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Effect of Optical Fibers on Selected Characteristics of Concrete

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Abstract **-** The incorporation of optical fibers into concrete has the potential to greatly reduce power consumption for lighting in buildings, leading to increased energy efficiency. The goal of this study is to examine the properties of concrete that has optical fibers infused into it in order to establish the minimum optical fiber content required to sustain both the structural integrity and light transmission properties of the concrete. The investigation employs four distinct samples, subjecting them to assessments of compressive strength, flexural strength, and light transmission subsequent to conducting flow table and air content tests. The sample series encompasses varying proportions of optical fibers, specifically 0%, 3%, 5%, and 6% by volume. The outcomes reveal a positive correlation between light transmission and the concentration of optical fibers. Nevertheless, a notable reduction in mechanical strength becomes apparent beyond an optical fiber content of 3%. This study aims to provide information on the complex interactions between optical fiber content and concrete's structural stability and light transmission. The results not only highlight the potential for optimizing light-related energy consumption in buildings through optical fiber integration, but they also highlight how crucial it is to maintain a balance between improved illumination and structural strength in the quest for sustainable and energy-efficient building materials.

Keywords**:** Mechanical properties, Optical fibers, Translucent concrete, Transparent concretes

1. Introduction

Incorporating optical fibers into concrete has a significant influence on lowering the amount of light energy used by buildings and enhancing their luminous and aesthetically pleasing appearance. However, it may have negative effects on the mechanical properties of the concrete. The Increase in optical fiber capacity has an inverse relationship with compressive strength, as indicated by several investigations [1][2][3]. Nevertheless, certain studies cast doubt on the theory by showing that increasing the fiber concentration increases both compressive and flexural strength [4][5].

This study intends to determine the optimum limit of fiber utilization, bridging the gaps between diverse opinions on the effects to ensure concrete strength with the added property of light transmission. To achieve this, compressive strength, flexural strength and light transmission tests were conducted and evaluated for four sample series with varying amounts of fiber content.

2. Materials and specimen preparation

2.1. Optical Fibers

Optical fibers were manufactured using the rod-tube method, modified for the purposes of the research. The preform was made in the form of a Shott F2 glass rod with a diameter of 30 mm. They were pulled under the following parameters: oven temperature (800-860) °C, preform feeding speed (3-5) mm/min, drum speed (15-30) rpm, depending on the diameter of the optical fiber. The size of the single optical fiber is 1mm in diameter.

2.2. Concrete

The concrete mixtures were made with CEM I 42,5R Portland cement. Table 1 provides an overview of the mixture proportions utilized in the concrete, including key elements such as cement, water, sand, aggregate, admixture, and the water-cement ratio.

Table 1: Mixture proportion for concrete

Mixture properties	**Quantity**
Cement 42.5R, (kg/m^3)	320
Water (kg/m^3)	160
Sand 0.125 – 4mm (kg/m^3)	732
Aggregate (kg/m^3)	1203
Admixture (% mass from concrete)	3.2
Water – Cement ratio (W/C)	0.5

3. Test Methods

In the preliminary phase of the experimentation, essential workability tests were meticulously executed, comprising the Air Content Test within fresh concrete and the Flow Table Test. These fundamental assessments form the cornerstone of the research objective, which is to comprehensively understand the influence of optical fibers on the workability of transparent concrete.

3.1. Air Content Test

The air content of the concrete was quantified using the pressure air method, with Eurocode [6] serving as the reference standard for this test. The disparity between the original and diminished volumes of concrete represents the proportion of air content within the concrete matrix. This methodological precision adheres to established standards, ensuring the reliability and accuracy of our findings.

3.2. Flow Table Test

The Flow Table Test, conducted in accordance with Eurocode [7]. This examination critically evaluates the quality of the concrete mixture in terms of uniformity, cohesion, and susceptibility to segregation. The concrete flow, which is measured by the percentage increase in the average diameter of the distributed concrete over the base diameter of the mold, was accurately measured in each of the three iterations of the test, which were conducted to assure precision. The computation is executed using Eq (1).

$$Flow\ \% = \frac{Average\ Spread\ diameter\ (cm) - Original\ base\ diameter\ (cm)}{Original\ base\ diameter\ (cm)} * 100\% \tag{1}$$

3.3. Concrete Strength Test

Following workability tests, the mechanical characteristics of concretes with different optical fiber contents has been examined. It commenced with compressive strength testing, focusing on four different sample variables, each with a distinct weight of optical fibers. Specifically, Sample I, II, III, and IV contained 0g (0%), 25g (3%), 33.3g (5%), and 45g (6%) of optical fiber content, respectively. For each interval and fiber content in the Compressive Strength Test, conducted at 7, 14, and 28-day intervals, three samples were employed. The development of compressive strength over time has been tracked with this method, which providing insights into the ways in which different optical fiber volumes affect concrete components. According to Eurocode [8] guidelines, this test followed established standards for precise and reliable results. Throughout the experiment, the rate of load application incrementally rose at a rate of 2400N per second until reaching the point of maximum load, as illustrated in Figure 1, coinciding with the occurrence of specimen fracture.

Figure 1: Compressive strength test

Following the completion of the Compressive Strength Test, the subsequent strength evaluation was the flexural strength assessment of the concrete sample series. The flexural strength differences were examined relative to optical fiber content, considering that the sole variation between samples was the volume percentage of optical fibers. Each sample underwent flexural strength assessment after 7, 14, and 28 days of curing, following the consistent testing protocol outlined in Eurocode [9]. Specimens were strategically positioned on loading points, as depicted in Figure 2, and the force block was methodically applied at these points in contact with the specimen's surface. The point of failure remained consistent as the load is continuously applied to the specimen without sudden impact, ensuring a uniform and reliable evaluation of flexural strength characteristics.

Figure 2: Flexural strength test

3.4. Light Transmission Test

Ultimately, the light-transmitting capabilities of the concretes were assessed through the light transmission test, a crucial component of this research given that the primary motivation for employing transparent concrete lies in its transparency feature. The quantity of optical fiber integrated into the concrete plays a significant role in determining its light-transmitting properties. Subsequent to the preparation of the sample series for the light transmission test Figure 3, both ends of the sample were meticulously smoothed using hard paper to eliminate any undesired concrete dust particles that might impede light transmission.

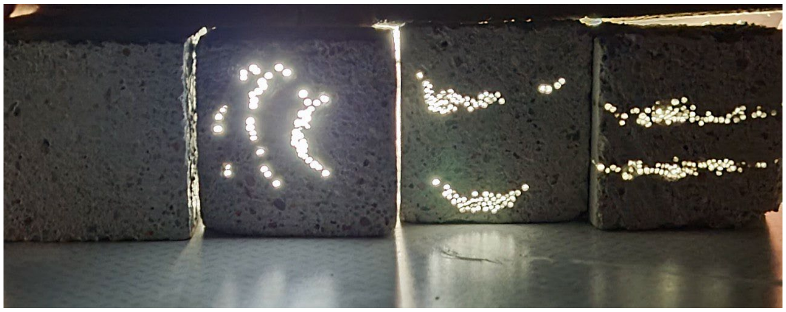

Figure 3: Samples ready for light transmission test

The light transmittance was measured using a light box (refer Figure 4). In this method, a prepared light box has a 20W bulb as the light source attached to one opening of the sphere. The other opening accommodates the spectral transmission measuring tool, positioned to measure the light passing through the transparent concrete placed between the light source and the measuring tool.

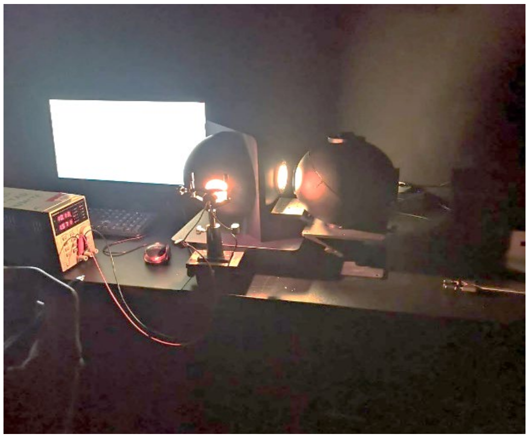

Figure 4: Apparatus for light transmission test

4. Results
4.1. Workability test
Following measurements in three different test trials, the results of the air content and flow table tests for fresh concrete workability are displayed on Table 2.

Table 2: Characteristics of the fresh concrete mix

Trial number	**Air content (%)**	**Average flow diameter (cm)**	**Flow percentage (%)**
I	13	17.05	70.5
II	12	17.3	73.0
III	12.5	17.2	72.0
Average	12.5	17.18	71.8

According to [7], if the flow rate determined as a percentage is in the range of 0% < 71.8% < 150%, the concrete mix is suitable for further testing.

4.2. Mechanical properties

The test results for compressive strength and flexural tensile strength after 7, 14 and 28 days are presented in Table 3. 3. Each result is the average value from the partial results of five samples for each series.

Table 3: Mechanical parameters of transparent concrete

Series	Age (days)	Compressive strength (MPa)	Flexural strength (MPa)
Series I (0% fiber content)	7	12.88	3.43
	14	17.53	3.88
	28	17.69	4.02
Series II (3% fiber content)	7	15.97	4.47
	14	19.79	4.87
	28	23.77	5.34
Series III (5% fiber content)	7	17.07	5.10
	14	22.80	5.73
	28	18.17	6.84
Series IV (6% fiber content)	7	17.59	6.24
	14	20.22	5.85
	28	19.50	5.14

The compressive strength of the second sample containing 3% of optical fibers displays a gradual increase over the curing period, as depicted in the aforementioned graph. However, after the 14 days of treatment, the compressive strength of samples III and IV experiences a decline. This decrease in strength can be attributed to the increased presence of optical fibers within the concrete, which compromises the cohesive binding between the concrete components, a phenomenon observed similarly in flexural strength testing. As indicated in the results, the sample series incorporating 3% of optical fibers demonstrates outstanding compressive strength among those subjected to the test.

The findings indicate a direct correlation between the number of optical fibers embedded in the concrete and flexural strength. Notably, the specimens exhibited an increase in strength with the ascent of fiber content during the initial curing phase.

In the second phase, characterized by a 14-days curing duration, the first three series, featuring 0%, 3%, and 5% of optical fiber content, demonstrated an upsurge in strength. In contrast, the last series, boasting the highest optical fiber quantity, experienced a decline in strength, albeit not dropping below that of the series with 5% optical fibers. Nevertheless, the strength of series IV witnessed a significant decrease in the final curing phase, resulting in lower flexural strength compared to series III and II. The presented results underscore that an escalation in the optical fiber count in concrete samples beyond 6% leads to a deterioration in their flexural strength.

4.3. Light transmission

The test results are presented in Table 4. They are given as a percentage representing the amount of light passing through the materials.

Table 4: Light transmission test results

Samples	Percentage of optical fibers with total area (%)	Percentage of light transmitted through the sample (%)
I	0	0
II	3	1.4
III	5	2
IV	6	2.9

The results of the light transmission test presented in Figure 5 unequivocally demonstrate that the concrete specimen containing the highest optical fiber content, specifically 6%, exhibits the maximum light transmission capability in comparison to the other specimens. This enhancement is attributed to the augmented quantity of fibers.

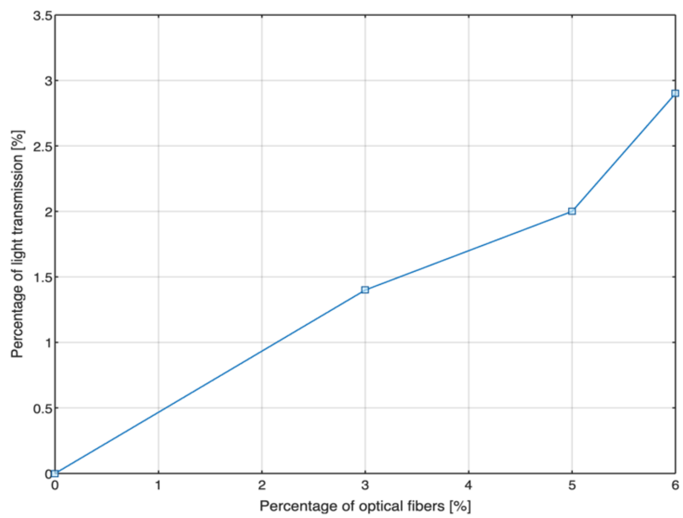

Figure 5: Light transmittance capacity of concrete specimens

5. Discussion

Several studies have explored the impact of optical fibers on the properties of transparent concrete. Li Y, Li J, and Guo H [10] found that an increase in fiber content led to a decrease in concrete's flexural strength. In their experiment, concrete with a 4.91% fiber content exhibited lower flexural strength than standard concrete, with a notable 19.5% strength reduction. Similarly, in our study, comparing concrete with 6% optical fiber to conventional fiber-less concrete revealed a 21.8% decrease in flexural strength.

Contrastingly, Naik R. R, & Prakash K. B [5] demonstrated that concrete with 2% fiber content experienced a 14.09% improvement in compressional strength and a 37.70% increase in flexural strength compared to normal concrete. While our experiments aligned with these findings, showcasing similar characteristics, the introduction of additional optical fibers resulted in a reduction in strength. Naik R. R. and Prakash K. B.'s [5] research highlights a clear correlation between optical fiber and mechanical strength, but it does not specify the maximum amount of optical fiber for optimal results.

Moreover, an experiment by Henriques Thiago dos S., Denise C. Dal Molin, and Angela B. Masuero [11] demonstrated a 25.5% drop in flexural strength and a 20% reduction in compressive strength with 5% optical fiber in concrete. In our study, the same fiber percentage showed a 2.7% increase in compressional strength and a remarkable

70.1% improvement in flexural strength. The disparity in findings can be attributed to the alignment of fibers. While Henriques Thiago dos S., Denise C. Dal Molin, and Angela B. Masuero [11] randomly positioned fibers, our study ensured ensured longitudinal alignment, enhancing concrete strength, especially under tensile pressures.

As mentioned earlier, the observed decrease in strength of concretes with optical fibers is attributed to poor bonding between the concrete structures, supported by evidence of samples losing strength over curing time. This rationale is corroborated by Altlomate, A., Alatshan, F., Mashiri, & Jadan [12]. Consequently, our experiment suggests that compressive compressive strength starts declining after 3% optical fiber content, while flexural strength decreases after 5%.

6. Conclusion

According to this research findings, utilizing 3% by volume of optical fibers is a good technique to acquire a concrete's desired light transmission capability and maintain the mechanical properties of the concrete. Although it has been shown that adding optical fibers to concrete in amounts more than 3% by volume improves its capacity to transmit light, doing so may degrade the material's flexural and compressive strengths, making it unsuitable for use in structural applications.

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