Fly ash utilization in lightweight aggregates for sustainable construction

Jyoti Kamal[1], U.K.Mishra[2]

PhD student, Civil Engg. Deptt, N.I.T, Rourkela, India[1]

Assistant Professor, Civil Engg. Deptt, N.I.T, Rourkela, India[2]

[1]jyotikamal.gec@gmail.com, [2]ukmishra@nitrkl.ac.in

Abstract: This study describes the development of new lightweight angular fly ash aggregate (FAA) and consequent comparison of properties of FAA with traditional aggregate (gravel) and commercially available low-density round shaped aggregates LDA (Pellets). The manufacturing process of these FAA involves blending of fly ash with water at various ratios of water to fly ash and placing the mix in the mould. This is followed by sintering the cubes at high temperature and crushing them to obtain the aggregate of different sizes. The properties of both round and angular lightweight aggregates like crushing value, impact value, bulk density, porosity, specific gravity and water absorption are compared with the properties of the conventional aggregates (gravel). The compressive strength of concrete cubes of mix M20 with different percentage of coarse aggregates replaced by LDA (Pellets) and FAA are also determined. This study concludes that FAA is lightweight and also can be used as a substitute for conventional aggregates for sustainable construction.

Keywords—sustainable materials; Fly ash aggregates ;LDA (pellets); gravel; Compressive Strength; Lightweight; Sintering.

1. INTRODUCTION

The thermal power 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. Utilization of fly ash aggregate may also reduce the consumption of natural aggregates significantly.

Ramamurthy and Harikrishnan (2006) observed that binders enhance the strength of aggregates by changing the microstructure of aggregates during the sintering process. Kayali (2008) suggested the use of lightweight concrete produced from lightweight aggregate which is manufactured by sintering fly ash. Kockal and Ozturan (2009) studied lightweight fly ash aggregate concrete behaviour. The compressive and split tensile strength test results were almost same as normal weight concrete. Kockal and Ozturan (2010) also discussed how the lightweight fly ash aggregate property affects the concrete property. The concrete produced from sintered or cold bonded lightweight fly ash aggregates is durable, have sufficient strength and air entrained having comparable performance with the normal weight concretes. Shanmugasundaram et al. (2010) 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. Shivakumar and Gomathi (2011) concluded that fly ash can be used for aggregate preparation and these lightweight aggregates are suitable for concrete production. Prasath Kumar et al. (2014) 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 manufacture strong lightweight angular fly ash aggregate which can be used for partial or complete replacement of conventional aggregate.To explore the possibility of using FAA in concrete, the mechanical properties of FAA concrete is compared with concretes made with LDA and natural aggregate.

2. 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 and commercially available round fly ash aggregates LDA (pellets). To study the effect of fly ash aggregates on concrete, specimens were casted in cubes and were tested.

Fly ash required for the manufacture of aggregate is obtained from Bhushan Steel plant, Sambalpur 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. Locally Available fine and coarse aggregates were used. The grading of 20mm and 10 mm size coarse aggregates was done as per IS 383-1970. The maximum nominal size of the aggregate is 20mm and specific gravity is 2.83.

2.1 .Manufacturing Procedure of Angular fly ash aggregates from Fly ash

i) Blending and Placing Procedure: Fly ash was weighed and placed in a trough for mixing. Instead of adding total water at once initially, 70 % of the water was added. The slurry mixture blended and mixed for three minutes. A superplasticizer (PERMA LATEX SBR) was then added and mixing continued for another period of three minutes. The remaining amount of water was then added and the mixing was continued for further three minutes till the mixing gets completed. After proper mixing, the slurry was put into moulds.

Fig. 1: Moulds with Fly Ash Slurry

ii) Heat treatment: After demolding the cubes were kept in the oven at 50°C for 48 hours. The cubes were then kept in a blast furnace in which temperature was raised to 1250^0 C slowly in 7 hours and kept at the final temperature for 3 hours. The blast furnace was then switched off and the samples were allowed to cool down gradually over a period of 48 hours before taking out the sintered briquettes.

Fig. 2: Muffle Furnace

iii) Crushing and Sizing: The sintered briquettes were then placed in a crusher. 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 aggregates were used for performing aggregate tests.

Fig. 3: Crushed Aggregates

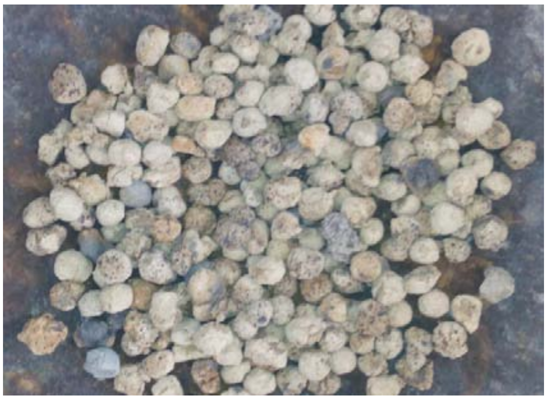


Fig. 4: LDA (Pellets, available in Market)

Fig. 5: Gravel (Natural Aggregates)

2.2. Mix Proportions

For the production of lightweight concrete, the traditional coarse aggregate was partially replaced with LDA (pellets) and Fly ash Aggregates at 10%, 20%, 30%, 40% and 50%. The 7th and 28th-day compressive strength of the cubes casted with this concrete was found out for different replacement percentage as mentioned above. The Mix design was done for concrete M20 grade. Unless the FA aggregates are satisfactorily pre-wetted, they may absorb mixing water and gives very low slump. For this reason, it is important to soak aggregates for 24 hrs. in water before casting of concrete. The superplasticizer SIKAMENT 2004 NS is used to get the desired workability.

Table 1: MIX DESIGN REPORT

Sl. No.	Particulars	Result
1	Characteristic Compressive strength in N/Sq.mm	20
2	Maximum size of Aggregate in mm	20.0
3	Target Average Compressive Strength (N/mm²)	26.6
4	Workability in terms of Slump in mm	75-100
5	Mode of Compaction	Vibration
6	Mix Particulars:	
	a. Water-Cement Ratio	0.45
	b. Materials per cubic meter of concrete in Kg.	
	i) Water	180
	ii) Cement (OPC 43 Grade)	400
	iii) Fine Aggregate	762
	iv) Coarse Aggregate	1122
	c. Mix Portion by weight	1:1.90:2.80
	d. Admixture % by wt of cement	0.8%

3. RESULTS AND DISCUSSION

Different water to fly ash ratios and sintering temperatures were tried for manufacturing of fly ash aggregates. Of all the trials with different water to fly ash ratios and different sintering temperatures, aggregates made with water to fly ash ratio of 0.4 and temperature of 1250^0C, gave best results. The different parameters of concrete such as are workability; compressive strength and density of all the concrete mixes were found out and compared.

3.1. Physical Properties of LDA, FA Aggregates and Gravel

The physical properties of the prepared angular fly ash aggregates and round fly ash aggregates were compared with the properties of conventional aggregates.

Table 2: Physical properties of aggregates

Properties	Gravel	LDA (pellets)	Fly ash Aggregates	Limit	References
Impact Strength (%)	15.37	28.69	21.99	< 45%	IS 2386 Part 4
Crushing Strength (%)	17.47	30.3	22.87	< 45%	IS 2386 Part 4
Specific Gravity(gm/cc)	2.83	1.99	1.428	-	IS 2386 Part 3
Water Absorption (%)	0.5	15.23	18.38	-	IS 2386 Part 3
Bulk Density (Kg/m^3)	1560	898	782.5	-	IS 2386 Part 3
Voids (%)	40.68	42.31	48.05	-	IS 2386 Part 3

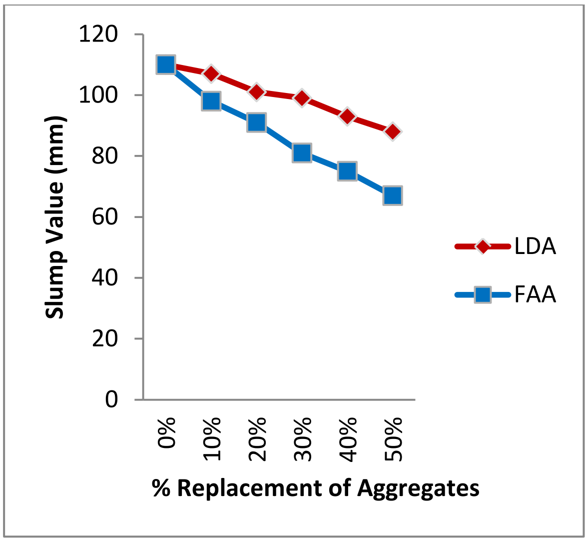
Crushing value and impact Value of round fly ash pellets (LDA) and manufactured angular fly ash aggregates (FAA) is within permissible limit. FA aggregates have lower crushing value and impact value compared to LDA pellets indicating that FA aggregates have higher resistance to compressive load when compared to LDA pellets. Specific gravities of round fly ash pellets and manufactured angular fly ash aggregates are less than the conventional coarse aggregate (Gravel). Water absorption of round fly ash pellets and FAA are much higher than the Conventional coarse aggregate (Gravel). Bulk density of round fly ash pellets and manufactured angular fly ash aggregates are lower than that of Gravel. Void ratios of round fly ash pellets and manufactured angular fly aggregates are higher than that of Gravel. Overall angular fly ash aggregates (FAA) performed well compared to round fly ash pellets (LDA).

3.2 Workability of concrete and Density of Concrete Cubes.

The workability of the concrete mixes was found out using Slump Cone Test method. The workability is found to be decreasing with increase in the replacement percentage of Coarse aggregate by FA Aggregates and LDA (pellets). These lightweight Aggregates concrete probably has less workability due to the high water absorption of Aggregates. LDA (pellets) concrete is more workable than FAAC due to round shape of aggregates which reduces the friction between the aggregate-paste interfaces.

Table 3: Results for Slump Value and Density

% Replacement of Aggregates	Slump Value(mm)		Density(Kg/m^3)	
	LDA (Pellets)	FA Aggregates	LDA (Pellets)	FA Aggregates
0 %	111	111	2474.07	2474.07
10 %	107	98	2322.96	2215.61
20 %	101	91	2251.85	2165.42
30 %	99	81	2231.11	2050.21
40 %	93	75	2204.49	1910.65
50 %	88	67	2183.70	1824.92



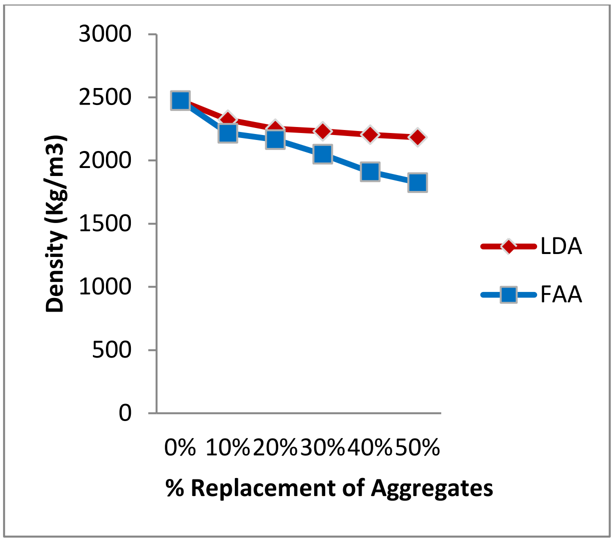


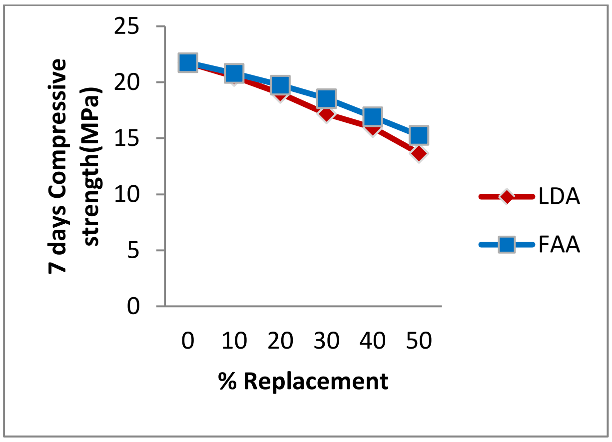
Fig 6: Workability of concrete **Fig 7: 28 Days Density of Concrete Cubes**

3.3. Compressive Strength of Concrete cubes.

There is a gradual decrease in compressive strength of both the concretes with the increase in replacement percentage of coarse aggregate with LDA and FAA respectively. However, the strength of cubes at 28 days is higher than target strength 26.6 N/mm2 up to 30% replacement of LDA and 40% replacement of FA aggregates. Angular FA Aggregates show more strength than round low density pellets due to more surface area of rough textured FA Aggregates than LDA. Due to more surface area of angular aggregates than round aggregates, it shows high bond strength. Also angular aggregates shows more interlocking effect as compared to round aggregates that is responsible for increase in strength of concrete. It can be concluded that LDA and FAA can be used for coarse aggregates replacement in concrete and it reduces the depletion of natural resources.

Table 4: Results for Compressive Strength of Concrete cubes

% Replacement of Aggregates	7 Days strength(N/mm^2)		28 Days Strength (N/mm^2)	
	LDA Pellets	FA Aggregates	LDA Pellets	FA Aggregates
0	21.75	21.75	33.40	33.40
10	20.52	20.80	31.58	32.35
20	19.01	19.75	29.40	30.86
30	17.19	18.54	26.78	28.53
40	15.95	16.93	24.18	26.62
50	13.66	15.27	21.20	23.38



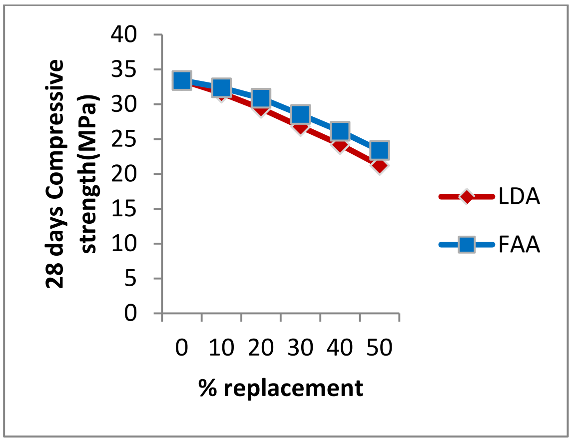


Fig 8: 7 Days Compressive Strength **Fig 9: 28 Days Compressive Strength**

4. CONCLUSIONS

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) LDA (pellets) and 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 when compared to LDA pellets.

iii) Water absorption of LDA (pellets) is 15.23 and FA aggregates is 18.38 which 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) Specific gravities of round fly ash pellets and manufactured angular fly ash aggregates are less than the conventional coarse aggregate (Gravel).

v) LDA (pellets) concrete is more workable than FAAC due to round shape of aggregates which reduces the friction between the aggregate-paste interfaces.

vi) From compressive strength test results, it is clear that angular fly ash aggregates (FAA) performed well compared to round fly ash aggregates (LDA pellets). It is due to more surface area and better interlocking effects of rough textured angular aggregates than round pellets which contributes in strength of concrete.

vii)Though FAA and LDA concrete shows lower values of compressive strength compared to normal aggregate concrete, it fulfils the minimum requirements that is essential for its utilization in structural applications.

REFERENCES

1. Ramamurthy and K.I.Harikrishnan "Influence of binders on properties of sintered fly ash aggregate", *New building materials and construction world journal, June* (2006) (pp: 80 to 88)

2. Kayali O. "Fly ash lightweight aggregates in high performance concrete." *Constr. Building Material*, 22: (2008) 2393-2399

3.Subasi.S , Full length research paper on "The effects of using fly ash on high strength lightweight concrete produced with expanded clay aggregate", *Scientific Research and Essay* Vol. 4 (4) April, (2009), pp. 275-288,.

4. Niyazi Ugur Kockal, Turan Ozturan. Effects of lightweight fly ash aggregate properties on the behaviour of lightweight concretes. *J. Hazard. Material*. 179: (2010) 954-965.

5. Shanmuga sundaram.S. Jayanti. S., Sundararajan. R., Umarani.C. Jagadeesan. K.,. "Study on Utilization of Fly ash aggregates in Concrete."*Modern Applied science*. Vol 4 (5) (2010).

6. Niyazi Ugur Kockal, Turan Ozturan. Durability of lightweight concretes with lightweight fly ash aggregates. *Constr. Build. Material*. 25: (2011) 1430-1438

7. Priyadharshini.P, Mohan Ganesh.G, Santhi.A.S, , Experimental study on Cold Bonded Fly Ash Aggregates, 2, *ISSN 0976 □ 4399*, (2011).

8. Sivakumar.A and Gomati.P. Review on "Pelletized fly ash lightweight aggregate concrete", *Journal of Civil Engineering and Construction Technology* Vol. 3(2), (2011) pp. 42-48.

9. Prasath Kumar.V.R., Anand.K.S, Midhun Kumar.V. "An Experimental Study on Partial replacement of Natural coarse Aggregates with Fly Ash Coarse aggregates (FACA)."*International journal for research in applied science and engineering technology (IJRASET)*. 2(6), (2014), 2321-9653.

10. IS: 383-1970. Specifications for coarse and fine Aggregates from natural sources for concrete, *Bureau of Indian standards, New Delhi, India*

11. IS 2386: 1963 – Methods of tests for aggregates for concrete, *Bureau of Indian standards*, *New Delhi*, *India*

12. IS: 10262-2009. Guidelines for concrete mix design proportioning, *Bureau of Indian standards, New Delhi, India*