Study of Strength Characteristics of Fly Ash Aggregates in Light Weight Concrete

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Abstract - Granite aggregate and river sand are the vital elements in concrete and its extensive use results in destruction of hills causing geological and environmental imbalance. The concern about the depletion of natural sources and the effect on environment has particularly focused attention on possibility of using aggregates from waste materials as an alternative to naturally occurring materials. Fly ash is a by-product obtained from coal based thermal power plants. It can be used for making artificial aggregates. In this study, it is an approach is to be made with 100% replacement of the fine aggregates and partial replacement (10%, 20% to 100%) of coarse aggregates by fly ash aggregates. A mix design was done for M_{25} grade concrete by IS method. Fly ash coarse aggregates can be prepared by mixing fly ash with cement and water. The various proportions of cement and fly ash ratio of 10:90, 15:85, 20:80 and 25:75 were tried to get fly ash aggregates. The best proportion is finalized based on the various properties of fly ash coarse aggregates and it is found to be 25:75.The concrete cubes, cylinders and prisms are casted with replacement of fly ash aggregates. The compressive strength, split tensile strength at 28 days are investigated. Test results indicate significant improvement in the strength properties of plain concrete by the inclusion of fly ash aggregates as partial replacement I natural aggregates.

Keywords – Artificial aggregates , Fly ash, Compressive Strength

I.INTRODUCTION

Concrete is the most widely used man – made building material in the World, owing to its versatility and relatively low cost. The increase in demand for the natural ingredients of concrete is met by partially replacing the building materials by the waste materials obtained from various industries as by – product. Aggregate is the main constituent of concrete, occupying more than 70% of the concrete matrix. In order to meet the shortage of availability of natural aggregate, artificially manufactured aggregate and certain industrial by – products can be used as alternatives.

India produces approximately 120 million tones of fly ash annually. Fly ash based artificial lightweight aggregate offer potential for large-scale utilization in the construction industry. Apart from using it in concrete industry as cement replacement, fly ash usages by other related industries have been for cube and prism manufacture, cellular concrete, prefabricated items and road construction. Yet about 75% of fly ash remains unutilized. The management of coal fly ash produced by coal thermal power station is a major problem in many parts of the word. However, its generation tends to increase every year. Although some coal fly ash is used in a range of applications, particularly as a substitute for cement in concrete. Large amount remain unused and thus required disposal. At present, coal fly ash is used in civil engineering for production of cement, concrete, cube and artificial aggregate.

The environmental impacts of crushed stone aggregate, extraction are of increasing concern in many parts of the country. The impacts include loss of forests, noise, dust, blasting vibrations and pollution hazards unplanned exploitation of rocks may lead to landslides of weak and steep hill slopes. Now days due to industrialization there is a scarcity of electricity thought India. In India having 85 thermal power plants are there for generation of electricity. In each thermal plant due to generation of electricity 85 million tones of fly ash coming as residual per annum. Major challenge is complete usage of fly ash as an aggregate in a construction industry. Hence fly ash can be used in making artificial light weight coarse aggregates. The aggregates so prepared are known as Fly ash aggregates.

1.2 LIGHT WEIGHT AGGREGATE CONCRETE

These aggregates can be manufactured in different proportion of fly ash, cement; the aggregate which is thus manufactured is light weight aggregate. Design and construction by this type of concrete containing light weight aggregates are economical; due to the nature that light weight reduces the self weight. It involves initially dry mixing of cement and fly ash by adopting some amount of water to the mix. Mixing of these constituent in a mixer to form aggregates. In conventional concrete, weight of concrete is one of the parameters to compare with weight of fly ash aggregate concrete. Normally density of concrete is in the order of 2200 to 2600 kg/m^3. This heavy self weight makes it as uneconomical structural material compared to low self weight of fly ash aggregate concrete. In order to produce concrete of desired density to suit the required application, the self weight of structural and non structural members are to be reduced. Hence economy is achieved in the design of supporting structural elements which lead to the development of light weight concrete. Lightweight concrete is defined as a concrete that has been made lighter than the conventional concrete by changing material composition or production method. Lightweight aggregate concrete is made by replacing the usual material aggregate by lightweight aggregates. Though lightweight concrete can’t always substitute normal concrete for its strength potential, it has its own advantages like reduced dead load, and thus economic structures and enhanced seismic resistance, high sound absorption and good fire resistance.

1.3 NEED FOR THE USE OF FLY ASH

Ordinary Portland Cement (OPC) is a product of four principal mineralogical phases. These phases are Tricalcium Silicate-C_3S ($3CaO.SiO_2$), Dicalcium Silicate – C_2S ($2CaO.SiO_2$), Tricalcium Aluminate- C_3A ($3CaO.Al_2 O_3$) and Tetracalcium alumino-ferrite – C_4AF($4CaO. Al_2O_3 Fe_2O_3$). 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:

$$\underset{\text{tricalcium silicate}}{2C_3S} + \underset{\text{water}}{6H} \longrightarrow \underset{\text{C-S-H gel}}{C_3S_2H_3} + \underset{\text{Calcium hydroxide}}{3CH}$$

$$\underset{\text{dicalcium silicate}}{2C_2S} + \underset{\text{water}}{4H} \longrightarrow \underset{\text{C-S-H gel}}{C_3 S_2H_3} + \underset{\text{Calcium hydroxide}}{CH}$$

The hydration rods from C_3S and C_2S are similar but quantity of calcium hydroxide (lime) released is higher in C_3S as compared to C_2S. The reaction of C_3A 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:

$$\underset{\text{tricalcium aluminate}}{C_3A} + \underset{\text{gypsum}}{3(CSH_2)} + \underset{\text{water}}{26H} \longrightarrow \underset{\text{ettringite}}{C_3A(CS)_3H_{32}}$$

$$C_3A + CSH_2 + 10H \longrightarrow \underset{\text{Mono sulpho aluminate hydrate}}{C_3ACSH_{12}}$$

Tetracalcium alumino-ferrite forms hydration product similar to those of C_3A, with iron substituting partially for alumina in the crystal structures of ettringite and mono sulpho-aluminate hydrate.

Above reactions indicate that during the hydration process of cement, lime is released out and remains as surplus in the hydrated cement. This leached out surplus lime renders deleterious effect to concrete such as make the concrete porous, give chance to the development of micro- cracks, weakening the bond with aggregates and thus affect the durability of concrete.

If fly ash is available in the mix, this surplus lime becomes the source for pozzolanic reaction with fly ash and forms additional C-S-H gel having similar binding properties in the concrete as those produced by hydration of cement paste. The reaction of fly ash with surplus lime continues as long as lime is present in the pores of liquid cement paste. The process can also be understood as follows:

II. MATERIALS PROPERTIES

The following materials were used for preparing the test specimens

i) Ordinary Portland cement 53 grade confirming to IS: 8112-1989
ii) Fly ash (FA) obtained from Thermal power plant, Mettur confirming to IS: 3812-1981
iii) Local river sand confirming to Grading Zone II of IS: 383- 1970
iv) Fly ash Fine Aggregate (FAFA) obtained from cement fly ash proportions 10:90, 15:85, 20:80, 25:75
v) Hard Broken Granite stone (HBG) confirming to graded aggregate of size 20mm as per IS: 383-1970
vi) Fly ash Coarse Aggregates (FACA) obtained from cement fly ash proportion 10:90, 15:85, 20:80, 25:75
vii) Water

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 bond property. The water cement ratio is 0.3

Proportions for fly ash aggregates

Class F Fly ash is obtained from Mettur thermal power plant Four different proportions of cement and fly ash such as 10:90, 15:85, 20:80 and 25:75 were tried. The physical properties was tested for each ratio and the best results was obtained in 25:75

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. These pellets are taken out and dried in air for 7 days and water cured 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 .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.

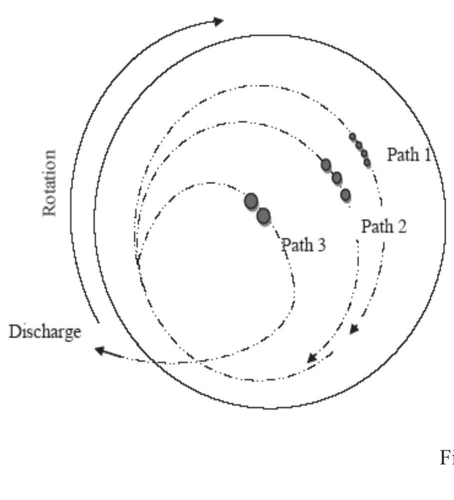


Fig.1 Pelletizing process

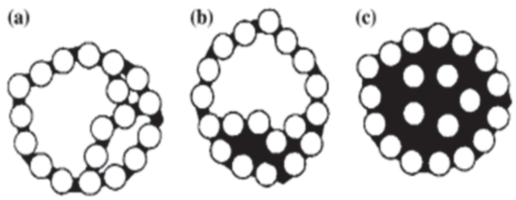


Fig 2 Mechanism of pellets formation

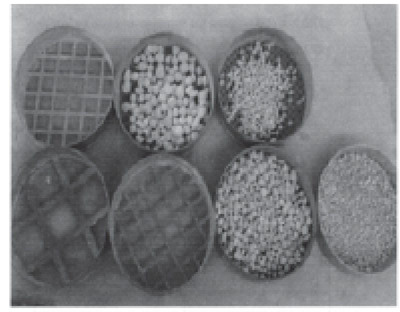


Fig 3 Segregation of fly ash aggregates

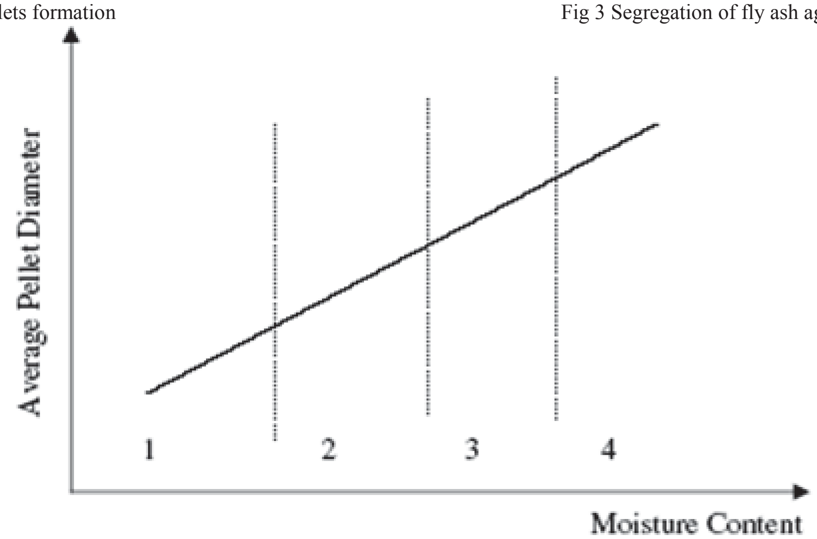


Fig 4 Effect of moisture in pellet formation

Fig 5 Fly ash aggregates and conventional aggregates

Material Properties

Below table shows the chemical composition of Fly Ash (Class F) at Mettur Thermal Power Station (MTPS) Fly ash (Class F) obtained from Mettur Thermal Power Station (MTPS) was used in the experimental work.

Properties of Cement (OPC 53)

Table – 2 Physical Properties of cement

S.No	Properties	Test Results
1	Normal Consistency	26.25%
2	Initial Setting Time	35 mins (>30 min)
3	Final Setting Time	180 mins (< 600 min)
4	Fineness (by Sieve Analysis)	2 %
5	Specific Gravity	3.15 (3-3.25)

Properties of Aggregates

(i) Physical properties of Conventional Fine Aggregate (CFA) and Fly Ash Fine Aggregate (FAFA)

Table-3 Comparison of conventional aggregates with fly ash fine aggregates

PROPERTIES	CONVENTIONAL FINE AGGREGATES	ARTIFICAL FINE AGGREGATES
Specific Gravity	2.563	1.74
Fineness modulus	2.831	2.995
Water absorption (in 1 hr)	8.33%	9.54 %
Bulk density	partial -1445 kg/m^3 full - 1725.9 kg/m^3	partial – 829.424 kg/m^3 full – 1067.04 kg/m^3

(ii) Physical properties of Conventional Coarse Aggregate (CCA) and Fly Ash Coarse Aggregate (FACA)

Table-4 Comparison of conventional aggregates with fly ash coarse aggregates

PROPERTIES	CONVENTIONAL COARSE AGGREGATES	ARTIFICAL COARSE AGGREGATES
Specific Gravity	2.65	1.727
Fineness modulus	7.50	4.2626
Moisture content (in 1 hr)	1.53%	11.84%
Bulk density	partial -1720 kg/m^3 full – 1773.33 kg/m^3	partial -793.854 kg/m^3 full – 924.816 kg/m^3

III. EXPERIMENTAL INVESTIGATION

Mix Proportioning

Mix design for M25 grade concrete was done by using IS method. As per the design, the mix proportion is 1: 1.36:2.41:0.45

Casting of Test Specimens

The concrete Cubes of size 15cm x 15cm x 15cm and cylinders of diameter 15cm and height 30cm were cast by using conventional fine aggregate (CFA) and conventional coarse aggregate (CCA) and using fly fine and coarse aggregates in various proportions. The specimens were demoulded after 1 day and immersed in water for 28 days for curing.

Similarly 3 fly ash concrete cubes and cylinders were casted for each proportions from 0% to 100% in the cement fly ash aggregate ratio 25:75

Fresh concrete properties

Table-5 Comparison of conventional concrete with fly ash aggregate replaced concrete

Type of Concrete	Slump(mm)	Workability
Conventional Concrete	80	Medium
Fly ash aggregate concrete	64	Medium

Hardened Concrete Properties

(i) Compression Test

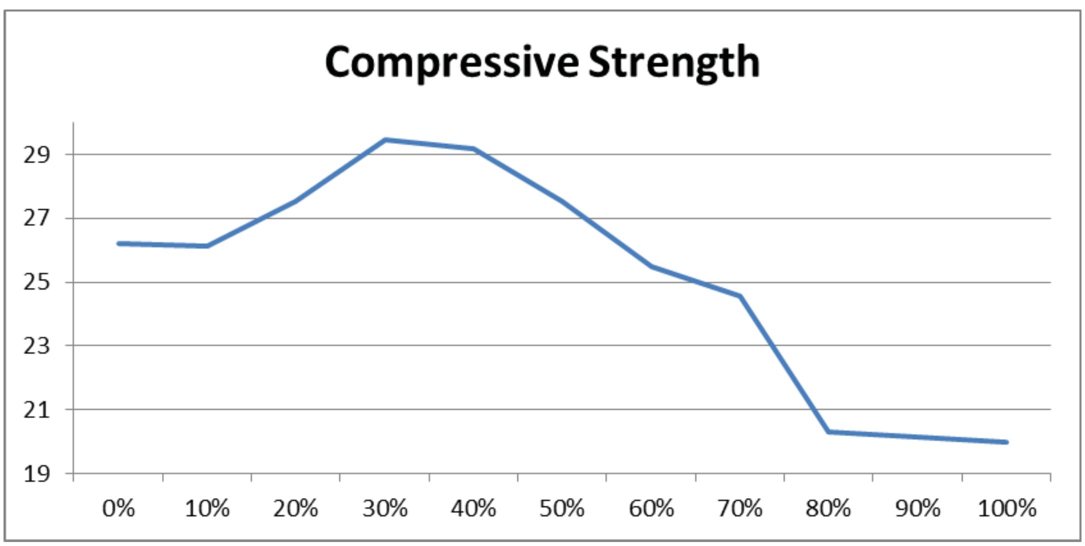
15cm x 15cm x 15cm concrete cubes were tested as per IS 516- 1959. The test was conducted in 120T compression testing machine. The load was applied at the rate approximately 140 $kg/cm^2/min$ until the failure of specimen. The maximum load applied to the specimen until failure was recorded and shown in the table below.

Table -6 Compressive Strength test results of fly ash aggregate concrete

S.No.	Replacement Percentages		Compressive Strength (MPa)
	Fine Aggregates	Coarse Aggregates	
1	0 %	0%	32.8
2	100%	0%	26.22
3	100%	10%	26.13
4	100%	20%	27.52
5	100%	30%	29.48
6	100%	40%	29.20
7	100%	50%	27.52
8	100%	60%	25.49
9	100%	70%	24.57
10	100%	80%	20.31
11	100%	90%	20.15
12	100%	100%	19.98

From test results the 30% coarse and 100% fine aggregate replacement gives better performance. The replacement percentages upto 60% coarse replacement satisfies the minimum target strength of 25MPa.

Compressive Strength (MPa)



Replacement Percentages

Fig 6 Compressive Strength on 28 days curing

Fig 7 Compressive Strength testing

(ii) Split Tension test

Concrete Cylinders of 15cm diameter and 30cm height were tested for split tensile strength as per IS 5816-1976. The specimen was placed horizontally between the loading surfaces for the compression testing machine and the load was applied without shock until the failure of the specimen. The split tensile strength is tabulated below.

Theoretical tensile strength = $0.7 \sqrt{f_{ck}} = 3.5$ N/mm^2

Table -7 Split Tensile Test results of fly ash aggregate concrete

S.No.	Replacement Percentages		Split Tensile Strength (N/mm^2)
	Fine Aggregates	Coarse Aggregates	
1	0 %	0%	3.2
2	100%	0%	2.82
3	100%	10%	2.63
4	100%	20%	2.942
5	100%	30%	3.124
6	100%	40%	3.084
7	100%	50%	2.35
8	100%	60%	2.90
9	100%	70%	1.95
10	100%	80%	2.76
11	100%	90%	2.41
12	100%	100%	2.89

From test results the 30% coarse and 100% fine aggregate replacement gives better strength result and it is close to the tensile strength of conventional concrete.

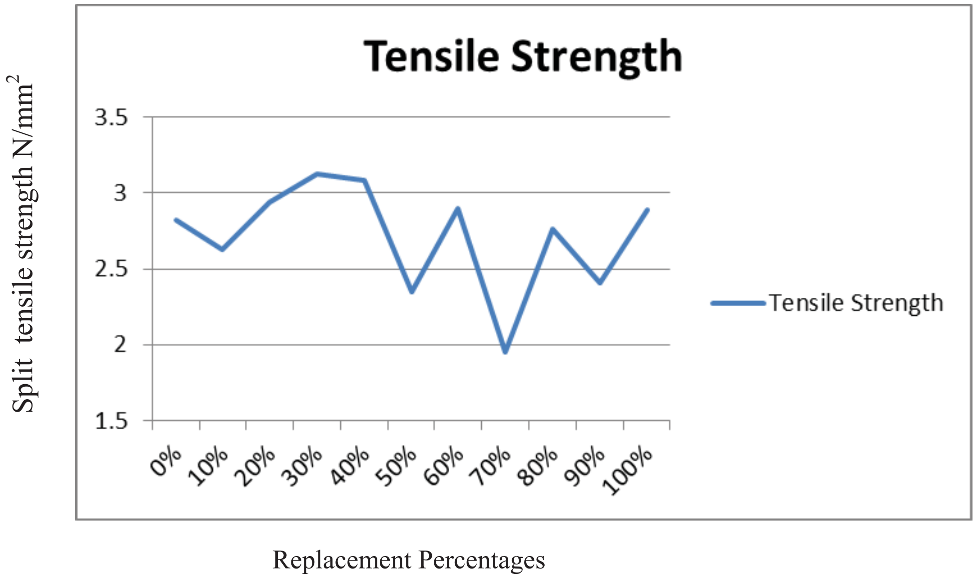


Fig 8 Split Tensile Strength on 28 days curing

Fig 9 Split Tensile Strength Testing

IV. CONCLUSION

From the experimental study, the best cement fly ash ratio for fly ash aggregate production obtained from the testing of physical properties is 25:75. It was found that 30% replacement in coarse and 100% fine aggregate gives better strength results. It can be concluded that the optimum replacement level for fine aggregates is 100% with 30% partial coarse aggregate replacement for the economical mix of concrete. Disposal of fly ash has become a vast problem, hence the usage of fly ash as aggregates gives a better solution for waste management problems. As fly ash aggregate concrete satisfies the mechanical properties of conventional concrete, a particular attention may be given for the usage of fly ash aggregates in concrete

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