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Experimental Investigation on Self Compacting Concrete using Light Weight Aggregate

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Abstract : Light Weight Self Compacting Concrete (LWSCC) combines the advantages of being light in weight and easily flowable in elements with congested reinforcement. In this project Self Compacting Concrete (SCC) is made in which LECA (Light Expanded Clay Aggregate) is used to make the concrete light in weight leading to Light Weight Self Compacting Concrete (LWSCC). Fine aggregate in Self Compacting Concrete (SCC) is replaced with LECA by 0%, 5%, 10% and 15% by volume of fine aggregate. Mix design is made as per ENFARC guidelines and checked for workability criteria. The compressive strength for 5% replacement increased when compared to that of 0% replacement due to that the spherical shape of LECA aggregates contributed to better self compaction and hence higher strength. For further replacement there was a decline in strength due to weaker nature and unavailability of water for hydration due to pronounced water absorption characteristics of LECA. Hence 5% is considered as optimum in replacing fine aggregate in self compacting concrete by Light Expanded Clay Aggregate (LECA).
Keywords : light weight concrete; self compacting concrete; light weight self compacting concrete; LECA.

1.0 Introduction

Concrete is the most important building material used in the construction industry. Density of the normal concrete is in the order of 2200 to 2600 kg/m^3. This heavy self weight results in larger dimensions of load bearing elements and foundations making it to some extent an uneconomical material. Attempts have been made to reduce the self weight of concrete and evolve light weight concrete with densities of the order of 300 to 1850 kg/m^3. Very often light weight concrete is made by use of light weight aggregates which are porous in nature and have low specific gravity. Light weight aggregates can be classified into two categories namely natural light weight aggregates and artificial light weight aggregates. Natural light weight aggregates are not found in many places and they are also not of uniform quality. As such they are not used widely in making light weight concrete. Some of the natural light weight aggregates are pumice, diatomite, scoria, volcanic cinders, saw dust and rice husk out of which pumice is the only one which is used widely. Artificial light weight aggregate may consist of processed shale, clay, clinker or other material. The production includes a burning process where the material expands and as a result has less density. Due to expansion, some artificial light weight aggregate may be absorptive. Artificial light weight includes artificial cinders, foamed slag, bloated clay, expanded shale and slate, sintered fly ash, exfoliated vermiculite, and expanded perlite, thermocole beads. Light weight aggregate like bloated clay and sintered fly ash are round in shape and have a smooth texture while other artificial aggregates are angular and have a rough surface. In this experimental investigation, bloated clay by its commercial name LECA (Light Expanded Clay Aggregate) is used. LECA is an aggregate made by expanding clay at average temperature of 1200 C° in rotary kiln. LECA is usually produced from 0.1 mm up to 25 mm and supplied in various range sizes, which some of the commons grades are (0-4) mm, (4-10) mm, (10-25) mm and 0-25 mm which has 510, 330 , 250 and 280 kg/m^3 average density.

Another recent trend in construction industry is Self compacting concrete having higher fluidity without segregation and is capable of filling every corner of form work under its self weight even in the presence of congested reinforcement. It eliminates the need for vibration either external or internal for the compaction of concrete. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete. SCC is often produced with low water-cement ratio while chemical and mineral admixtures are added to enhance the flowability. Superplasticizer, a chemical admixture is composed of polymer chains of lignosulfonates, sulphonated naphthalene and melamine based polycondensates that carries a very high anionic charge (negative charge). Cement is a colloidal system i.e. cement is dispersed in water. The prominent force in a colloidal system is Van der Waals attraction system which leads to flocculation of cement particles. When the cement particles form as floc, a particular quantity of water gets entrapped between them. This results in an ineffective usage of water which reduces the workability of concrete. When chemical admixture also called as superplasticizer is added that the polymers are adsorbed on the surface of the cement particles, giving them a negative charge so that they repel each other. Because of the electrostatic repulsion forces the cement particles are dispersed and the result is that the entrapped water is left free and hence less mixing water is required to achieve a desired workability and strength. Mineral admixtures are particles finer then cement when added to the cement paste provides high flowability and stability at the same time.

Studies[1] was made earlier to use Light Expanded Clay Aggregate (LECA) in Self Compacting Concrete by varying different parameters like LECA/Sand ratio 1, 1.5 and 2 and percentage replacement of coarse aggregate by LECA by 35%, 50% and 65%. Workability and strength results showed optimum results at 1.5 LECA/Sand ratio and there was no considerable increase in strength with replacement of coarse aggregate by LECA. Light weight aggregate LECA is used as a replacement of fine aggregate from 0% to 20% at 5% interval by volume of fine aggregate[2]. All the mix combinations of LECA and control mix satisfied workability criteria. The self compacting concrete mix with LECA 5% attained higher strength and hence LECA can be used as a replacement of fine aggregate.

Mineral admixtures are particles finer than cement which has effects on fresh and hardened properties of Light Weight Self Compacting Concrete[3]. Specimens with combinations of light weight aggregate and admixtures (Silica fume, fly ash, and filler) were prepared and tested. Mixtures that contained silica fume showed best results and compatible with light weight aggregate while fly ash showed considerable results next to silica fume. Silica fume was more expensive while fly ash is cheaper and easily available. Hence fly ash was considered as a suitable admixture to be used as mineral admixture in SCC.

Hence in this project attempt has been made to combine the advantages of Light Weight Concrete (LWC) and Self Compacting Concrete (SCC) leading to Light Weight Self Compacting Concrete (LWSCC) by using LECA as a partial replacement of fine aggregate by volume of fine aggregate.

2.0 Materials

Cement is a material with adhesive and cohesive properties which make it capable of bonding the constituents of concrete into a compact mass. Grade 53 Ordinary Portland cement of specific gravity 3.149 conforming to IS: 12269 – 1989[4] was used in this project. Fly ash of specific gravity 1.585 was used as Mineral admixture. Locally available river sand, with a specific gravity of 2.66, moisture content 2.4% and grading zone III, conforming to IS: 383 – 1970 [5]was used as natural fine aggregate. Natural crushed coarse aggregate, 12.5 mm size, with a specific gravity of 2.73 and water absorption 0.45% conforming to IS: 383 – 1970[5] was used in this study. Light Expanded Clay Aggregate (LECA) of size 4-10 mm was used as a partial replacement of fine aggregate by its volume. The specific gravity and water absorption of LECA aggregate are 1.785 and 56%, respectively (Fig. 1).

Fig 1 Light Expanded Clay Aggregate (LECA)

Superplasticizer which is also known as high range water reducers are chemical admixtures used where well-dispersed particle suspension is required mainly in self compacting concrete. Two commercial types of superplasticizers have been tried. Initially “TEC MIX 640” obtained from Techy Chemy, a light brown liquid of specific gravity 1.08 was tried. It is a High range superplasticizer admixture used in concrete (Fig. 2).

Fig 2 TEC MIX 640

The result obtained from the above superplasticizer was found to be unsatisfactory. Hence superplasticizer named “Enfiiq SuperPlast-400” obtained from ENFIIQ Civil Innovative Systems; a brown liquid of specific gravity 1.17 to 1.19 was used as an alternative. It is high range water reducing superplastizer admixture with set retarding effect to produce free flowing concrete (Fig. 3).

Fig. 3. Enfiiq Super Plast - 400

3.0 Concrete mix proportioning

A. Initial mix composition

The LWSCC mix design was prepared as per EFNARC guidelines [6]. The design of the mix involves obtaining the quantities of the key components by choosing within the indicative typical ranges in order to obtain self-compactibility are given below.

- Air content may generally be set at 2 per cent, or a higher value specified when freeze thaw resistant concrete is to be designed.
- Coarse aggregate volume should be between 50 per cent and 60 per cent. When the volume of coarse aggregate in concrete exceeds a certain limit, there is an increased risk of blockage when the concrete passes through spaces between steel bars.
- The optimal volume content of sand in the mortar varies between 40 – 50 % depending on paste properties.
- Paste comprises cement and water. Water/powder ratio by volume should lie between 0.80 to 1.10

Based on the above typical ranges, the mix ratio was obtained as 1 : 1.61 : 1.44 with water cement ratio of 0.33. In order to meet the requirements of self compacting concrete i.e. self compacting concrete should contain a chemical and mineral admixture to enhance the flow properties. Following admixtures are added,

- Chemical Admixture **-** Super plasticizer with commercial name 'Tec Mix 640' is added 3% by weight of cement
- Mineral Admixture **-** Cement is replaced with Fly ash by 10% of weight of cement.

B. Workablity tests

The required quantities of concrete ingredients are collected as per initial mix design. Ingredients like cement fly ash, sand, coarse aggregate were mixed either by hand mix or machine mix thoroughly in dry condition. Superplasticizer is added to the mixing water and stirred to obtain uniform consistency before being added to the concrete mix. The superplasticizer mixed in water was added to the mix and once again the ingredients are mixed.

Based on the EFNARC guidelines [6] some of the available fresh property tests such as Slump flow, J-ring, V-funnel, L-box and U-box tests were conducted to evaluate the fresh properties.

The slump flow test is done to assess the horizontal flow of concrete in the absence of obstruction (Fig. 4). It is a most commonly used test and gives good assessment of filling ability. It can be used at site. The test also indicates the resistance to segregation. Higher flow value, indicates its ability to fill formwork under its own weight easily. Spread diameter of at least 650mm is required for SCC. In case of severe segregation, most coarse aggregate will remain in the centre of the pool of concrete and mortar and paste at the periphery of concrete.

Fig. 4. Progress of slump flow test

J-Ring test (Fig. 5) denotes the passing ability of the concrete in presence of congested reinforcement. The equipment consist of steel ring with reinforcing bars 10mm diameter 100mm in length. The bars can be placed at different distance apart to stimulate the congestion of reinforcement at the site. Generally these sections are placed 3 x maximum size of aggregate. The acceptable difference in height between inside and outside the ring should be between 0 and 10mm.

Fig. 5. Progress of J-ring test

The V-funnel test (Fig. 6) is used to determine the filling ability (flowability) of the concrete. The flow time should be between 8 and 12 seconds. The V-funnel at $T_{5minutes}$ test determines the segregation resistance of concrete. The flow time should be between 8 and 15 seconds.

Fig. 6. Progress of V-funnel test

The L-box test assesses the flow of concrete, and also the extent to which the concrete is subjected to blocking by reinforcement (Fig. 7). If the concrete flows as freely as water, at rest it will be horizontal. Therefore the ratio between heights at farther end and near end will be equal to 1. Therefore nearer the test values, the blocking ratio is to unity, the better the flow of concrete.

Fig. 7. Progress of L-box test

The U-box test is used to measure the filling ability of concrete (Fig. 8). The difference in height of concrete within the two compartments should be between 0 and 30mm.

Fig. 8. Progress of U-box test

EFNARC [6] specified the acceptance criteria for the workability tests for self compacting concrete (Table 1).

Table 1 Acceptance criteria for self compacting concrete

S.No.	Property	Test methods	Unit	Minimum	Maximum
1	Filling ability	Slump flow	mm	650	800
		T_{50cm} slump	sec	2	5
		V - funnel	sec	6	12
2	Passing ability	L - Box	h_2/h_1	0.8	1.0
		U - Box	(h_2-h_1) mm	0	30
		J - ring	mm	0	10
3	Segregation resistance	V – funnel at $T_{5minutes}$	sec	6	15

The results obtained from the workability tests did not meet the acceptance criteria specified by EFNARC [6]. Hence further modifications are made in the mix proportion.

C. Adjustment of mix

In the event that satisfactory performance was not obtained, redesign of the mix was made. Depending on the apparent problem, the following courses of action was suggested

- Using additional quantity or different types of mineral admixture.
- Modifying the proportions of the sand or the coarse aggregate.
- Using a viscosity modifying agent, if not already included in the mix.
- Adjusting the dosage of the superplasticizer and/or the viscosity modifying agent.
- Using alternative types of superplasticizer (and/or VMA), more compatible with local materials.
- Adjusting the dosage of admixture to modify the water content, and hence the water/powder ratio.

Making modifications in the type of super plasticizer, dosage of super plasticizer, using additional quantity of mineral admixture and modifying the water content, the adjusted mix ratio which met the workability criteria is as below,

- Mix ratio was 1 : 1.61 : 1.44 with water cement ratio of 0.47.
- Chemical Admixture - Super plasticizer with commercial name 'Enfiiq Super Plast 400' is added 6% by weight of cement
- Mineral Admixture - Cement is replaced by Fly ash with 20% by weight

4.0 Preparation and Testing of Specimens

D. Preparation of Specimens

The aim of the work was to combine the advantages of Light Weight Concrete (LWC) and Self Compacting Concrete (SCC) leading to Light Weight Self Compacting Concrete (LWSCC). Fine aggregate in Self Compacting Concrete (SCC) is replaced with LECA by 0%, 5%, 10% and 15% by volume of fine aggregate. A total of 4 mixtures were prepared. The required quantities of concrete ingredients are collected and mixed. Fresh property tests such as Slump flow, J-ring, V-funnel, L-box and U-box tests were conducted. After the completion of workability tests, the concrete is poured into concrete moulds by a scoop. After that the surface of concrete in moulds is finished. Care should be taken that the concrete moulds should not be vibrated. The specimens are taken out from the moulds after the final setting time is reached and kept for curing. The specimens are marked with letters “LWSCC" and the next character designate the percent of replacement of fine aggregate by volume.

E. Testing of Specimens

The compressive strength of concrete is the most important among the various strength of concrete. The compressive strength test on cube specimens was conducted (Fig. 9) in compression testing machine as per IS 516: 1964 [7,8].

Fig. 9 Compression strength test at 7 days (LWSCC 0 & LWSCC 5)

The specimen was placed in machine and load was applied at a rate of 140kg/cm^2/ min till the specimen fails. The compressive strength of the specimen is calculated by dividing the maximum load applied to cross sectional area of specimen.

5.0 Result and Discussions

F. Properties of fresh concrete

The properties of fresh self compacting concrete made with LECA as partial replacement for fine aggregate is reported (Table 2).

Table 2 Properties of fresh self compacting concrete

Test methods	Range	LWSCC 0	LWSCC 5	LWSCC 10	LWSCC 15
Slump flow	650-800	621	645	682	697
T_{50cm} slump	2-5	3.3	3.2	3.0	2.8
V - funnel	6-12	9	8.3	7.5	6
L - Box	0.8-1.0	0.84	0.86	0.91	0.94
U - Box	0-30	27	24	22	19
J - ring	0-10	5.0	4.3	3.2	2.7
V – funnel at $T_{5minutes}$	6-15	13.2	12	10.4	8.8

From the results of properties of fresh self compacting concrete it is evident that the filling ability, passing ability & segregation resistance of all mixes are in conformity with EFNARC [6]. Further the properties of fresh self compacting concrete indicate that there is an increase in workability upon addition of LECA. This is due to the following reasons,

The shape of aggregate directly influence the fresh properties of SCC like filling ability, passing ability & segregation resistance and its paste demand. The more spherical the aggregate particles the less they are likely to cause blocking and hence high flow. LECA aggregate being spherical in shape increases the flow when used in large quantities.

The surface texture of aggregate determines its resistance to internal friction. When internal friction is less, the flow is high. LECA aggregates being smooth in surface texture have less internal friction and hence high flow.

G. Compression strenth

The 7^{th} day and 28^{th} compression strength of the cube specimens with various replacement levels of fine aggregate by LECA are presented in below table (Table 3).

Table 3 Results of compression strength test

S. No.	Mix ID	Compressive Strength at 7 days (N/mm^2)	Compressive Strength at 28 days (N/mm^2)
1	LWSCC 0	24.667	30.074
2	LWSCC 5	26.074	33.778
3	LWSCC 10	22.222	26.667
4	LWSCC 15	15.259	21.037

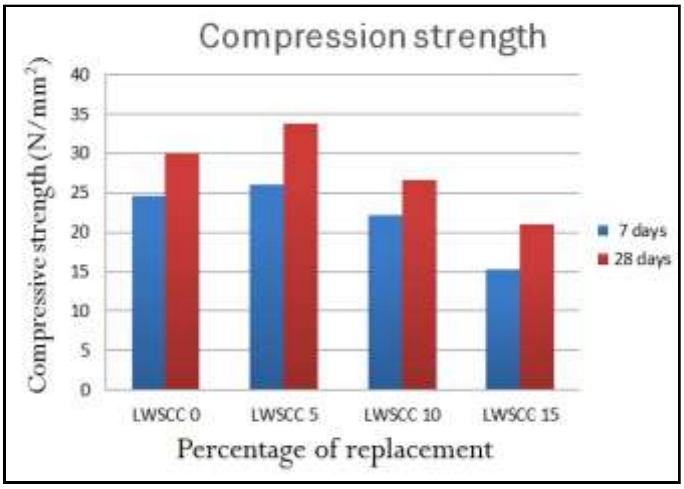

Fig. 10 Compression strength test at 7 days and 28 days

From the figure (Fig. 10) it can be seen that the compressive strength of LWSCC 0 at 7 days and 28 days was 24.667 N/mm^2 and 30.074 N/mm^2 respectively. It increased gradually to 26.074 N/mm^2 and 33.778 N/mm^2 respectively for LWSCC 5. This was due to the fact that the spherical shape of LECA aggregates contributed to better self compaction and hence higher strength.

Later the compressive strength at 7 days and 28 days decreased to 22.222 N/mm^2 and 26.667 N/mm^2 respectively for LWSCC 10 which is due to that when LECA added in large quantities results in light weight and hence weaker nature. Beyond 15 % of LECA content in fine aggregate i.e. LWSCC 15, the compressive strength reduces suddenly to 15.259 N/mm^2 and 21.037 N/mm^2 at 7 days and 28 days respectively, which is probable due to weaker nature and unavailability of enough water for hydration due to very pronounced water absorption characteristics of LECA.

6.0 Conclusions

The filling ability, passing ability, and segregation resistance of all LWSCC mixes are within the acceptance criteria of EFNARC guidelines. The spherical shape of LECA and smooth surface texture improved the workability properties of the fresh concrete mix and hence flowability.

The compressive strength of the SCC with fine aggregate replaced by LECA by 5% of volume of fine aggregate was high when compared to that of conventional SCC as the spherical shape of LECA aggregates contributed to better self compaction and hence higher strength. For further replacement of fine aggregate by LECA there was a decline is compression strength

Hence 5% is considered as optimum in replacing fine aggregate in self compacting concrete by Light Expanded Clay Aggregate (LECA).

7.0 References

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