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Effect of ultrafine fly ash on mechanical properties of high volume fly ash mortar

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HIGHLIGHTS

- The addition of ultra fine fly ash increased the 7-day compressive strength of HVFA mortars.
- The above addition also increased the 28-day compressive strength of HVFA mortars.
- Ultra fine fly ash is effective in consumption of C-H in high volume fly ash system.

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ABSTRACT

This paper presents the effect ultrafine fly ash (UFFA) on compressive strength development of mortars containing high volume class F fly ash as partial replacement of cement. The experimental works are divided into two parts. Part one is conducted in binary blended cement mortar where Portland cement (PC) type I is replaced by UFFA at level of 5%, 8%, 10%, 12% and 15% (by wt). In this part, cement mortar and high volume fly ash (HVFA) mortars containing 40%, 50%, 60% and 70% of class F fly ash are also prepared and used as control mortars. The UFFA level which exhibited highest compressive strength is then selected and used in part two where the effect of UFFA in high volume fly ash replacement is evaluated. The study reveals that the cement mortars with 8% UFFA of cement replacement exhibited higher compressive strength at 7 and 28 days than control mortars. There is also a great improvement on compressive strength of HVFA mortars, particularly at early age. The large surface area of the UFFA promotes the hydration process and enhances the microstructure of the cement mortars to yields better strength and mechanical properties. In this study, the microstructure and phase identification after 28 days are also presented based on backscattered electron (BSE) image and x-ray diffraction (XRD) analysis of paste samples. The results indicate the effectiveness of UFFA in producing high packing density and in accelerating the pozzolanic activity to produce more C-S-H gel by consuming calcium hydroxide (CH) in order to improve the mechanical properties of HVFA mortars.

1. Introduction

Concrete is one of the most widely used construction materials in the world. As the consumption of concrete rises, the world production of cement is continuing and grew to a significant amount of 3.6 billion tonnes in 2011 [1]. Portland cement production, however, is a highly energy intensive process, and emits CO_2 during calcination process which has a crucial effect on global warming. In this connection it is suggested that efforts must be taken on finding environmentally friendly concrete with high performance in strength and durability.

For many years, the incorporation of fly ash as partial replacement of cement in concrete is a common practice. The quantity of fly ash to replace the cement for typical application is limited to 15–20% by mass of the total cementitious material [2]. It is accepted that as a by-product of industrial process, the utilization of fly ash has made some progress in addressing the challenges of sustainable construction. In addition, fly ash has pozzolanic activity which is attributed to the presence of SiO_2 and Al_2O_3. It reacts with calcium hydroxide during cement hydration, to form additional Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH) which are effective in forming denser matrix leading to higher strength and better durability [2–4].

The use of high volume fly ash as partial replacement of cement in concrete has also been studied extensively. The main concern in this respect is determining whether or not cement can be replaced by fly ash above the limiting quantity of 15–20% by mass in concrete. Indeed, the small percentage is beneficial in optimizing workability and low cost but it may not improve durability to any considerable extent [5]. On the other hand, due to the

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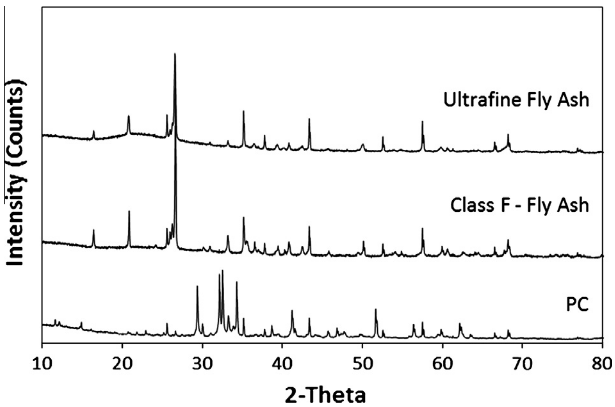

Fig. 1. XRD analysis of PC, Class F-FA and UFFA.

Table 1
Phase abundance (weight%) of fly ash samples.

Phase	Weight%	
	Class f fly ash	Ultrafine fly ash
Hematite	1.7	–
Maghemite-C	2.8	0.7
Mullite	16.8	–
Mullite	–	6.0
Quartz	15.0	11.7
Amorphous Content	63	81

Table 2
Chemical composition and physical properties of materials.

Chemical analysis	Cement (%)	Class F fly ash (%)	Ultrafine fly ash (%)
SiO_2	20.2	51.80	73.4
Al_2O_3	4.9	26.40	17.7
Fe_2O_3	2.8	13.20	4.4
CaO	63.9	1.61	0.9
MgO	2.0	1.17	0.6
MnO	–	0.10	<0.1
K_2O	–	0.68	1.03
Na_2O	–	0.31	0.11
P_2O_5	–	1.39	0.2
TiO_2	–	1.44	0.7
SO_3	2.4	0.21	0.2
Physical Properties			
Particle size	25–40% ⩽ 7 μm	40% of 10 μm	Mean size 3.4 μm
Specific gravity	2.7–3.2	2.6	2.0–2.55
Surface area (m^2/g)	–	–	2.51
Loss on ignition (%)	2.4	0.5	0.6

properties of fly ash particles, a higher tendency for possessing some negative effects in terms of early age strength and durability properties can be expected [6,7]. Moreover, the optimization of high volume fly ash has raised many arguments and limitations regardless of the fact that the variation of constituent in fly ash such as alkalis, sulphates, lime and organics may affect the crystallization and slow down the pozzolanic reaction [8]. In order to overcome this deficiency, the incorporation of very small size pozzolanic materials such as silica fume in HVFA system has been established [9–11]. Finer materials are expected to be easily dissolved and accelerate the pozzolanic reaction to improve the strength characteristics of mortars and concretes.

Among many ultrafine pozzolanic materials ultrafine fly ash (UFFA) is recently developed. UFFA is produced by a proprietary separation system with a mean particle diameter of 1–5 μm and contains 20% more amorphous silica than typical class F fly ash [12]. Generally, ultrafine fly ash (UFFA) is produced from pure class F fly ash by grinding, and separating the ultrafine particles through the air-classification process. The classification system is performed for the removal of coarse particles by size and weight to retain the finer ash fraction. In some cases, this system is beneficial not only in producing finer materials, but also in reducing the carbon content and minimizing the variability of constituents in typical fly ash [13]. The finer particle size, therefore, improves the morphology, mineralogy and chemical composition of materials. Moreover, when compared to cement production, the UFFA production does not require high energy-intensive process thus can result in a cost saving [14]. The other benefits include reducing consumption of natural resources and reducing CO_2 emission to stabilize climate change. On the other hand, it has been reported that a reduction in the particle size of fly ash increases the amorphous SiO_2 content and tends to decrease the amount of SO_3 which can prevent the hydration reaction of harmful ions in concrete or mortar [15].

When the UFFA is used to replace cement content, there is strong indication that an enhancement of strength and higher long-term durability can be obtained. It is because of the smaller particle size of UFFA offers greater surface area for hydration and hence accelerates the pozzolanic reaction. So, the complete hydration reaction can be attained at earlier ages when compared to the ordinary class F fly ash. In addition, the smaller particle is effective to densify the pores structure and, it increases the particle packing affect to increase the density of concrete or mortar. However, the UFFA, when present at appreciably high levels, it tends to increase the water demand as a consequence of accelerated reaction under fineness and high surface area. Too much water can yield a low strength performance. Therefore, the typical dosage rates of UFFA are suggested to be ranged from 8% to 12% of the total binder content [16]. This dosage is lower than the percentage used for class F fly ash in blended cement concrete. In conventional concretes, class F fly ash typically comprises 20% to 30% by mass of cementitious material. This fact indicates that UFFA is sufficient to obtain the most economical concrete mix that satisfies the strength and durability requirements in conjunction with the application of class F fly ash and even the highest reactive pozzolanic material, e.g. silica fume.

Based on previous experimental research some beneficial effects have been reported that UFFA was able to enhance the compressive strength when used as partial replacement of cement with low w/c ratio. Obla et al. [12] studied the effect of ultrafine fly ash in concrete on compressive strength and some durability properties. It was concluded that the concrete containing UFFA has higher strength and has a tendency to minimize alkali-silica reaction expansion. It was also found that the strength activity index at 7 and 28 days was 25% to 30% higher than unprocessed fly ash (class F fly ash). Chindaprasirt et al. [17] studied the effect of different fineness of fly ash on pore structure and microstructure of fly ash cement pastes. They reported that the blended cement paste containing finer fly ash particles exhibited a denser matrix and resulted in higher compressive strength and lower total porosity. Hossain et al. [18] observed the effect of UFFA compared to silica fume concrete. It was revealed in their study that the replacement of cement with 12% UFFA content improved cracking resistance when compared to conventional Portland cement concrete and silica fume concrete. Subramaniam et al. [19] carried out an experimental investigation on UFFA concrete with two replacement levels i.e. 8% and 12%. It was concluded that the compressive strength of 8% UFFA was slightly decreased at 1 day but did not hamper the long-term strength development. On the other hand, increasing the UFFA content to 12% resulted in an increase in the resistance of shrinkage cracking. Similarly, the results of the study by Choi et al. [7] showed that the compressive strength