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Early age assessment of cement mortar incorporated high volume fly ash

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Abstract. The technique of replacing the cement with other alternative materials focuses on the production of materials with similar performance and reduced environmental impacts relative to traditional cement. The main aim of this study is to investigate the effect of replacing the cement content with high volume of Pulverised Fuel Ash (PFA) on the mechanical performance of cement mortar. Three mixtures were prepared with different percentages of PFA (20%, 40% and 60%) as replacement of cement along with other mixture that made with 100% cement as a control mixture. In order to evaluate the performance of the cement mortars, compressive strength and Ultrasonic Pulse Velocity (UPV) tests after 7, 14 and 28 days of curing was used. The results indicated that for all ages of curing, the increase of PFA contents caused a reduction in the compressive strength and UPV in comparison with the control mixture. After 28 days of curing, the results indicated that the mixture incorporated 20% PFA has similar UPV value relative to the control mixture. Such findings will significantly contribute in reducing the cost of the produced mortar by reducing the amount of used cement and this consequently reduce the cement demands/manufacturing. Less production of cement will reduce the Carbon Dioxide (CO_2) emissions of the cement industry.

1. Introduction
After water, the second most used material in the world is concrete [1]. Cement is the indispensable component in concrete. When blend cement, sand and water produced cement mortar (The word "mortar" comes from Latin mortarium, meaning crushed). It is the most common and economic binding materials used in construction industry. It is used in many phases of civil engineering workings such as masonry, brickwork, flooring, roofing, etc. wherefore, the demand for cement is increasing. According

to International Energy Agency (IEA) [2] and particularly in India, the growing countries of Asia and Africa, cement is not expected to decline in the coming years, to build and develop their infrastructure, but contrarily it is gradually increasing. Cement industry caused for about 5-8% of greenhouse gases that affected badly on the weather [3-12]. The third-largest anthropogenic source (human-caused) emissions of carbon dioxide, after destroying forests and burning fossil fuels for transport and electricity generation is the manufacturing of cement industry [13-17]. Cement industry produces about 7% of global anthropogenic emissions of CO_2 [18-29] .

The main raw materials used in cement industry are clay and limestone in addition to sand and iron. From a chemically point of view, cement is composed of four oxides: SiO_2, Al_2O_3, CaO, and Fe_2O_3. A rock that consists mostly of calcium carbonate ($CaCO_3$) is limestone. In order to break $CaCO_3$ down into CaO and CO_2 the calcined limestone is heated in a furnace. The resulting CO_2 is free to the atmosphere. Calcination releases about 0.5 kg of carbon dioxide in producing 1 kg of clinker (dry powder). In order to complete this chemical reaction, in special ovens or kilns a large amounts of fuel are burned to provide heat for calcination. During calcination of limestone in conventional kilns much of the heat energy supplied by fuel-burning is wasted, through replacing more efficient equipment and using “dry” calcination processes rather than “wet” calcination processes, direct fuel usage can be reduced by up to 48%, which would reduce CO_2 emissions by 27% [2]. Without diminishing profits, some estimates of how much efficiency can be enhanced are as low as 11%, which would yield a CO2 reduction of only 5% [2]. To reduce CO_2, low carbon fuels can be used such as natural gas, as well as converting construction practices to the use of mixed cement, it is the cement in which is used industrial wastes such as coal fly ash (the ash left over from burning coal in power plants) or volcanic ash instead of some limestone-based clinker [30].

In coal-fired electricity power stations when pulverized coal burns, it’s produced ash that’s call pulverized fuel ash (PFA). Electrostatic precipitators remove very fine ash from the flue gases. The PFA chemical composition is slightly different from Portland Cement (PC). In order to hydrate the PFA, it needs lime and water together not water directly. In combination with PC, always used fly ash, usually in range (20% PFA to 80% PC) up to (40% PFA to 60% PC) according to application. The aim of using fly ash in the concrete engineering as important mineral admixtures is reducing concrete materials cost, environmental problems reducing and conserving energy and resources [19, 23].

2. Materials and Methodology

2.1. Materials

The Portland Cement (PC) and Pulverised Fuel Ash (PFA) materials were used in this research. The cement was PC type CEM-II/A/LL 32.5-N. By CEMEX ltd Company, Warwickshire, UK, both PC and PFA were supplied.

By an Energy Dispersive X-ray Florescence Spectrometer (EDXRF) type Shimadzu EDX-720, the elemental composition of PC and PFA was analysed. The PC and PFA chemical compositions are shown in Table 1.

Table 1. Chemical composition of PC and PFA.

Item	PC	PFA
CaO %	65.21	4.81
SiO_2 %	24.56	58.83
Al_2O_3 %	1.70	18.83
Fe_2O_3 %	1.64	5.54
MgO %	1.30	3.86
Na_2O %	1.34	1.17
K_2O %	0.82	2.04
SO_3 %	2.62	1.06
TiO_2 %	-	1.19
LOI %	0.28	2.67
pH	12.73	10.68
Specific Gravity	2.94	2.49

2.2. Mixing proportions

In this study, three different binary blends designed by using different proportion mixtures of PC and PFA in addition to the traditional binder (0% PFA) as illustrated in Table 2. The ratio of sand to binder (S/B) and water to binder (W/B) were, 2.5 and 0.4, respectively for all mortar blends.

Table 2. Mixing proportions.

No.	Cement %	PFA %	Ratio of Sand to binder	Ratio of Water to binder
Control Mix	100	0	2.5	0.4
PFA 20%	80	20	2.5	0.4
PFA 40%	60	40	2.5	0.4
PFA 60%	40	60	2.5	0.4

2.3. Experiments method

In this study, the UPV test and compressive strength test for all samples were subjected to an extensive range of curing period included early (1,2,3 and 7 days) ages and later (14, 21 and 28 days), to assess how compressive strength and UPV of different samples affected by curing period.

2.3.1. Compressive strength

According to BS EN 196-1 [31], the test of compressive strength was achieved by using two specimens with dimensions of 40x40x160 mm at different curing periods (1-28 days), to evaluate the mechanical characteristics of the cement mortars. Every specimen was broken by three loading points into two part of the prism samples and the result of compressive strength was represented by an average value of four parts.

2.3.2. UPV test

UPV test of concrete is a non-destructive test to evaluate the durability and homogeneity of concrete according to BS 1881-203 [32]. (Three specimens with dimensions of (10x10x10) cm were produced for each mixing proportion at each curing period).

3. Experimental Results

3.1. The compressive strength results

All mixtures strength was increased constantly with time. Figures (1 and 2) showed that compared with control mix, all the mixtures contains (PFA) given lower strength at all ages and strength decreased as PFA content increased.

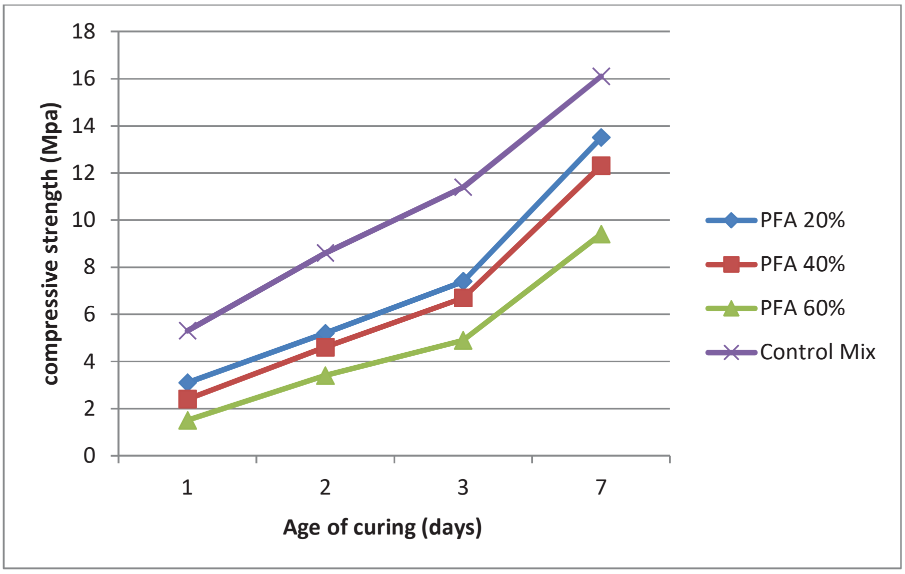

Figure 1. Compressive strength development of different mixtures at early ages.

The mixtures PFA20%, PFA40% and PFA60% have showed about 58%, 45% and 28% of the control mix's compressive strength, at one day of the curing period. The mixtures compressive strength was improved relative to the control blend at 7 days of curing. In comparison with control mixture, the compressive strength of PFA20%, PFA40% and PFA60% at 7 days were 83%, 76% and 58%, respectively. With an increasing the percentages of PFA, during the first week there is a decrease in compressive strength might be refer to the slow gaining of strength for blend mortars with high volume of PFA at early curing periods [33, 34]. The control mixture improvement was about 18% after 14 days of curing, while all other mixtures compressive strength have been improved by about 21% relative to that at the 7 days of curing. The mixtures PFA20%, PFA40% and PFA60% compressive strength were about 85%, 74% and 67%, respectively, 14 days after curing. The mixture PFA20% compressive strength was 19.7 MPa, at the age of 28 days that was about 84% of the control mixture compressive strength (23.2 MPa). Nevertheless, the blends PFA40% and PFA60% providing about 75% and 68%, respectively relative to control mixture's compressive strength.

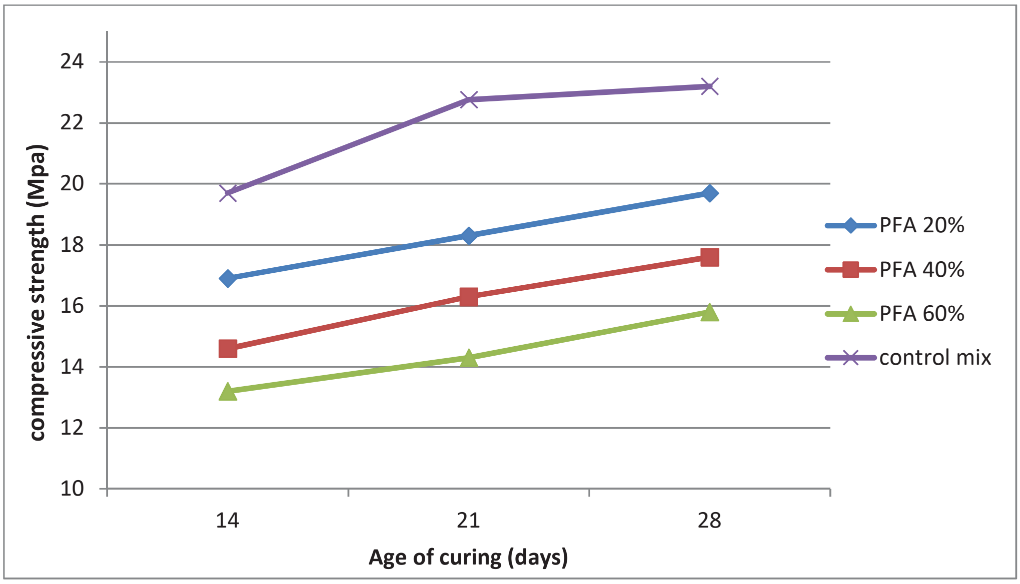

Figure 2. Compressive strength development of different mix proportion at later ages

3.2. The UPV results

Figures 3 and 4 present the results of the UPV of all mixtures during the investigated curing periods. As can be seen from both Figure 3 that the value of the UPV decreased when the PFA content increasing at early ages (1, 2, 3 and 7 days). Additionally, for all mixtures with PFA, the UPV values were lower than that of the control mix. On the other hand, increasing the age of curing to 14 and days, the results showed that the mixture with PFA 60% showed higher UPV value relative to the mixture PFA 40%. At the age of 28 days, the results in Figure 4 showed that the mixture PFA 20% has similar UPV value relative to the control mixture. Moreover, after 28 days of curing the mixture PFA 40% has better UPV value relative to the mixture PFA 60%.

It has been reported previously by Mohseni et al. [35] and Shubbar et al. [36] that the UPV value of mortar is in the range between 3660 m/s to 4575 m/s, the mortar can be classified as good durability mortar. According to Figure 4, the mixture PFA 20% can be classified as good durability mortar after only 3 days of curing, while the other mixtures (PFA 40 % and PFA 60%) needed about 21 days of curing to become mortars with good durability.

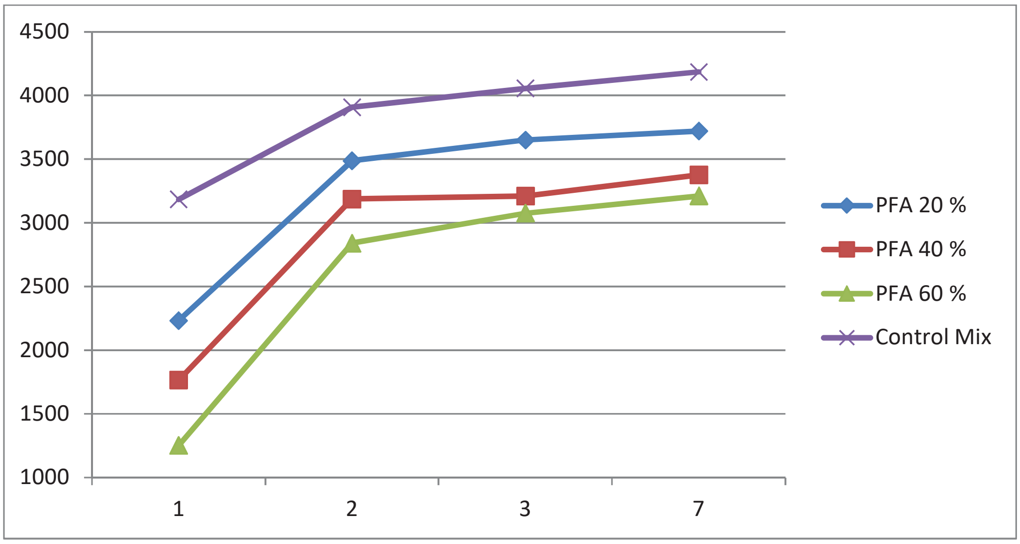

Figure 3. UPV result of different mix proportion at early ages (days)

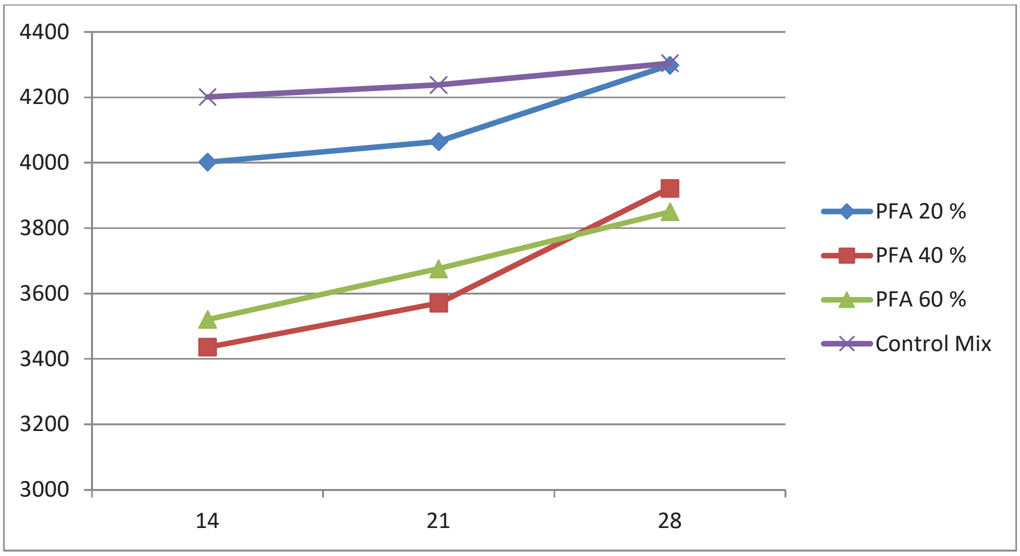

Figure 4. UPV result of different mixtures at later ages (days)

4. Conclusion
The main conclusions from the results of this study are following:

- At early ages (1, 2, 3 and 7) days there was an illustrated significantly decreasing in compressive strength for all sample with different PFA content.
- The use of PFA showed significant increase in the degradation of compressive strength at ages 1 & 7 days with higher percentages of PFA.
- At later ages (14, 21 and 28) days there was a slight strength gain for all sample.

- UPV test showed a decreased in homogeneity and durability of concrete with higher percentages of PFA.
- After 28 days of curing, the mixture PFA 40% showed similar UPV value relative to the control mixture.

For future investigations, authors highly recommending the use of other waste and by/product materials in combination with PFA to enhance the properties of the produced mortars. For example, industrial wastes such as Ground Granulated Blast Furnace Slag (GGBS), Cement Kiln Dust (CKD), stainless steel, silica fume and crude oil wastes [37-58] municipal solid wastes [59] and waste from water and wastewater planes [60-63].

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