Ash Development Association of Australia

# AUSTRALIAN EXPERIENCE WITH FLY ASH IN CONCRETE: APPLICATIONS AND OPPORTUNITIES

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## INTRODUCTION

The use of fly ash as a partial cement replacement in typical concrete serves many purposes. In many Australian states, fly ash concretes form the benchmark Normal Class Concrete types described in Australian Standards AS3600 (1) and AS1379 (2) and supplied to most major projects. Fly ash adds many benefits to concrete that facilitates improved design and construction solutions on projects. This Technical Note summarises the Australian experience with fly ash in concrete and describes its key benefits in commercial construction.

## AUSTRALIAN EXPERIENCE WITH FLY ASH IN CONCRETE

The first recorded use of fly ash in a construction application in Australia dates back to 1949. Fly ash, imported from Chicago, Illinois, U.S.A. was used in grout for "Prepact" shaft linings at the Tumut Number 1 Power Station of the Snowy Mountains Hydro-Electric Scheme in New South Wales (3). The potential use of fly ash in concrete products in Australia was first investigated in 1950 (4, 5) and a major R&D report on fly ash about that time was published in the USA (6). Laboratory experiments were carried out in Western Australia to evaluate the use of East Perth Power Station fly ash as a pozzolan. A conclusion was that the compressive strengths of concrete made with this fly ash were, after 6 months, similar to strengths of equivalent OPC (GP equivalent) concretes. It was further concluded that this fly ash could be effectively used to replace 25% by weight of cement in concrete. This ash was later used in the grout for application in monolith sections of Mundaring Weir in Western Australia (7).

A study of fly ash in concrete was carried out in Sydney in 1953 (8, 9) where material from Bunnerong, White Bay, Ultimo and Pyrmont Power Stations were being assessed for their concrete making properties. Such studies formed the basis for fly ash to be used commercially in premixed concrete in Australia Importantly, it was concluded that concretesand describes its key benefits in commercial construction.

with fly ash replacements of up to 25% by weight of cement displayed little comparative strength reduction with prolonged curing. When fly ash was used as a proportional replacement of fine aggregate, an increased compressive strength of the concrete was observed (4) mainly as a result of a lower concrete water demand. The commercial use of fly ash in concrete thereafter harnessed the dual benefits of cement replacement as well as sand optimization where improved concrete water demands could be achieved in construction (3, 4). The first use of fly ash concrete in Australia was in New South Wales in Keepit Dam, a structure constructed by the Water Conservation and Irrigation Commission in 1959 (10). Part of the non-overflow section of the south abutment was cast using fly ash concrete, with fly ash corning from the Pyrmont Power Station in Sydney.

Since the early 1960's in Australia, fly ash has been used very successfully to produce high quality structural concretes and significant research work has been completed to understand its properties (11, 12).

Over the last 20 years, current practice has developed to a stage where over 90% of concrete placed contains one or more of the supplementary cementitious materials (SCM's) of which fly ash is the most commonly used (12). In the bulk of cases, these supplementary cementitious materials are used to economically achieve specified strength and durability requirements for structural elements. There is a wealth of published information showing the benefits of using fly ash, examples being in resisting high sulfate and marine environments, and to mitigate ASR influences in concrete (13, 14).

## CURRENT APPLICATIONS OF FLY ASH IN CONCRETE

In Australia, concrete structures are designed to AS3600 (1) and bridge structures to AS5100 (15). The specification and supply of concrete is carried out generally in accordance with AS1379 (2). In relation to fly ash, AS1379 references two commonly used standards. These are AS3582.1, Supplementary Cementitious Materials for Use With Portland and Blended Cement, Part 1 – Fly Ash (15), and AS3972, Portland and Blended Cements (16).

The most commonly specified tests for concrete in projects are detailed in the various parts of AS1012 (17). Tests for concrete can be generally classified into three areas:-

- Early age concrete properties,
- Concrete mechanical properties (typically at 28 days to 56 days age), and
- Long-term properties of concrete (typically in excess of 56 days age)

The influence of fly ash in concrete is considered in some detail for each of the areas mentioned above in Tables 1, 2 and 3 respectively.

For each area, the specific influence of fly ash in concrete is described for each key concrete test parameter. Observations presented in Tables 1, 2 and 3 are general in nature. The Ash Development Association of Australia (ADAA) recommends specific testing on fly ash, other constituents and resulting concretes to verify observations in specific applications.

Table 1 - Influence of Fly Ash on Early Age Properties of Concrete

| Concrete Parameters | Australian Standard | Typical Influence of Fly Ash in Concrete |
|---|---|---|
| Slump | AS1012 Part 3 | • Increases slump for samewater content<br>• Improves workability<br>• Improves pumping, placement and finishing |
| Air Content | AS1012 Part 4 | • Can reduce effect of airentraining admixtures – interaction is usually easily managed with proper mix design |
| Set Time | AS1012 Part 18 | • Works well with admixtures to achieve required initial and final set times |
| Density | AS1012 Part 5 | • Limited influence on density<br>• Improved workability can influence higher achieved densities in field concretes |
| Comp. Strength | AS1012 Part 9 | • Sufficient early age compressive strengths can be achieved through proper mix design |

A review of information in Table 1 shows the beneficial effect of using fly ash in improving constructability on projects.

This is generally facilitated through improvements in workability and a reduced water demand in concrete when compared with non-fly ash concretes.

Table 2 - Influence of Fly Ash on Mechanical Properties of Concrete (28 day to 56 day age)

| Concrete Parameters | Australian Standard | Typical Influence of Fly Ash in Concrete |
|---|---|---|
| 28 day Comp. Strength | AS1012 Part 9 | • Required compressive strengths can be efficiently achieved with reduced water demand<br>• Can be effectively included into high strength concretes |
| Indirect Tensile Strength | AS1012 Part 10 | • Usually a function of compressive strength and not affected by fly ash |
| Flexural Strength | AS10912 Part 11 | • Usually a function of compressive strength not affected by fly ash |
| Hardened Density | AS1012 Part 12 | • Limited influence on density<br>• Improved workability can achieve higher densities in field concretes |
| Drying Shrinkage | AS1012 Part 13 | • Usually reduces concrete drying shrinkage through lower water demand |
| Elastic Modulus | AS1012 Part 17 | • Limited influence on density<br>• Related to compressive strength |

A review of information in Table 2 shows that fly ash concretes can be designed to meet a wide range of performance criteria that required in construction and efficient operation of concrete infrastructure.

With appropriate water demand reductions, fly ash concretes often show lower drying shrinkage results when compared with other concrete types.

Such factors have made fly ash concretes the norm in terms of supply in many Australian States where the material is locally available.

Table 3 - Influence of Fly Ash on Long-Term Properties of Concrete (post 56 day age)

| Concrete Parameters | Australian Standard | Typical Influence of Fly Ash in Concrete |
|---|---|---|
| Long-Term Comp. Strength | AS1012 Part 9 | • Usually increased long-term strengths due to later age pozzolanic reactions |
| Creep | AS1012 Part 16 | • Linked to compressive strengths<br>• Usually reduced (usually good for design) |
| Durability | AS1012 Part 20 (& other) | • Usually improved<br>• Good at mitigating high chloride, high sulfate and ASR effects<br>• Many other properties enhanced |

A review of information in Table 3 (influence of fly ash on long-term properties of concrete) ADAA - Page 3 of 4 shows potential improvements in creep characteristics of concretes and durability in specific environments such as high sulfate, high chloride and reducing ASR potential (14).

## OPPORTUNITIES WITH THE USE OF FLY ASH IN CONCRETE

Fly ash concretes have generally been optimised to meet 28 day compressive strength requirements commonly specified on projects (12). In general, such specifications govern the amount of fly ash that can be included. Fly ash contents could be increased if project specifications were modified to allow the achievement of specified strengths at later ages. Such specifications are only applicable to particular structures, such as mass concrete elements.

Other construction methods like post-tensioned concrete might require specification of early age strengths. An improved understanding of the benefits and properties of fly ash in concrete would aid both material suppliers and concrete users. Such information helps to obtain optimised solutions on projects.

There is a significant debate relating to the sustainablity of concrete and the role fly ash might play (18). It is recognised that construction represents only a small proportion of energy produced when compared with operational energy in a building life cycle (18). Increasing levels of fly ash replacement for cement are seen by some to be a solution to this environmental issue.

Including fly ash into concrete will impart significant benefits to the construction of infrastructure, as described in earlier sections of this Technical Note. Care is needed to ensure that fly ash is included in concrete for the right design, construction and sustainability reasons noting the information outlined in Tables 1, 2 and 3.

## CONCLUSIONS

The beneficial effects of fly ash in properly designed concrete from reduced concrete water demand provides a more consistent product than that produced without fly ash. There are specific benefits of including fly ash in concrete for enhancing:-

- Early age plastic and hardening concrete properties,
- Concrete mechanical properties at ages from 28 days to 56 days and
- Long-term properties of concrete at ages in excess of 56 days

Further opportunities exist for increasing the use of fly ash in concrete through a better understanding of the material and how it affects concrete within which it is included. Of importance is the fact that fly ash can often reduce the cost of a concrete mix that is designed to meet specific criteria. In addition, environmental benefits can also be achieved with appropriate inclusion of fly ash in concrete.

Importantly, the ADAA advocates the inclusion of fly ash in concrete where appropriate design, constructional, sustainability and other project factors are considered in taking account of relevant technically based information. The aim is always to develop ways in which complex project issues can be resolved using the beneficial properties of fly ash.

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