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Study on Mechanical and Durability properties of Sintered Fly Ash Aggregate Structural Concrete

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ABSTRACT: Light-weight concrete offers many advantages compared to conventional concrete. A special type of light-weight concrete known as Structural Light-Weight Concrete (SLWC) has been comparatively lighter than Conventional Concrete(CC) but strong enough to be employed for structural purposes. Structural light-weight concrete combines the advantages of Convention Concrete and eliminating all the disadvantages. LWA have been prepared by sintering fly ash by crushing the product into appropriate sizes. These aggregates have special characteristics that make them more suitable for high strength and better performance concrete. The dead load of various structural elements can be reduced considerably because the concrete produced by using light weight aggregates (LWA) is lighter by 22% compared to standard aggregate. High performance concrete requires aggregates which hashigh durability. The significance of the fresh aggregates depends in achieving the superior qualities without increase the cement content. In this paper an attempt has been madeto assess the mechanical and durability properties of SLWCs by incorporating sintered fly ash aggregate as coarse aggregate. Specimens are prepared to find the various properties of SLWC in terms of Compressive strength, split tensile strength are water absorption andare compared with standard aggregate concrete. The tests have been carried out on three different mix design proportions such as M25, M35 and M45and noticed that the compressive strength of Mix designs withSLWCs exhibits results on par with mix design with standard aggregates, the split tensile strength of SLWCs is less compared to standard aggregate concrete and M25 with SLWCs has higher water absorption compared to standard aggregate concrete.

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I. INTRODUCTION:

The properties of concrete depend on the type of aggregates employed. Most of the aggregates used in India have been of granite basis, crumpledin nature. Its usage in concrete has triggereddisparity both ecologically and environmentally. Unexpected exploitation of heavy rock masses has led landslides of delicate and vertical mountslopes. The fear of about the exhaustion of usual resources and the consequence on atmosphere has made to think in the direction of un naturallyformed (from waste materials) aggregates as an alternative to the natural granite origin aggregates. This practice has providedanswer towards the management of waste and protection of natural assetsto an enormous extent [1].To an extent of 60–70% of concrete has been filled by aggregates irrespective of its type. Expanded shale, clay, slate aggregate, blast furnace slag aggregate, **sintered fly ash aggregate**have beenwidely used to producesynthetic lightweight aggregates (LWA) suitable for structural applications. Sintered fly ash aggregate has been considered as the best for structural uses[2]. These aggregates have beenmanufactured by sintering the mix of fly ash, partial plastic clay as binder and coke gust at a certain percentage and sintering them at a temperature between 1200 °C to 1300 °C in Chain Grate Sintering System laboratory by the Down Draft Sintering Technique [3]. Sintered fly ash LWA have been prepared by Down Draft Sintering Technique [4].Fly ash, an unwanted material has created two difficulties namely i) disposal of fly ash ii) environment destructiondue to water and aircontamination on a great scale. Close to 267 thermal power stations in India havecreating over 80-100 milliontons fly ash per annumout of which merely 60% has been utilized effectively. Therefore, the making of sintered fly ash LWAhas been a major step towards utilization of a huge amount of fly ash in concrete. Non-availability of worthy technology to produce sintered fly-ash LWA and the lack of a market has preventedmany Indian industrialists from manufacturing sintered fly-ash aggregate.In recent times a few of the industries in Indiahave concentrated their focus on the development of sintered fly ash LWA commercially on a huge scale from the fly ash obtained from their captive power plants. No Indian standards have been in existence for the LWAs so far. Recently, the authors by their pilot studies have established that this material has a substantial prospective for use in structural concrete [5]. The LWAs produced with fly ash have been light owing to the existence of air voids and accountable for their absorbency. This absorbency acts as an important factor in the mix design and also in the concreteperformance. Preparation of Light Weight Aggregate Concrete (LWAC) in applied circumstances has become more difficult because of the absorption produced by the LWA. Porous LWAs have become extremely sensitive as the water concrete proportion varies. The wetness content during the mixing period state has a main worry for LWAC. The North American style has been to use the LWA in a soaked state; differing to this, Norwegian method selects dry LWA having a wetness content less than 8% [6].Dry LWA has been employed to nullify the problems associated with pre – soaked LWA moisture content variations. With this method reduction in the fresh mix density has been achieved [7]. Dry state aggregates have been preferred in view of the improved durability and cost of production. It has been observed that concrete using air dried and pre-soaked aggregates has no difference in compressive strength and workability by adding additional water during mixing to compensate water absorption [8]. Design parameters namely % of water absorption throughoutthe mixing of concrete and selection of diverse aggregate dimensions etc.have made the mix design of SLWAC further complex compared to standard concrete. Considering this as reason, asimple design technique has been developed to yield SLWAC prepared with natural sand. Currently, owing to the dearth of suitable mix design techniques, the concretes prepared have limited structural performance. In view of this,usage of sintered fly ash LWAhas been limited to non-structural elements.Till now no consistent study has been made to control the water absorbed by theporous aggregate during concrete mixing. In theearlier techniques, the % of water absorption has been estimated by completely dipping the aggregates in water for a definite amount of time. Also, apooled aggregate categorizing has beenabsent from all the existing methods. The central focus of this work has been tostudy various properties of M25, M35 and M45 mix design in terms of its compression strength, split tensile strength and water absorption and to compare these values with standard concrete.

Objectives

- To Develop the mix design for producing M25, M35 and M45 concretes using sintered fly ash aggregate
- To compare the mechanical properties of the Structural LWC with standardaggregate concrete or conventional concrete.
- To compare the durability performance of the LWC developed with conventional concrete.

Materials Used

The test specimens have been prepared using following materials.

- Cement (OPC 53 grade)
- Sintered fly ash aggregates – size (10mm passing)
- River sand as fine aggregate - 4.75 mm passing
- Water
- Super Plasticizer (Glenium B-233)

Experimental Program

General:

Structural LWC (SLWC) has been prepared with sintered fly ash and tested for compressive strength, split tensile strength and water absorption (according to ASTM C642-13).

Specimen specifications:

100mm x 100mm x 100 mm sizecubes have been casted and subjected for testing the compressive strength. 100 mm diameter and 200 mm height cylinders have been prepared for testing the split tensile strength.100mm x 100mm x 100 mm dimensions' cubes have been casted for estimating % of water absorption and this testing has been carried out after curing 28 days.

Properties of Material:

Ordinary Portland Cement (OPC), sand (as fine aggregate), sintered fly ash (Coarse aggregate), Potable water have been used for casting cubes and cylinders in M25,M35 and M45 mix designs.

i) Cement

Ordinary Portland cement (BrilaA1 cement) of 53 grade confirming to IS: 296-1989 has been used. Physical properties of Ordinary Portland Cement are given below in table.1.

Table 1. Properties of cements

S.No.	Property	Test results
1	Cement Consistency	32%
2	CementSpecific gravity	3.14
3	Initial setting time	36min
4	Final setting time	289min

ii) Sintered Fly Ash

The sintered fly ash as coarse aggregate has been manufactured by mixing sintering the combination of fly ash, partial plastic clay as binder and coke wind at a specificpercentage and sintering them at a temperature ranging from 1200 °C to 1300 °C in a Lab Chain Grate Sintering System by the Down Draft Sintering Technique. These coarse aggregates have been made into spherical form and completely dried at a temperature of 1100 ºC in muffle furnace. The properties of sintered fly ash aggregates have been given in table 2.

Table 2. Sintered fly ash Properties

S.NO.	PHYSICAL PROPERTY	TEST RESULTS
1	Maximum size	10mm
2	Fineness modulus	2.275
3	Specific gravity	1.785
4	Water Absorption(%)	17%
5	Bulk density	905kg/m^3

iii) River Sand as Fine Aggregates

The locally existing sand confining to zone II was used in accordance with IS:383-1970.

iv) Physical Properties of Fine Aggregate

- Aggregate zone: - II Zone
- Fine aggregate Specific gravity: - 2.64
- Modulus of Fineness = 2.99
- Bulk density: 1281 Kg/m^3

v) Master Glenium B233 confirming to BASF

Table3. Master Glenium B233 Properties

S.No	Properties	Results
1	Specific gravity	1.08
2	Type	Poly carboxylated ether

Mix design for SLWAC

There are various mix designs reported in the literature and are as shown in Table.4.No explicit mix design technique has been establishedby means of sintered fly ash aggregates for SLWCs to accomplish a fixed strength such as in standard concretes till recently. Manu S. Nadesan and P. Dinakar have proposed a new mix design specification for SLWAC as shown in table 4 [10]. Using the concept of mix design for SLWAC proposed by Manu S. Nadesan and Dinakarhave developed three mix designsnamely M25, M35 and M45. For these mix designs, compression strength, split tensile strength and water absorption analysis have been carried out for various structures.

Table 4. Concrete mix design factorscomparison

Mix design method	Applica-bility	Aggregates[$] Type	CA/TA	Water content	Water-cement ratio	Remarks
ACI 211.1 (11) ACI 211.1(12) ACI 211.1(13)	All grades up to 83MPa	Nominal maximum size of aggregate	0.52 to 0.74	166 to 211	0.25 to 0.82	ACI 211.2 offers rules for design of LWC up to 41MPa.
DIN 1045 (14)	Grades of all up to 55 MPa	Only Rounded	Collective aggregate grading	135 to 220	0.40 to 0.75	No rules for design of LWC.
BS(BRE) (15)	Grades of all up to 75 MPa	Only crumpled and Un crumpled	0.40 to 0.80	115 to 250	0.30 to 0.90	Also gives rules for design of LWC.
EN 206 (16)	Grades of all up to 88 MPa	Only Rounded	0.40 to 0.80	115 to 250	0.30 to 0.90	Also gives rules for design of LWC.
IS10262 (17)	Grades of all up to 55 MPa	Rounded angular, and sub angular	0.40 to 0.75	165 to 208	0.40 to 0.60	No rules for design of LWC.
Proposed Technique by Manu S.Nadesa, P. Dinakar[10]	Grades of all up to 70 MPa	Only rounded sintered fly ash LWA	Collective aggregate grading using DIN standard	166 to 211	0.25 to 0.75	Exclusively for the design of sintered fly ash LWC.

$: CA: Course aggregate, Water content inkg/m^{3}LWC: Light Weight Concrete,TA: Total aggregate

II. RESULTS AND DISCUSSIONS

i) Density

The outcomesof the air dry and oven dry concentrations of all the Light weight and conventionalconcretes(normal concrete) have been estimated and given in table 5. The plastic massesof LWCs and conventional concrete have been varied between 1720 to 1960 kg/m3, 2240 to 2470 kg/m3 respectively. It has been noticed that approximately 22%of reductionin density has been achieved and the results obey with the outcome of the earlier study [9].Combining lightweight fine aggregates in the concrete matrix further reduction in densities may be obtained.

Table 5. Densities of Developed Concrete

S.No.	Mix designation[#]	Density(kg/m^3)	
		Air dry density	Oven dry density
1	SLWC 25	1870	1720
2	SLWC 35	1950	1830
3	SLWC 45	1960	1810
4	CC25	2470	2310
5	CC35	2410	2240
6	CC45	2452	2260

CC- Conventional Concrete: SLWC- Structural Light Weight Concrete

ii) Mix Proportions for Developed Concretes

To validate standard and SLWCs, the three different mix designs namely M25, M35 and M45 have been considered. The mix details for ConventionalConcrete (CC) also known as normal concrete and Structural LWC (SLWC) have been given in Table. 6. and table. 7respectively.

Table 6. Mix proportions forConventional Concrete

Grade of concrete (Mpa)	**M25**	**M35**	**M45**
Water cement ratio	0.65	0.55	0.45
Cement(kg)	339.2	400.87	416.44
Coarse aggregate(kg)	856.7	831.2	907
Sand(kg)	955.15	926.6	1008.3
Water(kg)	220.48	22.048	156.58
Super plasticizer	-	-	0.5

Table 7. Mix proportions for Structural Light Weight Concrete

Grade of concrete (Mpa)	SLW25	SLW35	SLW45
Water cement ratio	0.65	0.55	0.45
Cement(kg)	261.5	309.09	377.77
Total aggregate (kgm^3)	0.727	0.7118	0.6900
Sintered fly ash aggregate(kg)	882.43	863.74	835.09
Sand(kg)	614.16	601.15	574.46
Water	170	170	170
Absorbed water	150.01	146.83	141.96
Net water	320.01	316.83	311.96

iii) Compressive strength:

The least compressive strength necessary for structural LWC has been 17 MPa as per ASTM C 330 [18] standards. All the mix design concretes namely M 25, M 35 and M 45 have fulfilled this criterion. The compressive strengths attained for various concretes have been shown in fig1. Based on the standard deviance ofall the concretes at 7 and 28 daysit has been noticed thatthe reliability of the compressive strength of LWACs has been assured because all the aggregates have been produced in a measuredcondition. The strength attainment behavior of LWCs has been almost comparable to that of standard aggregate concretes.Usually, regular aggregates, water that does not takepart in the hydration may remain within the cement matrix.It has been observed that the excess water present in the mortar matrix may be absorbed by LWAs.Without incorporating of any mineral admixtures the compressive strengths of M25, M35 and M45 grades concrete has been obtained on par with standard aggregate concrete.

7 & 28 days compressive strength

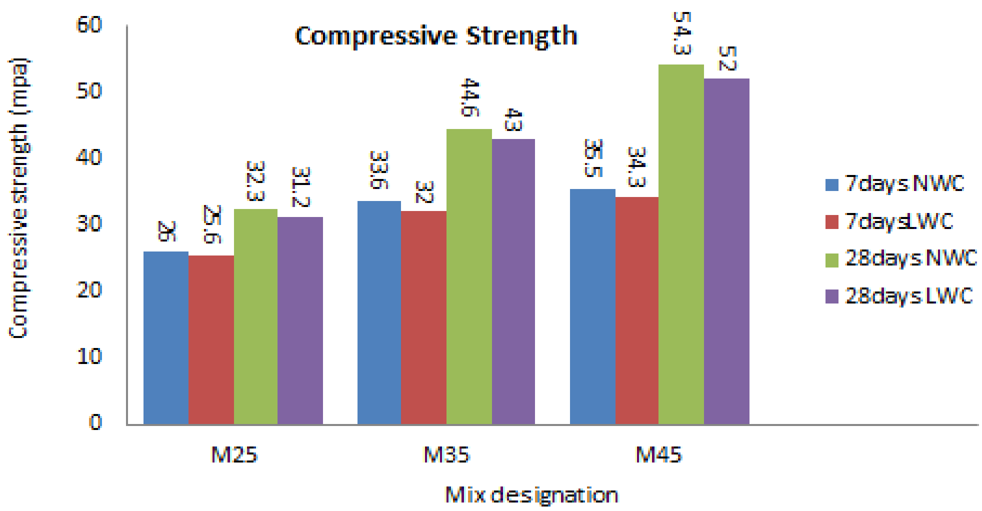

Fig1. Compressive strengths

Table 8.Compressive strength.

Sno	Mix Desig-nation	Type of concrete#	Compressive strength at 7days curing (N/mm^2)	Average compressive strength at 7 days curing (N/mm^2)	Compressive strength at 28days curing (N/mm^2)	Average compressive strength at 28 days curing (N/mm^2)
1	M25	CC	32	26	35	32.3
			24		32	
			22		30	
		LWC	29	25.6	33	31.3
			25		30	
			23		31	
2	M35	CC	40	33.6	48	44.6
			33		44	
			28		42	
		LWC	08	32	38	43
			32		46	
			26		45	
3	M45	CC	43	35.5	50	53.5
			36		58	
			28		52	
		LWC	27	34.3	49	52.3
			39		57	
			37		51	

#CC: Convention Concrete; LWC: Light Weight Concrete

iv) Split Tensile Strength

Splitting tensile strength values have been obtained as 3.46,3.86 and 4.37 MPa at 28 days for NWC for M25, M35 and M45 respectively. The minimum tensile strength required for structural grade concrete is 2 MPa for LWC according to ASTM C 330 [18]. It has been observed that Splitting tensile values for M25, M35 and M45 have been obtained as 2.62, 2.93 and 3.38 MPa at 28 daysfor SLWCs.Splitting tensile strength of SLWCs has been less than the standard concrete aggregates. The lesser splitting tensile may be due to the inner curing of the SLWAC. Even though inner curing helpsincessant hydration it may also delay the contraction of mortar matrix nearby the aggregates. Due to this differential contraction, early micro cracks have been observed within the mortar matrix or may cause the development of equilibrating stress.

Table 9. Split Tensile Strength

Sno	Mix designation	Type of concrete#	Split tensile strength at 28days curing in N/mm2
1	M25	CC	3.46
		LWC	2.62
2	M35	CC	3.86
		LWC	2.93
3	M45	CC	4.37
		LWC	3.48

#CC: Convention Concrete; LWC: Light Weight Concrete

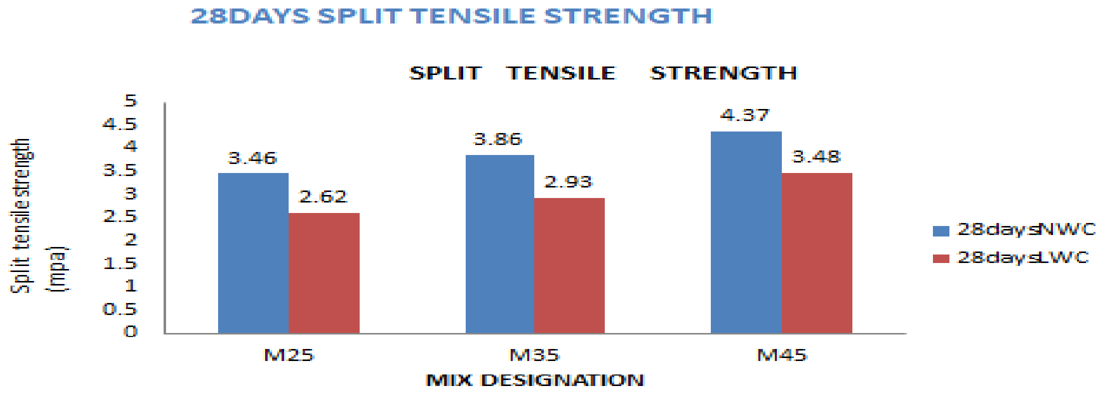

Fig 2. Split tensile strength

v) Water Absorption Test

Water Absorption Testhas been performed to determine density, % of absorption and % of voids in the hardened mix design concrete. Water Absorption test has been conducted at 28 days for all specimens considered in this project.This test has been used to develop the data required for conversions between mass and volume for concrete and to the determine confirmation with specifications for concrete to show changes from place to place within a mass of concrete. As a part of this project the test has been conducted for 28 days and observed that M25 mix with SLWCs aggregates has 61.2 % of higher water absorption and 80.2% voids compared to M25 mix with standard concrete aggregates.

Table10. Water Absorption Test

Mix designation	Type of concrete#	Absorption after immersion (%)	volume of permeable pore space voids(%)
M25	CC	6.9	6.2
	LWC	11.16	17.3
M35	CC	7.2	10.1
	LWC	10.10	16.09
M45	CC	6.9	10.7
	LWC	9.0	13.7

#NWC: Convention Concrete; LWC: Light Weight Concrete

Table11. Water Absorption Test

Mix designation	Absorption after immersion	Absorption %increased or Decreased w.r.t to standard concrete	Volume of permeable pore space voids%	Voids % increased or decreased w.r.t to standard concrete
LW25	11.16	61.2	17.3	80.2
LM35	10.10	39.6	16.09	59.14
LW45	9.0	30.4	13.7	28.03

III. CONCLUSIONS:

The findings of the current real world investigation have been listedbelow and as follows:

As a part of this work M25, M35 and M45 mix designs with standard aggregates and Structural LWC aggregates have been used for casting cubes and cylinders. Various metrics like Compressivestrength, split tensile strength and % of water absorption have been estimated for cubes and cylinders and found that

i) The compressive strength of Mix design with SLWCs exhibit results on parwith mix design with standardaggregates.
ii) The split tensile strength of SLWCs is less compared to standard aggregate concrete. However,split tensile strength of SLWCs is

satisfying the requirements of structural applications according to ASTM C330.

iii) It has been observed that M25 with SLWCs has higher water absorption compared to standard aggregate concrete.

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