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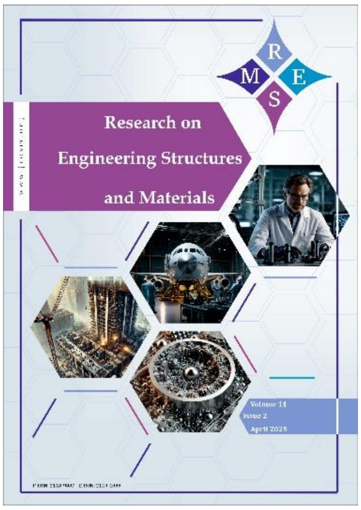

Mechanical properties and optical efficiency of light-transmitting concrete using plastic optical fibre and industrial wastes

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Research Article

Mechanical properties and optical efficiency of light-transmitting concrete using plastic optical fibre and industrial wastes

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Abstract

Construction is a global industry that is currently experiencing significant transformations. Today, the rise in population has led to an increase in energy consumption, alongside an increase in high-rise construction in urban areas. The shade from tall structures contributed to increased energy use. This provides a way to diminish energy consumption related to building illumination by implementing innovative approaches. The light-transmitting concrete, comes into light in this scenario. In the present study, the influence of different percentages of optical fibre on the distinct properties of light-transmitting concrete at the various curing ages was examined. The plastic optical fibre with 0%, 0.5%, 1%, 1.5%, 2%, and 2.5% was used in the concrete. The different mechanical properties and cost analysis of the various mixes were investigated. The optimized percentage of optical fibre (1%) was used with the industrial wastes, such as ground granulated blast furnace slag (20%) and micro silica (10%), to study the performance of concrete. Results showed that the incorporation of plastic optical fibre (1%) with the industrial wastes, i.e., blast furnace slag at 20%, increased the strength by 17% while maintaining the light-transmitting characteristics of concrete as compared to the control mix. However, the use of optical fibre (1%) hiked the cost of construction by 40% due to the higher cost of optical fibre.

1. Introduction

Concrete is the predominant construction material in the industry because of its cost-effectiveness, durability, and strength. Concrete has become a key material in modern construction, with advanced applications in high-rise structures, tunnels, bridges, and pavements, particularly in urban infrastructure development [1-3]. This elevates the necessity for artificial illumination to preserve the visibility and brightness of indoor activities. According to the United Nations Environment Program 2013, artificial lighting accounted for approximately 20% of global electricity consumption and 6% of CO_2 emissions [4]. Various methods have been implemented to mitigate energy consumption resulting from the utilization of artificial light, including the development of new, innovative construction materials, i.e., Light Transmitting Concrete (LTC), that can transmit light [5-6].

In 2001, Aron Losonczi, a Hungarian architect, was the first to develop and manufacture translucent concrete, also known as LTC [7]. LTC facilitates the transmission of light through the concrete, thereby enhancing visibility and decreasing the building's energy consumption for light. LTC is employed in a diverse array of applications, including pavements, road markings, sidewalks, speed humps, staircases, and tunnels, in addition to its usage in architectural features and building materials [8-11]. In addition, LTC can be employed as load-bearing or non-bearing wall partitions

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to permit daylight to enter the interior spaces, thereby improving the illuminance level of the interior environment. Nevertheless, LTC is not yet extensively embraced and implemented in the construction sector as a green construction material [12].

The addition of optical fibre in self-compacting concrete increased the compressive and tensile strength of the light-transmitting concrete [13]. The strength of LTC increased with the increase in the percentage of optical fibre [5]. The optical fibre of 1 mm diameter increased the strength of concrete; afterwards, it reduced the strength of LTC [14]. The compressive strength increases with the addition of POF ratios because the loading machine is orientated perpendicularly to the POF arrangement, which is maintained at a consistent spacing within the cubic specimens [11]. In the case of artificial light, peak values were obtained at the nearest tested distance, with an increase in the distance between the light source and the LTC value of light transmission decreasing [4, 15]. TSCC absorbs a segment of this light while dispersing another segment. This may be evident in the transmission rates of TSCC light and specific aberrations of the Gaussian curve in the graphs [11]. The incorporation of optical fibre and resin in light-transmitting concrete led to reduced electricity consumption. Polymethyl methacrylate tubes increased the illumination energy efficiency [16]. Chiew et al. [10] developed an artificial neural network model to predict the light transmittance of the light-transmitting concrete. Results showed that the incidence angle affected the light transmittance of LTC. Pourkazemi et al. [17] studied the mechanical characteristics and energy consumption of concrete using different illuminating materials such as plastic optical fibre, ribbed resin rod, glass waste, and epoxy resin. Results showed that the materials increased the strength and light transmittance characteristics. It was found that all the materials in the concrete were suitable for cold climates. Nam et al. [12] studied the influence of polymethyl methacrylate (PMMA) up to 30% in the light-transmitting concrete. The compressive strength decreased, and light transmittance ability increased with the increase in PMMA content. Chiew et al. [18] investigated the performance of self-compacting concrete LTC using optical fibre under the sunlight. It was reported that the use of optical fibre reduced the compressive strength and enhanced the light transmittance ability.

1.1 Objectives and Significance

In the present study, the optical fibre with various proportions, i.e., 0%, 0.5%, 1%, 1.5%, 2%, and 2.5%, in the LTC was used to study the different properties, i.e., compressive strength by destructive and non-destructive tests, ultrasonic pulse velocity, dynamic modulus, and cost. The optimized proportion of optical fibre will be used for further study. The industrial wastes, i.e., ground granulated blast furnace slag (GGBFS) at 20% and micro silica (MS) at 10%, were incorporated in the light-transmitting concrete with an optimized percentage of optical fibre (1%). The correlation of compressive strength between the destructive test and the non-destructive test was derived. The objective of the study is to find the optimized percentage of plastic optical fibre in concrete. The novelty of the present work is to find out the optimum content of optical fibre in the concrete in terms of strength. Also, the feasibility of industrial wastes, i.e., MS and GGBFS, with plastic optical fibre was examined in LTC in different aspects, i.e., strength, durability, and cost. The performance of the different mixes was evaluated.

2. Methodology

The present investigation employed 43-grade ordinary Portland cement in accordance with IS:8112 [19]. Crushed sand and coarse aggregates of 10 mm size, compliant with IS:383 [20], were utilized. The physical parameters of cement and aggregates are presented in Tables 1 and 2, respectively. The potable water was utilized during the testing procedures. The plastic optical fibre was utilized with concentrations of 0%, 0.5%, 1%, 1.5%, 2%, and 2.5%. The optical fibre was procured from Elyssion Designs, and its parameters are presented in Table 3. The concrete mix design was conducted according to IS:10262 [21], with the mix designation provided in Table 4.

The compressive strength was used to optimize the percentage of optical fibre at 7, 28, 90, and 150 days of water curing. The effect of the optimized percentage of optical fibre on the various properties of light-transmitting concrete was investigated by combining it with industrial waste, including GGBFS and MS. The concrete mix proportions that have been optimized are reported in

Table 5. In this instance, the optimal content of optical fibre in the concrete was 1%, and the GGBFS at 20% and MS at 10% were selected.

Table 1. Physical properties of cement

Sr. No.	Property	Observed Value
1	Consistency	29.5%
2	Fineness	4%
3	Initial Setting time	135 min
4	Final Setting Time	245 min
5	Specific gravity	3.14
	Compressive Strength	
6	7 days	24.2 MPa
	28 days	44.5 MPa

Table 2. Physical properties of aggregates

Sr. No.	Property	Sand	Coarse Aggregates
1	Type	Crushed sand	Crushed aggregates
2	Fineness modulus	3.1	6.5
3	Zone	II	-
4	Specific gravity	2.61	2.72
5	Water absorption	2.5%	2.9%

Table 3. Properties of optical fibre

Sr. No.	Property	Value
1	Material	Plastic
2	Diameter	0.75 mm
3	Cladding material	Methyl methacrylate (MMA)

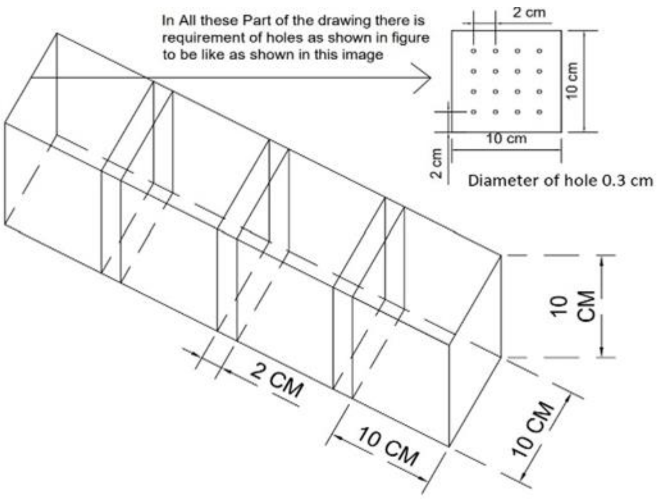
Table 4. Mix designation of concrete (kg/m^3)

Sr. No	Mix No.	Cement, kg/m^3	Sand, kg/m^3	Aggregates, kg/m^3	Water, kg/m^3	Optical fibre (%)
1	LT0	390	944	1026	187.2	0
2	LT1	390	944	1026	187.2	0.5
3	LT2	390	944	1026	187.2	1
4	LT3	390	944	1026	187.2	1.5
5	LT4	390	944	1026	187.2	2
6	LT5	390	944	1026	187.2	2.5

Table 5. Mix designation of the optimized mix, kg/m^3

Sr. No	Mix No.	Cement, kg/m^3	Sand, kg/m^3	Aggregates, kg/m^3	Water, kg/m^3	Optical fibre (%)	GGBFS, kg/m^3	SF, kg/m^3
1	OM0	390	944	1026	187.2	0	0	0
2	OM1	390	944	1026	187.2	1	0	0
3	OM2	312	944	1026	187.2	1	78	0
4	OM3	351	944	1026	187.2	1	0	39

The placement of fibre in the LTC cube specimens for optimized optical fibre (1%) has been shown in the fig. 1 (a). The fibre was placed in the horizontal direction. The size of the specimen was 10 cm, and the spacing of the fibre was 2 cm. The optical fibre was inserted in four rows in one direction (horizontal) in the cube specimens, as shown in fig. 1(b). The oiling was done on the wooden specimens for the easy removal of the specimens from the mold, and the specimens after casting are shown in fig. 1(c). The fibres were passed through the inserted holes in the horizontal direction only. The diameter of the holes varied as the volume of the optical fibre increased while keeping the spacing of the holes constant, as shown in table 6. The concrete was poured in thin layers was compacted gently between the layers, which minimizes the fibre displacement due to the placement of concrete in the mold.



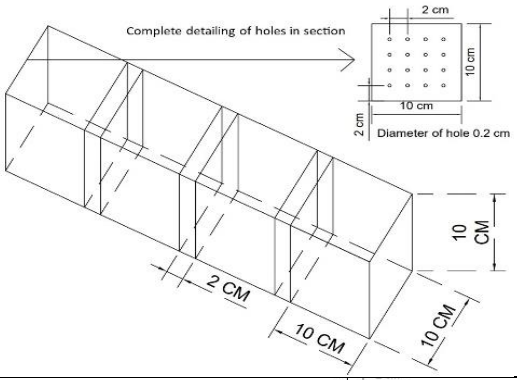
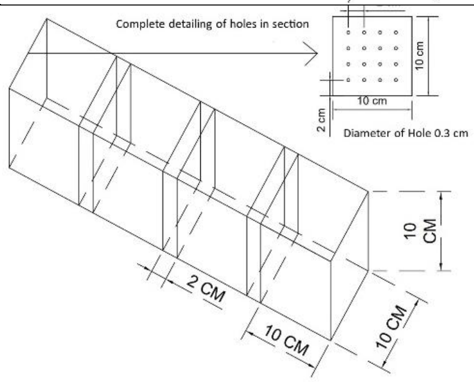
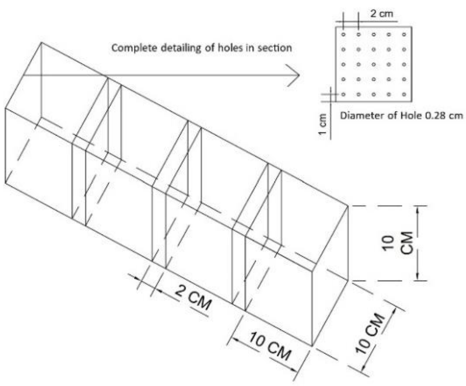
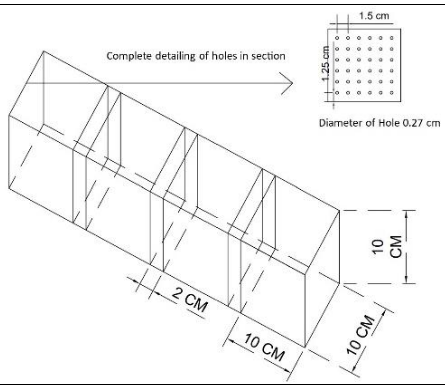
(a)

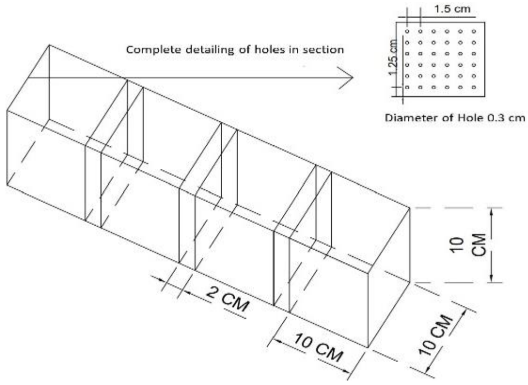
(b) (c)

Fig. 1. Arrangement of optical fibre in specimens: (a) Drawing; (b) Pictorial view; (c) Casted Specimens

The details of the test conducted on the specimens have been given in table 7. The methodology of the experimental work is shown in Fig. 2. The three specimens were casted for each test and the average value of the three specimens was taken for the final results of any parameter, i.e., compressive strength, elastic modulus, and chemical resistance of the concrete mixes.

Table 6. Description of the quantity of optical fibre in LTC

Sr. No.	Volume of fibre (%)	No. of holes	Diameter of holes (cm)	Spacing (cm)	Drawing
1	0	0	0	0	NA
2	0.5	16	2	2	
3	1	16	3	2	
4	1.5	25	2.8	2	
5	2.0	36	2.7	1.5	

6	2.5	36	3	1.5	

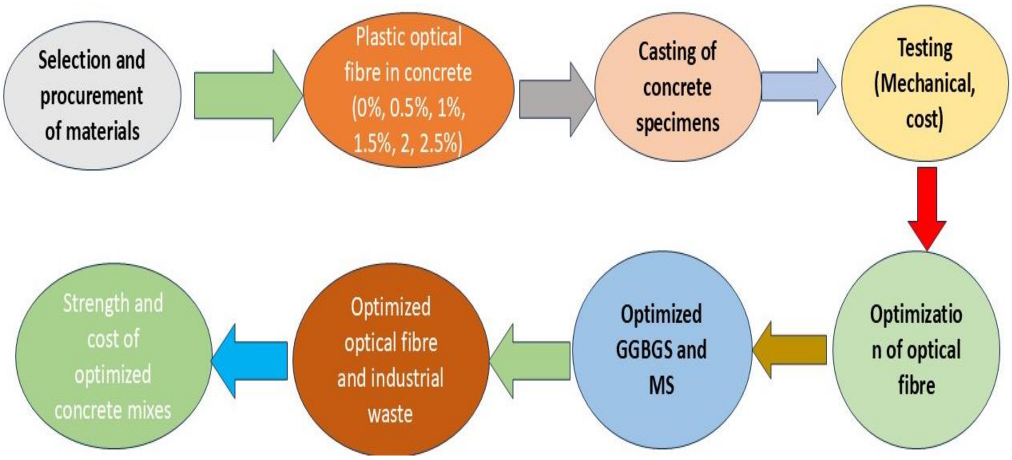


Fig. 2. Methodology for the experimental program of LTC

Table 7. Details of the test procedure

Sr. No.	Name of test	Specimens Size (mm)	Shape of specimens	Curing ages (Days)	References
1	Compressive Strength	100 mm x 100 mm x 100mm	Cube	7, 28, 90, 150	[22]
2	Light transmittance	100 mm x 100 mm x 100mm	Cube	28	[23]
3	Ultrasonic pulse velocity	100 mm x 100 mm x 100mm	Cube	28	[24]
4	Rebound hammer	100 mm x 100 mm x 100mm	Cube	28	[25]
5	Dynamic modulus	100 mm x 100 mm x 100mm	Cube	28	[26]
6	Cost	-	-	-	[27]
7.	Chemical resistance	100 mm x 100 mm x 100mm	Cube	7, 28, 62 after 28 days of water curing	[28]

The light transmittance of the concrete specimens was determined in accordance with Robles et al. [23]. The arrangement of the test procedure has been illustrated in fig. 3. In the present work, a white bulb of 40 W was used to measure the light-transmitting ability of different mix proportions of LTC. The light source was kept at a distance of 10 cm from the specimens so that the light could be uniformly distributed throughout the surface of the concrete cube. The Sigma Instruments 101 Digital Lux Meter was used to measure the light transmittance of concrete. The external outsourcers were not present in the lab room to avoid the disturbance in the results during the experimentation. The cost of the different mix proportions of LTC was determined based on the cost of materials used. The local market price of the raw material was used and is given in table 8. The cost of the industrial wastes, such as MS and GGBFS, was not included because most of the materials are freely available.

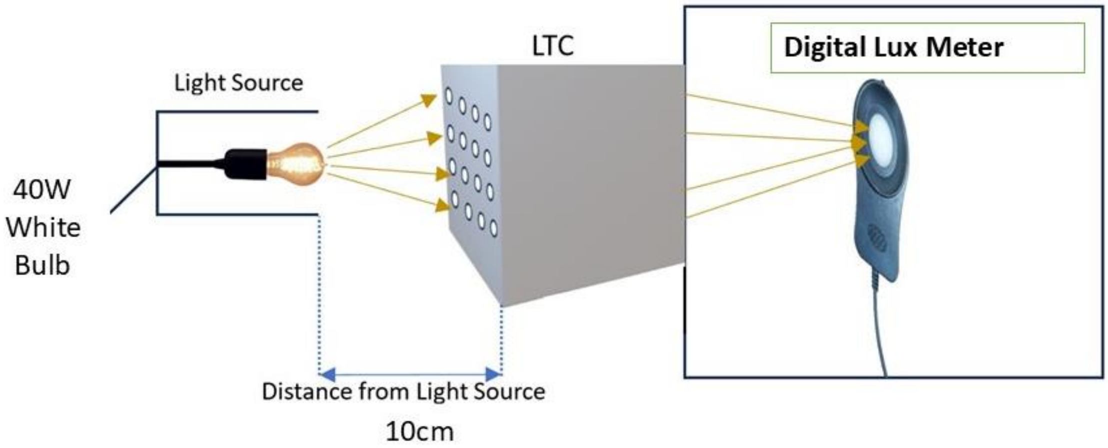


Fig. 3. Testing arrangement of light transmittance of LTC

Table 8. Cost of raw materials used

Material	Cement, kg	Sand, kg	Aggregate, kg	Water, kg	Optical fibre, kg	MS, kg	GGBFS, kg
Cost (INR)	7	1.2	1.5	0.05	7000	-	-

3. Results and Discussion

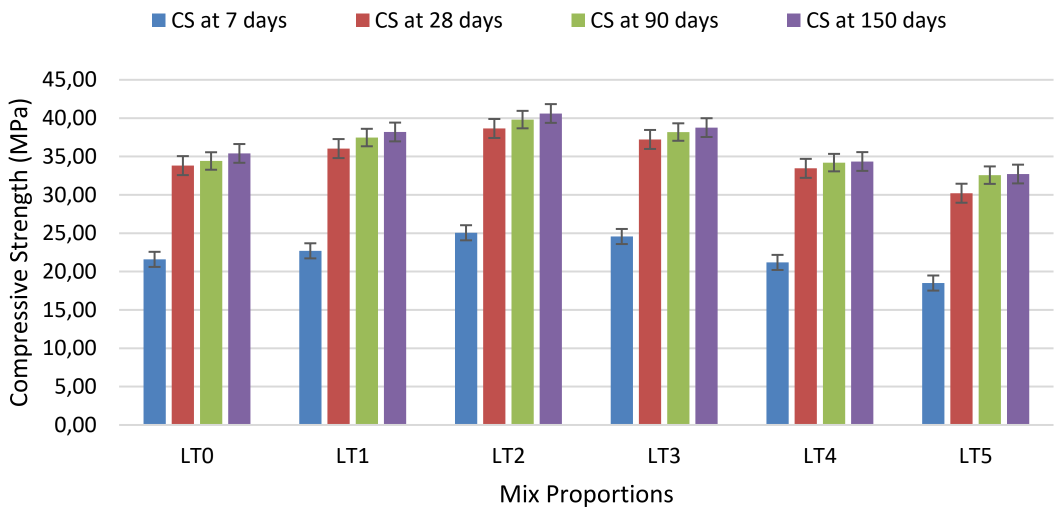
The practicality of the light-transmitting concrete was assessed at varying curing ages, with varying percentages of plastic optical fibre. The concrete's economic efficacy, durability, and strength were assessed.

3.1 Compressive Strength

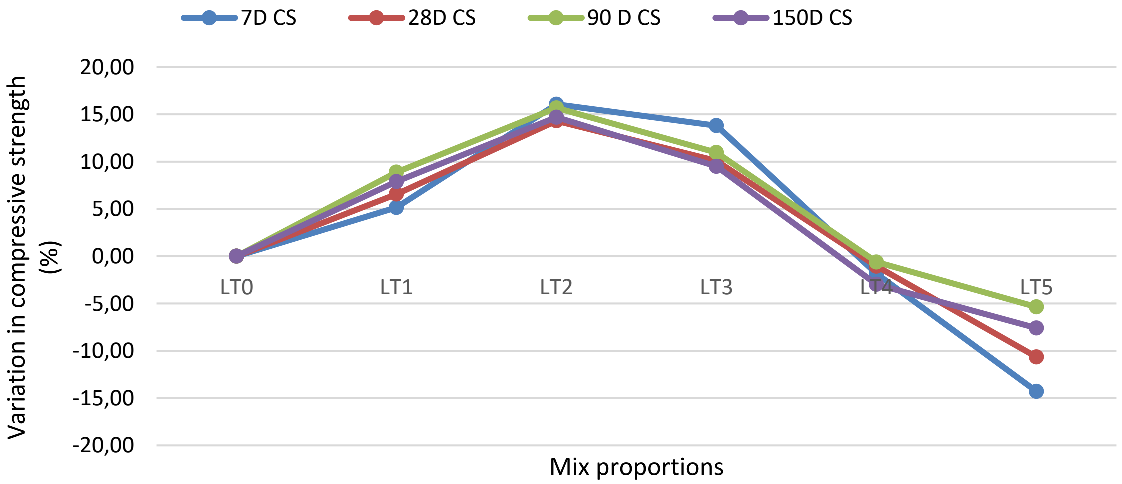
The CS of light-transmitting concrete containing varying percentages of optical fibre, specifically 0%, 0.5%, 1%, 2%, and 2.5%, was experimentally examined at 7, 28, 90, and 150 days of water curing. Figure 4 (a) illustrates the variation of compressive strength of LTC with the increase in fibre content at different curing ages. The compressive strength of the LTC improved with the incorporation of optical fibre in concrete, as depicted in the figure 4 (b). The addition of optical fibre improved the compressive strength of concrete up to 1.5%, after which the strength diminished. The increase in the strength of the concrete was due to the cement hydration process in the inter-transition zone and an increase in the contact area between fibre and mixtures, resulting in stronger inter-adhesion [10, 16]. However, the optical fibre at 1% had the maximum increase in strength, afterward, it declined. The strength at 1.5% optical fibre was more than the control mix but less than that of 1% optical fibre, as illustrated in fig. 4 (b).

The reduction in strength after a certain extent may be due to more smaller spacing arrangements of POF resulting in weakened cubes as a result of the smaller interconnecting distances when macrocracks propagate under a compressive load [5]. Another reason for the reduction in the strength of LTC after 1% of optical fibre may be attributed to the negligible strength of optical fibre and poor bonding of excess fibre within the matrix of concrete [29].

The statistical analysis of the compressive strength of LTC using the one-way ANOVA was carried out. The compressive strength at 7, 28, 90, and 150 days was considered. The sum, average, and variance of all compressive strength have been shown in the table 9. The results indicate a distinct trend of rising average compressive strength with curing age, which is characteristic of concrete behavior. The F-value and p-value of the strength parameters were also calculated.



(a)



(b)

Fig. 4. (a) Compressive strength of LTC with the variation in optical fibre and (b) Percentage variation in compressive strength of concrete

Table 9. Statistical analysis of compressive strength

ANOVA: Single Factor				
Groups	Count	Sum	Average	Variance
7D CS	6	133.62	22.27	5.81
28D CS	6	209.39	34.90	9.20
90D CS	6	216.67	36.11	7.78
150D CS	6	220.05	36.67	8.97

ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	845.301	3	281.767	35.47	3.36E-08	3.09839
Within Groups	158.859	20	7.94294			
Total	1004.16	23				

The F-value (35.47) markedly exceeds the critical F-value (F crit = 3.098), signifying a significant difference between the groups. The p-value is 3.36E-08 (or 0.0000000336), far lower than the conventional alpha level of 0.05, so affirming that the variations in compressive strength among the curing times are statistically significant. The ANOVA results strongly indicate that the compressive strength of concrete is significantly influenced by the curing duration. The average compressive strength increases in tandem with the number of curing days. The statistical significance of the variation between group means is suggested by the extremely low p-value, which suggests that these discrepancies are not the result of random chance.

3.2 Strength by Rebound Hammer

The assessment of the concrete's compressive strength was carried out using a method that did not involve any destruction, specifically the rebound hammer test. A similar pattern was observed in both the destructive and non-destructive tests, which both produced the same results. Compressive strength of the LTC was enhanced by the addition of plastic fibre up to 1%; nevertheless, strength reduced following the incorporation of plastic fibre. Within the range of 29.91 MPa to 40.97 MPa, the compressive strength of LTC was observed across all of the mix proportions. Figure 5 illustrates the variation in compressive strength that was caused by the rebound hammer test. The mechanisms behind the increase or reduction in compressive strength are discussed earlier in the section that is dedicated to compressive strength [5, 10, 16].

The rebound hammer test was performed on concrete surfaces free from visible fibre insertions. If the hammer strikes directly on a fibre, the rebound value may be significantly lower than that on plain concrete due to the fibre's soft and flexible characteristics. Even when the impact occurs adjacent to a fibre, it alters the localized stress distribution under the hammer, leading to inconsistent rebound readings. Moreover, the test is ideally conducted on a smooth and uniform surface, but the presence of fibres causes surface irregularities and micro-scale discontinuities. These inconsistencies result in erratic rebound values, making it difficult to obtain reliable and representative estimates of the actual compressive strength of the concrete matrix.

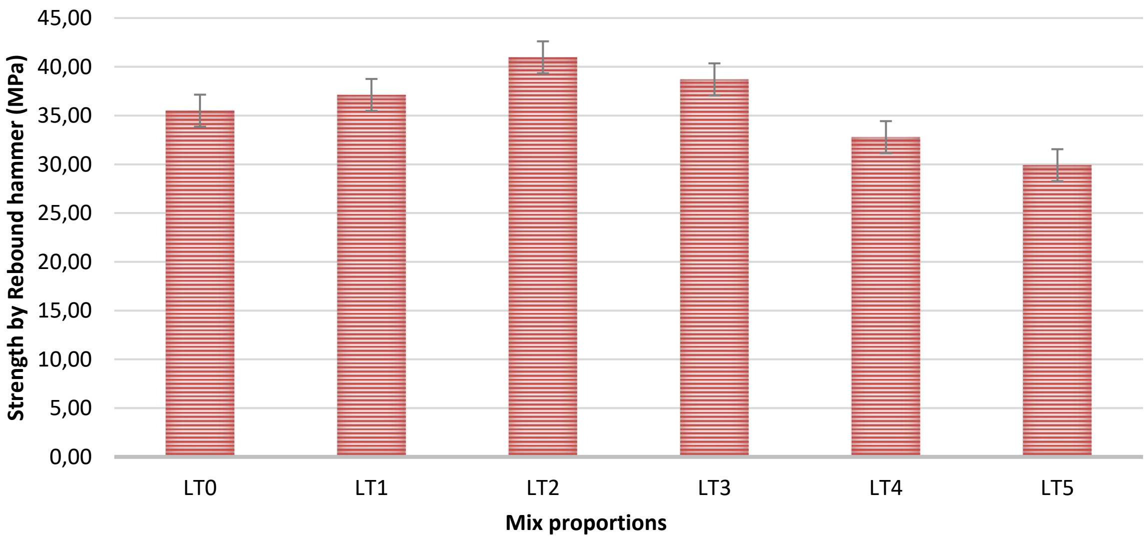


Fig. 5. Compressive strength of LTC by rebound hammer test

3.3 Light Transmittance Characteristics

The addition of optical fibre in the LTC increased the transmission of light [5, 14]. The light transmittance increased with the increase in fibre content, and the increase may be due to the higher surface area of the fibre to the concrete surface area, which allows lighter to pass, resulting in higher light transmittance [10, 16]. The light transmittance properties of the LTC have an impact on the customer. The light transmittance was measured in lux, and the variation is presented in percentage as shown in fig.6.

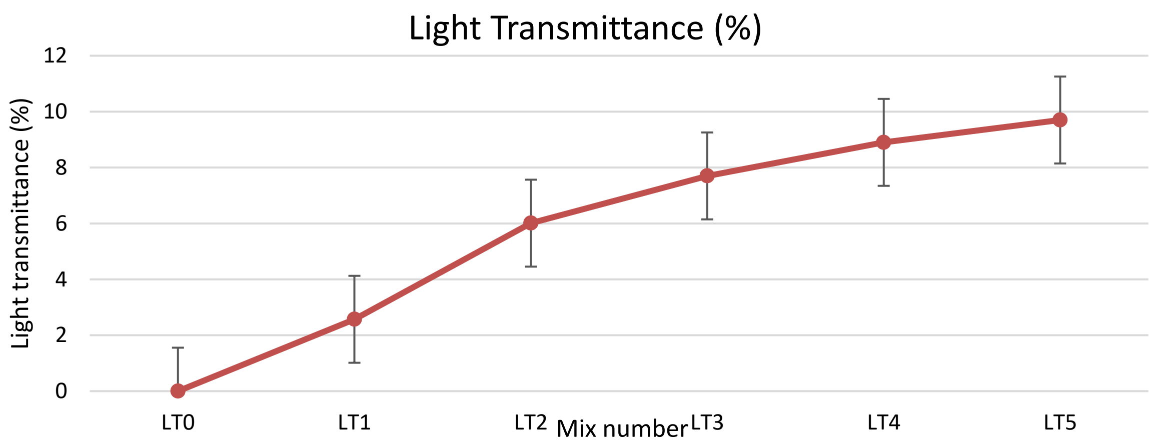


Fig. 6. Variation of light transmittance of LTC

3.4 Ultrasonic Pulse Velocity

At the end of the 28-day water curing period, the ultrasonic pulse velocity (UPV) of various mix proportions of LTC was measured and presented in fig. 7. The variation in the UPV of the various blends is depicted in figure 6 to illustrate the variation with respect to control mix. It is an indicator of the quality and uniformity of the concrete mixtures. Depending on the velocity measured from the equipment, the quality of the concrete ranged from very good to exceptional, and the inclusion of fibre into the concrete brought about these variations. Additionally, the inclusion of fibre may improve the UPV value due to the compaction and the internal connectivity.

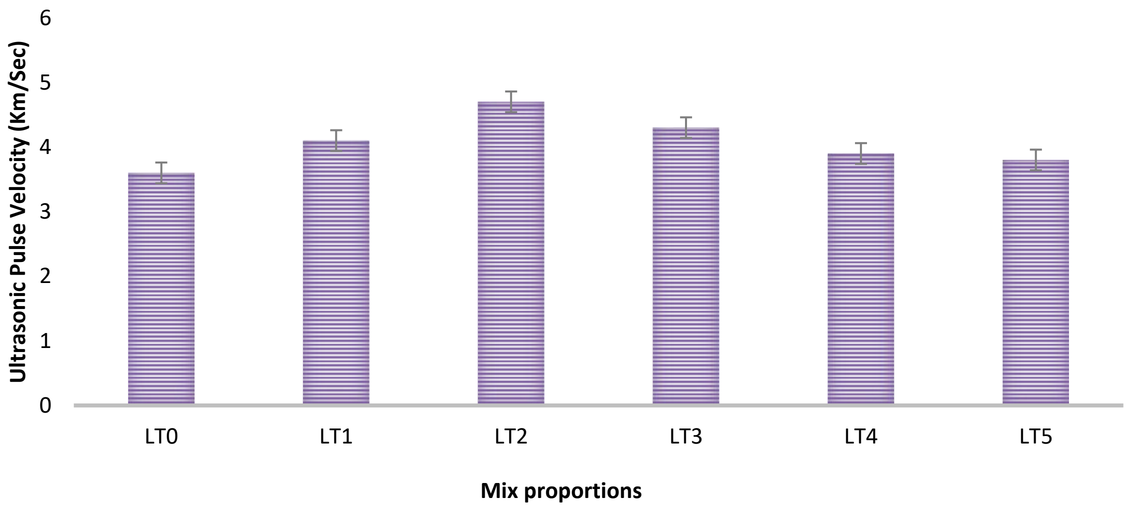


Fig. 7. Variation of ultrasonic pulse velocity of LTC

There is one limitation during the testing of the ultrasonic pulse velocity of the concrete consisting of fibre that the results may be affected due to variation in the acoustic impedance of fibre and concrete. The flexible and non-homogeneous nature of optical fibre can obstruct the obtaining of accurate signals and values.

3.5 Dynamic Modulus

The dynamic modulus of LTC was determined from the UPV test at 28 days. The variation in the dynamic modulus of different mixes of LTC has been shown in fig.8. The dynamic modulus of LTC was in the same trend as the compressive strength. The increase may be due to an improvement in the internal load transfer efficiency, resulting in an increase in the stiffness and dynamic modulus. The increase in the UPV value enhanced the dynamic modulus of concrete. The value of modulus varied from 26.44 GPa to 45.1 GPa for all the mix proportions. The dynamic modulus of LTC of mix LT2 was the maximum among all the mix proportions.

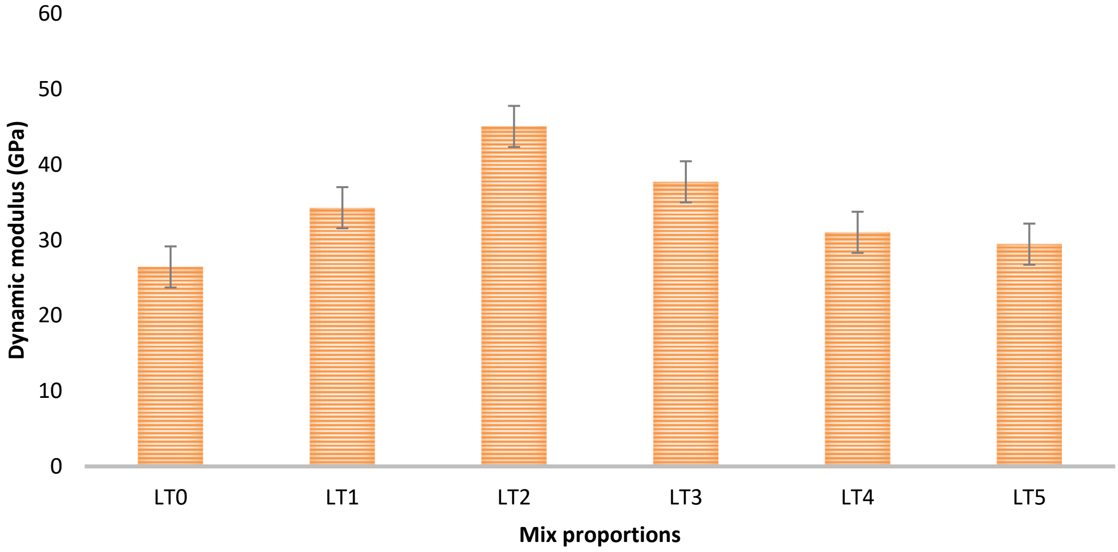


Fig. 8. Variation of the dynamic modulus of LTC

3.6 Cost Analysis

The cost of the different mixes of LTC was calculated. The addition of optical fibre hiked the cost of concrete, and the cost increased with the increase in fibre, as given in fig. 9. The increase in the cost of LTC was due to the high cost of optical fibre. The cost of the different mix proportions varied from INR 5411 to INR 308580. The maximum increase in cost was for mix LT5. The cost of the other raw materials was negligible compared to optical fibre in concrete production.

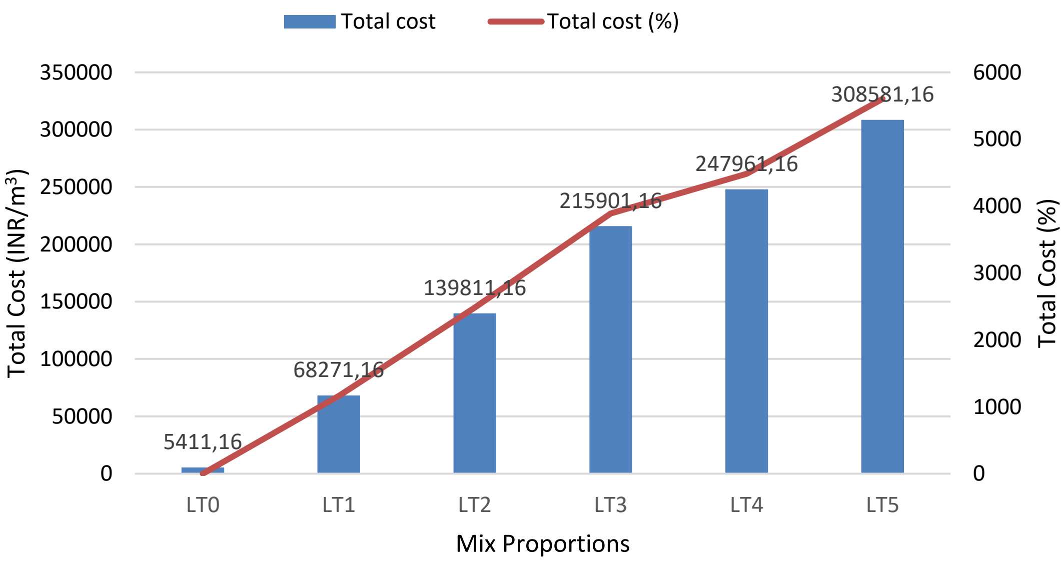


Fig. 9. Variation of the cost of different mix proportions of concrete

3.7 Correlation Between Strength by Destructive and Non-Destructive Tests

The correlation between the CS determined by the destructive and non-destructive methods at 28 days was derived. A linear correlation was derived, and a good correlation coefficient of 0.96 was found, as shown in fig. 10. The regression equation of the linear was derived and is given as below in equation 1;

$$y = 0.7419x + 8.3153 \quad (1)$$

A relationship is established that illustrates the effect of one parameter on another variable through the use of these relationships. The determination coefficient, denoted as R^2, is a coefficient that determines the variance of a variable. The confidence in the correlation is quantified by the R^2 value. This equation can be used to predict the compressive strength of the concrete from the rebound hammer value without destroying the samples. There was a strong linear relationship between these two parameters; hence, the prediction of compressive strength will give nearly accurate results.

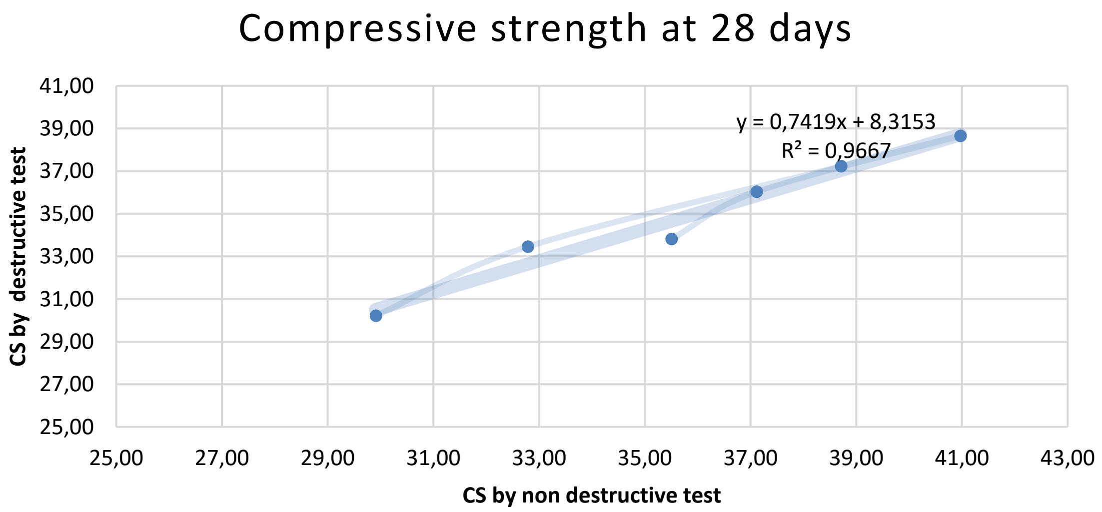


Fig. 10. Correlation between destructive test and non-destructive test of LTC

The predicted value will be determined from the eq.1 and error between the experimental and the predicted value of compressive strength at 28 days was determined and given in table 10. The error values indicate how closely the predicted results align with the experimental measurements. A positive error value represents an overestimation of the predicted value compared to the experimental result, while a negative error value indicates an underestimation.

Table 10. Error of predicted and experimental value

Mix No.	Error (%)
LT0	-1.92
LT1	1.02
LT2	0.31
LT3	1.00
LT4	3.07
LT5	-0.37

3.8 Optimized Mix with Industrial Wastes

From the above experiment results, the optical fibre at 1% was selected as the optimum mix proportion in terms of strength, modulus, cost, and light transmittance. The incorporation of industrial wastes such as GGBFS and MS can improve the performance of cement composites [30-36]. Therefore, GGBFS (20%) and MS (10%) individually were used in the LTC to investigate the performance of concrete specimens. The performance of concrete mixes was evaluated in terms of strength and durability.

3.8.1 Compressive Strength

The optical fibre at 1% was selected for further study from the above results. Further, the industrial wastes such as GGBFS (20%) and micro silica (10%) were used in the LTC. The CS of LTC was determined with the optimized content of fibre and industrial waste. The compressive strength of the optimized mix proportions has been determined at different curing ages, i.e., 7, 28, and 90 days, and variation in strength has been illustrated in the fig. 11.

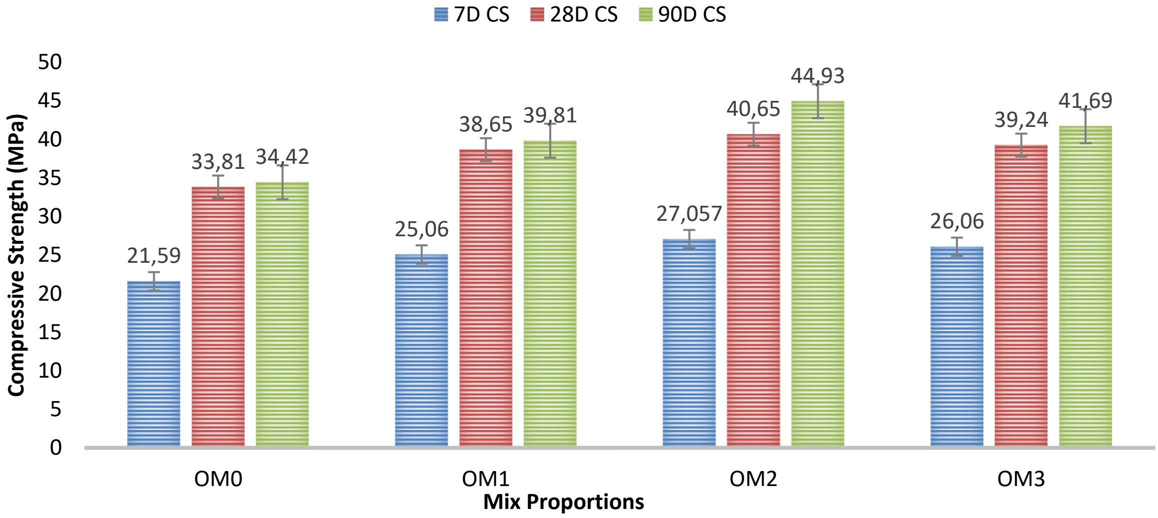


Fig. 11. Variation of compressive strength of optimized mixes of LTC

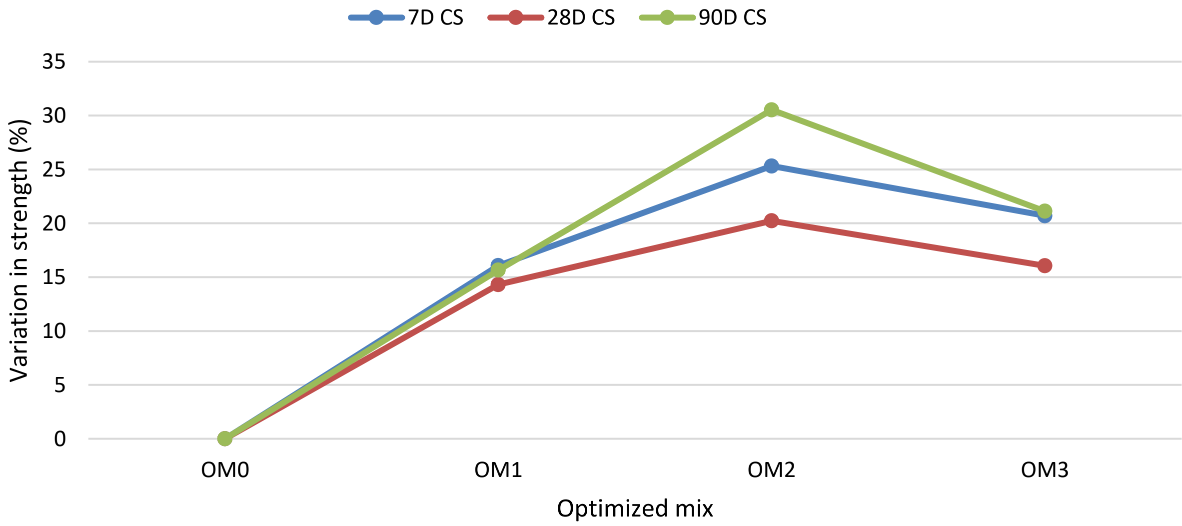


Fig. 12. Percentage change in strength of optimized mix with respect to control mix

As can be seen in Figure 12, the incorporation of industrial wastes like GGBFS and micro silica resulted in an increase in the compressive strength of the optimized mix proportions through all stages of the curing process. When compared to the control mix, the strength was greatly improved by the GGBFS and MS that were derived from industrial waste [30, 36]. The pozzolanic reaction of industrial by-products and the pore-filling impact of their finer particles may be responsible for the development of the increased strength [32-36]. As can be seen in figure 13, the incorporation of GGBFS and MS resulted in an increase in the compressive strength of LTC by 20% and 16% after 28 days of water curing for conventional concrete and by 5% and 2%, respectively, as compared to light-transmitting concrete. The statistical analysis of the compressive strength of the optimized mixes was carried out using ANOVA and is given in table 11.

The results show noticeable differences in the average values of compressive strength across the curing periods, indicating potential variations among them. The ANOVA results reveal that the calculated F-value (24.23) is much higher than the critical F-value (F crit = 4.256), confirming a significant difference between the groups. Additionally, the p-value (0.000238) is far below the conventional alpha level of 0.05, which clearly indicates that the differences among the group means are statistically significant. This statistical analysis suggests that the observed variations between the groups are not due to random chance but rather due to inherent differences in their data sets. The large F-value and very low p-value strongly support the conclusion that at least one group mean is significantly different from the others.

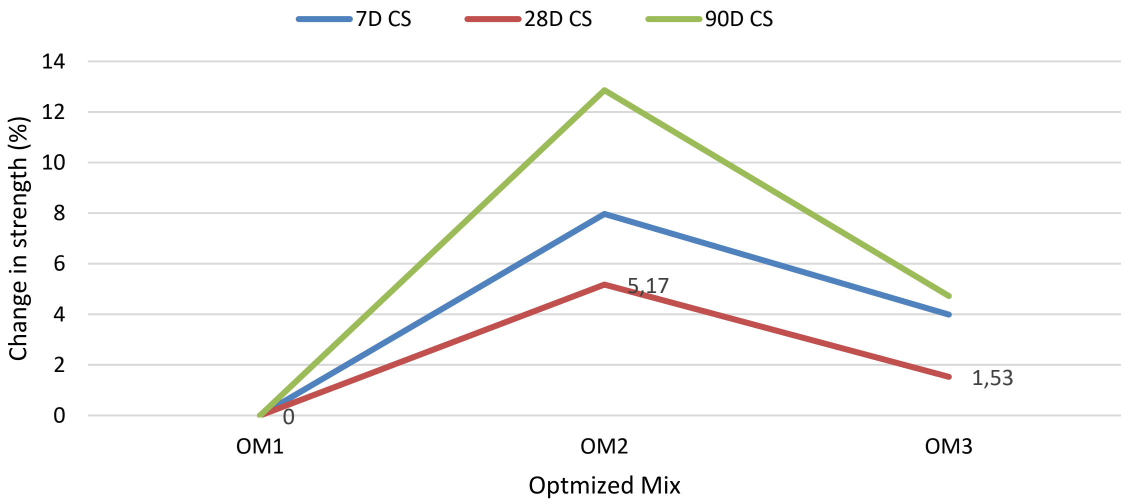


Fig. 13. Percentage change in strength with reference to optical fibre in LTC

Table 11. Statistical analysis of optimized mixes of concrete

ANOVA: Single Factor				
Summary				
Groups	Count	Sum	Average	Variance
7D Compressive Strength	4	99.767	24.94175	5.65765892
28 D Compressive Strength	4	152.35	38.0875	8.836025
90 D Compressive Strength	4	160.85	40.2125	19.3842917

ANOVA						
Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	547.362898	2	273.681449	24.2353427	0.000238	4.25649473
Within Groups	101.633927	9	11.2926585			
Total	648.996825	11				

3.8.2 Chemical Resistance

The chemical resistance of the concrete consisting of optical fibre and industrial wastes was investigated experimentally at 7, 28, and 62 days. The concrete specimens were subjected to a magnesium sulphate solution, and a variation in strength has been shown in fig. 14. It has been observed that the incorporation of industrial wastes enhanced the chemical resistance due to their pore-filling effect and pozzolanic reactions at all exposure periods. The hydration product formed during the pozzolanic reaction densified the matrix and restricted the penetration of external agents into the concrete matrix [34, 36]. The industrial waste GGBFS was found to be more predominant than MS in improving the chemical resistance of LTC. However, the concrete with optical fibre also improved the chemical resistance of the concrete mixtures may be due to dense packing of the matrix compared to the control mix, i.e., concrete without optical fibre.

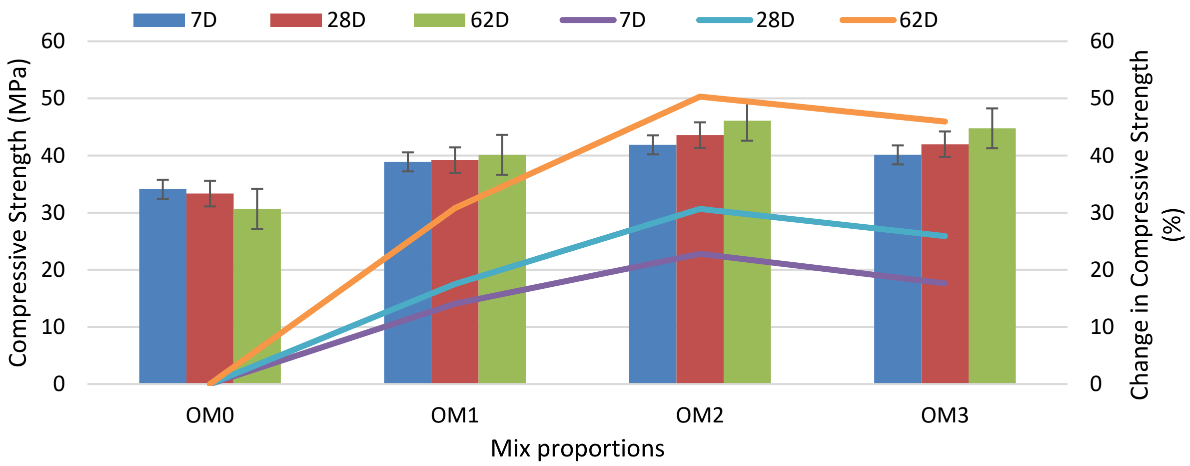


Fig. 14. Variation of compressive strength against the chemical attack

The percentage variation in the compressive strength of LTC against the exposure to sulphate solution at exposure periods of 7, 28, and 62 days has been illustrated in fig 14. The maximum increase in resistance was observed in the case of mix OM2 of 23%, 30%, and 50% compared to the control mix at exposure times of 7, 28, and 62 days, respectively.

3.8.3 Cost Analysis

The cost analysis of the optimized mix proportions was carried out. The use of optical fibre hiked the cost of concrete production, whereas the addition of industrial wastes declined the cost of concrete. The cost of mixes varied from 5411 INR to 145222.32 INR. The optical fibre increased the cost, while GGBFS and MS reduced the cost as illustrated in fig. 15.

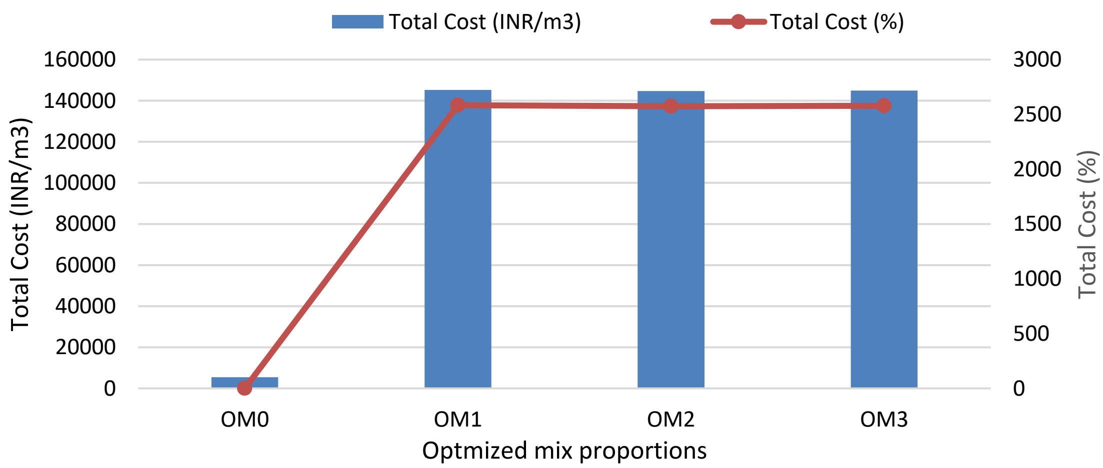


Fig. 15. Cost of optimized mixes

5. Conclusions

In the present study, the different proportions of optical fibre, i.e., 0%, 0.5%, 1%, 1.5%, 2%, and 2.5%, in the concrete were studied in various aspects. The strength, dynamic modulus, and cost of the various mix proportions were investigated. The conclusions of the present study are given below

- At all curing ages, the addition of optical fibre up to 1.5% in LTC improved the compressive strength afterwards; the strength reduced. However, the maximum strength was observed at 1% of the optical fibre of 38.65 MPa at 28 days of water curing.
- The maximum increase in compressive strength was observed as 15% for all curing ages at 1% of optical fibre.
- It was found that the compressive strength, as measured by both the destructive test and the non-destructive test, specifically the rebound hammer, exhibited similar patterns.
- The insertion of plastic optical fibre in concrete resulted in a rise in the ultrasonic pulse velocity value, which indicates that the quality of the concrete is of good to excellent quality.
- The incorporation of optical fibre into the light-transmitting concrete increased the dynamic modulus of the concrete.
- The light transmittance ability of the light-transmitting concrete increased as the number of optical fibres in the concrete rose. The maximum increase in light transmittance was reported to be 10%.
- There was a huge hike in the cost of light-transmitting concrete as a result of the additional optical fibre technology. However, the cost of manufacturing LTC is expected to compensate for the cost of artificial lighting.
- In terms of strength, light transmittance, and cost of the concrete, it was discovered that the optical fibre at a concentration of 1% was the most optimal.
- The inclusion of industrial wastes, i.e., GGBFS (20%) and MS (10%) along with the optimized percentage of optical fibre, improved the strength of the LTC by 5% and 2% at 28 days of water curing.
- The incorporation of industrial by-products enhanced the chemical resistance of LTC against the sulphate exposure at different ages, which may be due to the pore-filling effect and pozzolanic reactivity.
- The addition of industrial waste in LTC reduced the cost of concrete production compared to control mix. The GGBFS and MS declined the cost of LTC by 1% optical fibre by 7% and 4%, respectively.
- Therefore, LTC can be used in corporate logos, signage, façade panels, interior wall partitions, decorative panels, underground structures, tunnel linings, pavement, and footpaths due to their illuminating characteristics.

The use of optical fibre in concrete resulted in an improvement in the material's strength; nevertheless, this was accompanied by a rise in the cost of the concrete. The high cost and complex casting technique of LTC remain major obstacles to its commercial application. In addition to enhancing the building's aesthetic, the light-transmitting properties of the concrete helped to save energy by lowering the amount of artificial light that was required to illuminate the establishment. The use of industrial wastes with optical fibre has improved the strength and durability performance of the concrete. Thereby, the cost of the LTC can be compensated up to a certain extent with the addition of industrial by-products.

6. Future Scope

In the present study, the mechanical strength, light-transmitting ability, elastic modulus, and cost analysis of the concrete containing plastic optical fibre were studied. The industrial wastes, such as micro silica at 10% and ground granulated blast furnace slag at 20%, were used in the light transmitting concrete with 1% of plastic optical fibre. The compressive strength, chemical resistance, and cost analysis of optimized mix proportions were investigated. However, a few parameters are not covered in this study.

The durability properties, such as water absorption, chemical resistance, permeability, electrical resistivity, freeze-thaw resistance, effect of humidity and temperature variation, etc., of the light transmitting concrete were unexplored. The life cycle analysis, including life-cycle cost benefits due to energy savings, accounts for labour complexity, installation costs, and availability of POFs. The long-term behavior of plastic optical fibre i.e., the mechanical and optical degradation of the fibre under exposure to harsh environmental conditions, can be suggested for the direction of future investigation. The microstructural analysis of the different mixes can be discussed to explore the hydration products and develop the correlation between the micro and macro-characteristics of the different LTC mixes. The microstructural characterization of the different mix proportions under the normal and the harsh environmental conditions can also be compared and discussed further. Also, the statistical analysis can be derived among the different parameters.

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