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ENGINEERING PROPERTIES OF FLY ASH CONCRETE

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RINGKASAN: *Dengan menggunakan arang batu sebagai satu daripada sumber penjanaan elektrik di stesen janakuasa Tenaga Nasional di Kapar, kebolehdapatan abu terbang di Malaysia terjamin. Abu terbang yang terkawal mutunya, bila dimasukkan ke dalam konkrit boleh memperbaiki banyak sifat-sifat segar dan terkeras konkrit dengan sengaja. Data-data rekabentuk mengenai sifat-sifat konkrit yang menggunakan abu terbang dari stesen janakuasa tempatan tidak boleh diperolehi. Siasatan-siasatan mendalam mengenai ciri-ciri bahan, struktur dan ketahanlasakan konkrit abu terbang 'Malaysia' sedang dijalankan di Universiti Malaya untuk membekalkan data-data yang sangat diperlukan. Kertas ini membentangkan sebahagian daripada sifat-sifat kejuruteraan konkrit abu terbang Malaysia. Ujian-ujian kebolehkerjaan, kekuatan-kekuatan mampatan, lenturan dan pemisahan tegangan, pengecutan keringan, modulus keanjalan dan juga ujian-ujian tanpa musnah, dilakukan ke atas spesimen-spesimen konkrit abu terbang dan juga konkrit kawalan OPC. Data menunjukkan bahawa konkrit yang mengandungi 25% abu terbang sebagai gantian simen mempamerkan sifat-sifat kejuruteraan yang serupa atau lebih baik daripada konkrit biasa tanpa abu terbang. Keputusan-keputusan yang memberangsangkan ini menonjolkan kebaikan-kebaikan teknikal konkrit mengandungi abu terbang dan ini akan memperluaskan kegunaan bahan ini dalam industri pembinaan Malaysia.*

ABSTRACT: By using coal as a source of electricity generation at the Tenaga Nasional's Kapar power station, the availability of fly ash in Malaysia is now assured. Quality controlled fly ash when incorporated in concrete enabled many of the properties in the fresh and hardened states to be intentionally improved. No design data on the properties of concrete using fly ash from the local power station is available. In-depth investigations into the material, structural and durability characteristics of 'Malaysian' fly ash concrete are conducted at the University of Malaya to provide the much-needed data. This paper presents some of the engineering properties of 'Malaysian' fly ash concrete. Workability, compressive, flexural, tensile splitting, drying shrinkage, elastic modulus and non-destructive tests were performed on fly ash and control OPC concrete specimens. Data show that concrete containing 25% fly ash replacement of cement exhibit superior or similar engineering properties to that of normal concrete without fly ash. These encouraging results demonstrated the technical merits of incorporating fly ash in concrete and should pave the way for wide scale use of this versatile material in the Malaysian construction industry.

KEYWORDS: Fly ash; concrete; superplasticizer; compressive strength; flexural strength; tensile splitting strength; drying shrinkage; modulus of elasticity; non-destructive tests.

INTRODUCTION

Fly ash (FA) or pulverized fuel ash, is an industrial by-product of electricity generation from the combustion of pulverized coal. The technical benefits of incorporating FA in concrete are numerous, and among others include improved workability, lower heat of hydration, higher long term strengths and improved time dependent properties (Berry and Malhotra, 1986; Dhir, 1986; Mahmud, 1986; Swamy and Mahmud, 1986 and Swamy and Mahmud, 1989). With the commissioning of Phase II of the Sultan Salahuddin Abdul Aziz Power Station in Kapar, Selangor in 1988, Malaysia is fortunate to have this versatile supplementary cementitious material available. Subsequently, a Malaysian standard (MS 1226) on the use of fly ash (pulverized fuel ash) as a cementitious material in structural concrete was drafted in 1991.

Although fly ash concrete have been used in a number of projects in the Klang Valley area (these include the foundations of the KL Telecom Tower and the 85 storey twin tower block of the prestigious Kuala Lumpur City Centre projects), very little is known about the performance of this concrete in local environment. This paper attempts to provide the much-needed information. It presents the engineering properties of concrete made using 'Kapar' fly ash. Detailed strength property of this type of concrete has been published earlier (Mahmud *et al.,* 1991) and comparative performance of concrete containing fly ash as a separate component or as blended cement in concrete mixes will be reported later (Mahmud)

EXPERIMENTAL PROGRAMME

Materials

Ordinary Portland Cement from a single source was used throughout the investigation. River sand passing through 5mm sieve and crushed granite passing through 20mm sieve was used as fine and coarse aggregates respectively. The fly ash was obtained from Kapar power station, complying with MS 1226 in relation to physical properties and chemical composition. The superplasticizer used was Rheobuild 1000, at a dosage of 1 litre per 100 kg of total cementitious content.

Mix Design

The control normal concrete mix without fly ash (OPC) was designed to have 28 days target mean strength of 40 N/mm^2 (Table 1). To study the engineering properties of fly ash concrete, two mixes containing 25% fly ash, with or without superplasticizer were casted; 25% direct replacement of cement with fly ash was taken as the optimum replacement level for maximum compressive strength (Mahmud *et al.,* 1991 and Mahmud and Ahmad, 1989). The water content of the superplasticized fly ash concrete mix (mix 25SFA) was reduced by 25% compared to the fly ash mix without superplasticizer (mix 25FA). All mixes contain total cementitious content of 410 kg/m^3, and 630 and 1095 kg/m^3 of fine and coarse aggregates respectively. All the mixes were maintained at a slump of 60±20mm.

Table 1. Engineering properties of hardened concretes

Concrete Mix No.		OPC*	25FA*	25SFA*
w/c+a ratio		0.56	0.45	0.40
Slump (mm)		60	75	75
Compressive Strength (CS) (N/mm^2)	7d	33.0	40.4	40.8
	28d	42.5	57.9	59.1
	56d	45.7	60.9	68.5
Flexural Strength (FS) (N/mm^2)	7d	4.6	4.3	4.8
	28d	5.2	5.3	5.9
Tensile Splitting St. (TS) (N/mm^2)	7d	2.8	2.5	2.9
	28d	3.25	3.25	3.35
FS/CS Ratio (%)	28d	12	9	10
TS/CS Ratio (%)	28d	8	6	6
Elastic Modulus (kN/mm^2)	28d	22.1	25.0	26.7

*OPC - Normal OPC Concrete, 25FA - Fly ash concrete, 25SFA - Superplasticized fly ash concrete

TESTS

To study the engineering properties of concrete containing fly ash, the following tests were conducted:

1. Slump test to ascertain the workability of concrete mixes.
2. Compression test on 100mm cubes
3. Flexural strength test on 100 x 100 x 500mm prisms.
4. Tensile splitting test on 150mm dia. x 300mm cylinders.
5. Static modulus of elasticity on 150mm dia. x 300mm cylinders.
6. Drying shrinkage on 100 x 100 x 500mm prisms.
7. Non destructive tests
   i) Rebound Hammer on 100mm cubes
   ii) Pulse velocity on 100mm cubes and 500mm long prisms.

Specimens were demoulded within 24 hours after casting and left in a water tank until the day of testing. All the tests were conducted according to MS 1226 and the results given are the average of three specimens.

RESULTS AND DISCUSSION

Workability

Table 1 indicates that the incorporation of fly ash reduces the water requirement of a concrete mix without affecting its workability. Compared to the control OPC concrete, water reduction of 20% is possible when 25% of the cement content was replaced by fly ash (Mix 25FA). This is because fly ash is essentially a spherical material. Partially replacing cement with this material will create a 'ball bearing' effect that leads to increased dispersion of the cement agglomerates, freeing more paste to lubricate the aggregates thus improving the workability of the concrete mix. Higher water reduction is possible with the combined use of fly ash and a superplasticizer (Mix 25SFA). Due to the cement dispersion effects brought about by the combined use of these two admixtures, the water content of the mix can be reduced by 29% whilst maintaining the same workability as that of the control mix. Lower w/c+a ratio implies more durable concrete.

Compressive Strength

Provided that quality controlled fly ash is being used, concrete containing 25% fly ash replacement of cement can give similar or higher strength than a normal concrete without fly ash (Table 1). This finding is similar to that found in an earlier report (Mahmud *et al.,* 1991). Irrespective of age, the fly ash concrete mixes 25FA and 25SFA exhibited superior strengths than the control OPC concrete without fly ash. This is due to the secondary pozzolanic reaction between silica from the ash and lime from cement hydration, forming extra cementing compounds. The superplasticized fly ash mix 25SFA exhibited the highest strengths at all ages. This is expected because the water to total cementitious content ratio of this mix is the lowest of the three mixes. Lower water content of a mix will ensure more durable concrete.

The benefit of incorporating fly ash to a concrete mix is clearly evident from Table 1. For the normal OPC concrete, strength increase from 7 to 56 days is 38% whereas strength increase for the 25FA and 25SFA mixes for this period are 50% and 68% respectively. Due to the pozzolanic activity of the fly ash particles, their incorporation is essential to the long-term strength development of concrete.

Flexural Strength

Flexural strength property of fly ash concrete with or without a superplasticizer was found to be similar to or superior than that of a normal OPC concrete. The results in Table 1 show that at 7 days, the flexural strength of the fly ash concrete mix 25FA is marginally lower than the control OPC concrete. As with the compressive strength results, the superplasticized fly ash mix exhibited the highest flexural strength, irrespective of age. At 28 days, the strength of fly ash concrete in flexure is marginally higher than that of the OPC concrete, indicating possible use of this concrete in the construction of pavements and highways. In the absence of more data, the ratio of flexural to compressive strength of fly ash concrete can be taken as 10%.

Tensile Splitting Strength

Data from the tensile splitting strength tests show a similar trend to that of the flexural strength. At 7 days, the fly ash concrete mix 25FA exhibited marginally lower splitting strength than the normal OPC concrete. However, at 28 days the strengths of the two concretes are identical. The superplasticized fly ash concrete offered the highest flexural and splitting strengths. This is understandable because of the three mixes, this concrete exhibited the highest compressive strength. Due to the slow pozzolanic reaction of the fly ash particles, the tensile strength properties of fly ash concrete will be higher than the normal concrete without fly ash at later ages. The ratios of the tensile splitting strength to that of the compressive strength for normal and fly ash concrete can be taken as 8% and 6% respectively.

Elastic Modulus of Elasticity

The elastic modulus of elasticity of fly ash concrete, with or without a superplasticizer was found to be higher than normal concrete. Increase of 13 - 21% over the control OPC concrete was noted. This result highlights the stability of fly ash concrete, whereby for the same stress level, fly ash concrete shows less tendency to strain than normal concrete. Long term beneficial effects on deflections under load can be expected when fly ash is used in structural concrete (Mahmud, 1988). Superior elastic property shown by the fly ash concrete is due to the densification filler effect of the finer ash particles as well as the unhydrated fly ash particles acting as fine aggregates in the concrete mixes.

Drying Shrinkage

Data on drying shrinkage for the three concrete mixes are given in Table 2. Data show that up to the age of 60 days, there is no significant variation in shrinkage between the three concretes. The fly ash concrete in fact showed marginally lower shrinkage than the normal OPC concrete at 28 and 60 days. This can be attributed to the reduced water demand caused by the inclusion of the ash particles. Furthermore, the incorporation of fly ash produces a finer paste structure thereby restricting the loss of pore water within the paste system and consequently, the drying shrinkage is reduced (Swamy and Mahmud, 1989).

Table 2. Shrinkage of concretes at various ages (microstrains)

Age (Days)	OPC*	25FA*	25SFA*
7	90	90	90
28	211	210	210
60	240	235	225

*OPC - Normal OPC Concrete, 25FA - Fly ash concrete, 25SFA - Superplasticized fly ash concrete

Non-Destructive Tests

The rebound hammer test results for the control and fly ash concrete specimens are shown in Table 3. The test was conducted in an attempt to correlate between the results of the non-destructive and the destructive compression tests. 'Rebound Number' of the specimens was taken and by using the manufacturer's calibrated chart, the estimated compressive strength of the concrete was obtained. Irrespective of the type of concrete, the estimated strengths using the Rebound Hammer technique was found to be within 96 - 98% of the actual strengths. This indicates that the rebound hammer test can be used to predict the strength of fly ash concrete.

Table 3. Non-destructive test results

Concrete Mix No.	OPC*	25FA*	25SFA*
Compressive Strength (CS) (N/mm^2)	41.8	43.2	59.4
Estimated Compressive Strength ** (N/mm^2)	40.9	42.1	57.0
Ultrasonic Pulse Velocity (UPV) (Km/s)	3.99	4.12	4.54
UPV/CS Ratio (%)	10	10	8

*OPC - Normal OPC Concrete, 25FA - Fly ash concrete, 25SFA - Superplasticized fly ash concrete
**Derived from the manufacturer's calibrated chart (Rebound Hammer)

Results of the ultrasonic pulse velocity test show that fly ash concrete, with or without a superplasticizer exhibit higher pulse velocity than the control OPC concrete. Higher pulse velocity registered by the fly ash concrete indicates the absence of internal cracks, thus confirming the enhanced quality of fly ash concrete. These results also show the suitability of this test to determine the homogeneity and uniformity of normal and fly ash concrete mixes.

CONCLUSION

Fly ash concrete, with or without a superplasticizer, exhibit superior compressive, elastic modulus, flexural and tensile splitting strengths compared to a normal concrete without fly ash. Inclusion of fly ash improves the workability of a concrete mix and is considered essential to its long-term strength development. Drying shrinkage of fly ash concrete was found to be smaller than the control OPC concrete. Values obtained from the rebound hammer and ultrasonic pulse velocity tests indicate that non-destructive tests can be performed equally well on fly ash concrete.

From the data collected, it can be concluded that fly ash obtained from the Kapar power station can be used as a cementitious component in structural concrete. This type of concrete can give similar or superior engineering properties than that of normal concrete without fly ash. These positive results should pave the way for wider use of this versatile material in the local concrete construction industry.

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