



ROCKCRETE
EQUIPMENT (PTY) LTD

Company Reg No.: 1947/024677/07

Concrete Technology

Shotcrete – What is it?

➤ DEFINITION

Concrete projected into place at high velocity and compacted by its own momentum

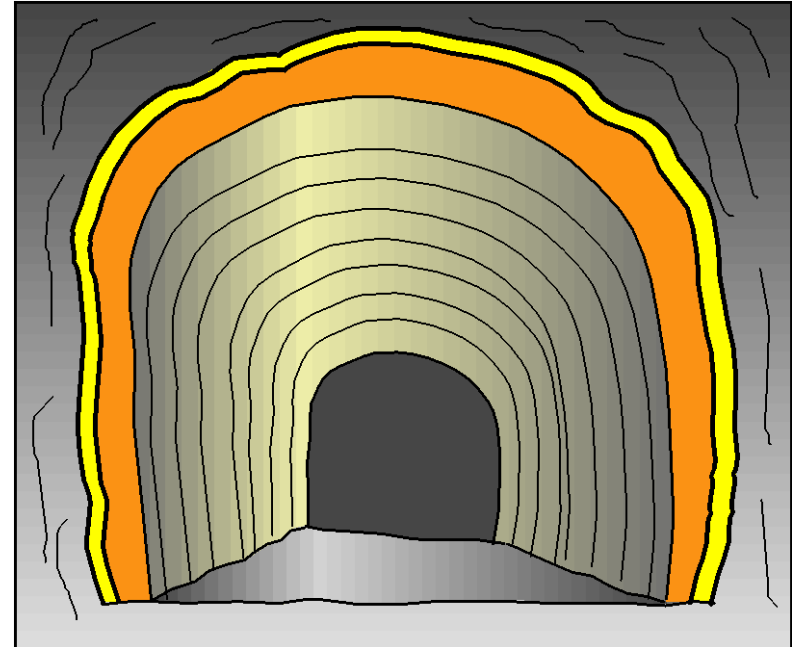
➤ CAN BE EITHER WET OR DRY SPRAYED

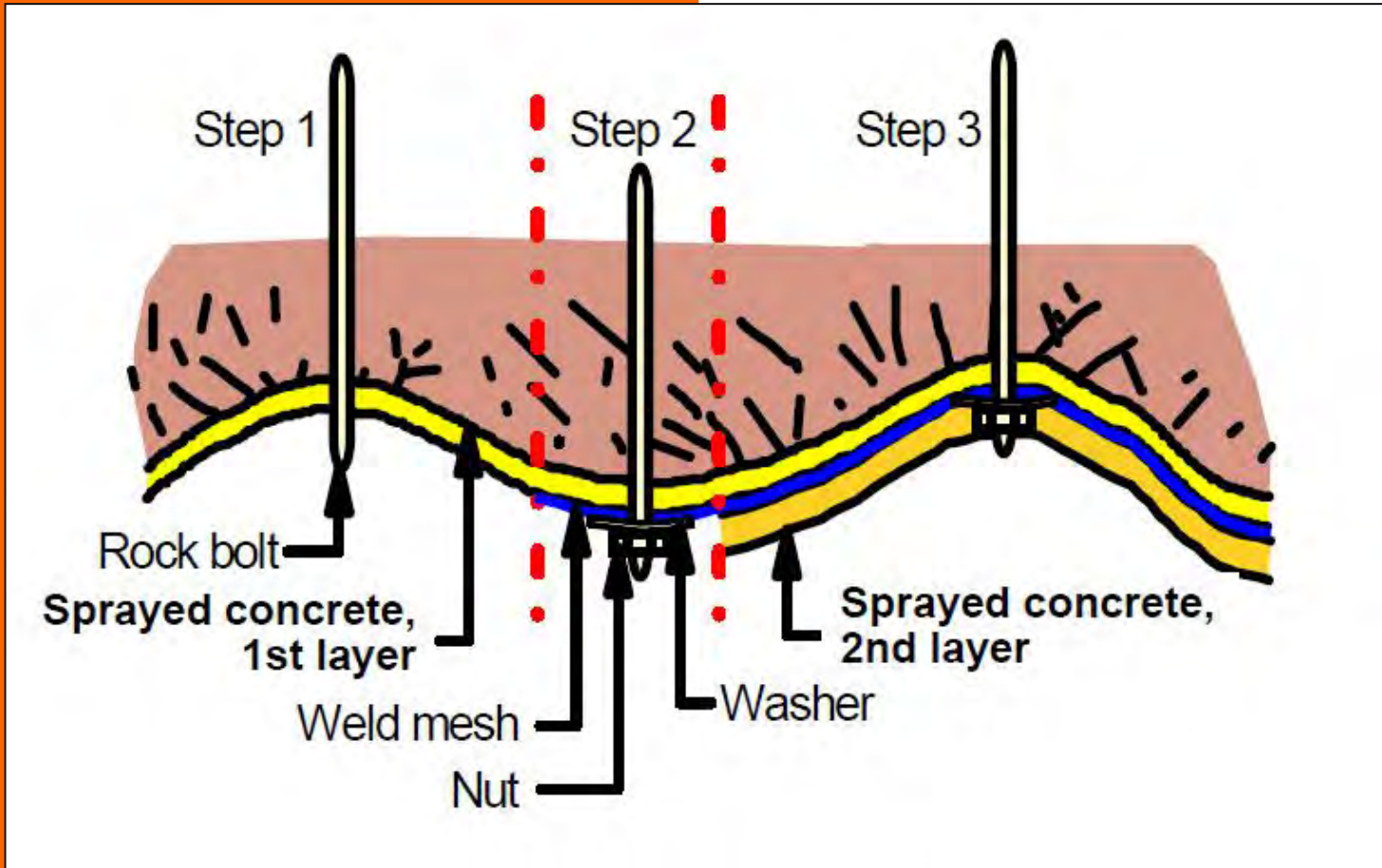
➤ REMEMBER

☺ Shotcrete is concrete

Sprayed Concrete

Purpose of Shotcreting is to support ground or rock to be safe for next working phase and prevent collapse of excavated area and is also used as final layer in tunnelling.





Spraying Methods

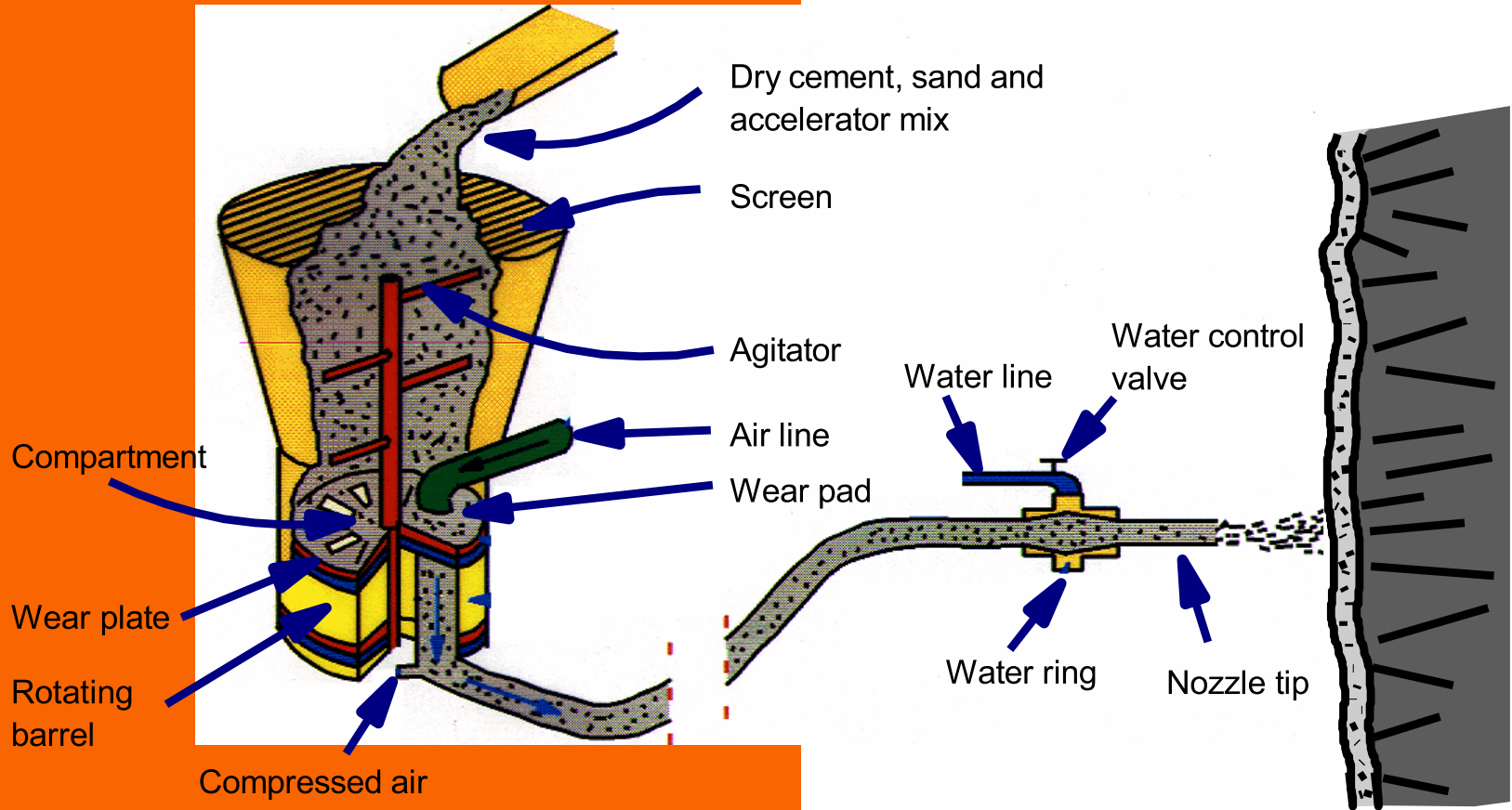
Dry method

- Old way to do, cheap
- Is normally used only for small spraying amounts and repairs
- Almost allways hand spraying, needs more people



Equipment

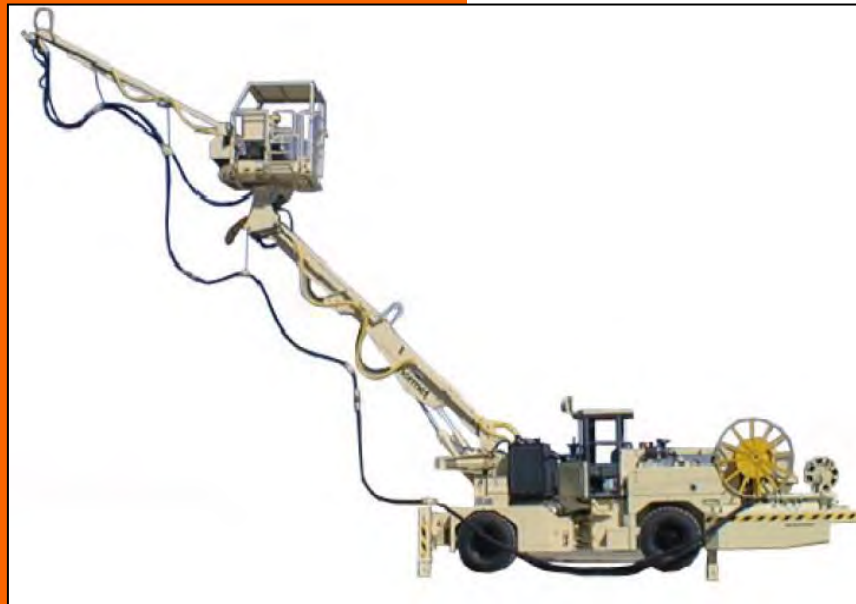
Dry method



Spraying Methods

Wet spraying

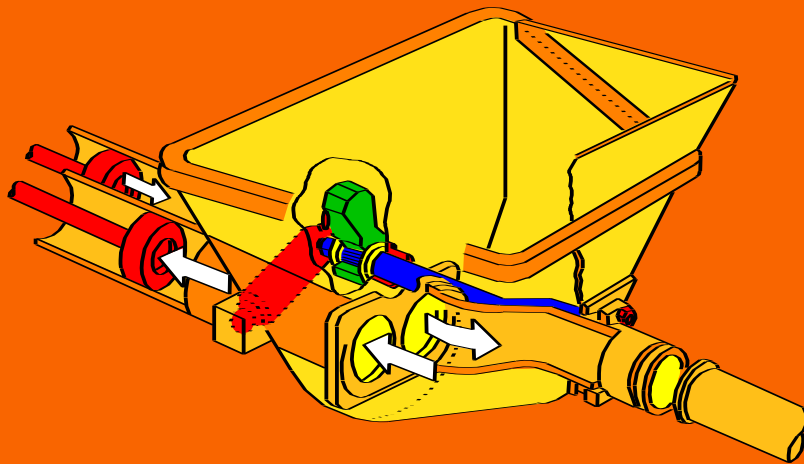
- Modern method
- For large spraying quantities
- Average spraying usually 12 – 16 m³/h
- Almost always mechanised spraying, can be operated by two people



Equipment

Wet method

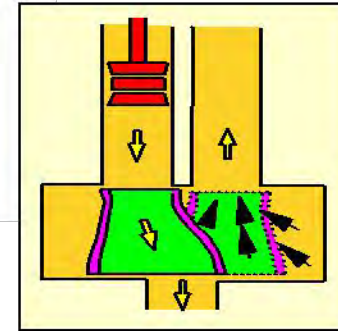
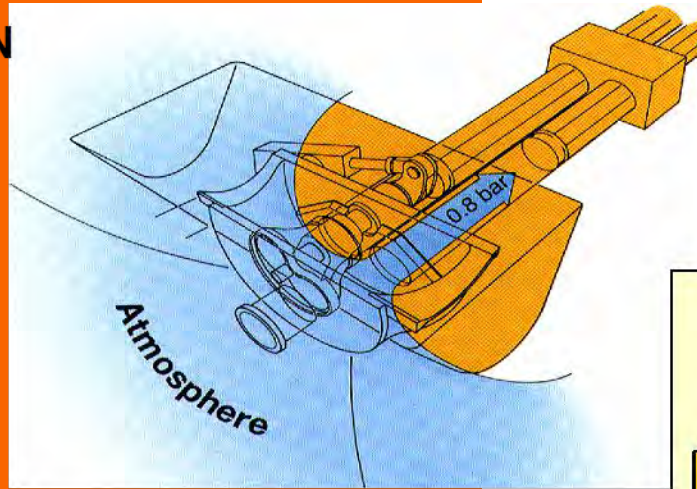
- Usually self propelled carrier
- Usually electro-hydraulic
- Piston type -pump
- Usually with onborad compressor
- Additive dosing system
- Spraying manipulator



Double-piston pump
(wet-mix spraying)

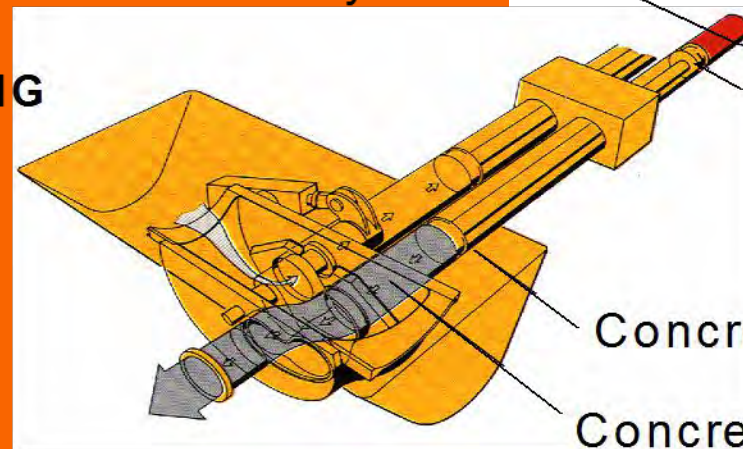
Concrete Pumps

SUCTION



Hydraulic oil

PUSHING

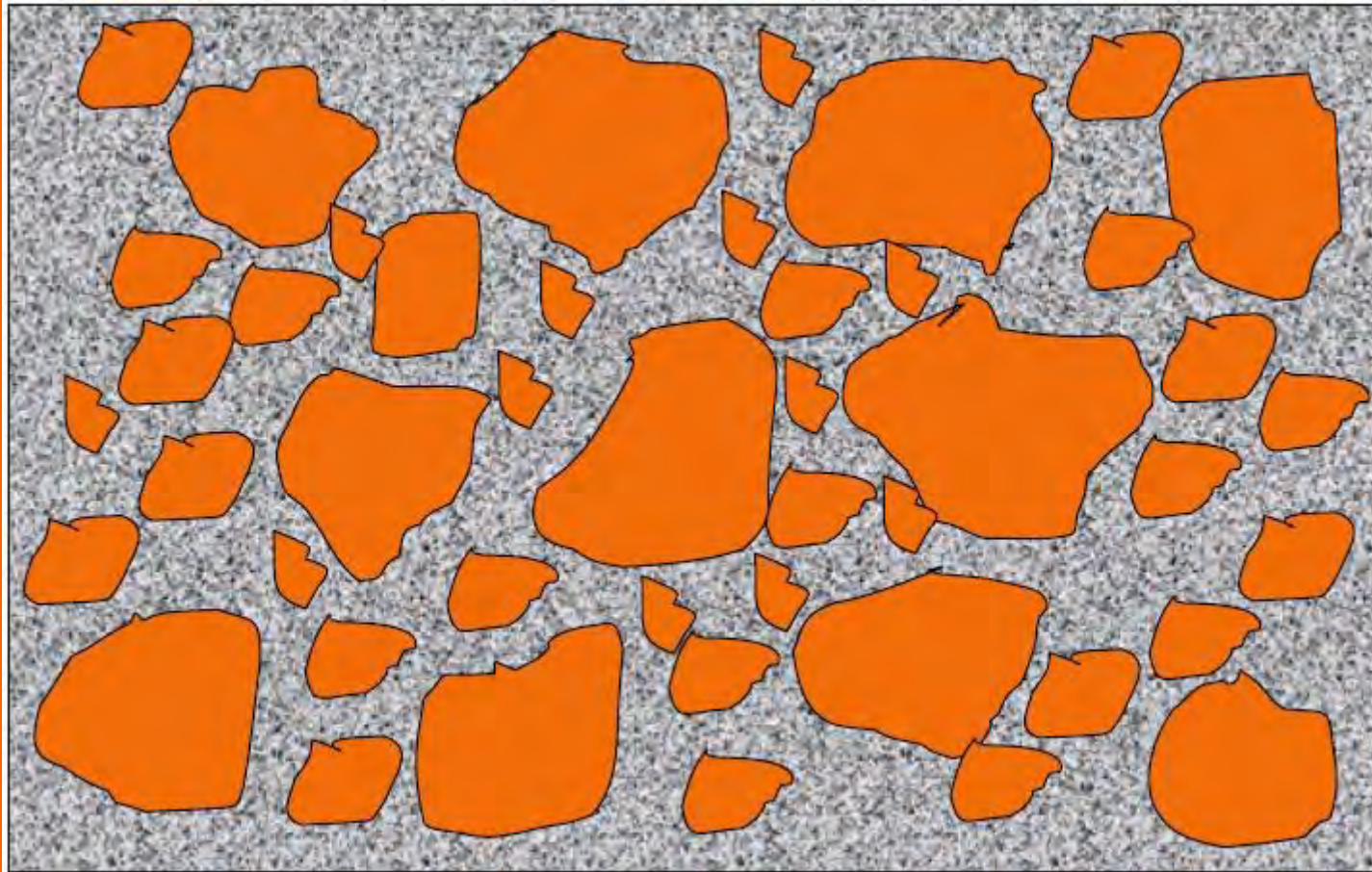


Hydraulic piston

Concrete piston

Concrete

The Concrete Mix



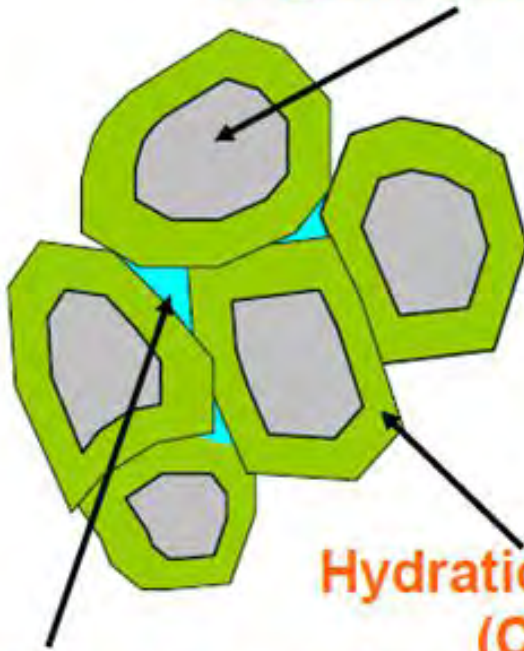
Why does concrete go hard?

- Not a result of drying out
- A chemical reaction between cement and water –**hydration**
 - causes cement particles to stick to each other and to the aggregate
- No water - No hydration - concrete does not harden properly.

Why is curing so important?

(Cement + water =
CSH)

Original cement particle



Hydration products
(CSH)

Water to complete
the hydration

- The term “hydration of cement” describes the reaction between the cement and the water which make calcium silicate hydrates (CSH)
- The CSH is the “gel” or binder that gives concrete its strength
- If the water in the concrete evaporates too quickly, these important hydration processes are not given a chance to create a dense, strong matrix between the aggregates
- Curing is needed to keep the water in the sprayed concrete as long as possible to help hydration of the cement
- Good curing gives
 - Higher compressive strengths
 - Higher bond strengths
 - Increased durability
 - Less shrinkage cracking

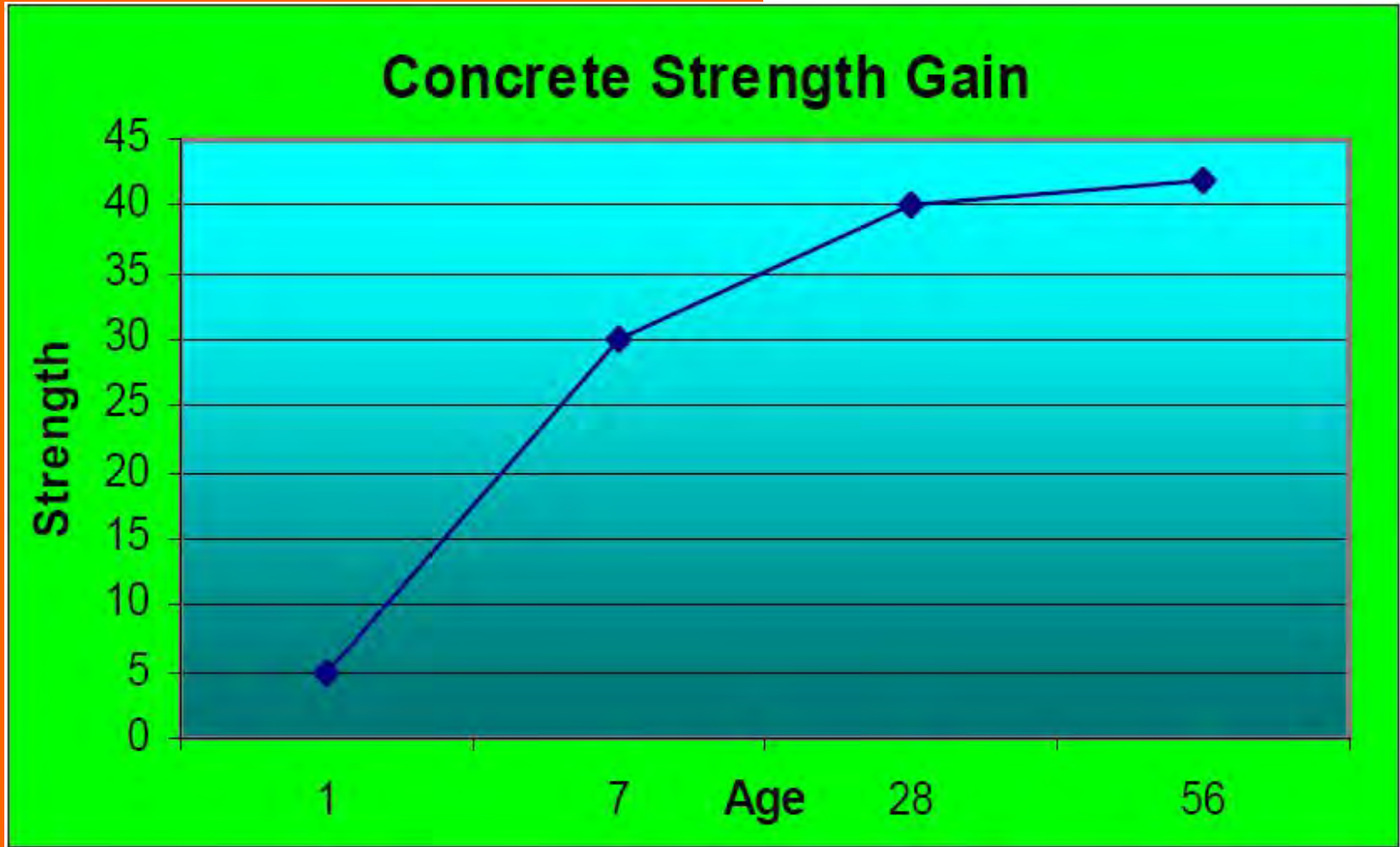
Hydration

- Time taken for reaction dependent on:
 - ratio of water to cement (W/C ratio)
 - ambient temperature
- Average mix will remain workable for around two hours

Strenght of Concrete

- Developed by hydration
 - Cement particles sticking together
 - Cement particles sticking to aggregate
- Mechanical interlock of materials

Typical Strength Gain



Strength of Concrete

- Dependent on water-cement ratio (w/c or wcr)
- i.e. amount of water in mix divided by amount of cement
- e.g. 170 litres water per m³ divided by 340 kg cement per m³
= 0.50 water-cement ratio

Strength of Concrete

Dependent on water-cement ratio

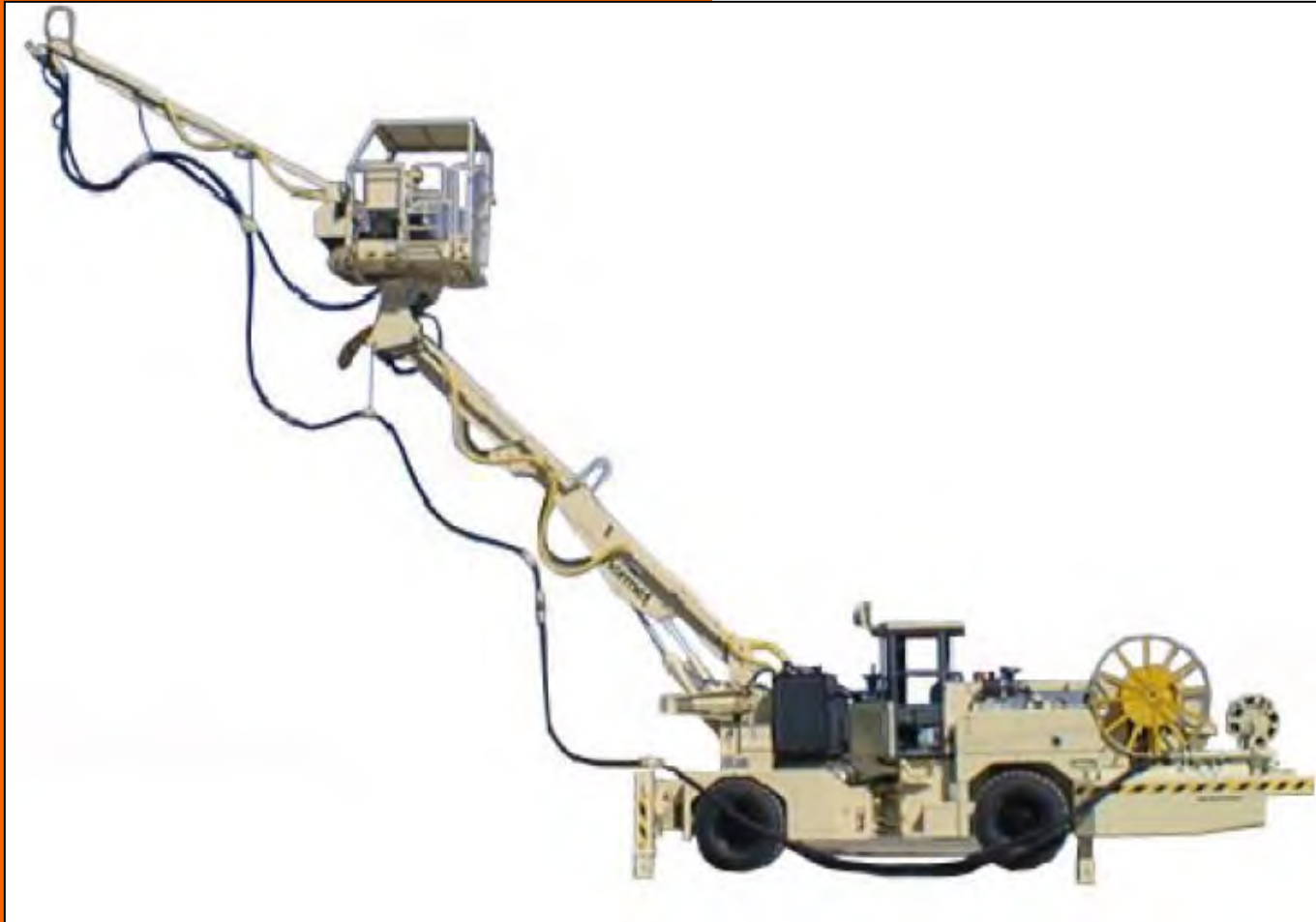
➤ **More water**

concrete more workable, BUT concrete strength lower

➤ **Less water**

concrete strength higher BUT concrete less workable

Shotcrete



Wet Shotcrete Set-up

- Batch Plant- ***Pan mixer (High Sheer)***
- Materials- ***Aggregates, Cement, Water, Fibre and Additives***
- Transport- ***Concrete Truck or Agi Car***
- Spraying Equipment- ***Spraymec***
- Applicator- ***Trained, Certified Nozzleman***
- Control- ***Thickness, Flow and Accelerator***
- Quality Control- ***Cubes, Panels***
- House Keeping- ***Clean Equipment, etc...***

Batch Plant

Batch Plant produce concrete!



Makes a concrete from specified formulae!

Basic Mix Design Technology

Basic concrete technology:

- Mix design and constituents of sprayed concrete
- Factors to consider in sprayed concrete mix design
- Concrete properties: workability, pumpability, setting, strength development
- w/c ratio
- Relevant standards
- Mix design programme

Batch Plant



- Moisture Content
- Weather Conditions
- Temperatures
- Rain
- Ice
- Wind

- *Calibration-Scales, Water meter Additive Dosing Systems*
- *Condition- Panmixer - Discharge Door and Paddles Spacing*
Truck Mixer - Cleanliness of barrel inner
- *Mix Design - Ensure correct mix design on PLC*
- *Mixing- Proper Mixing Time and sequence of additions*

Materials

➤ Concrete

- **Cement**
- **Water**
- **Sand**
- **Gravel**
- **Additives**
 - Hydration control
 - Retarders
 - Plastizisers
- **Fibres**



Aggregates

➤ Accelerators

- Water glass (silicates)
- Aluminates
- Alkali free accelerators

Mix Design – Oyo Tolgoi

| Material | Relative Density | Kg/m ³ | Liters/m ³ |
|---------------------|------------------|-------------------|-----------------------|
| Cement | 3.14 | 480 | 153 |
| CSF | 2.1 | 25 | 12 |
| Sand | 2.6 | 1115 | 429 |
| Stone 10mm | 2.7 | 500 | 185 |
| Rheobuild 1100 | 1.1 | 7 | 6 |
| Accelerator (SA160) | 1.4 | 25 | 18 |
| Fibre (Barchip) | | 5kg | |
| Water | 1 | 215 | 215 |
| Total | | 2120 | 1000 |

W?C/R

0.45

Slump 180mm

Cement Types

- Portland Cement (52.5 CEM 1)
 - EN 197-1
- Stored by EVERY Premix plant



Constituents – Cement 1

- 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 concrete¹**
 - **Note 1): Cement chemistry can affect the performance of admixtures, especially accelerators**



Materials of Cement

- Additions react with components of cement
- They may be added to replace some of the cement, reducing cost and/or provide enhanced properties (durability) to the concrete.
- 3 Main additions are used:
 - **Fly ash (PFA) EN 450**
(relatively slow reaction with cement)
 - **Ground granulated Blast-furnace slag (GGBS) EN 15167** (slow reaction with cement)
 - **Silica Fume EN 13263**
(relatively good reaction)
- **Note these additions may already be present in EN 197 cements designated as CEM II or III. This may affect the setting time and strength development of prepared concrete.**

Cementitious Materials

- Ground Granulated Blast furnace Slag (ggbfs)
 - EN 15167-1
 - by-product of steel industry



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 addition in sprayed concrete because of its limited availability and its adverse effect on setting and early strength development
 - selected molten slag quenched & ground

Cementitious Materials

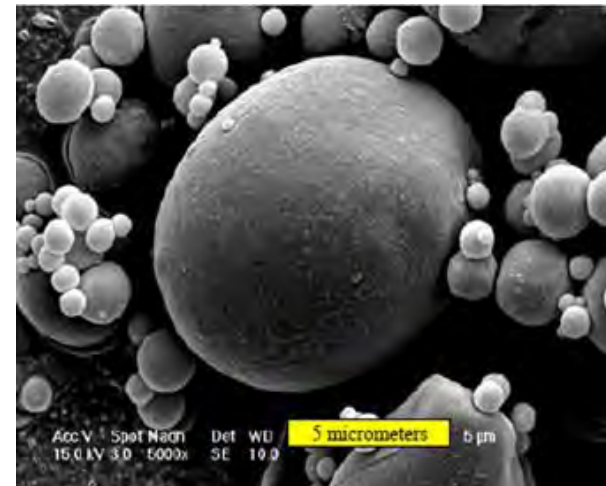
- Pulverised Fuel Ash (pfa)
 - EN 450



Constituents – Fly Ash (PFA)

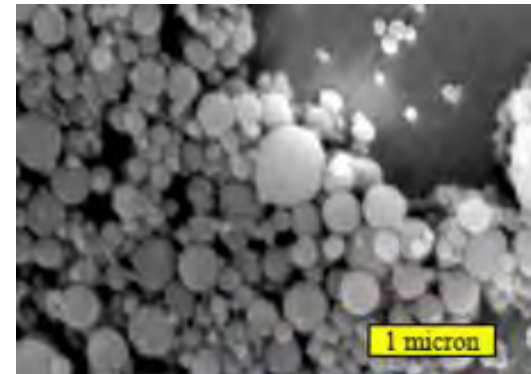
– **waste product produced when pulverised coal is burned in power station furnaces**

- Finely divided, mainly spherical pozzolanic material derived from power stations
 - In plastic (fresh) concrete
 - Improves workability
 - Reduces water demand
 - Improves cohesion → pumping
 - Cement replacement (may delay setting and strength development)
 - In hardened concrete
 - Improves durability
 - Improves final strength



Silica Fume (SF)

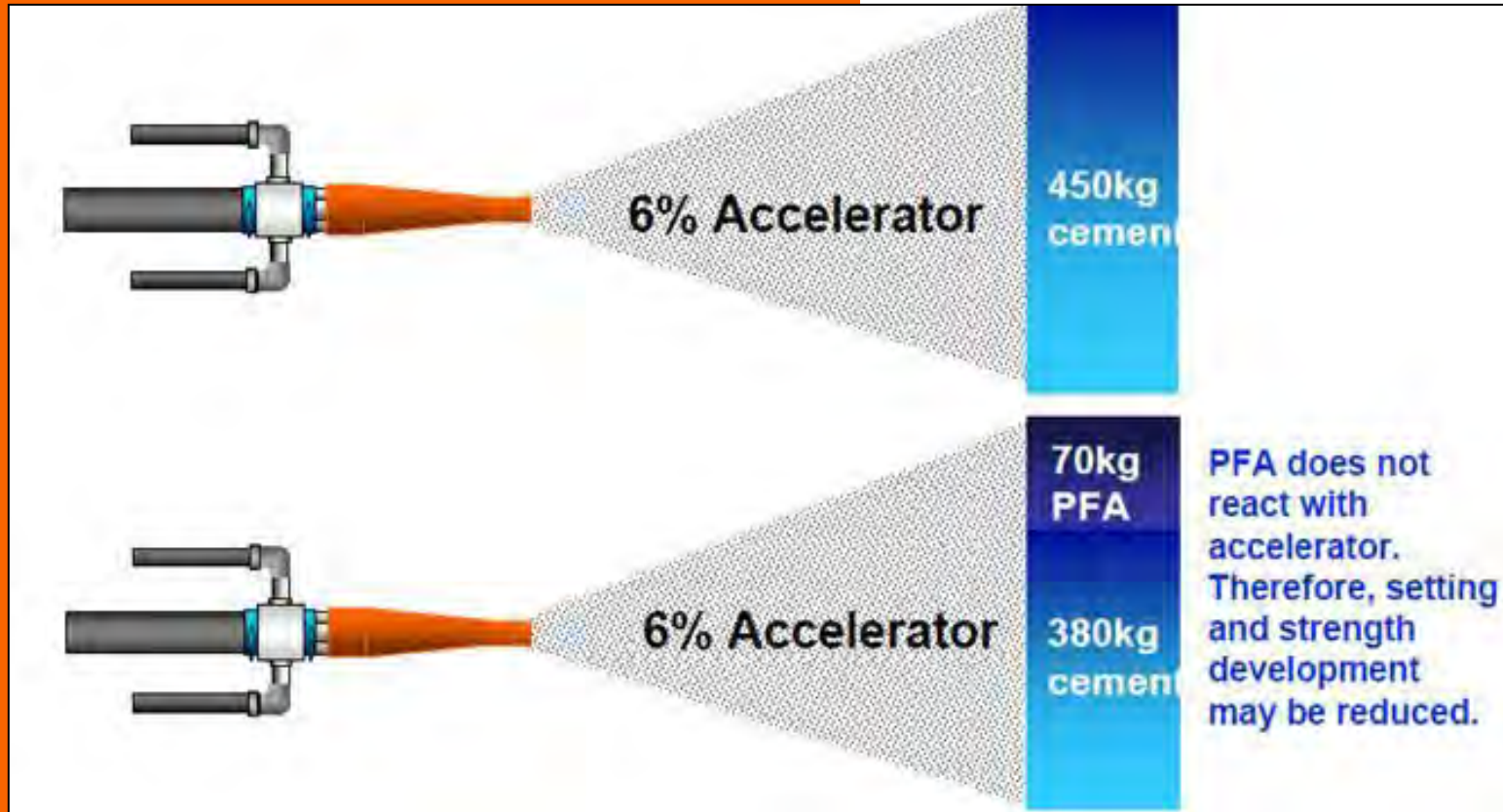
- 100 X finer than cement, reactive (to cement, not to accelerator) spherical particles
 - **In plastic (fresh) concrete**
 - Improves cohesion and adhesion, reducing rebound
 - Improves pump ability and reduces blockage
 - Improves build up before sagging
 - **In hardened concrete**
 - Provides higher compressive & flexural strengths
 - Reduces permeability
 - Suppress alkali aggregate reactions & chemical attack
 - Reduces steel corrosion due to chloride ion penetration
- Be aware that the use of silica fume may increase water demand.
SF may require higher accelerator dosage.



Cementitious Materials

- **ggbs and pfa**
 - are not cements
 - will not gain strength like CEM-1
 - are blended with CEM-1 to give “alternative” cementitious materials

Materials



- Mixes with PFA or GGBS tend to need significantly more accelerator as the OPC portion needs to work harder to get the required set.
- However, very high doses of accelerator may result in other problems, including poor quality/durability of the sprayed concrete as well as increased cost.

Blended Cement Types (EN 197)

Blends of CEM I and ggbs

- CIIIA-S
 - 6% - 20% ggbs
- CIIIB-S
 - 21% - 35% ggbs
- CIIIA
 - 36% - 65% ggbs
- CIIIB
 - 66% - 85% ggbs

Blended Cement Types (EN 197)

Blends of CEM I and pfa

- CIIA-V
 - 6% - 20% pfa
- CIIB-V
 - 21% - 35% pfa
- CIIIA
 - 36% - 55% pfa

Water

- Have to use clean and fresh water.
- **Rule of thumb:**
Water what you can drink, can be used with a concrete!



Water

Water is necessary:

- To pump concrete.
- To react with and hydrate the cement.
- The concrete should not be allowed to dry out by evaporation after spraying.

Water

Water: Cement ratio (W/C) is critical to:

- Early setting and strength development.
- Long term strength.
- Durability and resistance to chemical attack.
- W/C should be less than 0.45 and preferably more less than 0.40

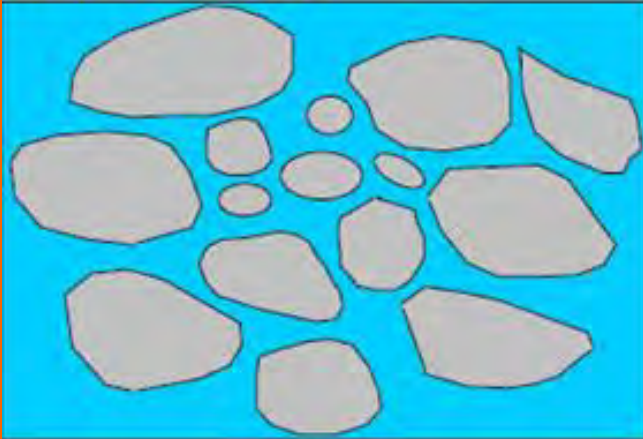
Water/Cement

Low W/C

Cement particles close packed.

High Strength

Low permeability

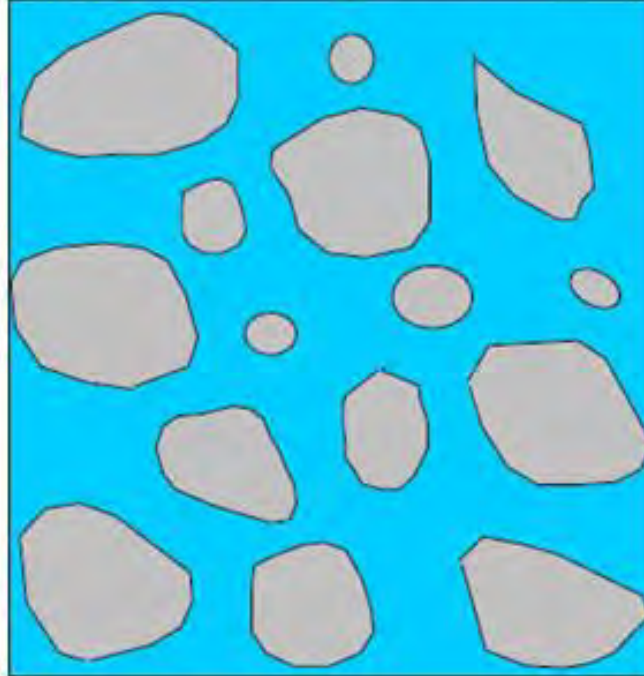


High W/C

Cement particles spaced.

Low strength

High porosity and permeability



If the cement particles are spaced too far apart because of excessive water addition, the hydration products cannot fill the gaps, leaving a low strength, porous concrete

Aggregates

- Should comply with EN 12620
 - “Aggregates for Concrete”



- Primarily sourced from quarries/sand & gravel pits or marine dredging



Aggregate Types

- Land based sand & gravel



Aggregate Types

- Marine sand & gravel



Aggregate Types

- Crushed rocks
 - limestone
 - granite/basalt



Aggregate Types

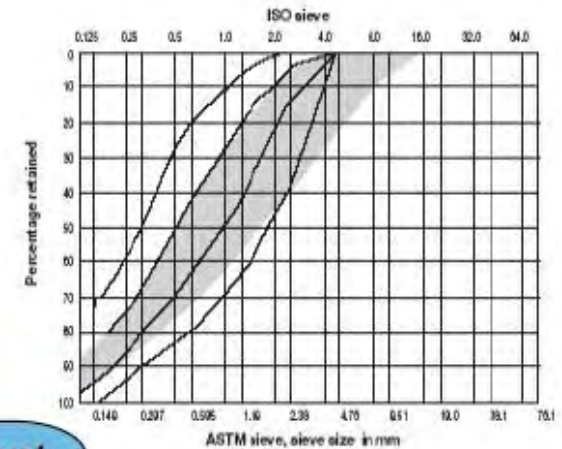
- Artificial
- Recycled



Composition of Sand/Aggregate

Sand/aggregate grading curve influences:

- Water demand
- Workability
- Reactivity with Accelerator
- Rebound
- Shrinkage
- Durability

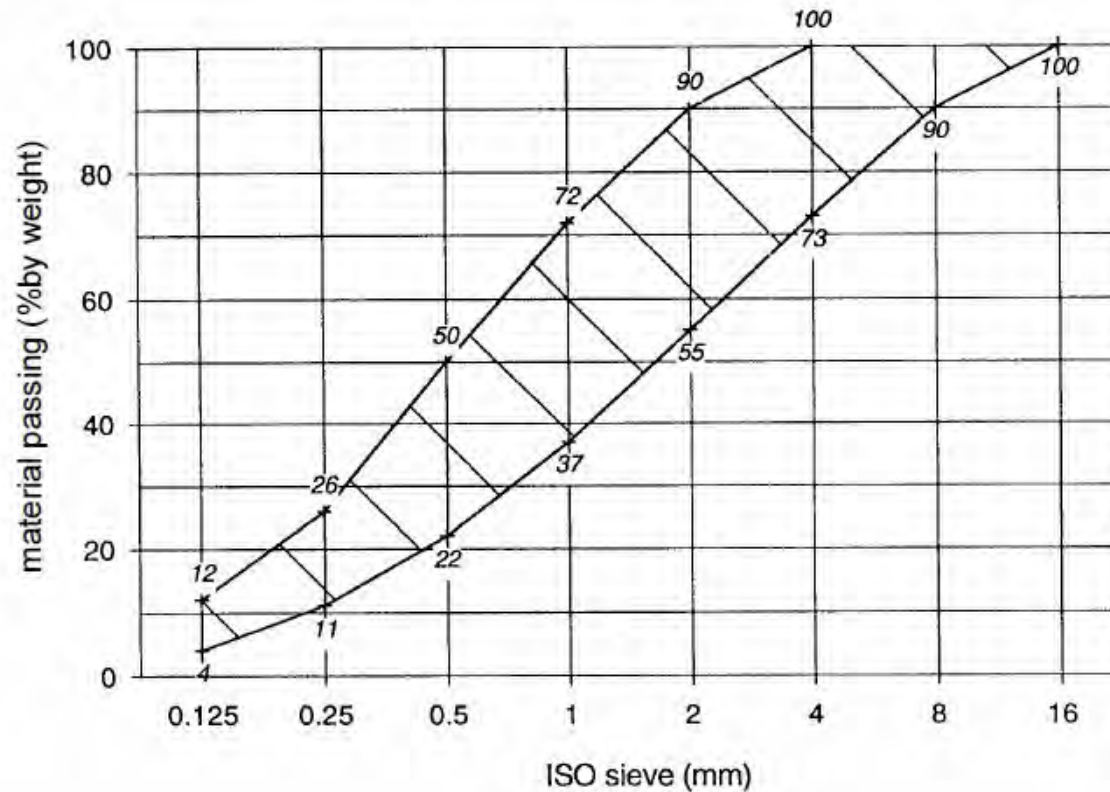


Mixing of different fractions in the right proportions is the clue



Constituents — Aggregates

EFNARC programme for combining aggregates for Sprayed Concrete



Aggregate sizes

- Coarse Aggregate (EN 12620)
20-40, 10-20, 6-14, 4-10 mm

- Concrete sand (EN 12620)
0-4, 0-2, 0-1 mm



Admixtures

- Can modify the properties of concrete to enhance performance in a particular situation
- Cannot make a poor concrete good!

Admixture Types

- Water Reducers/Plasticisers
- Air entrainers
- Superplasticisers
- Waterproofers
- Retarders
- Accelerators
- Hydration controllers

Water Reducers/Plasticisers

➤ **Will either:**

- Increase workability at the same water content, or
- Reduce the water content at the same workability
- Produce cost effective concrete

Air entrainers

- Give frost resistance to hardened concrete
 - used in external paving
- Does not give protection to fresh concrete!
- Works by “entraining” millions of tiny bubbles into the concrete, which act as expansion chambers” for freezing water.

Constituents – fibres (1)



- Micro Synthetic Fibres EN 14889-2
 - **Monofilament and Fibrillated**
 - **(Typically added at 1.0 – 3.0 kg/m³ or 0.1 – 0.3% by volume)**

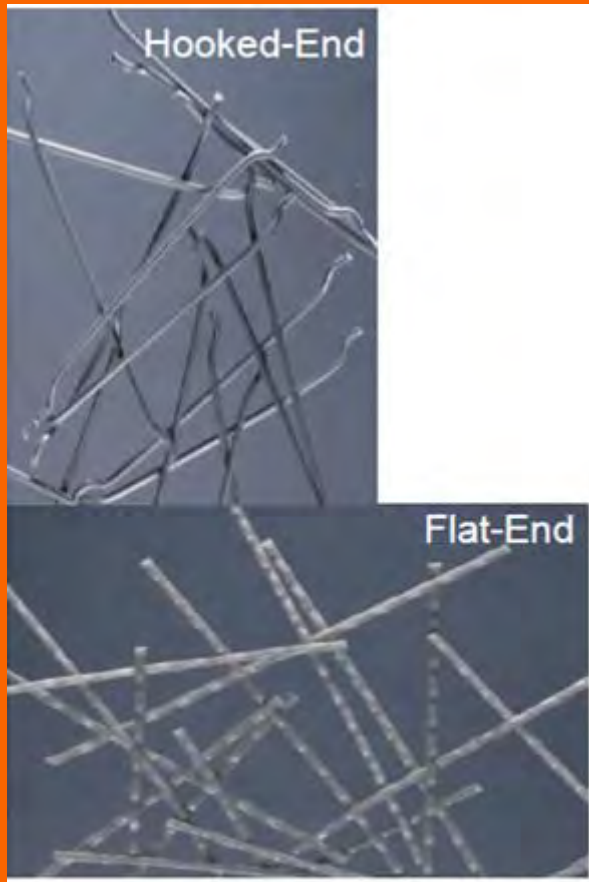


- Steel Fibres EN 14889-1
 - **Deformed, hooked-end, flat-end etc.**
 - **(Typically added at 25 – 60kg/m³ or 0.45 – 0.75% by volume)**



- Macro Synthetic Fibres EN 14889-2
 - **Continuously deformed – structural alternative to steel**
 - **(Typically added at 4.5 – 9.0 kg/m³ or 0.5 – 1.0% by volume)**

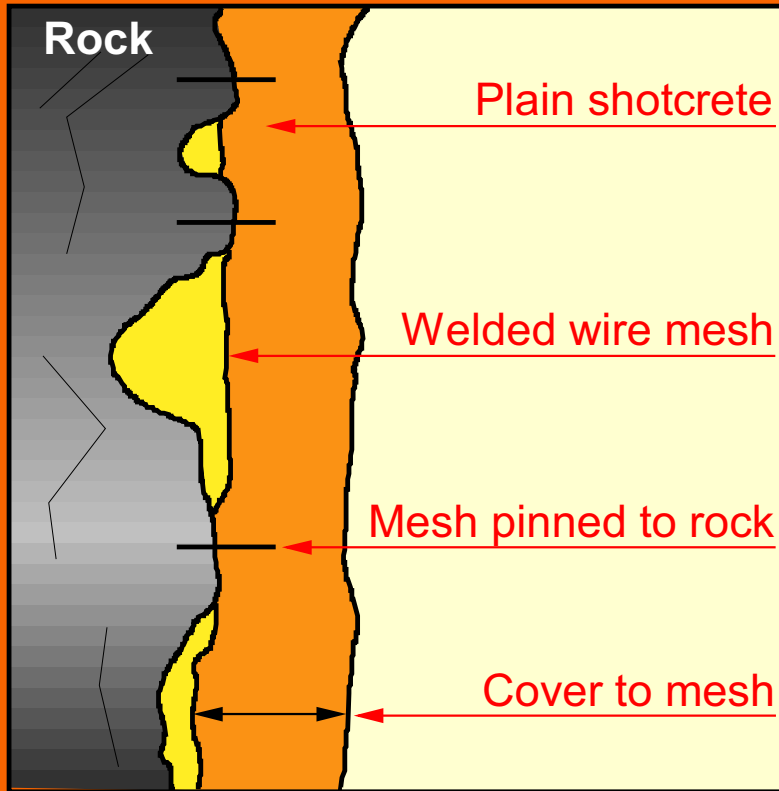
Constituents – fibres (2)



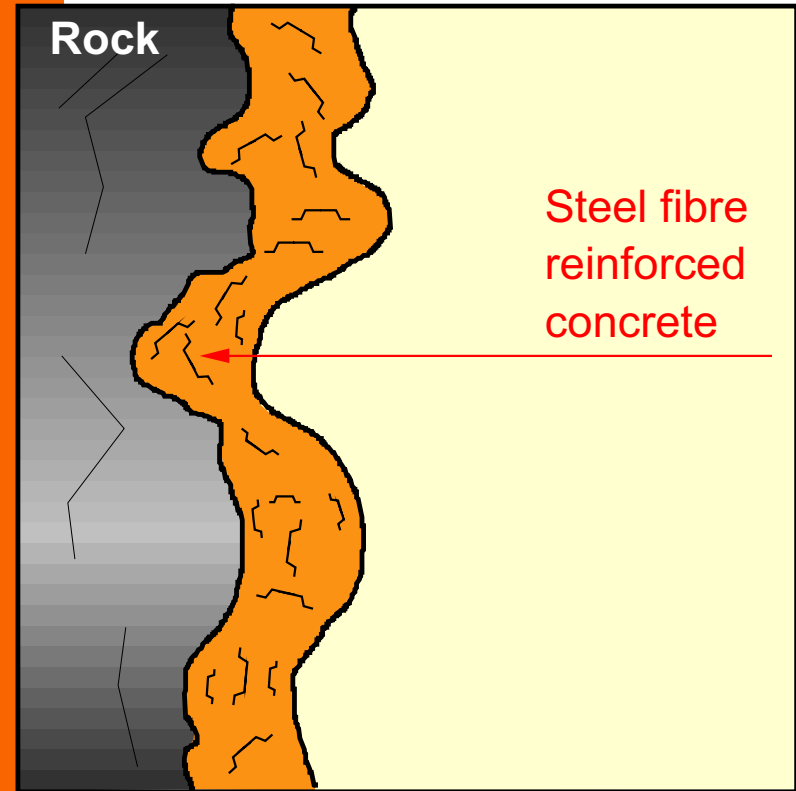
Contribution of all Fibres in Sprayed Concrete:

- 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 spilling 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

Sprayed concrete consumption with wire mesh and steel fibres



**MESH REINFORCED
CONCRETE**



**STEEL FIBRE REINFORCED
CONCRETE**

Constituents — fibres (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 plasticising admixtures



Accelerators for sprayed concrete

Constituents – set accelerators (2)

➤ Currently, there are 3 types of set accelerators available:

▪ Silicate Based

- High alkali content (Na_2O) and caustic (irritant) pH above 11, required personal protection against skin and eye burns. Display fast stiffening, but can significantly decrease the final strength (up to 50%) and durability, especially when overdosed. **Risk of Alkali Silicate Reaction (ASR) and leaching of water soluble portions.**
- Typical dosages are 6 – 14% by weight of cement
- ***Very slow strength development and little possibility to build high total thickness overhead***

▪ Aluminate base

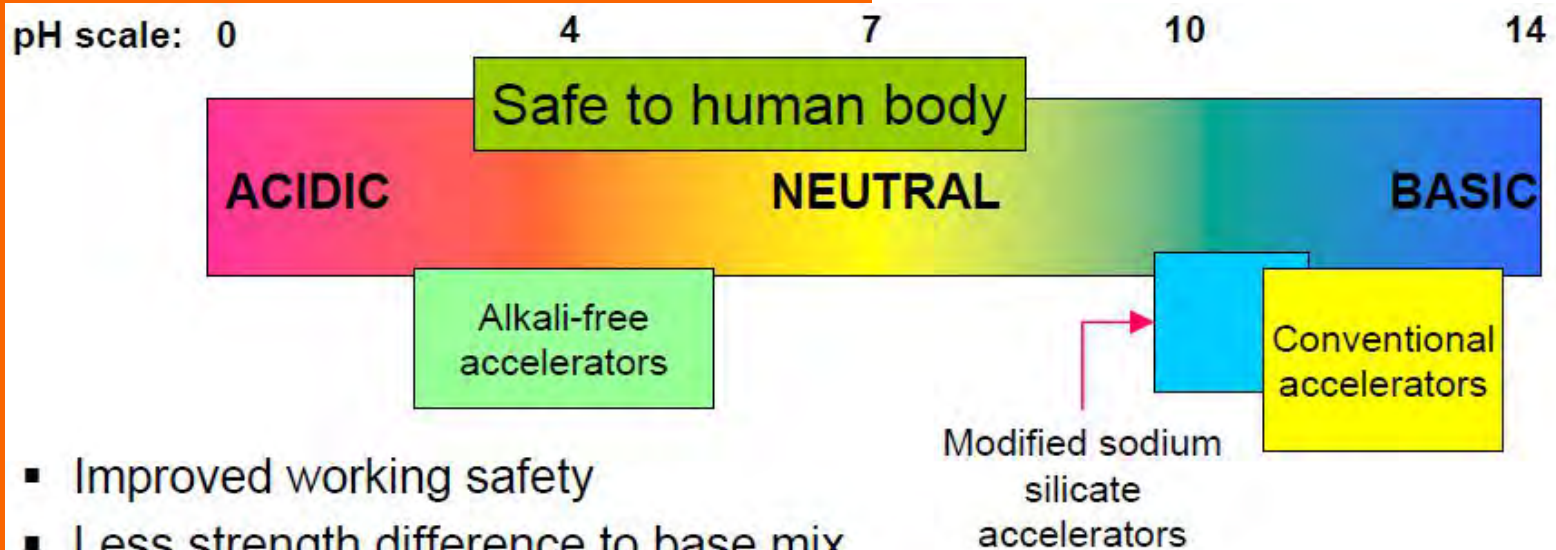
- Alkaline and caustic, pH above 12, require personal protection against skin and eye burns. Take part in the hydraulic reactions of cement and show very good stiffening and hardening effects, but can significantly decrease the final strength (up to 30%) and durability, especially when overdosed. Risk of **Alkali Silicate Reaction (ASR)**
- Typical dosage are 3 – 8% by weight of cement

• Alkali-free

- Alkali-free ($\text{Na}_2\text{O} < 1\%$) accelerators are preferred because they ***are less hazardous (non caustic) and give a better working environment. Has fast setting and good strength development provided correct type for compatibility with cement.*** These accelerators have a positive effect even on the final strength and durability of the concrete. For permanent sprayed concrete. It is always recommended to use alkali-free accelerators
- Typical dosage are 5 – 10% by weight of cement

Type of set accelerator should be selected based on the type of application, specification, **cement compatibility** and local conditions

Alkali-free accelerators: Human- and structure-friendly!



- Improved working safety
- Less strength difference to base mix
- Less dust and rebound
- Lowered risk of ASR
- Improved sulphate resistance when using standard OPC
- Reduced environmental impact in hardened concrete
- **Due to their low pH, for all AFA accelerators tanks made of plastic or stainless steel are needed on the robots.**

Benefits of alkali-free accelerators (AFA) over traditional accelerators

AFA ↔ Silicates

- Faster setting
- Higher early strength
- Faster strength developments
- Reduced loss of final strength
- Reduced permeability
- Dramatic reduction in rebound
- Ability to apply large thicknesses
- Better durability
- Reduced risk for alkali-aggregate reaction
- Better working environment and improved safety (less dust)
- Environment friendly

AFA ↔ Aluminates

- Less sensitive to cements
- Dramatic reduction in loss of final strength
- Better durability
- Reduced risk of alkali-aggregate reaction
- Better working environment and improved safety
- Reduced permeability
- Environment friendly

Set accelerators – strength development/final strength

- Strengths development is strongly dependent on cement type, cement factor, w/c ratio, accelerator type and dosage, and temperature
- A temperature increase of 10° C will roughly double chemical reaction time (and vice versa)!
- Accelerator type, dosage and mainly w/c ratio are a great importance not only for strength development, but also for final strength and quality of sprayed concrete
- Excellent results in terms of long strength can be obtained by using alkali-free accelerators at moderate dosages (<8%)
- Accelerator temperature not below 15°C, preferably above 20 °C

Good Concrete?