Indian based fly ash & international based fly ash: A review paper

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Abstract. Large amount of fly ash are produces from various thermal power plant and their disposal is becoming one of the major environmental challenge. Till few years back, fly ash generated by the burning of coal fired power plants was considered as material of very low value, useful only for landfill. But its usefulness as pozzolanic additive to cement is an important discovery. Therefore, studies have been carried out to reuse high volume fly ash as cement replacement in building materials. This paper presents an overview of the previous studies carried out on the use of high volume Indian & international fly ash as a partial replacement of cement in concrete mixtures. Fresh properties, mechanical properties, abrasion resistance, porosity, water absorption, compressive strength, flexural tensile strength of mortar and concrete mixtures containing high volume fly ash as cement replacement have been reviewed.

1. Introduction
In India, most of the fly ash are of class F type. Out of which 20-25% is being utilized in cement-based materials. In order to increase its percentage utilization, an investigation was carried out for its large scale utilization. Concrete mixtures were prepared by replacing cement with 40, 50, and 60% of fly ash. The concrete construction industry is not sustainable as it consumes huge quantities of important raw materials and the principal binder in concrete is Portland cement, the production of which is a major contributor to greenhouse gas that results in global warming and other climatic change. Many concrete structures suffer from lack of durability which has an adverse effect on the resource productivity of the industry. Because the high-volume fly ash concrete system addresses all these sustainability issues, its use will enable the concrete construction industry to become more sustainable. Continuous research studies by various engineering research laboratories revealed its varied usefulness as an additive for enhancing the various qualities of concrete including its workability, strength and durability. Partial replacement of cement with fly ash in concrete save much of the energy required for production of OPC and also facilitates the economical disposal of millions of tons of fly ash. It has been found that in order to improve the other qualities of concrete like resistance of sulphate attack and thermal cracking, larger percentage of fly ash is to be used in concrete. The fly ash is less permeable to water, protecting reinforcing steel from corrosion and adding to the concrete’s durability. It improves the workability of concrete because it aids in the placement of concrete into formwork and around reinforcing steel. Initially, the strength of high volume fly ash concrete is low but with the passage of time, it gains required strength. This can cause problems when slow strength gain means delays in construction. Fly ash admixtures can lengthen the time it takes for concrete to set. Sometimes this is
desirable, particularly in hot weather which speeds up concrete set times, but at other times it is inconvenience and can cause delays in construction.

2. General properties of fly ash
Thermal power plants in India are primarily dependent on the combustion of bituminous coal. The low-lime fly ash similar to class F is the primary variety generated in India and significantly smaller volumes of high lime fly ash i.e. class C are also available. Indian low-lime fly ashes are characterized by a relatively higher concentration of SiO$_2$ and Al$_2$O$_3$ and lower contents of Fe$_2$O$_3$. The reactivity of fly ashes is dependent on their glass content and other mineral phases present. Indian fly ashes are more crystalline than those obtained in other countries, the glass content ranges from 47.0 to 60.9% [2]. The properties of the Indian fly ashes are highly crystalline, relatively coarse and widely variable, the size of fly ash particles remains in the range of 3–9 μm.

International fly ash consists of inorganic, incombustible matter present in the coal that has been fused during combustion into a glassy, amorphous structure. These fly ash particles are generally spherical in shape and range in size from 2 μm to 10 μm consist mostly of silicon dioxide (SiO$_2$), aluminium oxide (Al$_2$O$_3$) and iron oxide (Fe$_2$O$_3$). Fly ash like soil contains trace concentrations of the following heavy metals nickel, vanadium, cadmium, barium, chromium, copper, molybdenum, zinc and lead. The particle sizes in fly ash vary from <1 μm up to more than 100 μm with the typical particle size measuring under 20 μm.

3. Abrasion resistance
R Siddique [7] reported that abrasion resistance of concrete having cement replacement up to 40% Indian fly ash was comparable to the normal concrete. Beyond 40% fly ash content, concretes exhibited slightly lower resistance to wear as compared to normal concrete. The abrasion resistant is primarily dependent on compressive strength of concrete. Abrasion resistant of concrete was found to increase with increase in age for all mixtures. Siddique [14,15] reported a reduction in the abrasion resistance of concrete specimens with the inclusion of 45% and 50% FA as cement replacement. This reduction increased with increasing fly ash content. Siddique et al. [14] reported 73%, 35% and 37.3% reduction in the 7, 28 and 56 days abrasion resistance of concrete with the inclusion of 50% fly ash as cement replacement. Kumar et al. [13] reported a reduction in the abrasion resistance of concrete specimens with the inclusion of 50% and 60% fly ash as cement replacement. However, abrasion resistance of high volume fly ash concrete mixture with 60% fly ash at 0.30 w/c ratio was adequate from concrete pavement consideration. Yasasvi Challapalli et al. [9] reported that abrasion resistance of fly ash concrete with 30 to 50 percent cement replacement was lower than the no-fly ash concrete. Abrasion resistance of concrete was strongly affected by its compressive strength, irrespective of fly ash content. Fly ash concrete up to 30% cement replacement exhibited abrasion resistance similar to the concrete without fly ash at 28 and 70 days.

The abrasion resistance of international fly ash increases as compressive strength increased. Cengiz Duran Atis [23] reported that for high strength grades (more than 40 MPa) the abrasion resistance of high volume fly ash concrete with 70% replacement of cement was found to be higher than that of counterpart normal concrete and concrete made with 50% fly ash. High volume fly ash concrete showed better abrasion resistance than NPC concrete, particularly at high compressive strengths. Langan et al. [10] reported a reduction in the abrasion resistance of concrete specimens with the inclusion of 50% fly ash cement replacement. Nassar [17] examined the abrasion resistance by incorporating 25% and 50% class C fly ash. The samples containing 50% fly ash showed better resistance to abrasion as compared to 25% fly ash samples.

4. Porosity and water absorption
Filho et al. reported 32% increment in the concrete specimen porosity with the inclusion of 50% fly ash as cement replacement. The porosity in the concrete containing fly ash is more as compared to normal concrete. This reduces the pore size, and changed the transport properties of chloride ions and
reduced the pass charge and the chloride ion diffusion coefficient. P. Nath and Sarker reported that incorporation of fly ash reduced the sorptivity of concrete in early age and it decreased further at six months. Poon et al. [11] reported 16% and 47% increment in the porosity of paste specimens at ages of 28 and 90 days respectively by partially replacing cement with 45% fly ash when the w/c ratio was 0.24. The inclusion of HVFA in the matrix increased its porosity and water absorption. Both the porosity and water absorption increased with increasing fly ash content.

5. Compressive strength

Srila Dey [12] had reported that the compressive strength of high volume fly ash concrete decreases with the increase in Indian fly ash content. Replacement of cement by fly ash in different proportions has resulted considerable variation in the properties of fresh concrete like cohesiveness, flow ability of the mix, reduced segregation and bleeding etc. Rafat Siddique [14] found that the compressive strength of fly ash concrete mixes with 10%, 20%, 30%, 40%, and 50% fine aggregate replacement with fly ash, were higher than the control mix at all ages. However, the rate of increase of strength decreases with the increase in fly ash content. Siddique [15] reported a reduction in the compressive strength of concretes with the inclusion of 45% and 50% fly ash as cement replacement, by volume. The reduction in the compressive strength was 40%, 33%, 23% and 18% at ages 7, 28, 91 and 365 days respectively, with the inclusion of 45% fly ash, while this reduction was 42%, 37%, 30% and 23% respectively, with the inclusion of 50% fly ash. Compressive strength of HVFA concrete decreased with the increase in fly ash content at all ages, as shown in Fig. 1. However, at each replacement level of cement with fly ash, an increase in strength was observed with the increase in age due to the pozzolanic reaction of fly ash. Compressive strength of fly ash concrete containing up to 50% cement replacement could be useful in most structural applications.

Fig. 1. Effect of FA content on the compressive strength.

Atis [23] reported that HVFA concrete attained satisfactory or higher compressive strength when compared to OPC concrete at later ages but however the rate of gain of strength in initial ages were slow. Nassar [17] observed the compressive strength at 7, 28 and 90 days of moist curing. Mix containing 25% class C fly ash exhibited higher strength than mix with 50% fly ash replacement. However, there was a continuous development of strength with age. At the age of 90 days, 50% fly ash mix surpasses the strength of mix with 25% replacement. Wang and Park [18] observed that at early stage the compressive strength of the fly ash blended concrete is less than the normal concrete. With the replacement of 15% and 25% fly ash in concrete, the strength of fly ash concrete surpasses the strength of normal mix whereas for high volume replacement of 45%-55% of fly ash, it was found that for higher water to cement ratio the compressive strength was less as that of normal concrete. But for less water-cement ratio it surpasses the strength of control mix.
6. Flexural Tensile Strength

Huang et al. [19] reported that the flexural strength of concrete decreased by incorporating 20% to 80% fly ash. The flexural strength of all mixes were developed continuously with age. However, the flexural strength of all mixes decreased as the percent replacement of fly ash increased as shown in Fig. 2. All the mixtures showed larger increase in the flexural strength between 28 days and 365 days. Jiang et al. reported 17% and 23% reduction in the flexural strength of concretes at ages of 56 and 120 days with the inclusion of 60% fly ash as cement replacement respectively. Sofi et al. [21] reported 5% reduction in the 28 days flexural strength of concrete specimens with the inclusion of 60% fly ash as cement replacement. Naik et al. [22] observed the flexural strength of concrete made with inclusion of 15-70% class C fly ash. Concrete containing fly ash showed continuous development of flexural strength with age. At the age of 3 days, the fly ash mixture (containing fly ash upto 30% cement replacement) showed lower flexural strength than reference mix and at 7 days age, it attained similar flexural strength as compared to reference mix.

![Fig. 2. Effect of fly ash content on the flexural tensile strength.](image)

Kumar et al. [13] proportioned the mix by replacing class F fly ash upto 60%. Fly ash obtained from thermal power plant of Dadri in India. Mixtures were prepared at three different water cement ratio (0.3, 0.34 and 0.40). At the age of 7 days and 28 days, the fly ash mixtures showed continuous decrease in flexural strength with the increase in fly ash content for all water cement ratios. In general, the mixtures containing 40% fly ash showed the maximum flexural strength at the age of 90 days and beyond. Siddique examined the properties of concrete by replacing 40%, 45% and 50% of cement by class F fly ash. It was observed that there is a continuous development of flexural strength with age. However, flexural strength of mixtures containing fly ash was less than the control mix.

7. Conclusions

- Indian fly ash are mostly of class F which is a low lime fly ash characterised by a relatively higher concentration of SiO\textsubscript{2} and Al\textsubscript{2}O\textsubscript{3} and lower contents of Fe\textsubscript{2}O\textsubscript{3} whereas international fly ash are mostly of class C which is a high lime fly ash, generally spherical in shape and range in size from 2 μm to 10 μm consist mostly of silicon dioxide (SiO\textsubscript{2}), aluminium oxide (Al\textsubscript{2}O\textsubscript{3}) and iron oxide (Fe\textsubscript{2}O\textsubscript{3}).
- High volume of fly ash in the concrete result in the reduction of drying shrinkage in the concrete.
- High volume fly ash concrete (upto 40% cement replacement) showed better abrasion resistant particularly at high compressive strength.
- The inclusion of high volume fly ash in the concrete increases the porosity and the percentage of water absorption, but decreases the permeability. Both the porosity and water absorption increased with increasing fly ash content.
• The compressive strength of high volume fly ash concrete is low at initial ages but with the passage of time i.e. beyond 28 days, it gains satisfactory or better compressive strength as compared to normal concrete.

• High volume fly ash concrete achieve satisfactory tensile strength as compared to normal concrete with the passage of time. However, the flexural strength of all mixes decreases as the percent replacement of fly ash increases.

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