International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

A Review on Replacement of Cement by Fly Ash in Concrete Mix Design

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ABSTRACT

Fly ash is a residue left after burning of coal in thermal power stations and need suitable disposal system so that it does not become hazardous and injurious to human life and environment. Besides the use of fly ash as partial replacement material, its use as aggregate in concrete can pave the way for large scale use of fine aggregate. Most of the previous research works were done by using conventional fine and coarse aggregates in concrete. In this research work, the fine and coarse aggregates were completely replaced by fly ash aggregates in concrete.

Fly ash is the common and well-known alternative material, which can be used for making concrete in construction. Fly ash is a by-product of coal combustion, and it is combination of fine particles from the boiler with fuel gases. These are the substitute material for the portland cement. Fly ash is improving the workability of concrete and applicable for concrete structures and also for the brickworks, wall constructions etc., Quarry dust is another building material, which generated from finely crushed rock. It can be used as a fine aggregate in concrete. The ingredients of concrete may partially replaced with fly ash and quarry dust using some determined quantity. The previous research outcome shows that if fly ash and quarry dust.

are used to partially replace the concrete materials maximum of 50%, it improves the strength of the concrete and also this is one of the ways to reduce the problems in construction due to lack of raw materials.

Mix design was done for M20 grade of concrete by IS method. The design of fly ash aggregate concrete mix based on the extensive experimental investigations at the Building

Research Station UK was followed to design the mix proportions for fly ash aggregate concrete. Ordinary Portland cement of 43 grade was selected and fly ash aggregates were prepared by mixing fly ash with 43 grade cement. The fly ash aggregates were sieved and the aggregates having size less than 4.75mm were taken as fly ash fine aggregate and above 4.75mm to 20mm were taken as fly ash coarse aggregate. 20mm size fly ash aggregates were sieved separately and used as fly ash coarse aggregate for the experimental work.

The properties of fly ash fine aggregates and fly ash coarse aggregates were determined. The aggregate crushing value and aggregate impact value of fly ash coarse aggregates were also determined.

The compressive strength of concrete specimens for different mix proportions were tested at 7 and 28 days of water curing. the compaction factor was taken from the measurement of workability. Considering the different rate and strength as parameters a comparative study has been conducted. By replacing different proportions of cement with Fly Ash, the compressive strength of cement has been checked and the results have been found effective and applicable. This paper analyses vividly the effects of Fly Ash as partial

replacement of cement in concrete and to ascertain the use of optimum quantity of Fly Ash for different qualities of concrete which will be acceptable, applicable and economical. The behaviour of concrete by partial replacement of cement with fly ash has been studied.

KEYWORDS: Fly-ash, Additive, Admixture, Ordinary Portland cement (OPC), Partial replacement, pozzolona Portland cement, high – performance beam, cyclic loading

INREODUCTION:

Concrete is a composite material consisting of coarse and fine aggregate which bonded with cement. In concrete, the Portland cement is the most common material in making of concrete. The requirements of construction materials are escalating and so that the demand and cost for cement and other raw materials are increasing day by day. To overcome these issues in construction the usage of alternative construction materials in construction fields is highly preferred and suggested.

Fly ash is the common and well-known alternative material, which can be used for making concrete in construction. Fly ash is a by-product of coal combustion, and it is combination of fine particles from the boiler with fuel gases. These are the substitute material for the portland cement. Fly ash is improving the workability of concrete and applicable for concrete structures and also for the brickworks, wall constructions etc., Quarry dust is another building material, which generated from finely crushed rock. It can be used as a fine aggregate in concrete. The ingredients of concrete may partially replaced with fly ash and quarry dust using some determined quantity. The previous research outcome shows that if fly ash and quarry dust are used to partially replace the concrete materials maximum of 50%, it improves the strength of the concrete and also this is one of the ways to reduce the problems in construction due to lack of raw materials.

Hence, in this research, the fly ash (class F) and quarry dust have been considered as an alternative for cement and fine aggregate, respectively. This study aims to examine the effect of replacing both cement and fine aggregate with fly ash (20%, 30%, 40% and 50%), quarry dust (20%, 30%, 40% and 50%) in various predetermined proportions. The structural properties like compressive, split tensile and flexural strength of hardened concretes were determined and compared with controlled concrete with proper design mix at 28 days curing. In addition, concrete specimens added with the fly ash and quarry dust were cured in various types of chemical solutions to determine the durability and loss of percentages of properties.

Concrete is the most widely used construction material in the world. There is a concern to more understanding and to improve its properties. Using waste and recycled materials in concrete mixes becoming increasingly important to manage and treat both the solid waste generated by industry and municipal waste. And fly ash is one of the waste material Fly Ash is produced by coal-fired power plants. Typically, coal is pulverized and mixed with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber, while the lighter fine ash particles, termed fly ash, remain suspended in the flue gas. Prior to exhausting the flue gas, fly ash is removed by particulate emission control devices, such as electrostatic precipitators or filter fabric baghouses. In the present era of growth and development, progress is taking place in all the fields. But, in the light of progress, man is ignoring nature and harming it. Construction area, with the use of virgin materials like cement, is also posing the threat of global warming and environmental degradation. The

challenge in front of civil engineering community is to provide sufficient, economical and comfortable infrastructure without causing any hardship for environment.

Also, the high strength reinforced concrete beam was tested under cyclic loading condition and also the residual strength and stiffness degradation factors for RC beam was found out in the specimens casted using fly ash and quarry dust. Finally, based on the obtained results, interpolated the suitable proportion of mix which gave more durability and structural strength to the concrete by satisfying the standard requirements of fresh and hard concrete as per IS standards.

LITERATURE REVIEW

LIGHT WEIGHT CONCRETE

An exhaustive research has been carried out to study the various properties of light weight concrete Serkan Subasi (2009) investigated the effect of using fly ash in high strength light weight aggregate concrete produced with expanded clay aggregate on physical and mechanical properties of the concrete. The cement content with 450 Kg/m3 among concrete mixtures produced high strength value and the mechanical properties could be enhanced by using 10% fly ash. A saving in cement content and cost could be achieved.

An experimental study was carried out by Nusret Bozkurt et al (2010) to investigate the influence of addition of pozzolanic materials and curing regions on the mechanical properties and the capillary water absorption (Sorptivity) characteristics of light weight concrete. The results showed a good correlation between the strength development of concrete and its sorptivity. As the compressive and tensile strength increased due to the hydration, the sorptivity coefficients decreased significantly.

Hjh Kamsiah Mohd.Ismail et al (1999) have studied the behaviour of light weight concrete and performance of aerated light weight concrete such as Compressive strength tests, water absorption and density and coMParisons made with other types of light weight concrete.

Celik Ozyildirim (2009) has studied the durability of structural light weight concrete which includes the physical and chemical aspects of durability, the effect of cracking and resistance of light weight aggregates to freezing and thawing.

Emre Sancak et al (2008) have investigated structural light weight concrete produced by Pumice and concrete with normal light weight aggregate. Compressive strength and weight loss of the concrete were determined after being exposed to high temperatures. They replaced the Portland cement by silica fume in different ratio and added super plasticizer. They observed the rate of deterioration was higher in normal weight concrete when coMPared to light weight concrete.

Chen et al (1999) have reported that concrete is considered to be a composite material consisting of mortar and coarse aggregate and its strength depends on the mortar strength and coarse aggregate strength. During the strength development stage of light weight aggregate concrete, a critical condition under which the type of stress distribution changes occurs as the values of the modulus of elasticity of the light weight aggregate and mortar become the same. The concrete strength corresponding to this instant is named “Dividing Strength”. The concept of a dividing strength can be utilized to optimize a mix design for light weight aggregate concrete.

LIGHT WEIGHT AGGREGATE

Rajamane et al (2004) have reported that it is possible to produce coarse aggregates from fly ash by pelletisation techniques for use in structural grade concrete. They also studied the properties like bulk density, specific gravity, water absorption and aggregate crushing value. The concrete made with the

bonded fly ash coarse aggregate has high slump, low density and also to produce minimum structural grade concrete as recommended in IS 456- 2000.The permeability indicating tests such as sorptivity, rate of water absorption, rapid chloride permeability test, etc. indicate satisfactory durability characteristics.

Ramamoorthy (2006) discussed on light weight concrete and light weight aggregate concrete and its classification. It is also reported on properties of various light weight aggregate concrete. It is also discussed on proportioning of light weight aggregate concrete by weight method.

Carlos Videla et al (2001) reported in his experimental work that fly ash agglomeration by agitation methods by disc pelletizer is a simple and effective process of manufacturing aggregates. Paste mixtures agglomerated using cement binders show five times smaller setting times values them mixtures agglomerated with lime. The aggregates manufactured with 5% weight of Portland pozzolanic cement possess the greatest viability for use at full-scale production**.**

An investigation was made **by Pantawee et al (2008)** on the use of natural pozzolanic diatomaceous and perlite to replace sand and cement at various percentages by mass of binder. They formed that the mortar containing diatomaceous replacing Portland cement effectively increased the compressive strength better than replacing sand. They also found the optimum content of perlite that contributed to the highest compressive strength.

Jongsung Sim et al (2011) have investigated the fundamental characteristics of concrete using recycled concrete aggregate. They replaced cement by fly ash and fine and coarse aggregates by recycled aggregates. They observed that compressive strength of mortar add concrete which used recycled aggregates generally decreased as the amount of the recycled materials increased. The recycled aggregate concrete achieved sufficient resistance to the chloride in penetration and carbonation resistance.

STRENGTH AND DURABILITY OF FLY ASH AGGREGATE CONCRETE

Rajamane et al (2004) have reported that it is possible to produce coarse aggregates from fly ash by pelletisation techniques for use in structural grade concrete. They also studied the properties like bulk density, specific gravity, water absorption and aggregate crushing value. The concrete made with the bonded fly ash coarse aggregate has high slump, low density and also to produce minimum structural grade concrete as recommended in IS 456-2000.The permeability indicating tests such as sorptivity, rate of water absorption, rapid chloride permeability test etc. indicate satisfactory durability characteristics.

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Iyer and Scott (2001) reported that the disposal of fly ash from coal-fired power stations causes significant economic and environment problems. A relatively small percentage of the material finds application as an ingredient in cement and other construction products, but the vast majority of material generated each year is held in ash dams or similar dumps. Alternative uses for fly ash as a value added product beyond incorporation in construction materials are needed. Utilization of fly ash in such areas as novel materials, waste management, recovery of metals and agriculture is reviewed in this article with the aim of looking at new areas that will expand the positive reuse of fly ash, thereby helping to reduce the environmental and economic iMPacts of disposal.

Pantawee et al (2008) have investigated the use of natural pozzolanic diatomaceous and perlite to replace

sand and cement at various percentages by mass of binder. They formed that the mortar containing diatomaceous replacing Portland cement effectively increased the compressive strength better than replacing sand. They also found the optimum content of perlite that contributed to the highest compressive strength. The mechanical properties of ceramic microspheres known as cenospheres as primary aggregate have been studied **by McBride et al (2002).**

They found that the addition of high volumes of cenospheres significantly lowered the density of concrete some loss in strength. The losses in strength are recovered by improving the interfacial strength between the cenospheres and the cement. They also used the admixture silica fume and the coupling agent silica fume. They found the improvement in mechanical properties and fracture toughness by the addition of silica fume.

MATERIALS AND METHODS

MATERIALS

The materials such as cement, fine aggregate, coarse aggregate, water, fly ash and fly ash aggregates were used in the present work. The methodology adopted for the formation of fly ash aggregates is also presented in this chapter. **Cement**

Ordinary Portland Cement of 43 grade confirming to IS: 8112-1989 was used for the present experimental investigation. Its specific gravity is 3.15. The cement was tested as per the procedure given in Indian Standards

Fine Aggregate

Natural river sand with fraction passing through 4.74 mm sieve and retained on 600µ sieve was used and tested as per IS:2386. The fineness modulus of sand is 2.68 with a specific gravity of 2.66.

Coarse Aggregate

Hard broken granite stone (HBG) coarse aggregates confirming to graded aggregate of size 20 mm as per IS:383-1970. Its specific gravity is 2.71. The coarse aggregates were tested as per the procedure given in IS: 2386-1963.

Water

Potable tap water available in the laboratory with pH value of 7.0 ± 1 and confirming to the requirements of IS: 456-2000 was used for mixing concrete and curing the specimens as well.

Fly Ash Fly ash (Class F) obtained from Mettur Thermal Power Station (MTPS) was used in the experimental work.

Formation of fly ash aggregates

The constituents like cement, fly ash and water produce the fly ash aggregates. Water is the binding material that paves the way for the function of the aggregate with good bonding (Khaled Ramadan et al 2007).

Proportions for fly ash aggregates Cement and fly ash are constituents for preparation of the aggregates. Also water is the binder which is added to increase the workability. Six different proportions of cement and fly ash such as 10:90, 12.5:87.5, 15:85, 17.5:82.5, 20:80 and 22.5:77.5 were tried. (Somnuk Tang Term Sirkal et al 2000).

Preparation of fly ash aggregates

Cement and fly ash were mixed in above six proportions in a concrete mixer. Water was added to the mix by adopting the water cement ratio of 0.3. The contents were thoroughly mixed in the drum until the

complete formation of fly ash aggregates. This method of formation of fly ash aggregates is called pelletisation. The fly ash aggregates are shown in Figure 3.1.

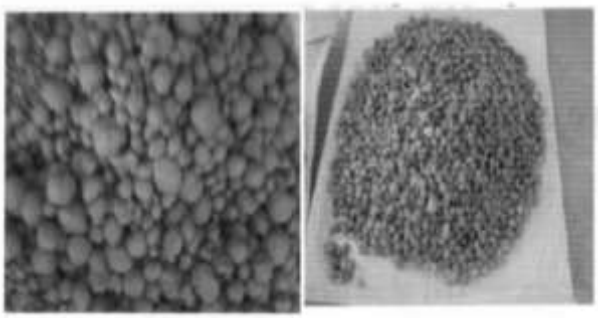

Figure 3.1 Fly Ash Aggregates

Drying and curing of fly ash aggregates

The fly ash aggregates were taken out from the mixer and allowed to dry for a day. Then the aggregates were cured in a water tank for 7 days.

Segregation of fly ash aggregates

After curing, they were segregated into fine and coarse aggregates based on size of pellets as shown in Figure 3.2. The aggregates having size less than 4.75 mm were sieved as fine aggregates and size more than 4.75 mm were sieved as coarse aggregate. From them 20 mm size coarse aggregates were sieved separately to use them as coarse aggregates. The physical properties of fly ash fine aggregate (FFA) and fly ash coarse aggregate (FCA) are given in Tables 3.6 and 3.7, respectively. The grading curves for conventional fine aggregate (CFA) and fly ash fine aggregate are shown in Figure 3.3. The grading curves for conventional coarse aggregate (CCA) and fly ash coarse aggregate are shown in Figure 3.4.

Figure 3.2 Segregation of Fly Ash Aggregates

Table 3.6 Physical Properties of Fly Ash Fine Aggregate

S. No	Test Particulars	Results Obtained
1.	Specific gravity	1.28
2.	Bulk density (Kg/m^3)	838
3.	Size (mm)	Below 4.75
4.	Fineness Modulus	2.70

Table 3.7 Physical Properties of Fly Ash Coarse Aggregate

S. No	Test Particulars	Results Obtained
1.	Shape	Spherical
2.	Specific gravity	1.3
3.	Bulk density (Kg/m^3)	913
4.	Size (mm)	4.75 to 20
5.	Crushing value (%)	25.6
6.	IMPact Value (%)	21.6

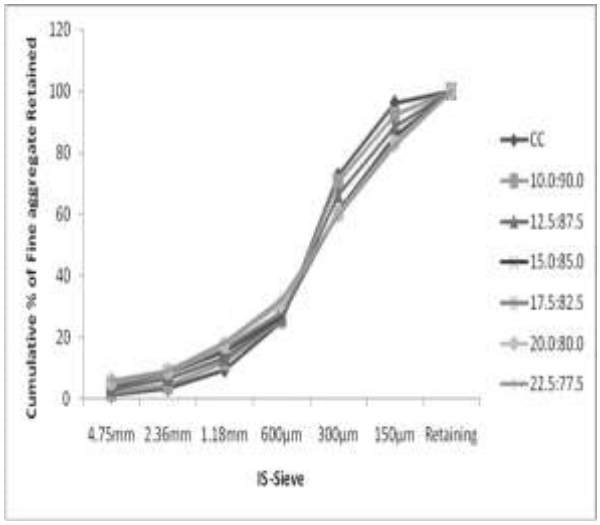

Figure 3.3 Grading Curves for Conventional Fine Aggregate and Fly Ash Fine Aggregate

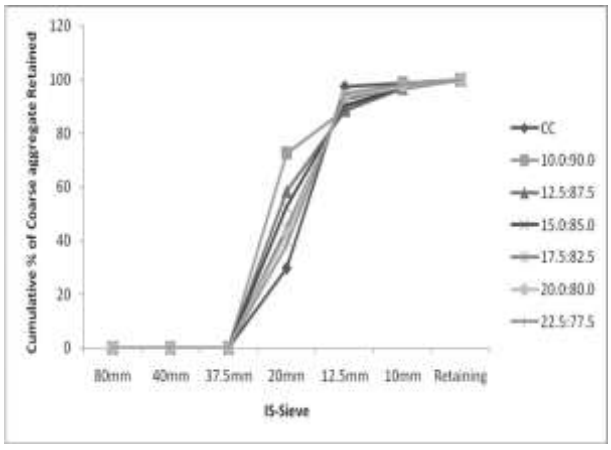

Figure 3.4 Grading Curves for Conventional Coarse Aggregate and Fly Ash Coarse Aggregate

MIX PROPORTIONING

The procedure for mix proportioning is to combine different concrete ingredients based on their properties to obtain the required properties of the fresh as well as the hardened concrete. The properties for the concrete are chosen from the structural design and the requirements of safe and functional structures. The requirements are consistency, workability, compressive strength, density, freeze-thaw resistance, water

permeability, thermal conductivity and service life of the structure (Andrew Short 1963). The stability against segregation of aggregate, insignificant internal water bleeding, homogeneity after transportation and compaction are the requirements which are implicit and expected of good quality concrete.

Mix Proportioning of Control Concrete

Control concrete having 28 days of compressive strength of 20 MPa was developed. The mix design was carried out based on IS 10262 - 1982. The mix design procedure and the mix design are presented in Appendix 1. The mix proportion and quantity of materials taken for one cubic meter are given in Table 3.8.

Mix Proportioning of Fly Ash Aggregate Concrete

The fly ash aggregate concrete mix design was done based on the experimental investigations at the building research station UK which has developed empirical graphs relating the important parameters like type of aggregate, cement content, water/ cement ratio, workability, strength and relative density. The mix design procedure and the mix proportioning of fly ash aggregate concrete are presented in Appendix.

RESULTS AND DISCUSSIONS:

The Mechanical properties such as compressive Strength, split tensile strength and Flexural Strength are presented in this chapter. The durability characteristics such as saturated water absorption, sorptivity, chloride ion penetration, corrosion, acid resistance and carbonation are also included. The relationship between strength and durability characteristics have been presented. The microstructure of fly ash aggregate concrete has been studied. Further the cost aspects of fly ash aggregate concrete have also been discussed.

Compressive Strength The compressive strength results at the different ages such as 1 day, 3 days, 7 days, 14 days. 28 days, 56 days and 90 days are presented in Table 4.1. The development of compressive strength with different ages are shown in the Figure 4.1 to 4.7 Fly ash aggregate concrete with fly ash aggregates obtained from cement fly ash proportions 15:85 showed 15%, 13%, 11%, 15%, 14%, 13% and 8% increase in compressive strength at the ages of 1 day, 3 days, 7 days, 14 days, 28 days, 56 days and 90 days, respectively over the control concrete **(Hjh Kamsiah Mohd.Ismail et al 2006).** Fly ash aggregate concrete with other proportions 10:90, 12.5:87.5, 17.5:82.5, 20:80 and 22.5:77.5 showed reduction in compressive strength at the ages of 1 day, 3 days, 7 days, 14 days, 28 days, 56 days and 90 days, respectively over control concrete. The optimum cement fly ash proportion is 15:85 which yields high compressive strength at all ages when compared to control concrete.

Fly ash aggregate concrete with cement fly ash proportion 15:85 yields higher compressive strength, split tensile strength and flexural strength than control concrete at all ages. This is due to the high pozzolanic nature to form more densely packed C-S-H gel in fly ash aggregate concrete. The elastic modulus is observed high in this proportion when compared to control concrete.

The fly ash aggregate proportion 22.5:77.5 has less saturated water absorption capacity than control concrete. This is due to the pozzolanic reaction and micro-pore filler effect of fly ash which improve the microstructure of concrete mixtures. The sorptivity of fly ash aggregate concrete with cement fly ash proportions 15:85, 17.5:82.5, 20:80 and 22.5:77.5 have less sorptivity when compared to control concrete due to better interlocking bond between the aggregate and the cement paste. All fly ash aggregate concrete with all cement fly ash proportions have more corrosion resistance than control concrete. This is due to high fineness of fly ash which forms cohesive paste and decrease the porosity and permeability. The cement fly ash proportion 15:85 has no resistance to chloride ion penetration than other concrete mixtures.

The fly ash forms a more cohesive paste because of its high fineness. Thus the porosity of the paste is decreased which results in the decrease in chloride ion penetration of the concrete.

All cement fly ash proportions have more acid resistance when compared to control concrete. Due to porous nature of the aggregate, the binder penetrates inside the aggregate which makes the bond much stronger and thus increasing the acid resistance. The carbonation resistance is high in FAAC with cement fly ash proportion 22.5:77.5. The dense matrix of FAAC decreases the permeability. Hence the carbonation depth significantly decreases and carbonation resistance increased in FAAC. High pull out resistances is observed in cement fly ash proportion 15:85.This due to high bond strength between cement paste and steel reinforcement.

There is a significant relationship between strength and durability characteristics of fly ash aggregate concrete. When the compressive strength increases the saturated water absorption and sorptivity decrease. When the corrosion and acid resistance increase, the compressive strength increases. The durability of fly ash aggregate concrete increases due to high fineness of fly ash. The porosity decreases due to cohesive nature of fly ash which results in decrease in saturated water absorption, sorptivity, chloride ion penetration and increase in corrosion resistance and acid resistance of the concrete. The cost of fly ash aggregate concrete with all cement fly ash proportions is significantly reduced when compared to control concrete.

In this paper various research papers are studied related to replacement of cement by fly ash and come to conclusion that:

- compressive strength of concrete increases up to an optimum level with increase level of fly ash and then start decreasing with the addition of fly ash. The optimum limit of mixing of Fly Ash is 45 % and more than that may not be safe for different concrete mixes
- PSC give more strength then PPC.
- Fly ash concrete is more workable and durable then cement concrete.
- Fly ash concrete is eco-friendly and economical.
- Replacement of cement by 15% to 25% by fly ash results in lower porosity of concrete, reduces the voids and cracks formation.
- chemical attacks can be improved by replacing cement with Fly ash up to certain limit.
- slower strength gain at early stages is major problem in making fly ash concrete.
- There is a limit in addition of fly ash content in concrete so that workability is maintained.
- With increase in fly ash content shrinkage of concrete decreases.

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