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Impact Assessment of Fly Ash as Partial Replacement of Cement along with Riverbed Material as Coarse Aggregate

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Abstract

Using supplementary cementations materials as the OPC replacement instead of environmental sustainability is a global trend. Fly Ash is considered an economical and ideal candidate and has been utilized in various projects worldwide since the 1950s. There are ample resources to produce fly ash in Pakistan. The processing expenditure makes it a handy material to economize the concrete mix designs by replacing the OPC in substantial amounts. This study addresses the effect of OPC replacement by fly ash on the compressive strength of three classes of concrete, class–A1, class–A and class–B, using the coarse aggregate from the Jhelum Riverbed–Mangla quarry. The compressive strengths of the three concrete classes were 5000 PSI for class–A1, 4000 PSI for class–A and 3000 PSI for class–B concrete; by utilizing ACI 318 guidelines, the target strengths were enhanced 6200 PSI, 5200 PSI and 4200 PSI respectively. A total of 25 trials were conducted by the 20% to 25% replacement of OPC by the Fly Ash Class-F in all the concrete classes by varying maximum sizes of the coarse aggregates. Results reflect that most of the Concrete Mix designs achieved the required strengths, indicating that the fly ash didn't hinder the durability of the concrete. There is a potential for achieving higher compressive strengths if a descent in w/cm ratios and ascent in the maximum coarse aggregate size is incorporated. Thus, fly ash is a commendable supplementary cementitious material rendering enhanced paste structure of the concrete and imparting an increase in durability. The reduction in the cost of the CMD makes it an ideal resource to be considered in all the construction projects encompassing bulk concrete quantities across Pakistan.

1. Introduction

The usage of concrete in the modern world encircles a broad spectrum of disciplines, including highways, canal linings, bridges, dams, and arty buildings. The peculiar inclination in concrete production

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resulted from incorporating steel reinforcement for compulsory tensile strength, novel advent in structural design, and prestressing and post-tensioning methods (USBR, Concrete Manual, 1981). The production of concrete has exceeded any other manufactured material in the world in terms of quantity (Lomborg and Bjorn, 2001), evident from the fact that as of 2006, the amount of production concrete surpasses 7.5 billion cubic meters annually, more than the entire population on the planet (USGS, 2007). The principal constituent of the concrete is hydraulic cement, which acts as a binder for all its ingredients. The production of cement throughout the world in the year 2010 was 3300 million tons (USGS, 2011). However, the first two years of the second decade experienced an increased production rate and the quantity spurred to 3585 million tons in 2011 and 3736 million tons in 2012 (Cement Report, 2013). The release of CO2 in the atmosphere during cement manufacturing is a twofold process; a direct emission resulting from the calcium carbonate heating producing lime and carbon dioxide (EIA-USDE, 2006) and an indirect emission via the energy utilized for the manufacturing process. The CO2 emission related to the cement industry alone accounts for 10% of the global manmade CO2 emissions annually, out of which 60% is the direct emission while 40% emission is indirect (EAA & E.C. Report, 2014). The production of such vast quantities of concrete poses a serious concern regarding environmental sustainability. The intensive quarrying to fetch the raw materials needed for the cement production and the excessive amount of CO2 emissions in the manufacturing process coupled with the fuel consumption demarcates the need of delineating alternatives for the cement in the concrete production. These alternatives are in the form of supplementary cementitious materials or SCMs.

The pozzolanic activity associated with the supplementary cementitious materials adds value to the concrete's fresh and hardened properties when used to replace the ordinary Portland cement partially. SCMs include the pozzolanic arterials, and some hydraulic materials are also included in this category (Bhardwaj et al., 1980). A pozzolan is a siliceous or siliceous and aluminous material that possesses little or no cementitious value with finely divided form and moisture. It chemically reacts with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties. The notable pozzolanic materials used generally in concrete include fly ash, slag, silica fume and a few naturally occurring materials like calcined clay & shale and volcanic ash. The hydraulic behaviour is exhibited by ground granulated blast furnace slag and calcium-enriched fly ashes, which display both hydraulic and pozzolanic characteristics because of their increased calcium contents (Thomas M, PCA Report). Anon, 1914 worked on delineating the potential of coal ashes as cementing material by exploiting their pozzolanic nature (American Coal Ash Association, 1992). However, USBR, in 1958, following the pioneering research conducted at the University of California, Berkeley (Davis, 1937; Berry, E. E., and Hemmings, R. T., 1983), utilized the fly ash as the supplementary cementitious material (Abdun-Nur, Edward, 1961). The incorporation of fly ash as supplementary cementitious material has experienced a considerable increase during the last 50 years. An estimated quantity of 15 million tons was consumed in concrete and grouts in the U.S. in 2005 (ACAA 2006; Cannon, Robert W., 1968).

The potential of fly ash in Pakistan is much more promising instead of the available coal resources and the function of several coal-based power plants. The processing of coal ash into the pozzolanic fly ash and its utilization in concrete reduces the amounts of OPC (Albinger, John M., 1984; Belot, J. R., Jr, 1967; Berry et al., 1980). The reduced usage of OPC reduces environmental degradation because of declined CO2 emission during cement production (Bhardwaj et al., 1980; Brink, R.H., and Halstead, W.J., 1956). This study was conducted to warrant the usage of fly ash as a partial cement replacement to batch a concrete satisfying all the essential properties. The effect of various percentages of fly ash as cement replacement on the compressive strength and durability of different concrete classes is the crux of our study. Three classes of concrete, Class – A1, Class – A and Class – B, having strengths of 5000 PSI, 4000 PSI and 3000 PSI, respectively, were batched with various percentages of OPC and Fly Ash utilizing the coarse aggregates from Jhelum Riverbed – Mangla source.

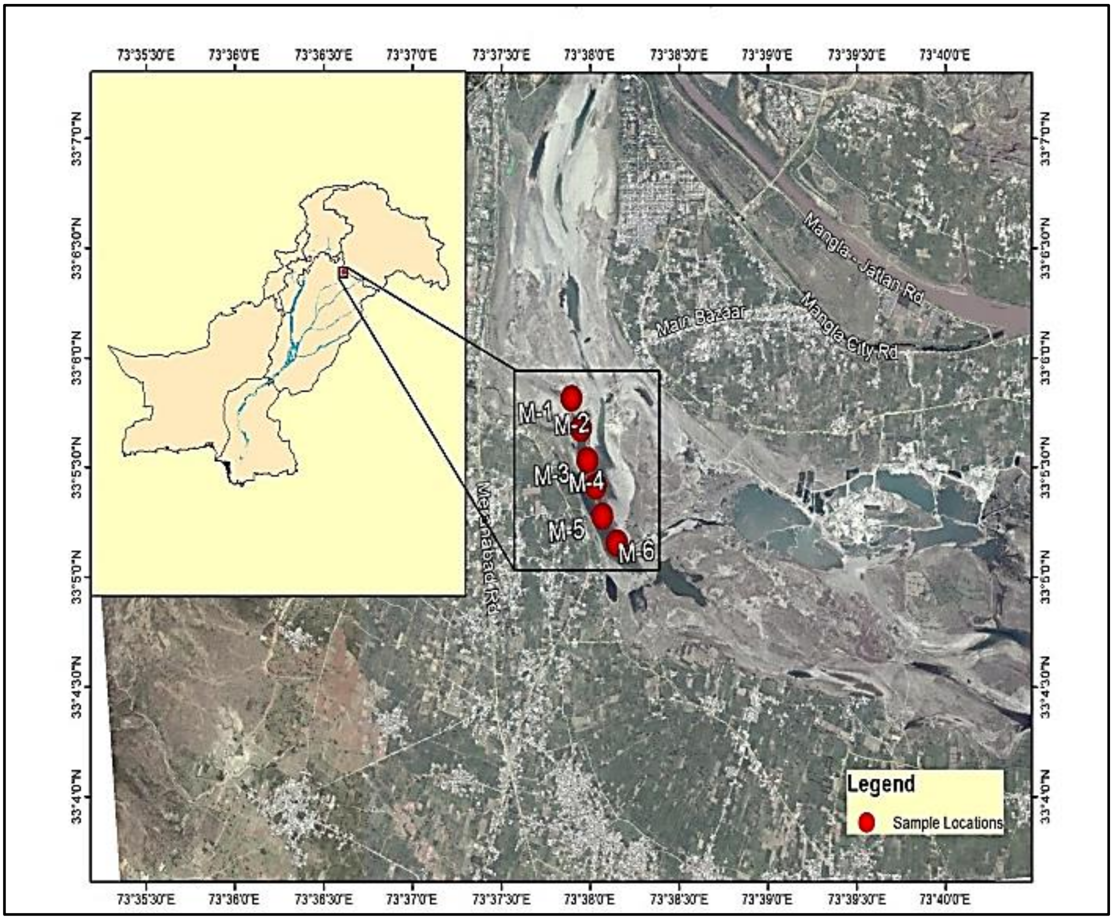

Fig. 1. Location map of Jhelum Riverbed – Mangla crushed aggregates quarry location.

2. Methods and Materials

A few sets of concrete mix designs (CMD) were conducted to appraise the partial replacement of OPC by Fly Ash on concrete's durability and compressive strength by utilizing the coarse aggregate from the Jhelum Riverbed – Mangla quarry comprising three classes of concrete. The characteristics of the materials used for these trials are elaborated in the following sections. The trial CMDs were conducted using ACI 211.1, standard practice for concrete mix design by absolute volume method. This illustrates that if the absolute volumes displaced by concrete ingredients other than fine aggregates are summed and subtracted from its unit volume, the remaining figure is the volume of fine aggregates (ACI 211.1, 2005). The mandatory figures to initiate the design process were the specific gravity, absorption (ASTM C127 / C128), and dry rodded unit weight (ASTM C29) values for coarse and fine aggregates. Several variations in the w/cm ratios and the total cementitious contents were interpolated along with the maximum aggregate sizes during all the trial CMDs programs to analyze the effect of fly ash on the compressive strength and durability of the concrete. Superplasticizer conforming to ASTM C494 was used in all the CMDs to achieve workability and slump retention. All the materials were mixed in the trials following ASTM C192. The initial and final slump was recorded using the test method specified in ASTM C143, and the Unit Weight & Yield of the freshly mixed concrete was calculated using ASTM C138. At the same time, the standard cylindrical specimen for the compressive strength analysis was cast by ASTM C192. These samples were moist cured for 3, 7 and 28 days before crushing in a moist room according to ASTM C511. The cylindrical specimen was capped as per ASTM C617, and finally, they were crushed to analyze their compressive strength per ASTM C39.

2.1 Binding Materials

Fauji cement, conforming to ASTM C150, Type – I, was used as the OPC in the trials conducted for various concrete classes. The supplementary cementitious material consisted of Fly Ash, confirming ASTM C618 Type F from Nukshi Star. The cement's physical properties are as follows (Fineness of cement is 3056, soundness of cement is 0.035, and final &initial setting time of cement is 168 & 223), respectively. The chemical composition of cement and fly ash is assessed for oxides, loss of ignition, and soluble residue (Table 1).

Table 1. Chemical composition (%) of the binding materials.

Chem. Comp. %	**Cement**	**Fly ash**
SiO_2	20.49	45.36
Al_2O_3	5.672	30.49
Fe_2O_3	3.430	0.980
CaO	62.52	7.980
MgO	1.285	0.939
SO_3	2.490	3.789
Loss of Ignition	1.569	5.600
Insoluble Residue	0.453	--

2.2 Coarse Aggregates

The durability and toughness of the coarse aggregates play a vital role in the hardened properties of the concrete. During this study, the quarry for the coarse aggregates comprised of Jhelum Riverbed crushed gravels – Mangla as depicted in figure 1, composed predominantly of mylonised quartzite, used in the concrete trial CMDs. The average physical properties of coarse aggregates are assessed (Table 2).

Table 2. Physical properties of coarse aggregates.

Test	**Size Range (mm)**		
	75-38	**38-19**	**19-5**
Specific Gravity	2.729	2.726	2.758
Absorption (%)	0.360	0.385	0.591
Rd. Unit Wt. (Kg/m^3)	1548	1610	1659
Soundness (%)	0.30	1.11	
L.A. Absorption		19.4	
#200passing (%)	0.8	0.5	0.8
Clay Lumps (%)		1.11	

2.3 Fine Aggregates

The choice of fine aggregates is critical in the design of any mix as the fineness of the fine aggregates directly affects the specific surface area of the mix, which is the crucial factor for total cementitious material and the water demand. The fine aggregates used in this study included two sources, one was Qibla Bandi, and the other was Chenab River sand. The fine aggregates mixture was used in all the trial CMDs. The average physical properties of the fine aggregates are measured (Table 3).

Table 3. Physical properties of fine aggregate.

Test	**Source of F. A**	
	Qibla Bandi	**Chenab**
Specific Gravity	2.700	2.660
Absorption (%)	1.155	1.275
Unit Wt. (Kg/m^3)	1775	1450
Soundness (%)	0.720	0.710
Fineness Modulus	3.663	1.604
Organic Impurities	Nill	Nill
Clay Lumps (%)	1.050	--
Sand Equiv. (%)	80	89

2.4 CMD Methodology

The water content of the CMDs was calculated by the quantities of total cementitious contents and the w/cm ratios. The maximum durability of any blend is directly proportional to the optimum dosage of water to the cementitious material ratio, which directly affects the density of the paste. The more the paste is dense, the more durable is the concrete. Potable water was utilized throughout the study.

3. Results and Discussion

Three classes of concrete, class – A1 with the compressive strength of 5000 PSI, class – A with the compressive strength of 4000 PSI and class – B with a compressive strength of 3000 PSI, were batched in the laboratory by replacing the various percentages of OPC with Fly Ash and using Jhelum Riverbed – Mangla as the source of coarse aggregates. As per ACI 318, "Required average compressive strength when data are not available to establish a standard deviation", the target strengths for classes A–1, class–A and class–B were taken as 6200 PSI, 5200 PSI and 4200 PSI respectively.

3.1 Class – A1 Concrete

A total of four trials were conducted for the class – A1 concrete comprising OPC replacement with Class F Fly Ash. The maximum size of the aggregate in all the trials was 19 mm. Trials # 1 and # 3 comprised the same total cementitious content of 440 Kg/m3 with the fly ash to OPC ratio of 20:80 and 25:75, respectively, having 25:75 respectively having a water/cement ratio of 0.43. Similarly, trials # 2 and # 4 consisted of 430 Kg/m3 of total cementitious content with fly ash to OPC at 20:80 and 25:75 and a water/cement ratio of 0.41 0.42, respectively. The results indicate that the 20% replacement of OPC with fly ash achieved the target strength of 6200 PSI, while the replacement of 25% couldn't meet the benchmark strength, as evident from figure 2 with good correlation.

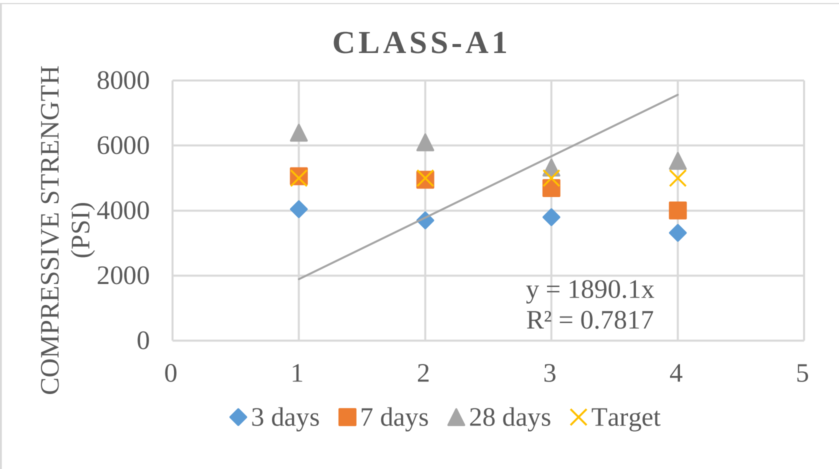

Fig. 2. Trial CMDs for class A1 concrete.

3.2 Class – A Concrete

The trials conducted for class–A concrete with Jhelum Riverbed – Mangla aggregates were characterized by OPC replacement by the Fly Ash, sub-divided into two sets. Set # 1 consisted of seven trials comprising 20% replacement of OPC with the Fly Ash, while set # 2 consisted of 25% replacement of OPC.

Inset # 1, trials # 1 and 2 utilized 37.5 mm maximum size of coarse aggregate, while the rest of the five trials consisted of 75 mm as the maximum aggregate size. The first two trials had a total cementitious content of 350 Kg/m^3; trials # 3, 4&6 consisted of 330 Kg/m^3; and trials # 5&7 comprised 340 Kg/m^3 of total cementitious content. The w/cm ratio for trials # 1, 6 and 7 was 0.49 while the w/cm ratios for trials # 2, 3, 4 and 5 were 0.46, 0.50, 0.42 and 0.44 respectively. Despite all the variation in the trail CMDs, all the trials of set # 1 achieved the target strength of 5200 PSI with good correlation (Figure 3). Similarly, set # 2 comprised a total of 6 trials. Trials # 1, 2 and 3 consisted of 19 mm maximum aggregate size, trial # 4 utilized 37.5 mm and trials # 5 and 6 were characterized by 75 mm as the maximum size of the aggregate. Trials # 1 to 4 utilized 350 Kg/m^3 of total cementitious content, while trials # 5 and 6 used 330 Kg/m^3 and 340 Kg/m^{3,} respectively, as the total cementitious content. The w/cm ratio for trials # 1 and 2 was 0.50, for trials # 3 and 4 was 0.48 and for the last two trials, it was 0.44. As depicted in figure 4, trials # 5 and 6 surpassed the target strength of 5200 PSI, having a larger maximum size of coarse aggregate and a lower water/cement ratio shows a good correlation. The first four trials, characterized by smaller maximum aggregate size and higher w/cm ratios, could not achieve the target strength.

Fig. 3. Trial CMDs for set # 1 for class–A concrete.

It can be deduced that decreasing the water/cement ratio and increasing the maximum aggregate size (paste densification and reduction in specific surface area) can yield higher target compressive strength at lower total cementitious material content at even higher percentages of OPC replacement with Fly Ash.

Fig. 4. Trial CMDs for set # 2 for class–A concrete.

3.3 Class – B Concrete

The trial CMDs conducted by the Jhelum Riverbed – Mangla aggregates for class – B concrete was again characterized into two sets comprising 20% and 25% replacement of OPC by the Fly Ash.

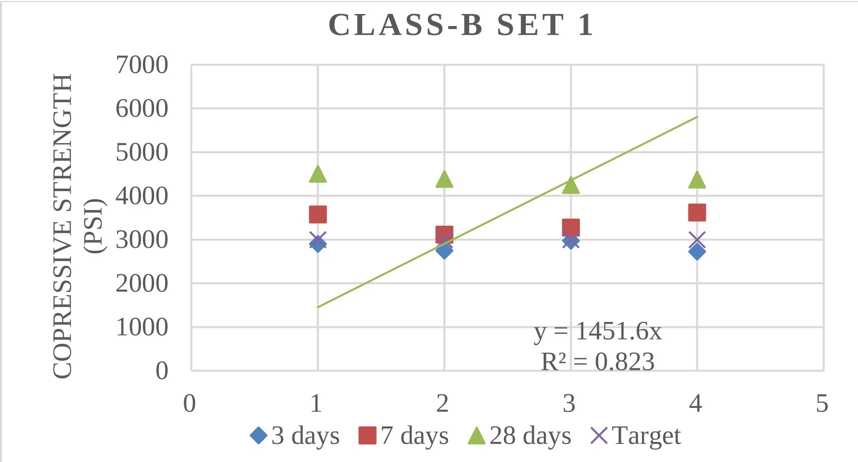

Fig. 5. Trial CMDs for set # 1 of class – B concrete.

Trial # 3 of set # 1 depicts the total cementitious set#2 content of 330 Kg/m^{3,} while the rest of the trials consisted of 300 Kg/m^3 of the total cementitious content. The w/cm ratio of trial # 1 was 0.53, while all other trials comprised the w/cm of 0.54. The maximum aggregate size for trials # 1 and 4 was 19.0 mm, while trials # 2 and 3 were 37.5 mm. As displayed in figure 5, all the trials achieved the target strength of 4200 PSI with a good correlation. All four trials of set # 2 comprised the total cementitious content of 300 Kg/m^3. Trials # 1 and 2 consisted of 37.5 mm as the maximum aggregate size and 0.52 as the w/cm, while trials # 3 and 4 comprised 19 mm as the maximum aggregate size and the w/cm of 0.54. Except for trial # 3, all the trials achieved the target strength of 4200 PSI, as shown in figure 6, with a good correlation.

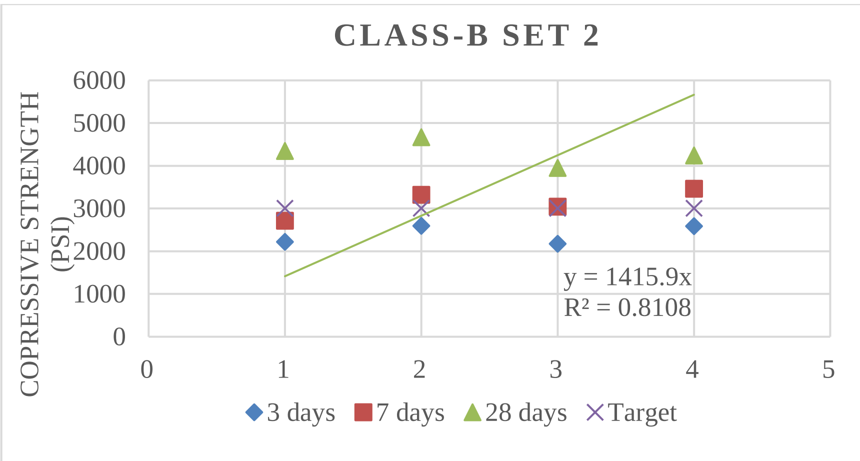

Fig. 6. Trial CMDs for set # 2 of class B concrete.

4. Conclusions

The Fly Ash can be used as a partial cement replacement without any retardation of the compressive strength of the concrete. The compressive strength of the CMDs depicted satisfactory values throughout the study. The CMDs that were unable to achieve the target strength can be modified by increasing the nominal maximum size or decreasing the w/c ratios. The usage of fly ash can significantly impact the economics of the mix as its processing cost is lower than the OPC. Furthermore, Fly Ash utilization is pivotal in developing a sustainable environment since it replaces the quantities of OPC, leading to decreased annual OPC production, thus reducing the amount of CO_2 emission in the atmosphere. Moreover, the raw material to produce Fly Ash is readily available locally. The Fly ash is a byproduct of the burning of coal abundantly available in Pakistan and doesn't pose an issue of scarcity or shortage. It is recommended to consider the utilization of Fly Ash in the concrete designs across countrywide construction projects, especially where the bulk volume of concrete pouring is deemed.

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