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Flexural Study on Slab Specimens with Partial to Fully Replacement of Natural Coarse Aggregate by Light Weight Expandable Clay Aggregate (LECA)

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Abstract:

In this investigation an experimental approach is carried out to study the flexural strength of conventional concrete with partial to fully replacement of coarse aggregate by light expandable clay aggregate (LECA). With the usage of LECA in concrete, the demand of coarse aggregate is reduced in the design of concrete structures. The light weight concrete gives low density when compared to conventional concrete and possess better insulation properties to heat and sound. The main aim of this project is to understand better about the strength properties particularly compressive strength of cubes and moment carrying capacity of reinforced cement concrete slabs made of light weight concrete against conventional concrete by replacing natural aggregates with LECA by 25%, 50%, 75% and 100% after 28 days of curing.

Keywords: LECA, Compressive Strength, Flexural strength, Strain Energy, Yield line theory.

1. INTRODUCTION

Generally the concrete prepared with natural aggregates has more density and it increases dead weight acting on the structures which becomes critical when structures are built in weak soils. LECA is light weight expandable clay aggregate which is obtained by heating clay particles to a temperature of 1200°c in a rotary kiln. Lightness of LECA is because of multi-separated air spaces which exist inside and among the aggregates. Density of aggregates ranges from 380-710Kg/m^3 depending on the size of particles. It has good thermal insulation with coefficient in the range of 0.09-0.101. It also has good sound insulation, fire resistance and even resists against acidic and alkaline substances. LECA is used for many purposes like road construction, floor and roof sloping, sewage system, water purification system, prefabricated panels and slabs, etc. Usage of LECA reduces the demand for natural aggregates which is going to become scarce in future. Also low weight of LECA makes it easy for transportation when compared to natural aggregates.

In building construction, weight of concrete plays a crucial role in design of structures and there are considerable advantages in reducing the density of concrete. Because of rapid urbanization the usage of precious raw materials is becoming more and more and may leave nothing for the next generations. In recent years more attention has been paid to the development of light weight artificial aggregates whose properties were comparable with natural aggregates. The use of lightweight aggregate in concrete has many advantages. These include: (a) Reduction of dead load that may result in reduced footing sizes and lighter and smaller upper structure. This may result in reduction in cement quantity and possible reduction in reinforcement. (b) Lighter and smaller pre-cast elements needing smaller and less expensive handling and transporting equipment. (c) Reductions in the sizes of columns, slabs and beam dimension that result in larger space availability. (d) High thermal insulation. (e) Enhanced fire resistance.

2. LITERATURE REVIEW

Michala Hubertova,et.al (2013) [1] made a report on durability of light weight expanded clay aggregate concrete. The objective of their research was to evaluate the durability of light weight concrete placed in chemically aggressive and gaseous environments (high concentrations of sulphate, chloride ions, automotive gas, oil and gaseous CO_2 and SO_2 environments).

Serkan Subasi (2009) [2] made a study on the effect of using fly ash on high strength light weight aggregate concrete produced with expanded clay aggregate on physical and mechanical properties of concrete. It was evident that high strength lightweight concrete was possible to produce by using expanded clay aggregate. It was seen that the cement content with 450 kg/m^3 among concrete mixtures had the highest strength values. The mechanical properties of concrete could be enhanced by using 10% fly ash thus a savings in cement could be achieved. **S. Sivakumar & B. Kameshwari** (2014) [3] presented a report which deals with the results of a real-time work carried out to form light weight concrete made with fly ash, bottom ash, and light expanded clay aggregate as mineral admixtures. Experimental investigation on concrete mix M_{20} was done by replacement of cement with fly ash, fine aggregate with bottom ash, and coarse aggregate with light expanded clay aggregate at the rates of 5%, 10%, 15%, 20%, 25%, 30%, and 35% in each mix and their compressive strength, flexural strength and split tensile strength of concrete were evaluated for 7, 28, and 56 days depending on the optimum dosage of replacement of mineral admixtures.

Smita badur,et.al (2008) [4] gave a report on utilization of hazardous wastes and by-products as a green concrete material through stabilization or solidification process. The hazardous solid wastes and industrial byproducts were used to make light weight concrete and best demonstrated available technology of stabilization or solidification was used to treat concrete thereby the demand for normal concrete can be reduced and also the impact of cement and concrete industries on environment can be lowered.

George C Hoff,et.al (2002) [5] presented a report on the use of lightweight fines for the internal curing of concrete.

Mahdy (2016) [6] made a study on structural light weight concrete using cured LECA. In this research a new technology was developed to enhance the quality of light weight aggregate (LECA) by immersing it in the solution of silica fume in order that the silica fume particles get through the aggregates and try to pack some voids and consequently obtain their strength, absorption and pozzolanic activity.

V. Swamynath & K. Muthumani (2017) [7] made a critical review on structural light weight concrete. Selection of lightweight aggregates depends on the selection of construction. Light weight aggregate can be used for structural, non structural and infill purposes.

From the brief literature review conducted here it appears that much less attention has been paid earlier on the study of flexural properties of modified concrete with partial to 100% replacement of natural aggregates with LECA. Hence the present investigation has been under taken.

3. Objective

- Reduction in the excess demand of natural aggregates by using LECA.
- Utilization of industrial wastes into a useful lightweight concrete.

4. Experimental Procedure

A total number of 15 cubes and 15 slabs were cast with 0%, 25%, 50%, 75% and 100% replacement of natural aggregates with LECA. Cube moulds of 150x150x150 mm and slab moulds of 600x600x50 mm were used for casting. After casting and curing for 28 days, the samples were tested for compressive strength of cubes and flexural strength of slabs with fixed edge condition on all four sides.

The mix proportions used are mentioned in Table 4.1 below.

Table 4.1: Mix Proportion of concrete

Mix	Percentage volume replacement of coarse aggregate with LECA	Number of cubes	Number of slabs
S0	0	3	3
S1	25	3	3
S2	50	3	3
S3	75	3	3
S4	100	3	3

5. Materials used and their properties

5.1 The following materials were used for preparing the concrete mix.

1. ACC grade 53 cement
2. Fine aggregate i.e. sand
3. Coarse aggregate: LECA and natural aggregates
4. Water
5. HYSD Fe 415 grade steel bars

Some typical properties of the materials used are presented in the following table.

Physical properties of materials:

S. No	Name of the material		Properties of the material	
1	OPC – 53 GRADE		Specific gravity	3.26
			Initial setting time	50 minutes
			Final setting time	460 minutes
			Fineness	5%
			Normal consistency	30%
2	Fine aggregate passing through 4.75 mm sieve.		Specific gravity	2.54
			Fineness modulus	2.75
3	Coarse aggregate	Natural aggregate	Specific gravity	2.60
			Fineness modulus	6.63
			Bulk density compacted	1620 Kg/m^3
		LECA	Size	4-10 mm
			Specific gravity	1.18
			Aggregate strength	>2.26 MPa
			Bulk density	645 kg/m^3
			Water absorption	18%
			Bulk porosity	35-40%
			Shape	Angular
4	Steel		Yield strength	415 N/mm^2

5.3 Light expandable clay aggregates:

Leca (Light Expandable Clay Aggregate) is an acronym term for which is produced in rotary kiln at about 1200 degree centigrade. The base material is plastic clay which is extensively preheated. Light Expandable Clay Aggregate was procured from Nexcus Buildcon Solution India. Typical physical characteristics of Light Expandable Clay aggregates are listed in above table. The industrial preparation method of LECA is shown in plate1 below.

Plate 1: Flow chart of LECA Manufacturing process

Plate 2: Light Expandable Clay Aggregate

6. Casting of specimens:

In this investigation design mix of M_{20} grade concrete is used. ACC 53 grade cement, 20mm natural aggregates, 4-10 mm LECA and sand are used. This gives a mix ratio of 1:1.583:2.88 with a w/c of 0.5. It is proposed to replace natural aggregate by saturated and surface dry LECA with varying percentages of 0, 25, 50, 75 and 100% and the quantities are calculated and estimated for cubes and slabs to be casted. A total number of 3 cubes and 3 slabs are cast for each replacement sample and thus 15 cubes and 15 slabs in total for all replacements are cast. Slab moulds were made with two L-shaped frames with a depth of 50 mm which were connected to a flat plate using nuts and bolts. Cross stiffeners were provided at the bottom to prevent any deflection. Gaps were sealed with wax and thin cardboard to prevent leakage of sand and cement. A reinforcement of Fe 415 grade steel of 10mm bar diameter with a spacing of 130mm was used in slabs. Cover blocks of about depth 10 mm were used at the bottom of the mould. Cube moulds of 150x150x150 mm and slab moulds of 600x600x50 mm were used for casting.

The concrete was poured in 3 layers with manual compaction through a tamping rod and concrete moulds were placed on vibration table for 7 seconds. After drying for 24 hrs in shade the moulds were demoulded and kept in water for 28 days of curing. A view of cubes cast is shown below in Plate 3. The reinforcement placed in slab moulds is shown in Plate 4. A view of cast slabs is presented in Plate 5.

Plate 3: cubes casted with cube moulds of 150x150 mm

Plate 4: Slab mould with reinforcement

Plate 5: Casting of slabs of 600x600x50mm

7. Testing of specimens

7.1 Compressive Strength: The specimens were removed from water after 28 days of curing and excess water is wiped out from the surface and dried under shade and white washing was done so that cracks are properly visible. The specimens were placed in the machine in such a manner that the load shall be applied concentrically. The load was applied gradually without shock and continuously till the specimen fails. Compressive strength is equal to compressive load divided by its cross sectional area. The results of cubes for all replacements are given in the below Table 7.1. The variations are shown graphically vide Fig 7.1.

7.2 Moment carrying capacity of slabs

7.2.1 Structural Loading Frame and Platform

Typical arrangement for testing square slabs of size 600mm X 600mm under fixed edge condition with uniformly distributed loading is used in this work. The loading platform consists of 4 welded steel beams of ISLB150 in square shape, which is supported on 4 columns of ISLB 150 placed at four corners. The load was applied from top in the form of dead load and self weight. All the structural elements were designed following the code Indian Standards IS-800:1984 [8]. A view of loading arrangement is as shown below in Plate 7. The slabs were placed on the platform over the clear span of 470mm under uniformly distributed load acting on them as shown in Plate 6. Plates were fixed on all the four sides of the slab through nuts and bolts in order to prevent any rotation and any differential settlements. The load was applied through a hydraulic jack using 25 tons pre calibrated proving ring at regular intervals. This load is transmitted to the entire slab specimen through a series of I- sections and thereby to the specially manufactured setup with series of iron balls welded to an iron plate placed over the specimen in the inverted position as Udl as shown vide Plate 6. Load applied in this form is called as loading tree or load spreaders so that load is uniformly distributed over the slab specimen. At the bottom of the slab, deflectometers of least count 0.01 mm were placed at centre and 2 nos each along the two diagonals to record the deflections. The load at the first crack and its corresponding deflection, the ultimate load and its corresponding deflection were recorded at the centre and critical sections for all the slabs.

Plate 6: Slab Testing Machine With Fixed Plates **Plate 7: Slab Testing Machine**

7.2.2 First crack load, ultimate load and strain energy stored in slabs for fixed condition

The load which is recorded at the occurrence of first crack on the bottom face of the slab which propagates to top of the slab is called as first crack. The maximum load recorded by the proving ring till the deflectometer deflects in reverse direction is called as ultimate load of slab. These values are recorded and tabulated in Table 7.1. Moment carrying capacity of the slab is calculated using IS code method and Yield Line theory as follows and the values are tabulated in the Table 7.2.
According to IS Code: 456:2000[8] (Annex D- 1.1, clause 24.4.1)

Moment carrying capacity of slab specimen under fixed end condition on all four sides =
$(\alpha_x * load\ carried\ per\ unit\ width * effective\ length^2)$

α_x=0.056 for fixed condition

According to **Yield Line Theory**, moment carrying capacity of slab is calculated as follows:

$M_X = \frac{Wl_x^2}{48}$

W= Collapse Load in KN,

l_x= Effective length of slab in m

Strain energy stored:

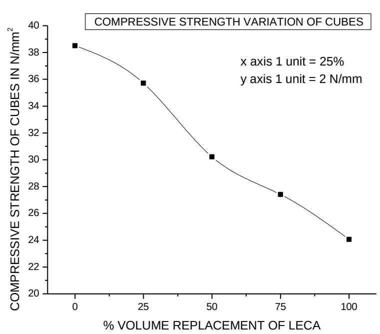
The external work done on an elastic member in causing it to distort from its unstressed state is transformed into strain energy which is in the form of potential energy. It is defined as the area under load deflection curve. The results are calculated and tabulated vide Table 7.2.

Table 7.1: Compressive Strength values of cube samples

Mix	% Volume replacement of coarse aggregate with LECA	Compressive strength in N/mm^2	Percentage decrease w.r.t S0
S0	0	38.50	0
S1	25	35.71	7.25
S2	50	30.22	21.50
S3	75	27.41	28.81
S4	100	24.06	37.51

Table 7.2: Moment Carrying Capacity and strain energy stored in Slabs in Fixed end Condition on all four sides

Mix	At First Crack			At Ultimate Load			
	Load (KN)	Moments(KN-m)		Load (KN)	Moments(KN-m)		Strain energy stored (KN-mm)
		IS method	Yield line theory		IS method	Yield line theory	
S0	178.72	3.03	1.34	781.37	14.65	5.86	274.10
S1	161.72	2.74	1.21	767.22	12.99	5.75	240.88
S2	136.28	2.31	1.02	730.44	12.37	5.47	198.79
S3	110.81	1.88	0.83	600.29	10.17	4.50	182.01
S4	85.35	1.45	0.64	512.56	8.68	3.84	168.40



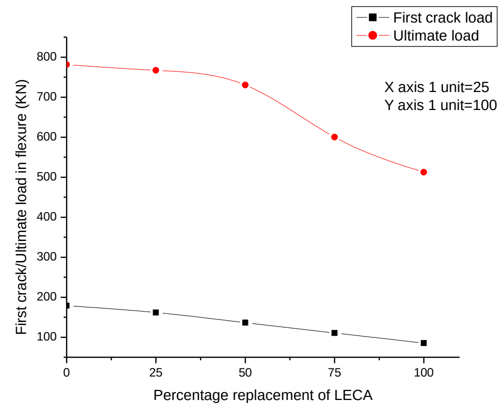
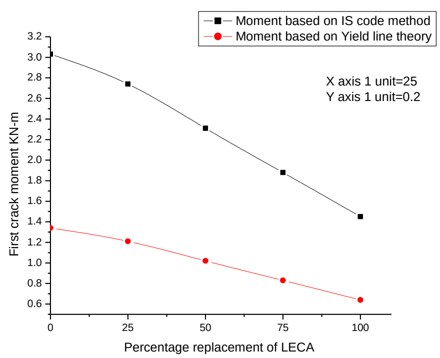


Fig: 7.1 Variation of Compressive strength Versus percentage volume replacement of LECA

Fig: 7.2 Variation of First crack / Ultimate Load Versus percentage replacement of LECA



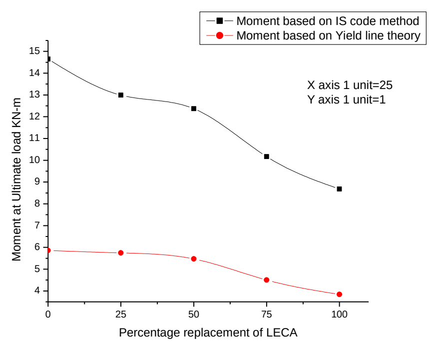


Fig: 7.3 Variation of first crack Moments Versus percentage replacement of LECA

Fig: 7.4 Variation of ultimate load Moments Versus percentage replacement of LECA

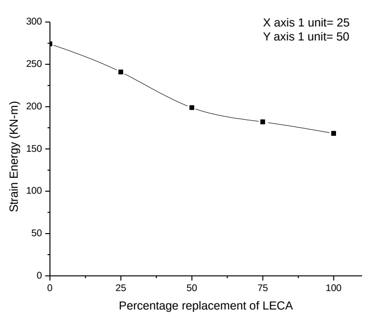


Fig 7.5 Variation of Strain energy Versus percentage replacement of LECA

8. Discussion of Test Results

8.1 Influence of replacement with LECA over compressive strength:

In the present study natural aggregate has been replaced with light expandable clay aggregates (LECA) with varying percentages of 0, 25, 50, 75 and 100% of natural coarse aggregate. The cube compressive strength is presented vide table 7.1 and graphically represented vide figure no 7.1. From them it is found that the cube compressive strength is reduced with the increase in percentage of replacement of LECA. Also it can be observed that even with 75% replacement target mean strength is achieved.

8.2 Influence of replacement with LECA in slabs over first crack load:

In slabs first crack is observed when the slab tries to relieve tension after the application of load. In the present study natural aggregate has been partially and fully replaced with LECA. The values are tabulated below in Table 7.2. The graphical variation of first crack load verses varying percentage replacements of 0, 25, 50, 75 and 100 are shown vide Fig 7.2. From the above figure it may be observed that with the increase in addition of light weight LECA the first crack load is decreased.

8.3 Influence of replacement with LECA in slabs over ultimate load:

In slabs ultimate load is occurred when the cracks are developed and spread over the entire slab and there will be no further increase in load. In the present study natural aggregate has been partially and fully replaced with LECA. The variation of ultimate load verses varying percentage replacements of 0, 25, 50, 75 and 100% are presented vide Table 7.2 From the above figure it may be observed that with the increase in addition of LECA the ultimate load is decreased. The graphical variation is as shown vide Fig 7.2.

8.4 Influence of replacement with LECA in slabs over moment carrying capacity using IS code method and Yield Line Theory:

In the present study natural aggregate has been partially and fully replaced with LECA. The moment carrying capacity in slabs with fixed condition on its entire four edges for first crack and ultimate load has been calculated using two approaches i.e., IS code method and yield line theory. The variation of moment carrying capacity of slab at first crack and ultimate load verses varying percentage replacement at 0, 25, 50, 75 and 100% of natural coarse aggregate with LECA are graphically represented vide Fig 7.3 and in Fig 7.4 respectively. From the above figures it may be observed that with the increase in addition of LECA the moment carrying capacity of slab at both first crack and ultimate condition is decreased. Also the moment carrying capacity calculated using IS code method is found to be higher than that of using yield line theory approach.

8.6 Influence of strain energy stored:

The variation of strain energy stored in slab verses varying percentage replacements at 0, 25, 50, 75 and 100% of natural coarse aggregate with LECA at 28 days are tabulated vide Table 7.2 and graphical representation is shown vide Fig 7.5. From the above figure it may be observed that with the increase in addition of LECA the strain energy stored in slab is decreased.

9. CONCLUSIONS:

1. From the study it is found that the cube compressive strength is decreased continuously with the increase in % replacement of natural aggregate by LECA from 0 to 100%. It varies from 38.5 to 24.06 N/mm^2. The target mean strength of M_{20} concrete with natural aggregate is 26.60 N/mm^2.

2. The values of moment carrying capacity of two way slabs with fixed end condition and under Udl calculated based on IS code method and Yield Line Theory for first crack and ultimate load is decreased continuously with the increase in % replacement of natural aggregate by LECA. Also the moment carrying capacity calculated by IS code method is higher when compared to that calculated using yield line theory.

3. LECA can be viewed as better replacement for normal aggregates and thus the demand of natural aggregates can be reduced to an appreciable extent.

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