EFNARC Nozzle Operator Certification Scheme

Goal is to achieve the highest standards in robotic wet sprayed concrete

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EFNARC - Nozzle Operator Certification Scheme

Developed by the EFNARC Nozzle Operator Technical Committee

EFNARC - Experts for Specialised Construction and Concrete Systems:
The Authoritative Voice of Contractors, Manufacturers, Raw Material Suppliers and Consultants in Specialised Construction and Concrete Systems Industry.

This version has been revised in the responsability of EFNARC Focus Group I "Nozzel Operator Certification Scheme" after input from various members and finally consolidated by Benedikt Lindlar, Sebastian Jehle, Alberto Rey (SIKA AG), and Michael Kompatscher, Erich Lassnig, Christina Buxtorf (Hagerbach Test Gallery Ltd). All questions and comments relating to the EFNARC Nozzle Operator Certification Scheme should be submitted to the EFNARC secretary: secretary@efnarc.org.

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Nozzle Operator Scheme and site related working practices

- The information given in this, and accompanying documents is believed to represent European best practice at the time of drafting (2022). However, EFNARC, its members and employees accept no liability arising from the use of this information.
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- EFNARC recognises that all sprayed concrete job sites are different. In difference to the information in this document, the Nozzle operator should always follow the site specific working practice and instructions.
- In the event of a problem on site that is outside his normal job specification or experience, the Nozzle Operator should always seek guidance from the site supervisor or engineer.
- The safety of the Nozzle Operator, others working in the area and of the whole job site should be of overriding priority. The Nozzle Operator should have the information, equipment, site specific operating instructions needed to ensure this level of safety.

The Nozzle Operator

Content:

- Concrete technology
- Spraying equipment
- Designer expectations
- Sprayed concrete application
- Surface finishing and curing
- Standards and testing
- Health, safety & environment

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Concrete technology

Mix design and constituents for sprayed concrete

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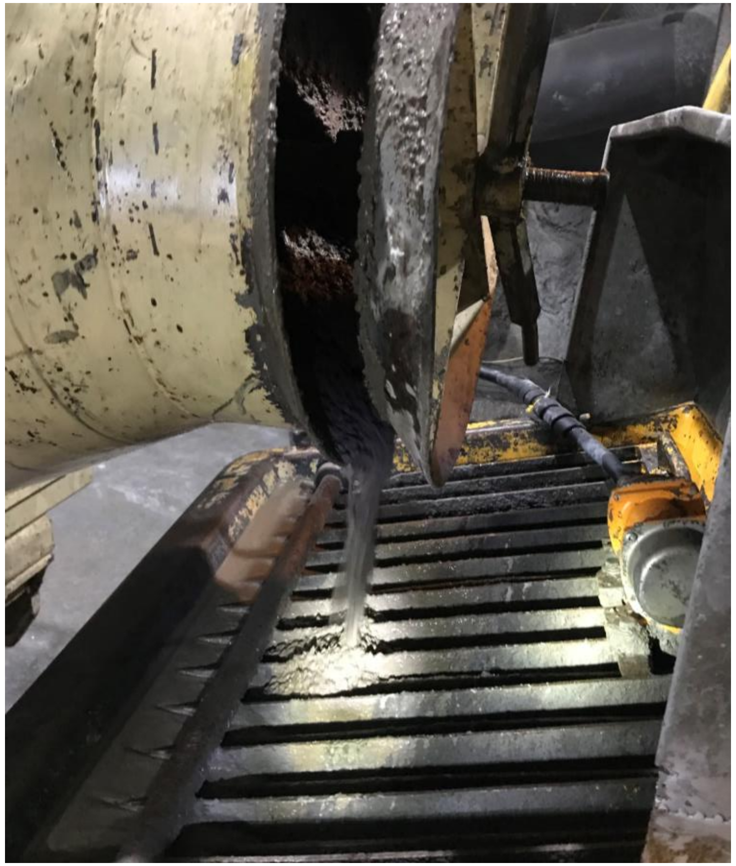
Factors to consider in sprayed concrete mix design

- Mix design should be undertaken by a competent concrete technologist, but the Nozzle Operator should be aware of the key features
- The Nozzle Operator and concrete technologist need to be aware
  - Required strength and thickness
  - Strength development
  - Type of set accelerator
  - Use of fibres
- Feedback between the Nozzle Operator and concrete technologist is recommended

Sprayed concrete constituents

- Aggregates
- Cement
- Water
- Additives
- Fibres
- Admixtures
- Set accelerator



Concrete properties and constituent effects

Workability / consistence / pumpability

- Mix design
- Admixture (superplasticizer)
- Aggregate grading and shape (round > crushed)
- Additives and fibres

Slump: > 16 cm
Flow: 50 – 70 cm
No seperation / segregation

Setting and strength

- Mix design (grading, w/c)
- Temperature
- Cement type
- Set accelerator (type and dosage)
- Type and amount of additives

Key for safety issues:
J2 for over head application

Cohesion and sagging

- Aggregate grading
- Paste content (cement + filler + additives + water)
- Additive type (Microsilica > Fly Ash > Slag)
- Admixtures
- Fibres

Application and SC quality

Constituents : cement (1/2)

- Cements should comply with the requirements of EN197 alternatively with the national standards or regulations valid in the place of use of the sprayed concrete
- Cement should be fresh and have established suitability for use with sprayed concrete:
  - Cement chemistry affects the performance of admixtures, especially accelerators
  - Further impurities, brought into the mix with the batching water, additives or any other constituent might adversely affect a well established cement – accelerator combination

Constituents : cement (2/2)

- The setting and strength development of the cement is dependent on the specific properties of the cement used. These factors include:
  - Cement type (CEM I - Portland Cement)
(CEM II, III – blended / composite cements)
  - Fineness (42.5 or 52.5)
  - C3A content (9 - 13%)
  - Gypsum content (3 - 6%)
  - Presence of (pre-blended) additives
  - Storage time / aging of cement
- For these reasons, the cement source should be chosen with care during pre-trials

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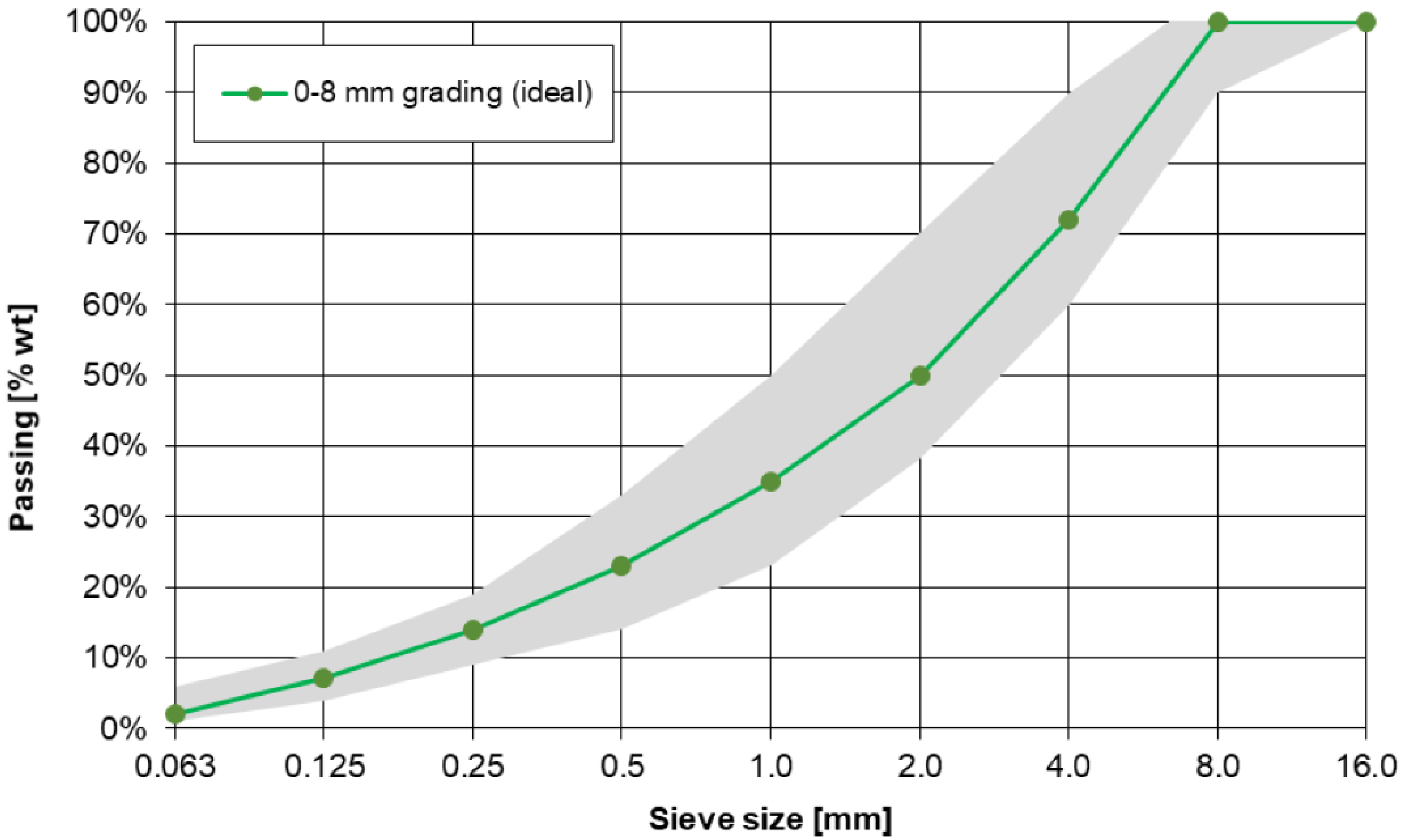
Constituents : aggregates (1/2)

- Aggregates should comply with the requirements of EN 12620 (preferably 8 mm, max. 16 mm) or alternatively with the national standards or regulations valid in the place of use of the sprayed concrete
- Crushed aggregates tend to be more difficult to pump compared to natural rounded aggregates.
- The use of additives and / or admixtures (pumping aids) may help in pumping especially with crushed aggregates
- Grading is important for mix homogeneity, pumpability, and rebound
  - see grading envelope for combining aggregates (next slide) taken from the EFNARC European Specification for Sprayed Concrete

Constituents : aggregates (2/2)



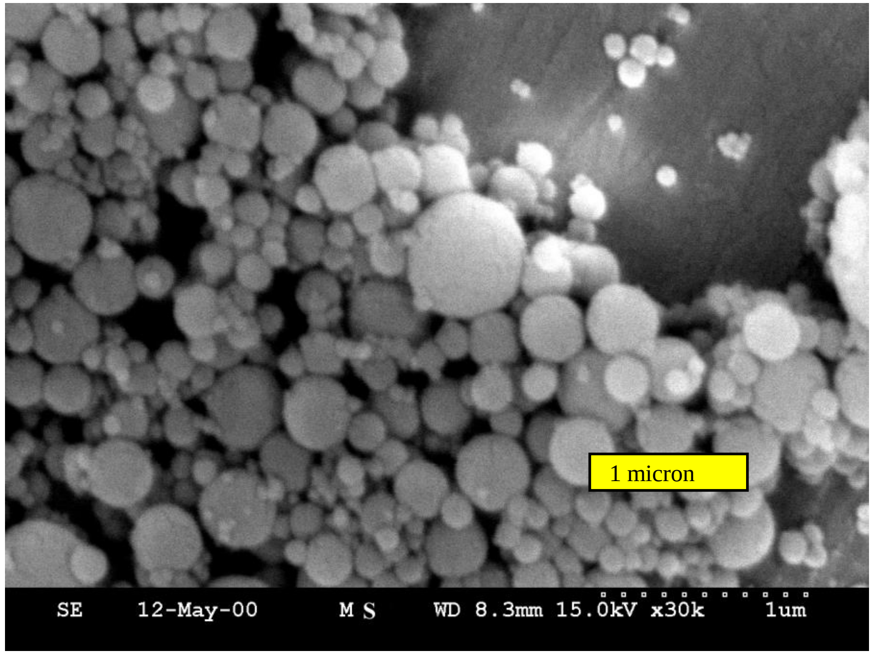
Constituents : additives

- Additives react with the cement solution, formed during the chemical reaction between cement and water
- They may be added to the mix or used to replace some of the cement, reducing cost and/or enhancing properties both in the fresh (e.g. pumpability) and in the hardened sprayed concrete (e.g. strength and durability)
- Three main additives are used:
  - Silica Fume EN 13263 (relatively fast reacting)
  - Fly Ash (PFA) EN 450 (relatively slow reacting)
  - Ground Granulated Blast-furnace Slag (GGBS) EN 15167 (slow reacting)

Note: Additives may already be present in cements designated as CEM II or III (EN 197). This may adversely affect the accelerator dosage, setting time and strength development of sprayed concrete

Constituents : silica fume

- Silica Fume is often also called microsilica
- Available as powder and aqueous slurry
- Highly reactive spherical silica particles, 100 x finer than cement
- In plastic (fresh) concrete:
  - Improves cohesion and adhesion
  - Improves pumpability and reduces blockage
  - Reduces rebound
  - Improves build up before sagging
- In hardened concrete:
  - Provides higher compressive & flexural strengths
  - Reduces permeability
  - Suppress alkali aggregate reactions & chemical attack
  - Reduces steel corrosion due to chloride ion penetration



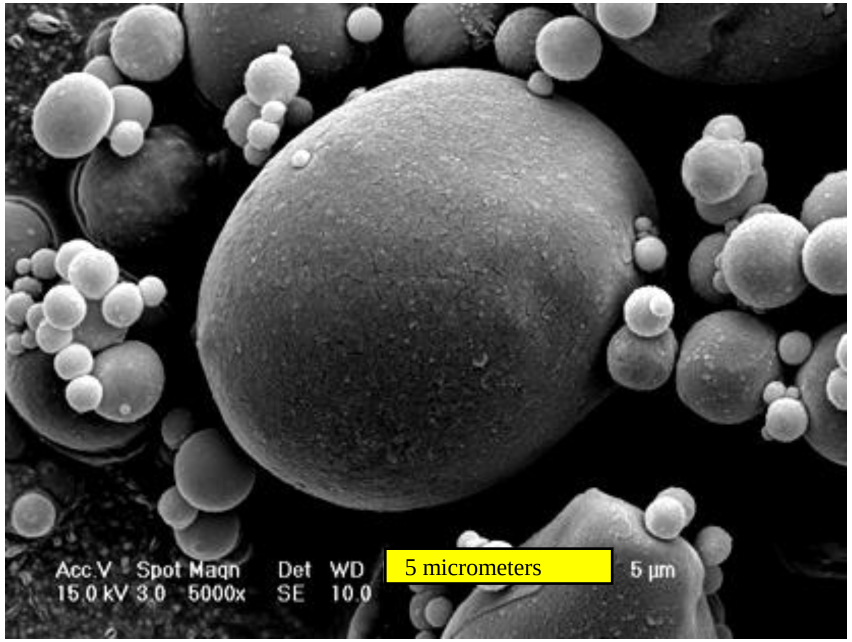
1 micrometre = 1/1000 millimetre

Note: The use of silica fume may increase water demand

Constituents : fly ash (PFA)

- Finely divided, mainly spherical pozzolanic material derived from power stations
- In plastic (fresh) concrete
  - Improves workability
  - Improves cohesion (pumping)
- In hardened concrete
  - Improves durability
  - Improves final strength

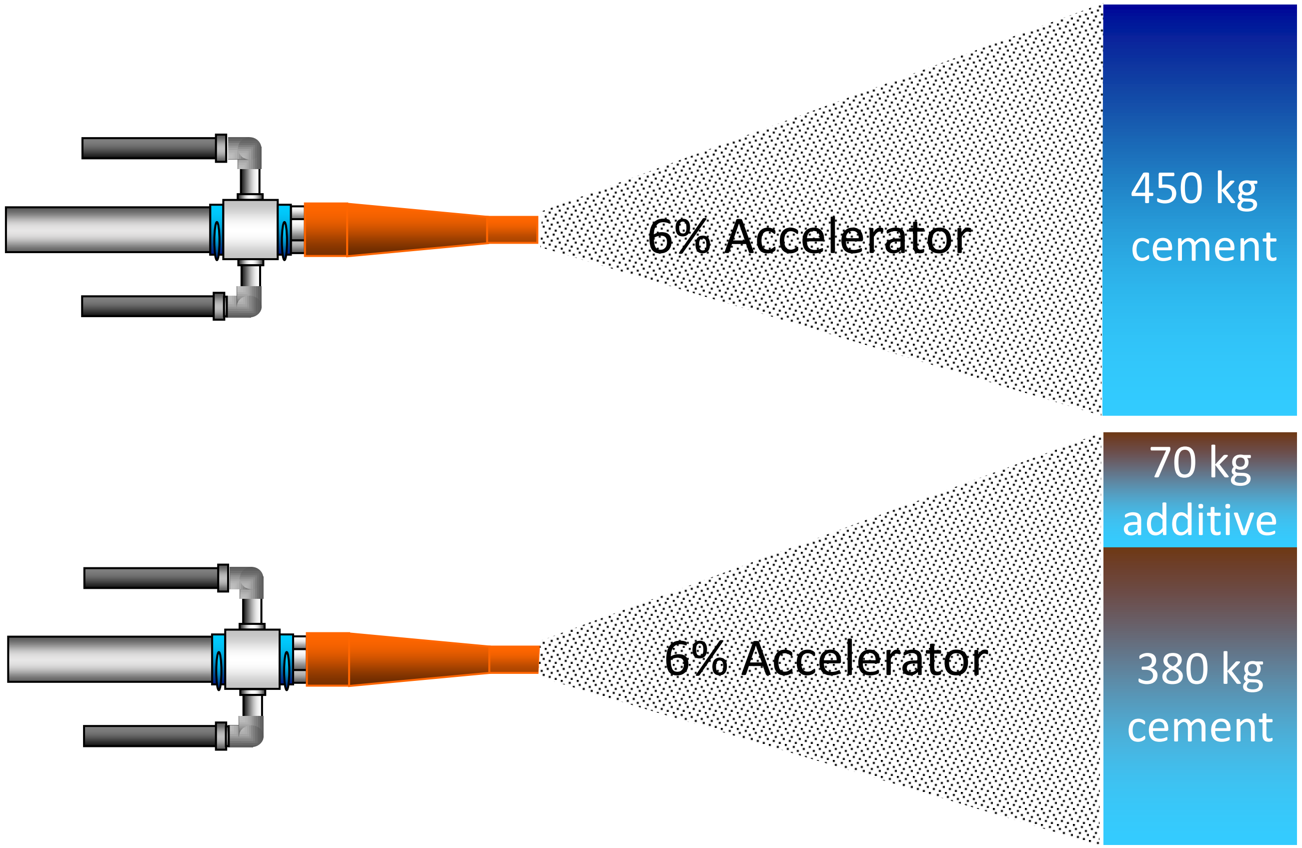
Note: Due to FA used as a cement replacement is shotcrete, setting and the strength development might be delayed



Constituents : GGBS

- Finely divided, latent hydraulic cementitious binder derived from steel blast-furnaces
- Added to normal concrete (at medium to high total binder content) to improve its long-term hardened properties
- Not often used as an additive in sprayed concrete because of its limited availability and its adverse effect on setting and early strength development

Additives / cement : accelerator interaction (1/2)



→ 27.0 kg/m^3 accelerator

→ 22.8 kg/m^3 accelerator

Note: Additives are not considered regarding accelerator dosage, thus, (in the above example) the accelerator dosage is reduced about 15% per cubic !

Additives / cement : accelerator interaction (2/2)

Additives:

• Have a significant water demand	→	w/c ratio is increased
	→	acceleration & strengths are reduced
• Mainly do not contribute to the acceleration chemistry	→	reduced reactivity of the cement solution / reduced acceleration
• Might chemically disturb the cement-accelerator interaction	→	slower strength evolution

Constituents : admixtures (1/2)

- Admixtures are chemicals, added in small amounts to change various properties of either the plastic (fresh) or hardened concrete
- Added during concrete batching at the plant or evtl. in the truck mixer
- The most important admixture used in sprayed concrete application are:
  - Superplasticizers
  - Hydration control admixtures
  - Pumping aids

Note: Shotcrete accelerators, as a special case of admixtures, are covered separately in the next section

Constituents : admixtures (2/2)

Superplasticiser

- Reduces the w/c ratio → improved strength and durability
- Improves workability → longer open time, improved pumpability
- Typical dosage 0.5 – 1.5 % bwc.

Hydration control admixture (Retarder)

- Retards the hydration until accelerator addition → maintains fresh concrete properties till its use
- Typical dosage 0.2 – 0.8 % bwc.

Pumping aid

- Improves cohesion, prevents mix segregation → improved pumpability

Constituents : SC accelerators (1/3)

Liquid accelerators are added in the process of concrete application on site, providing to the shotcrete a:

- Fast initial stiffening
- Early age strength development
- Improved overhead spraying performance
- Reduced sagging

The three main types of liquid accelerators are:

- Alkali free (Al-sulphate based)
- Aluminates (Alkali aluminate based)
- Silicates (Alkali silicate based)

Constituents : SC accelerators (2/3)

Sodium silicate based (waterglass)

- High alkali content (Na_2O) and caustic → personal protection against skin and eye burns (pH beyond 11)
  → leaching of shotcrete (high Na_2O)
  → risk of alkali silicate reaction (ASR)
- Typical dosage 5 – 15% bwc. → reduced final strength, up to 50%

Sodium/potassium Aluminates

- High alkali content (Na2O) → personal protection against skin and eye burns (pH beyond 12)
  → leaching of shotcrete (high Na_2O)
  → risk of alkali silicate reaction (ASR)
- Typical dosage 3 – 8% bwc. → reduced final strength, up to 30%

Constituents : SC accelerators (3/3)

Alkali free (Na_2O eq. < 1.0%)

- Based on Al-sulphate and Al-hydroxide → ettringite reaction as driving force of the SC acceleration
- pH ≈ 3.0 → non caustic to human tissue
- Less effective initial stiffening
- No alkali ions (Na_2O eq. < 1.0%) → no risk for leaching, clogging of drainage systems, and/or ASR → beneficial for final strength and durability
- Typical dosage 5 – 10% bwc.

Alkali free accelerators are recommended for high performance and permanent sprayed concrete

Shotcrete accelerators : strength development and final strength

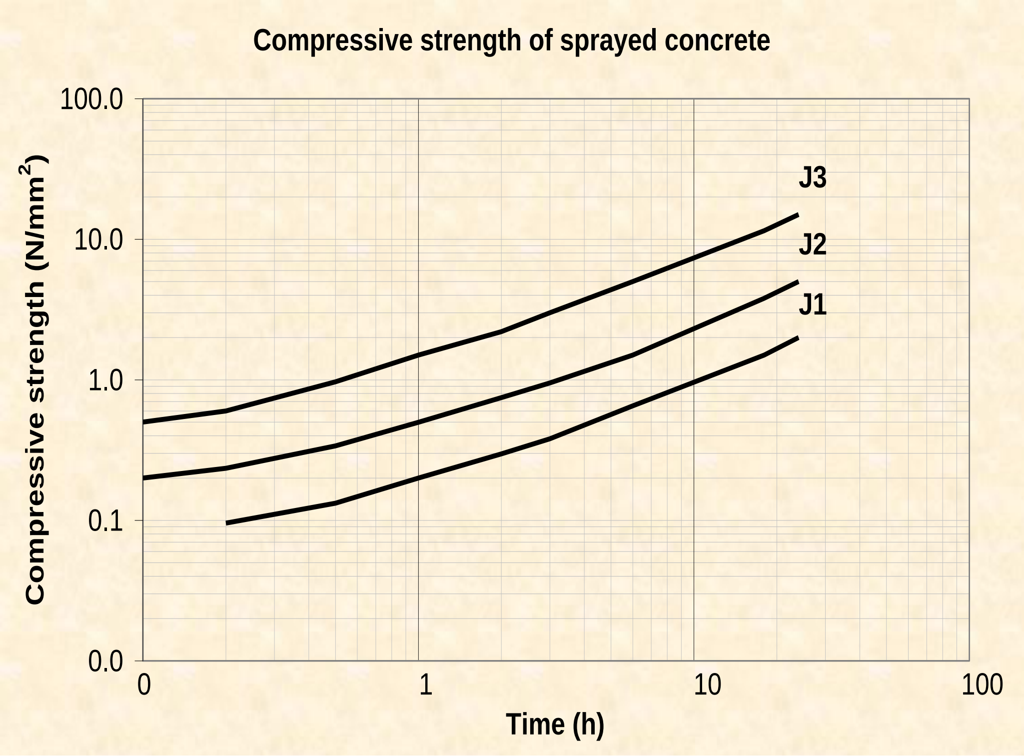
- Quick stiffening and early strength development is required in order to:
  - place shotcrete even over head
  - stabilise loose rocks
  - provide a safe working area for the construction team to work in
  - increase excavation speed
- Strength development is strongly depending on
  - cement type (reactivity)
  - w/c ratio
  - temperature
  - accelerator type and dosage
- Concrete temperature should be in the range of 15 – 25°C to ensure the expected accelerator reaction

Note: A temperature change by 10°C changes the speed of chemical reactions by a factor of 2-3 (van t'Hoff's rule)

- Accelerator temperature should be > 15°C, preferably > 20°C (lower viscosity facilitates dosing)

Shotcrete strength development

- Strength development curves according to EN14487-1
- J1, J2 and J3 are often used as a guideline for different soil/rock classes



J3 shotcrete
Only used in special cases (highly fragile rock, water afflux). High dust and rebound formation

J2 shotcrete
Used for usual excavation stabilization, overhead

J1 shotcrete
Appropriate in thin layers or slope and trench stabilization

Constituents : fibres (1/3)

Micro Synthetic Fibres EN 14889-2

- Monofilament and fibrillated
- Typically added at 1.5 - 2.0 kg/m³

Steel Fibres EN 14889-1

- Deformed, hooked-end, flat-end etc.
- Typically added at 25 - 60 kg/m³

Macro Synthetic Fibres EN 14889-2

- Continuously deformed – structural alternative to steel
- Typically added at 4.5 - 9.0 kg/m³

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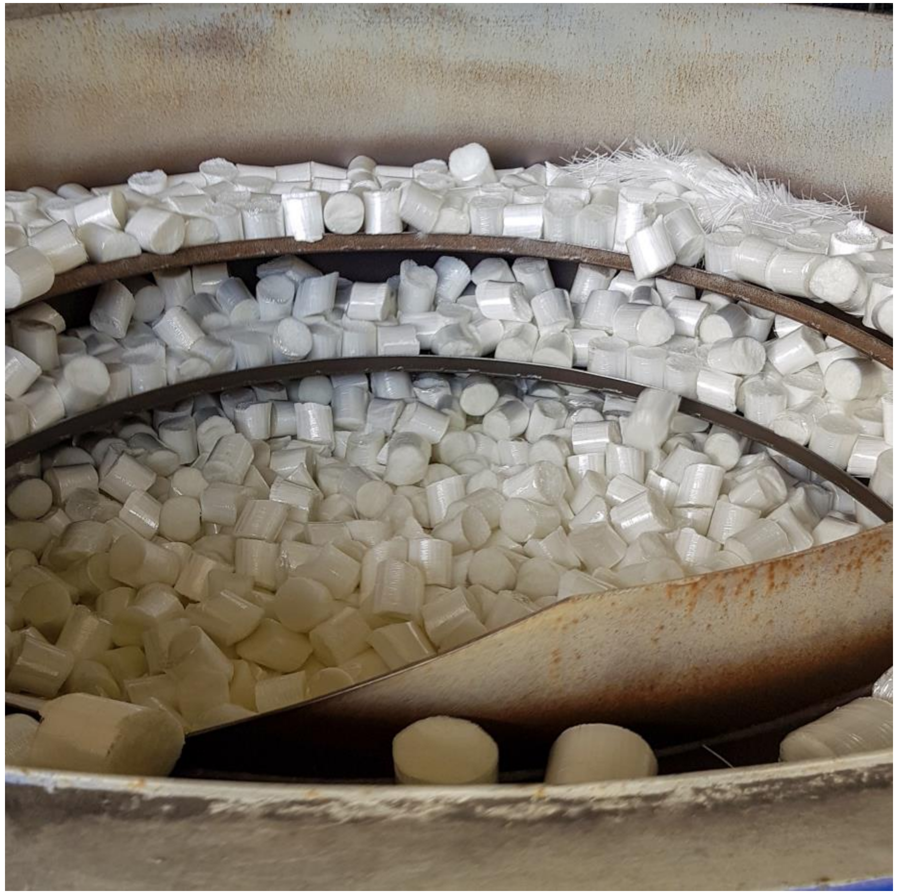
Constituents : fibres (2/3)

- All fibres give sprayed concrete:
  - Increased cohesion, build and sag resistance
  - Reduce or eliminate the need for steel mesh
  - Reduce plastic shrinkage and settlement cracking
  - Increase impact and shatter resistance
- Micro synthetic fibres:
  - Reduce explosive spalling in tunnel fires
- Steel and synthetic macro fibres:
  - Increase flexural toughness and shear strength
  - Increase resistance to long term cracking
  - Improved post crack strength and toughness

Constituents : fibres (3/3)

Factors related to mix design and use:

- Balling can be a problem if the length to diameter ratio is not low, if dosage is too high or if addition is too fast
- Fibre length should not exceed 60% of pump line diameter
- Good distribution of fibres depends on good dosing method and speed as well as the mixer
- The use of fibres may reduce workability this can be offset by the use of plasticizing admixtures



Constituents : water (1/2)

A low water-cement ratio (w/c) is crucial for:

- Setting and early strength development
- Long term strength
- Durability and resistance to chemical attack

➢ w/c should always be less that 0.50 and preferably less than 0.45

➢ Use a superplasticising admixture to give the required workability within this w/c range

Water is necessary:

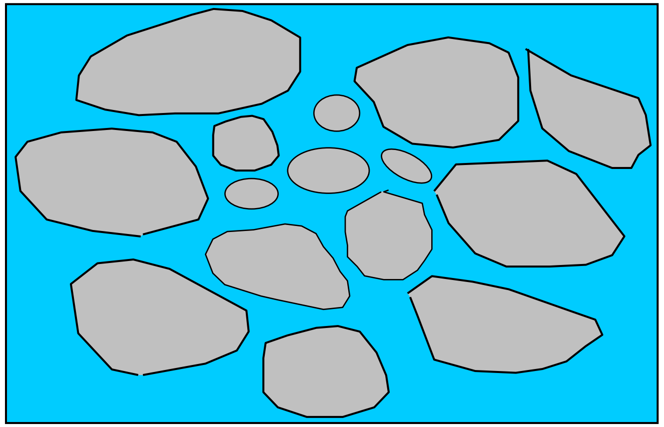
- To provide the consistence/lubrication to pump the concrete
- As reactant in the cement hydration

➢ The concrete should not be allowed to dry out by evaporation after spraying. See section on curing

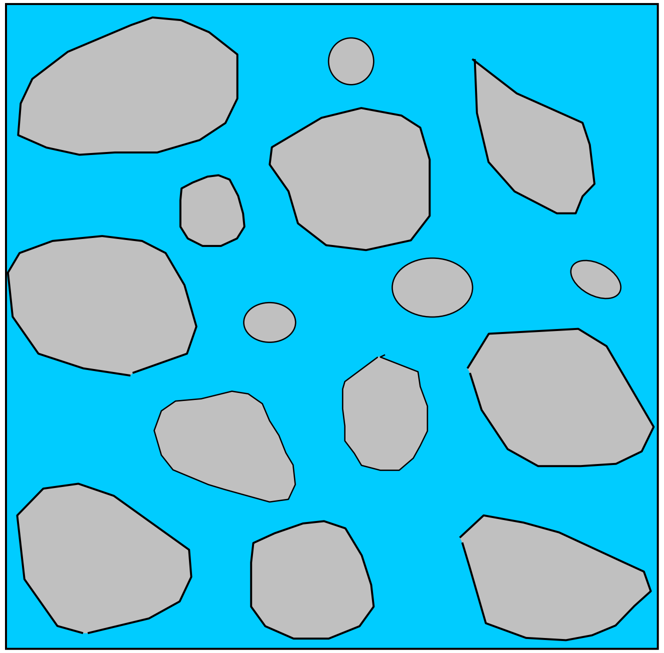
Constituents : water (2/2)

Effect on strength, permeability and durability of concrete

Low W/C
Cement particles close packed.
High Strength
Low permeability



High W/C
Cement particles spaced.
Low strength
High porosity and permeability



If the cement particles are too spaced apart by excess water, the hydration products cannot fill the gaps, leaving a low strength, porous concrete

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Typical sprayed concrete mix design

Example	Dosage [kg/m^3]	Volume [l]
Cement	420.0	133.3
Sand 0-4 mm (60%)	1029.8	388.6
Gravel 4-8 mm (40%)	686.5	259.1
Superplasticizer (1.0% bwc) *	4.2	3.8
Water (w/c = 0.45)	185.2	185.2
Air content (3%)		30.0
Total	**2325.7**	**1000.0**

* bwc = by weight of cement

Link to chapter:

Spraying equipment