POST-TENSIONED STRUCTURAL FLY ASH CONCRETE

Ash Development Association of Australia

REFERENCE DATA SHEET No. 9

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INTRODUCTION

One of the first major reviews of fly ash in concrete was presented at the 39th annual meeting of the Highway Research Board in the USA in 1961 (1). 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 done on understanding its properties (2 ,3). In many Australian states, fly ash concretes form the benchmark Normal Class Concrete types described in Australian Standards AS3600 (4) and AS1379 (5) and supplied to most major projects.

Post-tensioned concrete is a very good and efficient construction solution for many project applications particularly common in slab and beam elements. A significant amount of fly ash concrete is used in such applications, often being the default option for concrete mix selection. In recent times, questions have been raised as to the maximum amount of fly ash (usually expressed as a percentage of the binder) that is allowable in these applications. Of particular concern has been minimising the risk of anchor failure in such concretes, in part, thought to relate to early age mechanical properties of the concrete when final stressing is applied (6). Some anchor failures have been attributed to loss of bond between the concrete and the tendon possibly as a result of the inclusion of fly ash.

Some specifications limit the percentage of fly ash allowed in a post tensioned concrete mix to be no greater than 10% by weight of Portland cement (as opposed to total binder) (7). It is thought by some that higher fly ash percentages can limit early age mechanical properties of concrete and reduce bond between tendons and concrete.

This data sheet discusses implications of using fly ash in post-tensioned concrete given its extensive use and considering new and past research on critical factors that may influence the early stressing of concrete in post-tensioned slabs or beams.

INFLUENCE OF FLY ASH ON POST-TENSIONED CONCRETE PROPERTIES

Recent Research

The early stressing of concrete in a post-tensioned slab or beam relies on the compressive, bond and tensile strength of the concrete (6). Concrete incorporating fly ash can be optimised to meet early age strength requirements as well as later age specifications (1, 2). Fly ash inclusions of up to 30% by mass of binder are routinely used to make structural concretes in Australia as they provide advantages including improved workability, reduced drying shrinkage, preventing alkali-silica reaction, reduced heat generation, and improved durability.

The common criteria for acceptance of concrete used in post-tensioned applications having 12.7 mm diameter strands in Australia are (6):-

- Minimum 28 day characteristic cylinder strength (f_c) of 32 MPa
- Compressive strength at final stress transfer of 22 MPa typically at 3 to 5 days after concrete placement
- Compressive strength of 7 MPa at 24 hours after concrete placement for initial prestressing at 25% of the ultimate stress

Methodology

Research was conducted to determine the influence of fly ash percentage by weight of binder in concrete on tendon pull out load. Fly ash contents ranged between 0% (control) and 30% fly ash. Four trials were carried out to determine properties of fresh concrete, hardened concrete including compressive strength and indirect tensile strength development with time, and to test the bond strength between the strand and concrete matrix when compressive strengths were between 22 MPa and 24 MPa. Table 1 provides the mix designs used in the trials. The control mix included 350 kg/m^3 of Type GP cement (defined in AS3972). In the other three mixes, fine grade fly ash conforming to AS3582.1 was used at 10%, 20% and 30% of the total binder (Table 1) with binder contents in the range of 365 kg/m^3 to 400 kg/m^3.

Fresh Concrete Parameters

All concrete testing was carried out to the relevant parts of AS1012 (8). Measured slump for all mixes ranged between 90 mm and 95 mm. Air contents were measured to be 1% ± 0.2% for all mixes. Bleed characteristics of the fresh concrete (defined in AS1012.9) ranged between 1.1% and 1.7%. Values determined for all concretes indicated that mixes were consistent with those supplied to typical construction applications.

Constituent-Property	Control	Fly Ash 10%	Fly Ash 20%	Fly Ash 30%
Type GP	350	330	305	280
Fly Ash	0	35	75	120
20 mm Aggregate	720	720	725	725
10 mm Aggregate	280	280	280	280
Coarse Sand	560	565	565	565
Fine Sand	280	255	230	200
Water	196	188	187	187
Water Reducer	Included	Included	Included	Included
Water : Binder	0.56	0.51	0.49	0.47
Initial Set (hr:min)	3.15	4.35	4.50	5.20
Final Set (hr:min)	4.40	6.10	6.10	6.40

Table 1: Concrete Mix Details
(Note: Constituent values in kg/m^3)

Hardened Concrete Properties

As per AS 1012.9 (9), standard cylinders were conditioned and tested for compressive strength at 1, 3, 4, 7 and 28 days. The results are presented in Fig. 1. It can be observed that the strength development characteristics for concretes having up to 20% fly ash inclusion were similar. Slightly lower strengths were observed at comparable ages for concretes having 30% fly ash inclusion.

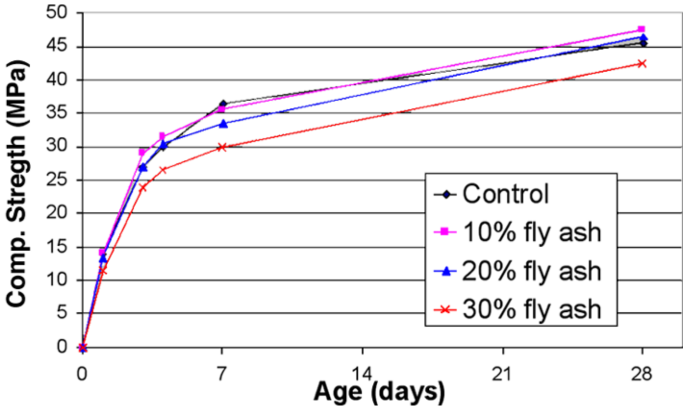

Fig. 1: Compressive Strength versus Time for Concretes Investigated

As per AS 1012 (8), concretes were tested for indirect tensile strength at 2, 4, and 28 days. The results are presented in Fig. 2. It can be observed from the data that indirect tensile strengths for the control concrete at early ages (less than 5 days) were higher than those measured for the fly ash concretes.

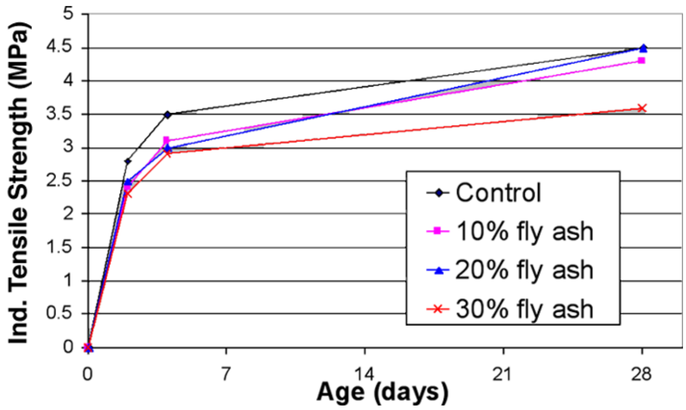

Fig. 2: Indirect Tensile Strength versus Time for Concretes Investigated

Bond (Pull-Out) Strength Determination

Special procedures were developed to determine the pull-out (bond) strength between steel tendons and concrete as there is no Australian standard procedure for measuring this parameter. Cylindrical moulds measuring 150 mm diameter and 300 mm in height were used to cast specimens for pull out testing. Prior to casting, a 50 mm layer of polystyrene foam was placed in each cylindrical mould to act as a bottom cover and strand locator. A 12.7 mm diameter seven wire post-tensioning strand was centrally located in the concrete cylinder having an embedment length of approximately 250 mm.

Three replicate specimens were cast for each concrete. Loads were applied at the AS1012 defined rate until initial failure occurred (defined as the first slip marked by a sudden and brief reversal of load). Pull-out tests were performed on the concrete specimens when measurements indicated that the compressive strength was between 23.5 MPa and 24.0 MPa. Generally, these strengths were achieved later particularly with higher levels of fly ash replacement (Fig. 1). Results of the tests are presented in Fig. 3.

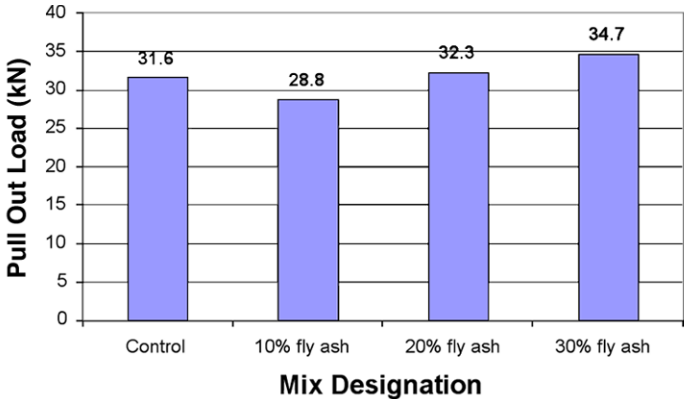

Fig. 3: Bond (Pull-Out) Strengths for Concrete Samples (Having Compressive Strengths between 23.5 MPa and 24.0 MPa)

It can be seen in Fig.3 that mean values of bond strength for all four concrete mixes range between 28.8 kN and 34.7 kN. Unlike the indirect tensile strength results, the mix with the 30% fly ash inclusion showed the highest bond strength. The evidence suggests that increasing fly ash proportions (up to 30% of total binder in concrete) will not decrease bond strength between tendons and concrete.

BOND, POST-TENSIONING, EARLY AGE STRENGTH AND THE INFLUENCE OF FLY ASH IN CONCRETE

Studies of bond in concrete date back to Duff Abrams work in 1925 in USA where it was found that bond strength was generally 10% to 15% of concrete compressive strength (10). There have been many studies on determining relationships between steel-concrete bond and concrete compressive strength (11,12). The influence of ambient temperature on early age strength of concrete and its relevance to prestressing was reported in 1958 by the Portland Cement Association (13). Reported studies indicated curvilinear relationships between concrete to steel bond and concrete compressive strength with a decreasing rate of bond increase with increasing compressive strength (13). Other studies have looked at the relationships between flexural bond and transfer bond (14).

The American Concrete Institute in its guide on fly ash in concrete (15) notes that concrete bond or adhesion to steel is dependent on a number of parameters, including the surface area of the steel in contact with the concrete, the location of reinforcement, and the density of the concrete. Fly ash usually increases paste volume and reduces bleeding. Thus, the contact at the lower interface where bleed water can collect may be increased, resulting in an increased surface contact area (15). The development length of reinforcement in concrete is primarily a function of concrete strength. With proper compaction and equivalent strength, the development length of reinforcement in concrete with fly ash should be at least equal to that in concrete without fly ash. These conclusions about concrete bond to steel are based on extrapolation of what is known about concrete without fly ash. It is concluded in ACI232 (15) that bond between tendons and concrete would be minimally affected by the use of fly ash.

More recent studies on performance of post-tensioned concrete have been reported by Sofi et al (16, 17). Whilst there are many factors found to influence post-tensioned anchor behaviour, none of these specifically relate to fly ash inclusion into concrete. Kuroda et al (18) reported on research specifically considering the influence of fly ash on bond strength. They concluded that there was general improvement in bond strength in concrete incorporating fly ash and that the degree of bond enhancement depended on the chemistry of the fly ash. Gustavson (19) reported in recent work that strand properties such as micro surface roughness and geometry strongly influenced bond to concrete. Furthermore, he reported that concrete density rather than strength influenced bond in the studies reported (19).

CONCLUSIONS

Fly ash is extensively used in concrete for structural applications. The use of fly ash in concrete in Australia dates back to the late 1950's. From studies conducted on fly ash inclusion into concrete specifically relating to post-tensioning applications, the following findings have been noted.

- Concrete strength gain characteristics for control (non fly ash) and fly ash concrete mixes are well understood and are often optimised for particular design and constructional applications.
- Bond (pull-out) strengths for control (Type GP cement only) concretes and fly ash concretes were similar.
- There is no evidence in the technical literature that suggests increasing fly ash proportions (up to 30% of total binder in concrete) will decrease bond strength between tendons and concrete.
- Fly ash concretes can be easily designed to meet early age requirements specified for post tensioning applications.

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