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Experimental study on the mechanical behaviour of sintered fly ash aggregate concrete with steel fiber

M. Puthiya Ramki[1], B. Ranjith Babu[2], Dr. R. Thenmozhi[3]

[1]*P.G. Scholar, Department of civil Engineering (Structures), Government College of Technology*

puthiyaramki@gmail.com

[2]*Assistant Professor of Civil Engineering, PSNA College of Engineering and Technology*

[3]*Head of the Department, Department of Civil Engineering (Structures), Government College of Technology*

Abstract

Management of industrial waste is one of the most important environmental issues. In India, the generation of electricity is overwhelmingly dependent on combustion of high-ash coal and as a result fly ash is produced in large amount. Hence it is proposed to use the fly ash, an industrial waste product in concrete for partial replacement of coarse aggregate. However, as the concrete is weak in tension, the concrete is reinforced with various fibres. This project investigates about the behaviour of light weight fly ash aggregate concrete reinforced with steel fibres. The light weight fly ash aggregates were replaced for natural coarse aggregate in 0%, 40% and 60% (by weight) and steel fibres were added to the concrete in 0.5% by weight of concrete. Properties of fly ash aggregates were studied and compared with the conventional natural aggregates. Based on IS: 10262-2009, mix design for M30 grade concrete was done and it was arrived as 1:2:2.26. The standard specimens were cast and tested to ascertain the mechanical properties (compressive, tensile and flexural strength) of fly ash aggregate concrete.

Keywords: Flyash aggregate, Mechanical properties, M30 Grade concrete, Replacement, Steel fibers

I. Introduction

Vit Cernya, et.al., (2016) undergone a detailed study on "Possibilities of lightweight high strength concrete production from sintered fly ash aggregate"It is also possible to produce high-strength lightweight concrete reaching strength up to 55 MPa. Experimental results show that the required strength value of 55 N/mm^2 was measured when sintered FA1 ash aggregate was used.Pilot firings in a horizontal furnace showed that the best raw material for this technique is FA1 ash which was the finest of the tested ashes with the largest specific surface.Erhan Guneyisi, et.al., (2013)carried out a work on "Durability aspect of concretes composed of cold bonded and sintered fly ash lightweight aggregates". The compressive strength test was applied to observe the strength level at the same age. The study revealed that S aggregate containing LWCs had relatively better performance than LWCs with CB aggregates. Moreover, the addition of SF provided further enhancement in permeability and corrosion resistance of the concretes.Erhan Guneyisi, et.al., (2013) done a work on "Effect of steel fiber addition and aspect ratio on bond strength of cold-bonded fly ash lightweight aggregate concretes"in this study three types of hooked-end steel fibers with the aspect ratios of 55, 65, and 80 were utilized with four different volume fractions of 0.35%, 0.70%, 1.00%, and 1.50% of concrete volume. As steel fiber volume fraction is increased, the bond strength also increased remarkably. The steel fiber with aspect ratio of 80 indicated the best bond strength value when compared with aspect ratio of 55 and 65. The compressive strength of the concrete increases upto 35% and split tensile strength increases upto 70%. Addition of steel fiber is effective upto 0.75% above which the compressive strength starts to fall. Tommy Yiu Lo, et.al., (2015) carried out a work on "Manufacturing of sintered lightweight aggregate using high-carbon fly ash and its effect on the mechanical properties and microstructure of concrete"the HCFA-LWA concrete showed 91% of the 28 days compressive strength in 7 days. The modulus of elasticity and tensile strength were also similar grades of LWA concretes. Hence, HCFA-LWA can be used for structural applications. The exploitation of HCFA-LWA in concrete would resolve the waste disposal complications that are related with fly ash and help diminish pollution to the environment.

II Material properties

A General

Plain Cement Concreteis a construction material generally used as binding materials and is composed of cement, (commonly Portland Cement) and, aggregate (generally a coarse aggregate made of gravels or crushed rocks such as limestone or granite, plus a fine aggregate such as sand), water, and chemical admixtures. In concrete, fine (sand) and coarse (gravel) aggregates make up about 75% of the total concrete materials. It is therefore significantly important to obtain the right type and quality of materials at site. The main ingredients of Light Weight Fly ash Aggregate Concrete (LWFA) are Cement, Fine aggregate, Coarse aggregate, Light Weight Fly ash Aggregate(LWFA), Steel fiber, Water and Super plasticizer.

B Cement

Cement is a binder, a substance used in construction that sets, hardens and adheres to other materials, binding them together. Cement is used with fine aggregate to produce mortar for masonry, or with sand and gravel aggregates to produce concrete. It binds the coarse aggregates and fine aggregates to act as a monolithic matter with help of water added. Hence selection of proper grade and quality of cement is important for obtaining a good mix. The raw materials used for the manufacture of cement consists mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding. Ordinary Portland cement (OPC) is by far the most important type of cement and is classified into three grades, namely 33 grade, 43 grade and 53 grade depending upon the strength of the concrete at 28 days. The cement used in this study is ULTRATECH CEMENT OPC 53 grade. The physical properties are obtained by conducting following tests on cement, as per IS 1727:1967, IS 4031(Part 4), IS 4031(Part 5). Properties of the cement are given in the Table 2.1.

Table 2. 1 Properties of cement

S.NO	PROPERTIES	VALUES
1	Specific Gravity	3.15
2	Standard consistency	33%
3	Initial setting time	28 minutes
4	Fineness	4%

C Fine aggregate

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. Fine aggregate is of natural sand, crushed stone sand or crushed gravel stone dust. It should be hard, durable chemically inert, clean and free from organic matter, not containing any appreciable amount of clay balls or pellets and other harmful impurities i. e. alkaline, salt, mica, decayed vegetation, lumps etc. It is defined by size, being finer than gravel and coarser than silt. Fine aggregates are materials that pass through an IS sieve that is as per IS 2386(Part 3)-1963 to find out its physical properties. less than 4.75mm gauge. Natural sand is commonly used fine aggregate and crushed stone are used in some places. Natural sand that got retained on a 2.36mm sieve was used in this investigation. The following tests are carried out on fine aggregate as per IS 2386(Part 3)-1963 to find out its physical properties.

Table 2.2 Properties of fine aggregate

S.No.	Properties	Values
1	Specific gravity	2.64
2	Water absorption	1%
3	Fineness modulus	2.548
4	Sieve analysis	Conforming to Zone II

D Coarse aggregates

The materials which are retained on a 4.75mm sieve are called coarse aggregates. The aggregates serve as the main source of strength to the concrete. Sources of coarse aggregates can be grouped into three main areas: Mining of mineral aggregate deposits, use of waste materials from the manufacture industries; and recycling of concrete. The aggregates can be classified as natural aggregates, artificial aggregates, normal weight aggregates, light weight aggregates and heavy weight aggregates. Coarse aggregates in cement concrete contributes to the heterogeneity of the cement concrete and there is weak interface between cement matrix and aggregate surface in cement concrete. Aggregates are selected depending on its size, texture, shape, strength, moisture content, grading etc. Natural aggregates that passed through 12mm sieve and got retained on 4.75mm sieve was used in this investigation. The following tests are carried out on the coarse aggregates as per IS 2386(Part 3)-1963 to find its properties.

Table 2.3 Properties of natural coarse aggregate

S.NO	PROPERTIES	VALUES
1.	Specific gravity	2.65
2.	Impact value	15.63%
3.	Crushing value	12.77%
4.	Water absorption	0.9%
5.	Bulk Density (Loose State)	1490kg/m^3
6	Bulk Density (Dense State)	1626kg/m^3

E Light weight fly ash aggregate

Lightweight aggregates can be produced using sintering or cold-bonded process. The production of Light Weight Fly Ash Aggregate by sintering process is carried out as follows: Fly ash, cement and water are thoroughly mixed and then fed into a mixer drum and made to rotate in the mixer drum approximately for 20minutes, thus forming pellets and this process is called as pelletizing. Then the pellets are heated at a temperature rate of 1000^{o}C to 1200^{o}C in a muffle furnace, thus resulting in high strength of the aggregate. This process of heating the aggregate at high temperature is called as sintering process. LWFA used in this investigation were bought from GBC India private limited, Ahmadabad. LWFA that passed through 12mm sieve and got retained on 4.75mm sieve was used in this investigation. The following tests are carried out on the coarse aggregates as per IS 2386(Part 3)-1963 to find its properties.

Table 2.4 Properties of light weight fly ash aggregate

S.NO	PROPERTIES	VALUES
1.	Specific gravity	1.4
2.	Impact value	27.78%
3.	Crushing value	19.42%
4.	Water absorption	16.8%
5.	Bulk Density (LooseState)	830kg/m^3
6.	Bulk Density (DenseState)	895kg/m^3

Figure 2.1 Light weight fly ash aggregate

F Steel fibers

Steel fiber is the most commonly used fiber. Steel fibers are added to concrete to improve the structural properties, particularly tensile and flexural strength. The extent of improvement in the mechanical properties achieved with steel fiber reinforced concrete over those of plain concrete depends on several factors, such as shape, size, volume, percentage and distribution of fibers. In this study hooked end steel fibers were used.

Table 2.5 Properties of steel fiber

S.NO.	PROPERTIES	VALUES
1.	Diameter	0.55 mm
2.	Length	30 mm
3.	Aspect ratio	55
4.	Density	7680 kg/m^3
5.	Tensile strength	>1450 MPa

Figure 2.2 Steel Fiber

G Super plasticizer

Super plasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. Their addition to concrete or mortar allows the reduction of the water to cement ratio, not affecting the workability of the mixture, and enables the production of self-consolidating concrete and high-performance concrete. It permits the reduction of water content up to 30 per cent without reducing the workability. Fosroc Conplast SP430 is used in this investigation.

Figure 2.3 Super plasticizer

III Mix Design

A Stipulations for proportioning

a. Grade designation	:	M30
b. Type of cement	:	OPC 53 grade
c. Maximum nominal size of aggregate	:	12.5 mm
d. Minimum cement content	:	320 kg/m^3
e. Maximum water-cement ratio	:	0.35
f. Workability	:	75-100 mm slump
g. Exposure condition	:	Severe
h. Type of aggregate	:	Crushed angular aggregate
i. Maximum cement content	:	450 kg/m^3
j. Chemical admixture type	:	Super Plasticizer

B Mix proportions

Cement	=	435.42 kg/m^3
Water	=	152.40 kg/m^3
Fine aggregate	=	872.28 kg/m^3
Coarse aggregate	=	987.36 kg/m^3
Chemical admixture	=	8.7 kg/m^3
Steel fiber	=	38.4 kg/m^3
Water cement ratio	=	0.35
Mix ratio	=	1 : 2.00 : 2.26 : 0.35 :0.5 (C : FA : CA : W/C : SF)

Table 3.1 Mix proportions for 1m^3 concrete

Mix ID	W/C ratio	Cement (kg/m^3)	Mixture constituents (kg/m^3)					
			FA	CA	FAA	Water	SP	SF
CC	0.35	435.42	872.28	987.36	0	152.4	8.7	0
LWA40		435.42	872.28	592.41	394.94	152.4	8.7	38.4
LWA60		435.42	872.28	394.94	592.41	152.4	8.7	38.4

FA - Fine Aggregate CA - Coarse Aggregate FAA - Fly Ash Aggregate SP - Super Plasticizer

SF - Steel Fiber

CC - Control concrete

LWA40 - 40% FAA replacement

LWA60 - 60% FAA replacement

IV Results and discussion

A Aggregate properties

The natural aggregates and the light weight fly ash aggregates were tested for the properties. The results are tabulated in the following section.

Table 4.1 Comparison of aggregate properties

Property	Natural aggregate	Fly Ash aggregate
Specific gravity	2.65	1.4
Impact value	15.63%	27.78%
Crushing value	12.77%	19.42%
Water absorption	0.9%	16.8%
Bulk Density (LooseState)	1490kg/m^3	830kg/m^3
Bulk Density (DenseState)	1626kg/m^3	895kg/m^3
Void ratio	38.65	35.84

From the comparison it shows that,

- The impact value and the crushing values of both the conventional and fly ash aggregate were within the permissible limits 45 according to IS code. But at the same time the impact value of fly ash aggregate is double that of natural aggregates.
- The water absorption of fly ash aggregate is relatively higher than the normal coarse aggregate and it is also more than the permissible limits 10 according to IS code.
- The density of fly ash aggregate is only 50% of that of conventional natural aggregates.
- The void ratio is equal for both the aggregates.

B Test on fresh concrete

Slump cone test

The slump cone test measures the workability and consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete. The slump cone consists of a metallic mould in the form of a frustum of a cone having 200mm bottom diameter, 100mm top diameter and 300mm height.

Figure 4.1 Slump cone test

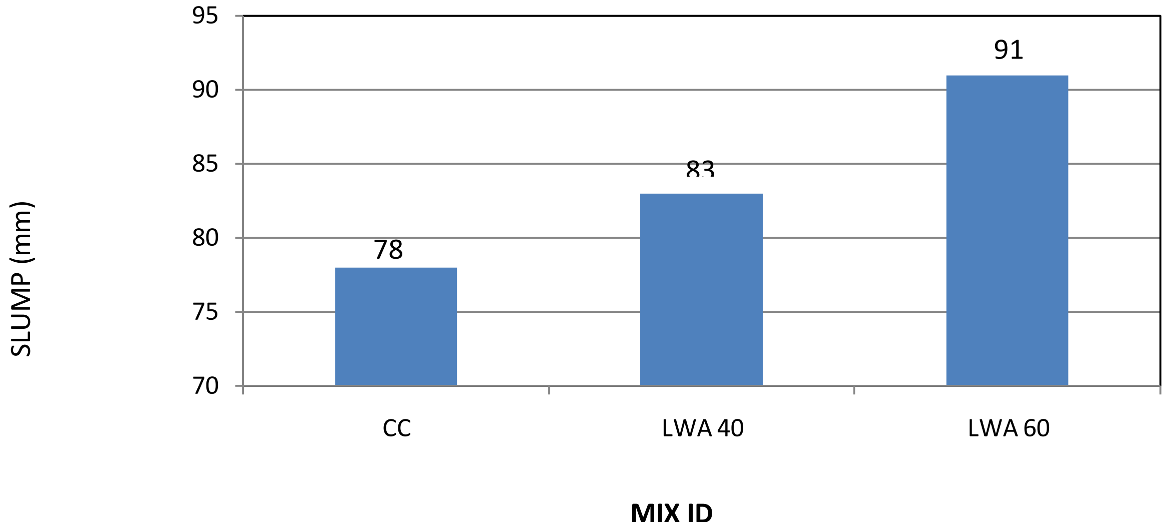

Figure 4.2 Slump value

From the graph the slump value increases as the fly ash aggregate percentage increases in the concrete mix.

C Tests on hardened concrete

Testing of hardened concrete plays an important role in controlling and confirming the quality of cement concrete. One of the purposes of testing hardened concrete is to confirm that the concrete used has developed the required strength. Fully cured hardened concrete must be strong enough to withstand the structural and service loads which will be applied on it. Compression test is the most common test conducted on hardened concrete because most of the desirable properties of concrete are qualitatively related to its compressive strength. Specimens are tested for 3,7 days compressive strength in Compression Testing Machine(CTM). Test results conducted on cubes are tabulated in table. Splitting tensile strength and flexural strength test are methods to determine the tensile strength of concrete. The concrete develops cracks when subjected to tensile forces and hence it is necessary to determine the tensile strength of concrete. Flexural strength is a measure of an unreinforced concrete beam or slab to resist failure in bending. The flexural strength is expressed as Modulus of Rupture. The results are tabulated below in table 4.2 and 4.3.

Table 4.2 Compressive strength of concrete

S.No.	**Mix**	**Compressive Strength (Mpa)**	
		3-DAYS	7-DAYS
1.	CC	19.2	27.5
2.	LWA 40	32.6	38.4
3.	LWA 60	28.8	35.2

Table 4.3 Tensile and flexural strength of concrete

S.No.	**Mix**	**Split Tensile Strength (Mpa)**		**Flexural Strength (Mpa)**	
		3-DAYS	7-DAYS	3-DAYS	7-DAYS
1.	CC	2.4	3.15	3.20	3.48
2.	LWA 40	2.8	3.4	2.85	3.46
3.	LWA 60	2.5	3.2	2.65	3.28

The compressive strength increases in 40% replacement of LWFA and reduces beyond it. The maximum compressive strength is attained at 40% replacement of LWFA. The split tensile strength also increases upto 40% replacement, after that the strength reduces. The 40% and 60% LWFA concrete's flexural strength falls below CC.

V Conclusion

Based on the tests performed and results found, the following conclusions are drawn

- The water absorption of fly ash aggregate is more than the permissible limit (10%), according to IS code. The water absorption of LWA is 16.8%.
- The crushing and impact value of both aggregates are well within the permissible limit according to IS code.
- The void ratio of both the aggregates are nearly same.
- The impact value of fly ash aggregate is almost double than the impact value of natural aggregate.
- For fresh concrete the result shows that, as the percentage of LWFA increases the workability increases.
- The result of 7days test shows that compressive strength of LWFA concrete increases by 39.63% and 28%, than that of control concrete, for LWFA replacement of 40% and 60% respectively.
- The tensile strength of 7days LWFA concrete increased by 7.93% and 1.58% than that of control concrete, for the replacement of 40% and 60% respectively.
- The flexural strength of LWAC goes on decreasing as the percentage of LWA increases.

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