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EXPERIMENTAL STUDY ON LIGHT TRANSMITTING TRANSLUCENT CONCRETE PANELS

Grinita George[1,*], Dr.Tilba Thomas[1]

[1]Department of Civil Engineering, St. Joseph's college of Engineering and Technology, APJ Abdul Kalam Technological University, Palai- 686579 , India
[*]grinitaann@gmail.com

ABSTRACT

Conservation of energy is an essential need in building sector. The overall building energy consumption is approximately 36 % of world's total energy consumption.Inorder to reduce the necessity of artificial lighting during day time which leads to higher energy requirements, development of novel materials which can be used by the construction sector is essential. In this article, development of translucent concrete panels by embedding plastic optic fibres which is capable of transmitting light from one end to the other is proposed as a unique solution to this issue.Behaviour of concrete and mortar panels of 5 cm and 3 cm embedded with plastic optic fiber were examined and compared.The concrete and mortar panels and cubes were embedded with 1.5 mm diameter plastic optic fibres in 6% volume ratio. The mortar panels embedded with optic fibres were able to exhibit lesser cracks and better surface finish. The light transmittance performance of translucent concrete was evaluated by using lux meter in different angles and using different colour bulbs. The results obtained has proved the utility of translucent concrete as an energy efficient substitute material which can be successfully utilized in sustainable constructions and also for the development of green buildings with minimal energy requirements.
Keywords - Translucent concrete, Energy efficiency , Sustainability, Transmittance.

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1. INTRODUCTION

The importance of sustainable building is becoming as a major concern for the construction sector worldwide. Sustainable building practises reduce the use of energy and raw materials and contribute significantly to environmental protection. The most important and often used building material in the construction sector is concrete. Concrete is opaque because of the density and opaqueness of its components, which prevents light from passing through it. Yet, by incorporating optical fibres with a concrete matrix, opaque concrete could be changed into translucent concrete. A new type of energy-efficient building material called translucent concrete (TC) enables light to pass through embedded optical fibres into the indoor space. In addition to light transmittance , translucent concrete can also be used in the construction of prisons, banks, and museums to provide safety, supervision, and security since it can exhibit the silhouettes of nearby objects that are on the brighter side of a wall.

Power generation and current conservation are key global issues presently. Due to various industrial and natural resources, the power generation sector encounters numerous issues every day. Commercial and residential buildings consumes most of the electricity for lighting. 34% or so of the world's energy demand is accounted for the building sector. Around 19% of the electricity distributed worldwide is used for artificial lighting. With the population growth, urbanisation, and development of high-rise buildings, the need for electric lighting has been steadily rising. The surrounding structures prevents natural sunlight from passing through when high-rise buildings are constructed close to one another. Buildings use artificial light exclusively during the day to keep their interiors bright, which consumes a lot of electric energy. Using natural daylight indoors reduces the need for artificial lighting, lowers energy costs, and improves occupant comfort levels. Indoor spaces illuminated by enough natural light have been shown to reduce occupant stress, enhance visual comfort, and promote employee retention. The creation of construction materials that can lower the consumption of energy for artificial lighting is essential.

The main objectives are

- To conduct an experimental investigation to find out the compressive strength of translucent self compacting concrete and light transmittance of concrete.
- To check the quality of the panel using UPV test

- To determine the light transmittance of concrete both in day light and artificial light

This paper contributes to the determination of new alternatives for sustainable construction around the world. Cement based translucent concrete is made out of normal concrete components such cement, fine aggregate, and water, as well as 2% to 6% optical fibre by volume of the entire specimen.Load bearing and non load bearing translucent concrete panels or façades should fulfill the strength, serviceability, and durability requirements to withstand expected ultimate loads with permissible deflection [1] . In this study, organic optical fibres were used to make light transmitting concrete. Composition, preparation, design methodology, physical and mechanical properties, and light transmitting capabilities were all studied.

2. MATERIALS AND METHODS

2.1 Materials and concrete mix

Self-compacting concrete (SCC) was used in this experiment to create LTC and establish homogeneity in the concrete mixes and optical fibres. Ordinary Portland Cement (OPC), silica fumes(SF), coarse aggregate with a maximum size of 10 mm, natural fine aggregate (sand),water,steel wool ,superplasticizer (SP),Optical Fiber (OP)were the materials used for casting. As 10% of the cement's weight, silica fumes were used.Silica fumes were used to increase cohesion, increase POF adhesion, prevent bleeding and segregation, and improve workability.The physical and chemical properties of cement are illustrated in Table 1. Locally available M.Sand was used as fine aggregate and coarse aggregate with maximum size of 10 mm was used. The tests of fine aggregate was conducted as per IS-650:1996 & IS-2386:1968.The tests for coarse aggregate was conducted as per IS-2386:1963 .Table 2 shows the physical properties of fine and coarse aggregate. A water-miscible polymeric liquid admixture called Polytancrete NGT is added at 3% as a superplasticizer.SP lessens the need for water, segregation, cracking, and permeability.The manufacture's data of POF with diameter 1.5 mm is shown in Table 3.Steel fiber is added in 0.5 % . Steel fibres can be utilised to replace or supplement structural reinforcement and will increase the concrete's ability to resist cracking.

Table 1 Physical and chemical properties of cementitious material.

Properties	Cement
Physical Properties	
Specific gravity	3.1
Standard consistency	32%
Setting time Initial	40 min
Setting time Final	270 min
Compressive Strength	
At 7 days	30.5N/mm^2
At 28 days	45.2 N/mm^2
Colour	Gray
Chemical Properties	
$CaO-0.7SO_3$	
$2.8 SiO_2+1.2 Al_2O_3+0.65 Fe_2O_3$	0.90
Al_2O_3 / Fe_2O_3	1.29
Insoluble Residue (% by mass)	2.87
Magnesia (% by mass)	1.07
Sulphuric Anhydride (%by mass)	2.04
Total Loss on Ignition (% by mass)	3.54
Total Chlorides (% by mass)	0.025

Table 2 Physical properties of fine and coarse aggregates.

Properties	Fine aggregate (Sand)	Coarse aggregate (Gravel)
Specific gravity	2.61	2.79
Bulk density (kg/L)	1.66	1.7
Fineness modulus	3.3	5.81
Maximum nominal size(mm)	-	10
Void Percentage (%)	37	38

Table 3 The data of manufacturer of 1.5 mm diameter POF.

Property	Item	1.5mm
Product Parameters	No.of fiber tested	1
	Fiber Core material	Poly methyl methacrylate (PMMA)
	Fiber Cladding Material	Fluorinated Polymer
	Core refractive index	1.49
	Minimum Bend Radius	30mm
Optical Properties	Transmission Loss	200 dB/km

2.2 Preparation of specimens

The mix design for the SCC specimens in the current study was based on previously completed research [3]. The 18 cubic specimens used in this investigation had the following measurements: 100 mm height, 100 mm width, and 100 mm length.For the installation of optical fibre, formworks made of plywood with drilled holes were made Fig 1. The ends of the optical fibres were then glued to the formwork with a hot glue gun.The holes were drilled in an 8 X 8 grid pattern, which provided a 15 mm fibre spacing. The minimum distance between optical fibres was determined to be 15 mm since the minimum size of coarse aggregate used was 10 mm.The panel size of 250mm length x 250 mm width x 50 mm depth and 250 mm length x 250mm width x 30 mm depth is used for light transmitting concrete panel board. Holes are drilled in the bottom face and optic fibres are hot glued Fig 2.12 mortar panels and 12 concrete panels were made for this study.All the specimens are demoulded after 24 hours, and curing is done in water for 7 days, 14 days and 28 days.

Fig 1:The formwork for cubic mould.

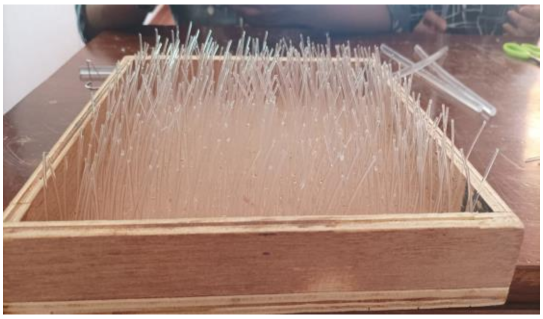

Fig 2:The formwork for panel mould.

The concrete mix proportion of M30 was used for cube and panels.The mix proportioning was done using IS 10262:2009, as per this method proportions of materials required for 1m^3 of concrete is 1:2.2:3.3 and W/C ratio was 0.45 .(Fig 3)The proportion used for preparation of mortar cube and panel was 1:3.Optic fiber added for 3 cubes was 45 m.Optic fiber added for 2 panels was 45m.Total fiber which is used for the study is 300 m. Compression test was carried out for every 3 specimens at 7 and 28 days to obtain the average compressive strength. Since compression tests are destructive, UPV tests, and light transmittance tests were carried out before the 28 days compressive strength tests. The UPV test was carried out on both faces of the parallel and perpendicular arrangements of the optical fibres.

Fig 3:Mould with POF after pouring concrete in cube and panel

2.3 Testing methods of light transmittance tests

Natural Light Transmittance test

Panel was placed in direct sunshine, and measurements were taken using a lux metre.For the experiment, a wooden box measuring 10 cm was made. Fig 4 shows the schematic form of natural light transmittance test. A panel was placed on the top face, and lux meter is placed below the panel.For the whole experiment, a distance of 10 cm was maintained.The test was conducted on a sunny day from 6 am to 6 pm.The values was noted in each hour.Fig 4 shows the schematic form of the test.

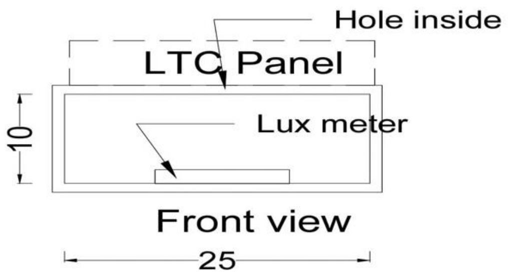

Fig 4 :Schematic form of natural light transmittance test.

Artificial Light Transmittance test

As shown in Fig. 5and 6 , a specially constructed wooden board setup was used for the experimental test of light transmission. The wooden board light test setup used in this study was created in accordance with the design described in Shing Mei Chiew et al. [2]. The light source was a 7 W LED lamp because it produces less heat and has more stable power for the same amount of needed light intensity than a halogen lamp or an incandescent lamp. The Lux meter which is used is Sigma Digital Lux meter 1010B upto 50,000 Lux,with Calibration Certificiate Light meter.The LTC's light transmittance was measured using a digital light metre with a 0 lux to 200,000 lux range in brightness. Throughout the experimental test, the distances between the light bulb and the LTC specimen and the light metre remained unchanged. The placement of the light bulb holders was altered at angles of 10, 30,60 and 90 degrees. The light incidence angle would have changed immediately if the light bulbs had been positioned differently in relation to the bulb holders. To guarantee the constancy of L_0, the initial light intensity (L_0) was measured after every change in light bulb position. Additionally, the control specimen underwent testing to ensure that the light meter's reading was 0 lux (no light was going through).

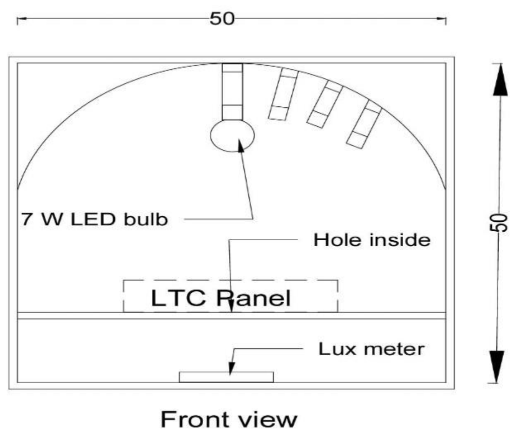

Fig 5 : Schematic form of Artifical light transmittance

Fig 6: Artificial light transmittance experimental setup

Three samples were evaluated for light transmittance using the same test environments, and the average value was computed. Light metre readings were obtained three times repeatedly for each specimen to ensure that the amount of light travelling through the specimens with the same parameters was constant. The amount of light transmitted for that specimen would be represented by the average value of these values. Eq. (1) can be used to compute the light transmittance (L_T) of LTC as follows:

$$L_T = \frac{Lt}{L0} \times 100\% \quad (1)$$

where Lt is the amount of light transmitted through the LTC (lux), and $L0$ is the initial light intensity detected without the specimen (lux). Zhu et al. (2019) looked into the effect of optical fibre diameter and light source colour on the luminance of LTC used in active-luminous traffic markers. They determined the relationship between the optical fibre width and the light transmitting rate under different colours of light sources (red, yellow, and green), as shown in Eqns. (2), (3), and (4), respectively, using regression analysis

For red colour light,

$$\mathrm{LT} = 60.49 - \frac{60.56}{1+e^{(d-4.28)/0.76}} = 1.45 \quad (2)$$

For yellow colour,

$$\mathrm{LT} = 47.06 - \frac{46.48}{1+e^{(d-4.15)/0.77}} = 2.02 \quad (3)$$

For green colour,

$$LT = 62.74 - \frac{62.65}{1+e^{(d-3.91)/0.81}} = 3.13 \quad (4)$$

where *LT* is the light-transmitting rate in % and d is the fibre diameter in mm.

2.4 Ultrasonic pulse velocity (UPV)

The homogeneity and quality of concrete can be assessed using the UPV method. A known distance in the concrete is traversed by the ultrasonic pulse, and its velocity is determined. The velocity from the ultrasonic pulse is determined by the solid's density and elastic constants, allowing the quality and strength of the concrete to be evaluated . It is possible to do UPV testing using direct, semi-direct, or in-direct approaches. The UPV testing on the LTC in this study was done using the direct method and indirect method. The receiver and transmitter probes were positioned in the centre of the cubic specimen, and both parallel and perpendicular to the optical fibre directions were measured. For panel both direct and semi direct method are used for measurement.For semi direct method the receiver and transmitter probes are positioned on the same face ,four values are taken from the same face of the panel. This is a study on whether the optical fiber's direction interfered with velocity, influencing the concrete's quality.

3. RESULTS AND DISCUSSIONS

3.1 Compressive strength of LTC

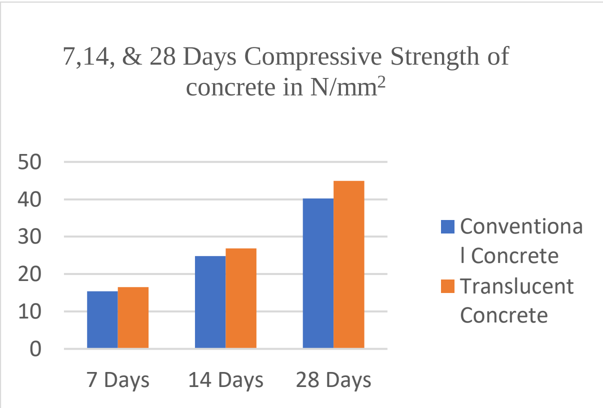

Fig 7 : Strength comparison of conventional concrete with translucent concrete

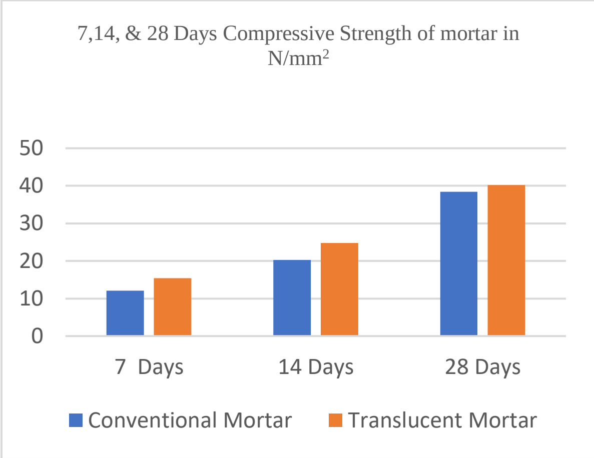

Fig 8: Strength comparison of conventional mortar with translucent mortar

The test is carried out conforming to IS 516 -1959 to obtain compressive strength of concrete at the 7days, 14 days and 28 days. The cubes are tested using 2000 KN capacity Aimil compressive testing machine (CTM).The results are presented in Fig 7.

The 7, 14 and 28 days compressive strength of translucent concrete is 16.52 N/mm^2,26.9 N/mm^{2}and 44.9 N/mm^2 .

3.2 Light transmittance of LTC

3.2.1 Natural Light transmittance

By placing the specimens in the sun and measuring the light intensity at a distance of 100 mm between the specimen and the Lux metre, natural light transmittance was examined.On a sunny day, the experiment was carried out in an open area from 6 am until 6 pm.Values were recorded every hour. To obtain the highest readings, the specimen was placed directly in the sunlight.The light transmittance is at its maximum between 12 noon and 1 o'clock.Fig 8 shows light transmittance percentage of the natural light at different time.

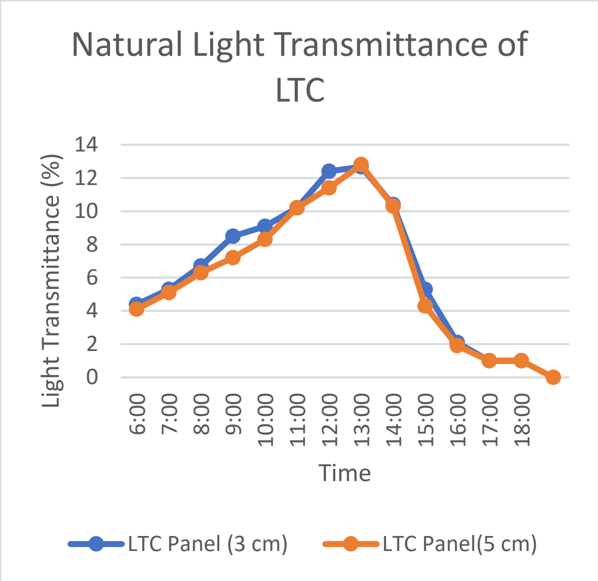

Fig 8 :Graph shows the transmittance percentage of natural light of LTC

3.2.2 Artificial Light Transmittance

As an expression of artificial light for the panels and cubes, 7 watt LED lights of red, yellow, green, and white were used to assess the specimens' ability to transmit artificial light.A Lux Metre was used to measure the panel's light transmission capabilities. As the distance between the light source and the specimen increased, optical power decreased.When the distance remained the same, the optical power of the specimens started to increase as the quantity of optical fibres increased.However, for the specimen, whether under white ,yellow,green or red light, the optical power tended to be the same as the distance increased to a certain range. In comparison to other colours, red light transmittance was lower. Fig. 9 shows the values obtained from the artificial light transmittance of 4 LED colour lamps.

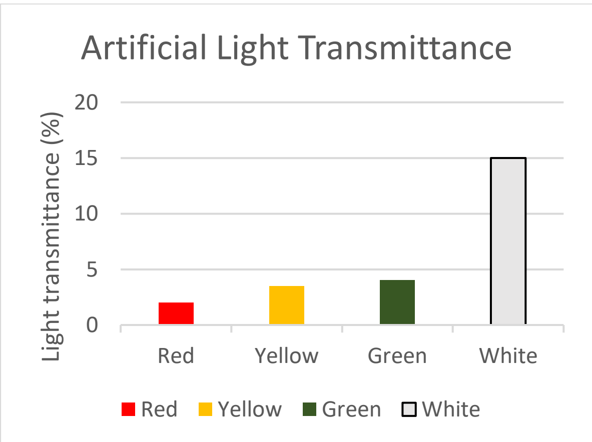

Fig 9 :Graph shows the Light transmittance percentage of artificial lights.

Fig 10 :Light transmitting concrete panels by using different colour LEDs.

3. 3 Ultrasonic Pulse Velocity Test

Concrete's density and elastic modulus are the key factors influencing the ultrasonic pulse velocity of the material. This in turn is dependent on the components and mixture ratios used to make concrete, as well as the techniques employed for placement, compaction, and curing.The quality grading is analysed from Table 1 of IS 516 (Part 5 / Sec 1):2018.The values obtained from the light transmitting mortar cubes are shown in the Table 4 and light transmitting concrete cubes are shown in Table 5.Both direct and indirect UPV test method is used for concrete panels and mortar panels .Mortar Panel shows more good quality grading in both direct and indirect method.Quality grading result of mortar and concrete panels are shown in the Table 6 .Fig 10 show the light transmitting concrete.

Table 4 Quality Grading of Light Transmitting Mortar Cubes

Mortar cube		Quality Grading
Average Velocity of Pulse Velocity by crossing probing(28 days)	5.396	Excellent
Average Velocity of Pulse Velocity by crossing probing(14 days)	5.76	Excellent

Table 5 Quality Grading of Light Transmitting Concrete cubes

Concrete cube		Quality Grading
Average Velocity of Pulse Velocity by crossing probing(28 days)	3.78	Good
Average Velocity of Pulse Velocity by crossing probing(14 days)	3.96	Good

Table 6 Quality Grading of LTC Panels both in direct and indirect method

Mortar Panel	3 cm		5 cm	
	Indirect	Direct	Indirect	Direct
Average Velocity of Pulse Velocity by crossing probing(28 days)	4.26	4.16	3.78	4.3
Quality Grading	Good	Good	Good	Good

Concrete Panel	3 cm		5 cm	
	Indirect	Direct	Indirect	Direct
Average Velocity of Pulse Velocity by crossing probing(28 days)	3.78	3.83	2.98	3.95
Quality Grading	Good	Good	Doubtful	Good

4. CONCLUSION

The aim of the present study was to increase the strength of the concrete and mortar panels.To reduce the use of concrete.To determine the quality of concrete and to determine the light transmittance of concrete both in day light and artificial light.Several conclusions can be drawn from the results of the experimintal tests.

- According to the test results, adding optical fibres to concrete boosted strength. By comparing the strength with that of normal M30 grade concrete, the effectiveness of the use of optical fibre is evaluated. The test results showed that the effectiveness is greater in all respects.
- When compared with concrete and mortar panels, it is observed that quality of mortar panels are more good than the concrete panels.
- Red light shows less light transmittance and therefore it can be used in the traffic. The translucent concrete used for lane markers on roads might include a variety of colours, allowing for dynamic modifications as needed by traffic fluctuations.Speed bumps in driveways and parking lots could be illuminated from below to increase their visibility and efficiency.
- As the light incident angle increased, the LTC's performance in terms of light transmittance dropped. Because 30° is the limit of the optical fiber's acceptance angle and most of the light is beyond the acceptance cone at that point, refraction rather than total internal reflection results. The result is that even with closer fibre separation, less light is being transferred. Even at a light incidence, the greater fibre diameter transmitted more light through total internal reflection.

We can draw the conclusion that the strength properties of concrete can be maintained while allowing for light transmission through the material. The use of translucent concrete panels as wall components is thus possible. To create a panel with the same dimensions, 6 concrete cubes are required.We can therefore use less concrete and optical fibre by using just one concrete panel.Panels installation is simple and reduce the amount of workmanship .Light Transmitting Concrete Panels can be used to construct green buildings, which uses less electricity. Cost is this concrete panel is the main drawback.To make each panel, we require a mould, and optical fibres are expensive.When pouring concrete into the panel, keen observations are needed. Concrete panels can be used for load bearing structures and mortar panels can be used for framed structures.The translucent concrete panels developed in this study are suitable for usage as architectural walls in green buildings, underground stations, in the structural facade of banks, as walls in prisons, and as safety and security advancements in museums. Additionally, it can be utilised to increase visibility in subways, roads, and airports.

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