Admixture Technical Sheet – ATS 8

Sprayed Concrete Admixtures

1 Function

Sprayed concrete is pumped to the point of application and then pneumatically propelled into place at high velocity. The applications are frequently vertical or overhead and this requires rapid stiffening if slumping or loss by concrete detaching from the substrate under its own weight is to be avoided. In tunnelling applications, sprayed concrete is often used to provide early structural support and this requires early strength development as well as very rapid stiffening.

Admixtures can be used in the fresh concrete to give stability and hydration control prior to spraying. Then by addition of an accelerating admixture at the spray nozzle, the rheology and setting of the concrete are controlled to ensure a satisfactory build up on the substrate with a minimum of un-bonded material causing rebound.

There are two processes:

- The dry process where the mix water and an accelerator are added to a dry mortar mix at the spray nozzle.
- The wet process where the mortar or concrete is premixed with a stabiliser / retarder prior to pumping to the nozzle where the accelerator is added.

The wet process has become the method of choice in recent times as it minimises dust emissions, the amount of material rebound and gives more controlled and consistent concrete.

2. Standards

These classes of admixture are covered by the requirements of BS EN 934 Part 5: Admixtures for Sprayed Concrete – Definitions requirements, conformity, marking and labelling.

All CAA manufacturers CE mark their products to show they conform to this standard.

3 Materials

Wet process sprayed concrete is based on ordinary structural concrete mix designs with typical cement contents in the range 400 to 500 kg/m$^{3.}$ The size of the coarse particles will normally be limited to about 8mm with a high proportion of sand in the mix. A good overall aggregate grading is essential and the use of EFNARC grading curves has become commonplace. The mix design is critical in the wet process to achieve a pumpable mix with workability retention and minimum segregation, which then has the required characteristics to be projected into place with correct thickness of build, good bond and low rebound.
Steel, polypropylene or macro synthetic fibres may be added to provide improved build and give internal reinforcement.

Admixtures used in wet process sprayed concrete to control stability and hydration during pumping and prior to spraying include:

- Conventional superplasticisers
- Modified polycarboxylate ether based superplasticisers
- Hydroxycarboxylic acid based retarders
- Phosphonate based retarders
- Polymer based water retaining admixtures

Historically the accelerators for both wet and dry shotcrete included:

- aluminates
- silicates
- carbonates

These are available in either liquid or powder form but are alkali salts with a high pH that have given rise to health and safety issues. Alkali Free liquid accelerators are now widely used in wet spray concrete.

Alkali free accelerators include:

- Aluminium sulphate
- Aluminium hydroxide
- Aluminium hydroxy-sulphate
- Calcium aluminate powder
- Calcium chloride or nitrate may also be used

These are alkali free and much safer and environmentally friendly but do not usually give such rapid early strength development, however, they do give superior long-term strength.

4 Mechanism

In the wet process the cement retarders / stabilisers are added at the time of mixing and inhibit cement hydration from a few hours up to several days depending on dosage. They can also provide a degree of thixotropy to the mix which prevents segregation in the pump lines during periods when spraying is stopped. Their retarding effect is immediately overcome by the accelerator addition at the nozzle.

The accelerators are usually liquids that are added at the spray nozzle and start to function in the second or so that the concrete takes to reach the substrate. The accelerating admixture reacts with components of the Portland cement to form a large number of fresh hydration surfaces. These swamp any retarder that is present and quickly form bridges between cement particles to produce a rapid set, which can occur in less than 1 minute with some systems. The chemistry of these reactions depends on the accelerating materials being used but initial hydration products range from calcium silicate to calcium sulpho or carbo aluminates.

5 Use

5.1 Dosage

The retarder/stabiliser dosage depends on the degree of retardation required and varies typically from 0.2 - 2.0%. As a guide, a typical 1% addition on cement will extend pumping life to at least the length of the working day (about 8 hours).

The accelerator dosage depends on the required build, setting time and early age strength development but is typically 2 - 8%. High dosages will give excellent build and initial and final sets. However, there is a penalty to pay in that the 28 day strength may be reduced, particularly when alkali types are used.

If the main purpose of the accelerator is to improve build then silica fume and or fibres can be added to form a more cohesive mix and alkali free accelerators can be used which will not reduce the ultimate strength. Silica fume is typically added at a dosage of up to 10% on cement to improve adhesion and cohesion. Steel fibres are used from 40 - 150 kg/m^3 ,polypropylene fibres at approximately 0.1% by volume and Marco synthetic fibres are typically 5-7 kg/m^3.

5.2 Cement types

Sprayed concrete admixtures are designed primarily for use with CEM I cements and most are affected by the C_3A content of the cement. It is therefore important to carry out trial mixes prior to the actual job.

Fly ash, slag and silica fume can be added as partial cement replacement materials and to reduce permeability. Special fast setting cements can also be used to replace conventional PC.

Other cements such as high alumina and calcium sulphoaluminate have been used but these need very different admixtures to those described above.

5.3 Admixture selection

Sprayed concrete admixtures normally form a package of products covering plasticisers, retarders, stabilisers and accelerators and will usually be purchased from a single manufacturer who will give advice on the most appropriate products for a particular application. The main considerations in selection are:

- The length of workability retention in the base mix.
- The distance it is to be pumped
- How quick the initial set is required
- Whether early strength gain is important
- The ultimate strength of the concrete
- Health and safety considerations in relation to the use of alkaline products

5.4 Overdosing

Overdosing with stabiliser/retarder; provided it is not too excessive, can be overcome by increasing the accelerator dosage. However, this will have a cost penalty and may reduce ultimate strengths. Overdosing with a plasticiser can result in mixes with poor stability and an increased tendency to sag / slump on vertical substrates.

Very high dosages of accelerator will lead to very rapid setting times, this may be desirable if very high layer thicknesses are required but can also result in increased rebound. Overdosing with accelerator and especially alkali-based accelerator will result in ultimate compressive strengths being significantly reduced.

6 Effects on properties of concrete

6.1 Strength

Strength is initially based on mix design and water cement ratio for normal structural concrete, however, the ultimate strength can be reduced by up to 50% with some types of sprayed concrete accelerator used at high dose. It is therefore important to carry out trials with the proposed mix and the maximum admixture dose that is likely to be used.

The early strength varies depending on mix design as well as the type and dose of admixture used. At 8 hours it can range from 0 to > 10 N/mm^2. The adoption of Alkali Free Accelerators plus a PCE super plasticiser has reduced the rate of strength loss v acceleration.

6.2 Workability (Consistence)

The workability of wet sprayed concrete is governed by its ability to be pumped, it is common practice to supply the mix with an F5 Flow (minimum 550mm) to EN 12350-5 or ASTM C1611/C1611M. Retarding/stabilising admixtures may be required to achieve this if long pump lines or interruptions to the spraying are likely to occur. Use of these types of sprayed concrete admixture can easily provide concrete with a working life of 6 hours and much greater periods are achievable.

At the nozzle, loss of some moisture to the pressurised air propellant coupled with the accelerating action of the admixture mean that the concrete will have lost much of its workability by the time it reaches the substrate where it continues to stiffen. Over fast stiffening on the substrate can result in increased rebound as subsequent passes of the sprayed mix cannot penetrate the surface so easily to form a good monolithic layer. However, if the concrete is still too workable, it may slump or detach from the substrate under its own weight.

6.3 Setting time

This is dependent on the type of admixture, the dose and the cement composition. In some cases very rapid set will be required to provide primary support. In other situations, sufficient stiffening to prevent slumping may be all that is required.

Alkali aluminates and Alkali Free accelerators must achieve the requirements of the new European Standard for Sprayed Concrete Admixtures: EN 934-5 which specifies <10 minutes to initial set and less than 60 minutes to final set.

6.5 Air Entrainment

Sprayed concrete does not result in air entrainment of the applied concrete. Air entrainers can be added and may assist with pumping and stability of the wet mix but on spraying, about half the entrained air is lost on impact with the receiving surface.

6.6 Bleeding

Bleeding of sprayed concrete will only occur during the wet stage prior to spraying and will also be associated with segregation of the mix. This will affect pumpability and workability in the event of delays and interruptions to spraying and it is for this reason that a stabilising retarding admixture should be used.

5.7 Heat of hydration

Sprayed concrete accelerators will often result in some early heat generation. However, this type of application does not usually require a very thick concrete section and the substrate onto which it is sprayed forms a cold heat sink and so the peak temperature reached is not high enough to result in cracking due to thermal shrinkage.

6.8 Durability

Sprayed concrete produces excellent compaction and low permeability and so is inherently very durable. The alkali based admixture may result in a lower strength than would be expected from an equivalent mix but the increased alkalinity helps to prevent deep carbonation and increases the passivation on the reinforcing bars. As a result, the durability record of this form of concrete is good.

7 Health and Safety of Admixtures

Most admixtures are non hazardous and pose no abnormal health and safety risk but as with all forms of chemical it is essential that the material safety data sheets are read and understood before use. Risk assessments should be conducted to ensure all users are provided with a safe means of use and relevant PPE.

8 Other information

Other CAA information sheets are available including Environmental Product Declarations, use of admixtures in drinking water applications, sustainability, storage and dispensing. These are available at www.admixtures.org.uk under the ‘Publications’ tab.