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High Strength Ultrafine Fly Ash Concrete with Silica Fume or Hydrated Lime Addition

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Abstract: *Production of sustainable concrete for infrastructure construction is targeted by the concrete industry in many ways, including the use of supplementary cementitious materials, admixtures and recycled aggregates. Hydrated lime being used by the building industry for many years and its effects on fly ash concrete properties is not fully understood. This paper reports the results of an experimental investigation into the engineering properties of ultrafine fly ash concrete with the addition of either hydrated lime or silica fume. The development of compressive strength, tensile strength, modulus of elasticity and drying shrinkage with age was studied. The results indicated that compared to the control fly ash concrete, 10% silica fume addition caused 28 and 56 days compressive strength to improve by 24% and 15%, respectively. On the other hand, the same amount of hydrated lime addition had reduced the compressive strength by 12% and 20% at the same ages, respectively. The modulus of elasticity of concrete was increased by the addition of both silica fume and hydrated lime. 56-day drying shrinkage was increased by 3% and 14%, by the silica fume and hydrated lime addition, respectively. Undesirable effect of hydrated lime addition on compressive strength could be related to increased internal porosity and non-reactive nature of the hydrated lime, although it could activate the pozzolanic reaction of fly ash from early age. On the other hand, the addition of extra-fine silica fume improved the compressive strength through the combination of both filler and pozzolanic effects. Silica fume and hydrated lime added fly ash concretes are more sensitive to curing condition.*

Keywords: *Fly ash, hydrated lime, Silica fume, Concrete properties.*

1. INTRODUCTION

Concrete industry is searching for innovative ways to reduce the impact of concrete production on environment. Commonly adopted strategy is one or more the following combinations: (a) reduction in cement content through the use of water reducing admixtures; (b) the use of supplementary cementitious materials (fly ash, slag, silica fume and limestone powder) as a partial replacement to cement; and (c) the use of recycled aggregates. The limited use of fly ash improves the strength of concrete due to the combination of physical (filler) and chemical (pozzolanic reaction) effects. Goldman and Bentur, 1993 reported that the filler effect is more than the effect of pozzolanic effect of fly ash, in particular at early ages.

Different approaches have been used to improve the early age strength of fly ash concrete. These include the use of high fineness fly ash (Chindaprasirt et al, 2005, Yazici and Arel, 2012), addition of silica fume (Metha and Gjorv, 1982, Sriravindrarajah et al, 2004), and addition of hydrated lime (Barbhuiya et al, 2009, Jeyakumar and Salma, 2011). Ling et al, 2013 reported that the use of lime water for mixing with pH varied between 10.5 and 12.5 influenced the strength development of high volume fly ash concrete. This could be due to early activation of fly ash which is dependent on the pH of concrete, as reported by Larbi et al, 1990. Newlon, 1976 reported that the corrosion potential of steel reduced by 8% in a 35 years old bridge deck having concrete with 12% hydrated lime. This experimental investigation evaluates the effectiveness of 10% addition of either hydrated lime or silica fume in a high strength ultrafine fly ash concrete. The development of compressive strength, tensile strength, modulus of elasticity and drying shrinkage with age was studied.

Table1. *Composition of the concrete mixes in kg/m*^{3}

Materials	Mix CF	Mix CFS	Mix CFL
Cement	427	415	415
Ultra-fine fly ash	142	142	142
Silica fume	-	57	-
Hydrated lime	-	-	57
Water	170	188	188
Superplastcisier (l)	6.46	4.64	4.64
Coarse aggregate	1025	1025	1025
Fine aggregate	685	680	680
Water/Binder	0.30	0.30	0.30

2. EXPERIMENTAL INVESTIGATION

2.1. Materials and Mix Compositions

The general purpose Portland cement (Type GP), conforming to AS3962, and low-calcium fly ash conforming to AS3582.1 were used. The fineness of the fly ash, expressed as the mass proportion retained on a 45μm mesh was 1% and the median particle size was 4.4μm. The fly ash had 70.7% silica, 20.7% alumina and 1.1% lime. The silica content of the silica fume was over 92%. Commercially available hydrated lime had the soundness below 10%, the residue on 600μm mesh of 5% and the free moisture below 2.5%. Crushed basalt, having a maximum aggregate size of 20mm, was used as coarse aggregate and crushed sand was used as fine aggregate.

The composition of concrete mixes was the main variable in this study (Table 1). The control fly ash concrete (Mix CF) had the cement content of 427 kg/m^3 and the fly ash content of 142 kg/m^3. The addition of 10% of the cementitious materials by weight with either silica fume or hydrated lime was used in Mixes CFS and CFL, respectively. All concrete mixes had the same water to binder ratio of 0.30, by weight and the same amounts of coarse and fine aggregates. Super plasticiser of varying quantity was added to the mixes to achieve sufficient workability for mixing and casting of concrete specimens.

2.2. Mixing, Casting and Testing of Specimens

The concrete mixes were mixed in a pan type of mixer. For each mix, 18 Nos of 100 mm cubes, 6 Nos of 100 mm diameter by 200 mm cylinders, 2 Nos of 150 mm diameter by 300 mm cylinders and 2 Nos of 75 mm by 75 mm by 280 mm prisms were cast in standard steel moulds for the determination of hardened concrete properties at various ages and curing conditions. During casting of the test specimens, fresh concrete was compacted using a vibrating table. The cast specimens were demoulded after about 24 h and subjected to appropriate curing condition.

Three cubes were left in the laboratory environment (20 $\pm$ 2^{o}C and 60 $\pm$ 15% R.H.). The rest of the concrete specimens were cured in water tank at 20^{o}C. At the age of 7 days, both prisms (shrinkage specimens) were removed from water and left in the laboratory environment. The shrinkage was measured on two longitudinal sides of each prism over a 200 mm gauge length, using a demountable mechanical strain gauge.

At any testing age, three identical cubes or cylinders were tested in compression or indirect tension and the mean results are reported. Two large cylinders (150 mm diameter by 300 mm high) were used to determine the modulus of elasticity at various ages. All the tests on hardened concrete specimens were conducted in accordance with the appropriate Australian Standard procedures (AS1012)

3. RESULTS AND DISCUSSION

3.1. Workability of Concrete

The control concrete mix (Mix CF) had a collapse slump when the recommended super plasticizer dosage of 1.14% of the binder content was used. The slump for the concrete containing silica fume (Mix CFS) was 100 mm compared to 160 mm for the concrete with quick lime (Mix CFL). With the same super plasticizer dosage, the reduced consistency for fly ash concrete with silica fume compared to that with fly ash concrete with hydrated was due to the high fineness of the silica fume.

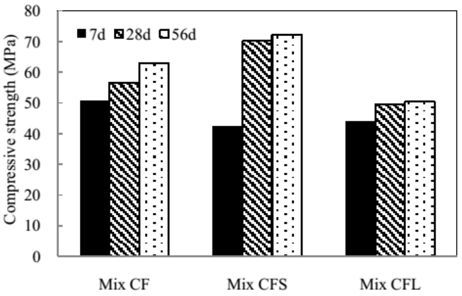

Fig1. *Development of compressive strength with age for water cured concretes*

3.2. Compressive Strength of Concrete

Fig. 1 shows the compressive strength of three concrete mixes with age under continuously water curing condition. The compressive strength was increased with increasing age at a decreasing rate for all three mixes due to the continuing hydration of cement and pozzolanic reaction of fly ash and silica fume.

28-day compressive strength for the control concrete (Mix CF) was 56.7 MPa, while that for the silica fume added concrete (Mix CFS) was 70.2 MPa. This corresponds to the strength increase of 24%, probably due to combined effects of cement hydration, pozzolanic reactivity and pour filling phenomenon. When 10% of hydrated lime was added (Mix CFL), 28-day strength was 49.6 MPa, a drop of 13% compared to that for the control concrete (Mix CF). At 56 days, the silica fume concrete (Mix CFS) showed an increase of 28% for compressive strength while the hydrated lime added concrete (Mix CFL) suffered 20% drop in compressive strength. This implies that the presence of non-reactive hydrated lime in the binder paste matrix has increased it porosity, thus causing reduction in strength at all ages. On the other hand silica fume contributes to strength development through the combined effect of filler and pozzolanic effects.

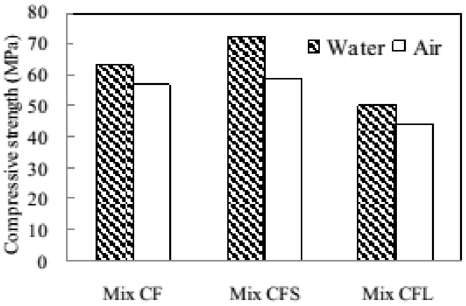

Fig2. *Effect of curing condition on 56-day compressive strength of concrete*

The positive contribution of silica fume and detrimental effect of hydrated lime on compressive strength are demonstrated at the chosen level of either silica fume or lime addition. However, Jayakumar and Salman, 2011 reported that for concrete with normal fly ash, the lime addition had increased the compressive strength. Further research is needed to study the interaction between fly ash fineness and lime addition on concrete properties.

The effect of curing condition on the 56-day compressive strength of the concretes is shown in Fig. 2. As expected, water curing was found to be the most effective curing method. The concrete specimens stored in unsaturated laboratory condition showed noticeable reduction of compressive strength. At 56-day compressive strength of air stored concretes were 9%, 19% and 14.5% lower than those for the water-cured concretes for the control, silica fume added and hydrated lime added concretes, respectively. Therefore, the moisture content of concrete had the most influence for the fly ash concrete with the silica fume.

3.3. Tensile Strength of Concrete

The indirect tensile strength of the control fly ash concrete (Mix CF) at 28 days was 4.38 MPa, which corresponds to 7.7% of the 28-day compressive strength. The corresponding tensile strength for silica fume added fly ash concrete (Mix CFS) and for hydrated lime added concrete (Mix CFL) was 5.07 MPa and 4.71 MPa. The results showed that the concretes containing either silica fume or hydrated lime showed 16% and 7.5% improvements in tensile strength, respectively. The tensile strength results for the hydrated lime added fly ash concrete contradict the observation with the compressive strength, as discussed earlier. Further research is needed for clarification.

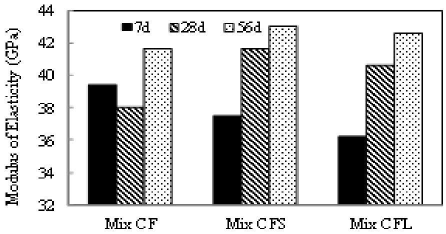

Fig3. *Development of modulus of elasticity with age for water cured concretes*

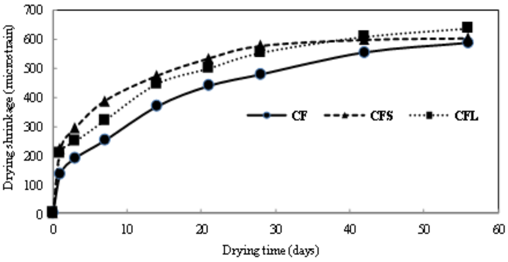

Fig4. *Development of drying shrinkage with age for water cured concretes*

3.4. Modulus of Elasticity of Concrete

Fig. 3 shows the development of modulus of elasticity with age for the water cured concrete up to 56 days. The modulus of concretes was increased with the age under water curing condition. At the age of 56 days, the modulus for the control fly ash concrete (Mix CF) was 41.6 GPa whereas that for the silica fume incorporated concrete (Mix CFS) was 43.0 GPa, an increase of 10.3%. For the hydrated lime added concrete (Mix CFL), the modulus was 42.6 GPa, an increase of 2% over that for the control fly ash concrete.

3.5. Drying Shrinkage of Concrete

The development of drying shrinkage with time for all three types of high strength fly ash concretes is shown in Fig. 4. The shrinkage was increased with time at a decreasing rate and found to stabiles after 56 days of drying at the laboratory environment. The silica fume added fly ash concrete (Mix CFS) showed higher shrinkage at early ages. However, after 56 days the drying shrinkage was the same. The hydrated lime added fly ash concrete (Mix CFL) showed a similar trend.

Using the measured data, the ultimate shrinkage was predicted for all three concretes. The ultimate shrinkage was 667, 625 and 715 microstrain for the control, silica fume added and hydrated lime added fly ash concretes, respectively. Therefore, the ultimate shrinkage was decreased by 6% for silica fume added concrete and increased by 7% for hydrated lime added concrete, when compared with the drying shrinkage for the control fly ash concrete. The difference in the shrinkage values are probably due to the changes that had occurred in the porosity by the addition of the silica fume and quick lime (Barbhiya et al, 2009). However, the binder paste is not found to a significant factor in determining the drying shrinkage of fly ash concrete.

4. CONCLUSIONS

The effects of either silica fume or hydrated lime addition (10% of the cementitious materials) on the hardened concrete properties were experimentally investigated. Based on the test results the following conclusions are made:

- For fly ash concrete, the compressive strength at all ages had improved by the addition of 10% silica fume whereas it was reduced by the addition of the same amount of hydrated lime, 56-day strength was decreased by 20%.
- The compressive strength of fly ash concrete with either silica fume or hydrated lime addition was more sensitive to curing condition compared to that for the control fly ash concrete.

- The addition of either silica fume or hydrated lime had improved the modulus of elasticity of fly ash concrete; a maximum modulus improvement of 10.3% was with silica fume added fly ash concrete.
- Drying shrinkage of fly ash concrete is marginally affected by the addition of either silica fume or hydrated lime.

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