Effect of Class-F fly ash as partial replacement with cement and fine aggregate in mortar

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Fly ash is investigated for its use as a replacement for cement and fine aggregate in cement mortar. This paper presents the results of the cement mortar of mix proportion 1:3, 1:4.5 and 1:6 cement mortar in which cement is partially replaced with Class-F fly ash as 0%, 10%, 20%, 25% and 30% by weight of cement. Richer the mix, higher the compressive strength has been obtained even with partial replacement of fly ash with cement. Test results indicate the significant improvement in the strength properties of mortar with fly ash as partial replacement with fine aggregate and with the cement in the cement mortar 1:6. It can be effectively used in masonry with the compressive strength of the brick unit ranges between 3-20 N/mm\textsuperscript{2}.

\textbf{Keywords:} Fly ash, Partial replacement, Compressive strength, Cement, Fine aggregate

Brick masonry construction is the most preferred one for low rise buildings, especially in the developing and under developed countries because of its ease in construction and economy. Unreinforced brick masonry has been used for the construction of a number of historical and monumental buildings. Nevertheless, brick masonry is the least understood in the aspect of strength and other performance related parameters, because of its complex behaviour and its non-homogeneity. Most of the walls of buildings and residential houses are masonry walls, made of burnt clay bricks or concrete blocks, with rendering on both sides. Even though mortar makes up as little as 7% of the total volume of a masonry wall, it plays a crucial role in the performance of the structure. It not only bonds the individual units together, but it also seals the building against moisture and air penetration. The mortar is literally the glue that holds the wall system together. The primary ingredient in mortar is Portland cement and fine aggregate. Sand is a widely used fine aggregate but in regions where it is not locally available, has added to the transportation costs and ultimately higher overall costs. On the other hand, disposal of waste materials are abundantly and cheaply available, they offer a good substitute to the sand for use in mortars\textsuperscript{3}. Fly ash is blended with other ingredients either during the manufacture of cements or proportioned with other aggregates when mixed. Mixing of fly ash in production of concrete serves two primary purposes: (i) it supplements or replaces fine aggregates and (ii) it provides effective pozzalonic action\textsuperscript{2}.

In recent times, the use of higher grades of ordinary Portland cement are being widely encouraged in most of the advanced countries to suit the conditions for producing high strength brick work. Brittle failure has been observed in relatively high strength mortars and the failure was sudden\textsuperscript{3}. However, it has been observed that the physical properties of cement based composites are primarily affected by the w/c ratio, the chemical composition, micro-structure and pore geometry of the cementitious materials, properties of aggregates, properties of cement – aggregate ratio and properties of cement-aggregate interfacial zone\textsuperscript{4}. In spite of very significant developments in the cement and concrete technology, the behaviour of mortars made with high strength cement is very negligible. The behaviour of high strength and high performance cementitious composite materials depends on the performance of the mortar matrix. Mehta and Monteiro\textsuperscript{5} indicated that fly ash is effective in reducing the thickness of the interfacial zone and porosity in the interfacial zone after prolonged curing. In high rise buildings one may use thinner and
stronger brick walls, Rajamanie and Sabitha discussed that addition of fly ash as cement replacement material reduces the strength of the mortar. Chindaprasirt obtained that the adequate strength developments were found in mortars made of the mixed cement and 20-40% fly ash from Mae Moh power plant in Thailand, as cement replacement for type N and type S mortars. Al-Rawas investigated on Incinerator ash for its potential use as a replacement for sand and cement in cement mortars. Deodhar and Patel concluded that use of very high strength brick or very rich mortar does not improve the strength of masonry. Brick masonry is strong in compression but weak in tension. In compression usually the mortar in joints fails earlier than the bricks and thus strength of mortar in compression determines the strength of brickwork. When the grade of bricks is specified, proper mortar mixes to match the specified strength of brick masonry should be adopted. This study attempts the comprehensive understanding of the influence of mix proportioning on the strength development in mortars with partial replacement of cement with fly ash and partial replacement of fine aggregate (sand) with fly ash.

Materials and Methods

Mortar compositions

The utilization of fly ash as cement replacement material in concrete or as additive in cement introduces many benefits from economical, technical and environmental points of view. Four set of mixture proportions were made. First was control mix (without fly ash), and the other mixes contained Class F fly ash obtained from Mettur thermal power plant. In the first three set the mortars were prepared with 1:3, 1:4.5 and 1:6 binder-to-sand ratio. The fly ash was blended with the mixed cement at replacement ratios of 100:0, 90:10, 80:20, 75:25 and 70:30. Use of the waste material fly ash as partial replacement with cement as 0%, 10%, 20%, 25% and 30% was investigated to obtain substitutes for the cement in the mortar. In the fourth set, the cement mortar 1:6 the fine aggregate (sand) is replaced with fly ash as 0%, 10% and 20% and the results were compared with the cement mortar with partial replacement of cement with the fly ash.

Effect of fly ash

The use of fly ash is accepted in recent years primarily due to saving cement, consuming industrial waste and making durable materials, especially due to the improvement in the quality stabilization of fly ash. Fly ash is another type of pozzolanic material widely being used as a cement replacement. Many researchers indicated that low-calcium fly ash (Class-F) also improves the interfacial zone microstructures. Portland cement hydrates to produce calcium hydroxide as much as 20% to 25% by weight. This compound, besides other alkali oxides like Na₂O and K₂O generates alkalinity. When the pozzolanic materials in the form of fly ash are added to the cements, the C-H of hydrated cement is consumed by the reactive SiO₂ portion of these pozzolanas. This pozzolanic reaction improves microstructure of cement composites as additional C-S-H gel is formed and also the pore size refinement of the hydrated cement occurs. Hydration of tricalcium-aluminate in the ash provides one of the primary cementitious products in many ashes. The rapid rate at which hydration of the tri-calcium-aluminate results in the rapid set of these materials and is the reason why delay in compaction result in lower strengths of the stabilized material.

Testing methodology

The evaluation of fly ash for use as a supplementary cementitious material (SCM), i.e., as a pozzolana, begins with the mortar testing. Mortar is similar to concrete in that it contains cement, water and aggregate, except that in mortar graded fine aggregate is the only aggregate present. ASTM C 311 describes the procedures used to test the fly ash in mortar. With the control mortar, i.e., without fly ash, 10% and 20% of the ordinary Portland cement (OPC) confirming IS 269 is replaced with the fly ash. The data from the fly ash mortar is compared with data from a “control” mortar without fly ash. Normally a mason uses his experience in varying the water content to obtain a mortar with suitable workability for his desired application. The water-to-binder ratio (W/B) of each mixture therefore varies considerably as 0.6-0.75 in brick work. Three cube samples were cast on the mould of size 7.07 × 7.07 × 7.07 cm for each 1:3, 1:4.5 and 1:6 cement mortars with partial replacement of cement with fly ash as 10%, 20%, 25% and 30% and the cement mortar of 1:6 and with partial replacement of fine aggregate with fly ash as 0%, 10% and 20% with w/c ratio as 0.6 were also cast. In case of fly ash mortar, it was observed that certain specimens could not be taken out from the steel mould in 24 h indicating that the rate of gain of strength was slower in first 2 days.
After about 48 h the specimens were de-moulded and moist curing was continued till the respective specimens were tested after 28 days for compressive strength.

**Compressive strength**

Compressive strength tests were performed on compression testing machine using cube samples\(^{20}\). Three samples per batch were tested with the average strength values reported in this paper. The loading rate on the cube is 0.1 mm/min. The comparative studies were made on their characteristics for different cement mortar ratio of 1:3, 1:4.5 and 1:6 with partial replacement of cement with fly ash as 0%, 10%, 20%, 25% and 30% and the cement mortar of 1:6 with partial replacement of fine aggregate with fly ash as 0%, 10% and 20%.

**Results and Discussion**

The compressive strengths of the mortars 1:3, 1:4.5 and 1:6 which can be used for brick mortar joints and plastering are given in Figs 1-3. The compressive strength of the mortar 1:3, 1:4.5 and 1:6 are compared in Fig. 4. Further, the compressive strength on cement mortar 1:6 with partial replacement of fine aggregate (sand) with fly ash as 0%, 10% and 20% and the results are shown in Fig. 5. The binder to cement ratio for 1:6 with substitution for cement and fine aggregate with fly ash is compared in Fig. 6.

**Fly ash as a substitute for cement**

Specimens with cement mortar ratio 1:3, 1:4.5 and 1:6 containing 10% fly ash as the partial replacement with cement produced a compressive strength slightly higher than the control mix at 28 days curing period. Specimens with 20-30% fly ash yielded compressive strength values lower than the control mix (Fig. 4)

It was observed that the 1:6 cement mortar with 10% partial replacement of cement with fly ash yielded higher compressive strength. This shows that the 10% fly ash replacement for cement in the cement mortar 1:6 produces the optimum compressive strength results for the brick strength of 3-9 N/mm\(^2\) in the brick work.

**Fly ash as a substitute for sand**

Specimens containing 20% fly ash with partial replacement of fine aggregate in cement mortar 1:6

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![Fig. 1 — Compressive strength of cement mortar 1:3 with partial replacement of fly ash with cement](image1)

![Fig. 2 — Compressive strength of cement mortar 1:4.5 with partial replacement of cement with fly ash](image2)

![Fig. 3 — Compressive strength of cement mortar 1:6 with partial replacement of cement with fly ash](image3)

![Fig. 4 — Mortar strength with partial replacement of fly ash with cement](image4)
produced higher compressive strength values than the control mix (0% fly ash). Based on the 28 days compressive strength results, the 20% fly ash replacement for fine aggregate in cement mortar 1:6 produced a maximum compressive strength value of about 16 N/mm² (Fig. 5). Therefore, from practical and economical point of view, it can be concluded that 20% fly ash is the optimum percent for fine aggregate replacement in cement mortar 1:6 for the higher brick strength of 8-20 N/mm² in brickwork.

The compressive strength in these mixes is attributed to both the continued hydration of Portland cement and the pozzolanic reactions between the fly ash and the calcium hydroxide component of Portland cement gains more strength in 28 days. It can be seen that there is increase in strength with the increase in fly ash percentage (Fig. 5). However, maximum strength occurs with 20% fine aggregate replacement with fly ash. This increase in strength due to the replacement of fine aggregate with fly ash is attributed to the pozzolanic action of fly ash. A comparative study has been made between the substitution of fly ash with cement and with fine aggregate in the cement mortar of 1:6 (Fig. 6).

In cement mortar of 1:6 with 20% fly ash as partial replacement with fine aggregate shows higher strength at early ages because of the inclusion of fly ash as the partial replacement of fine aggregate starts pozzolanic action and densification of the matrix and due to this, the strength of the fly ash mortar is higher than the strength of control mix (1:6) even at early ages.

**Conclusions**

From this study the following conclusion can be drawn:

The results presented in this paper, indicate that the incorporation of a Class-F fly ash in mixed cement is feasible for making masonry mortars in brick joints.

Adequate strength developments were found in mortars made of the mixed cement and fly ash as cement replacement for 1:3, 1:4.5 and 1:6 mortars.

Fly ash can be used in masonry mortar to improve the long-term bond strength. Partial replacement of the Portland cement with Class-F fly ash significantly improves the masonry bond strength.

Higher values of compressive strength observed for 10% replacement of cement with fly ash compared with the control cement mortar mix.

Mortars prepared using 20% fly ash replacement with fine aggregate in 1:6 cement mortar yielded a higher compressive strength than the control mix.

Thus, fly ash mortar can be utilized more efficiently than cement-sand mortar in the brick work.

When fly ash is added in cement mortar for brickwork, it not only improves long age strength of mortars but also makes the mortar very cohesive and there is overall saving of Portland cement and to a certain extent fine aggregate with the use of fly ash.

Fly ash as 10% partial replacement with cement can be adopted for the brick strength range of 3-9 N/mm² and fly ash as 20% partial replacement with fine aggregate can be adopted for the brick strength range 8-20 N/mm².

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