

Study on Utilization of Fly Ash Aggregates in Concrete

S. Shanmugasundaram

Assistant Professor/Civil, MPNMJ Engineering College, Chennimalai. – 638 112, India

Dr. S. Jayanthi

Assistant Professor/Civil, Thanthai Periyar Government Institute of Technology, Vellore – 632 002, India

Dr. R. Sundararajan

Principal, Government College of Technology, Coimbatore, India

Dr. C. Umarani

Assistant Professor/Civil, College of Engineering, Guindy, India

Dr. K. Jagadeesan

Principal, MPNMJ Engineering College, Chennimalai – 638 112, India

Abstract

In this study, the fine and coarse aggregates were completely replaced by fly ash aggregates in fly ash concrete. A mix design was done for M20 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 fine aggregates and fly ash coarse aggregates were studied. The aggregate crushing value and aggregate impact value of fly ash coarse aggregates were also studied. The cement and fly ash proportions of 10:90, 12.5:87.5, 15:85, 17.5:82.5, 20:80 and 22.5:77.5 were tried with a suitable water cement ratio 0.3 to get the fly ash aggregates. 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. This paper briefly presents the compressive strength development of fly ash aggregate concrete at different ages. The split tensile strength and flexural strength of all the concrete mixes were also investigated at different days of curing.

Keywords: Fly ash aggregates (FAA), Fly ash Fine Aggregates (FAFA), Fly ash Coarse Aggregate (FACA), Fly ash Aggregate Concrete (FAAC), Compressive Strength, Split tensile strength, Flexural strength, Control concrete (CC)

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 research work.

2. Materials Used

The following materials were used for preparing the test specimens

- i) Ordinary Portland cement 43 grade conforming to IS:8112-1989
- ii) Fly ash (FA) obtained from Thermal power plant, Mettur conforming 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, 12.5:87.5, 15:85, 17.5:82.5, 20:80 and 22.5:77.5.
- 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 10:90,12.5:87.5,15:85,17.5:77.5,20:80 and 22.5:77.5
- vii) Bore well water of MPNMJ Engineering College Campus for mixing and curing of specimens.

3. Properties of Aggregates

Table 1. Physical properties of Conventional Fine Aggregate (CFA) and Fly ash fine aggregate (FAFA)

S. No	Properties	CFA	(FAFA)
1	Specific gravity	2.70	1.28
2	Bulk density (Kg/m ³)	1808	838
3	Size (mm)	Below 4.75	Below 4.75
4	Fineness modulus	2.68	2.70

Table 2. Physical properties of Conventional Coarse Aggregate (CCA) and Fly ash Coarse Aggregate (FACA)

S. No	Properties	CCA	FACA
1	Shape	Angular	Spherical
2	Specific gravity	2.75	1.3
3	Bulk density (Kg/ m ³)	1685	913
4	Size (mm)	4.75mm to 20mm	4.75mm to 20mm
5	Crushing value (%)	24.94	25.6
6	Impact Value (%)	23.86	21.6

Table 3. 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. The comparison of chemical composition of fly ash produced at MTPS to that of world's standard is as below.

Chemical Composition			
Constituent		World Std. %	Fly ash used in thesis work %
Silica	SiO ₂	62.57	54.92
Alumina	Al ₂ O ₃	31.45	23.04
Ferric Oxide	Fe ₂ O ₃	1.87	-
Titanium Dioxide	TiO ₂	1.45	-
Manganese Oxide	MnO	0.005	-
Calcium Oxide	CaO	0.40	3.84
Magnesium Oxide	MgO	0.38	2.82
Sodium Oxide	Na ₂ O	0.05	-
Potassium Oxide	K ₂ O	0.82	-
Iron	Fe ₂ O	-	6.62
Phosphorus	P ₂ O ₅	-	0.30
Alkalimetal's Oxide		-	2.70
Sulphur	SO ₃	-	0.76
Magnesium	Mgo	-	2.82
Loss on Ignition	LOI	1.0	2.88

Table 4. Comparison of Workability of FAAC with Conventional Concrete

Type of Concrete	Workability Test			
	Slump (mm)	Workability	Compaction factor	Workability
Control concrete	40	Medium	0.91	High
Fly ash aggregate concrete	60	Medium	0.9	High

4. 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.

5. Proportions for Fly Ash Aggregates

Cement and fly ash are constituents for preparation of the aggregates. Also water is the binder when it is added to increase the workability. Six different proportions of cement and fly ash such as 10:90, 12.5:87.5, 15:85, 17.5:82.5, 20:80 and 22.5:77.5 were tried.

6. 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. The fly ash aggregates are shown in figure 1.

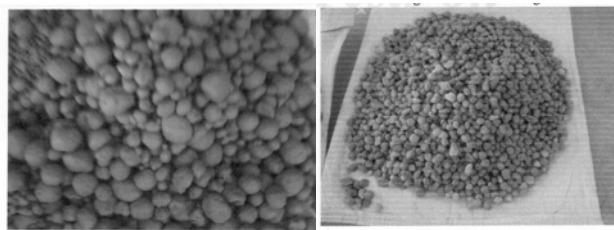


Figure 1. Fly ash Aggregates

7. Drying and Curing of Fly Ash Aggregates

The fly ash aggregates were taken out from the mixer and allowed to dry for a day. Then the aggregates were cured in a water tank for 7 days.

8. Segregation of Fly Ash Aggregates

After curing, they were segregated into fine and coarse aggregates based on size of pellets as shown in figure 2. 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.

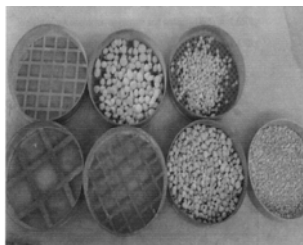


Figure 2. Segregation of fly ash aggregates

9. Mix Proportions

Mix design for M20 grade concrete was done by using IS method. As per the design, the mix proportion is 1:1.53:2.68:0.5.

10. Casting of Test Specimens

The Concrete Cubes (control specimens) of size 15cm x 15cm x 15cm were cast by using conventional fine aggregate (CFA) and conventional coarse aggregate (CCA) and using fly ash fine and fly ash coarse aggregates obtained from the above six cement fly ash proportions. The specimens were demoulded after 1 day and immersed in water for 1, 3, 7, 14, 28, 56 and 90days for curing.

Similarly 3 fly ash concrete cubes each were cast using fly ash aggregates obtained from cement fly ash proportions 12.5:87.5, 15:85, 17.5:82.5, 20:80 and 22.5:77.5 for different days of curing.

The concrete cylinders (Control Specimens) of diameter 15cm and height 30cm were cast by using conventional fine aggregate (CFA) and conventional coarse Aggregate (CCA). For FAAC, the specimens were cast with fly ash fine aggregates (FAFA) and fly ash coarse aggregates (FACA) obtained from the above six cement fly ash proportions. The specimens were demoulded after 1 day and immersed in water for 7 days and 28 days for curing.

Similarly 3 fly ash concrete cylinders were cast using fly ash aggregates obtained from cement fly ash proportions 12.5:87.5, 15:85, 17.5:82.5, 20:80 and 22.5:77.5 for ages of concrete 7 days and 28 days curing.

The concrete beams of (control specimens) of size 100mmX100mmX500mm were cast using conventional fine aggregate (CFA) and conventional coarse aggregate (CCA). For FAAC, the specimens were cast with fly ash fine aggregates (FAFA) and fly ash coarse aggregates (FACA) obtained from the above six cement fly ash proportions. The specimens were demoulded after 1 day and immersed in water for 7 days and 28 days for curing.

Similarly 3 fly ash concrete beams were cast using fly ash aggregates obtained from cement fly ash proportions 12.5:87.5, 15:85, 17.5:82.5, 20:80 and 22.5:77.5 for ages of concrete 7 days and 28 days.

11. 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 140kg/cm²/min until the failure of the specimen. The maximum load applied to the specimen until failure was recorded and shown in Table – 5.

Table 5. Compressive strength of fly ash aggregate concrete and control concrete with different ages of testing

Age of testing	Proportion Cement : Fly ash	Compressive Strength in N/mm ²
1 day	10 :90	2.62
	12.5:87.5	2.76
	15 :85	3.84
	17.5:82.5	2.57
	20 :80	2.21
	22.5:77.5	2.13
	Control concrete	3.33
3 days	10 :90	6.41
	12.5:87.5	6.55
	15 :85	9.43
	17.5:82.5	6.81
	20 :80	6.61
	22.5:77.5	6.28
	Control concrete	8.37
7 days	10 :90	11.62
	12.5:87.5	12.89
	15 :85	15.93
	17.5:82.5	13.10
	20 :80	12.90
	22.5:77.5	10.24
	Control	14.34

	concrete	
14 days	10 :90	14.20
	12.5:87.5	15.60
	15 :85	20.24
	17.5:82.5	16.20
	20 :80	15.80
	22.5:77.5	12.60
	Control concrete	17.62
28 days	10 :90	16.30
	12.5:87.5	17.23
	15 :85	23.71
	17.5:82.5	17.90
	20 :80	17.20
	22.5:77.5	14.80
	Control concrete	20.80
56 days	10 :90	17.12
	12.5:87.5	18.26
	15 :85	25.35
	17.5:82.5	19.20
	20 :80	18.32
	22.5:77.5	16.19
	Control concrete	22.44
90 days	10 :90	19.10
	12.5:87.5	19.40
	15 :85	27.03
	17.5:82.5	20.18
	20 :80	19.54
	22.5:77.5	18.64
	Control concrete	24.96

Fly ash aggregate concrete with fly ash aggregates prepared from cement fly ash proportions 15:85 showed 15%, 13%, 11%, 15%, 14%, 13% and 8% increase in Compressive strength at the ages of 1day, 3days, 7days, 14days, 28days, 56days and 90days respectively over the control concrete.

Fly ash aggregate concrete with fly ash aggregates prepared from other cement fly ash proportions 10:90, 12.5:87.5, 17.5:82.5, 20:80 and 22.5:77.5 showed reduction in compressive strength at the ages of 1day, 3days, 7days, 14days, 28days, 56days and 90days respectively over control concrete.

11.1 Development of Strength compared with respective 28days Compressive Strength

The strength development of control concrete compared with its corresponding 28days strength are 16%, 40%, 69%, 85%, 108% and 120% for 1, 3, 7, 14, 56 and 90days respectively.

The strength development of fly ash aggregate concrete with aggregates made from cement fly ash proportion 10:90 compared with its corresponding 28days strength are 16%, 39%, 71%, 87%, 105% and 117% for 1, 3, 7, 14, 56 and 90days respectively.

The strength gain for fly ash aggregate concrete with fly ash aggregates made from cement fly ash proportion 12.5:87.5 compared with its corresponding 28 days strength are 16%, 38%, 75%, 91%, 106% and 113% for 1, 3, 7, 14, 56 and 90days respectively.

The strength gain for fly ash aggregate concrete with fly ash aggregates made from cement fly ash proportion 15:85 compared with its corresponding 28days compressive strength are 16%, 40%, 67%, 85%, 106% and 114% at the age of 1, 3, 7, 14, 56 and 90days respectively.

The compressive strength gain at the ages of 1, 3, 7, 14, 56 and 90days for the fly ash aggregate concrete with fly ash aggregates made using cement fly ash proportion 17.5:82.5 are 14%, 38%, 73%, 91%, 107% and 113% respectively.

The strength gain for the fly ash aggregate concrete containing fly ash aggregates made by using cement fly ash proportion 20:80 showed the compressive strength at 1, 3, 7, 14, 56 and 90days were 13%, 38%, 75%, 92%, 107% and 114% respectively when compared to its 28days strength.

When comparing the strength gain at 28days of fly ash aggregate concrete with fly ash aggregates obtained from cement fly ash proportion 22.5:77.5 was 23%, 42%, 69%, 85%, 109%, and 126% at the ages of 1, 3, 7, 14, 56 and 90days respectively.

12. Split Tension Test

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 tabulated in Table - 6.

Table 6. Split tensile strength of fly ash aggregate concrete and control concrete with different ages of testing

Age of testing	Proportion Cement : Fly ash	Splitting tensile Strength in N/mm ²
7 days	10:90	3.15
	12.5:87.5	3.45
	15:85	4.60
	17.5:82.5	3.20
	20:80	3.05
	22.5:77.5	2.95
	Control concrete	4.10
28 days	10:90	3.70
	12.5:87.5	4.10
	15:85	5.56
	17.5:82.5	3.90
	20:80	3.65
	22.5:77.5	3.20
	Control concrete	4.84

The fly ash aggregate concrete beam with fly ash aggregate made from cement fly ash proportion 15:85 showed an increase in split tensile strength of 12% and 15% respectively at the ages of 7days and 28days compared with control concrete beam.

The cement fly ash proportions of 10:90, 12.5:87.5, 17.5:82.5, 20:80 and 22.5:77.5 showed reduction in split tensile strength of 35%, 16%, 22%, 26%, and 28%, respectively at the age of curing in 7days and 24%, 15%, 19%, 25%, and 34%, respectively at the age of curing in 28 days than control concrete specimen.

13. Flexural Strength Test

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 tabulated in Table - 7.

Table 7. Flexural strength of fly ash aggregate concrete and control concrete with different ages of testing

Age of testing	Proportion Cement : Fly ash	Flexural Strength in N/mm ²
7 days	10:90	4.10
	12.5:87.5	4.50
	15:85	5.49
	17.5:82.5	4.40
	20:80	4.20
	22.5:77.5	3.95
	Control concrete	4.95
28 days	10:90	4.40
	12.5:87.5	4.75
	15:85	6.22
	17.5:82.5	4.60
	20:80	4.35
	22.5:77.5	4.15
	Control concrete	5.36

The fly ash aggregate concrete containing fly ash aggregate made from cement fly ash proportion 15:85 showed increase in flexural strength of 11% and 16% respectively at the ages of curing in 7days and 28days than the control concrete specimen.

The cement fly ash proportions 10:90, 12.5:87.5, 17.5:82.5, 20:80 and 22.5:77.5 showed reduction in flexural strength of 17%, 9%, 11%, 15%, and 20%, respectively at the age of curing in 7days and 18%, 11%, 14%, 18%, and 23%, respectively at the age of curing in 28days than control concrete specimen.

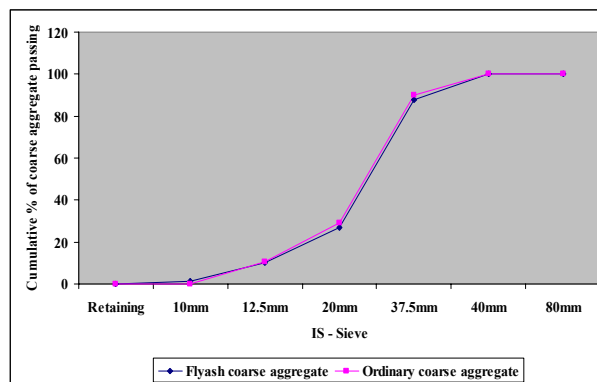


Figure 3(a). Grading curves for conventional coarse aggregate and fly ash coarse aggregate

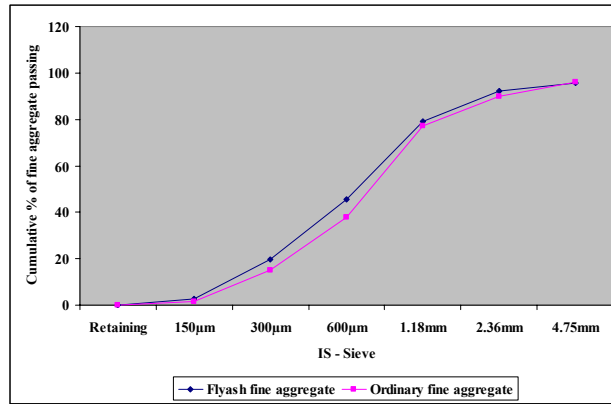


Figure 3 (b). Grading curves for conventional fine aggregate and fly ash fine aggregate

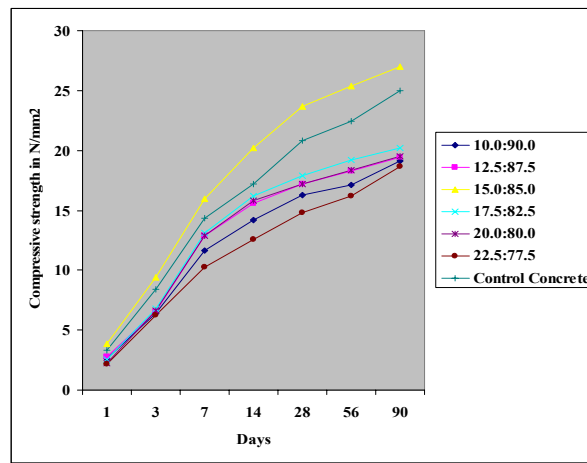


Figure 4. Comparison of Compressive strength of fly ash aggregate concrete and control concrete vs Number of days of curing

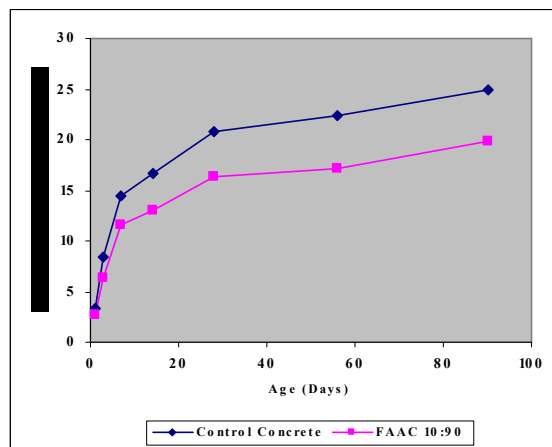


Figure 5. Comparison of compressive strength of control concrete and FAAC with FAA obtained from cement fly ash proportion 10:90 vs Number of days of curing

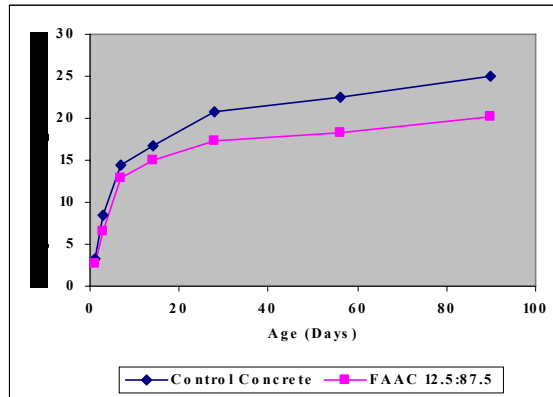


Figure 6. Comparison of compressive strength of control concrete and FAAC with FAA obtained from cement fly ash proportion 12.5:87.5 vs Number of days of curing

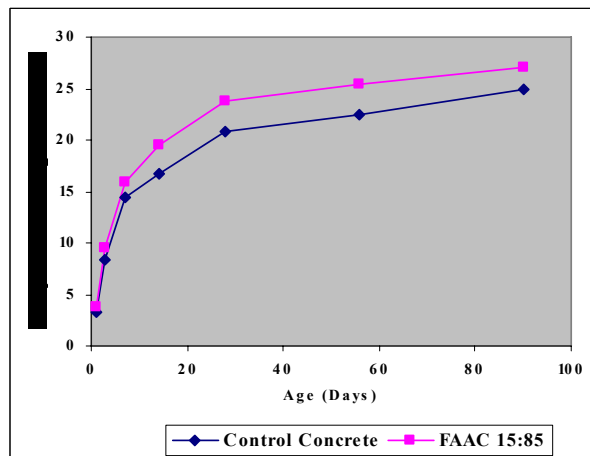


Figure 7. Comparison of compressive strength of control concrete and FAAC with FAA obtained from cement fly ash proportion 15:85 vs Number of days of curing

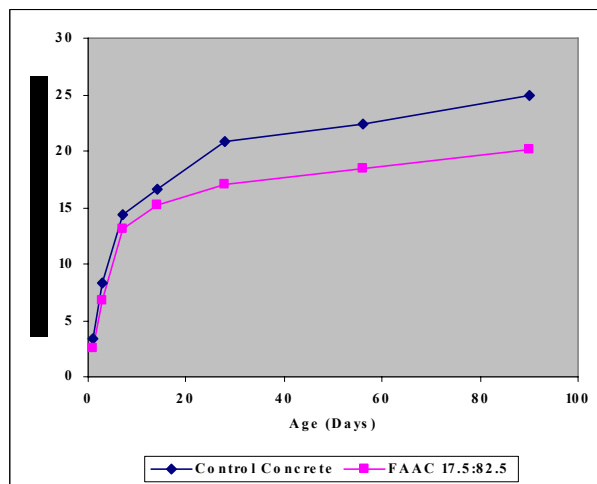


Figure 8. Comparison of compressive strength of control concrete and FAAC with FAA obtained from cement fly ash proportion 17.5:82.5 vs Number of days of curing

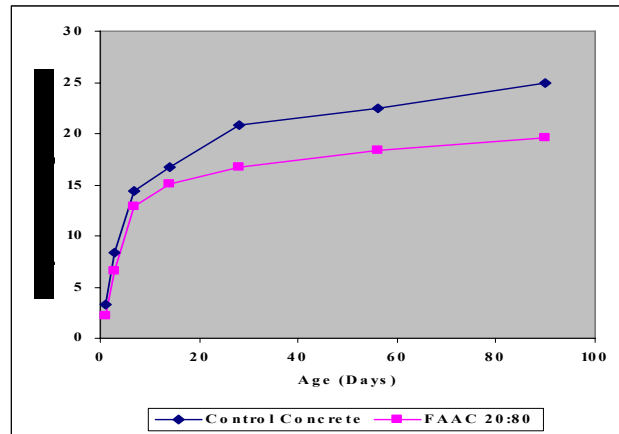


Figure 9. Comparison of compressive strength of control concrete and FAAC with FAA obtained from cement fly ash proportion 20:80 vs Number of days of curing

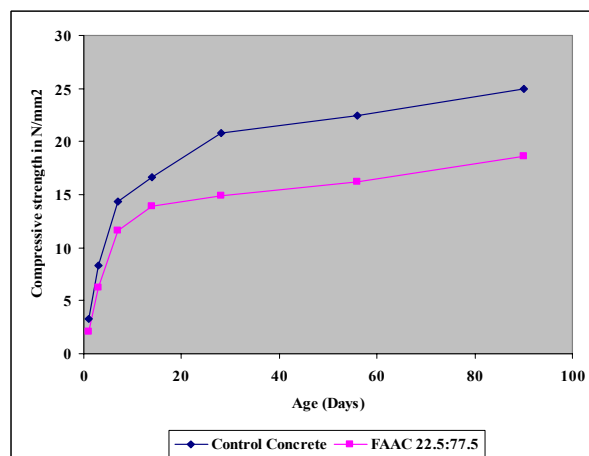


Figure 10. Comparison of compressive strength of control concrete and FAAC with FAA obtained from cement fly ash proportion 22.5:77.5 vs Number of days of curing

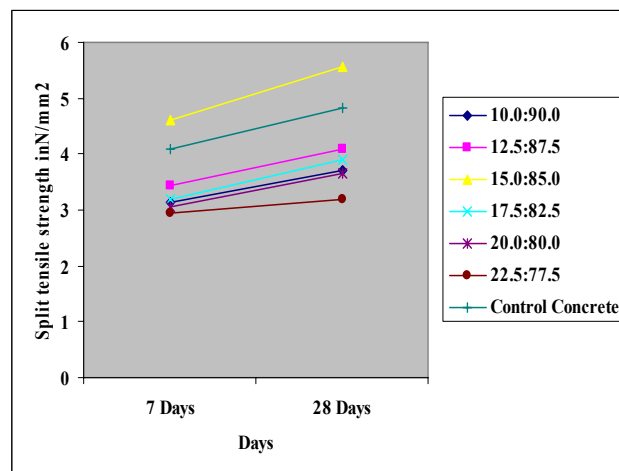


Figure 11. Comparison of Split Tensile strength of fly ash aggregate concrete and control concrete vs Number of days of curing

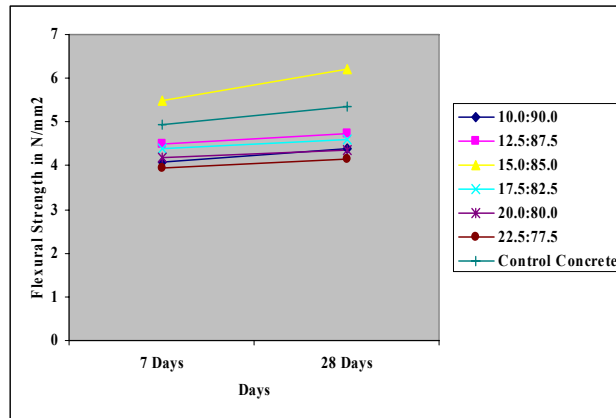


Figure 12. Comparison of Flexural strength of fly ash aggregate concrete and control concrete vs Number of days of curing

14. Conclusions

- From the experimental investigation, it was found that the compressive strength was increased for fly ash aggregate concrete cubes with cement fly ash proportion **15:85**, when compared to the control concrete cubes at all the ages of curing.
- The fly ash aggregate concrete cubes containing fly ash aggregates made using cement fly ash proportions 10:90, 12.5:87.5, 17.5:82.5, 20:80 and 22.5:77.5 showed reduction in compressive strength when compared to the control concrete at all the ages.
- The split tensile strength of fly ash aggregate concrete beams with fly ash aggregates of cement fly ash proportion **15:85** was increased when compared to the control concrete beams at all the ages of 7days and 28days of curing.
- The reduction in split tensile strength of FAAC specimen made with FAA of cement fly ash proportions 10:90, 12.5:87.5, 17.5:82.5, 20:80 and 22.5:77.5 while comparing the control concrete specimens at all the ages of 7days and 28days of curing.
- The increase in flexural strength of the specimen was observed for the fly ash aggregate concrete containing fly ash aggregates made using cement fly ash proportion **15:85** when compared to the control concrete at the ages of 7days and 28days of curing.
- The specimen made with FAA of cement fly ash proportions 10:90, 12.5:87.5, 17.5:82.5, 20:80 and 22.5:77.5 showed the reduction in flexural strength of fly ash aggregate concrete over the control concrete at the ages of 7days and 28days.
- The aggregates are vital elements in concrete. The usage of enormous quantities of aggregates results in destruction of hills causing geological and environmental imbalance.
- The environmental impacts of extracting river sand and crushed stone aggregates become a source of increasing concern in most parts of the Country. Pollution hazards, noise, dust, blasting vibrations, loss of forests and spoiling of natural environment are the bad impacts caused due to extraction of aggregates. Landslides of weak and steep hill slopes are induced due to unplanned exploitation of rocks.
- Considering the depletion of natural sources and the effect on environment, the disposal problems involved in disposing fly ash, light weight characteristics of fly ash aggregates with good mechanical properties (Compression strength, Split Tension strength and Flexural strength) as seen in the above investigation, a particular attention may be focused on the usage of fly ash aggregates in concrete.

15. Acknowledgement

The authors express their sincere thanks to the Correspondent of MPNMJ Engineering College, Chennimalai, Erode District for the support he has provided to carry out this experimental investigation.

16. Literature Review

N.P.Rajamani and P.S. Ambily, scientist, SERC, Chennai carried out the research work on "Selection of mortar for light weight aggregate concrete made with fly ash based aggregate". They concluded that conversion of fly

ash with aggregate is technically feasible 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 to select mortar which can produce fly ash aggregate concrete of strength up to 40Mpa. However concrete strengths more than 40Mpa can also be produced using less content of fly ash aggregates.

Dr.J.B.Behera, Dr.B.D.Nayak, Dr.H.S.Ray and Dr.B.Sarangi examined the use of sintered fly ash aggregate in concrete as a partial replacement of granite aggregate. 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.

Gao Li-Xiong, Yaoyan and Wang Ling, China building materials Academy, Beijing found light weight aggregate concrete made with sintered fly ash aggregate showed good workability, high compressive strength and low absorption of water.

Mehmet Gesoglu, Turan Ozturan and Erhan Gunegisi found the compressive strength of concrete ranging from 20 to 50Mpa was practically produced by using light weight fly ash aggregates. They also found the increase in splitting tensile strength of concrete due to increase in aggregate crushing strength of fly ash aggregates.

Haydar Arsian and Gokhan Baykal investigated the fly ash aggregates produced from fly ash and cement mixing by pelletization method and evaluated Engineering properties such as crushing strength, specific gravity, water absorption, particle size distribution, surface characteristics and shear strength properties of the manufactured aggregates experimentally. The experimental investigation showed that these aggregates are a good alternative for wide range of civil Engineering applications.

Rudolph Klotten, Metallurgical Engineer, Bakerstown road, Tarentum expressed that the largest potential outlet for light weight aggregates(LWA) manufactured from fly ash is in concrete, concrete products, block and masonry units. LWA offer better thermal and acoustical insulation, high fire resistance, easy cutting and drilling.

Gokhan Baykal and ATA Gurhan Doven studied the properties of fly ash aggregates made by pelletization process such as unit weight, specific gravity, water absorption, crushing value test, California bearing ratio (CBR), Direct shear tests, soundness tests, compressive and flexural strength and obtained good results when compared to conventional aggregates in concrete.

References

- Byung-Wan Jo, Seung-Kook Park and Jang-Bin Park. (2006). "Properties of concrete made with alkali activated fly ash light weight aggregate", *Cement and Concrete composites* (2006), PP 1 to 8.
- Dr. J.P. Behera, Dr. H.S. Ray, Dr. B.D. Nayak and Dr. B. Sarangi. (2004). "Light weight concrete with sintered fly ash aggregates". 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.
- Gao Li-Xiang, Yao Yan and Wang Ling. "Research on sintered fly ash aggregate of high strength and low absorption of water", Proceedings of International workshop on Sustainable development and Concrete Technology, PP 151 to 157.
- Gokhan Banjkal, Ata Gurhan Doren. (2000). "Utilisation of fly ash by pelletization process", application of areas and research results, resources, conservation and recycling 30 (2000), PP 59 to 77.
- IS 10262-1982 recommended guide lines for concrete mix design.
- M.S.Shetty. (2005). "Concrete Technology", S.Chand and Co Publishing Company, pp 53 to 62.
- Mehmet Gesoglu, Turen Oztumn and Guneyisi(2006), "Effects of cold bonded fly ash aggregate properties on the shrinkage cracking of light weight concretes", *cement and concrete composites* 28(2006) PP 592 – 605.
- Neville A.M. (1995). "Properties of concrete", IV Ed Longman, 824p.
- P.Kumar Mehta and Paulo J.M.Monteiro. "Concrete Microstructure, Properties and Materials" pp 226 to 230
- Rajamani N.P, Annie peter J. , Sabitha D. and Gopalakrishanan S. (2004). "Studies on development on bonded fly ash aggregates for use as coarse aggregate in structural grade concretes" *New building materials and construction world* Vol 10,issue 4, Oct (pp 60 to 70).
- Rajamani N.P and Ambily P.S. (2006). "Selection of mortar for light weight aggregate concrete made with fly ash based aggregate", *New building materials and construction world journal* June 2006(pp : 80 to 88) August 2006.

Tommy Y. Lo and H.Z. Cui. "Properties of green light weight aggregate concrete" proceedings of International workshop on sustainable development and Concrete Technology PP113 to 118.