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Experiment Study of Light Transmitting Concrete

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ABSTRACT

This research aims to study the performance of concrete using plastic optical fibre (POF) in concrete. In this study, the performance of light transmitting concrete (LTC) specimens made by using different dosages and spacing's of POF is investigated. The properties of the POF has been investigated and is discussed. The experimental results show that LTC can provide a high light transmitting ratio. This research contributes to the determination of new alternatives for sustainable construction around the world. Light transmitting concrete will help reduce power consumption in buildings, such as lighting, by allowing natural light access into building through external walls. This research adds distinctive knowledge to the area of sustainable construction studying the effect of POF on concrete properties and its performance. In addition, the use of POF in concrete led to an increase in compressive strength.

Key words: POF, LTC, Energy Saving, Nice View, architectural, environmental, Sustainable.

1. INTRODUCTION

Concrete is considered as one of the most significant materials used in the building industry. Each year billions cubic meters are produced. This trend in use of concrete is because of the many reasons, including its competence to resist mechanical loads, fire resistance and durability. Additionally, the raw materials of concrete are readily available and at competitive cost compared to other types of construction materials and systems.

The increase in the rate of development and modernization in construction sector has become significant in the in the past few years. One of these developments has been the inclusion of optical fibers in the concrete to make what is known as light transmitting concrete (LTC) or translucent concrete. It is one of the new trends and discoveries in the building industry to create environmentally friendly and bright building material. The economic growth and development of new technology around the world has led to the building of more civil engineering infrastructure such as high-rise buildings and underground construction. This urban growth is accompanied by an increase in energy consumption.

Lighting consumes a significant part, 19% of all electricity in the world [1]. For example, in the United States, and according to the estimations of energy information administration (EIA), nearly

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15% of the electricity was consumed for lighting in the residential and commercial sectors in 2014 [2]. The large amount of electricity influences many issues relating to climate change, economic growth and rising energy prices.

High-rise buildings for example, have significant lighting demands, even during daylight hours. This has led to thinking about the need to invent new, creative and sustainable construction materials. LTC technology is utilized to harness the vast amount of potential energy in sunlight as a source of light instead of electrical energy in order to reduce energy consumption. In addition, LTC technology contributes to reducing the negative image of concrete as gray, dark, harsh, rigid and opaque material.

The Concept of LTC

The basic idea of LTC is quite simple. LTC can be considered as eco-friendly, aesthetic and energy saving technology. This kind of concrete results from the addition of transparent material, which affects some of the properties of concrete. This transparent or translucent alternative material allows light to pass through concrete. The performance of LTC is similar to slits, enabling transmission light throughout the body of concrete. The function of this invention is to change the traditional image of concrete and to add an architectural modern touch. While, the main purpose is to use sunlight as a source of light in order to reduce consumption of energy in lighting. LTC can be applied in many applications including floors, pavements and load-bearing walls, furniture, facades, interior wall cladding, dividing walls, and partition walls.

There are two basic materials that are used to produce LTC; fine concrete and light transmitting material. Fine concrete consist of cement, fine aggregate and water. Many materials such as optical fiber, glass and plastic fiber, can be added to create LTC. However, the optical fiber may be considered as the most common material used to produce LTC.

Optical Fibers consists of three parts, core, cladding and coating. The light travels through the glass core center while the cladding is surrounding the core center and reflects the light into the core. The coating works to keep the fiber from damage and moisture.

In LTC, optical fiber occupies between 2 to 6% of concrete by volume. The distance between the rows of fibers ranges between 5mm and 10 mm.

The implementation of LTC in constructions has begun to increase in the last five years. Figure 1 shows examples of the application of LTC in different buildings around the world. One of these buildings that were built using the idea of LTC is the Italian pavilion at Shanghai World Expo 2010 in China. No optic fibers were used in this LTC, However, precast concrete panel protected by adding special plastic resins (polymer based material) to an innovative mortar was adopted. 3,774 LTC panels were used to cover a surface area of 1,887 m² (around 40% of the building's envelope). Each plate weighs 50 kg and has a dimension of 1×0.5 m and 5cm in thickness [3, 4]. Al-Aziz Mosque in Abu Dhabi is another example of the newly constructed building with using of LTC technology. The mosque was opened in 2015 and used optical fibers transmute the light. 1.8×1.4×0.3 m LTC panels with total area of 525 m2 were used in this building [5].

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The most important challenge facing this technique is the casting of LTC using skilled labor with the capacity to create this technology.

Location: Abu Dhabi, United Emirates

Completion: 2015

Thickness: 40 mm & 30 mm

Area: 525 m^2

Location: Shanghai, China

Completion: 2010

Area: 1,887 m^2

Location: Izmir, Turkey

Completion: 2015

Thickness: 20 mm

Area: 300 m^2

Location: Berlin, Germany

Completion: 2014

Thickness: 20 mm

Total area: 60 m^2

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Location: Tbilisi, Georgia	Location: Aachen, Germany
Completion :2011	Completion: 2012
Thickness: 15mm	Area: 102 m^2
Area: 300 m^2	

Figure 1: Application of light transmitted concrete [5] [3, 4]

Literature review

The concept of LTC was introduced by a young Hungarian architect Aron Losonzi in 2001. Losonzi begun working on his project with other scientists, while he was conducting his post-graduate study in Sweden at the Royal University College of Fine Arts. After returning to his hometown, Mr. Losonzi had completed his project and presented his design in exhibitions across Europe. [6, 7]. The spread of this innovative idea reflects a wide acceptance among researchers and those interested in the field of construction materials.

There are few previous studies that addressed the topic of LTC [8-15]. Bashbash et al. [14] examined the mechanical impact of adding plastic optical fiber (POF) into concrete. The results shows that the compressive strength of LTC increase when the amount of fiber increase. However, the flexural strength decreases with increase in fiber percentage. On the other hand, Sawant et al. [12] investigated the compressive behavior of LTC and found that the compressive strength of LTC is lower than the original mix without POF, when the percentage of fiber ranged between 0.06 to 1.59 %. While the results obtained by Salih et al. [11] showed apparent fluctuation of compressive and flexure strength depending on the fiber diameter and curing duration. Over all, the mechanical properties of concrete does not significantly affect after adding POF to produce LTC.

Other study conducted by Momin et al. [13] aimed to compare the behavior of LTC using glass rods and optical fibers. The Light transmittance of optical fibers LTC was clearly higher than glass LTC for the specimens used in this research. No previous study has been found investigate the behavior of LTC produced by adding transmitting resins. This paper aims to study and analyse the optical and mechanical properties of concrete mixes of LTC utilizing different percentages of POF.

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2. MATERIAL AND METHOD

2.1 Material

Light transmitting concrete produced consists of cement, water, sand with specific contents of optical fibers. Tap water was used in making and curing the specimens. In addition, Ordinary Portland cement product by Al-Burg cement plant, complying with the Libyan specification (No. 340-2009) was used in concrete mix. The cement was examined for the fineness (using sieve No. 200) and the result was: 9.3% (<22%) which complies with ASTM C 150. Natural fine aggregate available in Al-Jufra area was used in this research. The properties of fine aggregate are summarized in Table 1 Figure 2 illustrate the sieve analysis of sand. Sika ViscoCrete Tempo 12 was also used to acquire self-compacted concrete. Tap water was used as mixing water for all concrete mixes.

Table 1: Physical and mechanical properties of fine aggregates

Test	Tests Results	Standards
Specific Gravity:	2.7	BS 812 Part2:1995
Compacted Unit Weight (kg/m3)	1.034	ASTM C29
Voids Ratio %	18.8	ASTM C29
Fineness Modulus (FM)	3.05	ASTM C125
Nominal Maximum Size of Aggregate (mm)	2.36	ASTM C125
Clay Lumps and Friable Particles in Aggregate (%)	20	ASTM C142

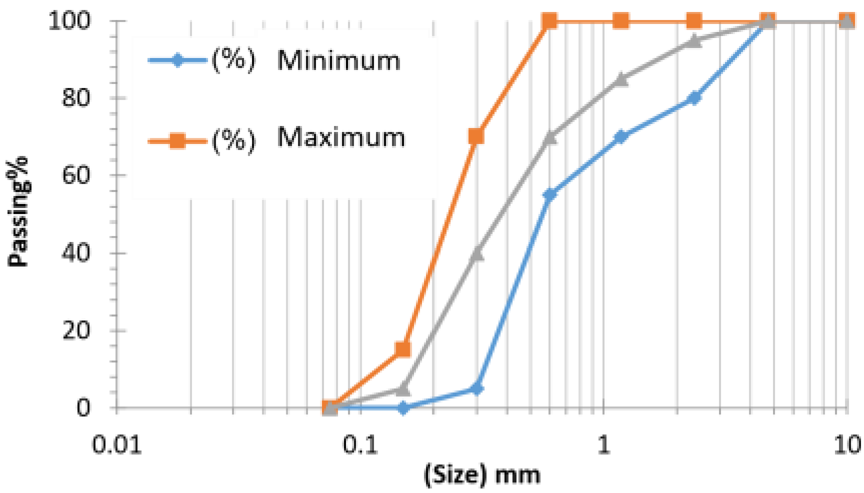

Figure 2: Particle-Size Distribution Curves of Sand

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2.1.1 Optical fiber preparation

The optical fibers used in this research were prepared through the stages outlined in this section. Firstly, optical fibers with different diameters; 0.3, 0.5, 0.75 and 1.5 mm were sourced. After that, the fibers were cut into specific lengths to be used in the concrete cubes. Finally, the fiber was inserted by passing them through holes in the 100mm cubic wood formwork made specifically for this research as shown in Figure 3.

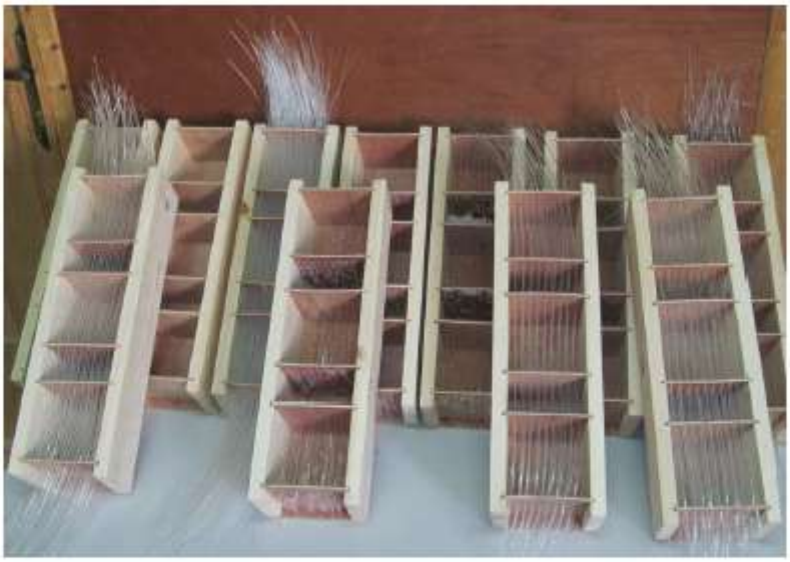


Figure 3: optical fibers inserted in 100mm cubic wood formwork.

2.2 Mix design

Six concrete mixtures containing different diameters and spaces of POF were prepared. Optical fibers with the dosage by mass were 0.06, 0.12, 0.36, 1.43 and 1.59% were distributed with specified spacing of 5mm and 10 mm in concrete. The trial method using slump test according to (ASTM C143), was used to design the concrete mix and get the appropriate water cement ratio (w/c = 0.4) with a slump of 190 mm. Table 2 illustrates the mix design proportion of concrete the specimens.

2.3 Curing conditions

The LTC specimens were firstly cured for 24 h under normal climatic conditions of the laboratory. After that, the LTC specimens were placed for 28 days in a curing pond filled with tap water.

3. THE EXPERIMENTAL PROGRAM:

Sixty-six concrete cubes were used to investigate the effect of POF on both concrete compressive strength and ultrasonic pulse velocity (UPV).

The properties of POF was established, which include microscopic inspection, water absorption, tensile strength and Young's modulus.

As part of the mechanical behavior of LTC, the compressive strength of concrete at 28 days was determined using cubic specimens of 10×10×10 cm according to (BS 1881: Part 116). In addition, the ultrasonic pulse velocity (UPV) in concrete was tested at 3, 7, 14, 21 and 28 days as recommended by (ASTM C597).

Table 2: Mix design proportion for 1 m^3 of concrete

Cubic	D0.3-S1	D0.5-S1	D0.75-S0.5	D0.75-S1	D1.5-S1
Spacing of Fibers (cm)	1	1	0.5	1	1
Diameter of fiber (cm)	0.3	0.5	0.75	0.75	1.5
Fiber (% by mass)	0.06	0.12	0.36	1.43	1.59
Cement (kg)			26		
Water (L)			10.4		
Fine aggregate (kg)			65		

4. RESULTS AND DISCUSSIONS

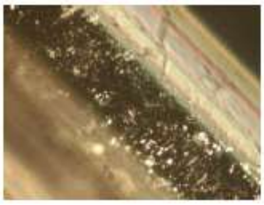
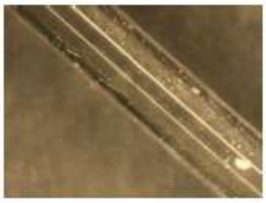
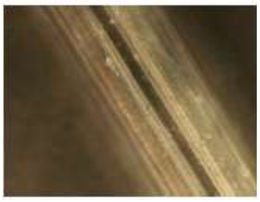
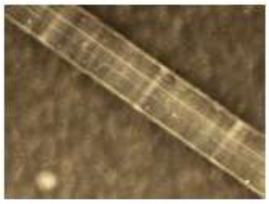
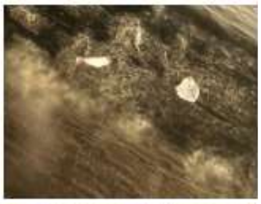
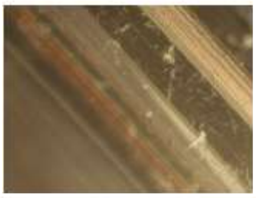
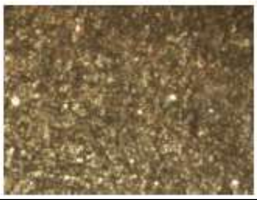
4.1 Mechanical Properties of POF:

The physical and mechanical properties of POF used in this study are shown in Table 3. It shows the diameters (d), absorption and tensile strength of POF was used. According to the microscopic inspection images shown in Table 4, the POF has three layers; the core, cladding and buffer coating. The core layer allows the light to transfer from one side to other, and the cladding layer keep the light inside the core layer, and the buffer coating protects the POF from scratches. It is apparent from the Table 4 that the external layer (buffer coating) has some scratches but these do not exceeds the layer thickness.

Table 3: The Physical and mechanical Properties of POF.

Test	Tests Results			
	Diameter			
	0.3 mm	0.5 mm	0.75 mm	1.5 mm
Tensile strength (MPa)	20	23	25	30
Modulus of elasticity (GPa)	9.25	10.20	13.60	15.02
Water absorption after 24 h	0.001 %			

Table 4: The Microscopic Inspection of POF.

note	LU Plan Flour 20X/0.45 A	LU Plan Flour 10X/0.30 A	LU Plan Flour 5X/0.15 A	D (mm)
Clear transparen, limpid buffer coating and many stratches on buffer coating layer.				0.3
Clear transparen, translucent buffer coating and little stratches on buffer coating layer.				0.5
Clear transparen, limpid buffer coating and medium scratches on buffer coating layer.				0.75
Clear transparen, limpid and sensitive buffer coating and many stratches on buffer coating layer.				1.5

4.2 Ultrasonic pulse velocity (UPV)

The ultrasonic pulse velocity method is an extremely useful and popular test for both in-situ and laboratory use. It involves measuring the time taken for an ultrasonic pulse to travel through a known distance in concrete, from which the quality, velocity and strength of concrete can be estimated. The principal is that the speed of propagation of stress waves depends on the density and the elastic constants of the solids.

Different test arrangements are possible, direct, semi direct and indirect test. The direct test is preferred, so it was adopted in this study. For in-situ measurements, the semi-direct and indirect methods can be used if access to the opposite side of a concrete wall is limited. The direct ultrasonic pulse velocity of the concrete cubes (10*10*10 cm) used in this research were measured according to ASTM C 597.

Figure 4 shows the ultrasonic pulse wave speed for six groups of concrete mix used in this study (36 cube specimens). According to Table 5 and Figure 4 demonstrate that the values of velocity of ultrasonic waves for all specimens increase gradually with the increase in age up to 28 days. This is

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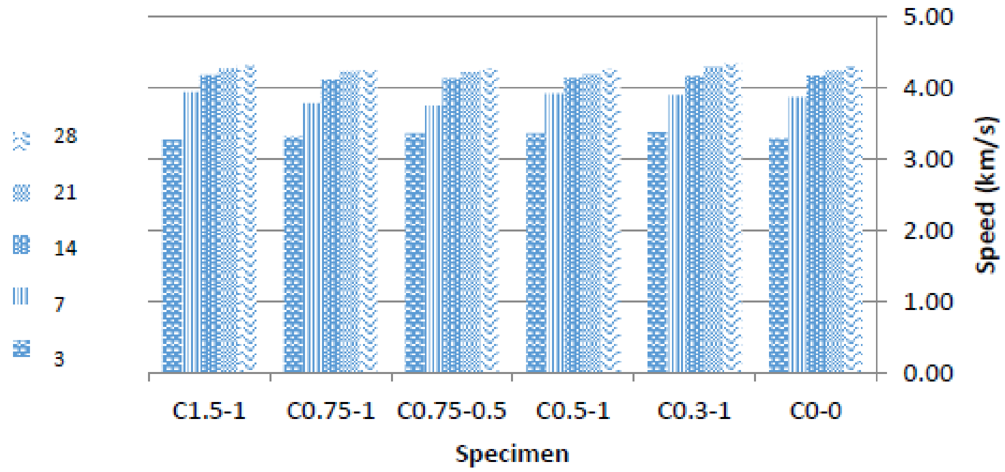
because of the progressive hydration of concrete with age. The UPV of all mixes remains approximately the same despite the increase in volume fraction of POF.

Based on Figure 4, the results of age (7 days) showed that the speed exceeds 3.5 m/s^2 indicating that the concrete used is of good quality, while for the ages of 14, 21 and 28 days, all of the results exceed 4 m/s^2, indicating that the concrete is of excellent quality (include a reference to which these limits are based on).

Table 5: The ultrasonic pulse velocity results.

Concrete mix.	Speed of ultrasonic pulse waves (km/sec)				
	3 days	7 days	14 days	21 days	28 days
D0-S0	3.28	3.86	4.17	4.24	4.30
D0.3-S1	3.38	3.89	4.16	4.29	4.33
D0.5-S1	3.35	3.91	4.14	4.19	4.25
D0.75-S0.5	3.35	3.75	4.13	4.22	4.26
D0.75-S1	3.31	3.78	4.11	4.22	4.24
D1.5-S1	3.27	3.94	4.17	4.27	4.31



The ultrasonic pulse velocity results Figure 4

4.3 Compressive strength

Compressive strength of concrete is one of the most significant and useful properties for the design of concrete structures. For instance, as a construction material, concrete is employed to resist compressive stresses. While, at locations where tensile strength or shear strength is of primary importance, the compressive strength is used to estimate the required property. The set-up of the compression strength testing of the 150×150×150 cubes.

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The effects of volume fraction of POF on compression strength at different ages are shown in Figure 5 and Table 6. The strength value is the average of three samples. At the different ages, there is a continuing improvement in the strength performance of all mixtures 0, 0.06, 0.12, 0.36, 1.43 and 1.59 % of POF.

The results show that the compressive strength increases with increasing POF percentage. The maximum compressive strength of LTC was 34.16 N/mm^2 and it occurs at 1.43% (D1.5-S1) of POF, and it is higher than the original concrete with 0 % POF, where the compression strength increased from 26.52 to 34.16 N/mm^2. For POF content at both 1.43% and 1.59% both the 7-day and 28 day compressive strengths are greater than the original mix with 0% POF. However, the results also show that despite the increase in POF percentage from 1.43% to 1.59%, the mix with 1.59% POF has a lower 28 day compressive strength compared to the mix with 1.43%. This might be due to the fact that smaller spacing arrangements of POF result in a weaker cubes due to the smaller interconnecting distances when macro cracks propagate under compressive load. This phenomenon will be investigated in future research. These results confirm that the POF usually have significant effect on the compression strength. This is a favorably sustainable outcome for strengthening of concrete structures to improve compressive strength.

Table 6 Compression strength for 7 and 28 days

Concrete mix	POF %	Compression strength (N/mm^2)	
		7 days	28 days
D0-S0	%0	20.9	26.52
D0.3-S1	%0.06	18.67	22.52
D0.5-S1	%0.12	20.92	22.95
D0.75-S1	%0.36	19.97	26.17
D1.5-S1	%1.43	23.92	34.16
D0.75-S0.5	%1.59	24.19	27.41

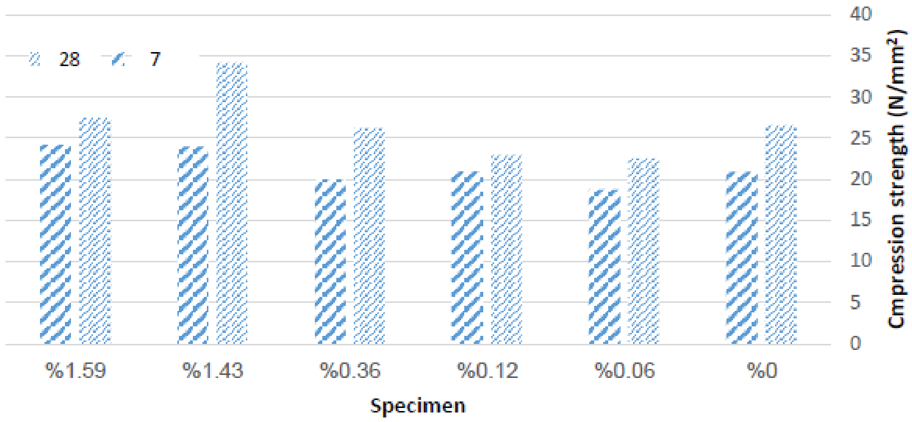

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Figure 5 Compression strength for 7 and 28 days

4.4 Light Transmittance Test

In order to study the light guiding property of LTC, 36 units of LTC with different POF volume ratios of 0 %, 0.06%, 0.12%, 0.36%, 1.43% and 1.59%, and the diameters of POF is 0.3, 0.5, 0.75 and 1.5 mm were used in this investigation. The light transmittance ability of the specimens were tested by an electrical circuit setup with an Light Dependent Resistor (LDR). The source of light used was a 40W lamp, with a resistance of 100Ω was applied in the circuit setup and uniform DC voltage of 10V is kept between the circuits. Figure 6 shows the experimental setup including a translucent concrete and experimental equipment for measurement of lux.

The transmission of light through the light transmitting concrete block depends on the percentage of optical fiber used on that surface area. The transmission of light increases with increase in percentage of optical fibers as shown in Table 7. The maximum intensity of light passing through the block for 0.06% of fibers is 1.74 lux, for 0.12% of fibers is 6.31 lux, for 0.36% of fibers 18.16 lux, 1.43% of fibers 75.53 lux and for 1.59% of fibers is 46.3 lux. The transmission of light at 1.59% shows that despite the increase in percentage of POF, smaller spacing might not be of great benefit to overall light transmission.

From Table 7 and Figure 7 it is clear that this average value of transmission of light through block will minimize the daily Electricity consumption.

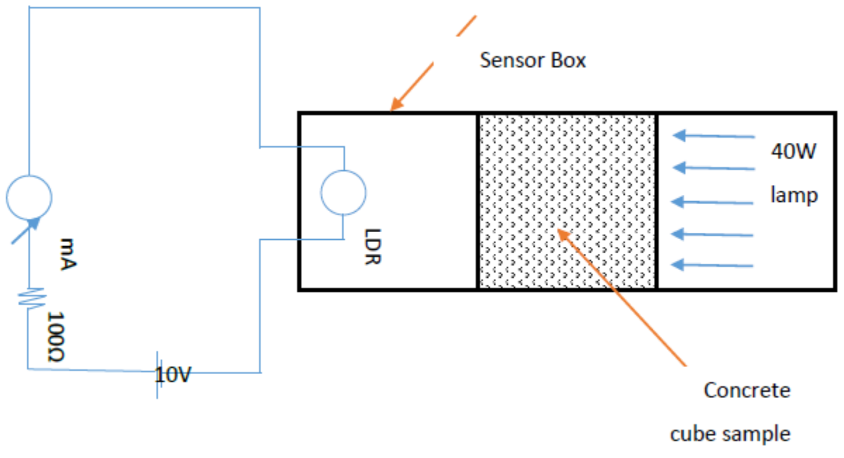

Figure 6: Experimental setup and equipment for measurement of lux.

Table 7 Amount of light passing through the concrete cubes

Concrete mix	Percentage of POF %	Increase of POF %	Amount of light passing LUX
D0-S0	0	0	0
D0.3-S1	%0.06	%100	1.74
D0.5-S1	%0.12	%77.89	6.31
D0.75-S1	%0.36	%69.76	18.16

D1.5-S1	%1.43	%74.24	75.53
D0.75-S0.5	%1.59	%33.58	46.3

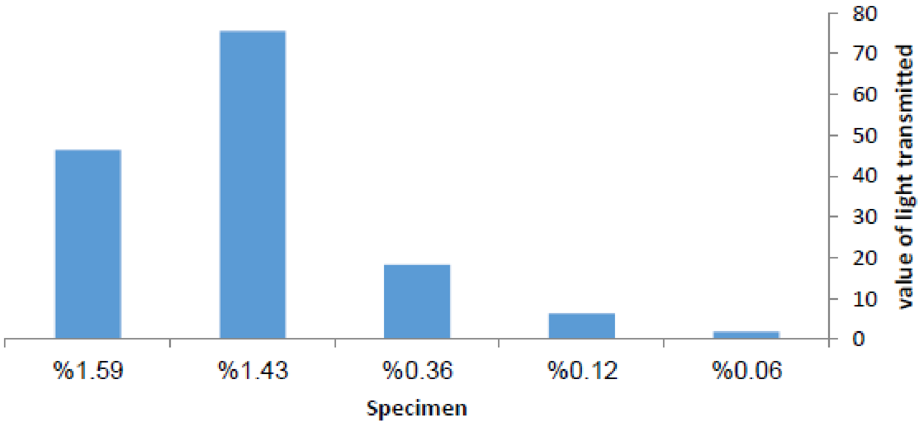

Figure 7 Amount of light passing through the concrete cubes

6. CONCLUSION

This study investigated the compressive behavior of light transmitting concrete (LTC). The properties of fibers used were also investigated. This paper contributes to new alternatives of concrete for sustainable construction.

Compressive strength with the original concrete mix samples was 26.52 N/mm^2 Adding POF to the concrete had a variation impact on the compressive strength. The greatest compressive strength of POF concrete (34.16 N/mm^2) was accomplished with 1.5 mm diameter fibers at 10 mm spaced. Based on the readings of ultrasonic pulse velocity UPV in the concrete samples, it is obvious that the compressive strength of the specimens increased with time. The maximum amount of light passing through the cubes was 75.53 LUX for a percentage of 1.43% of fibers.

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