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Performance Evaluation of Artificial Angular Fly Ash Aggregate

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Abstract

This experimental study describes the development of the lightweight angular fly ash aggregate (FAA) and consequent comparison of properties of FAA with natural aggregate (gravel). The manufacturing process of these FAA involves blending of fly ash with cement and alkali activators at various proportioning of cement to fly ash and placing the mix in the mould. This is followed by curing of the cubes for 7 days after letting it to dry for 24hrs and crushing them to obtain the aggregate of different sizes. After having the fly ash aggregate, the test are carried out in fresh state and hardened state of the fly ash aggregate concrete and the conventional concrete. Results are compared to see the efficiency level of flyash aggregate concrete.The properties of both angular fly ash aggregates like Specific gravity, water absorption, Impact value, and Abrasion value are compared with the properties of the conventional aggregates (gravel). This study concludes that FAA with proper mix proportioning can be used as a substitute for conventional aggregates for sustainable construction.

Keywords: *Sustainable materials, Fly ash aggregates*

Introduction

The industrial plants produce huge quantities of fly ash, which need to be disposed of safely or else it have disastrous consequences. The production of fly ash is increasing every year but the utilization of fly ash is not even half of its production. To utilize the fly ash in high volume, the innovative idea is to use fly ash aggregate as a replacement material for coarse aggregate in structural concrete. The use of fly ash aggregate in concrete is believed to reduce the overall cost of construction and solve the problems of disposal as well. The use of fly ash in portland cement concrete (PCC) has many benefits and improves concrete performance in both the fresh and hardened state. American coal ass association suggests that the Fly ash use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. Fly ash use is also cost effective. When fly ash is added to concrete, the amount of portland cement may be reduced .Utilization of fly ash aggregate may also reduce the consumption of natural aggregates significantly. Ramamurthy and Harikrishnan [1] observed that binders enhance the strength of aggregates by changing the microstructure of aggregates during the sintering process. Kayali [2] suggested the use of lightweight concrete produced from lightweight aggregate which is manufactured by sintering fly ash. Kockal and Ozturan [3] studied lightweight fly ash aggregate concrete behavior. The compressive and split tensile strength test results were almost the same as normal weight concrete. Kockal and Ozturan [4] also discussed how the lightweight fly ash aggregate property affects the concrete property. The concrete produced using sintered or cold bonded lightweight fly ash aggregates is durable, and have good strength [5]. Shanmuga sundaram et al. [6] investigated compressive strength, split tensile strength, and flexural strength of fly ash aggregate concrete at different days of curing by replacing fine and coarse aggregates completely by fly ash aggregate made by pelletization process. Sivakumar and Gomathi [7] concluded that fly ash can be used for aggregate preparation and these lightweight aggregates are suitable for concrete production. Prasath Kumar et al. [8] carried an experimental study on the replacement of coarse aggregate partially with fly ash aggregate. Lightweight round aggregates from fly ash have been manufactured commercially and a lot of research is going on to use lightweight round fly ash aggregates but no significant research was done on lightweight angular aggregates made from fly ash. The objective of this research is to evaluate the performance of the angular fly ash aggregate manufactured using different mix composition and suggest that aggregate made from which composition can be used for partial or complete replacement of conventional aggregate.

Experimental Program

Details of the materials used and manufacturing process of angular lightweight aggregates from fly ash (FAA) are explained in detail. Various tests are performed to determine the properties of these aggregates and then compare them with traditional coarse aggregates. To study the effect of fly ash aggregates on concrete, specimens were cast in cubes and were tested. Fly ash required for the manufacture of aggregate is obtained from a Steel plant, whose specific gravity was found to be 2.5 g/cc. The cement used was ordinary Portland cement (OPC) of 43 grade and conforming to the IS: 8112 (1959) having specific gravity 3.12. The grading of 20 mm and 10 mm size coarse aggregates was done as per IS 383-1970 [9].

Mix Proportions

For the production of angular fly ash agreegate, cement was partially replaced by the fly ash keeping water cement ratio 0.45 in all the mix and varying the alkali activators quantity as shown in the table

Table 1: Specimen Composition

Specimen	Flyash (kg)	Cement (kg)	Total (kg)	W/C	Naoh (ml)	Na2sio3 (ml)	Water (ml)	Total water+activators (ml)
F60C40	3	2	5	0.45	540	810	900	2250
F70C30	3.5	1.5	5	0.45	630	945	675	2250
F80C20	4	1	5	0.45	720	1080	450	2250
TOTAL	10.5	4.5	15		1890	2835	2025	6750

Manufacturing Procedure of Angular Fly Ash Aggregates from Fly Ash

1. Blending and Placing Procedure: Fly ash was weighed and placed in a trough for mixing. Dry mix of fly ash and cement was prepared and Instead of adding total water at once initially, 70% of the water was added. The slurry mixture was blended and mixed for 3 min. Alkali activators (NaOH - molar mass 40 g/mol. And Na_2Sio_3 - molar mass 122 g/mol) of 8M concentration per liter was then added and mixing continued for another period of 3 min. The remaining amount of water was then added and the mixing was continued for further 3 min till the mixing gets completed. After proper mixing, the slurry was put into moulds in three layers, each layers were well compacted using tamp to avoid the formation of air voids (Fig. 1). The cube Specimen prepared are shown in the figure

   Specimen I - Fly ash 80 % and Cement 20 % [**F80C20**].
   Specimen II - Flyash 70 % Cement 30 % [**F70C30**].

Specimen III - Flyash 60 % Cement 40 % [**F60C40**]

2. Curing: After demolding, the cubes were kept for curing in the water at room temperature.
3. Crushing and Sizing: The cubes were crushed using compressive testing machine. The aggregates were therefore crushed to produce the aggregate of maximum size of 20 mm. The crushed aggregates were then sieved through such that they pass through 12.5 mm sieve and retain on 10 mm sieve. These manufactured aggregates and gravel were then used for performing aggregate tests.

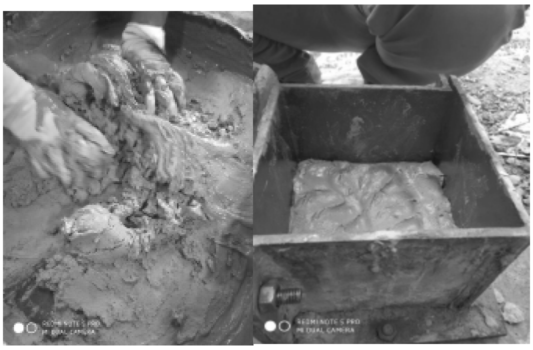

Figure 1 Sample preparation and mounding for cube test

Figure 2 Cube of different proportion of fly ash and cement

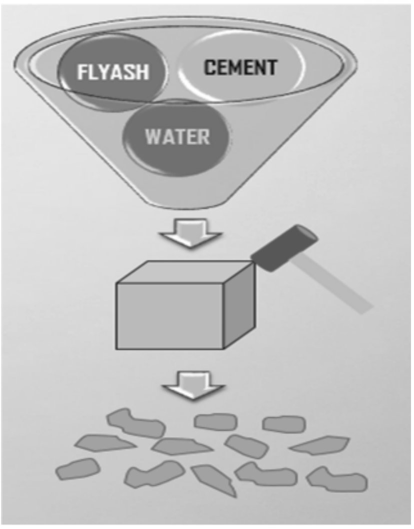

Figure 3 Methodology for the fly ash aggregate preparation

Figure 4 Cube test of sample

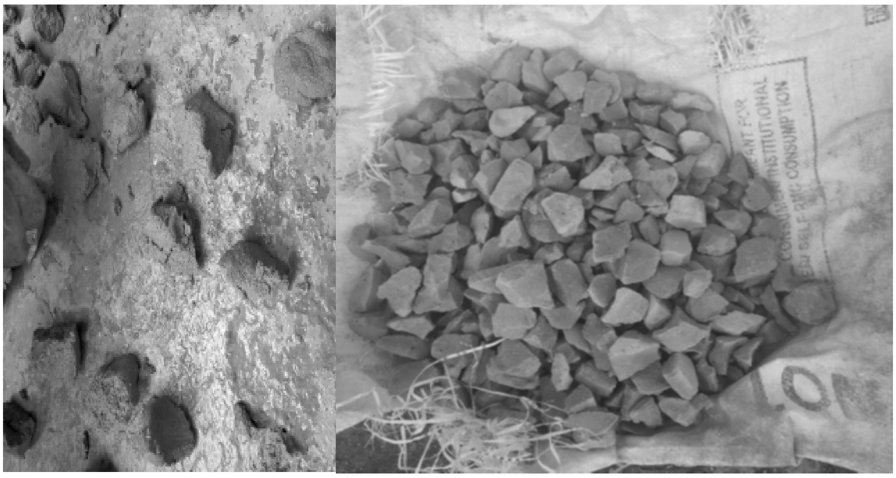

Figure 5 Fly ash cement aggregate preparation for sieve analysis

Results and Discussion

Different proportioning of fly ash with cement followed by addition of alkali activators were tried for manufacturing of fly ash aggregates. Of all the trials with different proportion of fly ash and cement, aggregates made with 60% of fly ash and 40% of cement mix gave the best results. The different parameters of aggregate such as are specific gravity; water absorption; impact value and abrasion value of all the sample mixes were found out and compared.

Physical Properties FA Aggregates and Gravel

The physical properties mf the prepared angular fly ash aggregates were compared with the properties of conventional aggregates. Abrasion value and impact value of manufactured angular fly ash aggregates (FAA) is within permissible limit. FA aggregates have lower Abrasion value and impact value compared to conventional aggregate indicating that FA aggregates have higher resistance to compressive load when compared to conventional aggregate. Specific gravities of manufactured angular fly ash aggregates are less than the conventional coarse aggregate (Gravel). Water absorption of FAA are much higher than the Conventional coarse aggregate (Gravel).

Figure 6 Impact test of the sample aggregates

Figure 7 Abrasion test of the sample aggregates

TESTING METHODOLOGY

1. SPECIFIC GRAVITY - As per IS2386 (Part III) of 1963.
2. WATER ABSORPTION - As per IS2386 (Part III) of 1963.
3. IMPACT VALUE - As per IS: 2386 Part IV – 1963.
4. ABRASION - As per IS: 2386 Part IV – 1963.

Test for Determination of Specific Gravity and water absorption

Indian Standard Specification IS: 2386 (Part III) of 1963 gives various procedures to find out the specific gravity of different sizes of aggregates. The following procedure is applicable to aggregate size larger than 10 mm. A sample of aggregate not less than 2 kg is taken. It is thoroughly washed to remove the finer particles and dust adhering to the aggregate. It is then placed in a wire basket and immersed in distilled water at a temperature between 22° to 32°C. Immediately after immersion, the entrapped air is removed from the sample by lifting the basket containing it 25 mm above the base of the tank and allowing it to drop 25 times at the rate of about one drop per sec. During the operation, care is taken that the basket and aggregate remain completely immersed in water. They are kept in water for a period of 24 ± 1/2 hours afterwards. The basket and aggregate are then jolted and weighed (weight A1) in water at a temperature 22° to 32° C. The basket and the aggregate are then removed from water and allowed to drain for a few minutes and then the aggregate is taken out from the basket and placed on dry cloth and the surface is gently dried with the cloth. The aggregate is transferred to the second dry cloth and further dried. The empty basket is again immersed in water, jolted 25 times and weighed in water (weight A2). The aggregate is exposed to atmosphere away from direct sunlight for not less than 10 minutes until it appears completely surface dry. Then the aggregate is weighed in air (weight B). Then the aggregate is kept in the oven at a temperature of 100 to 110°C and maintained at this temperature for 24 ± 1/2 hours. It is then cooled in the air-tight container, and weighed (weight C).

Specific Gravity = C/ (B – A); Apparent Sp. Gravity = C/ (C− A)

Water absorption (percent of dry weight) = 100 (B- C)/C

Where, A= the weight in gm of the saturated aggregate in water (A1 – A2),

B = the weight in gm of the saturated surface-dry aggregate in air, and

C = the weight in gm of oven-dried aggregate in air

Table 2: Specific gravity value of different specimen

S.NO	SPECIMEN	SPECIFIC GRAVITY
1	F60C40-AGGREGATE	2.3
2	F70C30-AGGREGATE	2
3	F80C20-GGREGATE	1.75
4	CONVENTIONAL AGGREGATE	2.5 – 3.0

- ✓ As specific gravity increases the strength of aggregate also increases hence, for better strength we can increase cement content or by providing strong binders.
- ✓ It is better to utilize less cement and to choose alternative binders to produce eco-friendly nature.

Table 3: Water Absorption value in percentage of various specimen

S.NO	SPECIMEN	WATER ABSORPTION (%)
1	F60C40-AGGREGATE	5
2	F70C30-AGGREGATE	8
3	F80C20-AGGREGATE	12
4	CONVENTIONAL AGGREGATE	0.5 - 1

- ✓ It was already observed the presence of voids after casting of flyash aggregate, hence it increase porous nature and allows water into it.
- ✓ We can see the more cement content the water absorption gets reduced.
- ✓ Presence of moisture in flyash aggregate could affect water cement ratio and could increase workability and may delay setting time so mix design should be done carefully by considering water absorption.

Test for determination of aggregate impact value

The aggregate impact value gives relative measure of the resistance of an aggregate to sudden shock or impact. Which in some aggregates differs from its resistance to a slow compressive load. Aggregate Impact Value Apparatus. The test sample consists of aggregate passing through 12.5 mm and retained on 10 mm I.S. Sieve. The aggregate shall be dried in an oven for a period of four hours at a temperature of 100°C to 110°C and cooled. The aggregate is filled about one-third full and tamped with 25 strokes by the tamping rod. A further similar quantity of aggregate is added and tamped in the standard manner. The measure is filled to over-flowing and then struck off level. The net weight of the aggregate in the measure is determined (weight A) and this weight of aggregate shall be used for the duplicate test on the same material. The whole sample is filled into a cylindrical steel cup firmly fixed on the base of the machine. A hammer weighing about 14 kg, is raised to a height of 380 mm above the upper surface of the aggregate in the cup and allowed to fall freely on the aggregate. The test sample shall be subjected to a total 15 such blows each being delivered at an interval of not less than one second. The crushed aggregate is removed from the cup and the whole of it is sieved on 2.36 mm I.S. Sieve. The fraction passing the sieve is weighed to an accuracy of 0.1 gm. (weight B). The fraction retained on the sieve is also weighed (weight C). If the total weight (B + C) is less than the initial weight A by more than one gm the result shall be discarded and a fresh test made. Two tests are made. The ratio of the weight of fines formed to the total sample weight in each test is expressed as percentage.

Therefore, Aggregate Impact Value = $B/A \times 100$

Where, B = weight of fraction passing 2.36 mm I.S. Sieve.

A = weight of oven-dried sample.

Table 4: Impact value in percentage of various specimen

S.NO	SPECIMEN	IMPACT VALUE (%)
1	F60C40-AGGREGATE	19
2	F70C30 –AGGREGATE	22.4
3	F80C20 –AGGREGATE	43.26
4	CONVENTIONAL AGGREGATE	15 - 20

- ✓ The aggregate impact value should not be more than 45 per cent by weight for aggregates used for concrete other than wearing surfaces and 30 per cent by weight for concrete to be used as wearing surfaces, such as runways, roads and pavements

Test for abrasion value

Test sample and abrasive charge are placed in the Los Angeles Abrasion testing machine and machine is rotated at a speed of 20 to 33 rev/min. For grading's A, B, C and D, the machine is rotated for 500 revolutions. For grading's E, F and G, it is rotated 1000 revolutions. At the completion of the above number of revolution, the material is discharged from the machine and a preliminary separation of the sample made on a sieve coarser than 1.7 m IS Sieve. Finer portion is then sieved on a 1.7 mm IS Sieve. The material coarser than 1.7 mm IS sieved is washed, dried in an oven at 105° to 110°C to a substantially constant weight and accurately weighed to the nearest gram. The difference between the original weight and the final weight of the test sample is expressed as a percentage of the original weight of the test sample. This value is reported as the percentage of wear. The percentage of wear should not be more than 16 per cent for concrete aggregates.

Table 5: Abrasion value in percentage of various specimen

S.NO	SPECIMEN	ABRASION VALUE (%)
1	F60C40-AGGREGATE	24
2	F70C30-AGGREGATE	33
3	F80C20-AGGREGATE	40
4	CONVENTIONAL AGGREGATE	15 - 25

- ✓ We have observed the flyash aggregate becomes chalky when it is taken in palm.
- ✓ The flyash aggregate could not resist much wear and tear compared to conventional aggregate it cannot be used for pavement.

Concrete Mix Design

Table 6: Preliminary data for mix design

Grade designation	M25
Type of cement	PPC conforming Cement (IS 1489–2015)
Maximum nominal Size of aggregate	20mm
Water – cement ratio	0.45
Minimum cement content	320 kg/m^3
Workability	150mm
Type of aggregate	Crushed Angular Aggregate
Chemical admixture	Nil

Cement

Cement used for preparing aggregate and concrete is Portland Pozzolana Cement (IS 1489–2015).PPC is considered equivalent to 33 grade OPC.

Table 7: Compressive strength of Cement

DESCRIPTIONS	**BIS SPECIFICATION** **PPC GRADE (As per IS 1489:2015)**
Compressive Strength (MPa)	
3 Days (72±1 hr.)	16 MPa
7 Days (168±2 hr.)	22 MPa
28 Days (672±4 hr.)	33 MPa

1) Target mean strength for mix design:

The concrete mix is proportioned to achieve far higher targeted compressive strength. That is given by relation, $F_{ck} = F_{ck} + (t \times s)$ According to IS 456: 2000, Assumed standard deviation for M25 grade of concrete is 4.

The targeted compressive strength,

$F_{ck} = 25 + (1.65 \times 4)$

$= 25 + 6.6$

$= 31.6 \text{ N/mm}^2$

2) Selection of water cement ratio:

The water cement ratio assumed on consideration to the water absorption rate by artificial aggregate that as by 17%. Hence it is considered after evaluating the quantity of aggregate. However the approximate water cement ratio can be given according to IS code that is 0.50 to cement lower than value of 0.55 for mild exposure to the environment.

3) Selection of water content:

Maximum water content for 20mm aggregate is 186 litre.

Estimated water content for 150 mm slump = 186 + $\frac{9}{100}$ x 186

= 203 litre.

The water content percent:

The decrease in water cement ratio (0.60 – 0.50) due to absorption = 8%

Foe increase in compaction factor = 3%

Total = 11%.

The required water content = 186 + (11/100 x 186)

= 186 + 20.46

= 206.46 kg/m^3

For decrease in water cement ratio by (0.60 – 0.50) is 0.1	= -2%
For zone 3 table 4 of IS 388 – 1970	= -1.5%
Total	= -3.5%
The aggregate %	= 35- 3.5
	= 31.5%

4) CALCULATION OF CEMENT CONTENT:

Water cement ratio = 0.5%

Cement content = $\frac{206}{0.5}$ = 412.92 kg/m^3

From table 5 of IS456, Minimum cement content for severe exposure is 320 kg/m^3

Hence ok.

5) Determination of FA and CA:

From IS 456, the specified size of air trapped in concrete considered to be 2%

100 – 2 = 98

$$V = \left[w + \frac{c}{Sc} + \frac{1}{p} - \frac{fa}{sfa}\right] x \left[\frac{1}{1000}\right]$$

$$0.98 = \left[206.46 + \frac{412.92}{3.15} + \frac{1}{0.315} - \frac{fa}{2.6}\right] x \left[\frac{1}{1000}\right]$$

FA= 0.740 kg/m^3

$$V = \left[w + \frac{c}{Sc} + \frac{1}{p} - \frac{ca}{sca}\right] x \left[\frac{1}{1000}\right]$$

$$0.98 = \left[206.45 + \frac{412.92}{3.15} + \frac{1}{0.315} - \frac{Ca}{2}\right] x \left[\frac{1}{1000}\right]$$

CA = 1.611 kg/m^3

For cube:

FA = 0.74 x 3375 = 2.497 kg

CA = 1.61 x 3375 = 5.433 kg

C = 0.412 x 3375 = 1.39 kg

W = 600 ml

For cylindrical:

FA = 0.74 x 785.4 = 0.581 kg

CA = 1.61x 785.4 = 1.264 kg

C = 0.41 x 785.4 = 0.329 kg

W = 161 ml

Table 8: Composition of ingredients in specimen

Materials	Cube Mould	Cylinder Mould
Cement	1.39 kg	0.322 Kg
Fine Aggregate	2.497 Kg	0.581 Kg
Coarse Aggregate	5.433 Kg	1.26 Kg
Water	600 ml	161 ml

Fresh concrete test

Different test are carried out in fresh state of green concrete. These test are primarily associated with the workability and durability of the concrete.

Table 9: Test Results for Fresh Concrete

TEST	F80C20 AGGREGATE MIX	F70C30 AGGREGATE MIX	F60C40 AGGREGATE MIX	CONVENTIONAL MIX
SLUMP CONE	50 mm	70 mm	85mm	80 mm
COMPACTION FACTOR	0.8 %	0.91 %	0.98%	0.94 %
VEE BEE CONSISTOMETER	14 sec	18 Sec	23Sec	8 Sec

Note: F-Fly ash, C-Cement, Number-%

Test on Hardened Concrete

Both the compressive strength test and split tensile test of the concrete specimen are carried out to check strength for aggregate with different proportion of fly ash and cement. Those test results are stated in table below:

Table 10: Strength comparison of conventional concrete and F80C20 Aggregate Concrete specimen

Day	Conventional Concrete		F80C20 Aggregate Concrete	
	Compressive Strength N/mm^2	Tensile Strength N/mm^2	Compressive Strength N/mm^2	Tensile Strength N/mm^2
7	17	2.31	3.5	0.21
14	20	2.68	6.11	0.60
28	25	3.39	11.33	1.06

Table 11: Strength comparison of conventional concrete and F70C30 Aggregate Concrete specimen

Day	Conventional Concrete		F70C30 Aggregate Concrete	
	Compressive Strength N/mm^2	Tensile Strength N/mm^2	Compressive Strength N/mm^2	Tensile Strength N/mm^2
7	17	2.31	6	0.14
14	20	2.68	11.92	0.38
28	25	3.39	23.77	0.56

Table 12: Strength comparison of conventional concrete and F60C40 Aggregate Concrete specimen

Day	Conventional Concrete		F60C40 Aggregate Concrete	
	Compressive Strength N/mm^2	Tensile Strength N/mm^2	Compressive Strength N/mm^2	Tensile Strength N/mm^2
7	17	2.31	12.45	0.11
14	20	2.68	16.32	0.18
28	25	3.39	23.88	0.29

Conclusions

Conclusions that can be drawn from our experimental study are listed below:

(i) The artificial aggregates production through the waste material is not only a good alternative for the natural aggregates extraction; it also provides an ecologically sustainable solution regarding waste management.

(ii) FA aggregate show crushing and impact values within the permissible limits. Impact and crushing value show that FAA aggregates have higher resistance to compressive load.

(iii) Water absorption of FA aggregates is very high when compared with natural gravel. But when it comes to lightweight aggregate concrete, up to 23% is allowed as per IS 2185 (Part II) 1989.

(iv) Flyash aggregate property depends on cement content and binder hence we conclude that F60C40 can be used for preparation of aggregate which can be used for light weight concrete application.

(v) Flyash aggregate has absorbed some moisture however F60C40 is low compared to other two proportions but way higher than conventional aggregate.

(vi) Impact value of flyash aggregate F60C40 was similar to conventional aggregate.

(vii) Abrasion value test suggested flyash aggregate can only resist less wear and tear compared to conventional aggregate

(viii) The fly ash aggregate concrete cubes for M25 grade containing fly ash aggregates made using cement fly ash proportions F80C20, F70C30 and F60C40 showed reduction in compressive strength and split tensile strength when compared to the conventional concrete at all the ages.

(ix) Cost of making conventional concrete is high when compared to Flyash aggregate concrete.

(x) It has low density hence it reduces dead load of structure.

(xi) However, it requires some advance techniques to improve strength at early stages to make it useful for engineering application.

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