Some Studies on Strength Properties of Light Weight Cinder Aggregate Concrete

Dr. V.Bhaskar Desai[*], Mr. A. Sathyam[**]

[*] Professor, Dept. of Civil Engineering, JNTUA College of Engineering, Anantapuramu – 515002, A.P.
[**] Conservation Assistant Gr-I, Archaeological Survey of India, Anantapuramu Sub Circle, Anantapuramu & Research Scholar, JNTUA College of Engineering, Anantapuramu – 515002, A.P.

Abstract- In this present experimental investigation an attempt is to be made to study the strength properties of light weight cinder aggregate cement concrete in different percentage proportions of 0, 25, 50, 75 and 100 by volume of light weight aggregate concrete can be prepared. By using this the properties such as compressive strength, split tensile strength, modulus of elasticity, density and shear stress etc., are studied by casting and testing around 105 samples consisting 15 no of plain cube specimens of size 150 x 150 x 150mm, 60 no of (Double Centered Notch) DCN specimens of size 150x150x150mm and 30 no of cylinders of size 150mm dia. and 300mm height.

Index Terms- Cinder, light weight aggregate, compressive strength, tensile strength, density, DCN specimens and Youngs modulus

I. INTRODUCTION

The advancement in the new construction materials has lead to develop high strength materials, which are generally selected to reduce the weight of the construction. Also the developments in the stress analysis methods enable a more reliable determination of local stresses in the materials, which permit safety factors to be reduced resulting in further weight savings. This induces low margins of safety for the structures designed with high strength materials. But the service stresses with aggressive environment may be high enough to induce cracks, particularly if pre existing flaws or high stress concentrations are present within the materials. As the residual strength of any structural material under the presence of cracks is low, when small cracks exists, the structures designed with high strength materials may fail at stresses below the highest service stresses for which they are designed.

II. REVIEW OF LITERATURE

A brief review of available studies related to the present strength properties of cementitious materials is presented.

According to Clarke, J.L (1) Tensile strength of concrete is important when considering cracking. Light weight aggregate concrete presents a flexural and tensile splitting strength slightly inferior to that of normal weight concrete of the same compressive strength.

Thorenfeldt, E reported that (2) Light Weight Aggregate Concrete has a faster hardening factor in the initial setting phase than conventional concrete, normally reaching 80 % of the 28 day strength within 7 days. The strength growth from 28 to 90 days is generally low and decreases with increasing concrete strength level. This is assumed to be a consequence of the strength limiting effect of the light weight aggregate.

As per Bryan, Dennis. S. P (3), Natural lightweight aggregates may be defined as inherently low density natural mineral materials. The primary user is the construction industry where weight reduction equates to cost savings. Principal products in which natural lightweight aggregate is utilized because of its lower density include lightweight Portland cement concrete and lightweight concrete masonry units. In addition, due to location, some natural lightweight aggregates compete with normal weight constructions aggregates for uses such as road base and common backfill material.

P.S. Raghuprasad, et.al (4), concluded that with the advent of industrial revolution and mass construction in various parts of the world, the pollution levels and the scarcity of materials have reached the peak. The coarse aggregate in the conventional solid concrete blocks were replaced partially with cinder (12 mm) and tested for compressive strength at the age of 3 days, 7 days and 21 days. From the results of investigation, it can be concluded that solid blocks with 15% replacement of coarse aggregate by cinder records more strength that the conventional one.

M. A. Caldarone and R. G. Burg (5), Structural lightweight concrete is defined as concrete made with low-density aggregate having an air-dry density of not more than 115 lb/ft3 (1850 kg/m³) and a 28-day compressive strength of more than 2500 psi (17.2 MPa). This paper presented the test results of very low-density structural lightweight concrete mixtures developed in the laboratory for the purpose of finding a suitable mixture for use on a historic building rehabilitation project. Mixture parameters included a specified compressive strength of 3000 psi at 28 days and an air-dry density approaching 70 lb/ft3. Various constituent materials, mixture proportions and curing methods were examined. The result of this research exemplifies the feasibility of achieving very low densities with structural concretes.

Watekins and Liu (6) conducted the finite element analysis technique simulating in-plane shear mode, Mode II, was used to analyse fracture behaviour in a short shear beam specimen in plain concrete and fracture toughness, K_{IIc} values were determined.

Owens, P.L. (7) had stated that Light weight aggregate concrete was used for structural purposes since the 20th century. As per this study, the Light weight aggregate concrete is a material with low unit weight and often made with spherical aggregates. The density of structural Light weight aggregate concrete typically ranges from 1400 to 2000 kg/m³ compared with that of about 2400 kg/m³for normal weight aggregate concrete.

N. Siva lingaRao, et.al (8), concluded that 60 percent replacement of conventional aggregate with cinder by volume along with cement replaced by 10 percent of silica fume by weight, yields the target mean strength of M20 concrete. It is worth to be noted that there is a slight increase in strength and other properties due to extended curing periods and the unit weight of the cinder concrete is varying from 1980Kg/m³ to 2000Kg/m³ with different percentages of cinder. It is also noted that there is a decrease in density after extended curing periods.

Prakash Desayi, Raghu Prasad B.K, and Bhaskar Desai.V, (9,10,11,12,13 & 14) arrived at Double Central Notched specimen geometry which fails in predominant Mode-II failure. They also made finite element analysis to arrive at stress intensity factor. Using this DCN geometry lot of experimental investigation using cement paste, mortar, plain concrete was carried out. Details of this geometry are presented in fig. 3.

III. MATERIAL PROPERTIES

The materials used in the present investigation are Ordinary Portland cement of 53 grade having a specific gravity of 3.07 with initial and final setting times of 33 minutes and 489 minutes respectively. Locally available river sand passing through IS 4.75mm sieve with specific gravity 2.6 and fineness modulus 4.10 is used. Natural granite aggregate passing through IS 20mm sieve with specific gravity 2.68 and compacted density 1620 Kg/m^3 is used. Cinder passing through IS 20mm sieve with specific gravity 2.05 and compacted density 1050 Kg/m^3 is used as aggregate. A view of constituent materials is shown in plate. 1

3.1 PROPERTIES OF CINDER:

The surface of the cinder is usually rough and highly porous due to mineral structure. No physical testing is usually performed to quantify the angularity of the material, however it is visually classified as having 100% crushed face. The water absorption for cinder is around 1.5%. This significant difference is thought to be the main reason of reduction in strength and durability of concrete made with cinder. Low specific gravity of cinder in comparison with natural aggregate resulted in the concrete made with cinder to be lighter than normal concrete.

IV. EXPERMENTAL INVESTIGATION

An experimental study has been conducted on concrete with partial replacement of conventional coarse aggregate by another light weight aggregate i.e. Cinder with few different volumetric fractional additions ranging from 0% to 100%. Concrete of M_{20} design mix is used in the present investigation. In addition to presenting conventional strength properties such as cube compressive strength, split tensile strength, modulus of elasticity by casting and testing standard cubes and cylinders. Mode-II fracture studies are also conducted and results are presented; making use of cinder aggregate in different proportion.

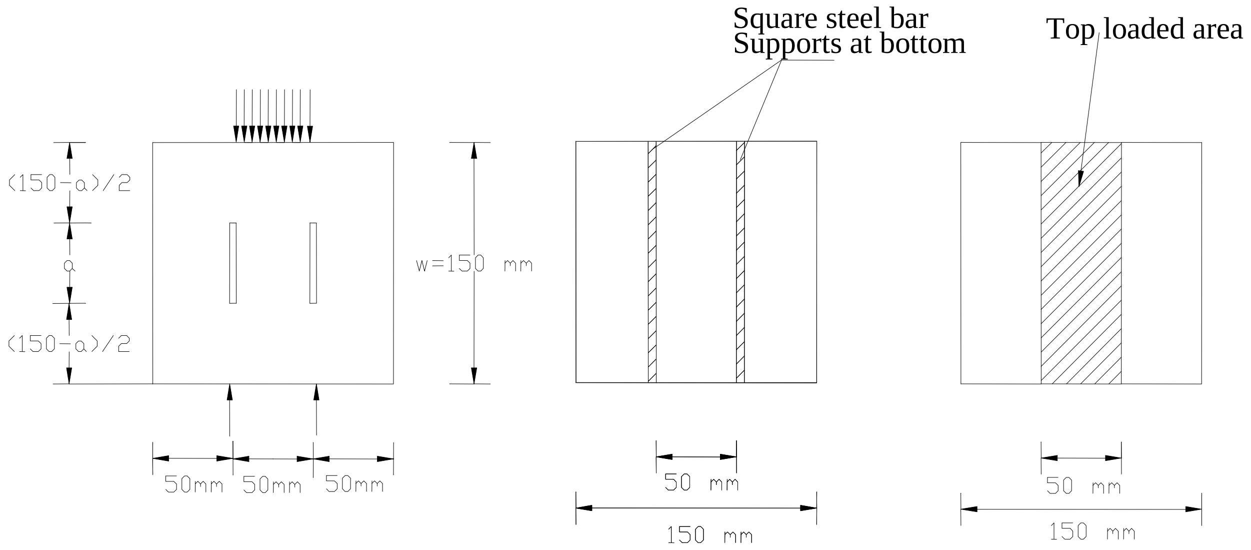
4.1 CASTING OF SPECIMENS:

The M_{20} concrete mix is designed using ISI method which gives a mix proportion of 1:1.55:3.04 with water cement ratio of 0.50. Five different mixes which are designated as follows:

TABLE: 1.

Name of the Mix	Replacement of Coarse Aggregate by Volume percentage		No of specimens cast
	Natural Aggregate	Cinder Aggregate	
C-0	100	0	21
C-25	75	25	21
C-50	50	50	21
C-75	25	75	21
C-100	0	100	21
		Total	105

To proceed with the experimental program initially steel moulds of size 150x150x150 mm were cleaned brushed with machine oil on all inner faces to facilitate easy removal of specimens afterwards. First fine aggregate and cement were added and mixed thoroughly and then conventional coarse aggregates with partially replaced Cinder was mixed with them. All of these were mixed thoroughly by hand mixing. Each time 3 no of cubes, 12 no of DCN specimens and 6 no of cylinders were cast. The notch depths provided were 45,60,75 and 90mm running throughout the width of the specimen. Thus the values of a/w ratio were 0.3, 0.4, 0.5, and 0.6 where ‘a’ is the notch depth and ‘w’ is the specimen depth 150mm. The distance between the notches is kept constant at 50mm and width of the notch was 2mm. The two supports in the form of square steel bars were formed throughout the width of the specimen slightly away from the notches. The load was applied within the notches.



(a) Loading and support arrangement in elevation while testing

(b) Bottom view while testing

(c) Top view while testing

FIG.1. DETAILS OF DCN TEST SPECIMEN GEOMETRY

For all test specimens, moulds were kept on the plat form and the concrete was poured into the moulds in three layers each layer being compacted thoroughly with tamping rod to avoid honey combing. Finally all specimens were vibrated on the table vibrator after filling up the moulds up to the brim. The vibration was effected for 7 seconds and it was maintained constant for all specimens and all other castings. However the specimens were demoulded after 24 hours of casting and were kept immersed in a clean water tank for curing. After 28 days of curing the specimens were taken out of water and and were allowed to dry under shade for few hours.

V. TESTING OF SPECIMENS

The cube and cylindrical specimen is kept vertically between the compressive plates of the testing machine. The load is applied uniformly until the specimens fails, and ultimate loads are recorded. The test results of cube and cylinder compressive strengths are furnished in table 2 and 3 respectively. This test setup is presented in plate 2 & 4 respectively. An attempt to find out the modulus of elasticity has been done by the 3000KN automatic compression testing machine with 0.5KN/sec rate of loading. The results of modulus of elasticity are furnished in table no 6. The cylindrical specimen was kept horizontally for finding the split tensile strength. The test setup is shown in plate 6. The compression test on the DCN cubes was conducted on 3000KN digital compression testing machine. The rate of loading applied is 0.5 KN/sec. For testing DCN specimens of size 150x150x150mm, notches were introduced at one third portion centrally as shown in fig. 1 during casting. The loading arrangement along with frame setup used for DCN specimen is shown in plate 8. Uniformly distributed load was applied over the central one third part between the notches and square cross section steel supports were provided at bottom along the outer edges of the notches, so that the central portion could get punched/sheared through along the notches on the application of loading.

5.1 DISCUSSION OF CRACK PATTERN AND TEST RESULTS:

In case of cubes under compression test initial cracks are developed at top and propagated to bottom with increase in load and then the cracks are widened at failure along the edge of the cube and more predominantly along the top side of casting and failure of the specimen as shown in plate 3. In case of cylinders under compression cracks are developed at top and bottom and with increase in load the cracks are widened at central height and the test set of specimen as shown in plate 5. In case of cylinders subjected to split tensile strength the cylinder is splitted into two pieces and the failure of the specimen as shown in plate 7. The failure of the DCN specimen are presented in plate 9 and crack patterns obtained for DCN specimen geometry for the four notch depths and cement concrete mixes are presented in Plates 10 to 14. During testing, for most of the specimens initial hair line cracks started at the top of one or both the notches, and as the load was increased further, the cracks widened and propagated at an inclination and sometimes to the middle of the top loaded zone. Simultaneously the cracks formed at the bottom of one or both the notches and propagated downwards at visible inclination. In some cases cracks branched into either side at the two edges of the supporting square bar at the bottom or at the edge of the loaded length at top or at both places.

5.1.1 INFLUENCE OF CINDER ON CUBE COMPRESSIVE STRENGTH:

The variation of compressive strengths and percentage of increase or decrease verses percentage of Cinder addition are shown in fig.2 and it is observed that with the addition of Cinder the cube compressive strength decreases continuously up to 100% replacement of Granite by Cinder, but more than the target mean strength of M_{20} concrete i.e., 26.6 N/mm^2 has been achieved even when the natural granite aggregate is replaced with 75% of cinder aggregate as tabulated in table 2. In addition for C-100 mix, the design strength of M_{20} concrete is achieved.

5.1.2 INFLUENCE OF CINDER ON CYLINDER COMPRESSIVE STRENGTH:

The variation of compressive strengths and percentage of increase or decrease verses percentage of Cinder addition are as shown in fig 3 and it is observed that with the addition of Cinder the cylinder compressive strength decreases continuously up to 100% replacement of Granite by Cinder as tabulated in table 3. The ratios of cube and cylinder compressive strengths are tabulated in table 4.

5.1.3 INFLUENCE OF CINDER ON SPLIT TENSILE STRENGTH ON CYLINDER SPECIMENS:

With increase in percentage of replacement of granite by Cinder aggregate, the split tensile strength is found to decrease continuously up to 100% as shown in fig 4, and the values are tabulated in table no .5

5.1.4 INFLUENCE OF CINDER ON YOUNG'S MODULUS (E):

With increase in percentage of replacement of granite by Cinder aggregate, the E value is found to decrease continuously up to 100% as shown in fig 5 & 6. These values are tabulated in table no 6. The youngs modulus is calculated by two approaches. i.e. by I.S.Code method[15] and using an empherical formula for light weight concrete[16]. The values calculated using both these approaches are observed to match more or less satisfactorily.

5.1.5 INFLUENCE OF CINDER ON DENSITY:

The variation of density and percentage of increase or decrease in density verses percentage of Cinder are shown in fig 7. From the fig, it is observed that with the addition of Cinder the density of the specimens decreases continuously up to 100% replacement of Granite by Cinder, and the values are tabulate in table no 7.

5.1.6 INFLUENCE OF CINDER ON IN-PLANE SHEAR STRENGTH:

All the DCN specimens with different a/w ratios i.e., 0.3, 0.4, 0.5, and 0.6 and with different percentages of cinder i.e., 0%, 25%, 50%, 75%, 100%, were tested with load in Mode-II (in-plane shear).

a) The variations of ultimate loads and the % of increase or decrease in ultimate loads versus percentage of cinder are presented in the fig 8 and percentage of decrease in ultimate load are presented in fig 9. These are presented for different a/w ratios (i.e., 0.3, 0.4, 0.5, 0.6). From these diagrams it is observed that with the increase in percentage of cinder and a/w ratio ultimate load decreases and also percentage decrease in ultimate load is increasing.

b) Super-imposed variations of ultimate shear stress, percentage increase or decrease in ultimate stress in in-plane shear Versus percentage of cinder for different a/w ratios (i.e., 0.3,0.4,0.5,0.6) is presented in fig 10. It is observed that the in plane shear stress at ultimate load is decreased with increasing percentage of cinder.

TABLE 2: CUBE COMPRESSIVE STRENGTH RESULTS

S.No	Name Of The Mix	Percentage Volume Replacement Of Coarse Aggregate (%)		Compressive Strength (N/mm^2)	Percentage Of Increase Or Decrease In Compressive Strength
		Natural Aggregate	Cinder Aggregate		
1.	C-0	100	0	41.08	0.00
2.	C-25	75	25	34.03	-17.16
3.	C-50	50	50	30.49	-25.78
4.	C-75	25	75	27.49	-33.08
5.	C-100	0	100	24.53	-40.29

TABLE 3: CYLINDER COMPRESSIVE STRENGTH RESULTS

S.No	Name of the mix	Percentage Volume Replacement Of Coarse Aggregate (%)		Cylinder compressive strength (N/mm^2)	Percentage Of Increase Or Decrease In Compressive Strength
		Natural Aggregate	Cinder Aggregate		
1.	C-0		0	28.01	0.00
2.	C-25		25	22.52	-19.60

3.	C-50		50	20.60	-26.45
4.	C-75		75	15.51	-44.63
5.	C-100		100	15.00	-46.45

TABLE 4:RATIO OF CYLINDER COMPRESSIVE STRENGTH TO CUBE COMPRESSIVE STRENGTH

S.No	Name of the mix	% of Cinder	Cylinder compressive strength (N/mm²)	Cube compressive strength (N/mm²)	Ratio of cylinder to cube compressive strength
1.	C-0	0	28.01	41.08	0.68
2.	C-25	25	22.52	34.03	0.66
3.	C-50	50	20.60	30.49	0.68
4.	C-75	75	15.51	27.49	0.56
5.	C-100	100	15.00	24.53	0.61

TABLE 5: SPLIT TENSILE STRENGTH RESULTS

S.No	Name of the mix	Percentage volume replacement of coarse aggregate (%)		Split tensile strength (N/mm^2)	Percentage of Increase or Decrease in split tensile strength
		Natural aggregate	Cinder aggregate		
1.	C-0	100	0	3.58	0.00
2.	C-25	75	25	3.11	-13.13
3.	C-50	50	50	2.93	-18.16
4.	C-75	25	75	2.63	-26.54
5.	C-100	0	100	2.38	-33.52

TABLE 6: YOUNG'S MODULUS

S. No	Name of the mix	Percentage volume replacement of coarse aggregate (%)		Young's modulus $E=5000\sqrt{f_{ck}}$ (N/mm²)	Young's modulus $E=k_{1x}k_{2x}1.486x10^{-3}x\,\sigma_b^{1/3}x\gamma^2$ (N/mm²) $K_1=0.95$, $K_2=1.026$
		Natural aggregate	Cinder aggregate		
1.	C-0	100	0	$3.20*10^4$	$3.28*10^4$
2.	C-25	75	25	$2.92*10^4$	$2.93*10^4$
3.	C-50	50	50	$2.76*10^4$	$2.61*10^4$
4.	C-75	25	75	$2.62*10^4$	$2.45*10^4$
5.	C-100	0	100	$2.48*10^4$	$2.15*10^4$

TABLE 7: DENSITY RESULTS

S.No	Name of the mix	Percentage volume replacement of coarse aggregate (%)		Density (kg/m^3)	Percentage Of Increase Or Decrease In Density
		Natural aggregate	Cinder		
1.	C-0	100	0	2563	0.0
2.	C-25	75	25	2501	-2.42
3.	C-50	50	50	2402	-6.28

4.	C-75	25	75	2366	-7.69
5.	C-100	0	100	2262	-11.74

TABLE 8: ULTIMATE LOAD IN MODE-II FOR DCN SPECIMENS WITH a/w RATIOS = 0.30, 0.40, 0.50, 0.60.

S.No	Name of mix	% volume replacement of coarse aggregate		**a/w=0.30**		**a/w=0.40**		**a/w=0.50**		**a/w=0.60**	
				Ultimate load (KN)	% increase or decrease in ultimate load	Ultimate load (KN)	% increase or decrease in ultimate load	Ultimate load (KN)	% increase or decrease in ultimate load	Ultimate load (KN)	% increase or decrease in ultimate load
		Natural	Cinder								
1.	C-0	100	0	144.00	0.00	105.00	0.0	83.00	0.0	62.00	0.0
2.	C-25	75	25	125.67	-12.73	104.00	-0.95	81.33	-2.01	56.67	-8.60
3.	C-50	50	50	104.33	-27.55	87.00	-17.14	72.33	-12.86	50.33	-18.82
4.	C-75	25	75	96.67	-32.87	67.00	-36.19	50.33	-39.36	38.33	-38.18
5.	C-100	0	100	69.00	-52.08	58.00	-44.76	48.00	-42.17	29.00	-53.23

TABLE 9: IN-PLANE SHEAR STRESS AT ULTIMATE LOAD FOR DCN SPECIMENS WITH a/w RATIOS = 0.30, 0.40, 0.50, 0.60.

S.No	Name of mix	% volume replacement of coarse aggregate		**a/w=0.30**		**a/w=0.40**		**a/w=0.50**		**a/w=0.60**	
				Ultimate load (KN)	In-plane shear stress in N/mm^2	Ultimate load (KN)	In-plane shear stress in N/mm^2	Ultimate load (KN)	In-plane shear stress in N/mm^2	Ultimate load (KN)	In-plane shear stress in N/mm^2
		Natural	Cinder								
1.	C-0	100	0	144.00	4.57	105.00	3.89	83.00	3.69	62.00	3.45
2.	C-25	75	25	125.67	3.99	104.00	3.85	81.33	3.61	56.67	3.15
3.	C-50	50	50	104.33	3.31	87.00	3.22	72.33	3.21	50.33	2.80
4.	C-75	25	75	96.67	3.07	67.00	2.48	50.33	2.24	38.33	2.13
5.	C-100	0	100	69.00	2.19	58.00	2.15	48.00	2.13	29.00	1.61

PLATES

PLATE 1: INGREDIENTS OF CONCRETE

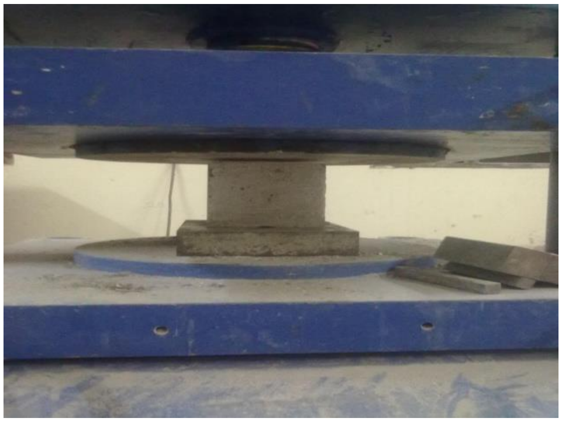


PLATE 2: TEST SETUP FOR CUBE COMPRESSIVE STRENGTH TEST BEFORE TESTING

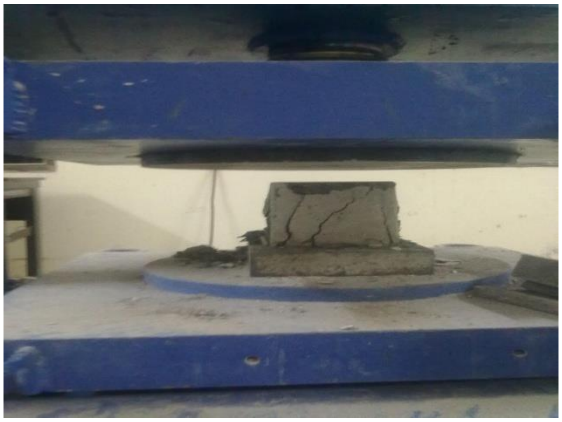


PLATE 3: VIEW SHOWS THE CUBE COMPRESSIVE STRENGTH TEST AFTER TESTING

PLATE 4: TEST SET UP FOR CYLINDER COMPRESSIVE STRENGTH BEFORE TESTING

PLATE 5. VIEW SHOWS THE CYLINDER AFTER TESTING

PLATE 6: TEST SET UP FOR CYLINDER SPLIT TENSILE STRENGTH BEFORE TESTING

PLATE 7. VIEW SHOWS THE SPLIT TENSILE STRENGTH AFTER TESTING

PLATE 8. TEST SET UP FOR MODE-II FRACTURE

PLATE 9. VIEW SHOWS THE MODE-II FAILURE OF NOTCHED CUBE

PLATE 10. VIEW SHOWS THE CRACK PATTERNS AFTER TESTING OF C-0 SPECIMENS

PLATE 11. VIEW SHOWS THE CRACK PATTERNS AFTER TESTING OF C-25 SPECIMENS

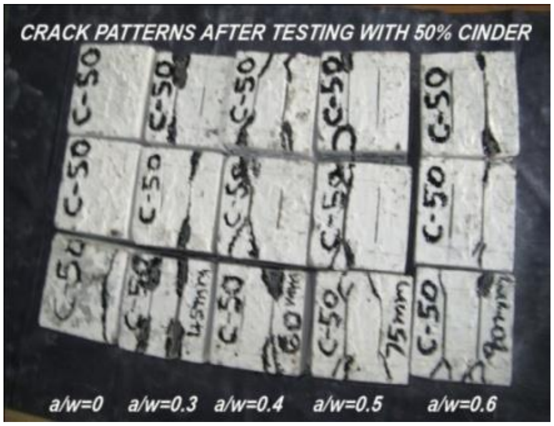


PLATE 12. VIEW SHOWS THE CRACK PATTERNS AFTER TESTING OF C-50 SPECIMENS

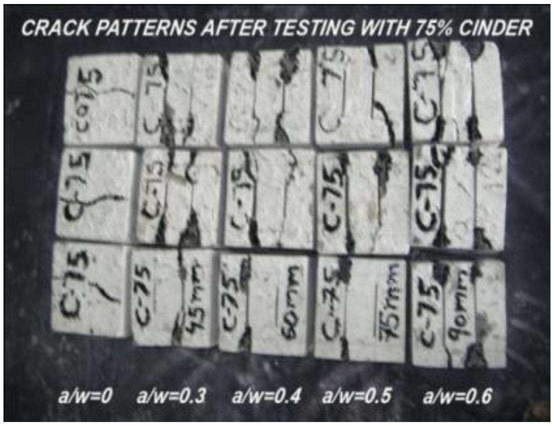


PLATE 13. VIEW SHOWS THE CRACK PATTERNS AFTER TESTING OF C-75 SPECIMENS

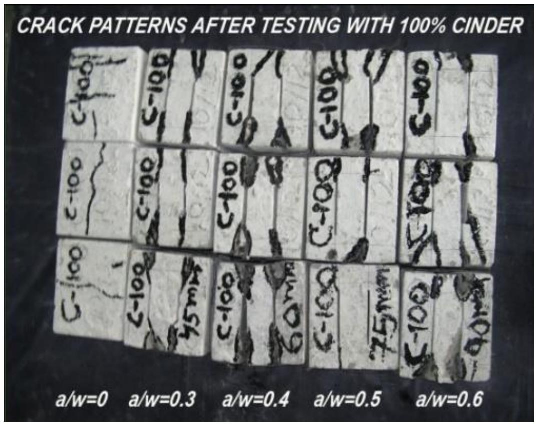


PLATE 14. VIEW SHOWS THE CRACK PATTERNS AFTER TESTING OF C-100 SPECIMENS

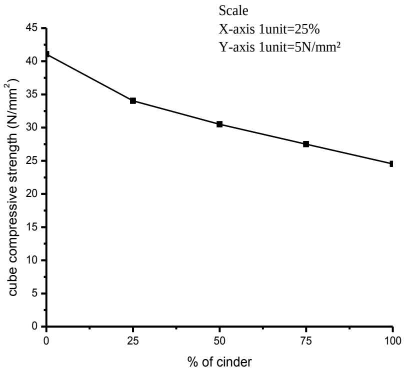


FIG 2: VARIATION BETWEEN CUBE COMPRESSIVE STRENGTH AND PERENTAGE REPLACING NATURAL AGGREGATE BY CINDER AGGREGATE

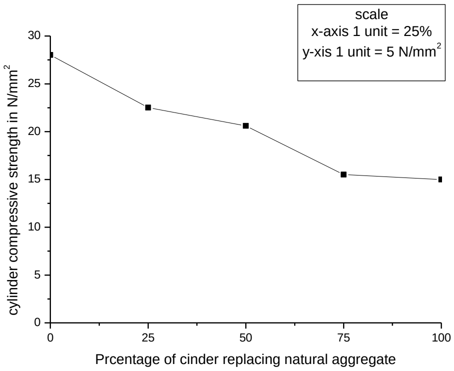


FIG 3: VARIATION BETWEEN CYLINDER COMPRESSIVE STRENGTH AND PERCENTAGE REPLACING NATURAL AGGREGATE BY CINDER AGGREGATE

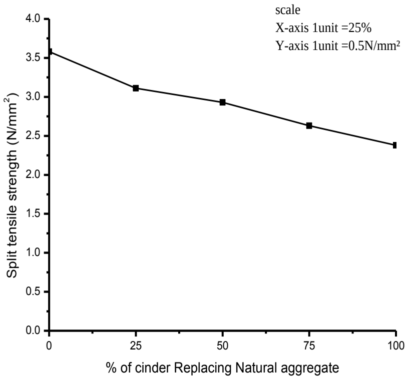


FIG 4: VARIATION BETWEEN SPLIT TENSILE STRENGTH AND PERCENTAGE REPLACING NATURAL AGGREGATE BY CINDER AGGREGATE

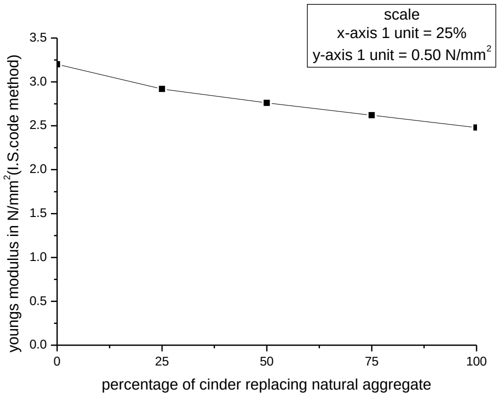


FIG 5: VARIATION BETWEEN YOUNGS MODULUS AND PERCENTAGE REPLACING NATURAL AGGREGATE BY CINDER AGGREGATE (I.S.CODE METHOD)

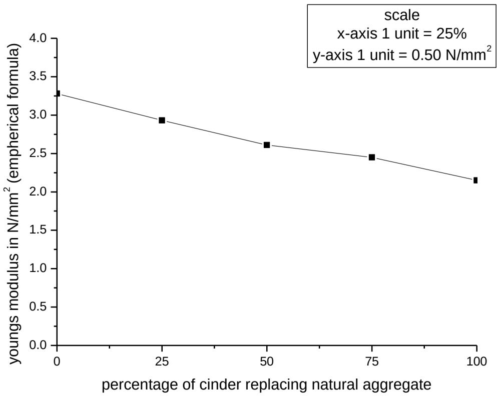


FIG 6: VARIATION BETWEEN YOUNGS MODULUS AND PERCENTAGE REPLACING NATURAL AGGREGATE BY CINDER AGGREGATE

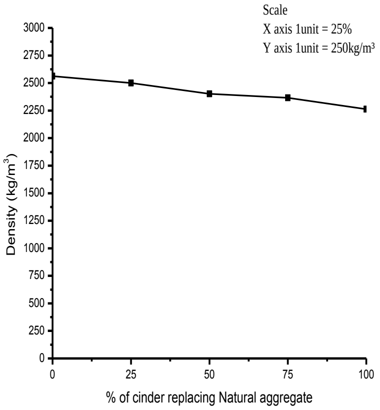


FIG 7: VARIATION BETWEEN DENSITY AND PERCENTAGE REPLACING NATURAL AGGREGATE BY CINDER AGGREGATE

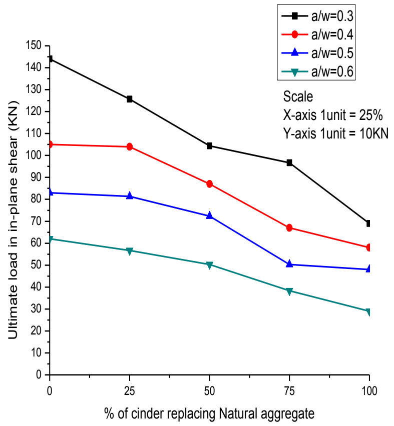


FIG 8: VARIATION BETWEEN ULTIMATE LOAD IN IN-PLANE SHEAR AND % OF CINDER REPLACING NATURAL AGGREGATE WITH a/w RATIOS =0.3,0.4,0.5,0.6

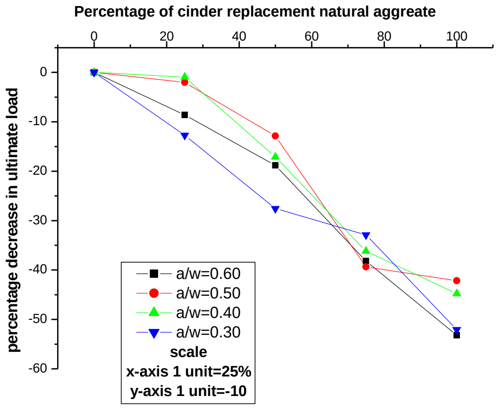


FIG 9: VARIATION BETWEEN PERCENTAGE OF ULTIMATE LOAD IN IN-PLANE SHEAR AND % OF CINDER REPLACING NATURAL AGGREGATE WITH a/w RATIOS =0.3,0.4,0.5,0.6

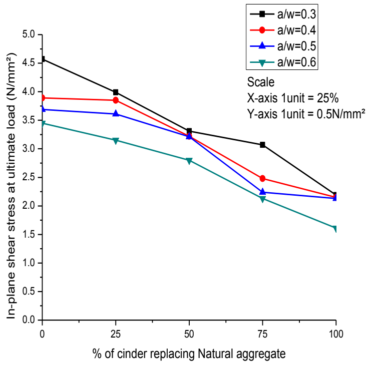


FIG 10: SUPER IMPOSED VARIATION BETWEEN IN-PLANE SHEAR STRESS AT ULTIMATE LOAD AND % OF CINDER REPLACING NATURAL AGGREGATE WITHA/W=0.3,0.4,0.5,0.6

VI. CONCLUSIONS

From the limited experimental study of the following conclusions are seem to be valid:

1. From the study it is concluded that the cube compressive strength is decreased continuously with the increase in percentage of cinder and also the percentage of decrease in cube compressive strength is increased continuously with increasing cinder. However even with 75% replacement of conventional aggregate by cinder aggregate more than target mean strength of concrete is achieved.
2. From the study it is concluded that the cylinder compressive strength is decreased continuously with the increase in percentage of cinder and also the percentage of decrease in cylinder compressive strength is increased continuously with increasing cinder.
3. From the study it is concluded that the split tensile strength is decreased continuously with increase in percentage of cinder and also the percentage of decrease

in split tensile strength is increased continuously with increasing cinder

4. From the study it may be concluded that the young's moduli have decreased continuously with the increase in percentage of cinder
5. From the analysis of test results it is concluded that the results arrived from I.S.code formula are satisfactorily matching with the results arrived from the empirical formula.
6. From the study it may be concluded that the densities have decreased continuously with the increase in percentage of cinder.
7. The cinder aggregate is no way inferior to the natural aggregate.

REFERENCES

[1] Clarke, J.L. Design Requirements. Structural Light weight Aggregate Concrete, Chapman & Hall, London, pp. 45-74, 1993.

[2] Thorenfeldt, E., Design Criteria of Light weight Aggregate Concrete. CEB/FIP International Symposium on Structural Light weight Aggregate Concrete, Sandefjord, Norway, pp. 720- 732, 1995.

[3] Bryan, Dennis. S. P, "Occurrence and uses of natural lightweight aggregate in the Western United States", Lightweight aggregate in Western United States, January 1989, pp. 89-193.

[4] P.S. Raghuprasad, R. Satish, D.B. Nirmala, A.V. Pradeep kumar, "Experimental investigation on solid concrete blocks with partial replacement of coarse aggregate with Cinder aggregate".

[5] M. A. Caldarone and R. G. Burg , "Development of very low density structural lightweight concrete", ACI journal, vol. 218, Febrauary 2004, pp. 177-188.

[6] Watkins, J. and Liu, K.L.W., "A Finite Element Study of Short Beam Test Specimens under Mode-II loading", The International Journal of Cement Composites and Light Weight Concrete, Vol.7, No.1, Feb.1985, pp.39-47.

[7] Owens, P.L. (1993). "Light weight aggregates for structural concrete," Structural Light weight Aggregate Concrete, Chapman & Hall, London, pp.1-18.

[8] N. Siva lingaRao, G. VenkataRamana, V. Bhaskar Desai, B. L.P. Swamy, "Properties of lightweight aggregate concrete with cinder and silicafume admixture", International Journal of Earth Sciences and Engineering, Vol. 4, No. 6, October 2011, pp. 907-912.

[9] Prakash Desayi, Raghu Prasad .B.K, and Bhaskar Desai . V, "Experimental determination of KIIc from compliance and fracture energy", proceedings national seminar on Aerostructures, organized by IIT, Kanpur, India, 29-30, Dec, 1993, pp. 33-34.

[10] Prakash desayi, B.K.Raghu Prasad and V.Bhaskar Desai, "Mode – II fracture of cementitious materials- part – I : Studies on specimens of some new geometries", Journal of Structural Engineering, Vol.26, No.1, April 1999, pp.11-18.

[11] Prakash desayi, B.K.Raghu Prasad and V.Bhaskar Desai, "Mode – II fracture of cementitious materials- part – II: Fracture toughness of cement paste, mortar, concrete and no-fines concrete. Journal of structural engg Vol. 26, No. 1, April 1999, pp. 19-27.

[12] Prakash desayi, B.K.Raghu Prasad and V.Bhaskar Desai, "Mode – II fracture of cementtiotus materials- part – III: Studies on shear strength and slip of cement paste, mortar, concrete and no-fines concrete. Journal of structural engg Vol. 26, No.2, July 1999, pp. 91-97.

[13] Prakash desayi, B.K.Raghu Prasad and V.Bhaskar Desai, conducted Mode-II fracture of cementitious materials- part-IV: Fracture toughness, shear strength and slip of fibre reinforced cement mortar and concrete. Journal of structural engg. Vol. 26, No. 4, Jan 2000, pp. 267-273.

[14] Prakash desayi, B.K.Raghu Prasad and V.Bhaskar Desai, conducted Mode-II fracture of cementitious materials- part-V: Size effect on fracture toughness shear strength and slip of cement mortar and concrete reinforced with and without fibers. Journal of structural engg, Vol, 27, No. 2, July 2000, pp.99-104.

[15] I.S.Code 456-2000 "Code of practice for plain and reinforced concrete" Bureau of Indian Standards, New Delhi.

[16] Takafumi Noguchi, et.al (2009) " A Practical Equation for Elastic Modulus of Concrete". ACI structural journal/Sept-Oct 2009, technical paper title no. 106-SXX.

AUTHORS

First Author – Dr. V.Bhaskar Desai, Professor, Dept. of Civil Engineering, JNTUA College of Engineering, Anantapuramu – 515002, A.P.

Second Author – Mr. A. Sathyam, Conservation Assistant Gr-I, Archaeological Survey of India, Anantapuramu Sub Circle, Anantapuramu & Research Scholar, JNTUA College of Engineering, Anantapuramu – 515002, A.P.