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DEVELOPMENT OF HIGH VOLUME FLY ASH CONCRETE USING ULTRA-FINE FLY ASH

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ABSTRACT

Given one ton of cement is producing nearly one ton of $CO_{2,}$ there is need to reduce the cement production worldwide to make the concrete sustainable. On the other hand, fly ash (FA) production levels worldwide have increased. Therefore, there is a need to examine the issue of increasing FA levels in concrete. High Volume Fly Ash Concrete (HVFAC), which is defined as the FA replacements above 50 % partly addresses this issue. The replacements can be up to 85%. But, unlike geopolymer concrete with 100% fly ash, HVFAC does not require heat curing which is an advantage over geopolymer concrete to be accepted by the construction industry. This research is aimed to produce high volume high performance fly ash concrete by reducing the drawback of low early strength of HVFAC. To achieve this, few key factors are considered in mix design and investigated studying microstructure of HVFAC. The factors being the w/b ratio, fineness of fly ash added, type of mixing water and dosage of super plasticizer. The experimental results of 50% replacement of cement with ultra-fine fly ash, raw fly ash with tap water and lime water as mixing water are presented in this paper.

KEYWORDS

Fly ash concrete, high volume fly ash concrete, limewater, ultra-fine fly ash, cement replacement.

INTRODUCTION

Concrete is the most widely used material on earth after water mainly due to its widely available ingredients, the cost of manufacture and its durability. But unfortunately concrete production has sustainability problem, especially because of its main ingredient the cement as each ton of cement produced releases approximately one ton of CO_2 which is causing environmental concerns. There is about 3.3 billion tons of cement produced in 2010 up from 1.37 billion tons in the year 1994 (U.S.G.S, 2011). Hence there is need for the use of alternative materials for cement which are also known as supplementary cementatious materials (SCMs) and are being used for some time.

The use of supplementary cementitious materials such as fly ash as partial replacement of Portland cement will reduce CO_2 emissions from concrete industry, since CO_2 is one of the main contributors to the greenhouse gas effect and the global warming of the planet. Though, replacement of cement by fly ash causes strength reduction, in this research addition of ultra-fine fly ash showed increase of strength similar to Ordinary Portland Cement.

One of the mineral admixtures possible to be used in concrete is fly ash, a by-product of combustion of ground or powdered coal exhaust fumes of coal-fired power stations. The use of Fly ash as a binder in concrete improves properties of both fresh concrete and hardened concrete, due to the high content of silica (SiO_2) in fly ash that binds the $Ca(OH)_2$ produced in cement hydration process to form the calcium silicate hydrate (C-S-H) gel which can improve the properties of both the fresh and hardened concrete (Oner et al., 2005). There are standards for fly ash since 1971.

HIGH VOLUME FLY ASH CONCRETE

Use of high volume of fly ash as part replacement of cement is environmentally beneficial (Malhotra, 2002). The term of high volume fly ash (HVFA) concrete was firstly introduced by Malhotra at CANMET in the 1980s. The HVFA concrete is a concrete in which at least 50% of its Portland cement by mass is replaced with ASTM class F or class C fly ash (Malhotra and Mehta, 2005). In addition, high volume fly ash concrete demonstrates the attributes of high-performance concrete (Bilodeau and Malhotra, 2000).

Advantages of HVFAC

There are distinct advantages in HVFA concrete where time and heat curing is not a major factor affecting compressive strength. The use of fly ash can improve workability, easier flowability, pumpability, compactability, reduce heat of hydration and increase resistance to sulfate attack, alkali-silica reactivity (ASR) and other types of deterioration as compared to normal mixes (Solis et al., 2010), some of these apply to standard fly ash concrete as well. HVFA concrete have very high durability with respect to the reinforcement corrosion, alkali-silica expansion, sulfate attack, and have superior dimensional stability and resistance to cracking from thermal shrinkage, autogenous shrinkage, and drying shrinkage (Mehta, 2004).

HVFA concrete has better surface finish and quicker finishing time when power finish is not required (Mehta, 2004). It has slower setting time and will have a corresponding effect on the joint cutting and lower power finishing times for slabs.

HVFA concrete has better cost economy due to lower material cost and highly favourable lifecycle cost (Mehta, 2004). These concretes have superior environmental friendliness due to ecological disposal of large quantities of fly ash, reduced carbon dioxide emissions, and enhancement of resource productivity of the concrete construction industry (Mehta, 2004 and Malhotra, 2002).

Factors Affecting Strength of HVFAC

In identifying methods of improving the performance of HVFA concrete two potential avenues to enhance reactivity of fly ash have been identified. According to Obla et al. (2003), one method to enhance reactivity of fly ash is reducing particle size. Xu (1997) has stated that the fly ash particles in the range of 10 to 150 µm mainly act as void fillers in concrete, whereas the particles smaller than 10 microns are more reasonably classified as pozzolanic reactive. The use of ultra-fine fly ash significantly increases the compressive strength of HVFA concrete if compared with the use of raw fly ash as reported by some researchers (Chindaprasirt et al., 2007, Kiattikomol et al., 2001).

It has been observed by other researchers that addition of lime to fly ash concrete improves durability. Since fly ash reacts with $Ca(OH)_2$ in concrete to form the binder, this phenomenon can be explained.

One major issue with HVFA concrete is the slower strength gain where usually 90 days will be needed to gain the full strength potential (Mehta, 2004). It is known that the strength development of HVFA concrete mixes is relatively slower due to the slow pozzolanic reaction of the fly ash. With HVFA concrete mixtures, the strength enhancement between 7 and 90 days often exceeds 100% (Mehta, 2004).

RESEARCH AT RMIT

A combination of reduced particle size and addition of lime in liquid form was explored by Dr. Patnaikuni and his team of researchers to develop a better performing HVFA concrete (Solikin et al., 2011) with 50% replacement. The methodology and the experimental results are presented in this paper.

The work presented here attempted to develop a HVFA concrete which has similar compressive strength as OPC. In developing the research program, a comprehensive review of previous attempts at HVFA concrete was conducted to understand the current state of the knowledge on HVFA concrete. Use of a polycarboxylate polymer has been shown to improve the properties when lower w/b ratio is used to increase the workability.

EXPERIMENTAL METHOD

Material

In the research program low calcium fly ash from Tarong power plant which is classified as ASTM class F fly ash (Sofi et al., 2007) was used. The chemical composition of Tarong fly ash is shown in Table 1.

Table 1. Chemical Properties of Tarong fly ash (mass %)

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	LOI
Tarong	65.9	28.89	0.38	1.97	0	0.15	0.06	0.05	0.26	0.08	0.03	1.24
ASTM Class F*	The sum of SiO_3 + Al_2O_3 + Fe_2O_3 min 70%										Max, 5%	Max, 6 %

One attempt made to enhance the strength performance of fly ash is thus reduction of the particle size by grinding of fly ash. Raw fly ash was ground in micronizer to obtain the ultra-fine fly ash before the fly ash was used as binder in concrete. The micronizer is a jet mill, using compressed air or gas to make high speed rotation of the particles in grinding chamber which further leads the material to particle-on-particle impact (Sturtevant, 2000).

The increase of fineness of fly ash after the grinding was tested using Blaine test apparatus to determine the surface area of fly ash. The surface area of fly ash increases from $364m^2/kg$ for raw fly ash to 525 m^2/kg for ultra-fine fly ash giving a 40% increase in the fineness of fly ash after the grinding process in micronizer. Scanning Electron Microscopic (SEM) analyses also confirmed that the particle size of ultra-fine fly ash is much smaller than that of the raw fly ash.

Lime Water as Mixing Water

An investigation was carried out to determine the influence of saturated lime water, a kind of alkaline liquid, as mixing water for high volume ultra-fine fly ash concrete on its strength and durability(Vijai et al., 2010). In addition previous research by the Dr Patnaikuni's team using saturated lime water as mixing water in concrete mortar gave same strength as normal cement mortar at early ages and higher strength at the age of 56 days (Solikin et al., 2011).

The lime water in this research was prepared by mixing 50% of tap water and 50% of saturated lime water. The saturated lime water was made by dissolving 3 grams of hydrated lime powder in 1 litre tap water. After allowing to sediment for 24 hours, the top layer of the water was taken and used as mixing water while the solid hydrated lime was left on the bed. The saturated lime water has different properties compared to tap water as shown in Table 2.

Table 2. Properties of mixing water

Water	Density	pH
Tap water	0.9909	8.5
Saturated lime water	0.9917	11.4

The density of saturated lime water was slightly higher than that of tap water since some hydrated lime particles are dissolved in it (0.08%). Furthermore, the alkalinity of saturated lime water is much higher than that of the tap water. The increase of alkalinity in lime water which resulted from $Ca(OH)_2$ (hydrated lime) will be useful when reacting with pozzolanic material like fly ash.

Mix Proportion of the Concrete

The mix design for the concrete was prepared based on proposed method of high performance concrete mix design (Aïtcin, 2004). The mix proportion for 1 m^3 concrete using w/binder ratio of 0.3 is given in Table 3.

As low w/binder ratio was used, this mix proportion needed high range water reducer (HRWR). The HRWR used was sodium naphthalene formaldehyde sulphonate with density of 1.2 kg/litre. The use of high volume ultra-fine fly ash reduced the use of HRWR by 1.6 times in comparison to HRWR used in normal cement concrete. Moreover, it needed only half of HRWR compared to high volume raw fly ash.

The smaller amount of plasticizer in fly ash concrete is because of the spherical shape of fly ash which reduces the friction between cement and aggregates and results in an increase of workability of fresh concrete (Sata et al., 2007). This reduction in amount of plasticizer will lead to lower cost of concrete production.

Table 3. Mix proportion of high volume ultra-fine fly ash concrete

Mix proportion	Cement	Fly ash	Water	Aggregate		HRWR
				fine	Coarse	
	(kg/m3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	($litre/m^3$)
Normal cement, tap water (No 5)	450.0	-	137.0	912.0	994.0	13.9
UFFA, tap water (No 1)	225.0	225.0	141.0	835.0	994.0	7.0
UFFA, lime water (No 10)	225.0	225.0	141.0	835.0	994.0	7.0
Raw fly ash, lime water (No 4)	225.0	225.0	139.0	811.0	994.0	10.2

EXPERIMENTAL PROGRAM

The experimental program consisted of strength test and durability test of concrete. Concrete strength was tested for its compressive strength.

All of the specimens were made of cylinders of 100 mm dia. and 200 mm height and then adjusted the height corresponding to the kind of test. All of the specimens were cured by immersing in a water tank with a temperature of 24^oC until the day of test.

RESULTS AND DISCUSSION

Compressive Strength

The result of compression strength of concrete at the age of 28 days and 56 days are shown in Table 4.

Table 4. Compressive strength of the concrete

	MPa	
	28 d	56 d
Normal cement, tap water (No 5)	79.0	84.5
UFFA, tap water (No 1)	71.0	74.5
UFFA, lime water (No 10)	78.5	85.0
Raw fly ash, lime water (No 4)	66.5	72.0

The compressive strength result shows that the high volume fly ash concrete could achieve strength which nearly met the strength of normal cement concrete even though the amount of ultra-fine fly ash used is 50% as cement replacement. The use of lime water as mixing water increased the compressive strength of high volume fly ash concrete in comparison to earlier studies by other researchers. More over the compressive strength of fly ash concrete is increased with the increase of curing age.

CONCLUSIONS

This research demonstrated the use of high volume fly ash as cement replacement can produce high strength concrete with small decrease of the compressive strength in comparison to normal cement concrete. The use of high volume fly ash also decreases significantly the amount of superplasticizer needed in comparison to normal cement concrete.

FURTHER RESEARCH

Further research is still going on replacements higher than 50%, in RMIT with another two PhD students.

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