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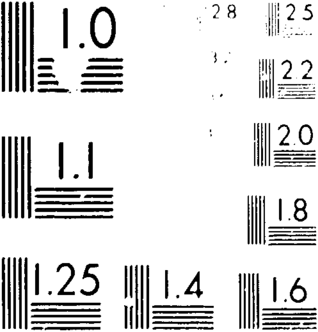
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GLADSTONE FLY ASH FOR USE IN CONCRETE*

by
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** Chief Engineer International, Pozzolanic Australia Pty. Ltd.

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CONTENTS

Fly Ash has been used in the production of concrete in Australia for over fifteen years, but it is only recently that the material has been available in Victoria. Other speakers at this function will have defined Fly Ash and Pozzolans, and described their use in concrete generally. It is also assumed that the production, classification and distribution of Fly Ash is also known.

As the company by which the author is employed is involved in the distribution of Gladstone Fly Ash in Victoria, most of the remarks following apply particularly to Gladstone Ash. However, most of the general statements apply to most good quality bituminous ashes.

Hundreds of papers have been written on the subject over the last thirty years, and an enormous amount of research has gone into the papers. However, it is important to realise that there is a great difference between Fly Ashes produced from various coals and various power stations. A considerable number of these are suitable for use in concrete - a reference to the Code AS 1129 will readily establish suitability.

Generally, to be suitable to produce superior concrete, a Fly Ash needs to be

- high on prime oxides (Silica, Alumina, Iron)
- low on carbon, sulphur, magnesium, alkalis
- moderate in calcium
- as fine as possible.

Figure 1 gives an analysis of Gladstone Ash. It is to be noted that the Ash shipped to Victoria is from the secondary precipitators, which ensures maximum fineness. Generally, the finer the Ash, the lower the water demand.

Fly Ash produces superior concrete due to four main factors:

(a) Water demand is reduced.
(b) The Chemical reaction between the silica - aluminates of the Ash, and the calcium hydroxide of the cement, improves density, and reduces leaching of soluble compounds.
(c) The very fine particles physically help fill the voids.
(d) The spherical shape allows better workability, and compaction, leading to denser concrete.

All this adds up to one characteristic - improved durability.

Most of the advantages of Fly Ash Concrete have been covered, but it is desirable to enlarge on some of them:

1. Compressive strength:

Figure 2 gives some typical results using Gladstone Secondary Ash, with North Australian and Victorian cement. Note that water is reduced in both cases - very large reductions with North Australian Cement Limited, and much smaller reductions in Victoria. One of the major differences is the much lower water demand of the Victorian mixes. Note also the slower rate of strength gain of the Ash mixes - e.g. at the 265 Kg. level with N.A.C.L. cement, the 7:28:90 ratio is 77:100:115, while with Fly Ash it is 62:100:132. This continued growth after 28 days is used to advantage in mass concrete, foundations etc., producing not only lower heat and shrinkage, but also lower costs.

Figure 3 shows a typical mix design for Victorian materials, aimed at producing at least equal 28 day strength, with improved workability.

2. Sulphate Resistance:

Much has been written of the improved resistance of Fly Ash Concrete to sulphate attack. The U.S. Bureau of Reclamation has an excellent publication "Fly Ash Increases Resistance of Concrete to Sulphate Attack" by J.T. Dikeou, covering results of their research into the subject. They have since established that the Fly Ashes which offer best advantages are bituminous Ashes, while lignite Ashes may increase deterioration. Their specifications now include a formula to determine suitability:

$$R = \frac{CaO - 5}{Fe_2O_3} \quad \text{(R = Resistance Factor)}$$

Where R = <0.75 - Resistance is greatly improved
= 0.75 to 1.5 - Resistance is moderately improved
= 1.5 to 3.0 - No significant change
= >3.0 - Resistance is reduced.

Note that for Gladstone Ash

$$R = \frac{5.83 - 5}{6.02}$$

$$= 0.14$$

For a U.S. mid west Ash, the R factor could be

$$R = \frac{26.1 - 5}{4.2}$$

$$= 5.02$$

Thus Fly Ash is a most important material in concrete exposed to sulphate soils, severage plants, sea water, and even salt laden sea breezes.

3. High Strength Concrete:

In some parts of the world there is an increasing demand for high strength concrete - compressive strengths in the 50 to 75 Mpa range. To achieve strengths of this order, concrete mix design needs to be very thorough, and materials and controls must be first class. Good quality Fly Ash can help obtain these strengths, by reducing water demand and increasing density. In the upper cement content bracket, it is evident that 70 Kg. Fly Ash will increase strength to a greater extent than 70 Kg. O.P.C.

Figure 4 shows the results of recent trial mixes for the new Gateway Bridge in Brisbane. While the nominal strength of concrete is 45 Mpa, high early strengths are required, resulting in higher than necessary 28 day strengths. It is evident that, at very early age, the Fly Ash mixes are behind the O.P.C. mixes, but later produce higher strengths, and may be able to offer a sound compromise due to lower shrinkage and creep.

Materials Services Corporation of Chicago, who produce much of the high strength concrete used in that area, have a policy of not supplying any concrete over 40 Mpa Concrete without Fly Ash.

4. Flexural Strength Concrete:

Two important factors in obtaining satisfactory flexural strengths are aggregate particle shape and water demand. It is essential to reduce water to the lowest possible amount which will give satisfactory workability. Fly Ash assists in this regard, not only by having a lower water demand to start with, but because it is easier to compact Ash mixes, coarser mixes may be used, lowering the water again. Even at 28 days, quite adequate strengths may be obtained, and at 90 days there is the added advantage of the growth in strength from 28 to 90 days. Note that flexural strengths are often specified at 90 days.

The Alabama Highway Department has been using Fly Ash in its pavements for 15 years now, and is extremely pleased with the results. Below is a comparison (Lab. trials) between their original O.P.C. mix, and their present Ash mix.

	O.P.C. MIX	FLY ASH MIX
O.P.C.	334	281
ASH	-	54
H_2O	170	149
SAND %	35.8	30.2
COMPRESSIVE STRENGTH 7 DAYS	20.5	17.5
COMPRESSIVE STRENGTH 28 DAYS	29.5	26.5
FLEXURAL STRENGTH 7 DAYS	3.5	4.5
FLEXURAL STRENGTH 28 DAYS	5.0	7.0

These mixes contained 4% air in the O.P.C. mix and 3% in the Fly Ash mix.

Today, over thirty U.S. states incorporate Fly Ash in their specifications. The Federal Highway Administration urges all states to change their specifications to allow the use of Fly Ash. In the area covered by our company's Western U.S. operations, Fly Ash is now used in highway concrete in Wyoming, Colorado, Utah, Oregon and California, including the massive Dumbarton Bridge in San Francisco (approx. 760,000 m^3 of concrete).

Figure 5 shows the results of concrete supplied to the Department of Housing and Construction at Amberley Air Base, Ipswich.

5. Creep:

Not a lot has been written on comparative creep of Fly Ash concrete, and the available literature is contradictory This no doubt relates to the quality of materials used by a particular researcher. In Australia, C.S.I.R.O. has done a certain amount of research into this subject, and in fact has carried out trials on both Brisbane and Gladstone Ashes, with the local cement and aggregates in both cases. John Wardlaw, of C.S.I.R.O., presented a paper at a C.I.A. Seminar on Fly Ash in Brisbane in July,'78 and I quote on the Brisbane results:
"Results to an age of one year have recently become available and preliminary analysis of these shows that, under the conditions of the test, there is little difference in drying shrinkage between the control and Fly Ash concretes, while the creep of the Fly Ash concrete is appreciably less than that of the controls".

6. Abrasion Resistance:

It would appear that resistance to abrasion depends on a number of factors, the foremost of which are concrete strength and surface quality. Fly Ash and O.P.C. pavements will perform equally at equal strength. It follows that, as strength increases with age, the ability of concrete to withstand abrasion will increase with time.

7. Steel Corrosion Resistance:

Larsen and Page, of the Florida Department of Transport, report that "corrosion protective properties are enhanced by the inclusion of Fly Ash". This referred to electrical energy required to cause "failure" of reinforcing steel due to corrosion.

As well as providing this protection, Fly Ash concrete for a given strength, is less permeable than O.P.C. concrete, giving physical protection to the steel.

Most Fly Ashes have a high PH factor. Although the Ash tends to use up the free lime which gives the high PH in O.P.C. concrete, the PH of Fly Ash concrete is very marginally less than conventional concrete, and is almost always at a level to guarantee reinforcement protection.

8. Low Strength Concrete:

In mass concrete, e.g. dam structures, Fly Ash or other pozzolans are usually specified to reduce heat of hydration. Currently in Southeast Queensland the Wivenhoe Dam and Power Station are under construction, using Darra cement, Swanbank Fly Ash, and river gravels. Most used mix is a 75 mm aggregate, 15 Mpa at 90 days mix, which uses 135 Kg/m^3 of O.P.C. + 80 Kg. - Fly Ash. This mix is in fact producing 18 - 20 Mpa at 28 days. Fly Ash as a proportion of cementitious material in this project varies from 27% to 37%, the higher content being in the low strength field.

9. Air Entrainment:

Higher amounts of carbon in Fly Ashes tend to make air entraining more difficult, it sometimes being necessary to increase the dosage rate of AEA to many times that necessary with O.P.C. mixes. However, in low carbon Ashes like Gladstone, only small increases ar necessary e.g. in recent tests in Queensland with Darra cement and Gladstone Ash, equal doses of AEA gave 6.1% for O.P.C., and 5.2% for Fly Ash.

Dosage rate will vary for variations in cement fineness, sand gradings, water demand, and a number of other factors. The Fly Ash is another variable, and will probably need testing to establish dosage levels for any given mix.

10. Placing of Concrete:

Generally, Fly Ash concrete is little different from conventional concrete. However, being more workable, less effort is required to produce a fatty surface, which sometimes leads to a problem. An inexperienced, or lazy, placer will work the Fly Ash mix less, neglecting the necessary compaction effort. This often leads to settlement cracking. It is really necessary to give these mixes as much effort as O.P.C. mixes - the bonus then being that the fatter surface requires less finishing effort to achieve equal smoothness.

11. Pumpability:

The fineness and sphercial shape of the Ash particles have a marked effect on the operation of concrete pumps. Even with less sand than a specially designed pump mix, the Ash mix will flow more easily. This is readily checked by comparing the pump pressures for a given slump concrete. Advantage may be taken of this by pumping at a lower slump than was previously possible.

12. Setting Times etc.:

Figure 6 shows lab. tests on concretes using Ashes of different fineness, and the affect that this has on setting times (initial set) at different concrete temperatures.

Figures 7 and 8 show results of tests comparing setting times under different conditions; in this case, concrete poured on a cold day, with and without Fly Ash, laboratory and field cured. Note that the big difference is between temperatures; the difference between Ash and O.P.C. is approximately the same in each case.

Figure 9 shows the strength tests on the same concretes. Note that the percentage of field strength of laboratory strength is the same in each case. On this occasion, the O.P.C. mix gave a very high strength (target strength was 30 Mpa for F'c 25 Mpa). A further trial gave almost equal strength, e.g. at 7 days, the O.P.C. was 1.2 Mpa ahead of the Ash (lab. results).

13. Acceptance by Authorities:

In Queensland, Fly Ash has very wide acceptance by engineers and Government Departments. The following Departments provide for Fly Ash in their specifications.

State:	Department of Works Department of Main Roads Department of Railways Qld. Housing Commission Water Resources Commission Co-ordinator Generals Department
Commonwealth:	Telecom Aust. Department Housing and Construction
Local Authorities:	Most city and shire councils approve its use. Brisbane City Council requires use of Fly Ash in Reservoirs and other water tight structures.