Experimental Study on Lightweight Fly Ash Aggregate Concrete

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Abstract- **Many researchers have been carried out in the area of fly ash utilization in the past. It mainly concentrated on replacement of cement with fly ash but production of artificial aggregates with fly ash helps in utilizing large volume of ash in concrete. The world is much in this part recently due to this large scale utilization which also reduces environmental Pollution and dwindling of natural resources. This paper mainly focuses on manufacturing Process of light weight aggregates using pelletizer and curing has been done in cold bonded Technique. The properties of these fly ash aggregates have been tested and compared with Natural gravel and the study shows that cold bonded fly ash aggregates can be used as an Aggregate replacement material in concrete. The strength property and density of concrete Made with artificial fly ash aggregates and natural gravel were also studied which confirms that introduction of fly ash aggregates in concrete reduces the compressive strength but meets the required strength to be used as a structural material.**

Index terms- Fly ash aggregates, artificial aggregates, light weight concrete, cold bonded Technique, Compressive strength, Flexural strength, Plastic shrinkage, Reinforced concrete beams

1. INTRODUCTION

In growing need for electricity in India, 70% of power is generated through thermal power plants. The environmental dreads from these plants include air pollution due to particulate
Emission, water pollution and shortage of land for dumping the fly ash. Further, the poor quality of Indian coal has high ash content, which worsens the disposal problem. Fly ash generation is estimated to be around 154 million tons in 2013-2014.Instead of dumping the fly ash as landfills; fly ash is widely used as cement replacement material, pavement base, blocks etc., in these days. To use fly ash in large volume the applications like embankment fill or aggregate replacement material should be considered.

The utilization of fly ash is about 30% as various engineering properties requirements that is for low technical applications such as in construction of fills and embankments, backfills, pavement base and sub base course; intermediate technical application such as in producing blended cement, concrete pipes, precast/ prestressed products materials, lightweight concrete bricks/blocks, autoclaved aerated concrete and lightweight aggregate[1]. Lightweight concrete is produced in different categories based on the no-fines concrete, aerated cellular concrete and lightweight aggregate concrete. With increasing concern over the excessive exploitation of natural aggregates, synthetic lightweight aggregate produced from environmental waste is a viable new source of Structural aggregate material.

2. LITERATURE REVIEW

intermediate technical application such as in producing blended cement, concrete pipes, precast/ prestressed products materials, lightweight concrete bricks/blocks, autoclaved aerated concrete and lightweight aggregate[1].Lightweight concrete is produced in different categories based on the no-fines concrete, aerated cellular concrete and lightweight aggregate concrete. With increasing concern over the excessive exploitation of natural aggregates, synthetic lightweight aggregate produced from environmental waste is a viable new source of structural aggregate material.
Types of Fly ash
The based on chemical composition of fly ash
1. Class F (Siliceous PFA)
2. Class C (Calcareous PFA)
The chemical composition of fly ash is given in the Table 1.The fly ash is obtained from NLC Ltd, Neyveli, which matches the specification of class C as per ASTM C 618. Figure 1, shows the microscopic

structure of raw fly ash before making fly ash pellets. The SEM image is taken with accelerating potential of 20 kV and 300X zooming. Most of the particles are 1 to 100 µm in size of solid spheres and hollow cenospheres. Irregular shaped unborn carbon particles are identified in larger size.

This matches the specification of class C as per ASTM C 618

Oxides (%)	Fly ash
SiO_2	57.65
CaO	11.64
Al_2O_3	15.29
Fe_2O_3	6.1
MgO	0.37
SO_3	1.82
LOI	2.86
Na_2O	0.44
K_2O	0.04
$SiO_2 + Al_2O_3 + Fe_2O_3$	79.04

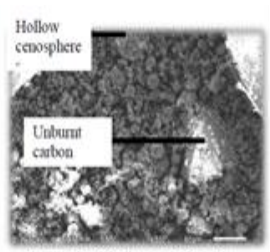


Figure 1: SEM image of fly ash

Figure 1 Figure 2

3. PREPARATION OF FLY ASH AGGREGATES

Artificial aggregates can be formed by different process like autoclaving, cold bonding or sintering². Research studies show better results on usage of various waste products as artificial aggregates mining residues, heavy metal sludge3 (Here, in this pilot study, fly ash aggregates are formed by cold bonded technique. Cold bonding is nothing but normal water curing. Pelletizer of 0.55 m in diameter and 0.250 m depth with a rotating speed of 40 rpm is used in the process of pelletization. An angle of 55 o is maintained as per previous studies which give better pelletization efficiency and good grading of pellets4.The influence of various binders in the formation of sintered fly ash aggregate is well studied by Though class C fly ash have CaO content for better binding property, the usage of Ca(OH)2 improves the efficiency and the duration and binder dosage in pelletization This also helps in the formation of CSH gel by reacting with silica present in fly ash which helps in attaining better strength. Hence, 2% of Ca (OH)2 of total weight of fly ash is added for better agglomeration. Also, high rate of hydration can be achieved with larger CSH gel formation. 8% of Ordinary Portland cement is used as the binder material. Fly ash and the binder are mixed well initially for 2 minutes in pelletizer and then water with Ca(OH)2 is sprayed in to it. Spraying should be done carefully to make sure that the water has been sprinkled not in the same place to avoid slurry muddy balls. The fresh pellets formed were then kept at room temperature for a day to attain initial strength and then water cured for 28 days. The usage of calcium hydroxide gave better initial strength to the pellets which helps in easy handling.

4. PRODUCTION OF FLY ASH AGGREGATE

The constituents like cement, fly ash, Bottom ash, and water produce the fly ash aggregates. Water is the binding material that paves way for the formation of the aggregate with good bond property. The production of FAA is the theme of this project. It is detailed below.

Table 1 Proportions for cement and fly ash, bottom ash

Mix Id	Fly ash (%)	Bottom ash (%)	Cement (%)	Lime (%)	Water ratio	Super plasticizer (%)
Mix-1	90	5	5	2	0.45	0.3

Cement and fly ash were mixed in above Three Proportions in a concrete mixer. Water was added to the mix by adopting the water cement ratio of 0.45. The contents were thoroughly mixed in the drum until the complete formation of fly ash aggregates. This method of formation of fly ash Aggregates are called pelletisation.

5. PROCESSING AND CURING OF FLY ASH AGGREGATE

The prepared 'Green Pellets' is allowed to dry for a day. Fly ash aggregates are then put for 28 days curing. The fly ash aggregates were weighed before and after curing process. It was found that no change was observed.

Figure 3: Formation of fly ash Figure 4: Prepared sample of Pellets

6. STUDY ON PROPERTIES OF FLY ASH AGGREGATES

Aggregates passing through 12.5 mm and retained in 10 mm sieve were used for both fly ash aggregates and natural gravel for the Mechanical tests (IS 2386 (Part 4): 1963). The crushing value gives the resistance of aggregate against gradually applied crushing load. Aggregate crushing value, impact values were found using IS 2386 (Part 4): 1963.
Specific gravity, water absorption, bulk density was calculated as per IS 2386 (Part 3): 1963.

Table 2: Material Properties

S. No	Properties	Cement	Sand	Fly ash(Class C)	Bottom ash	CA	FAA
1	Shape	-	-	-	-	Angular	Spherical
2	Specific gravity	3.15	2.64	2.28	2.38	2.72	1.98
3	Bulk density(Kg/ m3)	-	-	-	-	1496	913
4	Crushing value (%)	-	-	-	-	33.33	35.23
5	Impact Value (%)	-	-	-	--	25.33	38.23
6	Water Absorption (%)	-	--	-	-	1.0	13.25

Table 3.Mix ratio

Grade	Water	Cement	Fine aggregate	Coarse aggregate
M 30	140 lit	333 kg/m³	754 kg/m³	1290 kg/m³
	0.42	1	2.26	3.87

7. STUDY ON FLY ASH AGGREGATE CONCRETE

a) Mix Proportion

Mix has been designed as per IS 10262:2009 for 28 days strength of 38 MPa. Table 4 gives the various percentage replacement of mix proportion for Normal concrete made with natural gravel and fly aggregate concrete. In the proportion, coarse aggregate forms the major volume of 1290 Kg/m ³. This consumes large volume of fly ash.

Table 4.Various % Replacement in mix proportions

Mix id	Cement (%)	Fine aggregate (%)	Bottom ash (%)	Coarse aggregate (%)	Fly ash aggregate (%)
Control mix	100	100	-	100	-
Mix-1	100	100	-	75	25
Mix-2	100	100	-	50	50
Mix-3	100	60	40	75	25
Mix-4	100	60	40	50	50

Table 5.Various Mix proportions

Mix id	Cement (kg/m³)	BA (kg/m³)	FA (kg/m³)	CA (kg/m³)	FAA (kg/m³)	W/C ratio	Sp (%)
Control mix	333	0	754	1290	0	0.42	0.35
Mix-1	333	0	754	967.5	232.2	0.42	0.35
Mix-2	333	0	754	645	464.4	0.42	0.35
Mix-3	333	271.44	452.40	967.5	232.2	0.42	0.35
Mix-4	333	271.44	452.40	645	464.4	0.42	0.35

High range water reducing admixture was used as super plasticizer (SP) in this study. SP content was consumed lesser for fly ash aggregate (FAA) concrete because of its rounded nature that itself improved workability.

8. PREPARATION OF TEST SAMPLES

a) Compressive Strength Test Cube moulds of 100x100x100 mm were used for compressive strength study. Moulds were properly maintained by cleaning and oiling before each casting. Vibrating table was used for better compaction and filled in three layers.

Compressive strength Test on FAA Concrete

Figure 5: Compressive strength on FAA Concrete

b) Flexural Strength Test Flexural strength is the ability of a beam or slab to resist failure in bending. It is measured by loading un-reinforced concrete beam of size 500 x 100 x 100mm. Flexural strength value is about 12 to 20 percent of compressive strength.

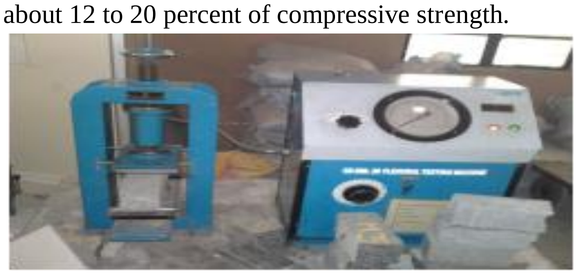


Figure 6: Flexural strength test

c) Plastic shrinkage Test Specimen Used Slab mould of dimension 500 x 250 x 75 mm was used with stress riser of 55 mm height at the centre and two base restraints of 35 mm height at 35 mm from both the ends, along the transverse direction as shown in Fig.8. Additionally, bolt and nut arrangements were provided at the ends to restrict the longitudinal movement of the concrete, increasing the possibility of cracking at the notch. Concrete has to be filled in this mould and kept in oven at a degree of 40ºc for 24 hrs. After 24 hrs, the mould has to be removed and observed for any cracks In the surface using stereo microscope.

Figure.7: Plastic shrinkage mould

d) Flexure Behaviour of Reinforcement concrete beam Test The size of the test beams are 1000mm length, 150mm breath and 100mm depth. The test beams were total length of 1000 mm and an effective span length of 900 mm between supports. The dimensions details for the test beams are shown in Table 6,and testing arrangements are shown in Figure 9. All beams were same dimensions and longitudinal reinforcement, loaded by two point load up to failure using a 400 kN UTM (Universal Testing Machine).The initiation of the cracks was detected using a magnifying lenses. Deflection of the beams during test at the mid-span and under the concentrated loads was measured using deflectometers.

Table:6 Properties of Test Beams

Beam Specimen	Fck (Mpa)	Ast	fy (Mpa)	Asc	Stirrups
Control mix	30	2#10	415	2#8	6ϕ100mm
Mix-1	30	2#10	415	2#8	6ϕ100mm
Mix-2	30	2#10	415	2#8	6ϕ100mm
Mix-3	30	2#10	415	2#8	6ϕ100mm
Mix-4	30	2#10	415	2#8	6ϕ100mm

Where
Ast = Area of tensile steel
Asc = Area of compressive steel
fy = yield strength of tensile steel

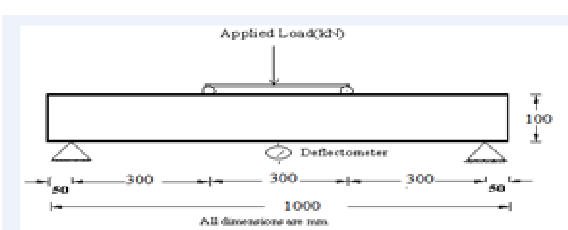


Figure 8: Details of test beams

9. EXPERIMENTAL INVESTIGATION

The experimental investigation is divided under 4 headings:

1. Compressive strength

Compressive strength for M30 Concrete with various mix proportion with FAA

Table 7: Compressive strength for various mix proportion

Compressive Strength			
Mix Id	Specification	Compressive Strength in N/mm²	
		7 day	28 days
CM	control mix	30.63	38.13
M-1	25% of FAA	24.23	31.23
M-2	50% of FAA	14.89	22.74
M-3	40% of B.A&25% FAA	22.56	29.5
M-4	40% of B.A &50%FAA	18.96	23.67

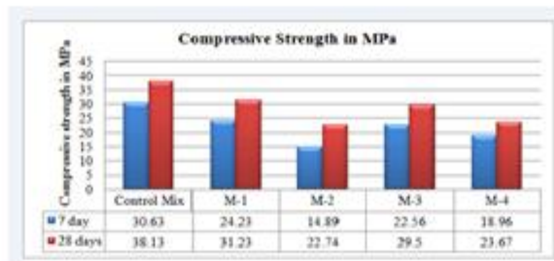


Figure 9: Compressive strength for various mix proportion

2. Flexural strength

Flexural strength for M30 concrete with various mix proportion with FAA

Table 8: Flexural Strength for various mix proportion

Flexural Strength Test		
Mix Id	Specification	Flexural Strength in N/mm²
		28 days
CM	control mix	6.06
M-1	25% of FAA	5.27
M-2	50% of FAA	3.4
M-3	40% of B.A&25% FAA	4.2
M-4	40% of B.A &50%FAA	3.67

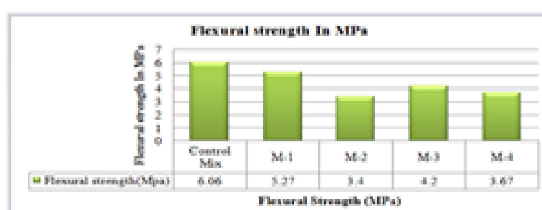


Figure 10: Flexural Strength for various mix proportion

3. Plastic shrinkage

Plastic shrinkage for M30 concrete with various mix proportion with FAA

Table 9: Plastic Shrinkage for Various mix proportion

Plastic shrinkage		
Mix Id	Specification	Crack Observation Observed after 24 hrs,
CM	control mix	No Cracks
M-1	25% of FAA	No Cracks
M-2	50% of FAA	No Cracks
M-3	40% of B.A&25% FAA	No Cracks
M-4	40% of B.A &50%FAA	No Cracks

4. Flexure Behaviour of Reinforced Fly ash aggregate concrete beam

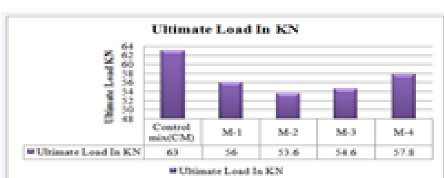
Fig.11. Experimental Setup of the Control RCC Beam

Flexure Behavior of RCC beam for M30 concrete with various mix proportion with FAA

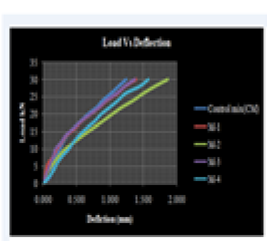
Table 10: The results obtained for RCC beam

Beam Id	At first cracking Load P_{cr}(kN)	At first cracking Deflection Δ_{cr} (mm)	At yielding Load P_y (kN)	At ultimate Load P_u (kN)	Mode of Failure
Control Mix(CM)	18	0.45	57	63	Flexure crack
M-1	20	0.71	45	56	Flexure crack
M-2	22	1.175	47	53.6	Flexure crack and Shear crack
M-3	20	0.70	45	54.6	Flexure crack and Shear crack
M-4	20	0.865	48	57.8	Flexure crack

Ultimate Load Carrying Capacity



Relation between Load and Deflection of Beams



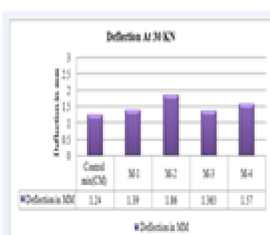


Fig.12. Relation between Load and Deflection of Beams

10. COST ANALYSIS

Comparison of Cost of both Conventional Concrete and Fly Ash Aggregate Concrete for ONE RCC Beam (1m x .1m x.15m)

Relating cost of both conventional concrete and fly ash aggregate concrete for one RCC beam (1m x .1m x.15m)

Table 10: Cost Analysis

		CONVENTIONAL CONCRETE		FLY ASH AGGREGATE CONCRETE	
S.NO	MATERIAL	QUANTITY(Kg)	RATE	QUANTITY(Kg)	RATE
1	Cement	5 kg	Rs 35/-	5 kg	Rs 35/-
2	Fine aggregate	12 kg	Rs 70/-	12 kg	Rs 70/-
3	Coarse aggregate	19.5 kg	Rs 87/-	13.93 kg	Rs 62/-
		Total	**Rs 192/-**	Total	**Rs 167/-**
				Saving	**Rs 25/-**

- The above table compares the cost of conventional concrete and fly ash aggregate concrete for a RCC 1 m Length beam.
- From comparison it is found the from RCC Control beam and RCC FAA beam ratio pellets shows more cost efficient i.e. nearly 13% of cost saving when compared conventional .
- The cost efficiency is directly proportion to efficiency in manufacturing of pellets. That is if the production is 100% efficient the cost efficiency will increase to a greater extend.

11. CONCLUSION

- The fly ash aggregate has been made by pelletizing and cold bonding technique and various proportions of replacement has been carried for the experimental study of strength property of LWA concrete.
- The rounded shape of fly ash aggregate gives better workability compared to the angular natural gravel.
- Low specific gravity compared to natural proves it to be a light weight aggregate material and fly ash has been consumed in large volume when it is used as a coarse aggregate replacement material due to its occupation of large volume in concrete. This in turn reduces the problem of dumping as landfills to greater extent.

- The M-1 mix (25%FAA) & M-3 mix (25%FAA and 40% of BA) replacement of coarse aggregate and fine aggregate achieves the required compressive strength of M30 grade concrete, but in M-2 mix (50% FAA) and M-4 mix (50%FAA and 40% of BA) replacement, the strength is decreased by 40% than the required strength in M30 grade at 28 days.
- In flexural strength property, the strength at 28 days of M-1and M-3 mix is around 13% lesser than the normal concrete but achieves more than the required value in M30 grade.
- Similar to control concrete all mixture had no cracks. This shows all the mixture has good durability as control mix (CM).
- The Avg. ultimate load of control beam is 63 kN for control mix and M-4 RCC beam is 57.8 kN. M-4 beam load carrying capacity decreases 8 % only compare to control beam (CM). Fly ash aggregate replacement (50%FAA & 40% BA) in concrete has shown good improvement in flexural strength.
- M-4 mix beam Load deflection study gave similar post crack behavior in comparison to Control beams (RCC beams).
- Displacement ductility vales are found to increase in case of control concrete beams.
- Based on ultimate load carrying capacity and deflection value M-4 mix gives good result when compare to control mix (CM).
- From comparison it is found the from RCC Control beam and RCC FAA beam ratio pellets shows more cost efficient i.e. nearly 13% of cost saving when compared conventional .
- Also it can be suggested that concrete with 30 % to 60 % of LWA can be used for structure with less live loads (i.e., residential buildings, dome structure & architectural works, etc.,
- By using LWA in concrete, reduces the dead load of structures which reduces the section of structural members which leads to economy of construction.

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