Mechanical Analysis of Fly Ash-Based Light Transmitting Concrete by using Optical Fiber

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Abstract – Fly ash-based light-transmitting concrete (FLTC) is an innovative and energy-efficient construction material known for its superior characteristics. FLTC is a high-quality translucent concrete that offers excellent mechanical properties, and effective light transmission. This research study aimed to evaluate the performance of FLTC by incorporating plastic optical fibers (POF) and replacing a portion of the cement with fly ash. The investigation focused on assessing the mechanical properties and light transmittance capabilities of FLTC. Seven different concrete mixes of M20 grade were prepared, varying the volume of POF from 0.5% to 4% and replacing 25% of the cement with fly ash. After 28 days of curing, tests were conducted to measure compressive strength, splitting tensile strength, and light transmittance. The mechanical properties of FLTC demonstrated improvement with increasing POF volume ratios, while the light transmittance notably increased with higher POF volume ratios. FLTC achieved a remarkable light transmittance of up to 5.48% for specimens containing 4% POF volume ratio and 0.75 mm POF diameter, while still maintaining good mechanical properties. Additionally, FLTC exhibited an increase in compressive strength by 27.3 MPa, a tensile strength increases of 17.8%, and an upv value (ultrasonic pulse velocity) of 3.41 km/s.

Index Terms – Fly ash based light transmitting concrete (FLTC), Ultrasonic pulse velocity test (UPV), compressive strength (CS), Plastic optical fiber test (POF), Tensile strength (TS), Fly Ash (FA), Light transmittance (LT), Specific gravity (Sp.g.), Fineness modulus (F.m), Water Absorption (W.a), Loss in ignition (LIG), Moisture Content (MC).

I. INTRODUCTION

Fly ash-based light transmitting concrete (FLTC) is a novel material that incorporates optical fibers to transmit light and has potential applications in energy-efficient and visually striking construction. While research has been conducted to investigate the mechanical properties of FLTC, there is still a need to explore its behaviour under different loading conditions. One promising technique for this analysis is the use of optical fiber sensors embedded in the material, which can provide real-time monitoring of the material’s strain and deformation. In the realm of construction innovation, the emergence of fly ash-based light transmitting concrete (FLTC) stands as a beacon of promise, offering a harmonious blend of sustainability, functionality, and aesthetic appeal. This novel material integrates optical fibers to transmit light, presenting a transformative approach to energy-efficient and visually captivating architectural designs. While FLTC holds immense potential, there remains a critical need to delve deeper into its mechanical behavior under varying loading conditions.

Central to the development of FLTC is the utilization of fly ash, a fine powder generated from coal combustion in power plants [1]. Traditionally considered a waste product, fly ash finds newfound purpose as a key component in sustainable construction materials [2]. When combined with lime and water, fly ash forms cementitious compounds akin to those found in Portland cement, paving the way for its integration into blended cement, mosaic tiles, hollow blocks, and other construction elements. Beyond its role in enhancing structural integrity, fly ash confers several advantages to concrete, including increased strength, improved segregation, and enhanced pumpability [16]. The imperative for sustainable construction practices underscores the urgency to reduce the environmental impact associated with traditional concrete production. Cement, a primary constituent of
concrete, exacts a significant toll on the environment, contributing approximately 7% of global CO2 emissions [17]. The relentless demand for raw materials in concrete production further exacerbates environmental concerns, leading to issues such as resource depletion and excessive waste generation. In response, researchers have turned to alternative materials, such as fly ash, to mitigate these challenges and foster a more sustainable built environment [18].

The incorporation of fly ash into concrete formulations presents a multifaceted solution to the environmental woes plaguing the construction industry. Not only does fly ash offer tangible benefits in terms of mechanical properties and durability, but it also helps alleviate the environmental burden associated with cement production. By partially replacing cement with fly ash, construction practitioners can significantly reduce carbon emissions, curb resource depletion, and mitigate waste generation [19,20]. The journey towards sustainable construction practices encompasses a diverse array of research endeavors, ranging from the optimization of green concrete formulations to the exploration of high-volume fly ash concrete. These efforts underscore the versatility and potential of fly ash as a sustainable building material, offering tangible pathways to reduce environmental impact while enhancing structural performance [21]. At the forefront of this sustainable construction revolution lies FLTC—a groundbreaking material that epitomizes the fusion of innovation and sustainability. By harnessing the power of optical fibers, FLTC transcends the boundaries of conventional concrete, ushering in a new era of energy-efficient and visually striking architectural design [22,23]. However, to fully unlock the potential of FLTC, a deeper understanding of its mechanical behavior under different loading conditions is essential.

In this paper, an investigation is conducted on the mechanical analysis of FLTC using optical fiber sensors. The main objective of this research work is to evaluate the material's performance under different loading conditions and investigate the relationship between its mechanical behavior and the distribution of optical fibers within it. Although studies have been conducted on the mechanical properties of traditional concrete using optical fibers, research on the application of this technique to FLTC is lacking in the literature. Thus, this research gap provides an opportunity for researchers to explore the potential of this technique and provide insights into the mechanical behavior of this innovative material. This research work seeks to fill a critical gap in the literature by elucidating the relationship between the distribution of optical fibers within FLTC and its mechanical performance. Through meticulous experimentation and analysis, we endeavor to contribute to the growing body of knowledge surrounding FLTC, panning the way for its widespread adoption in sustainable construction practices.

II. MATERIALS

A. Cement

Cement is a crucial material for research as well as the primary constituent of concrete. In this study, Ordinary Portland Cement (OPC) type 1 ASTM C150 [3] was used, which was manufactured by Fauji Cement Pakistan, a leading cement manufacturing company. Table 1 displays the properties of the OPC used in this research.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS (PSI)</td>
<td>10000</td>
</tr>
<tr>
<td>Density (kg/m3)</td>
<td>1440</td>
</tr>
<tr>
<td>Fineness by Blaine (cm2/g)</td>
<td>3000-3200</td>
</tr>
<tr>
<td>Initial Setting Time (min)</td>
<td>110</td>
</tr>
<tr>
<td>Final Setting Time (min)</td>
<td>180</td>
</tr>
</tbody>
</table>

B. Fine Aggregate

Sand is an important component of concrete and acts as a filler. However, sand concrete may not perform as intended. It has a filler effect and can improve the workability of concrete to some extent. Since sand makes up a greater proportion of concrete than cement, it is crucial that it be of good quality. The properties of sand are shown in Table 2.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sp.g</td>
<td>2.63</td>
</tr>
<tr>
<td>F.m</td>
<td>2.404</td>
</tr>
<tr>
<td>W.A</td>
<td>1.7</td>
</tr>
<tr>
<td>Bulk Density (compacted) (kg/m3)</td>
<td>1982</td>
</tr>
</tbody>
</table>

C. Coarse Aggregate

All the coarse aggregate used in the research work was obtained from the same crusher. Margalla crush is well-known throughout Pakistan for its high quality and desired characteristics. We chose aggregates that were less than or equal to 10mm in size for our investigation. The coarse aggregate properties are shown in Table 3.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sp.g</td>
<td>2.80</td>
</tr>
<tr>
<td>F.m</td>
<td>5.98</td>
</tr>
<tr>
<td>Bulk Density (compacted) (kg/m3)</td>
<td>1649.7</td>
</tr>
</tbody>
</table>
D. Fly Ash

Fly ash Class F, conforming to ASTM C618 requirements [4], was used as a partial replacement for cement. The specific gravity of fly ash was found to be 2.34. The properties of fly ash are specified in Table 4.

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM Requirements (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$ + Al$_2$O$_3$ + Fe$_2$O$_3$, min</td>
<td>70</td>
</tr>
<tr>
<td>SO$_3$, max</td>
<td>5</td>
</tr>
<tr>
<td>MC, max</td>
<td>3</td>
</tr>
<tr>
<td>LIG, max</td>
<td>6</td>
</tr>
</tbody>
</table>

E. Plastic Optic Fibers

An optical fiber is a slender and flexible transparent fiber, typically slightly thicker than a human hair, which can efficiently transmit light from one end to the other. These fibers can be made of glass or plastic material. Optical fibers find various applications, serving as light conduits in fields like medicine and other areas where strong illumination is needed. They can also be utilized in buildings to channel natural sunlight. By utilizing the principle of total internal reflection, optical fibers can effectively guide light, and they can have a diameter as small as 2mm. Plastic optical fibers (POF) specifically allow the transmission of sunlight or light from any source. When used in concrete, these fibers transmit light from one face of the concrete to the other. Light loss is minimal to non-existent. For sample preparation, we used POF with a diameter of 0.75mm, as shown in Figure 1.

III. WORKING PRINCIPLE OF FLTC

Natural light, including diffused light and sunlight, provides a complete range of colors that illuminate concrete panels or blocks. Among natural light sources, sunlight is particularly abundant. When these panels are placed either as standalone structures or in front of windows, there is no need for additional artificial lighting. FLTC concrete allows light to pass through concrete at the Nano optics scale. By precisely aligning and spacing tiny slits on top of each other, optical fibers can enhance light transmission. Similarly, plastic optical fibers (POF) function similarly to the aforementioned slits in concrete by enabling the passage of light through the material.

A. Total Internal Reflection

Total internal reflection occurs when light encounters a boundary at an angle greater than the critical angle within an optically dense medium. This results in the complete reflection of light back into the medium rather than its transmission or refraction. In practical terms, this phenomenon is extensively utilized in optical fibers to confine and transmit light within the fiber's core. Inside an optical fiber, light travels through the core and undergoes multiple reflections at the boundaries between the core and cladding. These reflections are facilitated by the principle of total internal reflection. By ensuring that light entering the fiber approaches the boundary at an angle greater than the critical angle, the light can be effectively contained within the core, enabling efficient transmission over extended distances. Figure 2 illustrates the passage of light through an optical fiber. To maintain this confined light propagation, it is crucial to control the acceptance angle of the fiber. The acceptance angle refers to the range of incident angles at which light can enter the fiber and propagate without leaking out. Light entering the fiber outside this angle range would experience excessive bending and ultimately escape the core. The size of the acceptance angle is determined by the difference in refractive indices between the fiber's core and cladding. A greater difference in refractive indices leads to a smaller acceptance angle, allowing for stricter confinement of the light within the core. This refractive index contrast between the core and cladding is carefully engineered.
during the fabrication of optical fibers to optimize their performance.

Therefore, through total internal reflection and the control of the acceptance angle, optical fibers enable efficient and low-loss transmission of light signals over long distances, making them indispensable in modern communication systems and other applications where light needs to be transmitted effectively.

![Diagram of Optical Fiber Working](image)

**Figure 2 Working of Optical Fiber**

In simpler terms, light can only enter an optical fiber at certain angles relative to the fiber's axis. This allowable range of angles is called the numerical aperture. It's determined by the difference in refractive index between the fiber's core and cladding.

\[
\theta_{acc} = \arcsin \left( \frac{1}{n_0} \sqrt{n_{core}^2 - n_{cladding}^2} \right)
\]

(1)

Where,

- \( n_{core} \) = Refractive index of core
- \( n_{cladding} \) = Refractive index of cladding
- \( n_0 \) = Refractive index of the medium around the fiber

**IV. TEST EQUIPMENT AND PROCEDURE**

**A. Mix Proportion**

Based on the results of the material characterization, an optimized mix design was developed for fly ash-based light transmitting concrete. The mix design aims to achieve the desired strength and LT properties of the concrete.

In this research, an experimental investigation was carried out in which cement was partially replaced by Fly Ash (class F). M20 Grade Concrete was prepared with a w/c ratio of 0.5 and concrete mix ratio of 1:1.5:3, with 25% cement replaced with fly ash, which remained constant throughout the experimentation. The quantity of optical fiber varied, and seven concrete mixes were prepared with 0.5% to 4% optical fiber, including a control mix. After casting, the specimens were covered with a plastic sheet to prevent water evaporation and placed in a curing chamber at a controlled temperature of 23±2°C and relative humidity of 95±5% for 28 days. In figure 3 flow chart shows the complete procedure of specimen's preparation according to ASTM C192/C192M [24]. In this work, the size of POF was 0.75mm in diameter, and the percentage of optical fiber and the details of the number of strands used are described in Table 5. The percentage of FA remained constant throughout the research, at 25%. The percentage of POF and the no of strands are shown in Table 5.

![Flow Diagram of Complete procedure](image)

**Figure 3 Flow Diagram of Complete procedure**
### B. Mold Preparation

For casting FLTC, a specific type of mold is created. A 150 x 150 x 150 mm cube mold is prepared, constructed with two plywood faces and a plywood base. According to ASTM C192/C192M - standard practice for making and curing concrete test specimens in the laboratory provides guidance on casting concrete specimens in a laboratory setting [24]. The two faces of plywood are pierced at regular spacing to keep the optical fibers in place during concrete casting in the mold. The optical fiber is cut into adequate length and fitted separately through the drilled holes, with the two drilled faces placed opposite each other to place the optical fiber in a single direction, as shown in Figure 4. The diameter and spacing of the holes are determined by the fiber content of the cube. Figure 4 shows the fiber strands in the molds.

<table>
<thead>
<tr>
<th>Percentage of POF</th>
<th>No of strands of POF</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5%</td>
<td>288</td>
</tr>
<tr>
<td>1.0%</td>
<td>576</td>
</tr>
<tr>
<td>2.0%</td>
<td>1152</td>
</tr>
<tr>
<td>2.5%</td>
<td>1440</td>
</tr>
<tr>
<td>3.0%</td>
<td>1728</td>
</tr>
<tr>
<td>4.0%</td>
<td>2304</td>
</tr>
</tbody>
</table>

### C. Preparation of FLTC Specimen

The fly ash-based light transmitting concrete (FLTC) specimens will be cast using molds of the required size and shape. The concrete specimens will contain optical fibers at various concentrations to study their effect on the mechanical properties. To prepare cubes of dimensions 150 x 150 x 150 mm, concrete with a proportion of 1:1.5:3 (cement: sand: aggregate) and a w/c ratio of 0.5 was used, with 25% of the cement being replaced with fly ash. The strength and LT of POF were studied using different percentages of plastic optical fibers, such as 0.50, 1.0, 2.0, 2.5, 3.0, and 4.0 percent. The fibers were woven and then placed in wooden molds, as shown in Figure 5a and 5b. Concrete was poured into the molds and then placed on a vibrating table. Vibrations were applied until there were no more vacancies in the fibers. The cubes were properly compacted on the vibrating table. Figure 5a and 5b shows the plywood mold and FLTC specimen, respectively.

![Figure 4 Fiber strands in the mold](image1)

![Figure 5a Plywood Mold](image2)
D. Test Performed

The mechanical properties of the FA based light transmitting concrete specimens were evaluated through various tests. The following tests were conducted:

1) **Compressive Strength Test**: To determine the CS of FLTC, compression tests were performed on cylindrical or cubical samples. During the test, a compressive load was steadily applied to the specimen until it reached the point of failure. The maximum load that the specimen could withstand before failure was considered its CS. In this study, the specimens were subjected to compression testing in accordance with the ASTM C39 standard [6]. A load-controlled universal testing machine (UTM) with a capacity of 1000 kN was used to conduct the tests. The specimens were subjected to a controlled compressive load rate of 0.2 MPa/second, and the mechanical response under compression was recorded.

2) **Tensile Strength Test**: The tensile strength (TS) of the FA based light transmitting concrete can be determined by conducting a TS test on cylindrical specimens. The test involves applying a force perpendicular to the longitudinal axis of the cylinder, causing the specimen to fail in tension. The maximum tensile stress that the specimen can withstand before failure is the (TS) of the material. To determine the splitting tensile strength, the samples were tested diametrically according to the ASTM C496 procedure [7].

3) **Light Transmittance Test**: The light transmittance test is a significant evaluation method used to assess the light transmission capability of fly ash-based light-transmitting concrete. This test measures the percentage of light that can pass through the material. Two common instruments used for this test are a spectrophotometer and a light meter. The spectrophotometer measures the amount of light absorbed and transmitted by the material across different wavelengths, while the light meter measures the intensity of light passing through the material at a specific wavelength. To perform the light transmittance test, a sample of fly ash-based light-transmitting concrete is prepared, usually in the form of a thin section or a small cube. This sample is positioned between a light source and a detector. The light source emits light at a specific wavelength, while the detector measures the amount of light that passes through the material. The percentage of light transmitted through the material is then calculated using the formula: Transmittance (%) = (Intensity of transmitted light / Intensity of incident light) x 100%. This test offers valuable insights into the optical properties of FA based light-transmitting concrete, aiding in the evaluation of its suitability for architectural and decorative purposes. A higher percentage of light transmittance indicates that the material can transmit more light, making it more suitable for applications where the visual appearance of the material is important.

4) **Ultrasonic Pulse Velocity Test**: The Ultrasonic Pulse Velocity (UPV) test is a non-destructive evaluation technique outlined in the ASTM C597 standard [8]. It serves as a valuable method for assessing the quality and structural soundness of concrete. Additionally, the UPV test can be effectively employed to evaluate the mechanical characteristics of light transmitting concrete that incorporates fly ash as a primary component. The UPV test works on the principle of measuring the velocity of ultrasonic waves that pass through the concrete. The test involves transmitting a high-frequency sound wave through the concrete using a transmitter [9]. The sound wave travels through the material and is detected by a receiver placed on the other side of the concrete. The time taken for the sound wave to travel through the concrete is measured, and the velocity of the wave is calculated using the following formula:

\[
\text{Velocity (m/s)} = \frac{\text{Distance travelled by the wave (m)}}{\text{Time taken for the wave to travel (s)}}
\]

The velocity of the ultrasonic wave is directly related to the density and elastic modulus of the material, and hence it can provide an indication of the mechanical properties of fly ash based light transmitting concrete. In the case of fly ash based light transmitting concrete, the UPV test can provide information on the homogeneity and uniformity of the material. Any variations in the distribution of optical fibers or the quality of mixing may result in changes in the UPV value. Therefore, the UPV test can be used to identify any potential defects or inconsistencies in the material. The expected results of the UPV test on fly ash based light transmitting concrete will depend on several factors, including the mix design, the quality of materials used, and the curing conditions. However, a higher UPV value generally indicates a denser and more homogenous material with better mechanical properties.
V. RESULTS AND DISCUSSION

A. Compressive Strength Test

The results of the Compression Strength Test show that the CS of (FLTC) concrete varies only slightly compared to the strength of the control sample, as shown in Figure 6. The average 28-day CS decreased from 25.9 N/mm² for the control sample to 22.2 N/mm² with 4% replacement of POF and 25% replacement of cement with (FA). It is also evident from the results that the best strength was achieved using 2% volume of POF and 25% FA content. This indicates that fiber reinforcement occurs up to a certain extent of fiber percentage in the concrete matrix. Beyond 2% volume, the strength begins to decrease. Based on the observation, inserting fibers into the concrete yields compressive strength, and an increase in fiber number leads to an increase in compressive strength up to a certain limit. Beyond that threshold, an increase in the number of fibers leads to a decrease in compressive strength. This is because the light transmission in FA based light-transmitting concrete relies on the proportion of fibers utilized. The test results of the compressive strength of FLTC are depicted in detail in Figure 6.

The addition of (POF) and (FA) in fly ash-based light-transmitting concrete (FLTC) has an impact on its compressive strength. The test results indicate that when 4% of POF is replaced and 25% of cement is substituted with FA, there is a reduction in compressive strength. This reduction can be attributed to the high WA and low tensile strength of POF, which may result in inadequate bonding with the cement matrix [10]. Moreover, an excessive amount of POF in the concrete mix can lead to fiber agglomeration, reducing the workability of the mix and affecting the homogeneity and strength of the concrete.

Conversely, an increase in CS is observed in the test results when 2% volume of POF is incorporated and 25% FA content is used. This increase can be attributed to the reinforcing effect of POF on the concrete matrix, which enhances its resistance to cracking and improves its load-carrying capacity.

Figure 6 Test results of Compressive Strength

B. Tensile Strength Test

The conventional tensile strength (TS) test typically results in the complete separation of cylindrical specimens made of regular and high-strength concrete, splitting them into two distinct parts. However, in the case of FLTC specimens, this splitting does not occur due to the strong cohesion between the groups of plastic optical fibers (POF) and the combination of FA and concrete. The POF positioned at fixed intervals enhances the cohesion within the specimens, as depicted in Figure 7. Moreover, it was observed that the (TS) of FLTC increases with higher POF volume ratios, while the amount of fly ash remains constant across all mixes. For example, when the POF volume ratios were increased from 0.5% to 4%, the 28-day tensile strength exhibited a respective increase of approximately 2.5%, 7.5%, 10%, 12.5%, 15%, and 17.5% compared to the control mixture.

The increase in (TS) in the presence of fly ash (FA) and with higher POF volume ratios can be attributed to two main factors. Firstly, the presence of POF groups acts as a bridge between cracks, enhancing the cohesion of the specimens and impeding crack growth, thereby improving the tensile strength. Same effect has been observed in a previous study by Arash Sedaghatdoost et al. (2017), where the addition of POF to concrete resulted in improved TS due to the bridging effect of POF groups [11].

Secondly, the increase in TS with higher POF volume ratios can be explained by the reinforcement effect of POF.
POF acts as a reinforcement within the concrete matrix, enhancing its tensile strength. Similar effects have been observed in previous study of Kumar et al. (2016), who reported an increase in splitting tensile strength when POF was added to concrete due to the reinforcement provided by POF [12]. Overall, the results indicate that incorporating POF into fly ash-based light-transmitting concrete can enhance its splitting tensile strength, making it more suitable for applications where TS is a critical factor.

![Figure 7 Test results of Tensile Strength](image)

**C. Light Transmittance Test**

The LT qualities of FLTC were investigated using a light transmittance test. As the main aim of FLTC is to transfer light and save energy, this is the most significant test. The transmittance ratio is calculated using the intensity of incident and transmitted light, which is measured with a spectrometer. Lumens are the unit of measurement for light intensity. Figure 9(a) and 9(b) shows sample of the FLTC specimen in which the light is clearly passed through optical fibers and one sample is half covered from other side and the difference is clear.

The light transmittance ratio of FLTC with different POF ratios, i.e. 0.50, 1.0, 2.0, 2.5, 3.0, 4.0%, using a light source of 100 W and 200 W, is shown in Table 6. It was observed that the light transmittance varied from 0.87% to 5.48% for the 100 W light source and 0.60% to 5.32% in the case of the 200 W light source. The maximum LT ratio of 5.48% was achieved by replacing 4% of the total volume with POF. This will allow natural daylight to pass through the sample easily and save electrical energy. It will also give an artistic look and improve the aesthetics of a building. It can be analyzed from Figure 9 that the LT Ratio increased with the increase in the percentage of POF. Previous research also shows the same trend for this test [13,14,15]. Figure 5 gives the details of the light passing through POF, and Table 6 describes the values obtained from the instrument.

**TABLE VI LIGHT TRANSMITTANCE OF VARIOUS POF RATIOS**

<table>
<thead>
<tr>
<th>POF Volum e Ratio</th>
<th>100 W Light Source (1500 lumens)</th>
<th>200 W light source (3000 lumens)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transmittance (lumens)</td>
<td>Transmittance Ratio %</td>
</tr>
<tr>
<td>0.5%</td>
<td>13.1</td>
<td>0.87%</td>
</tr>
<tr>
<td>1.0%</td>
<td>24.4</td>
<td>1.62%</td>
</tr>
<tr>
<td>2.0%</td>
<td>40.9</td>
<td>2.73%</td>
</tr>
<tr>
<td>2.5%</td>
<td>48.1</td>
<td>3.20%</td>
</tr>
<tr>
<td>3.0%</td>
<td>59.3</td>
<td>3.95%</td>
</tr>
<tr>
<td>4.0%</td>
<td>82.2</td>
<td>5.48%</td>
</tr>
</tbody>
</table>
D. Ultrasonic Pulse Velocity Test

The results of the Ultrasonic Pulse Velocity (UPV) test have shown that each sample maintains its uniformity and relative quality of concrete with minimal voids and cracks. An important point to consider is that the UPV is higher at the highest value of compressive strength because high CS implies that the concrete is more compact and has fewer voids and micro cracks. The addition of 2% fiber and 25% fly ash in the concrete matrix plays a role in reinforcing it, and thus, the UPV is also higher, as shown in Table 7. The curve in Figure 10 illustrates the relationship between CS and UPV of the fly ash-based light transmitting (FLTC) concrete. UPV is a non-destructive test that can provide information about the integrity, homogeneity, and density of concrete. In the case of FLTC concrete, the addition of POF and FA affects its density and homogeneity, which, in turn, impacts its UPV. The higher UPV observed in the samples with higher CS can be attributed to the fact that higher CS indicates higher density and fewer voids in the concrete, which improves the transmission of ultrasonic waves. Furthermore, the addition of 2% fiber volume in the FLTC concrete reinforces the matrix and improves its homogeneity, which also contributes to the higher UPV observed in the test results.

<table>
<thead>
<tr>
<th>UPV (km/s)</th>
<th>CS (Mpa)</th>
<th>POF</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.35</td>
<td>25.9</td>
<td>0%</td>
</tr>
<tr>
<td>3.35</td>
<td>25.6</td>
<td>0.50%</td>
</tr>
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<td>3.37</td>
<td>25.7</td>
<td>1.00%</td>
</tr>
<tr>
<td>3.41</td>
<td>27.3</td>
<td>2.00%</td>
</tr>
<tr>
<td>3.29</td>
<td>25.8</td>
<td>2.50%</td>
</tr>
<tr>
<td>3.29</td>
<td>24.0</td>
<td>3%</td>
</tr>
<tr>
<td>3.25</td>
<td>22.2</td>
<td>4%</td>
</tr>
</tbody>
</table>
VI. CONCLUSION

The experimental study investigated the properties of FA based light transmitting concrete (FLTC) containing plastic optical fibers (POF). Two tests were conducted, the light transmittance test and the compressive strength test, with an additional test of tensile strength. The light transmittance test measured the ratio of light transmitted through different POF ratios using a spectrometer. The highest light transmittance ratio of 5.48% was achieved by replacing 4% of the total volume with POF, allowing natural daylight to pass through the sample and save electrical energy. The compressive strength test showed that the strength of FLTC concrete varies only slightly compared to the control sample, with the best strength achieved using 2% volume of POF and 25% fly ash content. Beyond 2% volume, the strength begins to decrease. The splitting tensile strength test showed that the presence of POF as groups at fixed spacing increased the cohesion of the specimens, and the TS increased with the increase in POF volume ratios and diameters, but the fly ash content remained constant throughout all mixes. The reduction in compressive strength observed in the test results with 4% replacement of POF and 25% replacement of cement with FA is likely due to the high water absorption and low tensile strength of POF, which may have resulted in poor bonding with the cement matrix. Excessive POF content in the concrete mix can also lead to agglomeration of fibers, reducing the workability of the mix, which in turn affects the homogeneity and strength of the concrete. The increase in CS observed in the test results with 2% volume of POF and 25% FA content can be attributed to the reinforcing effect of POF on the concrete matrix, which can increase its resistance to cracking and improve its load-carrying capacity.

REFERENCES


