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Research Article

Structural Performance of Translucent Concrete Façade Panels

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Energy conservation is an emerging global issue for sustainable infrastructure development. The building sector energy demand accounts for approximately 34% of the world's energy demand, and artificial lighting consumes around 19% of the total delivered electricity globally. Developing a new kind of building material that can reduce the demand for artificial lighting energy is vital. This research attempts to address such issues through the development of translucent concrete façade using locally available materials that can be used as energy-saving building material. Bulk density, compressive strength, and flexural strength of translucent concrete containing 2%, 4%, and 6% volume ratios of plastic optical fibers (POF) were studied. Moreover, the flexural toughness of translucent concrete façade panels integrating 6% volume ratio of POF was also investigated. The experimental results showed that using up to 6% volume ratio of plastic optical fibers had no adverse effect on the bulk density of translucent concrete. Translucent concrete specimens exhibited relatively lower compressive and flexural strengths compared to the reference concrete. However, it was evidently observed that the compressive strength of translucent concrete increased with increasing the volume ratio of POF. The flexural strength of translucent concrete was observed to decline with increase in the volume ratio of POF. Results demonstrated that translucent concrete panels have better flexural toughness, ductility, and energy absorption capacity than the reference concrete panel. The energy-saving, environmental conservation, and aesthetic and structural performance improvements stemming from the application of translucent concrete façade panel as architectural wall would foster the development of green and resilient buildings as well as contribute to sustainable construction.

1. Introduction

Sustainable construction is becoming a major concern and emerging issue in the construction industry worldwide. Developing sustainable construction minimizes the depletion of raw materials and energy and plays a significant role in protecting the environment. It also promotes the practice and design of structures in an ecofriendly manner [1]. Concrete is the most crucial and extensively used construction material in the construction industry. The density and opaque nature of concrete ingredients hinders the transmission of light and consequently results in opaqueness of the material. However, concrete could be transformed from opaque to translucent by integrating optical fibers with a concrete matrix. Translucent concrete (TC) is a new energy-saving building material that permits transmission of light into the indoor environment through the embedded optical fibers. Besides light transmittance, translucent concrete is able to show the silhouettes of any proximal objects situated on the brighter side of the wall; thereby, it can also be used for application in the architecture of prison, bank, and museum to ensure safety, supervision, and security [2].

Residential and commercial buildings are one of the most electric lighting energy consuming sectors. The building sector energy demand accounts for approximately 34% of the world's energy demand [3]. Artificial lighting consumes around 19% of the total delivered electricity worldwide [4]. The electric lighting demand has constantly been increasing with the increase in the population, urbanization, and construction of high-rise buildings. When high-rise buildings are built close to each other, natural sunlight is hindered to pass through due to the obstruction from nearby structures. During daytime, the brightness of the indoor environment in buildings is entirely maintained by artificial light, which consumes a large amount of electric energy. Using natural sunlight in indoor environment reduces the need for artificial lighting and cost of energy and promotes better comfort environments for occupants. Indoor environments with adequate natural light illumination have been proven to decrease the stress of occupant, improve visual comfort, and render better employee retention [5]. Developing a new kind of building material that can reduce the demand for artificial lighting energy is vital. This research attempts to address such issues through the development of translucent concrete using locally available materials that can be used as energy-saving building material in a variety of architectural wall of buildings, without compromising the fundamental engineering properties of the material. Translucent concrete is aesthetically pleasant concrete that offers daylight scheme in buildings and overall fosters development of green buildings and sustainable construction.

Cement-based translucent concrete is a combination of conventional concrete components such as cement, fine aggregate, and water and around 2%–6% of optical fiber by percentage of the total specimen volume. Load bearing and nonload bearing translucent concrete panels or façades should fulfill the strength, serviceability, and durability requirements to withstand expected ultimate loads with permissible deflection [6]. Furthermore, the light transmittance performance should be enough to meet the minimum illuminance level for the optical activity of people in indoor environments and comply with standards such as the Australian/New Zealand Standard [7].

Hungarian architect Áron Losonczi introduced the first concept of light transmitting concrete in 2001, and the first prototype of the translucent concrete panel was successfully developed in 2003 [8]. TC is a new ecofriendly construction material, and there exist few previous experimental studies. Altlomate et al. [9] studied the strength and light transmittance of TC containing POF of diameters 0.3 mm, 0.5 mm, 0.75 mm, and 1.5 mm. The results showed that incorporation of POF has a variable effect on compressive strength. The direct ultrasonic pulse velocity (UPV) test result showed that the quality of TC was excellent despite inclusive of POF. Li et al. [10] examined the compressive and flexural strength of cement-based TC containing polymethyl methacrylate (PMMA) fibers. Both compressive and flexural strength of TC decreased when the volume of fibers increased. In addition, the strength of all TC specimens was lower than that of the reference concrete, and thus, incorporating PMMA fibers led to a reduction of compressive and flexural strengths despite the volume fraction of fibers. Li et al. [11] reported that the compressive strength of sulfoaluminate cement-based TC linearly decreased as the volume of optical fibers increased at various curing conditions. Salih et al. [12] studied TC prepared using self-compacting mortar (SCM) and POF as reinforcement. The inclusion of POF generally decreased the compressive and flexural strengths of TC. However, the variation on diameter and volume of POF showed the fluctuating effect on strength properties of TC. It was found that 2 mm diameter PMMA fibers produced TC with higher flexural and compressive strengths compared to 1 mm and 2 mm diameter fibers. Another research conducted by Tutikian and Marquetto [6] was the investigation of translucent concrete walls produced with a random arrangement of optical fibers for use in the precast construction of Brazil. The experimental results revealed that the compressive and tensile strengths in bending of TC decreased as the percentage volume of optical fibers increased.

There is no scientific work on the design, construction, and application of translucent concrete in East Africa as well as Africa. This research intends to add cognizance of translucent concrete in the construction industry of Africa and to gain insight into the development of translucent concrete façade panels using locally available materials which have gained a lot of momentum in recent years in the sustainable construction and building efficiency issues worldwide. Moreover, the effect of plastic optical fiber on the structural performance of translucent concrete panels has not been studied comprehensively. This research has also investigated the flexural toughness impact of incorporating plastic optical fiber in concrete panels.

2. Materials and Methods

2.1. Materials. The constituent materials used for the production of translucent concrete include cement, limestone powder, fine aggregate, recycled glass aggregate, water, Sika ViscoCrete-3088 superplasticizer, and plastic optical fibers. In this study, ordinary Portland cement Type I (CEM I 42.5N) conforming to the requirements of EN 197-1 [13] with an alkali content of 0.15% was used. Limestone powder (LP) with 85.5% of $CaCO_3$ content by mass which met the standard requirement (≥75%) of EN 197-1 [13] was used as filler. The fineness of the limestone powder passing through a sieve of 185 μm, 75 μm, 45 μm, and 2 μm was 100%, 90.85%, 75.77%, and 10.60%, respectively. River sand with a bulk density of 1610 kg/m^3 and sieved through #8 sieve (2.36 mm) was used as fine aggregate. Moreover, crushed soda-lime silicate waste glass that met the particle size distribution requirements of ASTM C33 [14] was used to substitute natural fine aggregate in the mix. The chemical composition detected by X-ray fluorescence (XRF) and physical properties of the constituent materials are detailed in Table 1. The particle size distribution curve of the fine aggregate and recycled glass aggregate is presented in Figure 1. Sika ViscoCrete-3088, polycarboxylate-based high-range water-reducing superplasticizer, was used as a chemical admixture to improve workability and maintain rheology of fresh self-compacting mortar (SCM) mixes. The density and pH value of the superplasticizer was 1.06 kg/l (at +20°C) and 5.5 ± 0.5, respectively. A polymethyl methacrylate- (PMMA-) made plastic optical fiber (POF) having a core refractive index and numerical aperture of 1.49% and 0.5, respectively, was used as a medium of light transmission in the test specimens. The specification of POF is detailed in Table 2.

Table 1: Chemical composition and physical properties of the constituent materials.

Properties	Material			
	Cement	LP	Fine aggregate	RGA
Chemical (%)				
CaO	63.37	47.86	4.17	10.67
SiO_2	20.61	12.2	79.96	81.98
Al_2O_3	5.05	0.60	8.65	0.86
Fe_2O_3	3.24	0.30	1.53	0.23
MgO	0.81	0.90	0.00	5.63
SO_3	2.75	0.00	1.27	0.19
K_2O	0.52	—	2.82	0.23
Na_2O	0.15	—	—	—
P_2O_5	—	0.15	0.79	0.12
Free CaO	0.63	—	—	—
C_3A	7.91	—	—	—
Insoluble residue (I.R.)	1.00	0.20	—	—
Loss on ignition (LOI)	2.90	37.65	—	—
Physical				
Specific gravity	3.15	2.80	2.37	2.32
Bulk density (kg/m^3)	1433	1365	1610	1545
Specific surface (cm^2/g)	3197	1029	—	—
Soundness (mm)	0.30	—	—	—
Normal consistency (%)	25.65	—	—	—

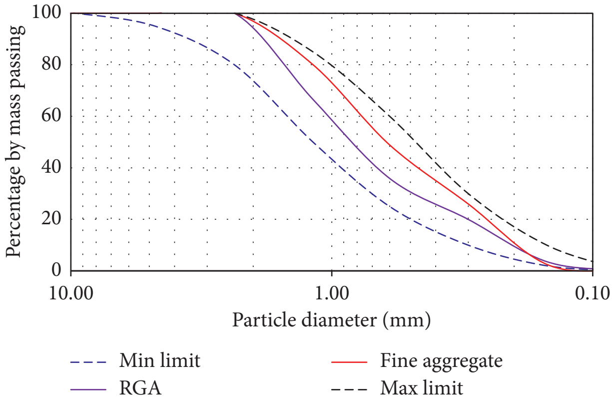

Figure 1: Particle size distribution of fine aggregate and RGA.

Table 2: Specification of the plastic optical fiber (POF).

Description	Property
Numerical aperture	0.5
Core material	Polymethyl methacrylate (PMMA)
Cladding material	Fluororesin
Outer diameter (Ø)	2 mm and 3 mm
Appearance/colour	Transparent, smooth
Refractive index profile	Step-index
Core refractive index (%)	1.49
Heat transfer	No
Conductivity	No
Outer jacket	No
Working temperature range	−40°C~ + 70°C
Allowable bending radius	≥10Ø
Elongation rate	≥4

2.2. Preparation of Translucent Concrete. Self-compacting mortar (SCM) mix was used in the prototyping of the translucent concrete and translucent concrete façade panels [15]. The SCM mix incorporated limestone powder and recycled glass aggregate (RGA) as 30% and 20% replacement of cement and fine aggregate, respectively. The SCM mix was designed and evaluated based on Japanese mix design method and EFNARC [16], respectively (Tables 3–5).

The compressive strength of translucent concrete was determined using specimens prepared on $50 \times 50 \times 50\,\text{mm}^3$ molds at 7 days and 28 days of curing according to ASTM C109 [17]. An average of three measurements was reported as the compressive strength of the translucent concrete specimens. The direction of loading was perpendicular to the arrangement and patterns of optical fibers incorporated with a constant rate of loading of 0.25 MPa/sec.

The modulus of rupture of translucent concrete specimens was determined at 7 days and 28 days according to the procedures outlined in ASTM C348 [16]. The concrete mix was poured into $40 \times 40 \times 160\,\text{mm}^3$ triple-gang molds without applying any compaction. Then after 24 hours casting, the specimens were demolded and cured in water at a temperature of $20 \pm 1^\circ$C until the age of testing. The prism specimens were subjected to third-point loading in rupture at a constant rate of 50 ± 10 N/sec. The typical translucent concrete specimens and plastic optical fiber are shown in Figure 2.

2.3. Fabrication Process of Translucent Concrete Panels. To investigate the structural performance of translucent concrete panels, precast concrete panels were prepared with 6% POF volume ratio. The 6% POF volume ratio was selected for translucent concrete panel production due to sufficient light transmittance ability obtained from the experimental light transmittance test conducted in [18].

The panels were fabricated as precast concrete reinforced with plastic optical fibers. The dimension of each panel was $100 \times 150 \times 300\,\text{mm}^3$. The total length of the panels was 400 mm with an effective span length of 300 mm. Orthogonal array holes were drilled in low-density polyethylene (LDPE) sheets according to the volume ratio of optical fibers incorporated, and the optical fibers were arranged in spatial distribution. Then, the prepared LDPE sheets were fixed in plywood molds. The SCM mix was poured into the molds without applying any external vibration. After 24 ± 2 hours of casting, the specimens were demolded and cured in water at a temperature of $20 \pm 1^\circ$C until the age of testing. Generally, three samples were prepared for three different panels including reference concrete panel and translucent concrete panels containing 2 mm and 3 mm POF diameters with 6% volume ratio. Details of the translucent concrete panels are presented in Table 6. The panel designation RCP is the reference concrete panel without optical fibers, whereas TCP-2 and TCP-3 refer to translucent concrete panels with 2 mm and 3 mm optical fibers, respectively.

2.4. Test Setup and Instrumentation of Translucent Concrete Panels. Each panel was tested under three-point bending at age of 28 days according to the study [19]. The test setup

Table 3: Mix design proportioning of SCM mix for the production of translucent concrete.

Mix designation	W/C	Cement (kg/m^3)	Limestone powder (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	RGA (kg/m^3)	Superplasticizer (kg/m^3)
SCM	0.46	547.42	208.54	251.74	948.00	237.00	6.80

Table 4: Details of POF integrated on translucent concrete specimens for the compressive strength test.

Sample designation (%)	POF diameter (mm)	POF volume ratio (%)	No. of POF incorporated	Average POF spacing (mm)
RC-0	—	—	—	—
Ø2-TC2	2	2	16	10
Ø2-TC4	2	4	32	7
Ø2-TC6	2	6	48	6
Ø3-TC2	3	2	7	12.5
Ø3-TC4	3	4	14	10
Ø3-TC6	3	6	21	8

Table 5: Details of POF integrated on translucent concrete specimens for the flexural strength test.

Sample designation (%)	POF diameter (mm)	POF volume ratio (%)	No. of POF incorporated	Average POF spacing (mm)
RC-0	—	—	—	—
Ø2-TC2	2	2	41	10.5
Ø2-TC4	2	4	82	8
Ø2-TC6	2	6	122	6.5
Ø3-TC2	3	2	18	14.5
Ø3-TC4	3	4	36	11
Ø3-TC6	3	6	54	9.5

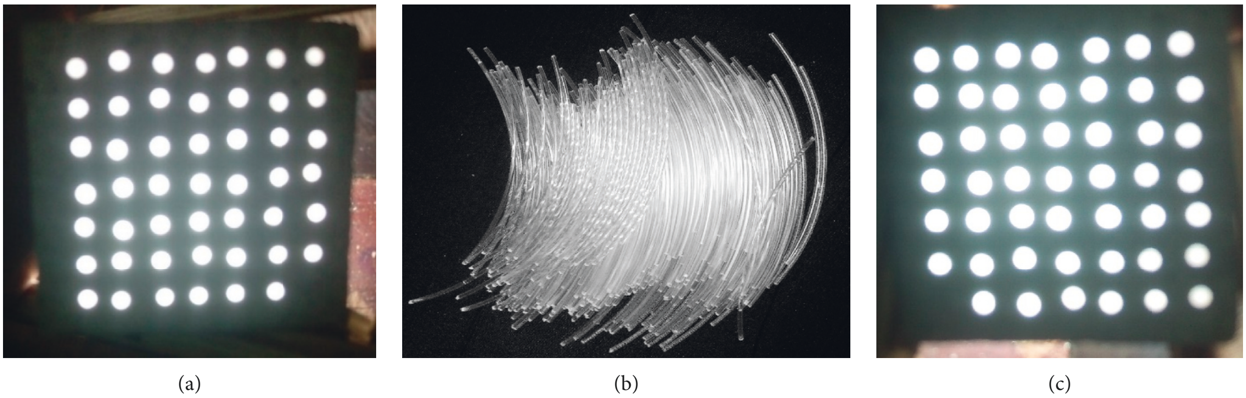
(a) (b) (c)

Figure 2: Typical translucent concrete specimens and plastic optical fiber.

Table 6: Details of POF integrated on translucent concrete panels.

Panel designation	Panel dimensions (mm)	POF diameter (mm)	POF volume ratio (%)	No. of POF incorporated	Average POF spacing (mm)
RCP	100 × 150 × 300	—	—	—	—
TCP-2	100 × 150 × 300	2	6	860	7
TCP-3	100 × 150 × 300	3	6	382	10

consisted of two steel column frames bolted to the reaction floor and a horizontal steel beam acting as loading frame bolted to the two columns. A steel plate was placed on the concrete floor center to the loading frame. Two steel reaction rollers were attached to the steel plate where the panels were resting. A hydraulic jack and load cell were placed between the panel and loading frame. The applied load on the panels was measured using a load cell placed directly above the hydraulic jack. The midspan deflection of the panels was determined using a 100 mm linear variable differential transducer (LVDT) placed at the bottom face. Midspan strain was measured with electrical resistance strain gauge mounted at the midspan of the panel. The experimental test setup is shown in Figure 3.

2.5. Load Analysis of the Translucent Concrete Panels. The load and moment carrying capacity, bending stress, shear stress, and normal stress of the translucent concrete panels were experimentally analyzed using the test results of the three-point flexural loading. The support condition of the panel was assumed as a simply supported system. Based on this assumption, the resulting bending moment at the midspan and the support reaction were determined. The bending stress, normal stress, shear stress, and modulus of elasticity were determined from the experimental test results.

3. Results and Discussion

3.1. Mechanical Properties of Translucent Concrete. Test results of the mechanical properties (compressive and flexural strengths) of translucent concrete are presented in Table 7.

3.1.1. Bulk Density. Figure 4 shows the bulk density value of hardened translucent concrete at 7 days and 28 days of age. Density was lower in translucent concrete (Ø2-TC and Ø3-TC) than in the reference concrete (RC-0%). The density of translucent concrete declined with rising volume ratio of POF, regardless of the optical fibers' diameter. This decline was the result of the lower density of optical fibers than the cement matrix. Density of the translucent concrete was decreased by about 0.22%, 1.17%, and 2.33% for Ø2-TC and 0.78%, 2.17%, and 3.39% for Ø3-TC compared to the reference concrete. The density values obtained in this study concurred with the observations reported previously in [12]. Generally, the density values of translucent concrete lay within the range of 2320–2400 kg/m^3.

3.1.2. Compressive Strength. The relative compressive strength test results of the translucent concrete (Ø2-TC and Ø3-TC) with respective to the reference concrete (RC-0%) are presented in Figure 5. It was clearly observed that all the translucent concrete specimens exhibited a compressive strength lower than that of the reference concrete, regardless of the optical fibers' diameter. On average, the 28-day compressive strength was 8%–24% lower for the translucent concrete than for the reference concrete. These findings concurred with the observations reported by Salih et al. [12], who deduced that the 28-day compressive strength of translucent concrete containing 1.5 mm, 2 mm, and 3 mm diameters of POF is 7.12%–28.50% lower than the reference concrete. However, it was also evidently observed that the compressive strength of translucent concrete increased with increasing the volume ratio of POF. Compared to translucent concrete incorporating 2% POF volume (2 mm diameter), the compressive strength of translucent concrete containing 4% and 6% volume ratios of POF of 2 mm diameter increased by 11.21% and 15.99%, respectively. However, the compressive strength of translucent concrete specimens with 4% and 6% of POF volume (3 mm diameter) relative to specimens containing 2% of POF volume (3 mm diameter) increased by 1.56% and 5.41%, respectively. The findings on the effect of POF are consistent with the results of a study conducted by Altlomate et al. [9], who reported that the inclusion of POF improves the compressive strength of concrete. The compressive strength of all specimens increased with increasing curing age. Figure 5 also depicts that the compressive strength was slightly lower in translucent concrete containing POF of 2 mm diameter than in the corresponding translucent concrete containing 3 mm POF diameter. The effect seems to be significant at 2% of POF volume ratio. The relatively smaller spacing arrangement of 2 mm POF than 3 mm POF might result in a smaller distance of cement matrix interconnection surrounding the surface of POF that consequently accelerates the formation of macrocrack during compressive loading [9]. The compressive strength values of the reference concrete and translucent concrete were within the range of 31–40 MPa.

3.1.3. Flexural Strength. The flexural strength test results of reference concrete (RC-0%) and translucent concrete (Ø3-TC and Ø2-TC) are graphically shown in Figure 6. The results appear to show that the flexural strength of all Ø3-TC and Ø2-TC specimens was lower than the strength of RC-0% specimens. In addition, it was clearly observed that the flexural strength of translucent concrete decreases with increasing POF volume ratio regardless of the difference in POF diameter. This may be attributed to the decrease in adhesion between the cement matrix and POF during bending. It was observed that the fracture of flexure specimens occurred in the interfacial transition zone along the POF surface and surrounding cement paste. The phenomenon can be explained as when the specimens are subjected to rapture, microcracks are formed in the interfacial transition zone that leads to split of the bondage and failure. The results obtained in this study supports the findings reported in [10, 12], which reported that incorporating POF decreases the flexural strength. Based on the average of three measurements, the 28-day flexural strength was 9%–24% lower for the translucent concrete than for the reference concrete. The relative percentage reduction in flexural strength for Ø3-TC specimens with 2%, 4%, and 6% POF volume ratios was 9.80%, 14.71%, and 24.02%, while for Ø2-TC specimens, it was 11.76%, 16.67% and 22.55%, respectively. Similar results were also reported by Salih et al. [12], who observed 17%–40% reduction of the modulus of rupture for specimens containing 1.5 mm, 2 mm, and 3 mm POF diameters of volume ratios 2%, 3%, and 4%.

3.2. Flexural Toughness of Translucent Concrete Panels. The load-deflection ($P-\delta$) of the translucent concrete panels as well as the reference concrete panel obtained from the experiment is shown in Figure 7. From the experimental investigation, it was observed that the ultimate load in

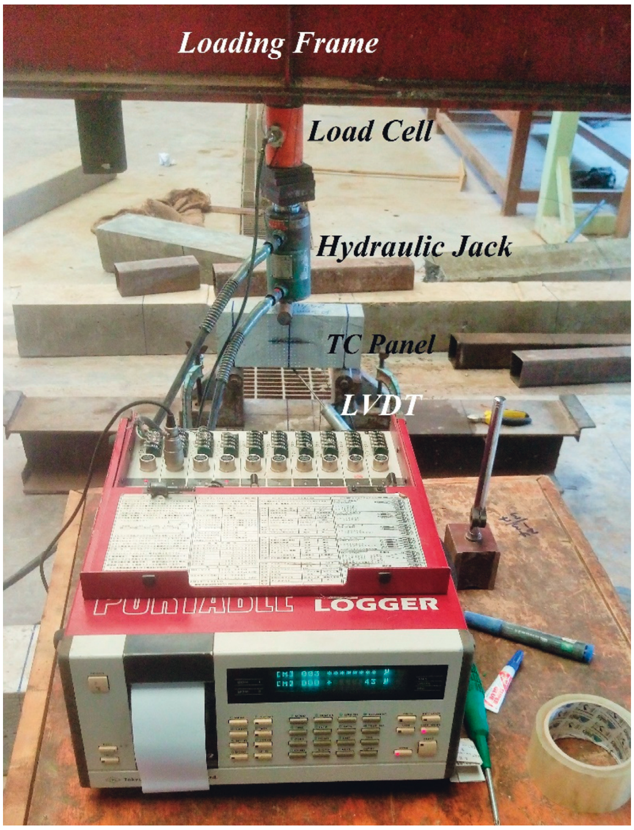

Figure 3: Experimental test setup.

Table 7: Mechanical properties of translucent concrete specimens.

Sample designation (%)	Bulk density (kg/m^3)	Compressive strength (MPa)		Flexural strength (MPa)	
		7 days	28 days	7 days	28 days
RC-0	2401.33 (0.88)	36.78 (0.96)	40.66 (0.76)	6.66 (0.16)	7.97 (0.17)
Ø2-TC2	2396.00 (0.76)	29.15 (0.54)	31.16 (0.64)	5.94 (0.17)	7.03 (0.10)
Ø2-TC4	2373.33 (0.98)	33.10 (0.83)	34.65 (0.89)	5.70 (0.15)	6.64 (0.06)
Ø2-TC6	2345.33 (0.83)	35.37 (0.91)	36.14 (0.59)	5.23 (0.15)	6.17 (0.23)
Ø3-TC2	2382.67 (1.09)	34.38 (0.87)	35.11 (0.71)	6.19 (0.49)	7.19 (0.31)
Ø3-TC4	2349.33 (0.92)	32.62 (0.94)	35.66 (0.98)	5.65 (0.01)	6.80 (0.10)
Ø3-TC6	2320.00 (1.02)	30.54 (0.92)	37.01 (1.05)	5.31 (0.12)	6.05 (0.14)

Note. The average value for three replicate specimens and standard deviation is given in parentheses.

flexure carried by TCP-2 and TCP-3 was 11.38 kN and 11.69 kN, respectively. The ultimate midspan deflection of TCP-2 and TCP-3 was 1.60 mm and 1.84 mm, respectively, while for the RCP, the ultimate load and ultimate midspan deflection were 23.23 kN and 1.43 mm, respectively. The results show that TCP-2 and TCP-3 carry 51.02% and 49.66% less ultimate load, respectively, than the RCP. However, the ultimate midspan deflection observed in the RCP was 10.64% and 22.22% less compared to that in TCP-2 and TCP-3, respectively.

The flexural toughness parameters (flexural toughness factor and flexural toughness) were determined from the P–δ plot (Figure 7) according to JSCE-SF4 on the basis of serviceability limit or failure criterion. JSCE-SF4 states that reinforced concrete is serviceable up to a deflection $\delta_{\mathrm{tb}} = \ell/150$ of the span considering severe serviceability conditions. Based on this philosophy, the flexural toughness of the translucent and reference concrete panels was determined and details are given in Table 8. It was clearly noted from the experimental test results that the TCP exhibited large deformation without remarkable load drop which indicates better ductility and energy absorption compared to the RCP. This decline in brittleness nature of concrete or improvement of ductility was the result of the inclusion of POF. Flexural toughness was 11.01% and 21.15% higher in TCP-2 and TCP-3, respectively, than that in the RCP. This finding was consistent with the research outcomes conducted by Salih et al. [20], who reported that the inclusion of POF improves the ductility of concrete. The results also show that the panels containing POF exhibited higher flexural

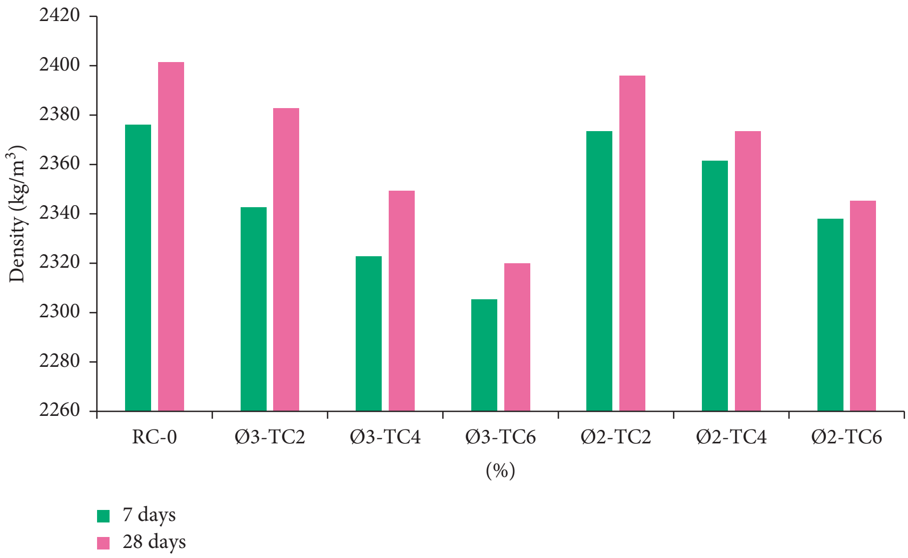

Figure 4: Bulk density of the translucent concrete at 7 days and 28 days of age.

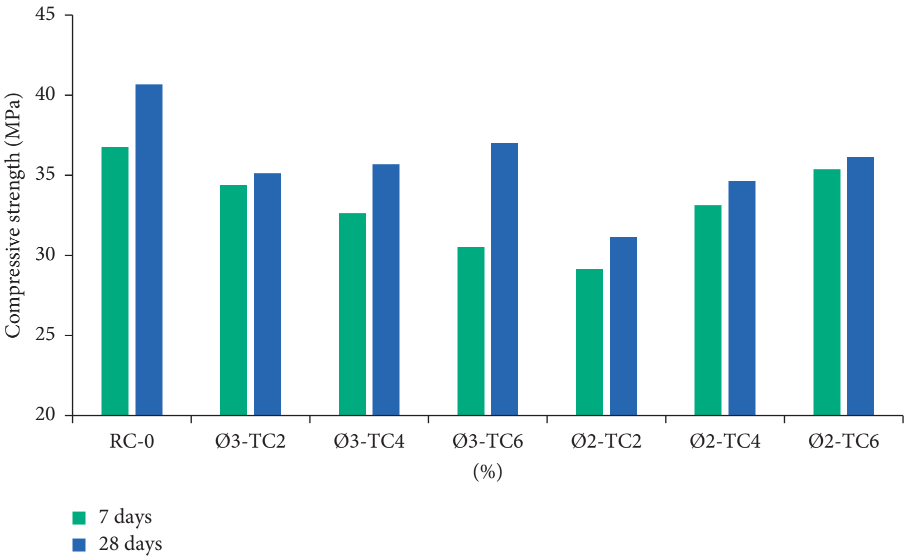

Figure 5: Compressive strength of the translucent concrete at 7 days and 28 days.

toughness factor relative to RCP. The failure condition in the RCP was sudden once the ultimate load carrying capacity exceeded without showing any crack and warning of failure, while the translucent concrete panels sustain a significant load when the deflection was increasing and showed flexural crack perpendicular to the optical fibers alignment below the neutral axis before failure.

3.3. Experimental Load Analysis of the Translucent Concrete Panels. Results of the experimental load analysis of the translucent and reference concrete panels are presented in Table 9. The bending stress-strain and normal stress-strain of the POF-reinforced concrete and RCP are shown in Figures 8 and 9, respectively.

The results showed that the ultimate bending moment carried by the TCP was less than the moment sustained by the RCP, by 51.02% for TCP-2 and 49.66% for TCP-3. A similar trend was also observed for the support reaction load, bending stress, normal stress, and shear stress that the reference panel carried and, and it structurally performs better than those panels reinforced with POF. However, strains measured experimentally showed that the strain of panels reinforced with POF was higher than that of the panel without POF. It is clear that all the panels exhibited a maximum lateral strain of magnitude over 0.0030 mm/mm. The strain was 13%–20% higher for the translucent panels than for the reference panel. This indicates that despite the load carrying capacity, incorporating POF improves energy dissipation and this allows for warning of failure through

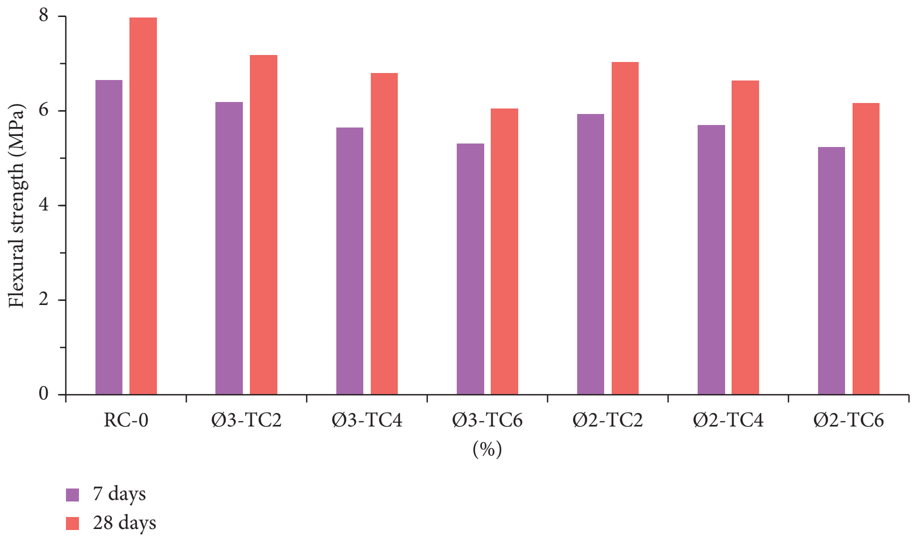

Figure 6: Flexural strength of the translucent concrete at 7 days and 28 days.

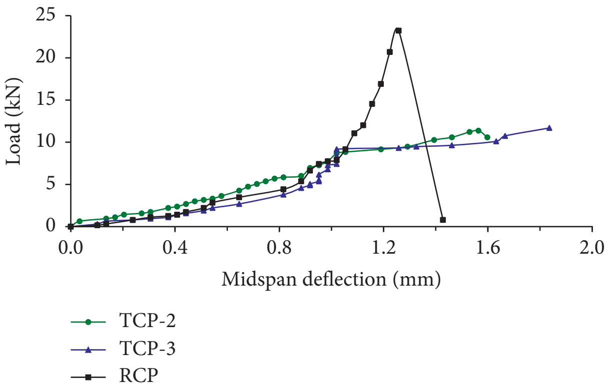

Figure 7: Load-deflection ($P-\delta$) graph of the translucent concrete panels.

Table 8: Flexural toughness parameters of TCPs and RCP.

Panel designation	Flexural toughness (kN·mm)	Flexural toughness factor (N/mm^2)
RCP	8.27	0.55
TCP-2	9.29	0.62
TCP-3	10.49	0.70

Table 9: Details of experimental load analysis results of the TCPs and RCP.

Experimental load analysis test results (at failure)	Panel designation		
	RCP	TCP-2	TCP-3
28-day compressive strength	40.66	36.14	37.01
Mass density (kg/m^3)	2401.33	2345.33	2320.00
Ultimate load (kN)	23.23	11.38	11.69
Maximum deflection (mm)	1.43	1.60	1.84
Maximum strain (mm/mm)	0.0030	0.0036	0.0034
Ultimate bending moment (kN·mm)	1741.95	853.20	876.90
Maximum support reaction (kN)	11.61	5.69	5.85
Maximum bending stress (N/mm^2)	4.65	2.28	2.34
Maximum normal stress (N/mm^2)	1.55	0.76	0.78
Maximum shear stress (N/mm^2)	2.32	1.14	1.17
Elasticity of modulus (GPa)	32.26	29.36	29.23
Shear modulus (GPa)	15.82	14.39	14.33

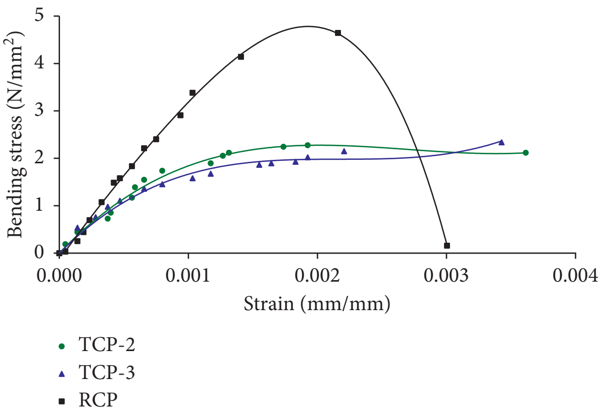

Figure 8: Bending stress-strain curve.

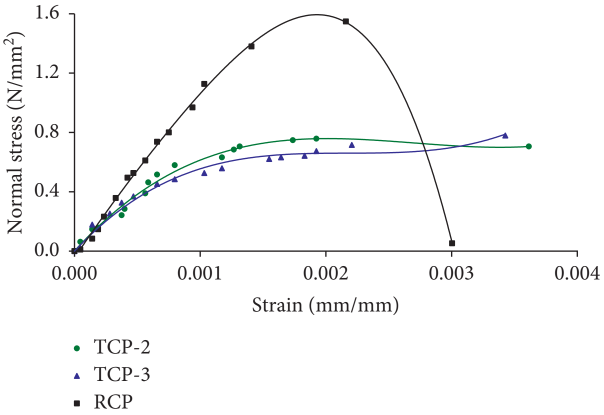

Figure 9: Normal stress-strain curve.

large excessive deflection. The ductile nature of the optical fibers attributed to the improved energy dissipation of TCPs. Furthermore, the failure mode and general response of the panels were reliant on the fiber material. The failure of panels occurred before reaching the serviceability limit midspan deflection, $\ell/150$, commonly used for architectural features.

The elasticity modulus and shear modulus of the RCP estimated by ACI 318 was 9% higher than the TCPs. The elasticity and shear modulus lay within the range of 29.2–32.2 GPa and 14.3–15.8 GPa, respectively. Elasticity modulus and shear modulus are fundamental parameters in designing of concrete structures. The higher elastic modulus indicates that the concrete panel can withstand higher stress, but it becomes brittle and sooner cracks appear, while the lower elastic modulus indicates the concrete panel can deform and bend easily. On the ground of elasticity modulus, the reference concrete panel was more brittle than the translucent concrete panels.

4. Conclusions

The conclusions to be drawn from the tests results obtained on the mechanical properties and structural performance of translucent concrete are as follows:

(1) It was clearly observed that all the translucent concrete specimens exhibited a compressive strength lower than the reference concrete. On average, the 28-day compressive strength was 8%–24% lower for the translucent concrete than for the reference concrete. The compressive strength of translucent concrete increased with increasing the volume ratio of plastic optical fibers (POF).

(2) The inclusion of POF in concrete was found to significantly decrease the flexural strength. The general trend observed indicate a reduction in flexural strength with increase in the POF volume ratio. The 28-day flexural strength was 9%–24% lower for the translucent concrete than for the reference concrete.

(3) It was evidently observed from the experimental test results that the translucent concrete panels exhibited large deformation without remarkable load drop which indicates better ductility and energy absorption compared to the reference concrete panel.

(4) The flexural toughness was 11%–22% higher in translucent concrete panels than that in the reference concrete panel. Thus, the inclusion of POF improves toughness behavior of concrete.

(5) The ultimate load, bending moment, shear stress, normal stress, and bending stress carrying capacity of the translucent concrete panels were 49%–51% lower than those of the reference panel.

(6) Generally, from serviceability limit state and ductility point of view, translucent concrete panels perform better than the reference concrete panels.

(7) The translucent concrete panels developed in this study are apt for application in architectural walls of green buildings, underground stations, in structural façade of banks, wall of prisons, and museums to increase security and supervision as well as safety. It can also be used in airports, subways, and road marks to add visibility.

Data Availability

The authors declare that data supporting the findings of this study are available within the article and supplementary information files.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Supplementary Materials

Figure 1: setup detail for structural performance of the translucent concrete panel. Figure 2: JSCE-SF4 flexural toughness and toughness factor definition. Figure 3: normal stress profile of the structural panel/façade. Figure 4: shear stress profile of the structural panel/façade. Supplementary Table 1: POF computation for translucent concrete specimens (compressive strength test cubes (Ø2 mm POF)). Supplementary Table 2: POF computation for translucent concrete specimens (compressive strength test cubes (Ø3 mm POF)). Supplementary Table 3: POF computation for translucent concrete specimens (flexural strength test cubes (Ø2 mm POF)). Supplementary Table 4: POF computation for translucent concrete specimens (flexural strength test cubes (Ø3 mm POF)). Supplementary Table 5: POF computation for the translucent concrete panel (6%v/v). Supplementary Table 6: experimental load analysis of the reference concrete panel. Supplementary Table 7: experimental load analysis of the translucent concrete panel (Ø2 mm, 6% POF). Supplementary Table 8: experimental load analysis of the translucent concrete panel (Ø3 mm, 6% POF). Supplementary Table 9: flexural toughness of the reference concrete panel. Supplementary Table 10: flexural toughness of the translucent concrete panel (Ø2 mm, 6% POF). Supplementary Table 11: flexural toughness of the translucent concrete panel (Ø3 mm, 6% POF). (*Supplementary Materials*)

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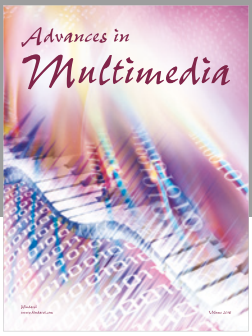
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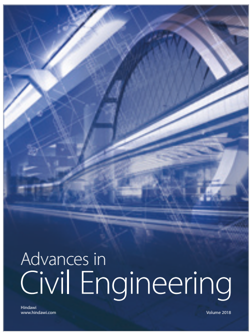
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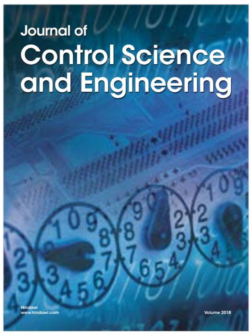
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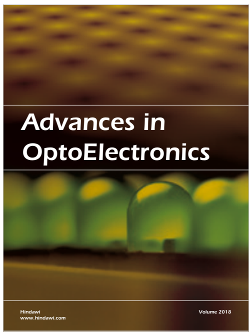
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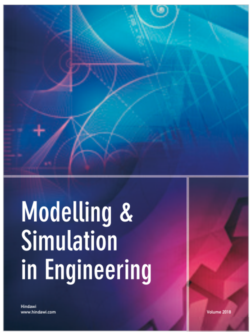
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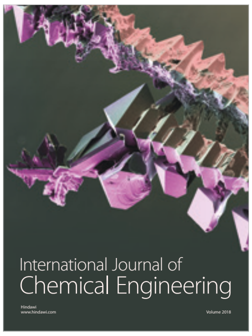
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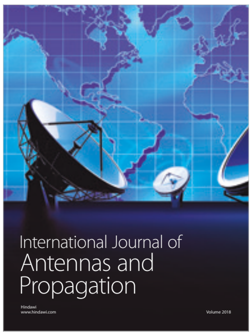
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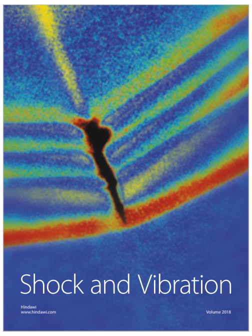
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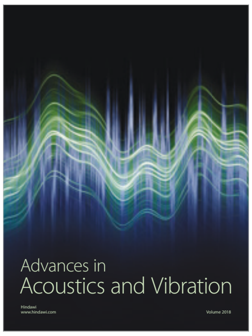
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