# Light Transmitting Concrete by using Optical Fiber

**A. B. Sawant, R. V. Jugdar, S. G. Sawant**

***Abstract - Small buildings are replaced by high rise buildings and sky scrapers. This arises one of the problem in deriving natural light in building, due to obstruction of nearby structures. Due to this problem use of artificial sources for illumination of building is increased by great amount. So it is very essential to reduce the artificial light consumption in structure. It is considered to be one of the best sensor materials available and has been used widely since 1990. Hungarian architect, Aron Losonczi, first introduced the idea of light transmitting concrete in 2001 and then successfully produced the first transparent concrete block in 2003, named LiTraCon. Since concrete is strong in compression and weak in tension and flexure.***

***Index Terms—OFRC, Transparent Concrete, Lux, LITCON***

## I. INTRODUCTION

### A. General

Concrete has a key role in development of infrastructure and housing. Due to great economic growth, population growth and space utilization worldwide, there is drastic change in construction technology. Small buildings are replaced by high rise buildings and sky scrapers. This arises one of the problem in deriving natural light in building, due to obstruction of nearby structures. Due to this problem use of artificial sources for illumination of building is increased by great amount. So it is very essential to reduce the artificial light consumption in structure.

It is considered to be one of the best sensor materials available and has been used widely since 1990. Hungarian architect, Aron Losonczi, first introduced the idea of light transmitting concrete in 2001 and then successfully produced the first transparent concrete block in 2003, named LiTraCon. Since concrete is strong in compression and weak in tension and flexure.

### B. Power Consumption

In total domestic usage of electricity; 30% of electricity is used for lightening purpose only, so it is necessary to utilize natural light for illuminating interior of building.

#### 1) Optical Fiber

The idea of using light to send messages has been developed since the eighth century B.C., when the Greeks used fire signals for sending alarms or calls for help. It was only in the mid 1960s did Charles K. Kao determined that glass had a loss of 20db/km, which spurred researchers into exploring methods for making glass more pure. This discovery sparked a revolution in the telecommunication industry as a new industry of processing optical fibers becomes commercially important. These optical fibers have great light transmission capability.

The typical fibers today are made out of glass or plastic since it is possible to make them thin and long. Also both glass and plastic are transparent at particular Wavelengths, which allow the fiber to guide light efficiently. The fiber is constructed with a core with high index surrounded by a layer of cladding at lower index. The core and cladding can be made out of both plastic and glass. For plastics, the core can be polystyrene or polymethyl methacrylate and the cladding is generally silicone or Teflon for glasses both the cladding and the core are made out of Silica with small amounts of dopants such as Boron, Germanium to change its Index.

Major differences exist between the two materials when it comes to making the optical fiber. In plastic core fibers they are more flexible and inexpensive compared to glass fibers. They are easier to install and can withstand greater stresses and weigh 60% less than glass fibre. But losses, giving them very limited use in communication applications. Such plastic fibers are practical for short run such as within buildings. Therefore, due to their restrictive nature glass core fibers are much more widely used because they are capable of transmitting light effectively over large distances.

#### 2) Common and Recommended Indoor Light Levels

The outdoor light level is approximately 10,000 lux on a clear day. In the building, in the area closest to windows, the light level may be reduced to approximately 1,000 lux. In the middle area its may be as low as levels. Earlier it was common with light levels in the range 100 - 300 lux for normal activities. Today the light level is more common in the range of 500 - 1000 lux - depending on activity. For precision and detailed works, the light level may even approach 1500 - 2000 lux.

### C. Objectives of Present Investigation (Paper)

Traditionally concrete members are considered as a structural member only, but in recent days this concept is changed and use of concrete as a decorative material for structure has come up. It is observed that high performance concrete using optical fibers can also be utilized as a decorative material to improve elegance of structure by making it partly transparent. Hence this project is defined for achieving objectives like;

- To make concrete partly transparent by using optical fibers in it to impart good appearance to structure.

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**A. B. Sawant**, Asst. Prof., Civil Engineering Department, KIT"s College of Engineering, Kolhapur, Maharashtra, India.
**R. V. Jugdar**, Asst. Prof., Civil Engineering Department, SIT College of Engineering, Yadrav (Ichalkaranji), Maharashtra, India.
**S. G. Sawant**, Asst. Prof., Civil Engineering Department, KIT"s College of Engineering, Kolhapur, Maharashtra, India.

- To study improvement in performance of concrete in light transmission by using optical fiber and improve performance of structure to derive natural light.
- To study Energy saving for illumination by using transparent block for building.
- To study cost effectiveness of this high performance concrete.

### *D. Light Theory*

The effectiveness of the wire depends on its ability to guide the light ray far distances with little scattering or absorption of the light as possible. Doing so means that the optical fiber must exhibit total internal reflection within the wire, Thus when considering the propagation of light for an optical fiber the refractive index of the dielectric medium needs to be accounted for. As light rays become incident on an interface between two dielectrics with different index of refractions, refraction occurs between the two mediums. This can be best described by using Snell's Law of Refraction which states, $N_1 \sin Ø_1 = N_2 \sin Ø_2$, This equation shows that at certain angles partial internal reflection will arise, as well at other angles total internal reflection will occur as shown in following figure.

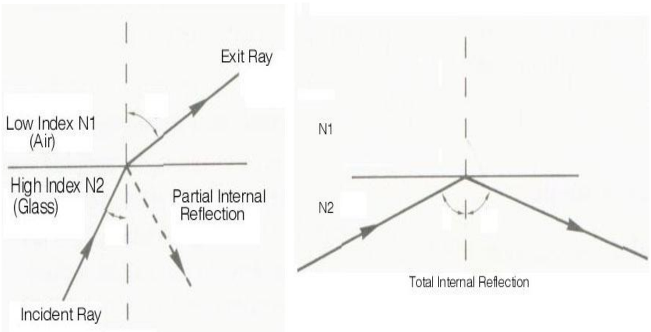


**Fig. 1: Light Ray Diagram**

This relationship can then be used to find the critical angle $Ø_c$ which serves as the limiting case of refraction and the angle of incidence. By launching the light ray at an angle $Ø > Ø_c$, within the optical fiber, A typical optical fiber with total internal reflection as seen in figure 2, it is reflected at the same angle to the normal, leading dielectric mediums is shown in figure 2, with the silica core having the index refraction of $n_1$ and the silica cladding with a lower index of refraction of $n_2$. With this setup it is possible to send packets of information through light rays which can propagate through an optical fiber with very little loss or distortion.

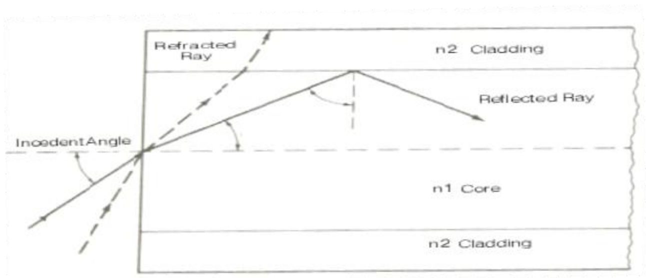


**Fig. 2: Total internal reflection between 2 dielectric mediums**

#### *1) Optical Fiber Types*

There are 3 basic types of optical fibers: multimode graded-index fiber, multimode step-index fiber and single-mode step-index fibers. A multimode fiber can propagate hundreds of light modes at one time while single-mode fibers only propagate one mode as shown in fig. 3

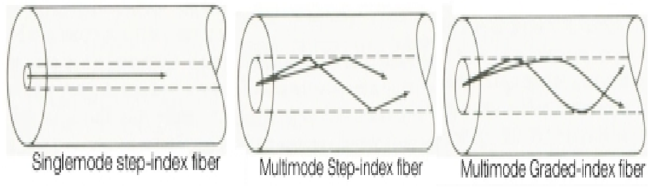


**Fig. 3: Optical Fibre**

The difference between graded-index and step-index fibers is that in a graded-index fiber it has a core whose refractive index varies with the distance from the fiber axis, while the step-index has core with the same refractive index throughout the fiber.

Single-mode fibers propagate light in one clearly defined path, intermodal dispersion effects is not present, allowing the fiber to operate at larger bandwidths than multimode fiber. On the other hand, multimode fibers have large intermodal dispersion effects due to the many light modes of propagations it handles at one time. In this paper the intensity of light passing through concrete blocks provided with optical fiber is measured in lux unit for measurement of light.

## II. CONCRETE DESIGN MIX (M 30)

**Table 1: Final M 30 Grade mix design**

| Final Mix Proportion | | | | |
|---|---|---|---|---|
| **1** | **2.562** | **4.167** | **0.42** | **4 lit** |

### *A. Casting of Cubes*

The specimens were prepared by compaction the concrete in three layers. Table vibrator was used for compaction of concrete. After completion of compaction, excess material was removed and the mould was leveled by using a travel.

### *B. De-Moulding and Curing of Cube Specimens*

The casted mould was kept undisturbed on the leveled platform. Then it was de-moulded carefully after 24 hours, from casting immediately after de-moulding, the cube specimens were marked by their respective identification mark/numbers (ID). Carefully transferred these cube to the curing tank for water curing.

## III. TESTING OF SPECIMENS

### *A. Compressive strength*

Testing of cubes was carried out in Compression Testing Machine of 2000 KN capacity to determine the compression strength of design mix.

#### *1) Testing of specimen for light reflection*

- Stage 1-Prepare the 5 plywood boxes of size 0.3m x 0.3m x 0.75m. Place 4 cubes of each percentage in separate box to check the intensity of reflected light through the concrete block from different percentage of fibers.


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- Stage 2-Prepare the 8 plywood boxes of depth 0.75m with different surface areas , for checking the reflection of light intensity through the concrete block for different surface areas with constant percentage of fiber.(for 4% & 5% of fibers only )

## IV. RESULT ANALYSIS

The results obtained from testing of conventional concrete and Optical Fiber concrete is tabulate. Two tests are carried out on the harden concrete such as Compressive Strength, Reflections of light through the concrete blocks. The optical fibers are used in the concrete block in 5 different percentages, ranges from 1% to 5% of the surface area. This concrete blocks are then tested for compressive strength after 3 days, 7 days. Reflection of light through concrete blocks of each percentage was checked before the 28 days compressive testing.

### *A. Compressive Strength Results:*

Concrete cubes were tested in Compression testing machine of 2000 KN capacity after curing period of 3 days, 7 days and 28 days. The obtained results are tabulated in table 2.

### *B. Reflection of Light through blocks (for different Percentage of Fiber):*

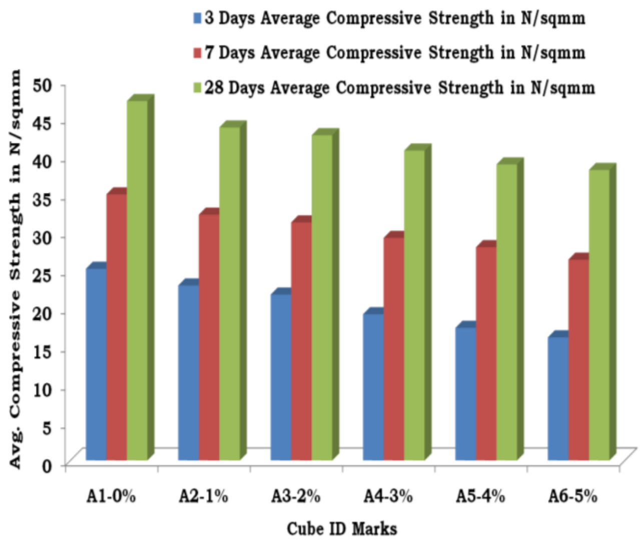
After 28 days curing before testing the cubes for compressive strength, the reflection of light through 4 concrete blocks (surface area 0.09 sqm) of each % of optical fiber was tested. The results obtained are tabulated in table 3.

### *C. Reflection of Light through blocks (From different block area):*

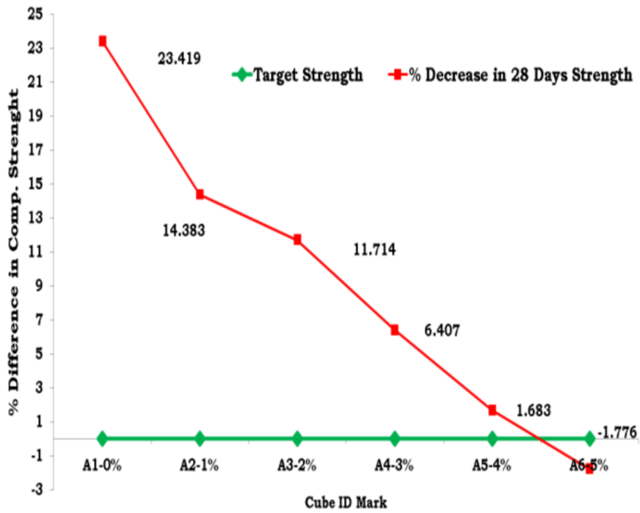
Then after, reflection of light was checked through the concrete blocks with 4 % and 5 % of optical fibers but for the different surface areas. Results of the same are tabulated in table 4 & 5.

**Table 2: Average Compressive Strength of Cubes**

| Cube ID Mark | Avg. Compressive Strength in N/mm$^2$ | | |
|---|---|---|---|
| | 3 Days | 7 Days | 28 Days |
| A1-0% | 25.176 | 34.956 | 47.208 |
| A2-1% | 22.991 | 32.289 | 43.752 |
| A3-2% | 21.783 | 31.275 | 42.731 |
| A4-3% | 19.208 | 29.23 | 40.701 |
| A5-4% | 17.417 | 28.012 | 38.894 |
| A6-5% | 16.165 | 26.378 | 38.161 |




**Graph 1: Avarage Compressive Strength (In Mpa)**




**Graph 2: % Difference in Compressive Strength**

**Table 3: Reflection of light through 4 concrete blocks( with different % of optical fibers)**

| Time | External Radiation Intensity In Lux. | Reflected Light Intensity (In %) From Blocks | | | | |
|---|---|---|---|---|---|---|
| | | 1 % | 2 % | 3 % | 4 % | 5 % |
| At Box Face | | | | | | |
| 7:00 | 1 | 0 | 0 | 0 | 0 | 0 |
| 8:00 | 80.5 | 3.1 | 3.7 | 4.7 | 5.6 | 7.5 |
| 9:00 | 276.8 | 2.5 | 3.5 | 4.8 | 6.1 | 6.2 |
| 10:00 | 456.5 | 2.5 | 3.1 | 4.8 | 6.7 | 5.7 |
| 11:00 | 558.8 | 3 | 3.6 | 5.7 | 7.5 | 6.8 |
| 12:00 | 649.5 | 3.4 | 3.7 | 5.8 | 7.7 | 6.9 |
| 13:00 | 758.5 | 3.7 | 4.2 | 6.2 | 8.3 | 7.7 |
| 14:00 | 683.3 | 2.8 | 3.5 | 5.2 | 7.9 | 6.1 |
| 15:00 | 527.8 | 2.8 | 3.3 | 5.1 | 7.4 | 6.2 |
| 16:00 | 413.8 | 2.5 | 3.3 | 5.1 | 6.9 | 5.3 |
| 17:00 | 231.8 | 2.7 | 2.9 | 3.6 | 5.6 | 5.9 |
| 18:00 | 104.8 | 1.2 | 1.4 | 1.9 | 2.4 | 2.6 |
| 19:00 | 0 | 0 | 0 | 0 | 0 | 0 |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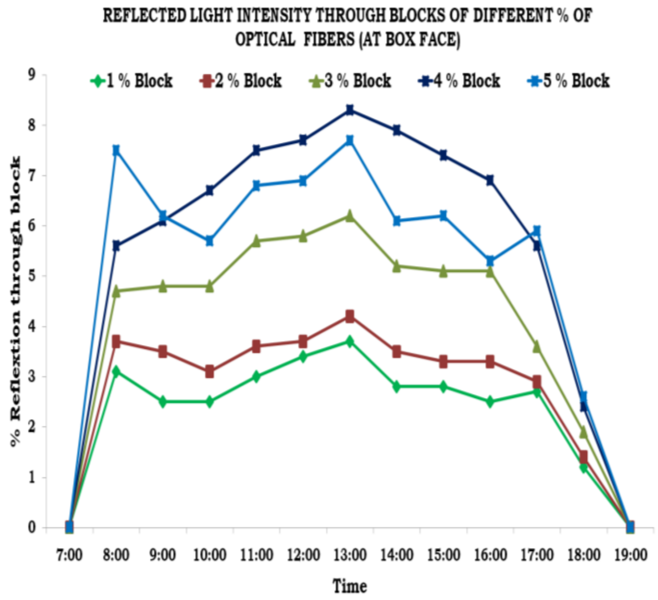
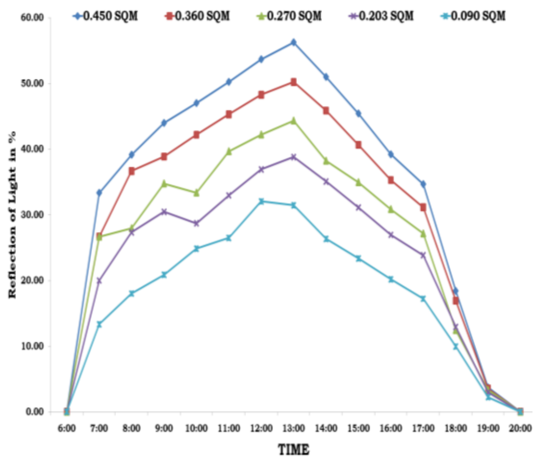



**Graph 3: Reflection of light through 4 concrete block, at Box Face**

**Table 4: Reflection of light through Different Surface areas with 5 % optical fibers**

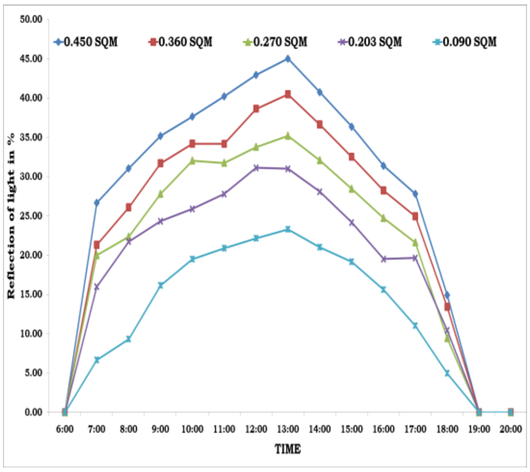
| Time | External Radiation Intensity In Lux. | Internal Radiation Intensity Near Cube Face In % At Box Face | | | | |
|---|---|---|---|---|---|---|
| | | 0.450 Sqm | 0.360 Sqm | 0.270 Sqm | 0.203 Sqm | 0.090 Sqm |
| 6.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7.0 | 15.00 | 33.33 | 26.67 | 26.67 | 20.00 | 13.33 |
| 8:0 | 161.00 | 39.13 | 36.65 | 27.95 | 27.33 | 18.01 |
| 9:0 | 489.00 | 43.97 | 38.85 | 34.76 | 30.47 | 20.86 |
| 10:0 | 749.00 | 47.00 | 42.19 | 33.38 | 28.70 | 24.83 |
| 11:0 | 910.00 | 50.22 | 45.27 | 39.67 | 32.97 | 26.48 |
| 12:0 | 1092.00 | 53.66 | 48.26 | 42.22 | 36.90 | 32.05 |
| 13:0 | 1193.00 | 56.24 | 50.21 | 44.34 | 38.81 | 31.43 |
| 14:0 | 1075.00 | 50.98 | 45.86 | 38.23 | 35.07 | 26.33 |
| 15:0 | 861.00 | 45.41 | 40.65 | 34.96 | 31.13 | 23.34 |
| 16:0 | 768.00 | 39.19 | 35.29 | 30.86 | 26.95 | 20.18 |
| 17:0 | 453.00 | 34.66 | 31.13 | 27.15 | 23.84 | 17.22 |
| 18:0 | 201.00 | 18.41 | 16.92 | 12.44 | 12.94 | 9.95 |
| 19:0 | 54.00 | 3.70 | 3.52 | 3.33 | 2.96 | 2.22 |
| 20:0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |




**Graph 4: Reflection of light through Different Surface areas with 5% optical fibers**

**Table 5: Reflection of light through Different Surface areas with 4 % optical fibers**

| Time | External Radiation Intensity In Lux. | Internal Radiation Intensity Near Cube Face In % At Box Face | | | | |
|---|---|---|---|---|---|---|
| | | 0.450 Sqm | 0.360 Sqm | 0.270 Sqm | 0.203 Sqm | 0.090 Sqm |
| 6.0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7.0 | 15.00 | 26.67 | 21.33 | 20.00 | 16.00 | 6.67 |
| 8:0 | 161.00 | 31.06 | 26.09 | 22.36 | 21.74 | 9.32 |
| 9:0 | 489.00 | 35.17 | 31.70 | 27.81 | 24.34 | 16.16 |
| 10:0 | 749.00 | 37.65 | 34.18 | 32.04 | 25.90 | 19.49 |
| 11:0 | 910.00 | 40.22 | 34.18 | 31.76 | 27.80 | 20.88 |
| 12:0 | 1092.00 | 42.95 | 38.64 | 33.79 | 31.14 | 22.16 |
| 13:0 | 1193.00 | 45.01 | 40.49 | 35.21 | 31.01 | 23.30 |
| 14:0 | 1075.00 | 40.74 | 36.65 | 32.09 | 28.09 | 21.02 |
| 15:0 | 861.00 | 36.35 | 32.52 | 28.46 | 24.16 | 19.16 |
| 16:0 | 768.00 | 31.38 | 28.26 | 24.74 | 19.53 | 15.63 |
| 17:0 | 453.00 | 27.81 | 24.94 | 21.63 | 19.65 | 11.04 |
| 18:0 | 201.00 | 14.93 | 13.43 | 9.45 | 10.45 | 4.98 |
| 19:0 | 54.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20:0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |




**Graph 5: Reflection of light through Different Surface areas with 4 % optical fibers**

## V. COST ANALYSIS

**Table 6: Cost Analysis of M30 Grade Concrete (Conventional and OFRC) for 1 cum**

| Material | Cement | Sand | Aggregate + Chemical | Optical Fibers | TOTAL |
|---|---|---|---|---|---|
| **Cube** | 2005 | 1024 | 1170 | | **4199** |
| **1 %** | 1982 | 1014 | 1166 | 19769 | **23927.66** |
| **2 %** | 1961 | 1004 | 1157 | 32026 | **36146.09** |
| **3 %** | 1925 | 994 | 1150 | 46259 | **50349.29** |
| **4 %** | 1925 | 982 | 1144 | 53376 | **57427.36** |
| **5 %** | 1905 | 972 | 1138 | 71168 | **75183.35** |

**Table 7: Comparison of Cost**

| Sr. No | Number of Cubes | Volume in CUM | Cost | |
|---|---|---|---|---|
| | | | Conventional Blocks | Optical Concrete Blocks |
| 1 | 20 | 0.068 | 285.50 | 3876.35 |
| 2 | 16 | 0.054 | 226.72 | 3101.08 |
| 3 | 12 | 0.041 | 172.14 | 2325.81 |
| 4 | 09 | 0.030 | 125.96 | 1744.36 |

## VI. EFFECTIVENESS OF LIGHT TRANSMITTING CONCRETE BLOCKS:

### A. *Power Consumption By Artificial Lighting :*

- Power consumption when one 60 Watt light bulb is Use for illumination for 30 days for 8 hours = 60 X 30 X 8 = 14400 = 14.4 Units

**Table 8: Tariff/charges for power supply to Residential and Public building**

| Residential | Public |
|---|---|
| Rs.4.85 | Rs.7.92 |

### B. *Pay Back Period:*

1) *For 0.45 sqm area (20 Blocks)*

With reference to comparison of cost table; Difference in Initial Cost for 20 No. of Cubes

= Rs. 3876.35 - Rs. 285.50 = Rs. 3590.85 /-

- Energy saving in residential room in one year = 14.4 X 4.85 X 12 = 838.08 /- Rs
- Period require to recover extra amount for OFRC transparent block $= \frac{3590.85}{838.08}$ = 4.285 Years ≈ 4.3 Years
- Energy saving in commercial/Industrial room in one yea r = 14.4 X 7.9 X 12 = 1368.58/- Rs
- Period require to recover extra amount for OFRC block $= \frac{3590.85}{1368.58}$ = 2.624 Years ≈ 2.7 Years

From above cost analysis and payback period calculation it was confirmed that, the recovery period for light transmitting block is 4.3 years for residential use and it is 2.7 years for commercial use. This payback period is too less as compared to benefits of light transmitting concrete. Similarly Payback period for other areas are tabulated below

**Table 9: Payback Period**

| Area in Sqm | No. of blocks | Payback for Residential | Payback for commercial |
|---|---|---|---|
| 0.45 | 20 | 4.3 | 2..7 |
| 0.36 | 16 | 3.5 | 2.1 |
| 0.27 | 12 | 2..6 | 1.6 |
| 0.20 | 09 | 2.0 | 1.2 |

## VII. DISCUSSION ON RESULT

### A. *Compressive Strength*

As per the experimental work the result shows that 3 days compressive strength of concrete block decrease from 25.176 $N/mm^2$ to 16.125 $N/mm^2$, compressive strength is decreased because of the increased percentage of optical fiber.

Similarly, for 7 days compressive strength decrease from 34.956$N/mm^2$ to 26.378$N/mm^2$ & for 28 days compressive strength decrease from 47.208 $N/mm^2$ to 38.167$N/mm^2$.

### B. *Reflection of Light*

From table no 3 to 5, the external radiation of sunlight is maximum at afternoon session than the morning & evening session i.e.1092, 1193 & 1075 in lux at 12pm, 1pm, 2pm resp.

The intensity of light passing through the concrete block with 1% of fiber (1% of surface area of concrete block) At box face is 125.5, 149.8 & 108.8 in lux. (11.5, 12.6 & 10.1 in percentage)

The intensity of light passing through the concrete block with 2% of fiber (2% of surface area of concrete block) At box face is 186,219& 161 in lux.(17,18.4 & 15 in percentage) The intensity of light passing through the concrete block with 3% of fiber (3% of surface area of concrete block) At box face is 215.3,247 & 201.8 in lux. (19.7, 20.7 & 18.8 in percentage)

The intensity of light passing through the concrete block with 4% of fiber (4% of surface area of concrete block) At box face is 217.3, 250.5 &203 in lux. (19.9, 21 &18.9 in percentage)

The intensity of light passing through the concrete block with 5% of fiber (5% of surface area of concrete block) At box face is 242,278 &226 in lux. (22.2, 23.3 & 21 in percentage)

### C. *Combine Discussion on Compressive Strength and Reflection of Light*

From above tabulated results and graph drawn according to the tables, it can be seen that the compressive strength of concrete block reduces with the increase the percentage of fibers.(i.e. percentage of surface area of concrete block)used in concrete block.

With reference to graph no 6 it can be seen that

- The intersection of 28 days compressive strength line and percentage of fiber used line. It gives the optimum percentage of fiber used in concrete block.
- It also shows to be that the intersection point of target compressive strength line and 28 days compressive strength line.

From this observation it can be observed that there is difference in the intersection points which allows increasing the percentage of fibers without dropping 28days compressive strength of concrete block than target strength.

As per observation and comments discuss in previous points further project work was carried out on 4% and 5% of fibers.(i.e percentage of surface area of concrete block),because for 5% fiber the compressive strength is slightly reduced than target strength and for 4% it is slightly higher than target strength.

## VIII. CONCLUSION

### A. *General*

With reference to previous discussions on manufacturing of Light Transmitting Concrete, Compressive Strength, capability of light transmission through it, and effectiveness of cost the following conclusions can be made.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### B. Conclusions Regarding Compressive Strength

As per discussion in result analysis it is concluded that for same design of M 30, the compressive strength of Light Transmitting Concrete (4%) is reduced by 30%, 20%, 18% for 3days,7days and 28days respectively that of conventional concrete. For achieving golden mean between compressive strength and percentage of optical fibers laid in cube, trial cubes with different percentage of fibers ( 1 % to 5%) are casted. These trial results give following graph, which gives optimum % of optical fibers to be used. Accordingly 4% fibers are used for further study.

**Table No. 9: Optical Fiber Percentage Wise Compressive Strength Result :**

| Optical Fiber laid in % of surface area | 0% | 1% | 2% | 3% | 4% | 5% |
|---|---|---|---|---|---|---|
| Comp. Strength in N/mm$^2$ | 47.208 | 43.752 | 42.731 | 40.701 | 38.894 | 38.161 |
| Radiation through block in Lux | 0 | 220 | 258 | 295 | 321 | 375 |

### C. Conclusions Regarding Transmission of Light Through Light Transmitting Block :

The transmission of light through light transmitting block is depend on percentage of optical fiber used of that surface area. The transmission of light is increases with increase in percentage of optical fiber. The intensity of light passing through the block is maximum at 13P.M. The maximum intensity of light passing through the block for 1% of fiber is 149.8 lux at box face similarly, for 2% of fiber is 219 lux , for 3% of fiber 247 lux, 4% of fiber 250.5 lux, for 5% of fiber is 278 lux. Earlier it was common with light levels in the range 100 - 300 lux for normal activities. Today the light level is more common in the range 500 - 1000 lux - depending on activity. For precision and detailed works, the light level may even approach 1500 - 2000 lux. From Table 3, 4 & 5 it can be concluded that, the condition of outdoor light varies from overcast day and full day light, but for maximum time during experimental analysis it is overcast outdoor light. Outdoor light intensity ranges from 0 lux to 1193 lux in day time between 7:00 A.M to 7:00 P.M. From Table No. 4 & 5 it is cleared that this average value of transmission of light through block is sufficient for daily activities such as general visits, Normal Office Work , PC Work, Detailed Drawing Work, Very Detailed Mechanical Works, Performance of visual tasks of low contrast and very small size for prolonged periods of time and at location such as Supermarkets, Mechanical Workshops, Office Landscapes, Study Library, Groceries, Show Rooms, Laboratories, Warehouses, Homes, Theaters, Archives, Classes. This diffused light is very useful for the place where mainly computer work is done.

### D. Conclusions Regarding Cost:

Even if initial cost of the light transmitting concrete is more than conventional concrete by 12 time, but due to continuous increase in tariff and pay back calculation done, from the payback analysis it can be concluded that a wall of 16 block (0.360 sqm area) constructed then the saving of electricity bill is 838.03/-Rs. So the payback period for excess amount invested for light transmitting block will be recovered in 3.5 years for domestic consumption and 2.1 years for commercial and industrial consumption. It will also reduce the carbon emission which is dangerous for the environment. Hence this can be treated as one of the high performance concrete. The use of this high performance light transmitting concrete is beneficial for protecting mother earth.

### E. Conclusion Regarding Compressive Strength and Reflection of Light

From tabulated results and graph drawn according to the tables, it can be conclude that the compressive strength of concrete block reduces with the increase the percentage of fibers.(i.e. percentage of surface area of concrete block)used in concrete block. As per observation and comments discuss in previous points further project work was carried out on 4% and 5% of fibers.(i.e percentage of surface area of concrete block),because for 5% fiber the compressive strength is slightly reduced than target strength and for 4% it is slightly higher than target strength.

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