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An Experimental Study on Partial Replacement of Natural Coarse Aggregate With Fly Ash Coarse Aggregate (FACA)

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Abstract: A construction industry plays vital role in India which leads into the economic developments. The materials like a cement, fine aggregate & natural coarse aggregate which is used to prepare concrete where once easily available in our country, but now there is high demand in materials which has gone to a high scenario. In this project an experimental investigation is done on the partial replacement of coarse aggregate with fly ash aggregate. The quantity of fly ash produced from thermal power plants in India is approximately 80 million tons each year, and its percentage utilization is less than 10%. Majority of fly ash produced is of Class F type. During the last few years, some cement companies have started using fly ash in manufacturing cement, known as 'pozzolana Portland cement, but the overall percentage utilization remains very low, and most of the fly ash is dumped at landfills. 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 interested 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.The production of fly ash aggregate is produced in ratio of 10:90, 15:85 and 20:80.Based upon the above mix ratio, fly ash aggregates are produced and used for casting the concrete cubes and cylinder for comparing the strength with conventional aggregate concrete at 7 and 28 days curing period.

Keywords: FACA, compressive strength, fl

1. INTRODUCTION

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/m3. This heavy self weight makes an 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 the concrete 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. Because of the above reasons the study on fly ash aggregate concrete is taken in this project work. A mix design was done for M30 grade of concrete by IS method. Ordinary Portland cement of 43 grade was selected and fly ash aggregates were prepared by mixing fly ash with cement and water. The properties of fly ash coarse aggregates were studied. The aggregate crushing value, abrasion value and aggregate impact value of fly ash coarse aggregates were also studied. The concrete cubes, cylinders and beams were cast with the fly ash aggregates obtained from the above six cement fly ash proportions. Then the compressive strength, split tensile strength and flexural strength were tested and compared with control concrete.

2. PREVIOUS STUDY

Selection of mortar for light weight aggregate concrete made with fly ash based aggregate

N.P.Rajamani and *P.S. Ambily*, scientist, SERC, Chennai carried out the research work on They concluded that conversion of fly ash with aggregate is technically feasible

ISSN: 2321-9653

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AN D ENGINEERING TECHNOLOGY (IJRASET)

and are found to be light weight in nature. They found fly ash aggregate concrete up to 20Mpa can be used for production of concrete blocks for masonry construction in structures. They also suggested selecting mortar which can produce fly ash aggregate concrete of strength up to40Mpa. However concrete strengths more than 40Mpa can also be produced using less content of fly ash aggregates.

Light weight concrete with sintered fly ash aggregates

Dr.J.P.Behera, Dr.H.S.Ray, Dr.B.D.Nayak and Dr. B. Sarangi.(2004) Examined the use of sintered fly ash aggregate in concrete as a partial replacement of granite aggregate. A study on partial replacement to normal granite aggregate. Institution of Engineers, India (IE(I)) Journal – CV Vol 85 August'2004, PP 84 to 87. They concluded that in addition to light weight characteristics, the sintered fly ash concrete possesses strength and deformation characteristics similar to concrete with natural granite aggregate.

Effect of fine aggregate replacement with class F fly ash on the mechanical properties of concrete

RafatSiddique Cement and Concrete Research 33 (2003) 539–547 Department of Civil Engineering, Thapar Institute of Engineering and Technology, Deemed University, Patiala 147004, India. Experimental investigation carried out to evaluate the mechanical properties of concrete mixtures in which fine aggregate (sand) was partially replaced with Class F fly ash. Fine aggregate (sand) was replaced with five percentages (10%, 20%, 30%, 40%, and 50%) of Class F fly ash by weight. Tests were performed for properties of fresh concrete. Compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity were determined at 7, 14, 28, 56, 91, and 365 days. Test results indicate significant improvement in the strength properties of plain concrete by the inclusion of fly ash as partial replacement of fine aggregate (sand), and can be effectively used in structural concrete.

3. PROPERTIES OF FLY ASH

PHYSICAL PROPERTIES

Fly ash consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. The carbonaceous material in fly ash is composed of angular particles. The particle size distribution of most bituminous coal fly ashes is generally similar to that of silt (less than a 0.075 mm or No. 200 sieve). Although sub bituminous coal fly ashes are also silt-sized, they are generally slightly coarser than bituminous coal fly ashes. The specific gravity of fly ash usually ranges from 2.1 to 3.0, while its specific surface area (measured by the Blaine air permeability method) may range from 170 to 1000 m^2/kg.

The colour of fly ash can vary from tan to gray to black, depending on the amount of unburned carbon in the ash. The lighter the colour, the lower the carbon content. Lignite or sub bituminous fly ashes are usually light tan to buff in colour, indicating relatively low amounts of carbon as well as the presence of some lime or calcium. Bituminous fly ashes are usually some shade of gray, with the lighter shades of gray generally indicating a higher quality of ash.

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 10% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds.

Table 1 Physical requirements for fly ash (IS 3812-2003)

Characteristics	Siliceous PFA (Class F)	Calcareous PFA (Class C)
Fineness, specific surface area in m^2/kg determined by the Blaine apparatus, min	320	320
Particles retained on 45µm IS sieve (wet sieving), % max	34	34
Lime reactivity, average compressive strength in N/mm^2, min	4.5	4.5
Compressive strength at 28 days, N/mm^2, min	80% of the strength of corresponding plain cement mortar works	80% of the strength of corresponding plain cement mortar works
Soundness, autoclave expansion or contraction, % max	0.8	0.8

ISSN: 2321-9653

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

CHEMICAL PROPERTIES

Fly ash material solidifies while suspended in the exhaust gases and is collected by electrostatic precipitators or filter bags. Since the particles solidify while suspended in the exhaust gases, fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. They consist mostly of silicon dioxide (SiO_2), which is present in two forms: amorphous, which is rounded and smooth, and crystalline, which is sharp, pointed and hazardous; aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3). Fly ashes are generally highly heterogeneous, consisting of a mixture of glassy particles with various identifiable crystalline phases such as quartz, mullite, and various iron oxides.

Two classes of fly ash are defined by ASTM C618: Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite).Not all fly ashes meet ASTM C618 requirements, although depending on the application, this may not be necessary. Ash used as a cement replacement must meet strict construction standards, but no standard environmental standards have been established in the United States. 75% of the ash must have a fineness of 45 µm or less, and have a carbon content, measured by the loss on ignition (LOI), of less than 4%. In the U.S., LOI needs to be under 6%. The particle size distribution of raw fly ash is very often fluctuating constantly, due to changing performance of the coal mills and the boiler performance. Especially important is the ongoing quality verification. This is mainly expressed by quality control seals like the Indian ISI mark or the DCL mark of the Dubai Municipality

Table 2 Chemical requirements for fly ash (IS 3812-2003)

characteristics	Siliceous PFA (~ ASTM Class F)	Calcareous PFA (~ ASTM Class C)
SiO_2+ Al_2O_3 + Fe_2O_3, % by mass, min	70	50
SiO_2, % by mass, min	35	25
Total sulphur as SO_3, % by mass, max	3.0	3.0
MgO, % by mass, max	5.0	5.0
Loss on ignition (LOI), % by mass, max	5.0	5.0
Available alkalis (Na_2Oeq), % by mass, max	1.5	1.5
Total chlorides, % by mass, max	0.05	0.05

Table 3 AASHTO M 295 (ASTM C 618) - Class F and C

Chemical Components	Range %	Class F	Class C
SiO_2 + Al_2O_3 + Fe_2O_3	min	70[1]	50
SiO_3	Max	5	5
Moisture Content	Max	3	3
Loss on ignition (LOI)	Max	5[1]	5[1]
Optional Chemical Requirements	Range%	Class F	Class C
Available alkalies	Max	1.5	1.5

Vol. 2 Issue VI, June 2014
ISSN: 2321-9653

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

Physical Requirements	Range%	Class F	Class C
Fineness (+325 Mesh)	Max	34	34
Pozzolanic activity/cement (7 days)	Min	75	75
Pozzolanic activity/cement (28 days)	Min	75	75
Water requirement	Max	105	105
Autoclave expansion	Max	0.8	0.8
Uniform requirements[2]: density	Max	5	5
Uniform requirements[2]: Fineness	max	5	5

Table 4 Influence of type of fly ash on its properties

Properties	Class C fly ash	Class F fly ash
Early strengths (< 28 days)	Very effective; Can replace cement 1:1	Effective; May replace cement as high as 1:2
Reduce Permeability	Effective	Very effective
Resistance to ASR	Effective but may require higher amounts	Very effective even at lower amounts
Resistance to sulphate attack	Less effective	Very effective

4. CLASSIFICATION OF FLY ASH

ASTM C618 Defines two classes of fly ash:

- Class C
- Class F

Primary difference between Class C and Class F fly ash is the amount of the amount of calcium, silica, alumina, and iron content in the ash.

Class F fly ash

- Produced from burning harder, older anthracite and bituminous coal.
- Contains less than 20% lime
- Requires cementing agent like PC, quick lime, hydrated lime
- Used in high sulfate exposure conditions
- Addition of air entrained needed
- Used for structural concretes, HP concretes, high sulfate exposure concretes.
- Useful in high fly ash content concrete mixes.

Class C fly ash

- Produced from burning younger lignite and sub bituminous coal
- Higher concentration of alkali and sulfate
- Contains more than 20% lime
- Self-cementing properties
- Does not require activator
- Not for use in high sulfate conditions
- Primarily residential construction
- Limited to low fly ash content concrete mixes

5. CURRENT MANAGEMENT OPTIONS

The quantity of fly ash produced from thermal power plants in India is approximately 80 million tons each year, and its percentage utilization is less than 10%. Majority of fly ash produced is of Class F type

Recycling and disposal

In 1996, approximately 14.6 million metric tons (16.2 million tons) of fly ash were used. Of this total, 11.85 million metric tons (13.3 million tons), or approximately 22 percent of the total quantity of fly ash produced, were used in construction-related applications. Table lists the leading construction applications in which fly ash were used during 1996. Approximately 70 to 75 percent of fly ash generated is still disposed of in landfills or storage lagoons.

Table 5 Fly ash construction-related applications (2011)

ISSN: 2321-9653

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

Applications	Quantity Used		
	Million Metric Tons	Million Tons	Percentage of Total used
Cement production and/or concrete products	7.2	8.0	60
Structural fills or embankments	1.9	2.2	17
Stabilization of waste materials	1.7	1.9	14
Road base or sub base materials	0.63	0.7	5
Flow able fill and grouting mixes	0.27	0.3	2
Mineral filler in asphalt paving	0.15	0.2	2
Approximate Total	11.85	13.3	100

6. PRODUCTION OF FLY ASH AGGREGATE

Proportion of fly ash aggregates

The constituents like cement, fly 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 6 Proportions for cement and fly ash

Ratio	Cement (%)	Fly Ash (%)
R1	10	90
R2	15	85
R3	20	80

Preparation of FAA

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.

Pelletisation

It is a process of agglomeration of moisturized fines in a rotating drum or disc, to produce ‘fresh pellet’ having strength enough for further handling. Formation of pellets is based on the mechanism involved in balling phenomenon of powdery materials. When a fine-grained material is moisturized, a thin liquid film develops on the surface of each grain and bridges are formed at points where the moisturized particles contact each other. The particles are rotated into balls bonding forces develop gradually. The initial bonding between particles is due to a water bridge or meniscus. When more liquid is added, the liquid film on the particle surface began to coalesce, but closed and air-filled cavities remain between the grains. The ball grows as more moisturized particles are coated onto the nucleus. Mechanical forces, produced by the balls bumping against each other and against the walls of the rotating device, expel the air enveloped in the balls. At this capillary stage, the liquid fills the free space between the particles. The filled pores become bridged over, and the capillary forces affect the particle coherence throughout the whole ball. The concave membrane on the surface of the liquid seals surface pores. Under uneven or excessive moisturizing, particle clusters are enveloped in the droplets that tend to produce large, irregular entities. Grain size distribution and surface texture of the material influence the efficiency of pelletisation process.In the present study green pellets were produced from a mixture of fly ash, ordinary Portland cement and water as binder in the concrete mixer, which performed as a pelletiser.

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.

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Figure 1 Formations of fly ash aggregates

Figure 2 Prepared sample of FAA

Figure 3 Curing of FAA

Segregation of fly ash aggregates

The cured aggregates are allowed to dry completely for segregating fine and coarse aggregates based on particle size. Sieving is adopted for the separation of aggregates.

Fly ash coarse aggregates have a size above 4.75mm to 20mm and fly ash fine aggregates have a size of less than 4.75mm. Fly ash aggregates of size 20mm are separated and used as coarse aggregate.

7. TESTING THE STRENGTH OF CONCRETE

Sieve analysis of fly ash aggregate

The blow graph shown the sieve analysis of fly ash aggregate

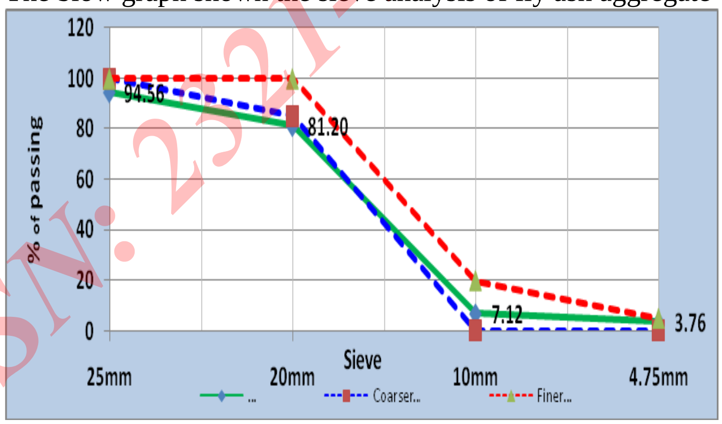


Figure 4 Sieve analysis of fly ash aggregate

specific gravity of fly ash aggregate

The specific gravity of fly ash aggregate can be obtain by using the formula given below

$$\text{Specific gravity} = \frac{\text{Dry weight of aggregate}}{\text{Weight of equal volume of water}}$$

Table 7 Specific gravity of FAA

Ratio	Specific gravity	Limits	Water absorption	Limits %
10:90	1.72	2.5 to 3.0	22.47%	0.1 to 2.0
15:85	1.83	2.5 to 3.0	20.41%	0.1 to 2.0
20:80	1.97	2.5 to 3.0	19.90%	0.1 to 2.0

Impact value of fly ash aggregate

The impact value of fly ash aggregate can be obtain by using the formula given below

Vol. 2 Issue VI, June 2014

ISSN: 2321-9653

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

$$\text{Aggregate Impact value} = \frac{\text{Weight of passing through 2.36mm sieve}}{\text{Weight of sample}} \times 100$$

Table 8 Impact value of FAA

Ratio	Impact value	Limits
10:90	53.6%	Not more than 45%
15:85	47.9%	Not more than 45%
20:80	45%	Not more than 45%

Crushing value of fly ash aggregate

The crushing value of fly ash aggregate can be obtain by using the formula given below

$$\text{Aggregate crushing value} = \frac{\text{Weight of passing through 2.36mm sieve}}{\text{Weight of sample}} \times 100$$

Table 9 Crushing value of FAA

Ratio	Crushing value	Limits
10:90	28.5%	Not exceed 30%
15:85	25.6%	Not exceed 30%
20:80	24.9%	Not exceed 30%

Abrasion value of fly ash aggregates

The abrasion value of fly ash aggregate can be obtain by using the formula given below

$$\text{Abrasion Value} = \frac{\text{Weight passing 1.7mm IS sieve}}{\text{Weight of aggregate sample}} \times 100$$

Table 10 Abrasion value of FAA

Ratio	Abrasion value	Limits
10:90	52.43%	vary from 30.0 to 50.0 percent
15:85	49.76%	vary from 30.0 to 50.0 percent
20:80	48.34%	vary from 30.0 to 50.0 percent

CONCRETE MIX DESIGN

IS method of mix design is based on IS 10262-1982

Table 11 Concrete Mix Design

Grade / Type of Mix	M30 Grade	M30 Grade	M30 Grade
Trial Mix Reference no.	FAAC 1	FAAC 2	FAAC 3
Material	Design	Design	Design
OPC	350	350	350
20mm Coarse Aggregates	548	548	548
Fly Ash Aggregates	385 (15:85)	385 (10:90)	385 (20:80)
River Sand	736	736	736
Water	183	180	178
Conplast SP430	0.52	0.51	0.48
Total	2202	2199	2197
Water to Cement Ratio	0.54	0.51	0.50
Workability – Slump Test Value in mm			
Initial	130	130	170

Vol. 2 Issue VI, June 2014
ISSN: 2321-9653

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

@ 45min	80	110	70

COMPRESSIVE STRENGTH OF CONCRETE (CUBES)

15cm x 15cm x 15cm concrete cubes were tested as per IS 516-1959. The test was conducted in 120Tcompression testing machine. The load was applied at the rate approximately 140kg/cm2/min until the failure of the specimen. The maximum load applied to the specimen until failure was reco[...]

Strength Result [...] and CCAC

T[...]essive strength of concrete gives an idea about the o[...]lity of a concrete.

Table 12 Comp[...]ength of FAAC and CCAC

Sl. No.	Structure Concerned		Age in days	Actual weight kg	Dial Reading/ max load (kN)	Comp. Strength (N/mm^2)	Average Comp. Strength (N/mm^2)
1	conventional concrete	M30	7	8.26	590	26.1	26.3
				8.30	595	26.5	
			28	8.38	850	37.9	38.2
				8.34	860	38.5	
2	M30 FAAC (Ratio 10:90)	M30	7	7.97	500	22.2	22.7
				8.05	520	23.2	
			28	8.10	750	33.2	33.4
				8.21	755	33.6	
3	M30 FAAC(Ratio 15:85)	M30	7	7.95	520	23.0	24
				7.98	560	25.0	
			28	8.13	815	36.2	37.3
				8.10	860	38.4	
4	M30 FAAC(Ratio 20:80)	M30	7	8.08	590	26.1	25.2
				8.10	545	24.3	
			28	8.13	770	34.2	35.1
				8.17	810	36.0	

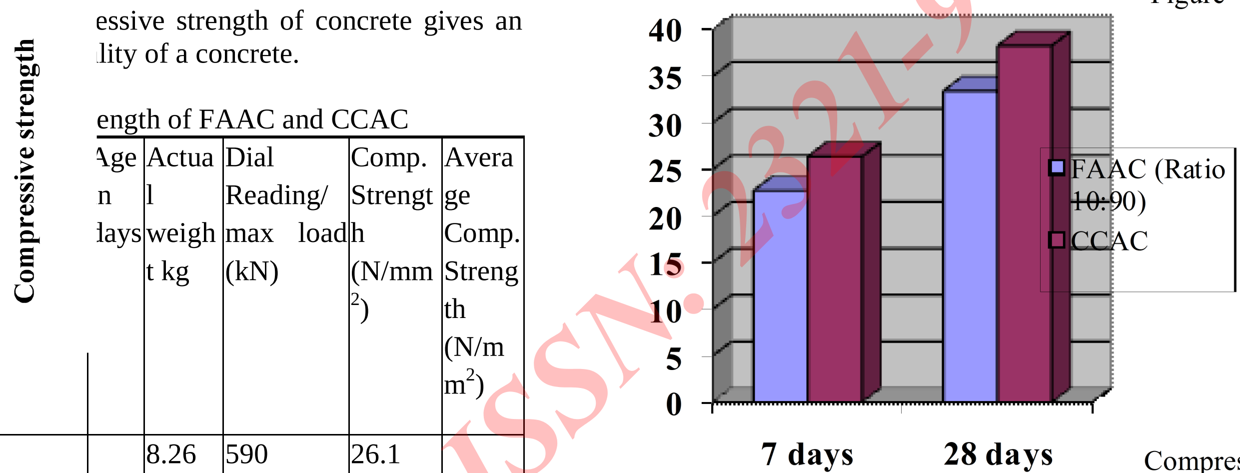
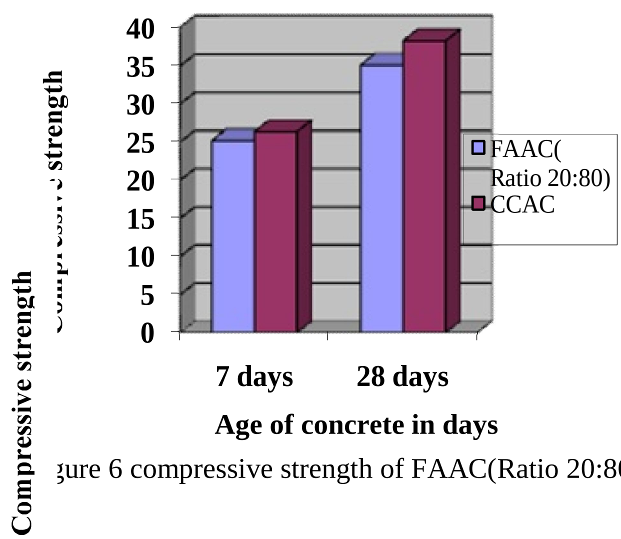


Figure 5 Compressive strength of FAAC (Ratio 10:90) and CCAC



gure 6 compressive strength of FAAC(Ratio 20:80) CCAC

Vol. 2 Issue VI, June 2014

ISSN: 2321-9653

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

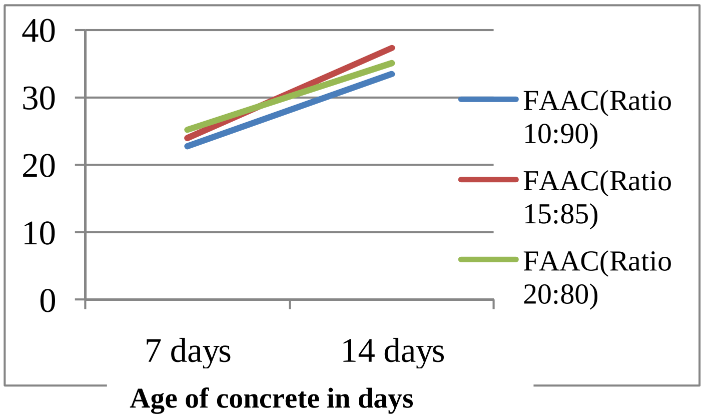


Figure 7 Compressive strength of FAAC

Inference: The compressive strength of FAAC is found to be 24 N/mm ^{2} at 7th day for 15:85 ratio same at 7th day compressive strength in CCA concrete 26.37N/mm ^{2} .This shows the FAAC strength at 7th almost equal to CCA.An end of 28th day compressive strength for FAAC and CCA is almost equal.

CONCRETE SPLIT TENSILE STRENGTH

Concrete cylinders of 15cm diameter and 30 cm height were tested for Split tensile strength as per IS 5816-1976.The specimen was placed horizontally between the loading surfaces of the compression testing machine and the load was applied without shock until the failure of the specimen. The maximum load at failure was recorded.

Table 12 Concrete Split Tensile Strength

Sl. No.	Structure Concreted	Grade of Concrete	Age in days	Actual weight kg	Dial Reading/max load (kN)	Comp. Strength (N/mm^2)	Average Comp. Strength (N/mm^2)
1	conventional concrete	M30	7	13.528	340	4.8	4.9
				13.523	355	5.0	
			28	13.485	400	5.6	5.7
				13.541	420	5.9	
2	M30 FAAC (Ratio 10:90)	M30	7	13.170	280	4.0	4.1
				13.187	300	4.2	
			28	13.220	360	5.1	4.9
				13.234	330	4.7	
3	M30 FAAC (Ratio 15:85)	M30	7	13.197	310	4.3	4.3
				13.205	310	4.3	
			28	13.254	350	4.9	5.0
				13.235	360	5.1	
4	M30 FAAC (Ratio 20:80)	M30	7	13.215	310	4.3	4.2
				13.205	290	4.1	
			28	13.255	370	5.2	5.1
				13.240	360	5.0	

Split tensile strength

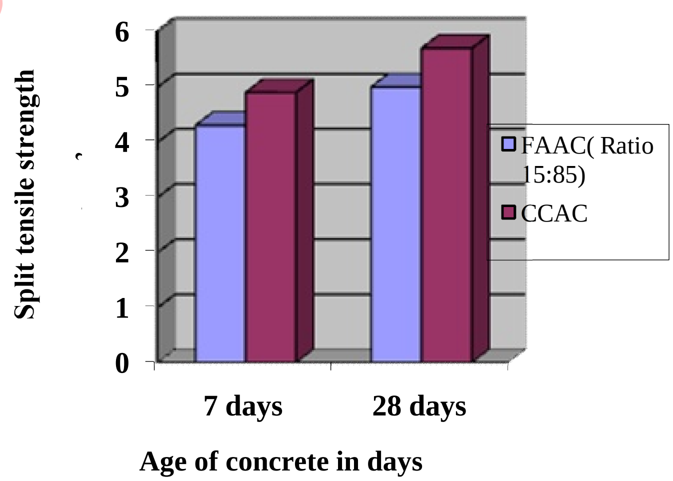


Figure 8 Split tensile strength of FAAC (Ratio 15:85) and CCAC

Vol. 2 Issue VI, June 2014

ISSN: 2321-9653

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

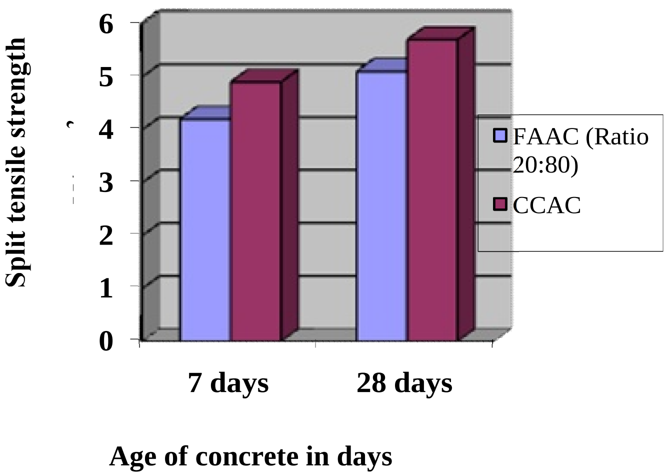


Figure 9 Split tensile strength of FAAC (Ratio 15:85) and CCAC

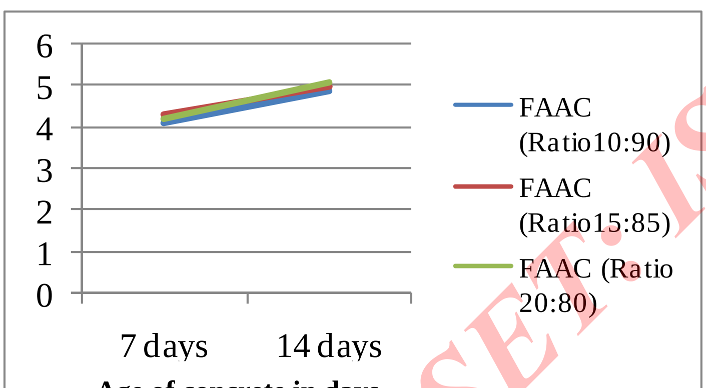


Figure 10 Split tensile strength of FAAC

Inference: The split tensile strength of FAAC is found to be 4.3 N/mm ^{2} at7th day for 15:85 ratio same at 7th day split tensile strength in CCA concrete 4.9N/mm ^{2} .This shows the FAAC strength at 7th almost equal to CCA. An end of 28th day split tensile strength for FAAC and CCA is almost equal.

FLEXURAL STRENGTH

The concrete beams of size 10cm x 10cm x 50cm were tested as per IS 516-1959. The load was applied through two similar rollers mounted at one third points of the supporting span. The load was applied without shock until the failure occurs. The maximum load at failure was recorded.

Table 13 Flexural strength of FAAC &CCAC

Sl. No.	Structure	Grade of	Age in	Average Flexural

	Concreted	Concrete	days	strength (N/mm^2)
1	conventional concrete	M30	7	4.8
			28	6.3
2	M30 FAAC (Ratio 10:90)	M30	7	3.5
			28	4.2
3	M30 FAAC (Ratio 15:85)	M30	7	3.9
			28	4.7
4	M30 FAAC (Ratio 20:80)	M30	7	3.9
			28	4.5

ISSN: 2321-9653

INTERNATIONAL JOURNAL FOR RESEARCH IN APPLIED SCIENCE AND ENGINEERING TECHNOLOGY (IJRASET)

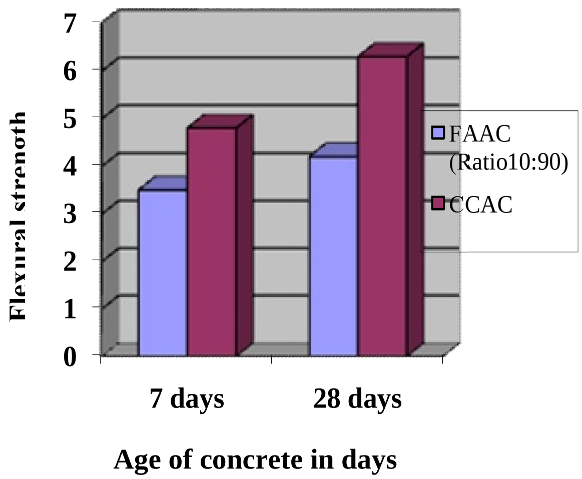


Figure 11 Flexural strength of FAAC (Ratio 10:90) and CCAC

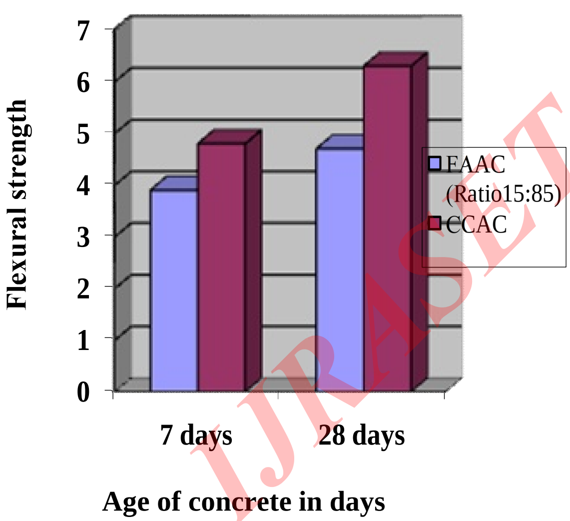
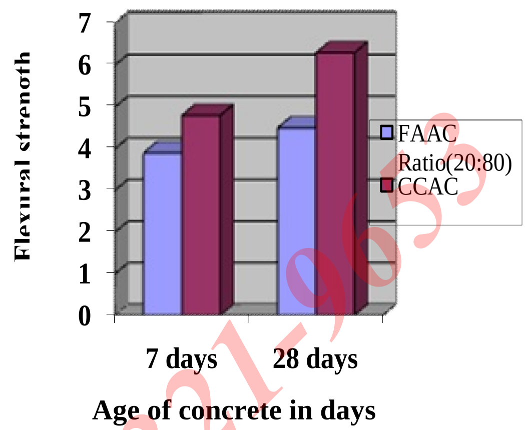


Figure 12 Flexural strength of FAAC (Ratio 15:85) and CCAC



ure 13 Flexural strength of FAAC (Ratio 20:80) and AC

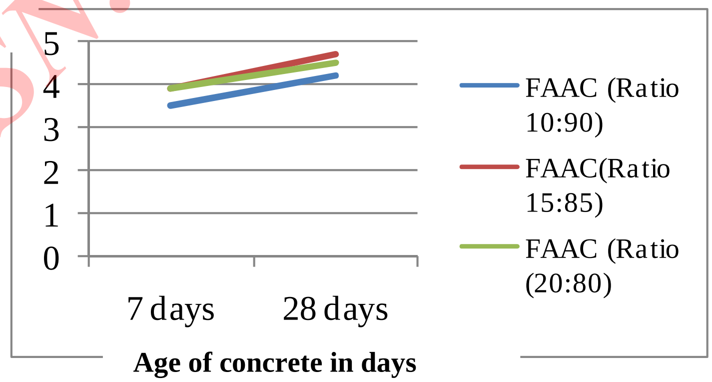


Figure 14 Flexural strength of FAAC

Inference: The flexural strength of FAAC is found to be 3.9 N/mm ^{2} at7th days for 15:85 ratio same at 7th day flexural strength in CCA concrete 4.8N/mm^2 .This shows the FAAC strength at 7th almost equal to CCA.An end of 28th day flexural strength for FAAC and CCA is almost equal.

7. CONCLUSION

Based upon the test carried out on compressive strength, Flexural strength and Split tensile strength test for conventional aggregate concrete and fly ash aggregate concrete.

On comparing the test result for CCAC & FAAC it is founded that the value is almost same for both concretes. This shows fly ash aggregate concrete has an equal strength while comparing to CCAC.

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Therefore FAA can be recommended as coarse aggregate for preparing of concrete which will reduce the usage of natural aggregate.

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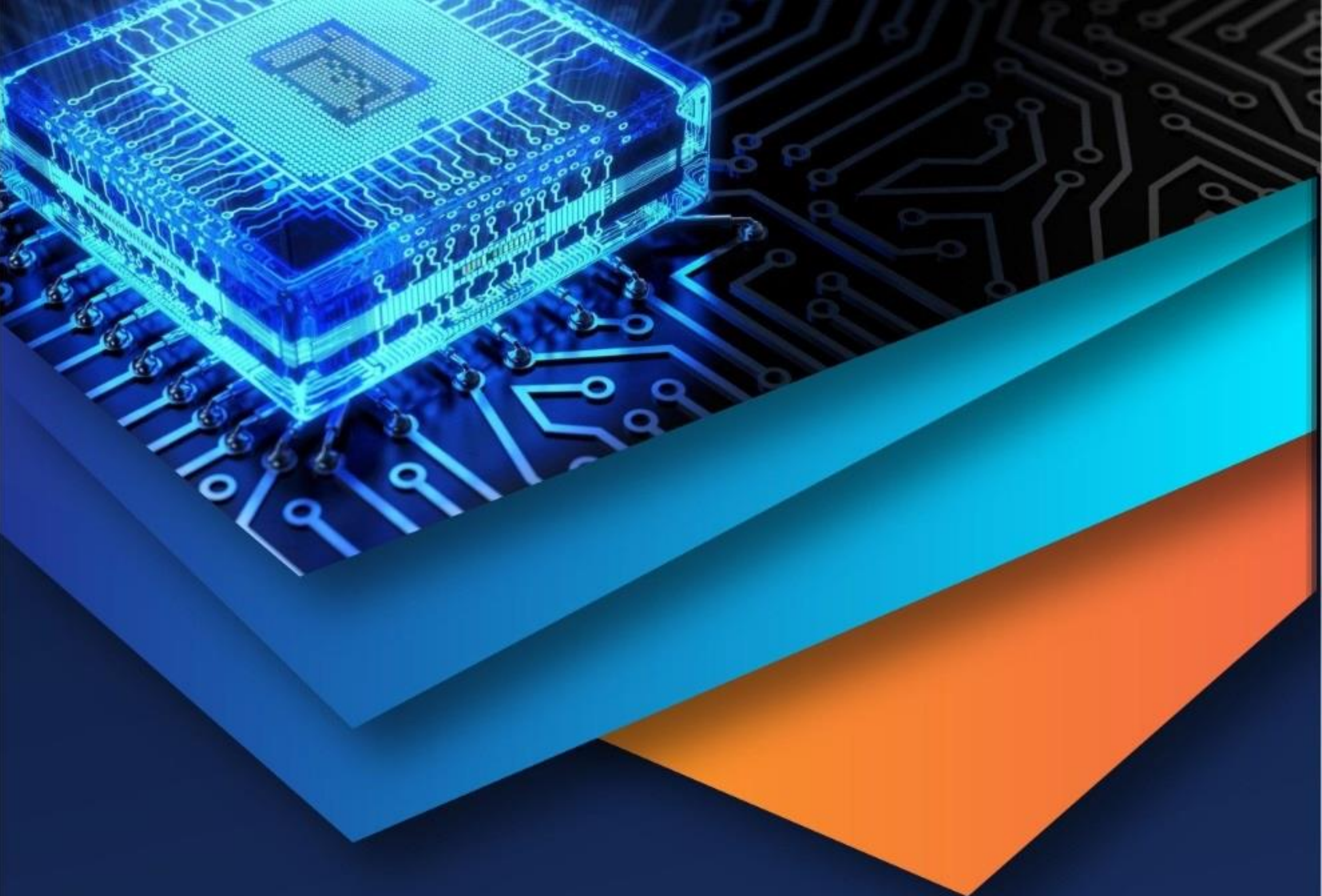

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