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Light Weight Concrete- Review and Code Provisions

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***Abstract:* -- Conventional concrete used for structural applications has density in range of (2200-2600 kg/m3)[1]. A need arises for reducing the concrete density and making the concrete lighter which will in turn reduce the dead load on structure. Reduction of density in concrete leads to Light weight concrete (LWC) with its density ranging from 300 to 1850 kg/m3 [1]. The current paper makes an attempt to understand the studies carried out in the area of properties related to LWC. ACI [2][3][4], European [5][6] and Indian codes [7] are further studied to understand the guidelines mentioned in the codes related to LWC.**

***Index Terms*:— Light weight concrete, density, Codes.**

I. INTRODUCTION

Conventional concrete with materials as cement, fine aggregate and coarse aggregate is still one of the widely used construction material, but its high density (2200-2600 kg/m3) increases the self weight of concrete elements and thus increases the total dead load on structure. High density concrete further leads to larger cross sections of members and more reinforcement leading to uneconomical design and lesser space. Lower density concrete reduces the dead load of structural elements resulting in designing of structural elements with smaller cross section and larger availability of space. LWC also displays improved thermal and sound insulation, reduced energy demand during construction and better fire resistance.

Light Weight Concrete (LWC) are classified as Structural Light weight concrete which has a density between 1350 and 1900 kg/m3 and is used for structural purposes with a minimum compressive strength of 17 MPa. Lower – density concrete with density between 300 and 800 kg/m3 is used mostly for non-structural applications and moderate density concrete with compressive strength between 7 and 17MPa and density between the above-mentioned categories of LWC [1]. Lightweight concrete can be achieved by using lightweight aggregates, or by omission of coarse or fine aggregates. Lightweight aggregates may be natural (scoria, pumice etc) or artificial aggregates (expanded clay, shale, slate etc.). Guidelines for development of LWC can be seen in ACI and European codes. Indian code however displays the mention of LWA in IS 456:2000. [7] The current paper is an attempt to study the literature and understand the research done in the area of LWC with reference to the fresh and hardened properties of same. Further an attempt is done to compare the provisions done in ACI, European codes and IS a code regarding LWC.

II. LITERATURE REVIEW

LWC as mentioned earlier is categorized mainly into three parts: Structural LWC, Moderate LWC and Lower density concrete. The materials used specially for LWC are Scoria, Metakolin, Pumice, Expanded clay, shale, Styrofoam etc. For the current study published research papers were reviewed and the work done in properties of fresh and hardened state of LWC are reported. Table 1 below reports the study of researchers with reference to Compressive strength (CS), Split tensile strength (STS), Flexural strength (FS), Modulus of elasticity (E) and Modulus of rupture (MR) of LWC.

Table 1 shows that research related to Light weight aggregate concrete (LWAC) with Styrofoam and Scoria as aggregates have focused and reported experimental findings on compressive strength, spilt tensile strength and modulus of elasticity of LWC. It was seen that concrete mix design with 5% and 10 % EPS can be used as structural concrete with Characteristic Compressive strengths of 18.63 MPa & 18.51 MPa respectively. Further an empirical equation correlating Modulus of Elasticity (E), density (wc), compressive strength (f/c) and EPS % (p) was proposed, E= (wc)1.5.(0.05.e -0.23p).(f/c)0.5 …………….eq.1 [11].

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A relationship between modulus (E), density (D) and cylinder strength (f) for polystyrene aggregate concrete was developed, E = 1.146.D1.1.f 0.5 ………..eq.2 [14].

It was investigated concrete containing Portland cement, fly ash, natural fine aggregate and Stabilized Polystyrene (SPS) aggregate. Workability of the concretes with Stabilized Polystyrene (SPS) aggregate increased with increasing the replacement level up to 60% then decreased for 100% replacement. A decrease in compressive strength of the concrete was seen which is due to the replacement of natural sand with SPS and the resulting increase in the surface area of very fine particles, which can lead to weakening of interfacial zone between the aggregates and the cement paste [19]. In EPS concrete with silica fume with density ranging from 1500 kg/m3 – 2000 kg/m3 were obtained. A decrease in strength can be seen when percentage of EPS increased from 21% to 36% and that of silica from 3% to 9%. The EPS based concrete showed more gradual failure as compared to conventional aggregate concrete in both compression and split tensile testing, proving that the EPS based concrete have high energy absorption. Absorption was also low indicating good quality concrete mainly due to silica and non-absorbent nature of EPS [20].

Table 1.a): Research papers description Table

Sr. No.	Authors	Material properties	28 day CS MPa	STS MPa	FS MPa	E MPa	MR
1.	Cui,C.et. al. (2016).	EPS beads 3mm φ & bulk density 16 kg/m³. Replace coarse aggregates to obtain targeted dry density of LWC	Increases with increase in dry density of concrete	-	-	-	-
2.	Alam.B. et.al (2013)	Styrofoam of size 0.5m² & bulk density 11.36 kg/m³. Replacement to coarse aggregates	For 10% EPS, CS decreases by 12.79%, for 20% EPS, CS decreases by 34.70% and for 20% EPS with 5% Silica, CS decreases by 42.32%. i.e. inversely proportional to % replacement.	-	-	-	-
3	Setiawan, A and I. Hidayat (2013)	Styrofoam of bulk density 16 – 27 kg/m³. Replace fine aggregate.	Decreases with increase in % replacement. Up to small amount of EPS, concrete gains strength as per NDC i.e. 65% at 7days and 88% at 14 days.	-	-	$E=(w_c)^{1.5} \cdot 0.05 \exp^{(-0.23p)} \cdot \sqrt{f'_c}$ Density (w_c), characteristics compressive strength (f'_c) and EPS %(p)	-
4.	Tamut, T (2014).	Styrofoam of 8-8 mm φ & 6.86 kg/m³. Replace course aggregates.	Decreases by 9% to 55% with increase in % replacement.	Higher the amount of EPS in concrete, lower will be the STS	-	-	-
5.	Ahmad, M.H (2008)	Styrofoam 10mm & 20mm φ + Pulverised Fly ash 10%. Replace course aggregates.	28 days CS is 57-62% & 180 days CS is 60.65% of NDC. A series of LWC using 10% PFA shows 8-15% increase in CS in comparison with a series without PFA. A series of LWC with EPS size 10mm shows 5-10% less CS in comparison with a series with EPS size 20mm.	-	-	-	-
6.	Ravindrarajah k., Tuck A. J.	EPS beads to replace course aggregates. Mix design done targeting water cement ratios.	Variation in water cement ratio from 0.8 to 0.35 yields variation in 28 days compressive strength from 5.8 MPa to 11.9 MPa.	STS decreases with variation of water cement ration from	-	$E = 1.146.D^{1.1}.f^{0.5}$	-
7.	Kilic, A. et.al 2003	Scoria Agg.+Mineral Adm. The lower limit of compressive strength for SLWHSC is 35 MPa. ASTM Type I NPC (42.5 MPa)	Strength increases with increase in scoria aggregates.	-	Increase in strength with increase in scoria aggregates.	-	-
8.	Kilic.A et.al 2009	Scoria & Pumice aggregates	Concrete with scoria decreases CS by 24% in comparison with NDC. Same concrete further decreases CS on increasing Pumice content.	-	Decrease in strength with increase in scoria aggregates.	-	-
9.	M. Jamal Shannag et.al 2014	Scoria aggregate used as both CA and FA	CS increases with increase in cement content and corresponding LWA	STS increases with in cement and scoria agg.	-	$E_c = 0.037 W^{1.5} \sqrt{f'_c}$	Higher MR for higher mixes of concrete.
10.	L.M. Aba 2015	Scoria aggregate	Shows 14% reduction in CS in comparison with NDC	-			Comparable with NDC.

Table 1 shows that research related to Light weight aggregate concrete (LWAC) with Styrofoam and Scoria as aggregates have focused and reported experimental findings on compressive strength, spilt tensile strength and modulus of elasticity of LWC. It was seen that concrete mix design with 5% and 10 % EPS can be used as structural concrete with Characteristic Compressive strengths of 18.63 MPa & 18.51 MPa respectively. Further an empirical equation correlating Modulus of Elasticity (E), density (wc), compressive strength (f/c) and EPS % (p) was proposed,

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In another study EPS concrete with 50% fly ash as a replacement to cement by weight was developed. The percentage of EPS varied from 0 - 95 and the density of samples varied from 550 kg/m3 to 2200 kg/m3. The strength decreased with increase in water – cement ratio and the percentage of EPS. In a study with fly ash, relation between cylinder compressive strength and ultrasonic pulse velocity (UPV) was developed (r = 0.973) with EPS based concrete, and is given by fcy=0.071e 1.597V………….eq.3. The relation between cylinder compressive strength and rebound number (N) was found to be fcy = 0.954e 0.093N ………….eq. 4 with (r = 0.989). Also the relation between split tensile strength and cube compressive strength was also given to be ft = 0.358fcu0.675……….eq.5 [21]. Use of fine silica fume with EPS increases the bond between EPS and cement paste and Increases compressive strength [22].

In a experimental design beam with 26 Mpa Styrofoam concrete was casted with transverse reinforcement as a control beam and test materials with external transverse reinforced and truss system, the results shows decreased flexural capacity with external reinforcement. The use of styrocon on the outer portion with Styrofoam content of 30%, 40% and 50% had flexural strength of 33.8 kN, 31.0 kN and 29.0 kN [23]. Mix design of structural lightweight concrete is complex and need additional parameters as strength of lightweight aggregate, limit strength and structural lightweight aggregate concrete potential strength. A biphasis model was developed to estimate the strength of Structural lightweight concrete [24].

It was prominently seen that with increase in percentage of Lightweight aggregates in LWC the strength shows a decreasing trend [25][10][11][12]. However in the studied literature seldom work was seen in the area of flexural strength and modulus of rupture. A small attempt was done to understand the behavior of structural elements such beams, columns and slabs with LWAC.

III.PROVISIONS FOR LWC IN CODES

As discussed above LWC is different from conventional concrete and thus codes as ACI codes [2][3][4] and European codes [5][6] mention separate provisions for the same. In this current section, the guidelines for LWAC as per ACI and European codes are studied and comparison of some basic properties is done as shown in the tables below. Table 2 shows the ACI guidelines for normal and LWC properties.

Table 2: Comparison of properties of normal and lightweight concrete as per ACI code

Properties (1)	ACI	
	Normal Concrete (2)	Lightweight Concrete (3)
Specified CS MPa	General: f_c' – 17 to none, Special Case: Min. f_c' – 21 and Max. f_c' – none [2]	General: Min. f_c' – 17 and Max. f_c' – none Special Case: Min. f_c' – 21 and Max. f_c' – 35 [2]
Poisons ratio	0.15 and 0.25. value of 0.2 adopted practically [4]	Same as (2). Is generally less for LWC when compared with normal weight concrete [26].
Modulus of Elasticity in MPa	For w_c (1440 – 2560 kg/m³) (21-35 MPa) $E_c = w_c^{1.5} 0.043 (f_c')^{0.5}$ and $E_c = 4700 (f_c')^{0.5}$ [2][3]	Multiply $(f_c')^{0.5}$ In (2) by λ^* [2][3]
Modulus of rupture in MPa	$f_{cr} = 0.62 (f_c')^{0.5}$ [2]	Multiply $(f_c')^{0.5}$ In (2) by λ^* [2]
Split tensile strength in MPa	$f_{ct} = 0.56 (f_{cm})^{0.5}$ (Average) f_{cm} – measured average CS of concrete [2]	Min - 2.0 [2]
Density Kg/m³	Typically 2155 – 2560. Generally adopted is 2320 – 2400 [2]	1440 – 1840 [2]

The λ^* factor specified in the table 3 is explained in the Table 4 for respective expressions as per ACI codes.

Table 3. : Modification factor for respective expressions [2]

Type of Concrete	Composition of Aggregates	Modification Factor λ
Normal Weight	Fine: ASTM C33M Coarse: ASTM C33M	1.0
Sand – lightweight coarse blend	Fine: ASTM C33M Coarse : ASTM C330M & ASTM C33M (Combination)	0.85 – 1.0
Sand - lightweight	Fine: ASTM C33M Coarse : ASTM C330M	0.85
Sand – lightweight fine blend	Fine: ASTM C330M & ASTM C33M (Combination) . Coarse : ASTM C33M	0.75 – 0.85
All lightweight	Fine: ASTM C330M. Coarse: ASTM C330M	0.75
If f_{ct} is available f_{ct} - average STS of lightweight concrete.		$f_{ct}/(6.7(f_c')^{0.5}) \leq 1.0$

Table 4 below shows the guidelines laid by CEN code for Normal and LWC [5][6].

Table 4. : Guidelines for properties of normal and lightweight concrete as per CEN code

Properties (1)	Euro code [Section 3.1 and 11.3]	
	Normal Concrete (4)	Lightweight Concrete (5)
Specified CS MPa	Min. - 12 (cylinder strength) 15 (cube strength) [5]	Min - 12 (cylinder strength) 13 (cube strength) [5]. Max. – 60 [27]
Poisons ratio	0.2	0.2
Modulus of Elasticity MPa	$E_{cm} = 22[(f_{cm})/10]^{0.3}$ where f_{cm} - mean value of concrete cylinder strength [5]	$E_{lcm} = (E_{cm}) \eta_E$ and $\eta_E = (\rho/2200)^2$ where ρ – oven dry density [5] [6]
Modulus of rupture MPa	$f_{ctm,fl} = f_{ctm}$ or $(1.6 - h/1000) f_{ctm}$ (Select max. value), f_{ctm} – mean axial tensile strength	Multiply f_{ctm} in (4) by η_1 $\eta_1 = 0.4 + 0.6(\rho/2200)$
Density Kg/m³	2000 - 2600 (Oven dry density) [6]	800 – 2000 (Oven dry density) [6]

A study on provision of properties related to LWC in Indian codes was also done. It was seen that IS 456-2000 makes a mention of LWA in section [5 clause 5.3.2]. However IS: 9142-1979, Reaffirmed 1997 Indian Standard gives Specification for Artificial Light Weight Aggregates for concrete masonry Units [8].

IV. CONCLUSIONS

The paper is an attempt to study the findings of research done by researchers in the area of LWC with special mention to Styrofoam as aggregates. In the further part of the study ACI and CEN codes were studied to understand the guidelines mentioned about LWC. The study shows that many researchers have focused on experimental design of LWC with percentage replacement of Styrofoam to investigate the properties of compressive strength, Split tensile strength, Modulus of elasticity and flexural strength. The finding mainly focuses on reduction of strength characteristics with increase in percentage of LWA in concrete. Few researchers have also made an attempt to model the relationship between Modulus of Elasticity, density, compressive strength etc. However seldom work can be seen with the study of behavior of beam column and slab made using Styrofoam in concrete.

ACI and CEN codes give special provision for LWC with reference to compressive strength, Poisson's ratio, Modulus of elasticity and density. ACI code also gives the correction factors to be applied for expressions in normal concrete for LWC. CEN codes provide expression for modulus of elasticity and modulus of rupture. Indian standard codes were also studied and a mention of LWA is done in IS 456:2000 in section 5 clause 5.3.2. Also IS 6042 makes a mention about construction of lightweight masonry [28].

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