mm and the height/diameter ratio shall be in the range 1.0 to 2.0. Test results from cores with height/diameter ratio different from 2.0 shall be converted to equivalent cylinder strengths using the values given in Table 3.

Alternatively the compressive strength can be determined from cubes cut from sprayed test panels. The minimum dimensions are 60 x 60 x 60mm and the samples tested in accordance with EN 4012.

The density is determined by weighing the sample in water and air in accordance with EN 6275 (water displacement method).

Normal testing ages are 7 and 28 days.

The test report shall contain:

- test specimen identification
- moisture condition of the test specimen
- test specimen dimensions
- curing conditions and age at test
- maximum load and compressive strength (to nearest 0.5MPa)

Table 4: Conversion factors to equivalent cube and cylinder strength

Height/diameter ratio of core	Cube factor	Cylinder factor
2.00	1.15	1.00
1.75	1.12	0.97
1.50	1.10	0.95
1.25	1.07	0.93
1.10	1.03	0.89
1.00	1.00	0.87
0.75	0.88	0.76

Source EFNARC

TRAINING AND CERTIFICATION

Spraying concrete is without doubt one of the most demanding activities in construction. Its success relies very heavily on the skills of the nozzleman and his team. It is vitally important therefore that specifiers and designers insist upon and verify the background and training methods adopted by their prospective contractors.

The Sprayed Concrete Association has for many years recommended a formal record keeping, training and certification scheme.

The nozzleman's actions on site are crucial in maintaining the quality and consistency of the final product. With the dry process they control water content and hence the mix design. With both dry and wet processes their skills determine the density and compaction of the sprayed material and the prevention of voids and "shadows" behind reinforcement. They will be able to place material overhead in multiple layers whilst minimising rebound and overspray, and will also be able to achieve the required surface finish to the sprayed material.

His support team will often hand batch materials and certainly be responsible for providing the nozzleman with a constant supply of controlled materials without risk of inconsistency or blockage.

Many of these skills will be learnt on site through experience. On site apprenticeship and training provides a firm grounding to trainees. Their progress should be recorded in a recognised log book such as that issued by the Sprayed Concrete Association.

Experienced operators have in the past been able to record their skills by the issue of "Grandfather Rights". This is a certificate signed by their employer confirming the holder's past experience and success.

As this route to certification is gradually phased out more formal approvals are now available. The Construction Skills Certificate Scheme (CSCS) now provides a simple method of extending certification to a common standard across the industry by accreditation.

The more recently introduced National Vocational Qualification (NVQ) is the goal to be aimed at by all competent employees. Both schemes are linked and supported by the Sprayed Concrete Association, the Construction Industry Training Board (CITB) and many employers.

Formal training schemes are offered by the CITB. These courses are usually residential and quite intensive. The desired result is a fully trained nozzleman who is not only capable of spraying concrete but also able to create test pieces for checking. He must also be able to understand the technicalities of the process.

It is vital therefore that training and certification within the industry is both supported and maintained. Any reluctance to provide that commitment could result in substandard work or potentially dangerous structures and the resultant Health and Safety risks.

The following information applies to both the wet and dry processes.

Overall Design

With sprayed concrete the Designer can have the freedom to achieve almost any shape. The Specifier should ensure that adequate plans with detailed dimensions are provided. This will enable the Contractor to accurately assess the Specifier's requirements.

Strength

The strength of sprayed concrete should be specified as follows:

Grade	Characteristic strength at 28 days
30	30N/mm²
40	40N/mm²
50	50N/mm²

The Contractor should be free to design the mix to achieve the specified characteristic strength. He should ensure that the gradation of fine and coarse aggregates is such that the mix can be pumped (wet or dry) without problems (such as "bleeding" within pumping lines in the case of a wet mix).

Reinforcement

The Designer may require the sprayed concrete to be reinforced. Mesh, bar or fibres could be specified. The reinforcement should be specified as for conventional concrete but with a limit on larger bar sizes. Reinforcing bars greater than 25mm should be avoided.

Clear spacing between parallel main bars, including laps, should be at least four times the bar diameter or 50mm whichever is the greater. Where concrete is sprayed against an existing structure the back cover to reinforcement should be between 25mm and 40mm depending on the concrete mix in use. Overlays in excess of 25mm thick shall be reinforced.

Where two layers of reinforcement are incorporated, the bars on the front face should be in line with those on the rear face. In constricted areas it may be preferable to spray the rear layer of reinforcement to ensure good encapsulation of the steel prior to fixing the front layer.

The Engineer should specify the type and spacing of fixings to ensure that the reinforcement can be adequately secured to prevent vibration or displacement during spraying, Cover shall be as for conventional concrete.

Glass, steel or other approved fibres may be used in appropriate quantities to modify the characteristic of the sprayed concrete. Certain lightweight reinforcing fabrics, which do not comply with the requirements of BS4483, may be specified.

Cement

Except where otherwise specified the cement should be Portland Cement complying with the requirements of EN197.

All cement should be fresh and after delivery should be stored in a dry area or in a purpose made bulk silo.

DESIGN AND SPECIFICATION

Aggregate

Aggregate should consist of sharp washed sand graded in accordance with BS882 (1984). Medium Grade is preferable. Where this grade is not readily available other fine aggregates may be employed if the Contractor can demonstrate that the specification can be achieved.

Coarse aggregate should comply with BS882 and in general should not exceed 16mm, although a maximum size of 10mm is preferable.

Some aggregates, such as proprietary lightweight aggregates that can only be pumped in a high slump condition, should not be specified without reference to a Specialist Contractor.

Water

Water should be clean and free from harmful matter. Where tests are required they should be in accordance with the requirements of BS3148.

Admixtures

Plasticisers and water reducing agents may be used with the approval of the Engineer. Admixtures, such as accelerators, may also be used with the approval of the Engineer but the method of introduction and concentration should be proposed by the Specialist Contractor.

Where admixtures are employed a typical dosage shall be specified. The effects of incorrect dosing should also be made clear, particularly with regard to strength and long term durability.

Plant

If site-batched concrete is to be used then the required proportions of cement to aggregate should be determined by weigh batching.

Alternatively, if the size of the contract does not warrant the provision of weigh-batching equipment, volume batching may be permitted.

The mixing equipment must be capable of thoroughly mixing the materials and of discharging the whole of each batch. It should be inspected and cleaned at least once each day. Hand mixing may be allowed on small contracts but in either case care should be taken that mixed materials are placed before the occurrence of initial set of the cement.

Pumping and delivery equipment should be specifically designed for sprayed concrete work and be capable of delivering a continuous, even flow of material to the nozzle. The equipment should be inspected and cleaned daily.

An uninterrupted supply of compressed

air to the nozzle should be maintained at a pressure sufficient to ensure even distribution of material.

Delivery pipes and hoses should be inspected before laying out to ensure they are clean and that coupling end rings are not damaged. Couplings and seals should be in good condition. Delivery hoses should be laid out prior to the commencement of work and during the course of the work should be maintained without kinks or sharp bends.

As required, the air or water line should be inspected for soundness and laid out alongside the concrete delivery line. In the area of work it should be attached to the delivery line at regular intervals.

Workmanship

The Contractor should be a member of the Sprayed Concrete Association or provide satisfactory written proof of expertise in sprayed concrete.

The Contractor should employ a full-time working Foreman on the project who has at least five years specialist spraying experience, including two years as a nozzleman. Also, he should have experience in concrete mix design and be fully conversant with the relevant codes of practice and specification.

The quality of sprayed concrete is largely dependent on the skill of the nozzleman. The nozzleman must be competent and experienced in such work and have a working knowledge of concrete practice. Pump operators should have a good working knowledge of the machinery they are using to ensure optimum performance.

The control of alignment and thickness of sprayed concrete is the responsibility of the Contractor. Where sharp edges or accurate lines are required, these should be set out by screed boards, guide wires and/or depth spacers. The contractor should ensure that these are suitably secured to prevent movement during application of the sprayed concrete.

After any specified interface preparation has been carried out, and immediately prior to the spraying operation, the surface must be thoroughly cleaned and dampened with a strong blast of air and water.

Sprayed concrete must not be placed on to a frozen substrate, nor placed when the air temperature falls below 5°C. It should be maintained at not less than this temperature until the final set is achieved.

Application should commence at the bottom of vertical or near vertical surfaces and each layer of sprayed concrete built up by making several passes of the nozzle over the work area.

For reinforced concrete the distance of the nozzle from the work should be between 600mm and 1500mm and held perpendicular to the application surface except when spraying around a reinforcing bar when the nozzle may be held closer and at a slight angle in order to facilitate full and total encasement. If the work is of a non-structural nature, the nozzle may be held at a greater distance provided the specification can be achieved.

The sprayed concrete should emerge from the nozzle in a steady flow, free from pulsation. Excessive cement “paste” or segregation caused by poor mix design should not be incorporated in the work. Should the flow become intermittent it should be directed away from the work.

A proportion of sprayed concrete will rebound and measures should be taken to prevent it from being incorporated in the finished work. The amount of rebound will vary according to a number of factors including the parent surface, location, the applied material’s mix and the type/quantity of reinforcing.

Maximum layer thickness is governed by the requirement that the material should not slump or sag in such a manner that it can cause a break in bond. The Contractor shall duly consider factors such as position of reinforcement; plane of application; mix design and constituents including admixtures that may contribute to slump and sag.

Where thick layers are applied the horizontal leading edge should be maintained at a slope. Where necessary to achieve greater overall thickness, subsequent layers must not be applied until the preceding layer has attained adequate strength. Prior to spraying subsequent layers, loose materials should be removed using a strong blast of air.

Construction joints should be tapered at approximately 30° and cut back square to the outer layer of reinforcement, unless otherwise specified by the Engineer. The entire joint should be thoroughly cleaned and dampened prior to the placement of adjacent sprayed concrete.

When applying additional layers the reinforcement should be cleaned of any previously deposited hardened material which might prevent a proper bond or encasement.

In general the sprayed concrete should be cured in accordance with the recommendation set out in EN 206. Where the ambient temperature exceeds 25°C or in exposed conditions where air movement may cause a rapid drying of the concrete surface, as the spraying proceeds the work should be immediately protected by wet hessian or a fog spray system. In these conditions no surface should be exposed for longer than one hour.

BIBLIOGRAPHY AND USEFUL PUBLICATIONS

In addition to the publications listed below, the Sprayed Concrete Association produces a number of documents related to Sprayed Concrete, a list of these publications may be obtained from Association House. Members of the Sprayed Concrete Association are happy to answer any questions regarding sprayed concrete application. The membership varies across the spectrum of contractors, material and plant supplier's and consultants.

ICE - design and practice guides - Sprayed concrete linings (NATM) for tunnels in soft ground.

In 1994, the collapse of two tunnels, one under construction beneath a street in Munich and the other under construction in the centre of London's Heathrow Airport, caused major concern in the international tunnelling community and to the public. These incidents brought into question the use of sprayed concrete, a system more commonly referred to the New Austrian Tunnelling method (NATM), for the initial support of tunnels in soft ground. As a result of this world-wide concern, the Institution of Civil Engineers has issued this guide to consider the implications of the use of sprayed concrete support methods in soft ground in urban areas and provide guidance on how the associated risks of this method can be minimized. The guide has been specifically complied to:

- respond to public concerns over the use of NATM in soft ground in urban areas;
- examine NATM design and construction principles and their applicability to soft ground in urban areas; and
- provide guidance on the proper use of sprayed concrete linings in soft ground in urban areas, with specific reference to London Clay.

Contents: Introduction - What is NATM - General experiences of SCL - Procurement of SCL Tunnels - Design - Guidelines on Construction - A comparison with segmentally lined tunnels - Conclusions - References.

Published by Thomas Telford
ISBN No. 0-7277-2512-2

EFNARC - European Specification For Sprayed Concrete

EFNARC was founded in March 1989 by five national trade associations representing producers and applicators of specialist building products. The Sprayed Concrete Technical Committee was formed in early 1991, which eventually led to the publication of a final version of this document in 1996.

This specification treats sprayed concrete as an entity and makes no reference to fields of application such as tunnelling which is the case of many other publications. The subjects covered are thorough and contain information to satisfy the requirements of specifiers, contractors and suppliers alike on all aspects of sprayed concrete. The specification has been specifically compiled to:

- provide guidance to meet the

requirements of all stages of sprayed concrete from selection of materials and design mix through to application, requirements, safety and quality control.

- provide a consistent level of information and guidance to all users of sprayed concrete throughout the European community.

Contents: Scope · Reference Standards · Definitions · Constituent Materials · Requirements For Concrete Composition · Requirements For Durability · Mix Composition · Execution Of Spraying · Requirements For Final Product · Test methods · Quality Control · Health & Safety.

Available from the Sprayed Concrete Association - ISBN No. 0-9522483-1-X

EFNARC – Specification For Sprayed Concrete – Guidelines For Specifiers & Contractors

This 1999 publication is to be read in conjunction with the EFNARC Specification for Sprayed Concrete. These guidelines refer to the Specifications regularly and all references relate to the clause numbers in the specification. The guidelines also contain a number of updates that supersede items in the Specification, particularly a list of the latest CEN test methods relevant to sprayed concrete and a revised section on the execution of spraying.

These guidelines have been produced to:

- provide a reference document aimed at use during the application of sprayed concrete and present the contractors and clients alike with guidance as to best practice methods
- work in conjunction with the EFNARC Sprayed Concrete Specification.

Contents: Foreword · References · Constituent Materials · Requirements For Concrete Composition · Requirements For Durability · Mix Composition · Execution Of Spraying · Requirements For Final Product · Test Methods · Quality Control · Environment, Health & Safety.

Available from the SCA

Simon Austin & Peter Robins - Sprayed Concrete Properties Design and Application

This book provides a comprehensive coverage of all aspects of sprayed concrete. Materials technology, design, installation and application are all dealt with. It forms an essential reference work for all who seek guidelines on the subject.

Contents: Sprayed Concrete as a Construction Material · Design and Installation · Applications.

Published by Whittles Publishing
ISBN 1 870325 01 X

Austrian Concrete Society – Guideline Shotcrete

This publication produced by the Austrian Concrete Society is a comprehensive document that has taken several years to produce. It applies to the production of structural components made of plain and reinforced concrete as well as the close-textured reinforced concrete placed by the method of spraying.

The document predominantly covers the testing and design of sprayed concrete mixes but does so by investigating the requirements placed on the finished material. There is some information covering the placement methods but this is limited. The one failing of this document is that currently all charts and graphs are still German which makes them awkward to use. Other than this point the document is technically good and covers all aspects of sprayed concrete.

Contents: Scope - Definitions - Environmental Compatibility of Shotcrete - Mix - Shotcreting Procedures - Requirements to be met by Shotcrete - Structural Requirements - Special Procedures - Testing - Quality Management - Testing Procedures - Standards, Guidelines.

This document is not generally available in this country but the Sprayed Concrete Association may be able to obtain copies.

HSE – Safety of New Austrian Tunnelling Method (NATM) Tunnels

On 21st October 1994 three parallel tunnels under construction beneath Heathrow Airport started to collapse. These tunnels were being constructed using a system referred to as NATM for the primary lining. This system failed. The HSE were requested to consider whether there were any broader health and safety implications concerning both the construction of NATM tunnels in the UK, and the safety of the finished tunnel in comparison with traditional methods. This report covers these subjects.

The report predominantly reviews safety of the NATM process throughout the world, it also relates this to current UK Safety Legislation. The report is interesting reading, in particular the sections which cover Safety Management of Sprayed Concrete operations, useful information to managers of sprayed concrete activities.

Contents: Introduction, scope & purpose of review - Summary of findings - Principal HSE conclusions - The NATM Process - World Wide Review of NATM Safety - UK. Health & Safety Legislation - NATM Safety Principles - Designing for Safety - Management Arrangements - Appendices - Glossary of Terms - References & Reading List

Published by HSE Books - ISBN No. 0-7176-1068-3

HSE – Post Construction Audit of Sprayed Concrete Tunnel Linings

This report researches the present practice in the auditing of the finished, sprayed concrete tunnel lining structure. As with many of the publications relating to sprayed concrete this focus's on tunnel linings specifically. A number of the procedures described could be applied to any type of sprayed concrete work of a structural nature. The systems are aimed at large sections of work and may not be suitable for small projects.

Contents: Summary - Introduction - Sprayed Concrete - Design of Sprayed Concrete Tunnel Linings - testing of Sprayed Concrete Tunnel Linings - Performance Requirements - Appropriate Testing Methods for Sprayed Concrete Tunnel Linings - Recommendations for Post Construction Audit - References

Published by HSE Books - ISBN No. 0-7176-1026-8

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Also available from the SCA:

Picture of the Directory

Picture of the EFNARC Spec

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where you can see a complete list of SCA members, news of events and other information