INFLUENCE OF FLY ASH REPLACEMENT ON STRENGTH PROPERTIES OF CEMENT MORTAR

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Abstract
Strength properties of fly ash mortars were evaluated through laboratory investigations. OPC of 53 grade replaced with class F fly ash with 5 - 25 % in the increments of 5 %. The results shown that at early age at all fly ash replacements the strength decreased with respect to normal mortar. However, after 28 days and above the mortars made with fly ash replacement up to 15% resulted higher strength than normal OPC mortar. Fly ash replacement of 20 and 25% always had lower strength than normal mortar. It was found that 10% fly ash is the optimum content for maximum strength.

Key words: civil engineering, construction materials, compressive strength, environment, efficiency, ferrocement, fly ash, mortar, split tensile strength, cost savings.

1. Introduction

Cement production involves high energy consumption and is responsible for approximately 7% of the worlds CO_2 emission [1]. It is well known that CO_2 is a major contributor to the greenhouse effect and consequently being responsible for global warming of the planet. Therefore, research on use of by-product cementing materials, such as fly ash, silica fume, metakaolin and rice husk ash in place of cement has been increased in concrete technology [2-6]. On the other hand, the growing demand for energy has caused higher consumption of coal and consequently increased fly ash production. Millions of tons of fly ash have been produced every year around the globe. However, the fly ash usage is not even 40%. In this scenario industrial by-product not only creates environmental problems and also occupies large land space for storage. Hence, replacing fly ash with cement is a viable option for energy saving, cost reduction and environmental protection.

Fly ash is one of the most common pozzolan and is being used quite extensively. The utilization of fly ash in concrete has increased rapidly as it contains high siliceous and aluminous compounds [7-9]. Investigations were conducted on different types of concretes such as normal concrete, self compacted concrete, fibre reinforced concrete, foamed concrete, light weight concrete and roller compacted concrete with fly ash. It was found that fly ash addition in any type of concrete improves concrete performance [9-12].

Apart from different concretes, mortar also has its intended uses in construction field. Mortar has been used for centuries as a means of adhering bricks or concrete blocks to one another. Further, cement mortar continues to be used in many different types of constructions like plastering and quick repairs. Few types of concretes like foamed concrete, ferrocement and shotcrete has no coarse aggregate in their production and characteristics of such materials exclusively depend on mortar. In general mortar is a mixture of cement, fine aggregate and water, in which, coarse aggregate is avoided. Although it is possible to obtain advantages of using fly ash in mortar as in concrete, limited research has been done in fly ash mortars. Furthermore, many empirical relationships between the concrete properties and fly ash efficiency in concrete are available. However, these relationships and efficiency of fly ash in mortar is scanty.

Therefore, to promote confident use of fly ash in mortar applications and thereby increase fly ash usage in mortar, the present work was formulated. As stated earlier, there were numerous studies on the strength characteristics of concrete containing fly ash. However, there is little study in the literature regarding the strengths of fly ash mortars. In addition, most of the studies present strength characteristics up to 3 months. A few works presents the results of 6 months or more. The current work presents the results of fly ash mortars up to 6 months.

2. Experimental investigations

2.1. Materials

The constituent materials used in this investigation were procured from local sources. Ordinary Portland cement of C53 grade conforming to both the requirements of IS: 12269 [13] and ASTM C 642-82 type I [14] was used. Class F fly ash was used, which was conforming to the ASTM C 618 [15]. Physical characteristics and chemical compositions of the materials were found to satisfy the requirements of both ASTM C 618, and IS: 3812-1981 [16]. Properties of both cement and fly ash are given in the Table 1. Well graded river sand finer than 2.36 mm was used. Locally available potable water was used for mixing and curing.

Table 1 Chemical composition and physical characteristics of cement and fly ash

	CEMENT	FLY ASH
Chemical Composition (%)		
Silica (SiO_2)	21.8	58.3
Alumina (Al_2O_3)	6.6	31.7
Ferric oxide (Fe_2O_3)	4.1	5.9
Calcium oxide (CaO)	60.1	2.0
Magnesium oxide (MgO)	2.1	0.1
Sodium oxide (Na_2O)	0.4	0.8
Potassium oxide (K_2O)	0.4	0.8
Sulphuric anhydride (SO_3)	2.2	0.2
Loss on Ignition (LOI)	2.4	0.3
Physical Characteristics		
Fineness (Blaine), m^2/kg	307	350
Standard consistency, %	33	NA
Normal consistency, %	28	NA
Specific gravity	3.15	2.06
Initial setting time, min	205	NA
Final setting time, min	287	NA
Compressive strength, N/mm^2		
1 day	24	NA
3 days	37.5	NA
7 days	49.5	NA
28 days	65	NA
Lime reactivity	NA	9.87

2.2. Mix proportions

In order to investigate strength properties of fly ash mortars, six mixes were employed. Reference mix (M0) that is, without fly ash was made with cement to fine aggregate ratio of 1:3. Cement content was then replaced with fly ash in 5% (M1), 10% (M2), 15% (M3), 20% (M4) and 25% (M5) to study effect of fly ash replacement. Water to cementitious ratio of 0.5 was adopted for all the mixes.

2.3. Mixing, compaction, specimen preparation and curing

The mortars were mixed in a planetary mixer of 100 l capacity. The mixing time kept to about 3 to 4 min. Mixing of the materials was in a sequence: (i) portion of design water poured into mixture drum; (ii) cement and fly ash gently placed; and (iii) sand was spread over the powder and started mixing. During mixing, the remaining design water was poured into the mix for thorough mix of mortars. Specimens were then prepared and left for 24 hours. The specimens were demoulded after 24 hours and immersed in normal water for curing until the test age.

3. Test program

The main objective of the present investigation was to study the performance of fly ash mortars in terms of strength with normal water curing and with no chemical admixtures in the mixes. Performance of the mortars was assessed through: compressive strength and split tensile strength for different test ages that is, 7, 28, 90 and 180 days.

3.1. Compressive strength studies

The compressive loading tests on mortars were conducted on a compression testing machine of capacity 2000 kN. For the compressive strength test, a loading rate of 2.5 kN/s was applied as per IS: 516–1959 [17]. The test was conducted on 50mm cube specimens.

3.2. Split Tensile Strength

Split tensile strength test was conducted in accordance with ASTM C496 [18]. Cylinders of 100 x 200 mm size were used for this test, the test specimens were placed between two platens with two pieces of 3 mm thick and approximately 25 mm wide plywood strips on the top and bottom of the specimens.

4. Results and discussion

4.1. Compressive strength

The compressive strength developments of fly ash mortars and reference control mortar are presented in Table 2. It can be seen from the table that, the strength increased with curing age for all fly ash replacement percentages including reference mortar. Strength gain with age for all the concretes is shown in Figure 1. The trend in the figure shows that the increase in strength was 40, 66 and 74% for curing ages of 28, 90 and 180 day respectively for reference mortar (M0) with respect to seven days of curing. As the fly ash percentage increased, the strength rate increased with curing period for all fly ash replacements (5-25%). The strength increase for 28, 90 and 180 day curing was 58, 87 and 101% for 5% fly ash mortar (M1). However, these values increased to 88.5, 125 and 144 for 25% fly ash mortar (M5) with corresponding 7 day curing.

Table 2 Compressive and split tensile strength of fly ash mortars investigated

S.No	Concrete Name	FA, %	Compressive Strength, N/mm^2				Split Tensile Strength, N/mm^2			
			7 days	28 days	90 days	180 days	7 days	28 days	90 days	180 days
1	M0	0	17.60	24.80	29.20	30.60	2.32	3.03	3.44	3.57
2	M1	5	15.80	25.00	29.60	31.80	2.17	3.18	3.54	3.73
3	M2	10	14.20	25.20	30.20	33.00	2.04	3.34	3.63	3.92
4	M3	15	12.80	24.80	29.40	31.00	1.88	3.06	3.50	3.66
5	M4	20	11.80	22.20	26.40	28.40	1.69	2.77	3.28	3.44
6	M5	25	10.40	19.60	23.40	25.40	1.53	2.55	2.99	3.15

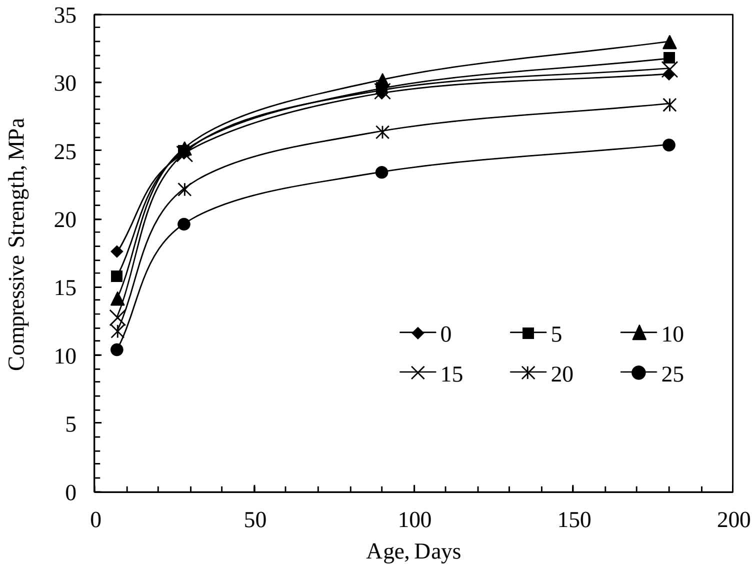

Figure1 Strength development with time

Relationship between fly ash percentage and compressive strength for different curing ages is shown in Figure 2. From the figure it can be understood that at 7 days of curing the strength decreased for all fly ash percentages, the strength was 17.6MPa at 7 days for reference mortar (M0) and it decreased to 10.4MPa for 25% fly ash mortar (M5). The strength decrease was as low as 10.2% for 5% fly ash (M1) and it was as high as 41% for 25% fly ash mix (M5) when compared to reference mortar at 7 days of curing.

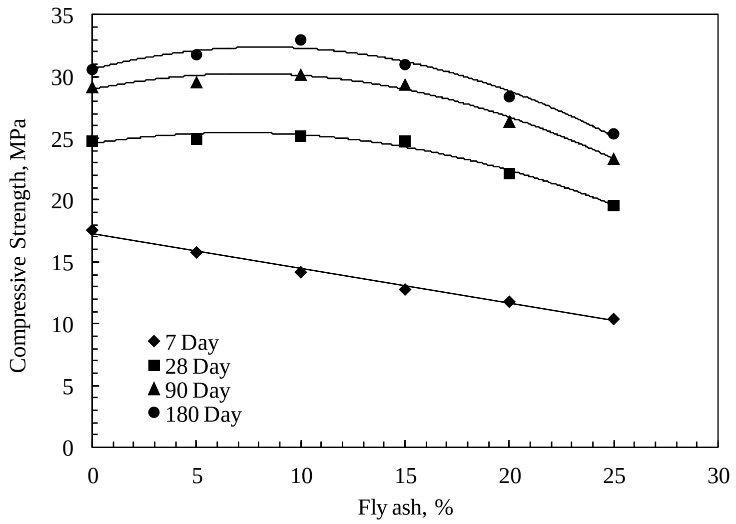

Figure 2 Relationship between compressive strength and fly ash percentage

From the figure it can be observed that 10% was the optimum content at which the strength was maximum and it was higher than reference mortar for 28, 90 and 180 days of curing. At 28 days of curing the strength was 1.61% higher for 10% fly ash mortar (M2) when compared to corresponding reference mortar. Similarly, the strength increased to respectively 3.42 and 7.84% for 90 and 180 days of curing for M2 when compared to corresponding reference mortar. Furthermore, the strength was nearly equal to corresponding reference mortar for 15% fly ash replacement (M3) at 28 days of curing and it increased at later curing age that is, over 90 days of curing. However, mortars with 20 and 25% (M4 and M5) fly ash replacements had lower strength than corresponding reference mortar for all curing ages.

4.2 Split tensile strength

The split tensile strength developments of fly ash mortars and reference control mortar are presented in Table 2. It can be seen from the table that, the split tensile strength increased with curing age for all fly ash replacement percentages including reference mortar. Split tensile strength gain with age for all the concretes is shown in

Figure 3. The trend in the figure shows that the increase in strength was 31, 48 and 54% for curing ages of 28, 90 and 180 day respectively for reference mortar (M0) with respect to seven days of curing. Similar to compressive strength, as the fly ash percentage increased, the strength rate increased with curing period for all fly ash replacements (5-25%). The strength increase for 28, 90 and 180 day curing was 46, 63 and 72% for 5% fly ash mortar (M1). However, these values increased to 67, 95 and 106 for 25% fly ash mortar (M5) with corresponding 7 day curing.

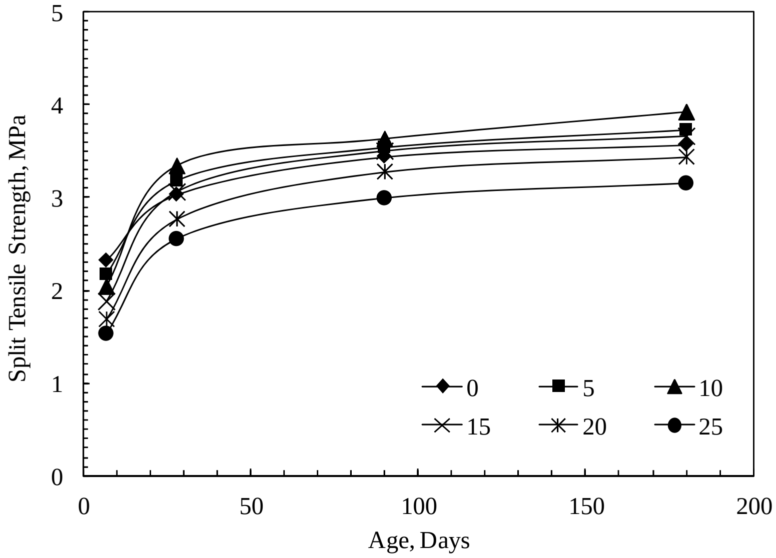

Figure 3 Split tensile strength development with time

Relationship between fly ash percentage and split tensile strength for different curing ages is shown in Figure 4. From the figure it can be understood that at 7 days of curing the strength decreased for all fly ash percentages, as in compressive strength. The split tensile strength was 2.32MPa at 7 days for reference mortar (M0) and it decreased to 1.53MPa for 25% fly ash mortar (M5). The strength decrease was as low as 6.47% for 5% fly ash (M1) and it was as high as 34.05% for 25% fly ash mix (M5) when compared to reference mortar at 7 days of curing.

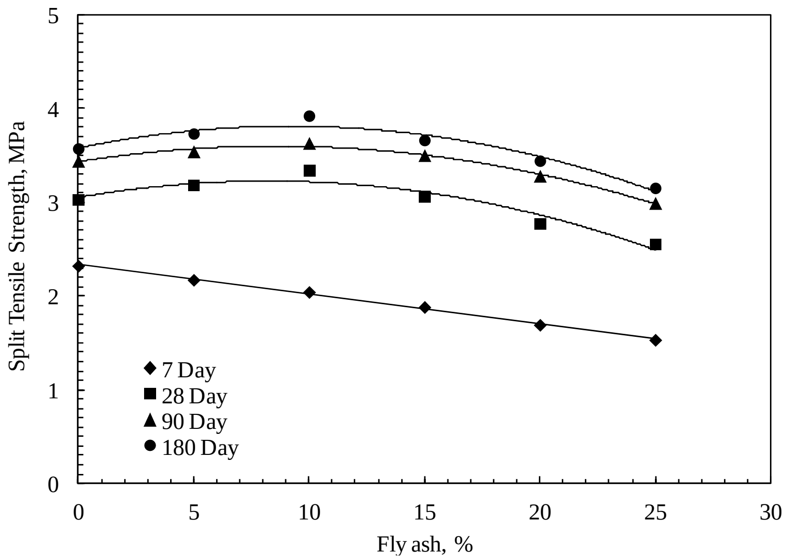

Figure 4 Relationship between split tensile strength and fly ash percentage

From the figure it can be observed that, similar to compressive strength, 10% fly ash was the optimum content at which the split tensile strength was maximum and it was higher than reference mortar for 28, 90 and 180 days of curing. At 28 days of curing the split tensile strength was 10.23% higher for 10% fly ash mortar (M2) when compared to corresponding reference mortar. Similarly, the strength increase was respectively 5.52% and 9.8% for 90 and 180 days of curing for M2 when compared to corresponding reference mortar. Furthermore, the split tensile strength was nearly equal to the corresponding reference mortar for 15% fly ash replacement (M3) at 28 days of curing and it increased at later curing age that is, over 90 days of curing. However, mortars with 20 and 25% (M4 and M5) fly ash replacements had lower split tensile strength than corresponding reference mortar for all curing ages.

4.3 Relationship between compressive and split tensile strength

There exist various empirical relationships to relate the compressive strength of concrete to its split tensile strength. Some of the prevalent published relationships are shown in Equations (1) and (2). Equation (1) was suggested by Raphael, 1984 [19] for normal concrete. Equation (2) was suggested by FIP, 1991 [20] for light weight aggregate concrete. In Figure 5 the trend of fly ash mortars that is, present data with different standard relationships of concrete was compared. Irrespective of fly ash percentage and curing age there is a good power relationship between compressive strength and split tensile strength. The trend shows that the existing relationships for concrete may not be valid for fly ash mortars. The close relationship obtained from the present data is shown in Equation (3). The R^2 value for the equation is 0.99. The difference in trend could be due to aggregate and specimen sizes.

$f_t = 0.3(f_c)^{2/3}$ (1)

where f_t is the splitting strength, and f_c is the compressive strength of cylinders, both in MPa.

$f_t = 0.23(f_{cu})^{0.67}$ (2)

where f_t is splitting strength and f_{cu} is compressive strength measured on cubes both in MPa.

$f_t = 0.25 f_c^{0.79}$ (3)

Where f_c is compressive strength of cube of size 50x50mm, f_t split tensile strength of cylinder 100x200mm in MPa

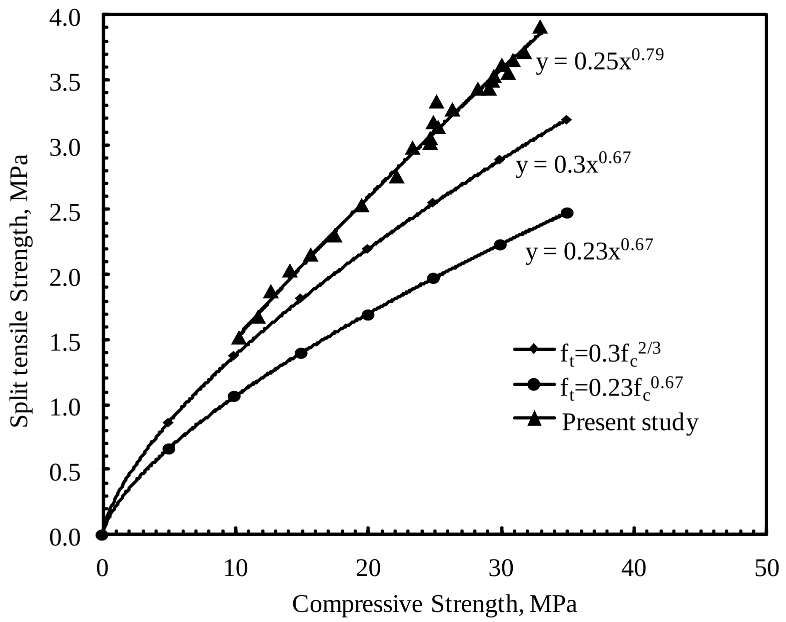

Figure 5 Relationship between compressive strength and split tensile strength

4.4 Fly ash efficiency

The efficiency of the fly ash mortars were computed based on the equation proposed by [21] which is based on the normalization of the compressive strength of concrete with the quantity of cementitious materials, the equation is as follows:

$$k = \frac{\left(\frac{f_c(t)_{fa}}{f_c(t)_{npc}} - 1\right)}{r_{fa}} + 1 \quad (4)$$

Where, k is the efficiency factor of fly ash, c is the quantity of total cementitious material(s), f_a is the quantity of fly ash, r_{fa} is the replacement ratio of fly ash (i.e., 0.3 for 30%, 0.5 for 50% replacement), $f_c(t)_{npc}$ is the compressive strength of NPC concrete at time t, $f_c(t)_{fa}$ is compressive strength of FA concrete at time t.

Based on the above equation and compressive strengths, the efficiency factors of the fly ash used in this study was computed according to the corresponding reference mortar mixtures through curing time. Figure 6 shows development of efficiency factor with curing for different fly ash percentages. It can be seen from the figure that the efficiency factor for all fly ash replacements (5 -25%) is negative at 7 day curing. the efficiency factor is reached to positive value for all the replacements at 28 days of curing.

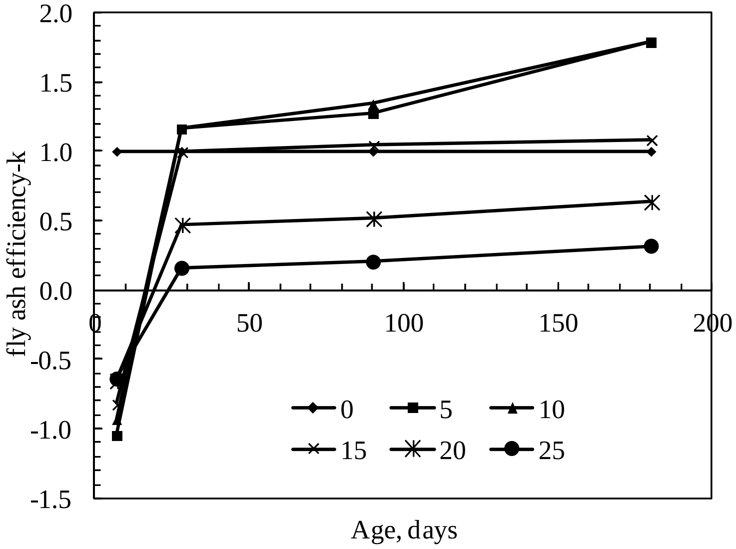

Figure 6 Influence of time on development of efficiency factor of fly ash mortars

The efficiency of 5 and 10% fly ash mortars (M1 and M2) was higher than reference mortar at 28 days and it was equal to reference mortar for 15% fly ash mortar (M3), the efficiency factor was lower than reference mortar for 20 and 25% (M4 and M5) fly ash replacement mortar. The efficiency factor increased with curing age for all fly ash replacements. The efficiency factor for 5, 10 and 15% (M1-M3) fly ash mortars exceeded the reference mortar. However, it was lower than reference mortar even at 180 days of curing for 20 and 25% (M4 and M5) fly ash mortars.

Figure 7 shows variation of fly ash coefficient with fly ash percentage for different curing ages. Fly ash efficiency k was negative for all fly ash replacement percentages at 7 days of curing. The k value decreased to about -1.0 for 5% (M1) fly ash replacement and reached to -0.64 for 25% (M5) fly ash replacement. At later curing ages that is, 28 day and above the k value was positive for all fly ash replacements. The k value was above 1 for 5% (M1) and 10% (M2) fly ash replacements and it was nearly equal to 1 for 15% (M3) fly ash replacement for 28, 90 and 180 days of curing. However, this value decreased to 0.5 and lower when fly ash percentage was 20 and above. From the figure it can be clearly observed that efficiency factor was either higher or equal to 1 up to 15% at later curing age that is, 28 days and above. However, further increase in fly ash percentage in mortar reduced efficiency factor.

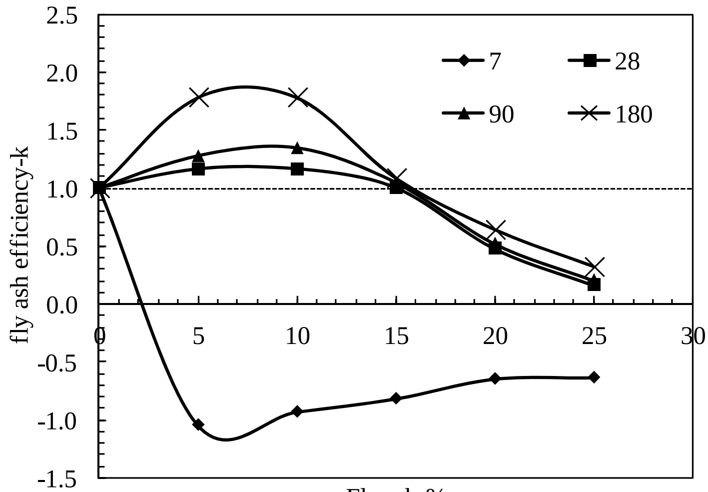

Figure 7 Variation of efficiency factor with fly ash percentage

Efficiency of fly ash in concrete with different fly ash percentages presented in literature [22] for 28 day of curing and efficiency factor of fly ash mortars of present investigation is presented in Figure 8. As in concrete, the maximum efficiency was at 10% for mortars. However, the efficiency factor was higher for fly ash mortars than fly ash concretes up to nearly 20%, further increase in fly ash percentage reduced efficiency factor for fly ash mortar than fly ash concrete.

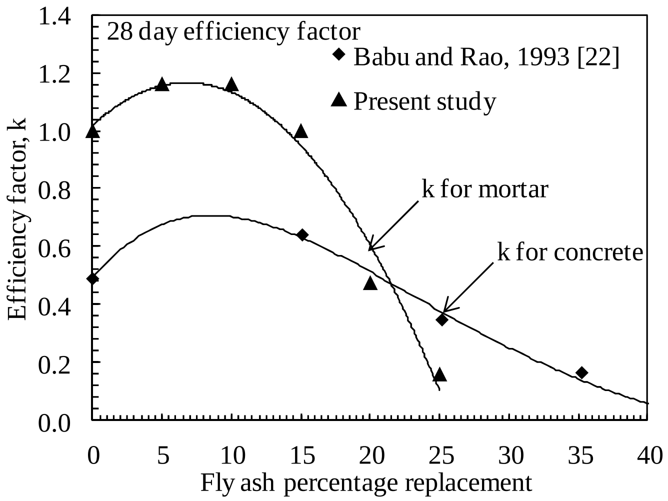

Figure 8 Comparison of efficiency of fly ash mortars with fly ash concrete

Although, there are studies conducted with fly ash concrete, this work provides strength characteristics of mortars made with different fly ash replacements and moist environment with 20^{o}C up to 180 days of age. In this work a relationship between compressive strength and split tensile strength was established for fly ash mortars. In addition, it was shown that the influence of fly ash percentage and curing age on fly ash mortars may be assessed with a simple efficiency factor.

5. Conclusions

1. Compressive strength increased with curing age for all fly ash replacements. Irrespective of fly ash percentage the compressive strength decreased at early age when compared to reference mortar. However, at later curing age mortars made with 5%, 10% and 15% showed higher strength than reference mortar.
2. Similar to compressive strength, the split tensile strength also increased with curing age for all fly ash replacements. Furthermore, irrespective of fly ash percentage the split tensile strength decreased at early age when compared to reference mortar. However, at later curing age mortars made with 5%, 10% and 15% showed higher split tensile strength than reference mortar.
3. Irrespective of fly ash percentage and curing period, there was good relationship between compressive strength and split tensile strength. Comparison of the relationship for mortars with concrete suggested that for mortars split tensile strength is higher for same compressive strength when compared to concrete.
4. The empirical relationship between splitting tensile strength and compressive strength of fly ash mortars was not in good agreement with the existing empirical equation suggested by Raphael (1984) and FIP (1991) for normal concrete.
5. Similar to concrete the maximum efficiency was at 10% for mortars. However, the efficiency factor was higher for fly ash mortars than fly ash concretes up to nearly 20%, further increase in fly ash percentage reduced efficiency factor for fly ash mortars than fly ash concretes in terms of strength.

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