34

Technical Note

SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCMs) IN CONCRETE

1. INTRODUCTION

This technical note provides the reader with basic information about the use of Supplementary Cementitious Materials (SCMs) in concrete. SCMs cover a range of products which include fly ash, ground granulated blast furnace slag, silica fume, superfine fly ash, rice husk ash and natural pozzolans.

The three major SCMs, namely, slag, fly ash and silica fume are now well established in a variety of engineering applications both in Australia and around the world. These materials each impart favourable properties to structural concretes when used in combination with ordinary portland cement. There are few disadvantages with these materials provided good mix design techniques are used and proper on-site procedures for placing, compacting, finishing and curing are followed. All these materials increase the durability and long term performance of structural concretes provided responsible site procedures are adopted.

2. FLY ASH

Fly ash is a by-product of the burning of finely divided coal in modern thermal power stations. It is extracted from the exhaust gases by electrostatic precipitation. It consists mostly of small spheres of glass of complex composition involving silica, ferric oxide and alumina. Only modern plants using high grade black coals produce fly ash suitable for use in concrete. Fly ash from the typical Victorian brown coal is considered unsuitable for use in concrete because of the presence of a large proportion of soluble salts in the fly ash. Fly ash is a true pozzolan in that it only produces cementitious compounds in association with the hydration products of portland cement. It has no independent cementing properties of its own.

3. BLAST FURNACE SLAG

Blast furnace slag is a by-product of the steel industry. It is developed in a molten form simultaneously with iron in a blast furnace. Rapid chilling in water produces a granular coarse sand like material. This can be either interground in a conventional grinding ball mill with portland cement clinker (i.e. pre-blending to produce slag cement) or ground separately to produce a fine powder resembling portland cement, known as ground granulated blast furnace slag (slag). Slag can also be blended with portland cement (i.e. post blending) or added at the batching plant to manufacture slag concrete. The components making slag are the same as portland cement, although in different proportions, which explains the cementitious nature of slag.

4. SILICA FUME

Silica fume is a by-product of the ferro-silicon industries. It consists mainly of spherical particles which are 100 times finer that cement and as such it is highly pozzolanic. Silica fume is also known as condensed silica fume (CSF) and microsilica. It is produced as a loose, very low density material (200 B 300 kg/m^3) which is further densified by air compaction (i.e. 550 B 700 kg/m^3) to improve handling and storage. Densified silica fume is the most common grade used in the premixed concrete. During densification silica fume particles agglomerate to grain sizes of about 0.5 mm. It is therefore vital that the agglomerations formed by densification breakdown during the mixing process in concrete

5. HOW SCMs WORK IN CONCRETE

SCMs react with portland cement in a two-stage process involving mainly calcium hydroxide ($Ca(OH)_2$) and to a lesser extent the small amount of alkalis (i.e. sodium and potassium hydroxide) produced as part of the cement hydration. Calcium hydroxide (free lime) is an undesirable component which does not assist either the strength or the cement paste to aggregate bond. It can be leached out causing efflorescence and is the weak link of concrete when subjected to the various types of potential attack. The SCMs continue to react slowly with the $Ca(OH)_2$ in solution and continue to consume $Ca(OH)_2$ to form additional calcium silicate hydrates (cementitious products) as long as $Ca(OH)_2$ is present in the pore water of the cement paste. The cementitious products of the reaction are basically of the same type and characteristics as the initial cement reaction, although they are generally found to be more gel-like and denser.

The formulation of these additional hydration compounds replaces voids and the weak $Ca(OH)_2$, which leads to a refinement of the pore structure. This effect results in much lower permeability/ volume of permeable voids (VPV), slower transportation of aggressive agents and much stronger and durable concrete. They also retard the negative effects of alkali aggregate reactivity (AAR).

6. REPLACEMENT LEVELS OF CEMENT WITH SCMs

The proportion of SCMs used as part of the total cementitious material content in concrete is influenced by a number of factors including the purpose for which the concrete is to be used, the exposure conditions and curing temperature. Typical slag blends for ordinary applications would contain 20% to 70% by mass of the total cementitious material. The standard commercially available levels range in the order of 20% to 40%, although for resistance to marine, sulphate or AAR conditions, slag replacement levels of the order of 50% to 65% would be required in association with low water/cementitious material ratio and proper curing.

The general use of fly ash has been at replacement levels of 10% to 25% although higher levels are required for resistance to aggressive environments or AAR. Replacement levels of the order of 30% to 40% of fly ash would be required for marine, sulphate, acidic and other aggressive conditions, subject to formwork stripping and curing requirements. Replacement levels for AAR would range from 10% to 30% depending on the type of aggregate and the magnitude of potential reactivity. Replacement levels of silica fume vary depending on the properties and performance required, although common replacement levels range between 3% and 15% by mass of cement.

The VicRoads specification allows the use of SCMs at moderate replacement levels either in single combination with portland cement or as triple blends (i.e. portland cement in combination with any two of fly ash, slag or silica fume). For single combination the allowable cement replacement levels by SCMs are up to 40% slag, up to 25% fly ash and up to 10% silica fume by mass. Conversely the minimum mass of portland cement in concrete mixes containing either slag, fly ash or silica fume is 60%, 75% or 90% respectively of the total mass of cementitious material in the concrete mix. In terms of triple blends the specification requires that portland cement used be a minimum of 60% and the individual contribution of slag, fly ash or silica fume must be a maximum of 40%, 25% or 10% respectively of the total mass of the cementitious material in the mix. The use of higher replacement levels is specified for special applications such as marine environments, chemical or sulphate attack, or AAR, or is considered on a case by case basis.

7. EFFECTS OF SCMs ON CONCRETE PROPERTIES

The use of SCMs can extend the life expectancy of concrete significantly. When used in concrete, which is properly cured, they greatly enhance the ability of concrete to resist the various types of potential attack and other prevailing in-service conditions far in excess of ordinary concrete. Benefits include:

- Improved workability and pumpability. Both slag and fly ash offer better dispersion and lubrication. Judicious use of superplasticisers also assists silica fume in this regard.
- Reduced bleeding and increased cohesion of the mix.
- Reduced heat of hydration which reduces temperature differentials and therefore potential for thermal cracking.
- Decreased permeability/volume of permeable voids (VPV) by modifying/refining the pore structure of concrete. Required VPV values are stated in the VicRoads Specification.
- Increased resistance to chlorides, sulphate and chemical attack.
- Increased resistance to AAR by making concrete more water tight and by the consumption of alkalis which reduces their availability for expansion reactions.
- Increased later age strengths.
- Increased resistance to abrasion, protection to steel reinforcement, frost attack and impact.
- Higher resistivities which result in smaller corrosion currents.
- Improved durability as a result of the beneficial effects as described above.

8. SPECIAL PRECAUTIONS

The significant improvements which SCMs impart on concrete cannot be fully realised unless some special precautions are taken to overcome difficulties that may arise. These include:

- Physical and chemical variability of SCMs, although this is now controlled by Australian Standards and QA Systems.
- Possible slower setting times and lower early strengths particularly at higher replacement levels. However, these disadvantages can be overcome by modification of concrete mixes, lower water contents and the judicious use of chemical admixtures.
- Longer formwork stripping times particularly for higher replacement levels.
- Curing methods/periods, finishing practices and possible occurrence of plastic shrinkage. Inadequate curing adversely affects all types of concrete, although concretes containing SCMs have been found to be more susceptible to poor curing practices, particularly at higher replacement levels.

These factors are adequately addressed by the VicRoads standard specification for moderate replacement levels of SCMs. However, higher replacement levels should be addressed as part of special requirements and expert advice should be sought.

9. REFERENCES

Andrews-Phaedonos, F. (1993), Use of Supplementary Cementitious Materials in Concrete B GGBF Slag, Fly Ash, Silica Fume, VicRoads. Internal Report. VicRoads Library Reference No. 666.893 AND 93

Andrews-Phaedonos, F. (1996), Establishing the Durability Performance of Structural Concrete, VicRoads. Internal Report. VicRoads Library Reference No. 624.1834 AND 96.

CONTACT OFFICER

For further information please contact the following GeoPave officer:

Fred Andrews-Phaedonos Phone (03) 9881 8939

GeoPave Facsimile (03) 9881 8900