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Additive to Cement –A Pozzolanic Material-Fly Ash

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Abstract- Fly ash is one of the residue generated by coalcombustion and is composed of the fine particles and showing cementitious property. Fly ash as a Pozzolana results in significant enhancement of the basic characteristics of concrete in both fresh and hardened states. This report investigates the effects of the fineness and replacement ratio of fly ash on the temperature rise, setting time, and compressive strength. This report shows that the fineness, has the significant effect on compressive strength of mortar not the chemical composition. The mortars with finer fly ashes gained higher compressive strength than those with the coarser ones. Fly ash is reduce heat of hydration in concrete. It improved impermeability of concrete mass increases resistance against ingress of moisture and harmful gases. Fly ash in cement concrete as a partial replacement of cement as well as an additive so as to provide an environmentally consistent way of its disposal and reuse. Converting released lime from heat of OPC into additional binding material contributing additional strength to concreate mass. Pore refinement due to reaction between fly ash and liberated lime improving impermeability.Role in the rheology, adhesiveness and strength of mortar, and key parameter with the fly ash replace by cement.

Keywords: Fly Ash, Compressive Strength, Concrete,

1. Introduction

Fly ash, a byproduct of the combustion of pulverized coal ash, has been widely used in the production of concrete as a replacement for cement. The benefits of using fly ash are that it reduces the cost of the concrete materials, reduces environmental concerns of CO2 production, and decreases the rise in temperature as concrete cures [8]. Concrete is a heterogeneous mix of cement, water and aggregates. The admixtures may be added in concrete in order to enhance some of the properties desired. Various materials are added such as fly ash, rice husk, and admixture to obtain concrete of desired property.

Pozzolona is a siliceous or alumino siliceous material that, in finely divided form and in the presence of moisture, chemically reacts with the calcium hydroxide released by the hydration of Portland cement to form calcium silicate hydrate and other cementitious compounds. The undesirable side effect of Pozzolana are the reduction in the rate of development of strength, an increase in the drying shrinkage and at times reduction in durability. In construction of massive structure resulting in saving cement and reduction of heat of hydration.The pozzolanic reaction rate of fly ashes towards hydrated lime increases with temperature andkinetics of this reaction is influenced by curing temperature the mechanical properties of fly ash concrete dependon several interesting parameters such as curing time, relative humidity, and curing temperature [6]. In SSCChemical admixtures are, however, expensive, and their use may increase the materials cost. Savings in labor cost might offset the increased cost, but the use of mineral admixtures such as fly ash, blast furnace slag, or limestone filler could increase the slump of the concrete mixture without increasing its cost.[6] one disadvantage of using fly ash in concrete work is the slow development of the early compressive strength. Fly ash into various fineness showed that the concrete with finer fraction of fly ash gave a better compressive strength than that without fly ash and the one with coarser fly ash reduced the compressive strength of concrete[11].Fly ash of fine particle size, low carbon content and effective pozzolanic reactivity with clinker. Fly ash with such characteristics is usually found to improve workability and contribute to strength development at a sufficiently early age to be an effective cementitious component of concrete [10].The use of certain pozzolona such as some fly ashes increases the durability through the pore refinement and the reduction in the calcium hydroxide of the cementpaste matrix. One of the most important aspects of durability of concrete is the resistance to sulfate attack[7].

Fly ash as a cement replacement in concrete is that early strength development may be delayed because fly ash has a relatively low surface area, which affects the pozzolanic reaction. At normal temperatures with concretes containing fly ash, the pozzolanic reaction is slow to begin with, and its contribution to strength occurs at late-term ages. This factor has been a big obstacle to the concrete industryĝs wholesale adoption of fly ash as a replacement material for cement [8].

2. Literature Survey

Extensive literature of the subject reveals that successful application of this technique have been made, some literature referred as follows:

Se Jin Choi et.al.2012 studied ñEffect of fly ash fineness on temperature rise, setting, and strength development of mortarò The author have investigated that peak temperature of the mortar was strongly correlated to the percentage of cement content of the mixture regardless of fly ash fineness. A 15% fly ash replacement caused a reduction in the peak temperature in the mortar of about 4 to 6°C. The setting time of fine fly ash mixes with 15 and 30% cement replaced was faster than that of the control mix. The variation of final setting time ratio of fly ash mix to control mix increased in similarity compared to the control mix as the fineness of fly ash increased. The compressive strength of mortar mixes using 60F and 90F fly ashes improved significantly compared to the 40F fly ash mortar. After 28 days, the compressive strength of fly ash mixes with 15, 30, and 45% cement replaced with 90F fly ash was higher than that of the control mix. The tensile strength of fly ash mixes was relatively higher than that of the control mix at the same value of compressive strength[8].

J. Paya et.al. in 2000 studied ñMechanical treatment of fly ashes ñand have investigating curing temperature increase yielded an important increase in compressive strength for fly ash replacing percentages from 15% to 60%.optimum compressive strength values for T60 fly ash mortars have been obtained for lower curing temperatures that low contain of fly ash (T0)fly ash mortars, indicating, again, the higher reactivity of GFA(Ground Fly Ash) from pozzolonic activity point of view. Optimum flexural strength (Rf) values were obtained for 30% fly ash replacing percentage, finding highest Rf values for GFA mortars cured at 80°C; whereas T0 mortars showed highest Rf values cured at 60°C [6].

P. Chindaprasirt et.al. in 2004 Studied ñInfluence of fly ash fineness on strength, drying shrinkage and sulfate resistance of blended cement mortarò and said that different fineness portions of fly ash appear to have a slight but consistent variation in physical and chemical properties consistent with other findings and also indicated that the fly ash with different fineness had a marked effect on the compressive strength as well as drying shrinkage and sulfate resistance. The incorporation of the fine fly ash reduced the water requirement of the mortar mixes. The coarse fly ash portion, lacking both the medium and the fine portions, on the contrary increased the water demand owing to the rougher surface of the coarser particles. The fine fly ash with high surface area was more reactive and thus resulted in the increase in strength. The fine fly ash also required less water owing to its spherical shape and smooth surface. Its packing or filling of the voids helped increase the compressive strength of the mortar [7].

Cengiz Duran Atis et.al.2003 studied ñStrength and shrinkage properties of mortar containing a nonstandard high-calcium fly ashò and said that Afsin-Elbistan FA(Fly Ash) developed satisfactory compressive and flexural tensile strengths 1 day after casting. In addition, FA mortar samples of 10% and 20% FA as cement replacement developed comparable strength with PC mortar at 28 days. Furthermore, the drying shrinkages of FA mortar samples were reduced about 30ï 40% when compared with PC mortar. The mortar samples containing 40% FA expanded instead of shrinking. Based on the strength and shrinkage measurement results, it was concluded that the nonstandard Afsin-Elbistan FA could be utilized in cement-based materials as mineral additive, particularly in concrete pavement, large industrial concrete floors, parking lot applications or rock bolt applications of rock engineering where shrinkage should be avoided. Based on expansive property of present FA, it may also be concluded that the FA may be utilized as cement reducing agent or in production of a shrinkage compensating cement. Howe1ver, further studies are needed to investigate long-term properties of the mortars produced before using the Afsin-Elbistan FA as a mineral additive or in production of a shrinkage compensating cement [1].

Gengying Li at.al, in 2004 studied ñInfluence of fly ash and its mean particle size on certain engineering properties of cement composite mortarsò and said that fluidity of mortars indicates that the workability of mortars will be enhanced due to the incorporating fly ash, especially incorporating ultra-fine fly ash. The mean PD (Particle Distribution) of fly ash will significantly influence the flow of mortars, as the mean PD increases, the flow decreases down to certain value and then gradually increases. The highest flow is obtained at a mean PD of 2.8 Am; and the lowest flow is reached at a mean PD of about 9F3 Am. Both the bond strength and the compressive strength results show that the strength development is significantly affected by the replacement with fly ash. Based on the results of this investigation, it can be concluded that replacing cement and lime with fly ash will significantly improve the long-term strength of well cured mortars. The results presented in this paper show that although the mortars with coarse fly ash contents might need a longer period of time to reach their ultimate strength, this strength could be higher than the ultimate strength that can be achieved using only cement and lime. The mixing coarse fly ash with fine and ultra-fine fly ash can significantly increase the later-age strength and does not significantly decrease the early-term strength of mortars. At the same time, the mortars with coarse fly ash contents have the highest strength gain and the control has the lowest strength gain. Both the bond strength and the compressive strength were affected by the mean PD of fly ash, the strength decreases as the mean PD increases, especially at the age of 28, 56 and 120 days. Fly ash and its mean size show higher influence on the bond strength than on the compressive strength [4].

Izhar Ahmed et.al. in 2012 studied ñEffects of Fly Ash on Properties of Concrete as per IS: 10262-2009ò and said that Fly ash based concrete mix shows better results of workability as compare to reference concrete. For all W/C ratio considered and percentage replacement of fly ash by OPC, compressive strength increases tremendously from 7 to 56 days. Relationships between water-cementitious material ratio and 28-day compressive strength of concrete containing fly ash are almost same as reference concrete. 56 days compressive strength of concrete containing fly ash shows much better results than reference mix. Concrete containing 10 % replacement of fly ash by weight of cement gives better results than 5 % and 15 % replacement. To achieve desired workability, water content for w/c ratio of 0.4 and 0.5 can be selected. W/C ratio can be selected from the relationship between water cement ratio and 28 days compressive strength of concrete [5].

3.Materials

3.1 Fly Ash

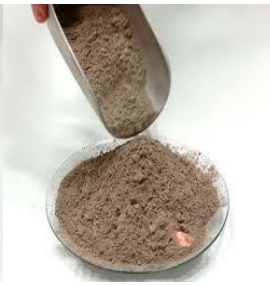
Two types of fly ash are commonly used in concrete: Class C and Class F. Class C are often high-calcium fly ashes with carbon content less than 2%; whereas, Class F are generally low-calcium fly ashes with carbon contents less than 5% but sometimes as high as 10%. In general, Class C ashes are produced from burning sub-bituminous or lignite coals and Class F ashes bituminous or anthracite coals. Performance properties between Class C and F ashes vary depending on the chemical and physical properties of the ash and how the ash interacts with cement in the concrete. Class F fly ash possess only pozzolonic properties whereas class C fly ash possess both cementitious and pozzolonic properties.

Many Class C ashes when exposed to water will react and become hard just like cement, but not Class F ashes.

Most, if not all, Class F ashes will only react with the byproducts formed when cement reacts with water.

The fly ash classified by their grinding particle it also known fly ash Blaine fineness of fly ash is divided into 40F(4125cm2/g), 60F(6686cm2/g), and 90F(9632cm2/g) which used in replacing of cement with 15, 30 , 45 and 60% by binder mass.

Class C



Class F

3.2 Ash Production and Its Availability

Coal is a major source of fuel for production of electricity in many countries in the world. In the process of electricity generation large quantity of fly ash get produced and becomes available as a byproduct of coal-based power stations. It is a fine powder resulting from the combustion of powdered coal - transported by the flue gases of the boiler and collected in the Electrostatic Precipitators (ESP). The bottom fly ash which collected in the bottom of boiler furnace. It is comparatively coarse material and contains higher unburnt carbon. It possesses zero or little pozzolonic property andfly ash. Bottom ash or both mixed together in any proportion with the large quantity of water to make it in slurry form and deposited in ponds where in water gets drained away. The deposited ash is called as pond ash. Fly ash and bottom ash or both mixed in any proportion and deposited in dry form in the shape of a mound is termed as mound ash is also called pulverized fuel ash as per IS 3812(part 1).

Conversion of waste into a resource material is an

age-old practice of civilization. Any country's economic & industrial growth depends on the availability of power. In India also, coal is a major source of fuel for power generation. About 60% power is produced using coal as fuel. Indian coal is having low calorific value (3000-3500 K cal.) & very high ash content (30-45%) resulting in huge quantity of ash is generated in the coal based thermal power stations. During 2005-06 about 112 million tonne of ash has been generated in 125 such power stations. With the present growth in power sector, it is expected that ash generation will reach to 175 million tonne per annum by 2012.

Table No1: Chemical Requirement for Indian Fly Ash (IS 3812:1981)

Sr. No.	Compound characteristic (%) by mass	Requirement
1.	Silicon dioxide (SiO_2) plus Aluminium oxide (Al_2O_3) plus iron oxide (Fe_2O_3) minimum	70.0
2.	Silicon dioxide(SiO_2) minimum	35.0
3.	Magnesium oxide (MgO) maximum	5.0
4.	Total Sulphur as Sulphur trioxide (SO_3) maximum	2.75
5.	Alkalis in term of sodium oxide (Na_2O) maximum	1.5
6.	Loss on ignition maximum	12

Fly ash produced in modern power stations of India is of good quality as it contains low Sulphur & very low unburnt carbon i.e. less loss on ignition. In order to make fly ash available for various applications, most of the new thermal power stations have set up dry fly ash evacuation & storage system. In this system fly ash from Electrostatic Precipitators (ESP) is evacuated through pneumatic system and stored in silos. From silos, it can be loaded in open truck/ closed tankers or can be bagged through suitable bagging machine. In the ESP, there are 6 to 8 fields (rows) depending on the design of ESP. The field at the boiler end is called as first field & counted subsequently 2, 3 onwards. The field at chimney end is called as last field. The coarse particles of fly ash are collected in first fields of ESP. The fineness of fly ash particles increases in subsequent fields of

ESP.

Table No2: The Breakdown of This Capacity State Wise and Approximate Fly Ash Generation

State	**Installed Capacity (MW)**	**Approx. Fly ash Generation usable for**
	Sector	

					Cement /RMC per Year (in tons)
	Central	**State**	**Private**	**Total**	**Total**
Andhra Pradesh	4600.00	5.092.50	450.00	10142.50	14244300.00
Bihar	2340.00	440.00	0.00	2780.00	3906000.00
Chhattisgarh	4920.00	1780.00	1483.00	8183.00	11970000.00
Delhi	705.00	382.50	0.00	1087.50	1575000
Gujarat	0.00	3970.00	632.00	10290.00	11346300
Haryana	1000.00	3270.00	660.00	4930.00	7408800
Jharkhand	2020.00	1260.00	1410.00	4690.00	5537700
Karnataka	0.00	2720.00	2060.00	4780.00	7056000
Madhya Pradesh	3260.00	2982.00	0.00	6242.50	7812000
Maharashtra	0.00	8742.50	2486.00	11228.50	16695000
Odisha	3460.00	420.00	1800.00	5680.00	8379000
Punjab	0.00	2620.00	0.00	2620.00	3906000
Rajasthan	250.00	3490.00	540.00	4280.00	4851000
Tamil Nadu	3240.00	2970.00	250.00	6460.00	5481000
Uttar Pradesh	731.00	4642.00	2805.00	14757.00	22465800
West Bengal	5790.00	5031.00	1260.00	12081.00	17917200
Total	**38895.00**	**49813.00**	**21524.00**	110232.00	**150,551,100**

i.3 Chemical Composition of Concrete with Fly Ash

Ordinary Portland Cement (OPC) is a product of four principal mineralogical phases. These phases are Tricalcium Silicate-C3S (3CaO.SiO2), Dicalcium Silicate C2S (2CaO.SiO2), Tricalcium Aluminate- C3A (3CaO. Al2O3) and Tetracalcium alumino-ferrite ï C4AF (4CaO. Al2O3 Fe2O3). The setting and hardening of the OPC takes place as a result of reaction between these principal compounds and water. The reaction between these compounds and water are shown as under

2C2S + 6H → C3S2H3 + 3CH
Tricalcium water C-S-H gel calcium Hydroxide

2C2S + 4H → C3 S2 H3 + CH
Tricalcium water C-S-H gel calcium Hydroxide

The hydration products from C3S and C2S are similar but quantity of calcium Hydroxide (lime) released is higher inC3Sas compared toC2S.

The reaction of C A with water takes place in presence of sulphate ions supplied by dissolution of gypsum present in OPC. This reaction is very fast and is shown as under

C3A + 3 (CSH2) + 26 H → C3 A (CS)3 H32
Tricalcium gypsum water ettringite Aluminate

C3A + 3 (CSH2) +10 H → C3 ACSH12
Tricalcium gypsum water monosulphoaluminate
Aluminate hydrate

The comparing chemical compound of class F fly ash and Portland cement in mention in Table No.3

Table No 3: Typical chemical compound in pozzolanic class F and Portland cement

Chemical Compound	Class F fly ash	Cement
SiO	54.90	2.60
Al_2O_3	25.80	4.30
Fe_2O_3	6.90	2.40
CaO	8.70	64.40
MgO	1.80	2.10
SO_2	0.60	2.30
Na_2O	0.60	0.60
K_2O	0.60	0.60

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Physical Properties

The fly ash particles are generally glassy, solid or hollow and spherical in shape. The hollow spherical particles are called as cenospheres. The fineness of individual fly ash particle rage from 1 micron to 1 mm size. The fineness of fly ash particles has a significant influence on its performance in cement concrete. The fineness of particles is measured by measuring specific surface area of fly ash by

Blaine's specific area technique. Greater the surface area more will be the fineness of fly ash. The other method used for measuring fineness of fly ash is dry and wet sieving. The specific gravity of fly ash varies over a wide range of 1.9 to 2.55. The physical properties of fly ash various location in India mention in Table No.4.

Table No4: Physical properties of Fly ash (India)

TPP	Specific gravity g/cc	Specific surface area (cm^2/g)	Lime reactivity (MPa)	Soundness Lechatelier's Method (mm)
Chandrapur	2.1	3065	5.7	4
Badarpur	2.0	3675	6.5	4
Tuticorin	2.0	3270	6.0	4
Simhadri	2.1	3449	7.4	3
Singrauli	2.0	3334	7.2	3
IS 3812 (Part – I) requirement	NS	3200	4.5	NS

1. **Utilization of Fly Ash**

6.1 High Volume Fly Ash Concrete (HVFAC)

Presently cement can be replaced upto 35% by fly ash as per Indian Standard in concrete but research from CANMET and similar institutions has shown that fly ash up to 50% can be used in structural grade concrete without affecting its mechanical and durability characteristics. Rather the long term strength, impermeability, impact resistance, resistance to acids is better of HVFAC. The appropriate promotional strategies and proper codal support can help to increase volume of HVFAC especially for heavy foundations, retaining walls, mass concreting works in irrigation and marine structures

6.2 Self-Compacting Concrete

Self-Compacting Concrete (SCC) has many applications and is emerging as a preferred construction material. Apart from cement, large quantity of fly ash to the extent of 200 to 300 kg/m3 of concrete can be used in SCC. The promotion of SCC would also increase utilization of fly ash.

6.3 Geo-Polymer Concrete

Fly ash can be activated with alkalies at suitable temperature for production of geo-polymer concrete. This type of concrete can utilize up to 90% to 95% fly ash as cementitious material and is reported to be in use in countries like Australia and New Zealand. In certain applications like precast elements use of geo-polymer concrete can not only increase utilization of fly ash and long term durability and appreciable economy.

6.4 Controlled Low Strength Material (CLSM)

CLSM is a low strength cementitious material which is widely used in USA, Canada and other countries as back fill material in utility trenches, bedding under pavements and filling abandoned underground structures. CLSM has compressive strength typically in the range of 1.2 to 2 MPa with cement content varying 25 kg to 75 kg/m3. The low strength of CLSM allows its re-excavation by normal means whenever needed in future. CLSM is composed of water, cement, fly ash and in some cases 10mm down aggregates. CLSM may utilize large quantity of fly ash varying from 800 to 1000kg/m3.

In India even the utility trenches are backfilled by soil, which is not properly compacted and settles down under load resulting in uneven road shoulders. It is very inconvenient to the pedestrians and road traffic and poses serious traffic hazard. The use of CLSM on large scale will help in increasing the use of fly ash and to create more durable and safe road infrastructure.

6.5 Roller Compacted Concrete (RCC)

Roller compacted concrete as concrete compacted by roller compaction. The concrete mixture in its unhardened state must support a roller while being compacted. In RCC cement consumption is lower because much leaner mix can be used. Mineral admixture like fly ash is used widely in RCC in large quantity as part replacement of cement and part replacement of fine aggregate.

RCC can be used for construction of dams, spillways, sub-base

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for highways and other mass concrete works. Recently large quantity of RCC has been used 6, 50,000 m3 in 12 months at Ghatghar dam in Maharashtra which was placed with belt conveyor delivering 400m3/hr. RCC is also being used for construction of sub-base on National Highway. However, there is large scope for use of RCC in various Civil Engineering works.

6.6 Fly Ash Brick

The share of fly ash based bricks /blocks are estimated about 12%. The balance is either clay bricks or cement concrete so it reduce the amount of clay in blocks. It mandatory that within 100 km radius of thermal power plant, in all types of construction works fly ash bricks (fly ash content 25% min) will be used.

6.7 Fly Ash Replacement of Sand

In view of shortage of good quality sand and environment concerns on its extracting from rivers, fly ash offers a viable alternative to part replace sand to the extent that grading remains within the provisions of IS 383: 1970, Code of practice for coarse and fine aggregates for concrete. Fly ash can replace 15% to 25% sand depending upon fineness modulus of sand for majority of concrete works. This concept is required to be promoted especially amongst the RMC producers and at major project sites.

6.8 Construction of Embankment

Fly ash can be effectively used in construction of embankments for Highways, flood control works, dykes and for other similar works. Large quantity of fly ash was used in construction of embankment for Noida-Greater Noida Express Way and its performance is reported quite satisfactory.

National Highways and other road projects have started using large quantity of fly ash for this purpose. Eastern parts of India are prone to floods and fly ash can be effectively used for construction of barriers against flood water and prevention of coastal erosion works.

6.8 Light Weight aggregates (LWA):

LWA is used in many European countries as part replacement of natural coarse aggregate to produce concrete of structural grade in density range of 1800-2000 kg/m3. LWA is also used in manufacture of bricks/blocks for wall construction. It is also used for insulation purposes to utilize appreciable quantity of pond and fly ash.

In India it has not yet become popular due to lack of appropriate production technology and project financial viability. However, more research and field work may help in developing appropriate technology to reduce cost of plant and LWA. However, LWA holds very promising future for use in various applications.

2. Environmental Benefits

Use of fly ash in concrete imparts several environmental benefits and thus it is eco- friendly. It saves the cement requirement for the same strength thus saving of raw materials such as limestone, coal etc. required for manufacture of cement. Manufacture of cement is high-energy intensive industry. In the manufacturing of one tonne of cement, about 1 tonne of CO2 is emitted and goes to atmosphere. Less requirement of cement means less emission of result in reduction in greenhouse gas emission. Due to low calorific value and high ash content in Indian Coal, thermal power plants in India, are producing huge quantity of fly ash. This huge quantity is being stored / disposed of in ash pond areas. The ash ponds acquire large areas of agricultural land. Use of fly ash reduces area requirement for pond, thus saving of good agricultural land.

2. Conclusions

The fly ash has pozzolanic as well as cementious properties but these properties are observed only in class C whereas class F has only pozzolanic properties. So, it reacts when the cementious material added to this and reaction takes place in presence of water. Chemical content in fly ash is similar to content of cement but content of CaO is 64.40 in cement and 8.70 in fly ash class F.Addition fly ash causes reduction in heat of hydration and thus reduction of thermal cracks also improves soundness of concrete mass.It also improves workability/pumpabilty of concrete.It converts released lime from hydration of OPC into additional bindingMaterial ï contributing additional strength to concrete mass. It improves impermeability of concrete mass, increases resistance againstingress of moisture and harmful gases result in increased durability. Requirement of cementis reduced for same strength thus reduced cost ofConcrete.

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