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Mandatory Tests for Light Weight Aggregates

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Abstract: Light weight concretes (LWC) are use in the construction industries more than 2200 years. Light weight concretes are light in weight and provide fire and sound proofing, easy to transport and construct. Variety of LWC's are made with variable densities and strengths. But there exists a lack of systemic understanding of durability parameters associated with LWC. In this paper mandatory tests are discussed for LWC which are of most significant at the design stage of LWC for structural purposes.

Keywords: transport properties, resistivity, porosity, warping and curling.

"1. **INTRODUCTION**"

The first light weight concrete (LWC) has been used for construction of the Port of Cosa built around 273 BC and natural volcanic materials were used to produce light weight concrete. There are several LEC structures in the Mediterranean region, but most notable structures were built during the early Roman Empire and include Pantheon Dome and the Coliseum. The Pantheon, finished in 27 BC, incorporated concrete varying in densities from the bottom to the top of the dome. Roman engineers had sufficient confidence in LWC to build a dome whose span of 43.3 m was not exceeded for almost two millenniums. The structure is in excellent condition and is still being used to this day for spiritual purposes [1]. The excellent cast surfaces that are visible to the observer slow clearly that these early builders had successfully mastered the art of casting concrete made with light weight aggregates.

Since World War I, the application of light weight concrete for structural applications in rapidly spread. Besides the weight savings, LWC has substantially better fire resistance qualities than normal weight concrete, and significantly lower heat transmission.

It has become a greater requirement and need to reduce the weight of structural element than increasing the strength of LWC, particularly in cases of heavy structures such as tall buildings and bridges where the own weight of the structure is one of the main problems that faces the designers. Another important demand in concrete structures into get monolithic fair-faced concrete, which does not only possess high visual qualities. Monolithic concrete structures are also particularly durable and the fact that no plastering or

cladding is required leads to cost saving and makes the structures more sustainable[2]. Today LWC are available in wide range of densities and strength LWC provides many advantages for design, construction and for comfort for living in addition to cost economy, easy to transport and construct. However, inspite of increasing use and demand for LWC, there is still a lack of inadequate explanations to identify durability related parameters.

In this paper some mandatory tests required to evaluate LWC for its durability is fully explained with necessary schematic and pictorial photographs for better understanding of the testing procedures for durable light weight concrete.

2. MANDATORY TESTS FOR LIGHT WEIGHT CONCRETES:

2.1 Investigation by FESEM:

The microstructure of foam concrete or any other light weight concrete is of considerable importance since it governs their mechanical properties, cement hydration and durability [3-5]. Recent technological advances in FESEM enable the observation to be performed a weak vacuum and thus allow better retention of moisture in the sample. As such, cement hydration and micro structure of the cement mortars can be studied without suffering from the micro-shrinkage or crystallization due to moisture evaporation [6]. FESEM images will morphology, reaction products, voids patent void sizes, pore connectivity fissures at magnification more than 8000 times. It can also show the polymer bridging on the micro structures of cement hydrates to know whether more continuous bridging at the sand surface or particle surfaces in the bulk binder matrix, also whether the bridging in coherent or not. Net work of film formed and its intensity etc [7].

2.2. Plastic Shrinkage cracking test:

A plate mould for the specimen was 600X600X40mm with sixteen diameter 10X 200 mm TMT steel to provide the boundary restraint and differential depth as shown in Fig 1 and 2. For each mixture, two plate specimens were tested. An environmental chamber equipped with a speed adjusted fan and other necessary devices was specifically constructed to keep the evaporation rate of water in a monitoring pan at 100 $g/m^2h \mp 10\%$ as shown in Fig 2 end to meet the specifications of ASTM C 1579-

06 [8]. Table 1 shows the transport mechanism of primary chloride for different environmental exposures.

Table 1: Primary Chloride transport mechanism for various exposures

Exposure	Example of Structures	Primary Chloride Transport mechanism
Submerged	Substructure below tide	Diffusion
Tidal	Substructures and super structures about high tide in the open sea	Permeation, Diffusion, and possibly Wick"s Action
Splash and Spray	Superstructures about high tide in the open sea	Capillary absorption and diffusion (Carbonation)
Coastal	Land based structures in coastal area or superstructures above high tide in river estuary or body of water in coastal area	Capillary absorption (Also Carbonation

The complete setups of plate and environmental chamber have been fully described in previous study [9]

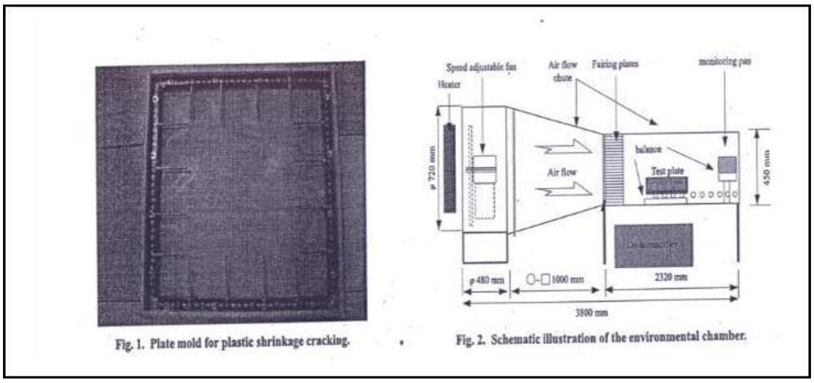

Figure. 1. Plate mould for plastic shrinkage cracking Fig 2.Schematic illustration of the environmental chamber

2.3. Test for Chloride Resistance

Transport Properties of Concrete

The chloride resistance of concrete is thus highly dependent on the porosity of concrete in terms of pore size, pore distribution and interconnectivity of pore system. The porosity of concrete is determined by

- The type of cement and other mix constituents
- Concrete mix proportions
- Compaction and curing

The transportation of chloride ions is a complicated process which involves diffusion, capillary suction, permeation, and convective flow through pore system and micro cracking network accompanied by physical adsorption and chemical binding [10].

2.3.1.Diffusion:

Diffusion is a process of transport of mass of free molecules or ions in the pore solution resulting in a net flow from regions of higher concentration to regions of low concentration of diffusion substance. This mode of operation takes place in fully saturated media such as fully submerged structures. For porous material like concrete, the diffusion co-efficient D, is the material characteristic property describing the transfer of a given substance driven by concentration gradient.

In steady state chloride diffusion, the effective driving force in the gradient of the free chloride ions in pore solution; the diffusion co-efficient is referred as

D_{free} or D_f. The D_f can be determined from difference in concentration of chloride ions in the two cells separated

by the concrete. This type of test is extremely time consuming.

In the transient or non-steady-state diffusion process, the mass balance equation describes the change of concentration in a unit volume with time. This can be accounted for by Fick‟s Second law of diffusion:

$$\frac{\partial c}{\partial t} = D\frac{\partial}{\partial x}\left(\frac{\partial C}{\partial x}\right) \qquad (1)$$

An analytical solution to the above equation is

$$C_x = C_s \left[1 - \mathrm{erf}\left(\frac{x}{2\sqrt{Dt}}\right)\right] \qquad (2)$$

Where,

x = Distance from the exposed surface

C_x = Chloride concentration at distance x

Cs = Surface chloride concentration

D = Chloride diffusion co-efficient

t = Exposure time

erf = the error function

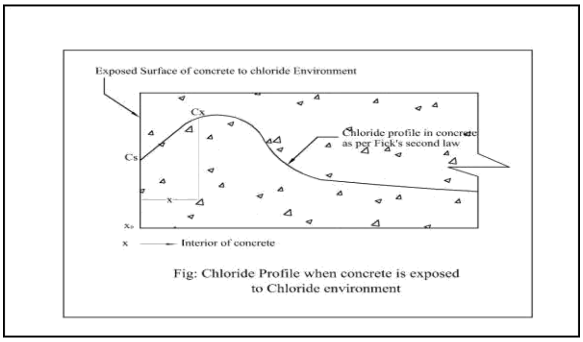

Figure.3: Chloride Profile when concrete in exposed to chloride environment

The diffusion co-efficient, D is determined from the best-fit curve represented by equation (2).

2.3.2. Capillary suction and Absorption:

Capillary absorption in the transport of liquids due to surface tension acting in capillaries. It is influenced by the viscosity, density and surface tension of the liquid and the pore structure (radius, continuity of capillaries) and surface energy of the concrete. Chloride can therefore be transported in liquids solution.

When concrete is not in permanent contact with a liquid such as in tidal zone, a non-steady state transport of the liquid prevails. In this case, the amount of liquid absorbed at the surface of the concrete as well as the amount of liquid transported at any distance from the surface is a function of time.

For short-term contact of the concrete with a liquid, the velocity of the take-up is referred to as initial absorption rate, as given by the mass of liquid absorbed per unit area and function of contact time, t

$$A = \frac{\Delta m}{A.f(tn)} \qquad (3)$$

a = absorption rate (g/m^2s^n)

Δm = take up of liquid

A = area in contact with water (m^2)

$f.t^n$ = time function

A time function is equal to $\sqrt{t}$ is usually valid but functions other than $\sqrt{t}$ may also be valid. In practice, non-steady state capillary absorption is the mode of transport measured as sorptivity (or) initial surface absorption test (ISAT)

Capillary suction may also develop into a steady state transport phenomenon if suitable boundary conditions are kept constant over time. Capillary absorption is an important mechanism with respect to the ingress of chlorides into concrete.

2.3.3 .Permeability:

Permeability is a measure of the flow of gas or liquid through a porous material caused by a pressure head. The permeability of concrete depends on the pore structures and viscosity of the liquid or gases. Dissolved chlorides and gases and therefore transported by convection with the permeating water into concrete.

Water permeability can be determined in two ways: steady-state and non steady-state water permeability. A coefficient of permeability is a material characteristic which is obtained in saturated flow which is obtained in saturated flow which occurs under a steady state flow when a constant flow rate is established. It is expressed as the volume of water per unit area of surface per unit time, flowing through a concrete under a constant pressure head and at a constant temperature. Thus water permeability has a unit of (m3/m^2.s). The permeability of concrete varies between 10-16 and 10-10 m/s. In a saturated sample the water flow in pores due to hydraulic pressure can be described by D‟Arcy‟s law:

$$Q=k_w\frac{\Delta PA}{t} \qquad (4)$$

Where,

Q	= water flow (m^3/s)
kw	= co-efficient of water permeability
ΔP	= pressure difference across the sample
A	= surface area of the sample (m^2)
t	= thickness of sample (m)

The time to steady state flow depends on the pressure applied as well as the composition, size and degree of saturation of the sample. A period of 2 days to 2 weeks may be required for concrete with a w/c ratio of 0.75 to 0.35 for vacuum-saturated samples under a 3.5 MPa pressure head.

Table 2: Chloride Ion Permeability

Charge passed(coulombs)	Chloride ion permeability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very low
<100	Negligible

Table 2 shows the chloride ion permeability category according to ASTM C 1202-12. The co-efficient of water permeability determined by both methods have been found to correlate well and a guide the selection of the more suitable method was developed based as 28 day compressive strength and the age of concrete at testing [11]. The guide is that the constant flow method is preferred if:

$$\mathbf{2.3\ T^2 + 1.1\ (f_c^2) < 10{,}400} \qquad \textbf{(5)}$$

Where,

T is the age of concrete when tested (days) f_c in the 28 day compressive strength (MPa)

2.3.4.**Migration**:

Migration is the transport of ions in electrolytes due to the action of an electrical field as the driving force. In an electrical field, positive ions will more preferentially to the negative electrode and negative ions to the positive one. Migration may generate a difference in concentration in a homogenous solution or many provoke a special flux in the direction of concentration gradients. This mode of transport may occur accidentally when there is a stray current leakage or intent actually in concrete rehabilitation techniques.

One popular technique measures chloride ion migration or the electrical conductance of concrete in the AASHTO T277 or ASTM C 1202, developed by D.Whiting. In these methods, a potential difference of 60V (DC) is applied across the ends of 50 mm thick slice of concrete cylinder, one of which is immersed in NaCl solution, the other in a NaOH solution. The amount of current passing through the concrete during six hours period is measured and the total charge passed, in coulombs, is used as an indicator the resistance of the concrete to chloride ion penetration [12].

Table 3. Tentative classification for Concrete Durability based on ISAT

Durability classification Ranking	ISAT-10 (ml/m^2/s) X10 $^{-2}$
1	<50
2	51-70
3	71-90
4	91-110
5	>110

2.4 Volume of permeable void

It is a method of determining the water absorption after immersion in water at room temperature, after immersion and boiling, and the volume of permeable voids (VPV) or volume of water absorption after a period in boiling water of a hardened concrete sample. The high temperature affects both the viscosity and the mobility of water molecules which may enable the greater displacement of pore system within the hardened concrete. Boiling resulted in 6% increase in absorption in following Fig.

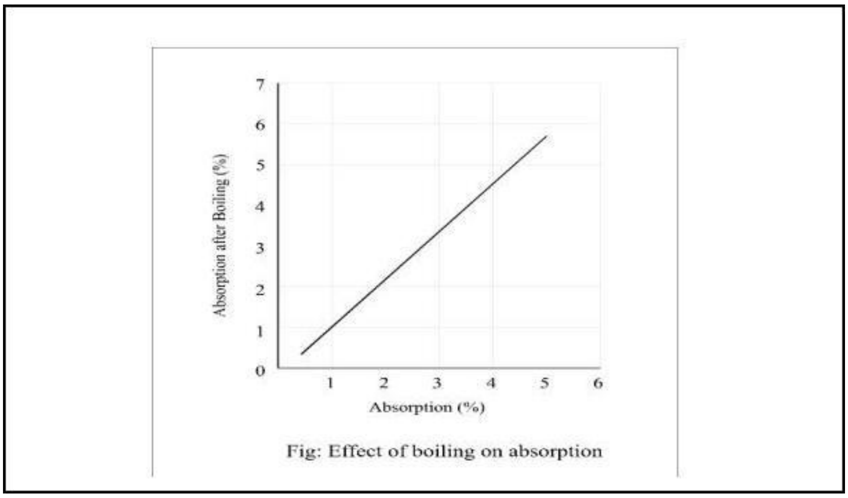

Figure 4.Effect of boiling on absorption

The ASTM C 642 method measures the volume of permeable voids (VPV) as a percentage of the volume of the solid. The Australian standard AS1012.21 test method has been adapted from the ASTM method. It measured the apparent volume of permeable voids (AVPV) as a percentage of the volume of the bulk materials, i.e. solid and voids. The AVPV has been used by Vic Roads to classify concrete durability as shown in following table 4.

Table 4: Vic Roads Classification of concrete

Durability based on the AVPV(%)

S.No	Durability Classification Indicator	Vibrated cylinders (AVPV)	Rodded Cylinder (AVPV)	Cores (AVPV)
1.	Excellent	<11	<12	<14
2.	Good	11-13	12-14	14-16
3.	Normal	13-14	14-15	16-17
4.	Marginal	14-16	15-17	17-19
5.	Bad	>16	>17	>19

2.5 Salt water ponding test: (90- days test)

Whiting [13] examined the relationship between VPV and the chloride content from 2 to 40 mm below surface as percentage by weight of concrete, after

a short-term 90-day AASHTO T-259-80 ponding test with 3% NaCl solution. The results indicate improvement in chloride resistance with reducing VPV shown in fig. It is also supports the critical range of VPV of around 12% as shown in Fig 5.

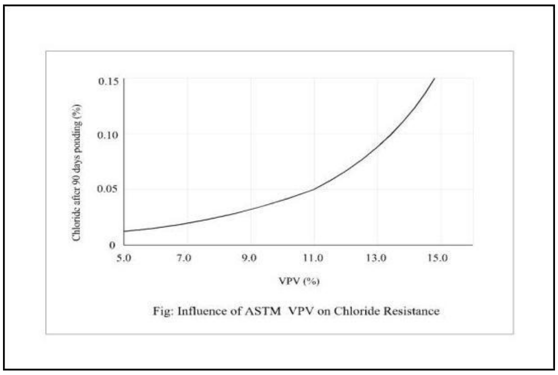

Figure 5: Influence of ASTM VPV on chloride resistance

2.6 Electrical Resistivity Test

Electrical resistivity of concrete is one of the most significant parameters controlling the rate of active corrosion of the embedded steel reinforcement. At site, resistivity of concrete can be measured using four probe electrical resistivity meter with surface contact on concrete. An alternating current (I) is passed via the concrete through the outer pair of contacts, and the resulting voltage (V) between the inner contacts is measured. For a semi-infinite homogenous material, the resistivity is given by

$$\rho = \frac{2\pi a V}{I}$$

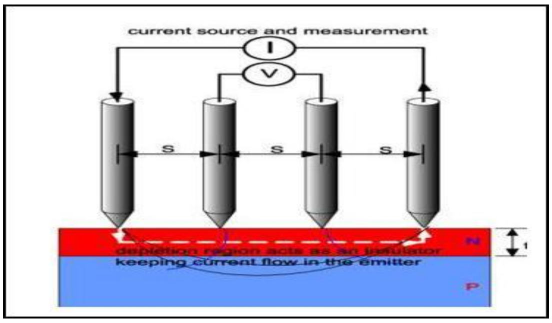

Figure.6: Arrangement of Electrical Resistivity Method

Where " a"/"s" is the contact spacing. It is found that field measurement of resistivity in varying with electrode spacing, concrete cover and presence of embedded steel. Measurement should be taken with electrode spacing of less than 30 mm and as far as possible from embedded steel. High resistivity concrete is defined as concrete with 28 day resistivity of greater than 4000 Ωcm or 56 –day resistivity of greater than 5000 Ωcm.

For low resistivity concrete,

$$C = [2822/(S^{1.28})]\sqrt{t} \qquad (7)$$

For high resistivity concrete,

$$C = [226{,}573/(S^{2.61})]\sqrt{t} \qquad (8)$$

Where,

C = Cover to reinforcement (mm)

S =Average 28-day Compressive Strength (MPa)

t = time taken to reach a probable active corrosion (years)

2.7. Determination of total Porosity

In this test three light weight concrete (LWC) specimens of each size of 50 X 50 X 50 mm are cast and cured in potable water for 28 days for curing. After curing the specimens are taken out of curing tanks and dried in sun light for 2 days and then they are placed in electric oven at 105°C for 48 hours for complete removal of water from the specimens. After specimens are taken out of oven, they are placed in vacuum desiccators for 3 hours duration and left overnight to get constant weight. The total porosity is computed using the formula [14]:

$$p(\%) = \frac{Wair - Wdry}{Wair - Wwater} \text{ X } 100 \qquad (9)$$

Where,

W_{air} = weight of the specimen in air in dry condition

W_{dry} = Wt. of oven dried specimen with constant dry weight,(taken out from oven)

W_{water} = weight of saturated specimen in water.

2.8.Oxygen/Air Permeability Test:

This test has been suggested by Department of Civil Engineering University of Leeds UK [14]. According to this, a 50 mm diameter X 40 mm thick concrete core is drilled out from a cube specimen of 100X100X100 mm size, and the specimens are dried at 105°C for 24 hours to attain constant dry weight and the cylindrical surface of the specimen in coated with epoxy resin to seal all the surface voids, capillaries and pores and fitted as shown in Fig 7.

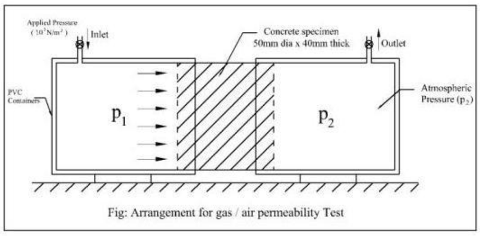

Figure 7: Arrangement of Air/gas Permeability Test Intrinsic gas permeability

$$K_o = 2\, l\, \upsilon\, \eta\, p_2 / [A.\,(p_1^2 - p_2^2)] \qquad (10)$$

Where,

υ = flow rate of gas (m^3/s)

η = viscosity of gas (Ns/m^2)

A = cross sectional area of specimen (m^2)

L = length of specimen (thickness)(m)

p_1 = absolute applied pressure (10^5 N/m^2)

p_2 = atmospheric pressure (1 bar)

for oxygen at 20°C,

η = 2.02 X 10-5 Ns/m^2

and now,

$$K_o=4.04X10^5\ \upsilon\ l\ /\ [A.(p_1^2-1)] \qquad (11)$$

2.9. Water Permeability Test

This test method is also suggested by Department of Civil Engineering University of Leeds, UK. In this method the depth of penetration of water due to applied pressure is measured in the concrete cylinder. The specimen size of 50 mm diameter X 100mm long as shown in Fig, cylindrical surface is sealed with epoxy resin to avoid loss of water or moisture. The specimen is fitted with PVC container as shown in Fig 8. The applied water pressure is 3 to 5 bar for duration of 3 to 4 hours. After that, the specimen is removed from the setup and split vertically and the depth of water penetration is measured. The coefficient of water penetration is measured (k_w) is computed using the relationship:

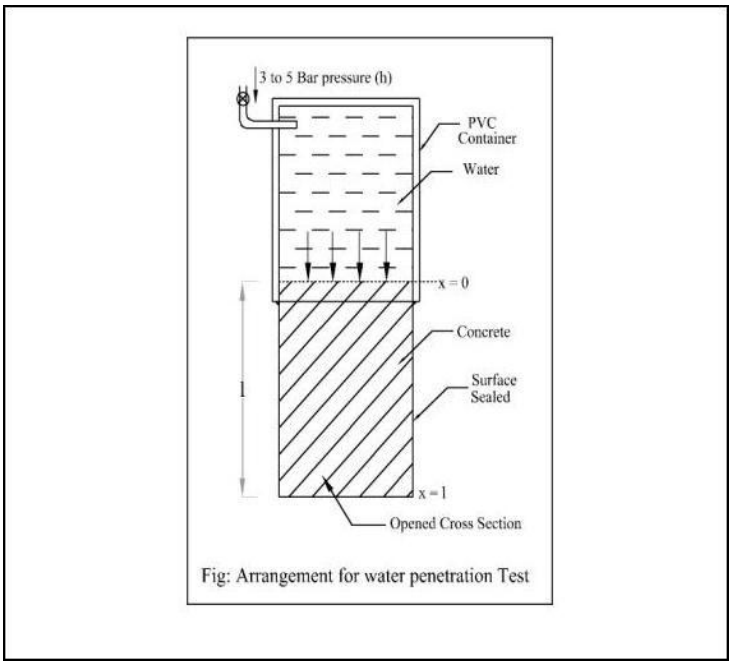

Figure 8: Arrangement for water penetration test

$$K_w = d^2 \upsilon / (2ht) \qquad (12)$$

Where,

Kw = coefficient of liquid permeability

d = depth of water penetration (m)

υ = porosity of concrete expressed as a fraction.

h = applied water pressure (head of water)

t = time to penetration to depth(s)

$$K_w = \frac{kw.\eta}{\rho g} \qquad (13)$$

Where,

η = viscosity of liquid (1.275 X 10-3 Ns/m^2)

ρ = density of liquid (kg/m^3)

g = gravity acceleration 9.81 m/s^2

$$K_w = 1.3 \text{ X } 10^{-7} \, k_w \qquad (14)$$

2.9.Testing of Thermal Exposure

Light weight concretes of cube size 100X100X100 mm are cast cured for 8 days in water. The specimens are taken out from the curing tank and kept for drying in the open air. Then the specimen of same group 8 numbers are placed in muffle furnace and heated slowly at the rate of $10^{o}C/s$. While heating air exhaust or vent may be kept open up to $105^{o}C$ and retained that temperature for complete expulsion of water from the LWC. Then the temperature can be increased to $150^{o}C$ and retained that temperature for 30 minutes. One sample from this group shall be taken out and examined for any color change, warping, distortion, cracks along the edges or any surface cracking, dimensional change, volumetric expansion, pop-outs etc. and then the same specimen has to be tested for cube compressive strength. The same procedure has to be followed (visual and strength test) at temperatures $200^{o}C$, $300^{o}C$, $350^{o}C$, $450^{o}C$, $650^{o}C$, $800^{o}C$ and $900^{o}C$. All the visual observations and the strength degradations are to be recorded separately, and the tolerance of temperature can be ascertained as which LWC is best for thermal exposure and up to what fire endurance limit.

2.10.Test for thermal Conductance of LWC:

In this experiment, a vertical muffle furnace is used with temperature controller as shown in Fig 9 operated on 3 phase AC. Panels of LWC of size 250X250mm with variable thickness 25mm, 40mm and 50mm are cast and cured.

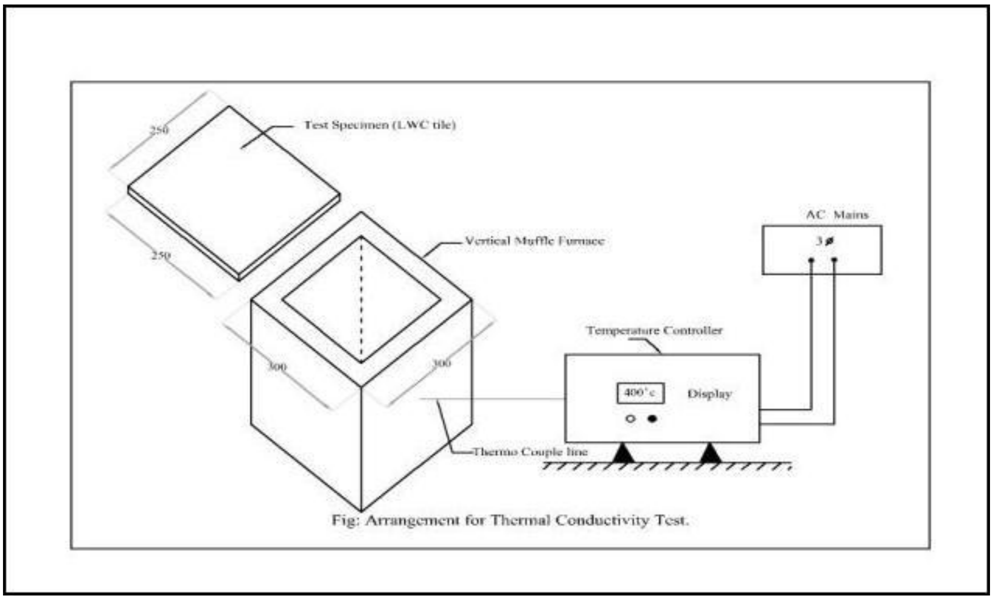

Figure 9: Arrangement for thermal conductivity test

These panels are subjected to thermal conductivity test after complete drying. The panel is kept covered on top of the vertical muffle furnace, which is connected to the temperature controller by a thermo couple. The temperature controller will display the temperature in degree centigrade by knob and fine tuning can also be done with other knob. First the required temperature is set and the panel is covered on top of the furnace. This temperature is maintained for 20 minutes; while doing this experiment, the panel top will be covered with wooden box so that the ambient temperature of top surface of panel is measured with layer gun thermometer. The temperature inside or the temperature at the bottom surface of the panel is known from the temperature controller. The difference in temperature is the gradient. This thermal gradient will vary with material composition and thickness of the panel. The higher difference in temperature or ”swing” shows the best insulating value of the LWC material.

2.11.FLAME RESISTANCE TEST:

Light weight concrete or foam concrete or aerated concrete are extremely fire and flame resistant and thus suitable for fire rated applications. Furthermore, the application of intense heat, such as an oxy torch held close to the surface, does not cause the concrete to spall or explode as in case concrete. The result of this is that the reinforcing steel remains cool and protected for much longer period.

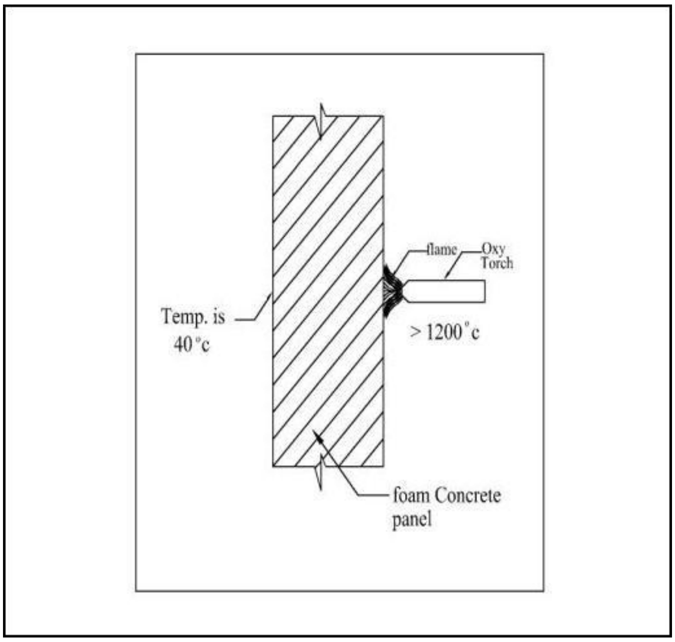

Figure 10: Arrangement of Flame resistance test

In this experiment, an oxy torch is used and the flame directed towards foam or LWC panel on one side to a direction of 4 hours rating time. The temperature of other side is measured by later thermometer or other thermometer. The temperature on flame side can be increased even up to 1200°C by adjusting the nozzle and thickness of flame. The test certificate from carious authorities indicates that 150 mm thick aerated concrete achieves in excess of a four hours fire rating. In another test carried out (PAN Pacific Group of Companies during 2014) in Australia, a aerated light weight wall panel 150 mm (6”) thickness was exposed to temperatures in the vicinity of 1200°C, with the unexposed surface only increasing by 46°C after 5 hours exposure. Therefore, the foam concrete even with reduced thickness will never produce burn, spall or give off gases, fumes or smoke.

2.12.Water Infiltration and Exfiltration Test

In this test, the infiltration can be explained that the quantity of water collected inside the foam concrete container over a period of time. Similarly exfiltration can be explained that the water from foam concrete container to come out of it over a period time.

In this test a test specimen made of LWC or foam concrete is made in cylindrical shape with 200 and 300 mm inner and outer diameter and with 300 mm height , as shown in fig, the bottom of the specimen is fixed with impermeable PVC plate with sealant so as to prevent entry of water from outside or inside.

To measure infiltration capacity of foam concrete the specimen is kept in a PVC container of 500X500X400 mm size tank, and water is filled outside the specimen till top of the specimen. Since the bottom portion is prevented for entry of water from outside, the water from circumferential area only will percolate and enter inside the cylindrical specimen. The duration of this test is for a period of one hour. Before placing the specimen inside the water in the sum of absorbed water + water collected inside (Q).

$$\text{The infiltration rate } = \frac{Q}{A.t}, \text{ (m/h)} \qquad (15)$$

Where,

Q = total quantity of water influenced.

A = cylindrical surface area, outer area (m^2)

t = duration of test (h)

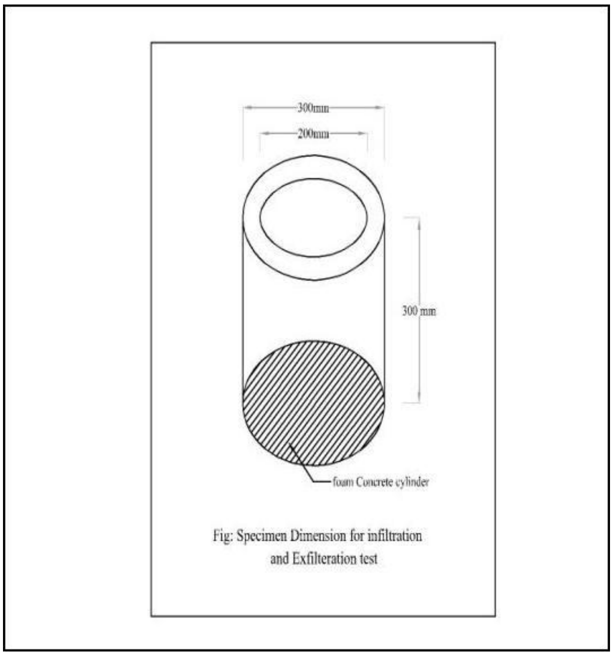

Figure 11: Specimen dimension for Infiltration and Exfilteration

For exfilteration test, the same specimen can be used, but water is filled inside the specimen and seeped or exfiltered water is measured. the sum of water absorbed and exfilrtered is the total quantity of exfiltered water(Q). The area A is inner surface area. The duration of test is one hour.

$$\text{The Exfilteration rate} = \frac{Q}{A.t}, \text{(m/h)}. \qquad (16)$$

3.CONCLUSION

There are several mandatory tests for light weight aggregates. In this paper some of the durability tests for light weight aggregates are explained.

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