

Development of Concrete Bricks with Optical Fibers and Waste Glass as Aggregates

A Dissertation submitted in partial fulfillment of the
requirement for the award of degree of

MASTER OF ENGINEERING

in

STRUCTURAL ENGINEERING

Submitted by

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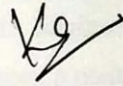
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DECLARATION

I hereby declare that the work which I have presented in dissertation entitled, "*Development of Concrete Bricks with Optical fibers and Waste Glass as Aggregates*", in partial fulfillment of the requirements for the award of degree of Master in Structural Engineering, submitted to Civil Engineering Department of Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of my own work carried under the supervision of Dr. Gurbir Kaur and Dr. Maneek Kumar. It refers to other researcher's work which is duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other university or institute or for award for any other degree except as reported in text and references.

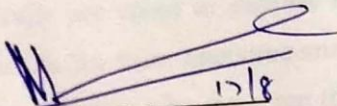
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ABSTRACT

With rapid ongoing development in the field of construction, the demand for construction materials is ever growing. Concrete is the most used material in almost all forms of construction and has a huge impact on the further innovation & developments in the field of construction. As we take mega steps towards development, there cometh along the issues of global warming and pollution. On an average construction industry is assumed to be among the top contributors to the pollution in the world.

As we march towards goals of further development, with keeping in mind the perspective of sustainability, it becomes important to incorporate it into the roots of the construction industry.

Hence, concrete nowadays is developed / composed of waste materials as additives or substitutes to make it more sustainable and eco-friendly. One such type materials are waste glass which is available in bulk quantity and is not recycled completely in India. As the glass is majorly composed of silica and it exhibits properties of a pozzolanic material. On the other hand, the addition of plastic optical fibers (POF) can also add light transmission property to the concrete and therefore add aesthetical value to the eco-friendly concrete.

Forming Concrete in the shape of a brick which is composed of waste and has the property of light transmission can be a product for the future. The general trend for durability and strength properties of concrete on the usage of waste glass is positive, whereas addition of fibers tends to reduce the strength of concrete due to its non-binding behavior. The waste glass can be partially replaced / added as a fine as well as coarse aggregate and the plastic optical fibers are added in the range of 3-5% of the total volume.

Keywords: *Concrete, Sustainable, Eco-Friendly, Translucent Concrete, Plastic Optical Fibers, Waste Glass, Aggregates, Eco-friendly Concrete Bricks.*

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LIST OF ABBREVIATIONS

RHA	Rice Husk Ash
FA	Fly Ash
GGBS	Ground Granulated Blast Furnace Slag
w/c	Water- Cement ratio
OPC	Ordinary Portland Cement
PPC	Pozzolanic Portland Cement
IS	Indian Standards (Codes)
BS	British Standards (Codes)
F.M	Fineness Modulus
ASTM	American Society for Testing & Materials
POF	Plastic Optical Fiber
WG	Waste Glass
LTCM	Light Transmitting Cement Mortar/ Light Transmitting Cement based material
SEM	Scanning Electron Microscopy
EDS	Energy Dispersive Spectroscopy
PMMA	Poly (Methyl Methacrylate)
ITZ	Interfacial-Transitional Zone
ASR	Alkali-Silica Reaction
TIR	Total Internal Reflection
OFIC	Optical Fiber Incorporated Concrete

CHAPTER 1-INTRODUCTION

1.1 GENERAL

With growth of economy and development of technology, more large-scale construction structures in the form of skyscrapers, both residential as well as commercial tall buildings are being built around the world. As the economic development is extensive in 21st century and requires high input / high output, thus it becomes important for developing countries to carry it forward in a sustainable manner. As known concrete is the most widely used material and can be considered to be the heart of ever-growing construction industry. With rapid ongoing development, there come the consequences in the form of environmental degradation. Expanding modern-day concrete jungle has an everlasting impact on all living beings and in particular the planet at large.

There is a strong need to understand and implement the sustainable development at the very roots of the construction industry. Keeping in sustainability perspective, researchers are developing more & more environment-friendly concretes with the inclusion of waste products into it. As estimated around 300 million metric tons of cement is produced and consumed annually in India only. The amount of cement produced is on the rise and so is the carbon produced by the high energy manufacturing method of cement. It is estimated that one ton of cement generates a nearly equal amount of carbon dioxide. Thus, there is a high need to find an alternate way or a more environmentally friendly cement concrete for further developments without damaging the environment further. Research is being carried out to incorporate waste materials from construction as well as other industries. Some of the materials that exhibit pozzolanic behavior and are by-products of other industries are fly ash, rice husk ash, waste glass and more. These materials are generally waste and are not recycled completely and thus prove to be a resourceful additive/alternative for the cementing materials.

Other materials that are being researched and found to be a possible in addition to the cement concrete matrix are waste plastic, waste rubber tyre, and furnace slag. There are different materials with different properties and parameters. Various materials like rha (rice husk ash), fly ash shows chemical reactivity whereas materials like waste plastic etc serve just as filler material in the concrete matrix.

1.2 CONCRETE WITH WASTE MATERIALS

As we know concrete is versatile and can incorporate a variety of waste materials. Research is being carried out to use waste materials and by-products from different sectors into the concrete mix. The waste materials are broadly classified into two categories:

1.2.1 Noble / Non- Reacting Waste Materials

The noble or the non reacting materials include the materials that do not show a chemical reaction to the cement. These materials possess inert behavior in the chemical reaction being carried out during the hydration of the cement. The noble materials are only added as filler and generally possess nonbonding behavior within the cement concrete. General examples of the noble / non-reacting waste materials are:

- I) Plastic Waste
- II) Metal Scrap Waste
- III) Wood Waste
- IV) Rubber Waste
- V) Rubble Waste
- VI) Coconut Fibers
- VII) Styrofoam



Fig 1.1 Different types of waste materials (wood, rubber etc) (Google image search)

Most of the materials mentioned above are chemically inert and have no effect on the hydration reaction of cement. These materials act just as filler material and are tested for specific parameters for usage. The material like metal scrap and coconut fibers tends to impart ductility to the concrete and improve the mechanical properties.

1.2.2 Active / Chemically Reacting Waste Materials

The active waste materials which also take part and impact the hydration reaction of cement are mentioned below:

- I) Agricultural Waste (Bagasse Ash etc)
- II) Crushed Fine Waste Glass
- III) Industrial Waste (Fly Ash, Sludge, GGBS etc)

All these materials affect the chemical reaction of cement hydration. Many industrial by-products containing high silica content exhibits pozzolanic behavior. Different parametric tests are conducted to measure the trend of impact and the extent of use of the waste material in the cement concrete.

1.3 SELECTION OF MATERIALS

The basic materials generally required for development of cement concrete include:

- *Cement*
- *Aggregates (Fine as well as Coarse)*
- *Water*
- *Admixtures (Optional)*
- *Fibers (Optional)*

1.3.1 Cement

Cement is the core cementitious material that acts as a binder and holds various other materials together as a single unit. Cement comes in two different forms, namely Ordinary Portland Cement and Pozzolanic Portland Cement, also called OPC & PPC respectively. The OPC is composed of complete cement and does not have any blended material in it whereas PPC contains blends in the form of pozzolanic fly ash replaced with cement (upto 35%). The various Indian standard codes for the different types of cement are mentioned below:

- Ordinary Portland Cement (OPC): (IS 269-1976) It is suitable for general construction
- Low Heat Cement (IS 269-1976) It is useful for a large-scale project and where a large mass of concrete is used.
- Rapid Hardening Cement: (IS 8041-1990) It is useful for rapid hardening requirement where the formwork has to be removed quickly.
- Pozzolanic cement: (IS 1489-1991) It consists of waste by-products as pozzolanic addition to cement and has high chemical resistivity.
- High Strength Cement (IS 8112-1989) It is generally used in case of pre-stressed concrete members.

Now days the Portland cement is referred to OPC and it comprises of limestone/chalk (calcium carbonate) with sand (silicone dioxide), with clay and other oxides of metal like aluminum, iron and tin heated at temperatures range of 1400-1500°C in a kiln. The material then undergoes de-carbonation which produced carbon dioxide for further production of calcium oxide. Heating further causes calcination (dry heating), in which varying calcium silicates are produced. Alite (C₃S) and belite (C₂S) are majority of the products formed. Clinker is produced by calcination, with nodules of mixed calcium silicates, which is then grinded to a fine powder and mixed with up to 10% gypsum to produce cement. The purpose of adding gypsum is to stop cement from setting too rapidly. In case of PPC, fly ash and other pozzolanic materials are blended in cement.

1.3.2 Aggregates

The aggregates are inert materials which are added to the concrete as filler materials to provide volume and strength to concrete. The aggregates are crushed stone and are classified into two major categories as follows:

- *Fine Aggregates*
- *Coarse Aggregates*

The Indian standard code for the Fine and Coarse Aggregates obtained from a natural source for concrete is IS 383: 1970.

Fine Aggregates

As per Indian Standards, the fine aggregates are referred to the aggregates passing through 4.75mm IS Sieve and shall be graded as per the below mentioned Table 1.1 (IS 2386- Part 1: 1963).

Table 1.1 Grading of Fine Aggregates as per IS 2386- Part I: 1963

Percentage Passing for				
Sieve Size	Grading Zone-I	Grading Zone-II	Grading Zone III	Grading Zone-IV
10 mm	100	100	100	100
4.75 mm	90 – 100	90 – 100	90 – 100	95 – 100
2.36 mm	60 – 95	75 – 100	85 – 100	95 – 100
1.18 mm	30 – 70	55 – 90	75 – 100	90 – 1000
600 micron	15 – 34	35 – 59	60 – 79	80 – 100
300 micron	5 – 20	8 – 30	12 – 40	15 – 50
150 micron	0 – 10	0 – 10	0 – 10	0 – 15

Thus, the fine aggregates are separated with respect to zone as per the fineness. It should be noted that the percentage finer is not overlapping at 600-micron size and hence it is referred as conforming size of the zone of aggregates. It is also clear that zone i is coarser as compared to the zone iv of fine aggregates. The characteristics and quality of the fine aggregates impact the property of concrete in fresh as well as the hardened state. The grading of fine aggregates in terms of fineness modulus affects the workability, water absorption, and strength of the concrete mix.

Coarse Aggregates

Bulk of the concrete volume is made by coarse aggregates. Natural gravel and crushed stones are mainly used as coarse aggregates. The aggregates add robustness to the concrete; as otherwise, it is a completely brittle material. Hence it can be termed as a composite material. The size and other parameters of the aggregates play an important role in providing strength and other properties to the concrete mix.

As per Indian standards, coarse aggregates is referred to aggregates retained on 4.75mm sieve and higher size. The coarse aggregate may be described as:

- i) Un-crushed gravel or stone which results from natural disintegration of rock,
- ii) Crushed gravel or stone which results from crushing of gravel or hard stone, and
- iii) Partially crushed gravel or stone which is a product of the blending of first two.

1.3.3 Water-Cement Ratio

The water-cement ratio is another important factor which has the highest impact on the strength of the concrete mix. It is defined as the extent of water added with respect to the cement (or binder) content. The water added should be free from chemicals and salts. Also, it must be noted that the water is used for complete hydration of the cement and adding flowability/workability to the concrete mix. Higher the water content, higher the ratio, more will the workability.

Generally, the lower water-cement ratio is used for concrete with high strength targets and a higher ratio for the nominal concrete mixes. The water-cement may vary from 0.15 to 0.5 depending on the type of concrete, its constituents, and the target properties. In case of the mixture that consists of other/ more binding materials except for cement, the ratio is termed as water binder ratio. The water content requirement is also affected by the size of aggregates and other binders. Adding admixtures like super plasticizers also help in reducing the ratio and utilizing the water content to a better extent. Thus, the water content can be varied with respect to the required property and constituents of the mix.

1.3.4 Admixtures

The chemical additives meant to enhance/change properties of the concrete mix are termed as concrete admixtures. There are various types of admixtures used for different purposes in the concrete. Some of the commonly used admixtures are mentioned below:

- Set Retarder: To slow down the chemical reaction taking place in the concrete for the setting.
- Air Entraining: To add air voids in order to increase free-thaw resistance and reduce bleeding/segregation.
- Water Reducing Admixture: To give desired workability and slump even at lower water/cement ratios.

The chemicals added take part in the hydration reaction and impart the desired property to the mix. Various chemicals are used in different situations as per the requirement of construction. Some of the basic benefits of adding the admixture are specified below:

- Improved Workability: Easy and quick placement of concrete. May require very less or no vibration to the mix. Useful for congested reinforcement spaces.
- Increased Strength: The admixture also tends to help concrete mix gain higher strength by giving a higher extent of chemical reaction of cement hydration. The water-reducing admixture can also give higher strength and workability at lower water-binder ratios.

The Dosage of the admixture is carefully experimented and tested for the desired results. The amount of chemical added is much dependent on the conditions, utility, and constituents of the mix. A general range of 0.2-2% by weight of the cement is used in most of the cases. It must also be noted that overdosage can have contrary effects and may cause segregation/bleeding and loss in strength or durability parameters of the mix.

1.3.5 Fibers

Fiber refers to the small reinforcing material which helps in binding the concrete matrix better, thereby imparting strength to concrete. Fibers can be circular or flat in cross-section. Generally, the fibers are defined by a parameter termed as the aspect ratio of the fiber. It is defined as the ratio of the length of the fiber to the diameter of fiber. On an average the aspect ratio of fibers lies between 30 and 150.

There are different types of fibers being majorly classified on the basis of material they are made of. Some of these types are listed below:

- i) Steel Fibers
- ii) Polypropylene Fiber or Polymer Fibers
- iii) Glass Fibers
- iv) Asbestos Fibers
- v) Carbon Fibers
- vi) Organic Fibers

As concrete is a brittle material and does not possess much ductility and tensile strength, fibers are added to enhance such properties. The benefits of adding fibers to the concrete mix are mentioned below:

- It improves the tensile strength and provides ductility to the concrete.
- It tends to reduce the air voids and water voids formed in the concrete mix
- Fibers also improve the durability properties of the concrete.
- Properly oriented fibers also tend to give better output in creep performance of the concrete.



Fig 1.2 Different types of fibers (Steel, Polypropylene etc) (Google Images)

It must also be noted that addition of fibers in higher volumes in the concrete matrix can also form a cluster and hence act otherwise to reduce the bonding and strength at the particular point. Thus it is important to uniformly distribute the fibers with right orientation. With the addition of fibers, the workability of the concrete also gets reduced. Different fibers have different parameters to be tested and their addition affects different set of properties of the concrete mix.

1.4 ADVANTAGES OF USING WASTE IN CONCRETE

As with the growing economy and development, the next problem rising in modern day is waste management. A lot of research and efforts are being put into utilize waste materials in a better way. Thus, to come up with a solution that can be applied to the mass scale is a real need of the hour. Considering the concrete materials and waste materials listed earlier, it is worth mentioning the research that has been carried out as a part to provide green / eco-friendly Concrete alternatives.

Thus the addition of industrial waste into the concrete can help solve major issues and also provides multi benefits mentioned below:

- *Solution to the rising waste management problem:-* As concrete is widely used and thus mass application can help sort the waste issues in any particular area.
- *Less Carbon footprint of the concrete:-* Addition of waste material will take up the volume in concrete, hence reducing the content of cement or other constituents used for the mix. This will help to make the concrete that would have less carbon footprint as compared to the traditional concrete.
- *Improvement in the concrete properties:-* Various waste materials with pozzolanic properties also have cementitious behavior and improve various properties like strength, water absorption and durability characteristics of the concrete mix. This helps in wider utilization of the waste in concrete development on a large scale.
- *Economical benefits to the society:-* Addition of certain type of waste materials can help reduce the cost of cement concrete. Hence, it becomes important to incorporate such waste materials into construction for low-cost housing construction projects.

As concrete is used worldwide, the waste inclusion can help on large scale. Thus it is clear from the above-mentioned points that, the addition of waste materials into concrete can help solve environmental, waste management, and economical construction issues. As the sustainable development is the need of the hour. Henceforth, it becomes important to carry forward the research in this field and bring out the results for real-world implementation.

1.5 APPLICATIONS OF ECO-FRIENDLY CONCRETE

Concrete with waste material as constituents exhibits different properties as compared to traditional concrete due to the presence of waste. Thus, this property variation can be leveraged in making eco-friendly concrete.

Considering the earlier mentioned waste materials, it is generally noticed that with additional inert / noble waste materials, the concrete tends to have lighter density and lower strength. For example, with the addition of plastic to concrete, it reduces the density and decreases the strength of the mix. Therefore, these kinds of concrete mixes properties can be used to form non-structural elements that do not require load-bearing properties. This sort of mix can also be implemented in pre-fabricated panels that can form temporary partition walls with nominal weight and strength.

Considering the case of metal or rubber waste, it is generally observed that these two materials tend to impart ductility to the concrete in the form of fibers. Thus, concrete containing rubber fibers or waste metal fibers can be useful in places of high deflection area in the structure.

In case of styrofoam, it is noted that the concrete losses its density to a large extent. The styrofoam also imparts high insulation to the concrete mix and thus, this sort of mix can be easily used in case of pre-cast walls or bricks which are non-load bearing. As higher insulation helps saves energy and hence, this concrete can provide best solution in terms of economy as well as energy saving. Moreover, styrofoam is not bio-degradable and using it in concrete will also reduce the carbon footprint of the concrete in a considerable way.

1.6 OBJECTIVES OF THE PRESENT STUDY

Every research work must be carried out with clear objectives in mind as for why is this work required with the real motive for doing it. The objectives of this research work are specified below:

- To use the opportunity of research for master's thesis for a real-world product development
- To use the knowledge and guidance provided for doing research in the right way
- To utilize knowledge and skills and develop something useful and impactful using research & development
- To instill the sustainable development in the roots of the construction industry
- To use research for a positive impact on the Environment and betterment of human life
- To use knowledge and bring out a solution for the current major problem being faced by the country and people in the construction sector
- To work towards the development of product and bring an Eco-friendly alternate product for clay bricks
- To inculcate waste materials with suitable properties to enhance the parameters of the developed product

The motivation for the research work done during this research comes with a reason to do something better for the world and leaving an impact using the knowledge and skills. The motive of this work is to use the technology and come out with innovative solutions for the problems in the construction sector. The key goal is to develop something that not only is better than the traditional but also is Environmental Friendly. The aim of the research work done is to bring out something that's helpful in the real world scenario and leaves a positive impact.

Thus, with the above target objective and the motive, the research work was carried out. With great support from the institution and faculty members, it becomes easy to work towards the goal. This research work is a small effort to bring out a change, a change that can help and motivate others to not just limit the research work up to academic records but work to bring the results in real-world scenario. The research results may or may not be the one desired, but the work shall not stop with the right motive and clear objectives.

1.7 ORIENTATION OF THE THESIS

The orientation of present study report has been summarized in the following points:

- 1) In the present report, the first chapter includes the basics of the concrete materials and different waste materials (with classification).
- 2) In the second chapter of this report, detailed literature studies and past research work done is presented.
- 3) Third chapter of the report deals with the summary of materials used and methodology involved in the research work.
- 4) Fourth chapter includes the results obtained from the previously mentioned experiments in the research work.
- 5) Fifth chapter mention the conclusion remarks from obtained results and scope of further research work.

CHAPTER 2-LITERATURE REVIEW

2.1 GENERAL

The literature review presented herein has been segregated on the basis of three main categories of the properties of concrete.

i) *Physical Properties of Concrete*

This includes the properties of concrete like density and workability which are considered important for the aspect of construction of bricks made out of concrete. Waste glass and plastic optical fibers (POF) affecting the above properties in a different way in different conditions are reviewed further in detail.

ii) *Mechanical Properties of Concrete*

The mechanical properties of the concrete in the form of brick/ block are majorly focused on compressive strength. Reviewed studies mention the impact of waste glass and plastic optical fibers (POF) on the mechanical properties of the concrete mix/ block with different adding proportions. These properties are majorly important in case of structures which are built with load bearing walls otherwise these parameters hold little importance due to usage of framed structures in the buildings.

iii) *Durability Properties of Concrete*

The durability aspect of the concrete in the form of a brick/block is considered to be a most important parameter to be tested for the impact of waste glass and plastic optical fibers (POF) addition. The durability characteristics generally include water absorption, chemical attack, permeability and other aspects. These parameters tell us the behavior of the mix over a long duration of time.

In the literature survey waste glass and plastic optical fibers were studied for their impact on the above-specified properties of the concrete mix.

2.2 PHYSICAL PROPERTIES OF CONCRETE

The below noted physical properties of concrete with waste glass were studied.

2.2.1 *Density*

Density is defined as the ratio of mass per unit volume of the concrete (in any well defined shape/form). The variation of density of the concrete mix with waste glass and plastic optical fibers were studied and following are the results reviewed.

i) *Waste Glass*

Bekir et al. (2003) found that glass has been an important part in human's life due to its versatility to take any shape and hardness. They studied the effect of different types of glass of different sizes, chemical composition and concrete properties. The unit weight of fine aggregates used in their study ranged from 0 to 4mm was 2584 kg/m³; for crushed stone of 4 to 6mm size range (CS I) was 2714 kg/m³; and for crushed stone with size range of 16 to 32mm (CS II) was 2715 kg/m³ in accordance with ISO 6783. The chemical composition of the glass used in this study is tabulated as Table 2.1.

Table 2.1 Chemical composition of waste glass used by Bekir et al (2003)

(Silica) SiO ₂ 70 – 75%	(Sodium) Na ₂ O 12 – 18%	(Potassium) K ₂ O 0 – 1%
(Calcium) CaO 5 – 14%	(Aluminium) Al ₂ O ₃ 0.5 – 2.5%	(Magnesium) MgO 0 – 4%

Bekir et al used WG as a coarse aggregate replacement. The waste glass content were 0, 15, 30, 45 and 60% of the total volume of coarse aggregates. The unit weight of WG used was 2400 Kg/m³. The unit weight of controlled concrete was 2340 kg/m³ and a fall of ~ 0.3% in unit weights was observed as mentioned in Table 2.2. The unit weight of concrete with WG up to 60% replacement was around 2335 KG/m³. This decrement was caused due to comparatively low specific gravity of WG.

Table 2.2 Variation of unit weight of concrete with waste glass by Bekir et al (2003)

Percentage of waste glass	The density of Fresh Concrete (Kg/m ³)
0 %	2340
15 %	2337
30 %	2336.4
45 %	2335.5
60 %	2335

Sadoon et al. (2014) reviewed WG replacement with the fine aggregates and using OPC in the concrete mix to determine its impact on fresh concrete and mechanical properties. The fine aggregate used was the natural sand with maximum size of 4.75mm and the coarse aggregate was natural quartzite gravel of maximum size 20mm with a bulk density 1530kg/m³. The chemical composition and particle size/ sieve analysis were determined for WG and is mentioned in Table 2.3 and Table 2.4. The unit weight of waste glass used was 1460 Kg/m³.

Table 2.3 Chemical composition of waste glass used by Sadoon et al (2014)

(Silica) SiO ₂ 65 – 71%	(Sodium) Na ₂ O 17 – 22%	(Potassium) K ₂ O 1 – 2%
(Calcium) CaO 6 – 12%	(Aluminium) Al ₂ O ₃ 1 – 2.5%	(Magnesium) MgO 0 – 3%

Table 2.4 Grading of waste glass aggregate used by Sadoon et al (2014)

Grading of glass aggregate Sieve size(mm)	Mass Retained (gms)	Retained %	Passing %	Cumulative Retained %	ASTM Standard Specification
4.75	0	0	100	0	95-100
2.36	1.7	0.17	99.83	0.17	80-100
1.18	357.7	35.77	64.04	35.94	50-85
0.60	230.9	23.09	40.97	59.03	25-60
0.30	200.2	20.02	20.95	79.05	5-30
0.15	113.2	11.32	9.63	90.37	0-10
Pan	96.3	9.63	0	0	0
Fineness modulus of glass, $\Sigma F/100 = 264.56/100 = 2.64$			264.56		

Four combinations of concrete mix proportion with the addition of waste glass were prepared. The following observations were made for the dry density of concrete mix at 7, 14 and 28 days. A mixing ratio of 1: 2.2: 2.7 was used in this research.

Table 2.5 Dry density of concrete with varying WG percentage by Sadoon et al (2014)

Type of Concrete mix	Dry density kg/m ³ at ages of		
	7 days	14 day	28 day
Control	2365	2378.6	2398
5% WG	2358.5	2364.3	2374.2
15% WG	2354.8	2362.9	2366.1
20% WG	2351.4	2359.7	2360.2

From Table 2.5 it is clearly noticed that the increase in WG content as fine aggregate tends to reduce the dry density of the concrete.

The reason for the above behavior is mentioned as attributed to the lower specific gravity of the WG than that of the fine aggregates used in the control mix and hence resulting in a lower density of the overall concrete mix. A higher percentage of decrease is observed in 28 days density as compared to dry density in 7 days.

2.2.2 Workability

Workability is defined as ease of working with concrete. It implies to higher flowability and lesser viscosity of the concrete. Generally workability is mentioned in terms of Slump value. The Slump test is a common standard test to determine the slump value of the concrete. The slump can be performed in labs and at site as well.

i) *Waste Glass*

Bekir et al. (2003) reviewed that the effect of different types of glass (varying sizes and chemical composition) on the fresh concrete properties. It was observed that with increasing proportion of WG, value of slump was decreasing by 0.2% due to the poor geometry of the waste glass aggregates (similar results in research reference for which the decline in slump was nearly 2%). High proportion of WG unevenly decreased air content as much as 27% whereas the air content of the concretes was 0.4–0.7%. This behavior was cited to be the result of the poor geometry of waste glass aggregates which caused the voids in air and water to occur in lower parts particularly. Due to low air content in concrete and smooth surface of WG reduction in porosity between WG and cement paste was observed. The resulting slump with varying WG percentage is specified in table 2.6. A uniform decrease in the slump is observed with increase in the inclusion of waste glass into the concrete mix.

Table 2.6 Variation of a slump with WG content Bekir et al (2003)

Percentage of waste glass	Slump (cm)
0 %	9.8
15 %	9.5
30 %	9.3
45 %	8.9
60 %	8.5

Table 2.7 Variation of flow table value with WG content by Bekir et al (2003)

Percentage of waste glass	Flow Table Value (cm)
0 %	5.4
15 %	5.7
30 %	6.0
45 %	6.4
60 %	6.7

Workability is also specified in terms of flow value by flow table test. Results in the flow table values are mentioned in table 2.7. The WG inclusion increased flow table values by nearly 4% attributed to the non absorbing property of the WG aggregates, as compared to traditional aggregates. It was concluded that poor geometry and non-absorbing behavior of waste glass tends neutralize the effects and have minimal effect of workability.

Mizi Et al. (2014) studied the effect of waste glass particles as partial replacement of fine aggregates on fluidity of concrete mix. In this research OPC and waste glass were used with several mix proportions. Reduction in slump values with increase in waste glass content was observed. Decrement shows logarithmic behavior with a high degree of fit. The values of slump test were 65, 56.5 and 52mm for the concretes with 5%, 15% and 20% of waste glass respectively, representing a reduction of 19, 29 and 35% respectively in comparison with 80mm for the control concrete as mentioned in table 2.8. The sharp and irregular shape of the glass particles in comparison to sand particles were cited to be reason for high friction and such resulted in less fluidity. In comparison with the results of previous work which showed that increasing the ratio of waste glass by 30%, 50% and 70% as aggregate resulted in a decrease in the slump by 19.6 –26.9%, 30.1–34.6% and 38.5–44.3% respectively. In case of control mix depending on surface parameters of the waste glass particles the reduction in fluidity can be significant. The following table 2.8 depicts the value of the slump obtained with varying glass aggregates percentage in the concrete mix. The value of slump shows a logarithmic decrement with increasing value of glass aggregate content in concrete mix.

Table 2.8 Decrease of slump increasing glass %age by Mizi et al (2014)

Percentage of waste glass	Slump Value (mm)
0 %	88
15 %	80
30 %	65
45 %	56.5
60 %	52

Two different applications of using waste glass as coarse aggregate or as fine aggregate in the concrete mix. The comparative analysis of above research shows that that the slump or the workability has higher reduction value when waste glass is used as coarse aggregate. It is attributed to irregular shape and sharp edges which may cause friction within the paste and reduces the flowing ability of the mix. On other side, it is also noted that the glass particles having higher silica content shows pozzolanic behavior when used as fine aggregate. It also noted rise in the flow diameter with the inclusion of waste glass with reason as less or no water absorption by the waste glass aggregates which in turn provides higher water content which in turn increase the flowability of the concrete.

It can be concluded that in case the wg is crushed to certain fineness level it act as pozzolanic materials (due to high silica content) and be used in as binder or replacement of the cement in the concrete mix. A similar behavior was also depicted in terms of the physical properties of the concrete, as with replacement of cement with waste glass.

The further section begins with the study of mechanical properties of concrete, which contains waste glass and plastic optical fibers. The various strength parameters like compressive strength, tensile strength, and flexural strength are measured with varying percentage of waste glass and plastic optical fibers. The review of research papers helps to understand the behavior of different parameters with different materials to be mixed in the concrete. In the final section, some specific durability properties of the concrete are also discussed and reviewed.

2.3 MECHANICAL PROPERTIES OF CONCRETE

The below mentioned mechanical properties of the concrete with waste glass and plastic optical fibers are reviewed.

2.3.1 *Compressive Strength*

It is the measure of compressive stress that the concrete mix can bear safely. The compressive strength is a major mechanical parameter and is largely affected by alteration of materials. Following research/review papers are reviewed to study the impact of WG on the compressive strength of concrete.

i) *Waste Glass*

Bekir et al. (2003) tested the compressive strength of the concrete having waste glass as coarse aggregates in the mix. The specified mix design and material details are discussed previously for this research. It was noted that 28 days compressive strength was 12.04–23.50 MPa of control mix specimen. Decrease was observed in compressive strength with increment in waste glass proportion in the concrete mix. It was observed that with 15% aggregate replacement by WG, decrease of 8% was noted in compressive strength and with 30% of WG content a decrease of 15% in the compressive strength was noted. Similarly decrease of 31% was determined when the WG was 45% proportion of the aggregates. A fall of 49% in compression strength was determined, in case when the WG proportion reached 60%. The results are tabulated in Table 2.9. It was cited that strength reduction is caused by cracks at inter phase due to incomplete adhesion on smooth surface of the glass. With the random irregular shape and geometry of the WG no homogenous mixture was obtained. Increase in glass content aggregates decreases the compressive strength. In another review, it was [21] reported that the addition of WG (15%) into concrete in crushed forms increased the compressive strength of concrete as much as 13%. It was found that the fine WG shows pozzolanic reactivity due to silica that resulted increase in compressive strength by increasing glass content. Another review [12] reported decrement in the compressive resistance as the WG content is increased in accordance with dosage and noted that the compressive strength was reduced by nearly 19% of that of control mix.

Table 2.9 Variation of Compressive Strength with waste glass by Bekir et al (2003)

Percentage of waste glass	Compressive Strength (MPa)
0 %	23.5
15 %	21.67
30 %	19.55
45 %	16.12
60 %	12.04

Sadoon et al. (2014) replaced fine aggregates with the waste glass particles. The mix design parameters and the material properties have been discussed previously in this report. Compressive strength of the control and waste glass concretes at 7, 14, and 28 days is shown Table 2.10. Slight rise in the compression strength with the addition of waste glass was observed. Results of this research show an increment of 5.28 % as compared to the control concrete mix, made of 20% waste glass fine aggregate. It was observed that the percentage increases in compressive strength with age overall increased with the increment of glass aggregate replacements. This was attributed to pozzolanic reaction by silica content of waste glass at later stage and thus contributes to an improvement at 28 days. The fineness of the glass aggregates is mentioned in Table 2.4 earlier. The finer part of the glass possesses the pozzolanic activity and thus causing the above trend. No such trend was observed with WG replacement of coarse aggregates in the research reviewed previously,

Similar observation was reported by one of their reference paper with a similar pattern of replacement of the fine aggregates with waste glass.

Table 2.10 Variation of compressive strength by Sadoon et al (2014)

Compressive strength→ Percentage of WG↓	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
0 %	24	29	32
5 %	26.5	29.5	31
15 %	23.5	30	31.5
20 %	26	28	34

Opposite behavior of trend is noted in above review studies of compressive strength. A reason for this is the replacement / using the WG aggregates as either coarse or fine aggregate. With more fineness higher amount of the silica content shows pozzolanic behavior. The strength tends to be higher when the finer particle size is used and it is expected to gain higher strengths during its lifetime due to pozzolanic reactions caused by glass particles.

From the above research reviews it can be established that the waste glass (WG) exhibits different behavior depending on the replacement and size of the crushed glass used. A similar deviation is depicted in the case of physical properties. High fineness allows more silica content present in the waste glass to react as a pozzolanic material which results in the formation of more cementitious material on reaction with calcium carbonate. This process helps to gain higher strength level on the later stage of concrete.

ii) *Plastic optical fibers*

Yue Li et al. (2015) used plastic optical fibers in the cement mortar and termed it as light transmitting cement mortar (LTCM). High consistency matrix material of LTCM was used. The mix design ratio used for the preparation was 1: 0.75: 4 (cement: sand: blast furnace slag) with 0.2 % of water reducing agent added to it. The optical fibers were woven in the form of fabric in the form of a monolayer. The fibres were distributed in a single direction with cotton yarn supporting at the other end as shown in Fig 2.1. The spacing of fibers was stabilized in the range of 3 to 6mm.

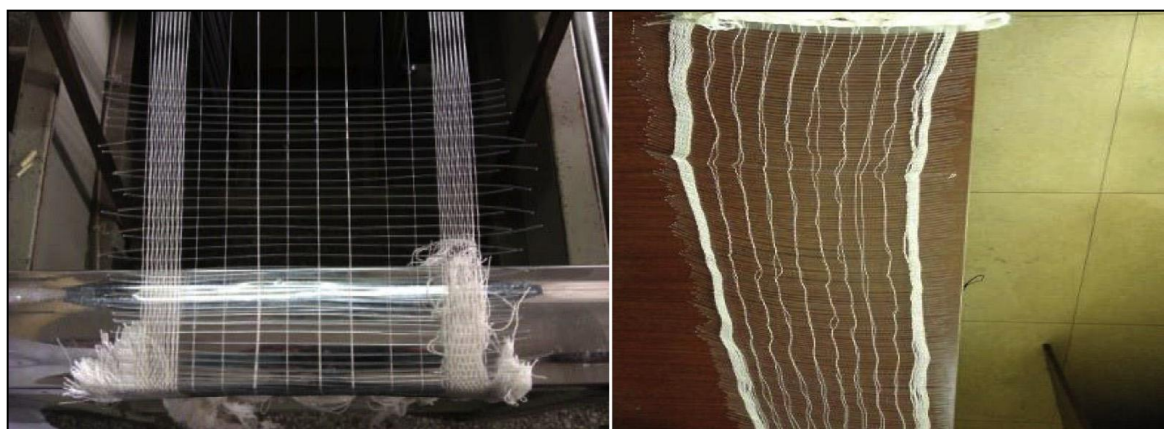


Fig 2.1 Preparation of Optical Fiber Fabric by Yue Li et al (2014)

The fixation of fiber fabric was done by steel bars inserted into the concrete mould. The steel bars are kept parallel, in the direction of the long axis, with specific design distance. The fiber fabric was twined between the parallel steel rods of the mould, and the fabric

was straightened by the steel bars. Also, the steel bars can be placed into certain design or a pattern with the open end of a wooden mould. The twining of the fiber fabric can form the design as per the pattern of steel rods and hence give the desired look as shown in Fig 2.2.

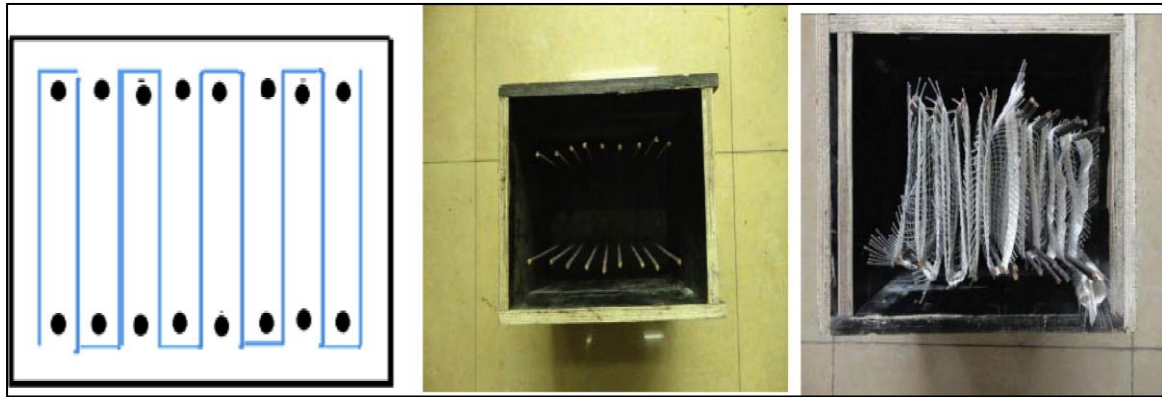


Fig 2.2 Steel Rods and twining of fiber fabric in the mould by Yue Li et al (2015)

The mechanical properties (compression resistance) specified in the Table 2.11 depicts that compressive strength of control mix mortar is slightly higher than that of light transmitting cement mortar. It is noticed that strength tends to decrease with increase in volume of fibers in the concrete mix. With the fiber inclusion of 4%, the compressive and the flexural strength is 81% & 83% of that normal cement mortar respectively. The mortar exhibits good consistency with no bleeding or segregation.

Table 2.11 Variation of compressive strength with POF % by Yue Li et al (2015)

Dia of POF (mm)	The volume of Optical Fiber (%)	Compressive Strength (MPa)
---	0	70.5
0.5	0.5	69.1
0.5	0.75	68.2
0.5	1	66.7
1	1	67.3
1	2	64.1
1	3	61.5

Thiago et al. (2017) used polymer optical fibers in cement mortar and termed it as light transmitting cement based material (LTCM). Materials used in this research were standard cement as per ASTM and sun-dried fine aggregates. High-efficiency water reducer was used in the mix and alongside partial replacement for 10% (by weight) of the cement with silica fume was used to avoid segregation. The diameter of the POF was noted to be 0.4 mm by three-point measurement.

The specimen with orderly arranged fibers was tested. Laser cut acrylic sheets were used for best distribution of the fibers (size 40 x 40 x 160 mm). Four samples were tested for each combination of POF content. Manual fabrication of the fibers into mould holes was done. The tested parameters for 0%, 2%, 3.5% and 5% POF were compression strength and flexural tensile strength, capillary water absorption and light transmittance, at 28 days. Results obtained of compressive strength at 28 days are given in Table 2.12.

Table 2.12 Depicts variation of compressive strength with POF % by Thiago et al (2017)

Fibers Arrangement	Fiber Volume	Average Resistance to Compression / Compressive Strength (MPa)
Sorted	0 %	56.81
Sorted	2 %	57.06
Sorted	3.5 %	53.99
Sorted	5 %	50.64

With increase in POF (plastic optical fibers) content decrease in compressive strength was observed. From Table 2.12, it is seen that value of 0% and 2% are statistically equal. Further increasing the POF content from 2% to 3.5%, there is significant fall in the compressive strength by nearly 5.38%. In next composition with POF content as 5%, decrease of 6.30% in the compressive strength was noted. Further it was noted that polymer fibers tend to have less decrement in the compressive strength as compared to other fibers used in the concrete mix. The loss of strength can be reasoned upon the smooth and non-bonding surface of the fibers. Whereas properties like tensile strength, modulus of elasticity of fibers may also be affected in same manner. In this research, even with the use of high tensile fiber an adverse behavior was observed due to the low grip of fiber and the matrix. Less gripping due to the parallel arrangement of fibers was also cited as one reason for the reduced strength.

2.3.2 *Flexural Strength*

It is the measure of tensile strength / bending that the concrete mix can bear safely. The flexural strength is a major mechanical parameter to be studied and is largely affected by alteration of materials. Further described are details of research paper reviewed about impact of material on the flexural strength of the concrete.

i) *Waste Glass*

Bekir et al. (2003) tested the tensile strength of the concrete having waste glass as coarse aggregates in the mix. The specified mix design and material details are already discussed earlier for this research work. Tensile strength test results produced results varying from 1.63–2.59 MPa as mentioned in Table 2.13. Trend of decreasing indirect tensile strength as much as 10% was noted with WG (waste glass) addition. Indirect tensile strength shows a decrease of 37% as a result of 60% of WG addition. The decrease in the tensile strength was due to the irregular shape of aggregates and poor interphase bonding between the paste and the glass aggregates. The tensile strength table for this research is shown below.

Table 2.13 Variation of Flexural Tensile strength with WG by Bakir et al (2013)

Percentage of waste glass	Flexural Tensile Strength (MPa)
0 %	2.59
15 %	2.34
30 %	2.24
45 %	2.10
60 %	1.63

Above results shows that value of flexural tensile strength tends to decrease with increase in the percentage of waste glass as coarse aggregate. As mentioned, one reason for this result is due to the irregular shape of aggregates and hence which forms weak interfacial zone between the glass surface and the concrete matrix. As WG content increases, high irregularity in the matrix and rise in weak interfacial zones. It is also noted that fall in strength is higher when WG content in concrete mix is above 30% and gives a lower strength value at higher WG content.

Sadoon et al. (2014) replaced fine aggregates with the waste glass particles. The mix design parameters and the material properties have been discussed earlier in this report. It was reported that flexural tensile strength for all mixes after being cured for 7, 14, and 28 days shows a mix value trend as given in Table 2.14. Results show positive deviation with overall tensile strength increased by the time for all mixes after 28 days. It was noted that addition of waste glass up to 5% had negligible impact on the strength whereas higher WG content had a significant influence on the early age strength. Opposite trend behavior at later stages, as the tensile strength of specimen with 20% WG content possessed higher strength by 18% than the normal was observed.

Table 2.14 Variation of Flexural Tensile Strength by Sadoon et al (2014)

Flexural Tensile strength→ Percentage of WG↓	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
0 %	2.1	2.4	2.5
5 %	2.0	2.1	2.5
15 %	1.4	1.5	2.7
20 %	1.6	1.7	3.0

ii) *Plastic optical fibers*

Yue Li et al. (2015) used plastic optical fibers in the cement mortar and termed it as light transmitting cement mortar (LTCM). Material properties have been described earlier. Table 2.15 shows variation of flexural strength with volume and diameter of the POF.

Table 2.15 Variation of compressive strength with POF % by Yue Li et al (2015)

Dia of POF (mm)	Volume of Optical Fiber (%)	Flex. Tensile Strength (MPa)
---	0	9.1
0.5	0.5	8.8
0.5	0.75	8.8
0.5	1	8.6
1	1	8.7
1	2	8.2
1	3	8.0

Flexural tensile strength was tested in perpendicular direction to the plastic optical fiber fabric placement. Similar trend as for compressive strength was observed. Due to the non-binding behavior of fibers with concrete matrix, strength reduced with increasing fiber content. It was observed that lower diameter with high number of fibers gives less decrement due to slight ductility imparted as compared with large diameter and less number of fibers.

Thiago et al. (2017) used polymer optical fibers in the cement mortar and termed it as Light Transmitting Cement based material (LTCM).

Below are the average 28- day's flexural tensile strength results in Table 2.16. It is noticed that fiber addition decreased speed of crack propagation, plastic deformation, better toughness, and improved ductility. Result shows higher variability as compared to the compression test. It is concluded that very high fiber content can significantly decrease the workability as well as the mechanical properties. Another cause for such behavior is due to the equidistant distribution of POFs in the mould. This forms fragile layers with less gripping by the extremely smooth fibers. Therefore, increasing the fiber content in sorted form tends to reduce the average flexural tensile strength.

Table 2.16 Variation of flexural tensile strength with POF % by Thiago et al (2017)

Fibers Arrangement	Fiber Volume	Average Flexural Tensile Strength(MPa)
Sorted	0 %	1.59
Sorted	2 %	1.30
Sorted	3.5 %	1.27
Sorted	5 %	1.30

From above results decrement on first addition of the fibers is observed. Afterward the decrement is negligible and the strength remains almost same for 2 % to 5 % fibers content. Observed behavior is due to ductility aspect added to the concrete mix with the presence of fibers. Moreover fibers also act as crack arrestor and increase the plastic deformation and not much loss or decrease in the strength is observed at a higher volume of the fiber content.

2.4 DURABILITY PROPERTIES OF CONCRETE

The durability properties of concrete containing waste glass and plastic optical fibers are reviewed further.

2.4.1 Alkali-Silica Reaction (ASR)

It is a swelling reaction that occurs over time in concrete between the highly alkaline cement mixes. The highly alkaline content can be found in silica rich aggregates and hence cause considerable expansion and crack issues. This is an important test for high alkaline or high silica aggregates concrete mix.

i) *Waste Glass*

Bekir et al. (2003) tested the concrete having waste glass as coarse aggregates for the alkali-silica reaction. The specified mix design and material details are already discussed earlier for this research work. The alkali-silica reaction test results are shown below in the Table 2.17. Specimen with 100 % of WG replacement had 0.2 % more expansion before 3 days. For specimen with 0 % of the WG content, the expansions were more than 0.2% after four days. It justifies that ASR (alkali-silica reaction) slows down with lesser WG content in the concrete mix. Further mechanical properties like compressive or flexural strength were not affected much by the color of the waste glass used, whereas it was observed that white glass caused higher dilatation than green / brown glass and ASR limit value after four days.

Table 2.17 Variation of Expansion with WG content by Bekir et al (2003)

% Expansion → Percentage of WG ↓	3 Days (MPa)	7 Days (MPa)	14 Days (MPa)
0 %	0.21	0.35	0.54
25 %	0.20	0.34	0.53
50 %	0.20	0.34	0.52
75 %	0.18	0.32	0.48
100 %	0.17	0.29	0.47

Sadoon et al. (2014) used the replacement of fine aggregates with the waste glass particles. The mix design parameters and the material properties have been discussed earlier in this report. The alkali-silica reaction (ASR) determines any reaction in concrete occurring between the active silica present in aggregates and alkali in cement. Reaction occurs between silica molecules of certain siliceous rocks and the hydroxide ions in the salts of sodium and potassium. It should be noted that the alkalis do not attack the reactive silica. The presence of alkalis is important as it has a high concentration of OH⁻ ions, which gives high pH value to help initiate the breakdown of the alkali-silica reaction. Expanding silica gel is produced by the reaction. The gel formed on the aggregate surface impacts the stability and strength of the concrete mix. It is observed that there is strength increment due to the filling of bond in the concrete matrix, and the process can be considered quite similar to the pozzolanic reaction. Below mentioned in Table 2.18 are the expansion values of the waste glass mixes at 3, 7 and 14 days.

It can be concluded that with the increase in WG contents to 20%, there is a clear reduction in the expansion value. This decrease may be attributed to the reduction of available alkali (as the lime is consumed by reaction with WG) and the expected reduction of the system alkalinity.

Table 2.18 Variation of Expansion with WG content by Sadoon et al (2014)

% Expansion → Percentage of WG ↓	3 Days (MPa)	7 Days (MPa)	14 Days (MPa)
0 %	0.015	0.030	0.080
5 %	0.009	0.019	0.060
15 %	0.009	0.010	0.030
20 %	0.008	0.008	0.020

Thus from the values in the above table, it can be clearly concluded that with the addition of the waste glass content into the concrete mix the expansion shows subtle decrement. As the silica content present in the glass shows the pozzolanic reaction. This pozzolanic reaction caused by the silica in the WG content reduces the amount of free alkali available for the reaction and hence causing a reduction in the expansion of the specimen with increasing glass content in the concrete mix.

Further discussed is the light transmission property for the concrete containing plastic optical fibers to find out the transmission from the tested sample in the review.

2.4.2 *Light Transmission*

Yue Li et al. (2015) used plastic optical fibers in the cement mortar and termed it as light transmitting cement mortar (LTCM). The mix ratio and the material properties have already been described earlier for this research. For specimen containing optical fibers an important to measure is transmission of lights through it with varying incident angles and light colors.

In this research, an optical power meter was used to measure the light transmission. The detector diameter of the 1-centimeter range measured the transmitted light from the optical fibers (1 to 4) of the specimens (as depicted in explanatory Fig 2.3).

The samples using POF of diameters 1 mm was labeled Sample A and with 0.5 mm was Sample B. Through the transmission test for both samples it was observed that the transmission increase with the increase in the number of fibers in the testing diameter range, irrespective of the color of the light.

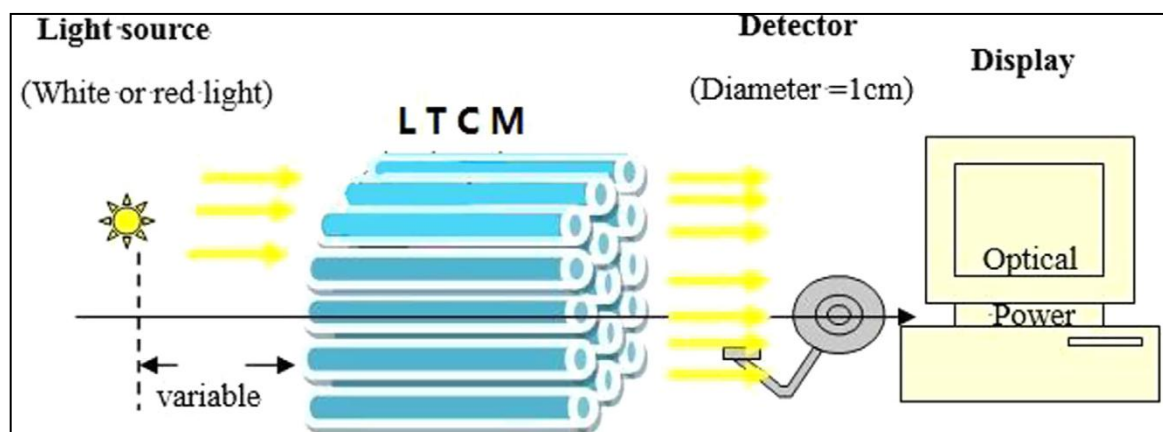


Fig 2.3 Transmission test explanatory picture for the LTCM Sample Yue Li et al (2015)

The equal transmission regardless of the color of the light is because the emergent light of each fiber is scattered, the spot gets larger with distance and thus the light incident on the detector losses intensity measured. It was also pointed that initially, the optical power output reduced significantly and further on the decline rate of slowed gradually, and then almost tends to be the same.

For single fiber in test zone of the sample with zero distance from the white light source, the ratio is 4.72 (which is higher than the ratio of section area of fiber). Further with the increasing distance, a decrease in the ratio is observed in the range of 2.5 to 3.5. However, in red light for no distance between the sample and the light source, the

observed ratio was 3.67 smaller than the ratio of fiber section area). In a Similar way, with the increasing distance, the ratio is reduced to a range of 1.5–2.5.

Secondly in case of two fibers in the test zone and no distance between white light source and sample, the output ratio comes out to be 4.5 (which is higher than the ratio of section area of the fiber). Decreasing behavior was observed in the ratio with gradually increasing distance. The ratio ranges between 3.5 and 4.5. For the red light source with no distance between the specimen and the light source, the observed ratio was 4.1 (slightly higher than the ratio of fiber section area). The ratio tends to decrease to a range of 1.8 and 3.6 with the increase in distance as shown in Fig 2.4 and Fig 2.5.

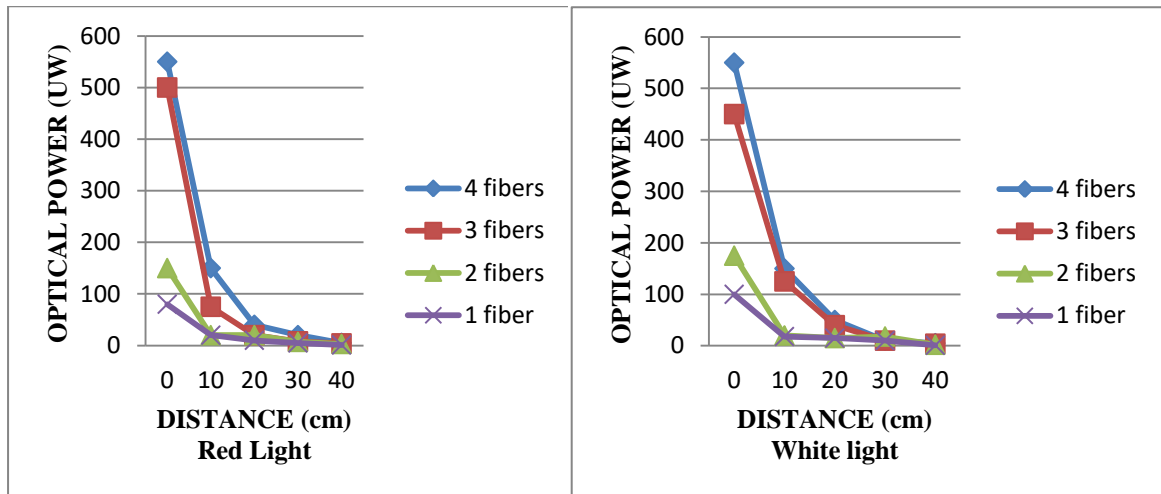


Fig 2.4 Transmission test explanatory picture for the LTCM Sample Yue Li et al (2015)

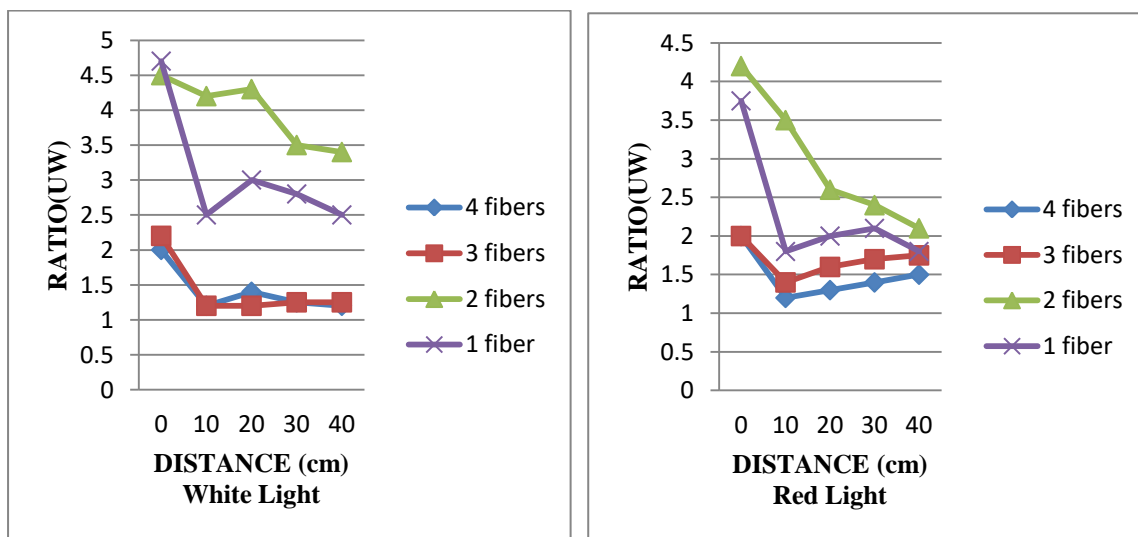


Fig 2.5 Optical power ratio for sample A & B by Yue Li et al (2015).

Thus it was concluded that the causes for above behavior are due to the interference of the light and scattering happened due to the complicated propagation of light. It was noted that ability to transmit light by the fiber is not a simple superposition of translucent area. Due to uneven and irregular sections of optical fibers there is a scattering of emergent light at the exit end causing the irregular distribution of incident light in the detection area. The wavelengths of lights received by the detector were affected by the small variation in the relative position of optical fibers. For distant fibers detector was not able to measure the scattered light. On the other side scattered lights were received by the detector by fibers in adjacent area

Microstructure analysis

SEM (Scanning Electron Microscopy) analysis was done for the sample A after 28 days. The results for the same are depicted below in Fig 2.6. Further SEM analysis and microscopic characteristics of LTCM (Light transmitting concrete mortar) were analyzed. Results showed the matrix was compact with evenly embedded fibers in the matrix. With the SEM of the PMMA fiber it was observed that the fracture section of was circular and rough. Few tiny gaps were found on the interface of cement matrix and fiber.

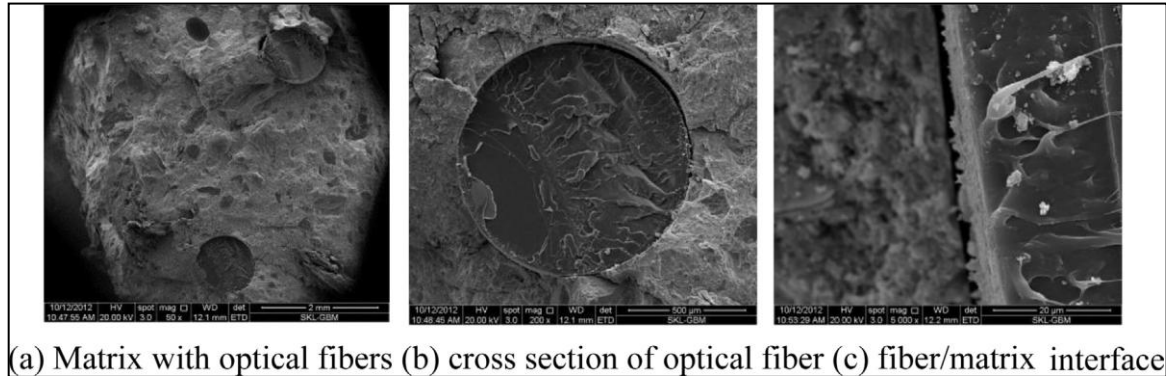


Fig 2.6 SEM images of LTCM and the fractured fiber cross section

The fractured section of the fiber and the interface between fiber and cement matrix was clearly visible in SEM analysis. A uniform matrix and non-bonding smooth surface of fibers was observed in Fig 2.6. The section of the fiber remains circular and was not affected by the cement matrix around. Similarly even distribution of the fibers was also observed from the SEM analysis of the mortar mix.

Thiago et al. (2017) used polymer optical fibers in the cement mortar and termed it as light transmitting cement based material (LTCM). The materials used in this research were standard cement as per ASTM and sun-dried fine aggregates. The details of this research are already mentioned earlier.

For the light transmission test specially designed & customized equipment was used. The custom built device had three parts. Top part had a hole for the light source, the middle portion had a rectangular opening (for 4x4x16cm sample) and the lower one had the photocell's light meter to measure transmittance. The box was painted with flat black gouache paint and covered with plywood. Fig2.7 shows the device used.

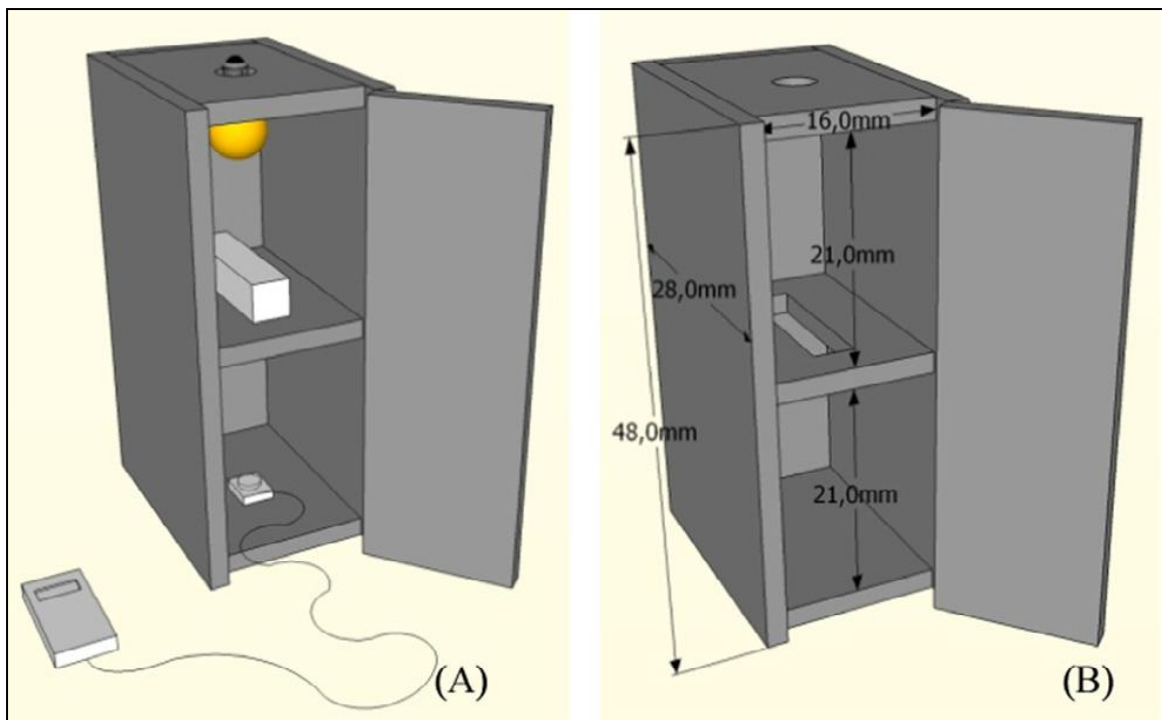


Fig 2.7 Custom Device to measure the light transmission by Thiago et al (2017)

Table 2.19 Variation of light transmission with fiber content by Thiago et al (2017)

Arrangement of fibers	Percentage of fibers (%)	Average light transmission (lux)
Sorted	0	0
Sorted	2	7.67
Sorted	3.5	11.33
Sorted	5	25

For the 0% fiber content, the samples do not possess any fibers in it. This test was performed only to check the sealing efficiency of the solid specimen. As results indicate in Table 2.19, the flux value is zero hence it confirms the efficient sealing of the specimen with no fibers. With fiber content increasing from 2% to 3.5%, the fiber content is increased by 75% which resulted in an increase of transmission by 48% from the specimen.

Whereas when the fiber content is increased from 3.5% to 5% levels, the fiber content is increased by nearly 43% and the rise in the transmission of light by 120%. As these results effectively suggest, 5% POF content was sufficient to develop the translucent concrete, considering the economic scenario and aesthetic value for commercial application.

Microstructure analysis

With help of the scanning electron microscopy (SEM), the verification of the cement fiber matrix was done. As observed in Fig 2.8, the interface had voids which reduced the grip and also decreased the compressive strength of the sample material with low fiber content and no fiber content. The below is SEM image of the interface.

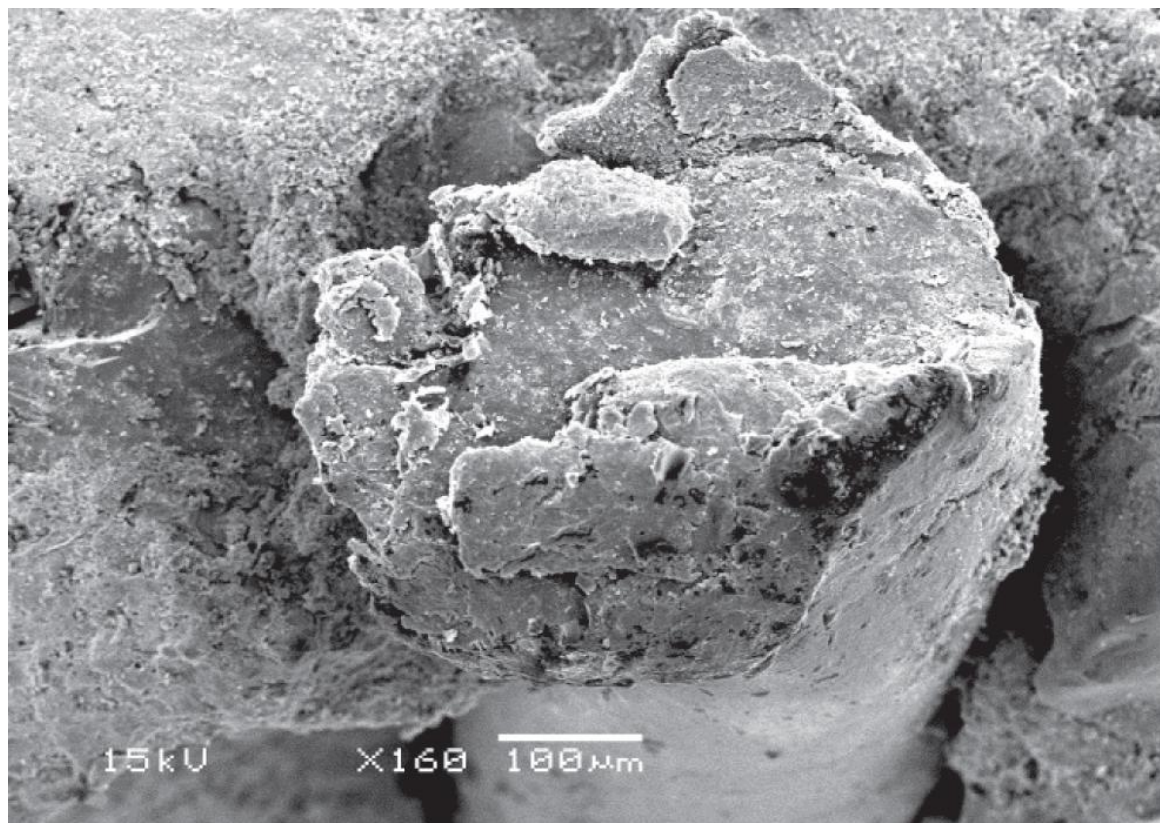


Fig 2.8 SEM of the Cement fiber interface with existing voids by Thiago et al. (2017)

2.5 RESEARCH GAP

Although a considerable amount of research work has been done in this innovative concrete with optical fibers, still there's a lot to be done to carry forward the work and bring it out for the practical application. Since its start of development, the translucent concrete or the Itcm has not been used much in real-world application. Thus, a unique perspective and different application based research are missing in the previous work done.

As seen the research gap lies in the fact, to make this product feasible for below mentioned three criteria:

- 1) Technical Feasibility
- 2) Economical Feasibility, and
- 3) Environmental Feasibility

Hence, in the technical feasibility, the research can be carried out to build a real-world utility product made from materials that are easily available in the mass quantity is most locations. In the economic analysis, the cost of the finalized product was kept in focus and research can be done to consider it for mass manufacturing at a better price to make the product viable for the user. Last will be the environmental feasibility, where the research may be carried out to make the product with higher durability and have less carbon footprint than the traditional ones. Also, the inclusion of any waste material into this concrete with better technical parameters will give it the eco-friendly edge.

As per the research gap in technical parameters, there lies a need for research work in the following domains from this LTCM:

- Utility-based research
For using this product as flooring, tests like surface absorption and surface abrasion are required to be done. For using this product on the wall as blocks/bricks apart from compression and light transmission, the testing for fire resistance ws required to be done. For using as a kerbstone, testing for compression and water absorption is required.
- Development based Research
The research development can be done for the inclusion of waste materials and also the addition of materials that enhance surface properties. Further development to make it more insulating and lightweight can be considered.

CHAPTER 3-MATERIALS, METHODOLOGY & TESTS

3.1 GENERAL

In this chapter detailed information of the materials, methodology and testing applied for this research is mentioned. It includes the different types of materials that are being used in the research. Characteristics and different technical properties of the materials are also specified. Further section described the methodology followed for conducting the research work. In methodology, the description of the mix design ratio followed by the mechanism followed to design and get the desired product is mentioned. Further in this chapter, the details of testing carried out during the research work are specified with the procedure used. In next chapter the results from the tests are discussed, which are followed by conclusion from this research work.

3.2 MATERIALS & ITS CHARACTERISTICS

The various materials that were used for this research work are listed below:

3.2.1 Pozzolanic Portland Cement (PPC)

3.2.2 Waste Glass (Aggregates)

3.2.3 Superplasticizer (Auramix V200)

3.2.4 Water

3.2.5 Plastic Optical Fibers (POF)

3.2.1 Pozzolanic Portland Cement(PPC)

Cement is the most used binder for the concrete mix. In proposed research, the pozzolanic portland cement (PPC) is used as the binder material. The cement binder tends to hold up the aggregates to bind them to form a solid object and impact strength. The cement forms the hardening paste on reaction with water. The pozzolanic cement refers to cement which have pozzolanic materials like fly ash as its constituents. The Indian standard code for the pozzolanic portland cement with its required technical parameter is IS 1489- part-I for the fly ash based cement. The fly ash used in the pozzolanic cement shall conform to is 3812: 1981. As per Indian standards, the pozzolanic portland cement shall be manufactured in conformation with is: 1489 (part 1). As per mentioned code, the PPC should be manufactured by uniform blending of portland cement and fine fly ash. The equipment and method used should achieve complete uniform and intimate blending for

mixing cement and fly ash. The blending should be carried out in well defined operational units using the approved blenders. Gypsum may be added to blending mix of cement and fly ash. Fly ash content ranges from 10 to 25 % by weight of cement in the clinker.

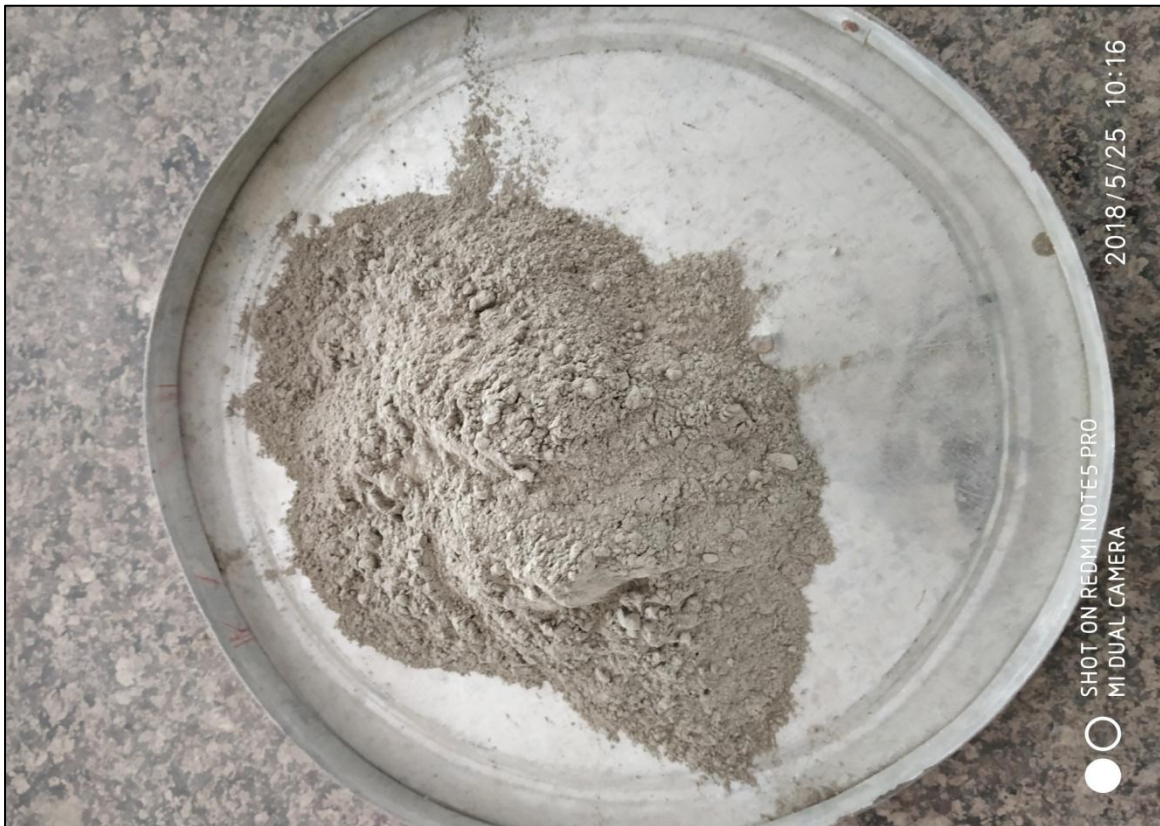


Fig 3.1 Shows the sample of Pozzolanic Cement used in this research.

The PPC (Pozzolanic Portland Cement) was tested as per Indian standards. Tests results of different parameters of the pozzolanic cement used in this research are mentioned in the Table 3.1.

Table 3.1 Characteristics of the Pozzolanic Cement used

Characteristics	Experimentally Obtained Value	Expected Value as per IS 1489: 1991-Part I	Testing Method, Reference to:
Specific Gravity	2.80		IS 4031: Part 11
Std. Consistency	28 %		IS 4031: Part 4
Initial Setting Time	35 minutes	30 minutes minimum	IS 4031: Part 5
Final Setting Time	650 minutes	600 minutes maximum	IS 4031: Part 5

3.2.2 *Waste Glass(Aggregates)*

In research work carried out, crushed waste glass is used as aggregate (fine as well as coarse). Waste glass was obtained from dump yard within university campus. Almost a ton of waste glass was obtained and crushed. The waste was carefully crushed by Los Angeles abrasion machine. Waste glass was originally the broken glass of windows, mirrors and utensils and lab equipment. The glass was crushed to be utilized as aggregate in the concrete mix. SEM-EDS (energy dispersive x-ray spectroscopy) analysis was performed in the waste glass powder and the shown in Fig 3.2.

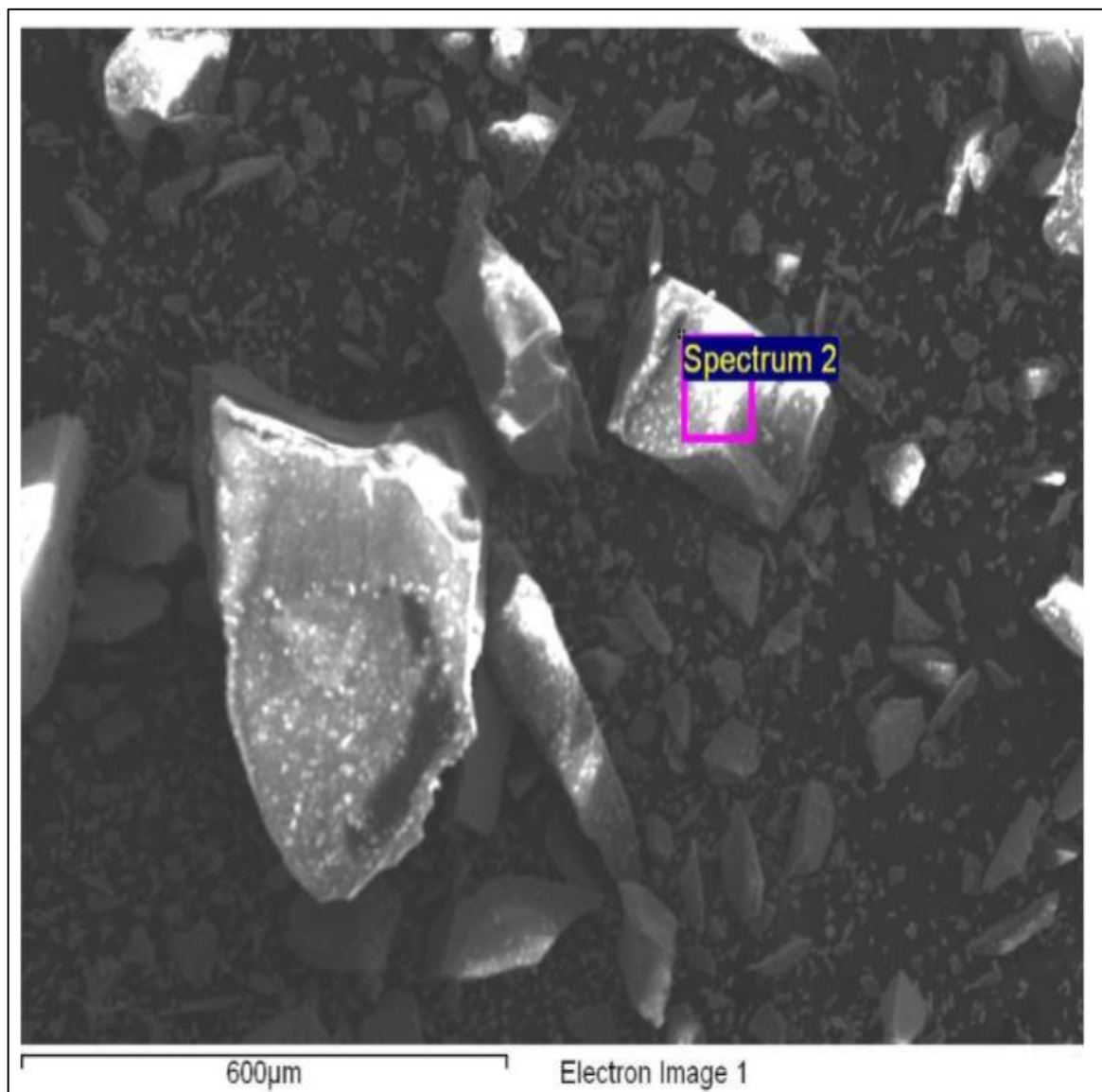


Fig 3.2 SEM imaging of waste crushed glass aggregates at the 600-micrometer size

The chemical composition of the waste glass was determined by the EDS (Energy Dispersive X-Ray Spectroscopy) analysis. An average of four readings for the chemical composition was taken and listed in the following Table 3.2

Table 3.2 Chemical composition of waste glass used in this research

Element	Compound	Formula	Avg. Content in Glass (%)
Silica	Silicon Oxide	SiO ₂	69.43%
Sodium	Sodium Oxide	Na ₂ O	18.40%
Calcium	Calcium Oxide	CaO	5.12%
Magnesium	Magnesium Oxide	MgO	5.57%
Aluminium	Aluminium Oxide	Al ₂ O ₃	1.31%
Iron	Iron Oxide	FeO	0.18%

Apart from the chemical analysis, sieve analysis was also carried out for the waste glass. In this glass was first crushed then sieved and stored as per the size of particles retained on the particular sieve. In concrete, the glass used was mixed as per the required size of the aggregate zone of fine aggregates as per the Indian standards mentioned earlier in Table 1.1



Fig 3.3 Waste Glass Aggregates after crushing by L.A Abrasion Machine

Table 3.3 Sieve Analysis of the Waste Glass used

Percentage Passing for			Percentage Retained	
Sieve Size	IS Grading Zone-IV	Waste Glass used	Waste Glass Used	Cumulative
10 mm	100	100	0	0
4.75 mm	95 – 100	95	5	5
2.36 mm	95 – 100	90	5	10
1.18 mm	90 – 100	85	5	15
600 micron	80 – 100	80	5	20
300 micron	15 – 50	30	50	70
150 micron	0 – 15	10	20	90
Pan	---	0	10	100

The Fineness modulus represents the average particle size in the aggregates used for concrete mix. The sieve analysis of the waste glass used in mentioned above. As seen and calculated the fineness modulus by the formula:

$$\text{Fineness Modulus (F.M)} = (\text{Sum of Cumulative percentage retained}) / 100$$

The above formula used to calculate the fineness modulus and thus, for the used waste glass aggregate the fineness modulus comes out to be 3.1.

This value gives an idea of the average size of the aggregate that lies between 3rd and 4th division of size from the bottom of the table of sieve analysis for the waste glass aggregates. Further after SEM-EDS and sieve analysis, the water absorption and the specific gravity of the aggregates was also tested. Thus, the following results were obtained for the waste glass aggregates:

- The Specific Gravity of the waste Glass aggregate used is 2.5.
- The Water absorption of the waste glass aggregates is nearly 1.2 % only.

- The bulking of the aggregates was also tested, but not much bulking was observed and hence termed to be less than that of 5 %.

Thus above results were determined as characteristics properties of the waste glass aggregates which are used in the concrete mix, in this research work.

3.2.3 Super Plasticizer (Auramix V200)

In the concrete mix used, the admixture used was super plasticizer- Auramix 200 by Fosroc chemicals. As per the technical details were given by the company, Fosroc Auramix V200 is ready to use liquid admixture. It is a chloride free and high-performance concrete rheology-modifying agent. The chemical is polymer based and designed to be used for highly fluid concrete.

The Fosroc Auramix V200 is specially manufactured to achieve the concrete with high fluidity. It was observed and noted that lack of binder material in the mix and higher dosage of the chemical can cause problems such as segregation or bleeding of the concrete mix. The admixture kept mix fluid quite uniform and easy placing for the concrete in the required space.

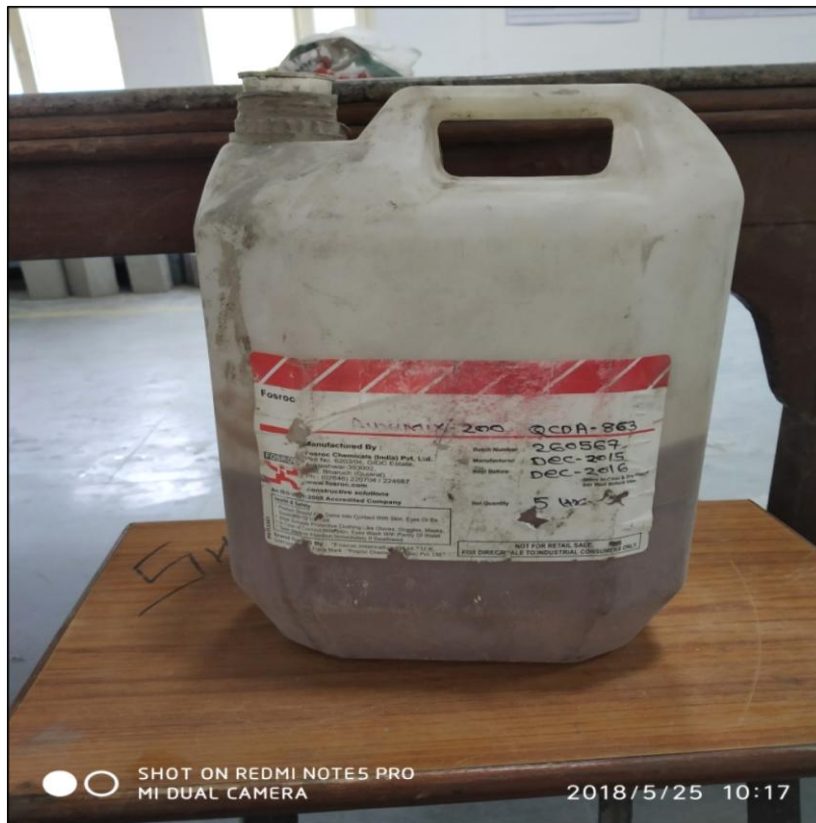


Fig 3.4 Fosroc Auramix V200 admixture used

The other parameters of the chemicals are specified as:

- Physical State and Appearance: Pale yellow liquid
- Specific Gravity @ 20°C: 1.010
- pH value of the chemical liquid: 7.0 – 8.0
- Chloride content: Nil to BS 5075

This chemical is carefully designed to work effectively at quite lower dosages in the concrete mix. Trials and prior experience can be used to determine the optimum dosage of Fosroc Auramix V200. Generally, normal dosage range lies between 0.1 to 0.5% of the cementitious material in the concrete mix. It should also be noted that the dosage above the normal range can be used in case of specific requirement.

3.2.4 *Water*

Water is a must require component to form concrete mix. It initiates and causes the hydration of cement/binder material in the concrete mix. Water used shall conform to IS-456: 2000. According to Indian standards water used in the concrete mixing should be clean and must not contain any considerable amounts of oils, acids, alkali, salts, sugar, organic materials or any type of material/chemical that can be deleterious to the concrete. Generally potable water is considered satisfactory to be used for concrete mixes. Certain provisions as per IS 456 are for water are:

- For neutralizing 100 ml of water to be used and taking phenolphthalein as indicator, the required value should not be more than 5 ml of 0.02 normal NaOH.
- Similarly, for neutralizing 100 ml of water to be used and using mixed indicator, the required value should not be more than 25 ml of 0.02 normal H₂SO₄.

The Indian Standard code IS 456: 2000 also mentions permissible limits for different chemical impurities for the water, to be used in concrete are mentioned in Table 3.4

Table 3.4 Permissible limits of Impurities for water as per Indian Standards

Impurity	Organic	Inorganic	Sulfate(SO ₃)	Chlorides(Cl)	Suspended Matter
IS-Code	IS 3025	IS 3025	IS 3025 (24)	IS 3025 (32)	IS 3025 (17)
Allowed Limits	200mg/l	3000 mg/l	400 mg/l	2000 mg/l (For PCC)	2000mg/l

3.2.5 Plastic Optical Fiber (POF)

In the concrete mix used for this research plastic optical fibers were also added. The plastic optical fibers used in this research were imported from China. The fibers are made of PMMA i.e. Poly (methyl methacrylate) or polymer fibers. The technical features of the fibers as specified by the manufacturing company are specified in Table 3.5

Table 3.5 Technical Parameter of the Optical Fibers used

Size of POF Available	0.25, 0.5, 0.75, 1, 1.5, 2, 2.5 & 3 mm	Allowable Bending Radius	No less than 10 times the diameter of the fiber
Fibre Core Material	PMMA	Numerical Aperture	0.5
Cladding Material	Fluoresin	Elongation at Yield	> 4
Appearance	Smooth, Transparent	Using Temp. Range	+70° to – 20° C

It is important to be noted that the optical fibers come only in form of rolls of a particular length of the specific diameter. These fibers were also tested for the hot surface, fire, and hot water. The sample roll of the plastic optical fiber is shown in Fig 3.5.



Fig 3.5 Technical Parameter of the Optical Fibers used

There are various other features of the plastic optical fibers (POF) mentioned by the manufacturers. Some of these features are as follows:

- Low loss of optical output in the visible region
- Ability to avoid infrared and ultraviolet and transmit visible light only
- Do not conduct or transfer heat from one end to the other
- Smooth surface
- Good flexibility
- Bendable shape
- Strong effect of light at the end of fiber

Apart from the features, there are various applications mentioned by the manufacturer for the particular use. These fibers are useful as special light source, as the fiber ends give soft glow lighting. The fibers does not transmit infrared or ultraviolet rays, thus not much heat is transfer, except the light. Hence, it can be used in special purpose of illumination in projects involving underwater works or oil stock house, and also aesthetically for museum illumination.

3.3 METHODOLOGY ADOPTED

In this research, there are certain methodologies used to achieve the target results. These methods are majorly classified into three major parts. In these divisions, work is separated from materials to development and the testing required. Thus, the adopted methodology is differentiated as:

- Research Methodology
- Development Methodology
- Testing Methodology

Thus it should be noted that in all of these three categories work is carried out in a systematic manner to do research for material selection and finding the optimum ratio of mix to be used for specific materials. In the next step, development of the certain technical aspects of the concrete mix is considered. In this approach, final target properties required are the target to be achieved. At last the technical parameters are tested as per the application based requirement of the concrete mix, as per Indian standards.

3.3.1 *Research Methodology*

In research methodology, major focus is kept on selection of material and its optimum content in the concrete mix for the required value of the technical parameters. Thus as per the research carried out, the materials shortlisted and used in this work as mentioned above were cement and waste glass (and admixture + water). This result was determined by thorough research for using waste material which is available in abundance in near surroundings and is not completely recycled. Also, the technical as well as sustainability parameters of the materials were taken into consideration.

In the mix design, the optimum content of the constituent materials to be utilized in the concrete mix is determined. Various trial mixes were obtained for using the waste glass and cement combination for best compressive strength and hence the optimum glass content was determined as follows (as detailed in Table 3.6). In trial mixes, the basic criteria for finalizing the ratio were the strength and the economy of the concrete mix for practical feasibility.

Table 3.6 Different Trial mixes used for concrete mix ratio

WATER / CEMENT RATIO	CEMENT CONTENT	WASTE GLASS CONTENT
0.40	1	1
	1	2
	1	2.5
	1	3
0.44	1	1
	1	2
	1	2.5
	1	3
0.48	1	1
	1	2
	1	2.5
	1	3

Thus it was finalized that the following mix ratio was having best economic and strength feasibility and hence, can be tested for other parameters.

W/C Ratio : 0.44	Cement : Waste Glass	1 : 2.5
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3.3.2 Development Methodology

The development method for this work is the core of the research. All the work carried out after finalizing the mix design ratio the various technical parameters tested were in accordance with the methodology called “*Reverse Engineering*”.

In reverse engineering the final parameters are fixed and trials are carried out with ingredients/constituents to get the desired results. Thus, it becomes important to finalize the materials to be utilized to achieve the desired results in time. In this research work reverse engineering was used for following technical parameters and with the desired result target discussed further. The research was aimed to develop an alternative to clay bricks which has better strength, durability and also comes in fully finished form as ready to use the product. The concrete brick/block should not require any surface treatment like plastering or painting on it. As to achieve these aspects with added aesthetical value the following parameters were kept in mind to be attained.

- *Workability*

The workability or the desired flowability for concrete to be poured into mould full of fibers and not cause bending or freeing the fibers.

- *Strength*

The strength is a basic parameter to be achieved for mix ratio and further testing to be used as load bearing brick/block wall

- *Colors*

Specific color addition and getting the desired color easily into the block to be used

- *Effective light Transmission*

Evenly spread fiber for uniform light transmission across the brick/block section

- *Ready to Use*

Polished and Finished smooth product for direct ready to use and no surface treatment required

3.3.3 Testing Methodology

The testing methodology used in this research is purely based on the application of the concrete mix made. Different tests have been performed for a different set of application and are specified below.

i) For Application as Bricks / Blocks

- Measurement and Density

The measurement of the sample blocks and bricks made were measured carefully as per the size of the mould. The edges were checked and smoothed by sandpaper and further grinding was done to make the block uniform and clear edges from all around. The measurement was done carefully using vernier caliper.

Similarly, the density of the block with the specified mix was determined and found to be $\sim 1980 \text{ kg/m}^3$ for the normal mix of ratio defined earlier. In this, after the careful measurement of the block (after grinded and smoothed surface) it was weighed and hence density (weight/volume) was calculated.

- Compressive Strength Test

The compressive strength is basic strength parameter to be determined for any concrete mix. As per Indian standards, the compressive strength is determined using the compression testing machine (CTM).

As per IS 516: 1959 the testing machine should be of reliable type and have capacity to load as per standards (as shown in Fig 3.6). Error less than ± 2 percent of the maximum load are permissible. The compression testing machine has two hard face steel bearing plates. The top plate has a ball seating in the form of a part of a sphere, where the centre of both coincides. The bottom plate was rigid and fixed for bearing. The size of bearing plates was greater than or equal to the size of specimen under testing. The bearing plates did not depart for more than 0.1mm from the specimen at any given point on the surface. The load was applied in gradual manner with fixed rate as specified in Indian standards. The peak value of load at failure was noted and the compressive strength was obtained by dividing the peak load with cross-sectional area of specimen. The mixing of concrete was done by pan mixer (Fig 3.7a) and concrete mixer (Fig 3.7b) depending upon volume.



Fig 3.6 Compression Testing Machine available in lab facility

In this CTM (Compression testing Machine, a sample of 70.6 x 70.6 x 70.6 mm was used with loading rate 35N.mm²/min determine the compressive strength of the concrete mix. This sample size was selected as per Indian standards for Concrete mortar.



Fig 3.7 Pan mixer (a) and the concrete mixer (b) used for mixing the concrete constituents

- Water Absorption

Water absorption describes the amount of water absorbed by the concrete block to get saturated. It is an important durability parameter. Water absorption relates to various other testing to measure the percolation of water into the concrete by testing permeability, surface absorption or sorptivity. All these tests intend to tell about the water penetration extent in the concrete.

The water absorption was carried out using concrete cubes of 70.6mm. As per IS 2185 (part 1) for concrete blocks (masonry), the blocks were kept immersed in water for 24 hours and then be weighed with a suspended by a metal wire and completely submerged in water. Samples were then removed from the water, drained for one minute by placing on a 10 mm or coarser wire mesh. Visible water on surface was removed by a damp cloth and then immediately weighted. Subsequently, the specimens were dried for 24 hours or more in 100-115 °C ovens with the well-ventilated condition. The drying is done until successive weighing for 2-hour interval show loss greater than 0.2 % of the previous reading as shown in Fig3.8.



Fig 3.8 Drying Oven available in lab facility

Thus, the water absorption percentage would be the difference between the wet and dry mass of the blocks divided by dry mass, multiplied by 100 for percentage result.

$$\text{Water Absorption (\%)} = \frac{A-B}{B} \times 100 \quad - (3.1)$$

here, A = Wet Mass & B = Dry Mass of Concrete block

- Slump Flow Test

Slump flow test is done for self-compacting concrete or concrete with high flowability. In this test, the measurement of the free horizontal flow of concrete without any obstruction is done. The slump flow test is simple and rapid test procedure and can be used on site with easy equipment. The test is commonly used and gives a good idea about filling ability of the concrete. It must be noted that this test did not give flowing of concrete in reinforcement but a better idea of chances or resistance to segregation. The test was used to determine the consistency of the flowing concrete.



Fig 3.9 Equipments for slump flow test

Equipment for this test includes a slump cone of standard size (200mm base, 100mm top dia, and 300mm height), a base plate of metal/non absorbing material (with markings for concentric circles with distance from center), and tools like scoop, trowel, rule, stopwatch (if required) as shown in fig 3.9.

Nearly 6 liters of concrete was required to perform this test. The procedure started with moistening of the equipment (base plate and inside of slump cone). The base plate was kept on clear horizontal stable and held firmly. For this test, concrete was filled in the cone with the scoop and not tamped. Extra concrete over the cone was removed. Further, the cone was raised vertically and concrete was allowed to flow freely. Simultaneously, the stopwatch was started and time taken to reach 500mm diameter by the flow was noted. In this lower time implies high flow rate.

as per general suggestions, time of 3-7 seconds would be good for construction/ civil engineering applications whereas for residential project 2-5 seconds is acceptable. In case of the different size of aggregates, the coarser one remains and the center and the mortar/ fine aggregates flow towards the end. This test is also significant for testing of segregation of aggregates in the flowing concrete.

- Light Transmission & Reflection

The light transmission is a test specifically required for the concrete blocks made using optical fibers. It possesses the ability to transmit the lights through them. With previous data of transmission parameters results provided by the manufacturer for the optical fiber, it is tested for transmission of fibers embedded into the concrete. The testing was done using optical power meter or spectrophotometer.



Fig 3.10 Transmission testing setup with an optical power meter

As seen in Fig 3.10, the device used a generator and a receptor. The sharp beam is generated and flashed onto the fiber strand embedded in the concrete. The receiver is kept behind the sample to measure the transmission of the light through the sample. Thus, with the changing angle i.e. horizontally as well as vertically the readings of the receiver were noted down. The procedure setup was carefully fixed for perpendicular pointing of the incident ray and corresponding angle of the receiver. Also, the measurements were taken with increasing distance of the source and the increasing distance of the receiver from the sample under testing.

In a similar way, the light reflection was also tested for the sample. As due to the presence of glass aggregates the sample was also able to reflect the light falling on the surface (fig 3.11). The reflection test was conducted using a same optical power meter and using incident light at a certain angle and also keeping the receiver at similar inclination to measure the reflection readings.

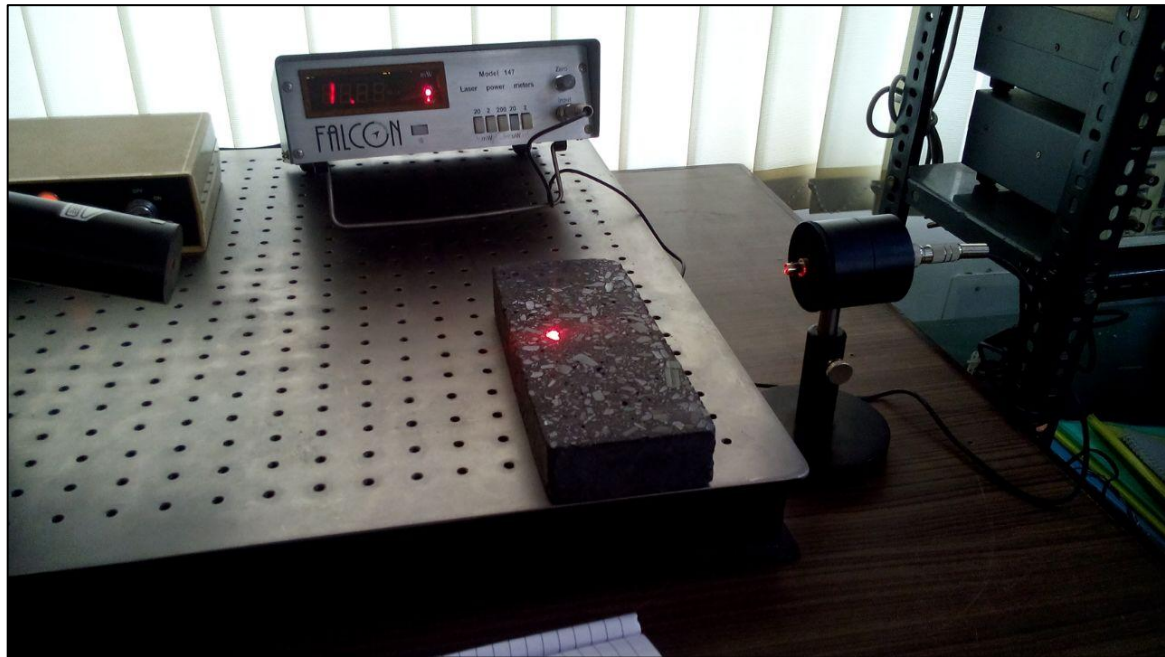


Fig 3.11 Light Reflection measurement using optical power meter setup

In this way, with an inclination of the source light and receiver, the reflection results were noted for a different angle of both parameters. Also, the reflection through the normal surface and through the visible glass aggregate on the surface was measured to understand the difference and see the visible change in reflection depending on the surface hit by the incident ray.

- Drilling / Cutting

Another important parameter for the masonry block is to be able to be drilled and cut. Thus, no such provisions for these testing are mentioned in Indian standard code. Thus, with practical experience and guidance from industry experts to get this project into the practical feasibility, the drilling and cutting were done without getting cracks due to the brittleness of the concrete. As in real-world application, the bricks or blocks are required to be cut to get into the desired shape/size of the wall (as depicted in fig 3.12). On the other hand, drilling and cutting is also a majorly required for embedding the conduits for electrical and plumbing works (Fig 3.13), if required.



Fig 3. 12 Subsequent drilling of the Sample at near edge in cross section



Fig 3.13 Concrete Block Sample with a Clear cut from the middle

- Sulfuric Acid Resistance

For application of bricks as well as tiles one of the additional test done was resistance to the sulfuric acid. In this test samples of the concrete mix specified were prepared. After 28 days of curing, the samples were kept in 2% H_2SO_4 (sulfuric acid solution) having pH 1.0 up to 28 days and for comparative analysis, similar samples were kept in room temperature condition in water curing. A constant pH of the acid solution was maintained and monitored using pH meter and thus a high concentration sulfuric acid was added subsequently to maintain the pH of solution (Fig 3.14). The surface deterioration, loss in mass of the sample and compressive strength was compared with as that of normal cured sample. The observations were made for the surface smoothness and loss in mass was noted along with compressive strength.



Fig 3.14 Compression testing of Sulfuric attacked sample

- Fire Test

The fire resistance of the sample block was tested for its resistance to fire. In this test main purpose was to identify the light transmission behavior of the fibers on subjection to fire. Thus, the sample was given an exposure of quick-fire flash for about one minute of extreme fire from all around. On the other hand, the sample with optimum thickness was exposed to direct heating of around 700 to 800° C. Thus, the observation was made for every 15 minutes to check the transmission property of the sample.



Fig 3.15 Flash Fire test of Sample for Transmission test

The Flashfire tested sample from all sides and lasted for nearly one minute (Fig 3.15). The light transmission was checked afterwards and results were noted.



Fig 3.16 Bunsen Burner setup and testing of Sample

The normal fire test was done using bunsen burner and the sample of 25mm thickness was kept under testing for nearly one hour at a constant temperature of $\sim 750^{\circ}\text{C}$ on the cross-section surface. The bunsen burner was used at constant gas supply with sample kept right above the flame as shown in (Fig 3.16). The optical fiber transmission and the surface of the sample were tested after exposure to fire by bunsen burner for 1 hour.

ii) *For Application as Table Top*

- Hot plate test

As for the application of the concrete as a countertop or the table top, this is a unique test required to be done for the mentioned application. As in this test, the concrete finished surface is subjected to a hot plate which is used while cooking. The main objective of this test was to identify the damage caused to the surface smoothness and cracks arising if any. This test is certainly required from the practical aspect of the application, whereas no such test is mentioned in any certain code or standards.

- Oil spilling

For mentioned application as a table top of concrete, one more important required test was for spills. Considering oil spills as a major problem which diminished the appearance of the concrete top, it becomes important to perform this test (shown in Fig 3.17). In this, a sample of concrete was having spilled oil over its surface for 30 minutes.



Fig 3.17 Sample will spill oil over its surface

Thus, the sample was left undisturbed to check the absorption of the spilled oil and the stain left over the affected area. The test was conducted using de-moulding oil for concrete formwork.

- Surface absorption

One of the major problems arising with the concrete countertops was its ability to absorb the spilled liquid over the surface. Due to this, not only the surface loses its appearance features but also gets cracked or gets bacteria grown on the surface. It becomes important to test the concrete to be used as a tabletop for surface absorption (as shown in Fig 3.18). Since with the presence of plastic optical fibers, there are chances of higher percolation of water on the surface having plastic optical fibers in it.



Fig 3.18 Initial Surface Absorption test for the sample cube

In accordance with BS 1881: part 206: 1996, this test it measures the extent of water penetration characteristics. For this, a pressure of 200mm water head is used, which was

extreme case of weather condition. The result output of penetration explained more about the quality of the surface finishing and the natural weathering effects on the surface.

This initial surface absorption method was applied to the surface with exposed aggregate and finished surface. The test is not applicable to the rough surface having honeycombing or cracks over it and hence can cause misleading results.

The test assembly is comprised of watertight cap sealed to the surface of concrete and connecting to the reservoir/water storage by plastic flexible pipes, having the scale and capillary tube. With the help of control tap fitted to the connection between the reservoir and cap to control the discharge, a typical test assembly is illustrated in above Fig 3.18.

The formula for calculating the flow from the reading of divisions is:

$$f = \frac{60}{t} \times D \times .01 \quad - (3.2)$$

Here, t = test time period (in seconds),

D = no. of scale divisions during period t,

f = flow in ml / m² / sec

Thus, the reading for the scale divisions was noted at 10 minutes, 30 minutes and 60 minutes from the testing time. Further, the result was plotted to measure the percolation of water through the surface. The surface having plastic optical fibers in cross section is subjected to this test.

CHAPTER 4- RESULTS AND DISCUSSIONS

For using the concrete mix for application specified above, certain technical parameters are required. The results from the tests performed (as mentioned in previous chapter) are depicted below. These results were majorly application oriented and show the possible chance of utilization of waste glass into concrete. The variation of results was compared with controlled mix (normal concrete with same size and ratio of normal aggregate as that of concrete mix).

4.1 MEASUREMENT & DENSITY

The parameters tested for the concrete cube of 70.6mm, 150mm and custom size samples included measurement of the samples which was done by using vernier caliper. The measurement taken was considered to be fairly accurate with an error of around 1-2mm. The deviation was cited to be due to presence of glass particles / aggregates on the edges, which sometimes tends to separate out during the grinding process. Further processing with a finer grit would make the surface and edges smooth and even from all sides.



Fig 4.1 Finished sample with smooth surface and well defined clear edges all around

The final finished sample grinding with clear edges on all sides is shown in Fig 4.1. The above sample is 25mm thick and is made of the concrete mix specified in this research. The darker shade is given by addition of black oxide color (~10% of cement) into the mix.

For testing density of the concrete mix, the results were calculated for controlled mix, the concrete with waste glass (different ratios) as aggregate and concrete with waste glass and plastic optical fibers (~2-3% by volume). The observed value of density is mentioned shown in Fig 4.2.

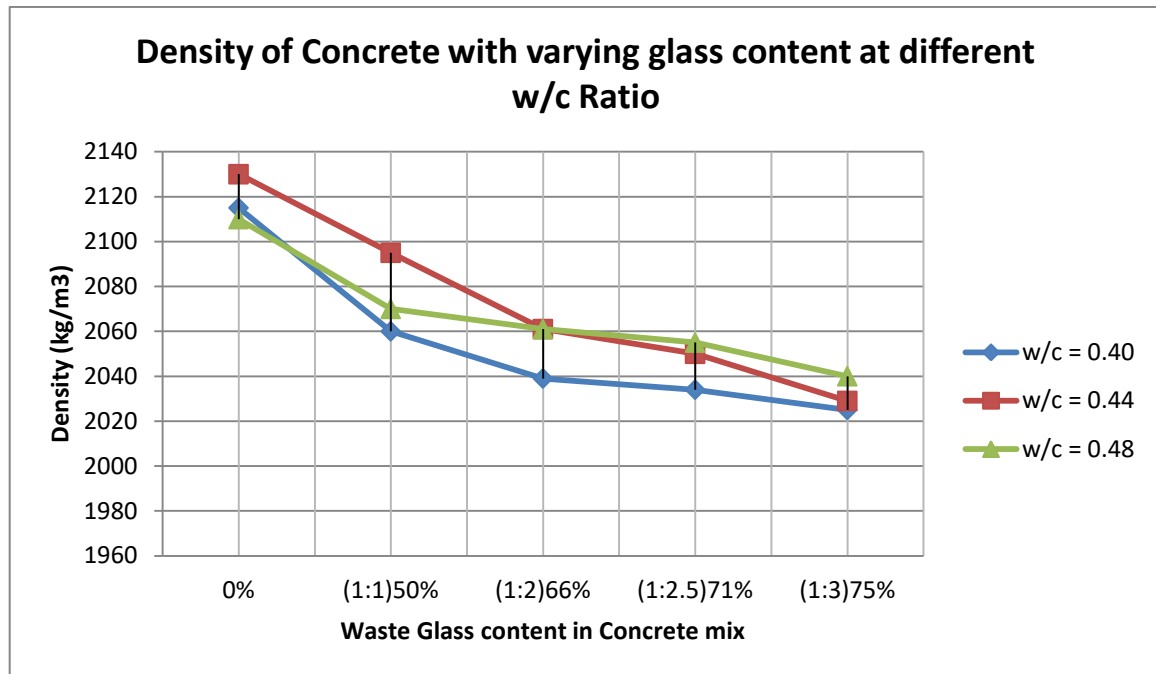


Fig 4.2 Variation of Density of concrete with changing waste glass at different w/c ratio

As per the required condition, the acceptable density can be optimum of strength to weight ratio of the mix. From the graph, sudden decrement with the addition of waste glass in the concrete was observed. As pointed in the literature, this might be due to the fact that the waste glass possesses a lower specific gravity as compared to that of aggregates and thus, resulting in a sudden decrease in density from 0 to 50% of glass content in concrete. Further higher glass content in the concrete shows a falling trend with decreasing density but to a comparatively lesser extent. Also as mentioned earlier, the waste glass has water absorption of nearly 1.2% only, as observed from the above curves the water-cement ratio tends to have no certain impact on the density. This was due to finer glass particles acting as pozzolanic material, high water content is required and thus the paste formed fills pores in concrete, which resulted in increase in density to a certain extent. The glass particles have low water absorption and give much water available for cement hydration and workability, which caused an increment in voids that reduced density to a certain extent. Hence, no certain behavior aspect of density with w/c ratio could be defined from this research.

Also, the variation of the density of fibers was observed to be decreased due to the non-binding plastic nature of the fibers. In general, there is a decrease of around 5-10% of the density of the concrete with the addition of 3-4 % fibers uniformly spread over the cross-section.

4.2 COMPRESSIVE STRENGTH

The compressive strength is an important parameter for concrete mix. In this research work, the compressive strength of various ratios was tested. The compressive strength tells the basic strength parameter required for the application as brick/block. Thus, a certain minimum value was taken into consideration. As for load bearing walls and non-load bearing walls have certain requirement of strength. The compressive strength result of the used ratios is mentioned below. The compressive strength is tested for 7 days and 28 days or curing as per Indian standards.

For 7 day strength, the curve obtained for compressive strength is shown in Fig 4.3..

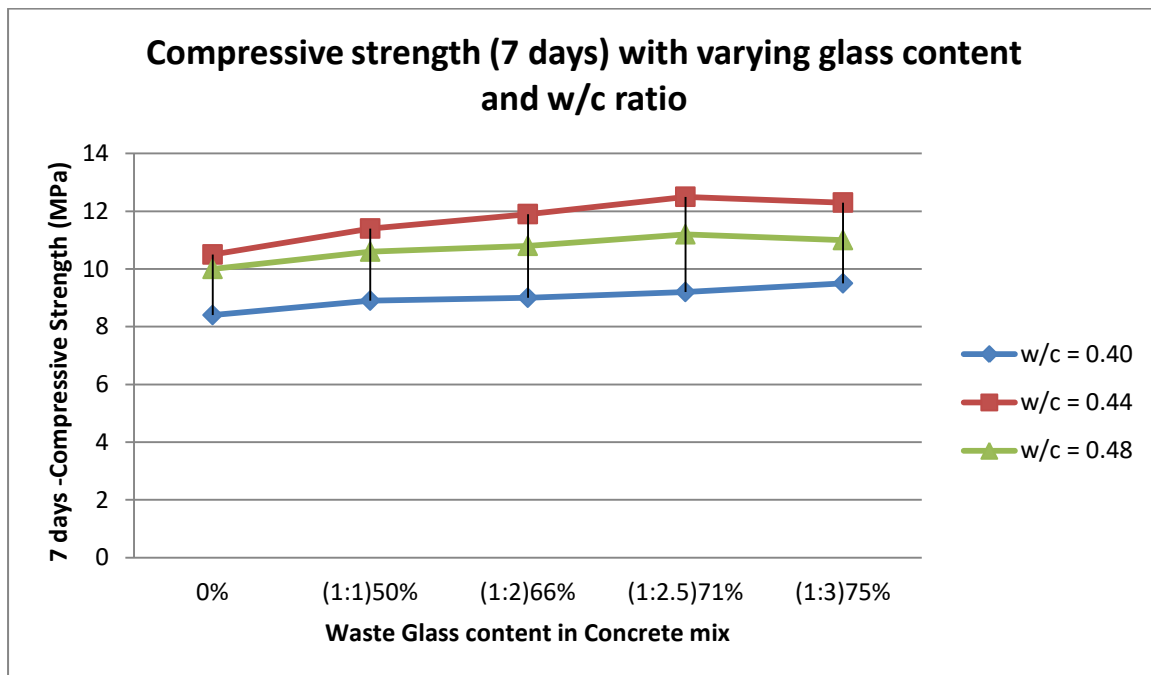


Fig 4.3 Variation of compressive strength at different WG content and w/c Ratio

Thus, it can be observed that the compressive strength tends to increase with an increase in glass content up to a certain limit. This behavior is possibly due to the pozzolanic reaction of silica present in the glass content which tends to improve the strength. Similarly, the 28 days strength of the specimen with variation as mentioned above was noted and is projected in the curve below.

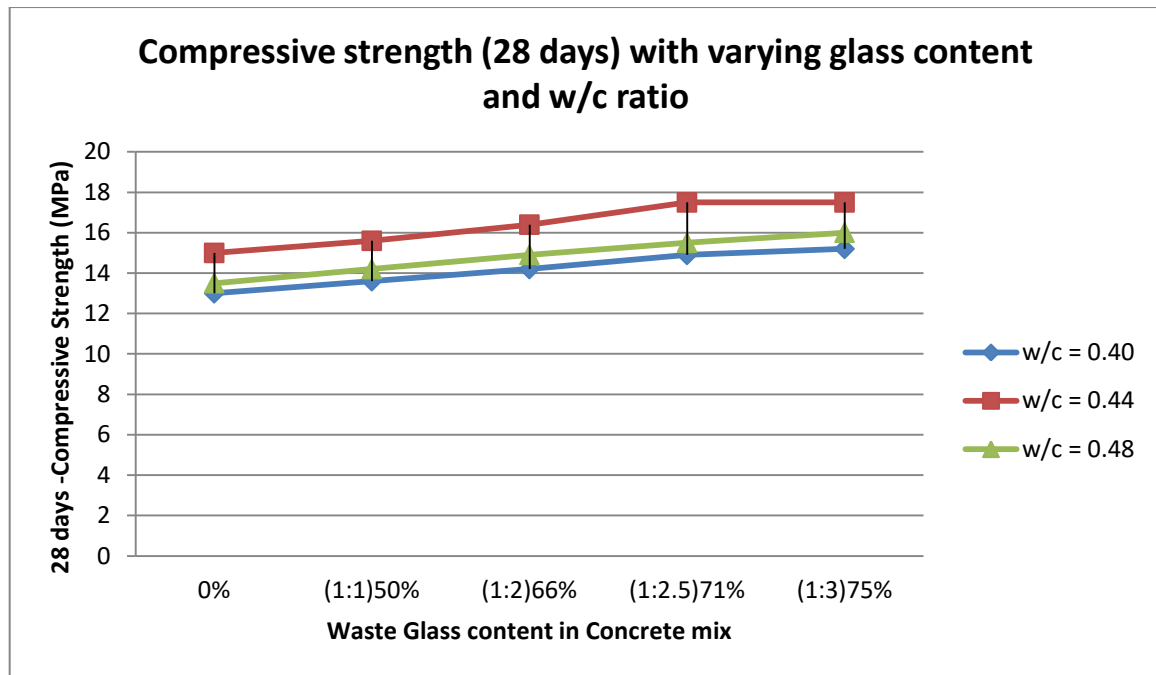


Fig 4.4 Variation of compressive strength at different WG content and w/c Ratio

Thus, it can be observed (Fig 4.4) that the 28 days compressive strength of the concrete mix tends to increase by 10-15% with the addition of waste glass. Further, it was observed that water-cement ratio of 0.44 gives the best result output with a maximum of 66% glass content (which is a ratio of 1:2.5 from concrete and waste glass aggregates).

Hence, for further testing and leaning up for a significant output in terms of practical application, a ratio of 1: 2.5 was used. Also, the water/cement ratio was fixed as 0.44.

For now, with the fixed ratio of the material, compression testing was carried for the concrete with above-finalized ratio and plastic optical fibers. The fiber content was kept close to a fixed volume of 1.4 %. This content was fixed considering the economic analysis and even distribution of fibers at 12mm apart from each other on the cross-section. The even distribution gave a better spread out for the lights even with the lower volume of fibers, which increased the transmission at a wider angle and also maintaining a lower price.

Specially designed moulds were used to cast the concrete for testing. The moulds had holes in opposite cross section for the fibers to be embedded and then concrete was poured on it. The casting was done carefully to not disturb the fiber alignment during pouring as well as vibration for settling concrete.

Table 4.1 Compressive strength of concrete with additives

CONCRETE ADDITIVE (Ratio Fixed 1:2.5) & w/c = 0.44	COMPRESSIVE STRENGTH (MPa)	
	7 days	28 days
POF (plastic optical fibers) (1.4% by volume)	9 MPa	11 MPa
Auramix V200 Plasticizer (0.5%)	15 MPa	20 MPa
POF + Auramix V 200 Plasticizer (0.5%)	13 MPa	19.2 MPa

It was observed (tabulated in Table 4.1) that with the addition of plastic optical fibers (POF) the strength tends to reduce up to 10-15% of that of the original concrete mix. On the other hand, the compressive strength increased by nearly 15% with the addition of 0.5% of Auramix V200 plasticizer. With the addition of POF and admixture, the final strength was around 19 MPa after 28 days of curing. All the further testing was done on concrete with POF and admixture with a fixed ratio of waste glass content.

4.3 WATER ABSORPTION

As with the fixed glass content and cement content in the mix, with a w/c ratio defined 0.44 for testing. The water absorption was carried out for three types of specimens.

- Specimen with normal aggregates (same size as of glass aggregates) and same content used.
- Specimen with a defined ratio of cement and waste glass.
- Specimen with a defined ratio of cement and waste glass with the addition of plastic optical fibers into it.

Thus these three types of specimen were tested for the water absorption with results is given in Table 4.2

Table 4.2 Water absorption for concrete with waste glass and plastic optical fibers

TYPE OF SPECIMEN	DRY WT (Gms)	WET WT (Gms)	WATER ABSORPTION (%)
Control Mix (1 : 2.5) w/c-0.44	666	749	12.46 %
Cement + WG (1 : 2.5) w/c-0.44	642	719	11.99 %
Cement + WG + POF (1.4 %)	635	712	12.12 %

Thus it was observed that with the addition of glass aggregates the water absorption tends to decrease by nearly 4 % of that of the controlled mix with same ratio and aggregate size. This decrement was due to less water absorption of aggregates and the filling up of pores by the cementitious paste, produced by the pozzolanic reaction caused by high silica content in the waste glass aggregates.

4.4 SLUMP FLOW TEST

For required casting, concrete required high fluidity due to the presence of fiber all around the cross-section. In case of less fluid concrete, a major problem was due to viscous concrete that made optical fibers de-aligned. Thus, to avoid this problem the admixture Auramix V200 plasticizer was added. The addition was done in reverse engineering manner to attain a certain value of flow, for free pouring in the mould and without much leakage from the holes of the mould.

Thus for the slump flow test, the concrete was left to flow freely under the slump cone test and the time period for 500mm was noted to be nearly 5 seconds. Also, the diameter of the flow/slump flow was measured to be around 670mm (average of diameter expansion at the end).



Fig 4.5 Water absorption for concrete with waste glass and plastic optical fibers

Measured value is recorded for further casting as flow required (shown in Fig 4.5) to be used for pouring into moulds with filled fibers. With irregular shape glass aggregates, there was not much segregation observed in this test.

4.5 LIGHT TRANSMISSION & REFLECTION

The emission of light is an important parameter to be tested for concrete containing plastic optical fibers. The transmission test was carried out using an optical power meter as mentioned in the testing in the previous chapter. The results noted for the transmission test with variation in distance of source, receiver, and change in the angle of the incident ray. The change in optical power with change in source distance is shown in Fig 4.6.

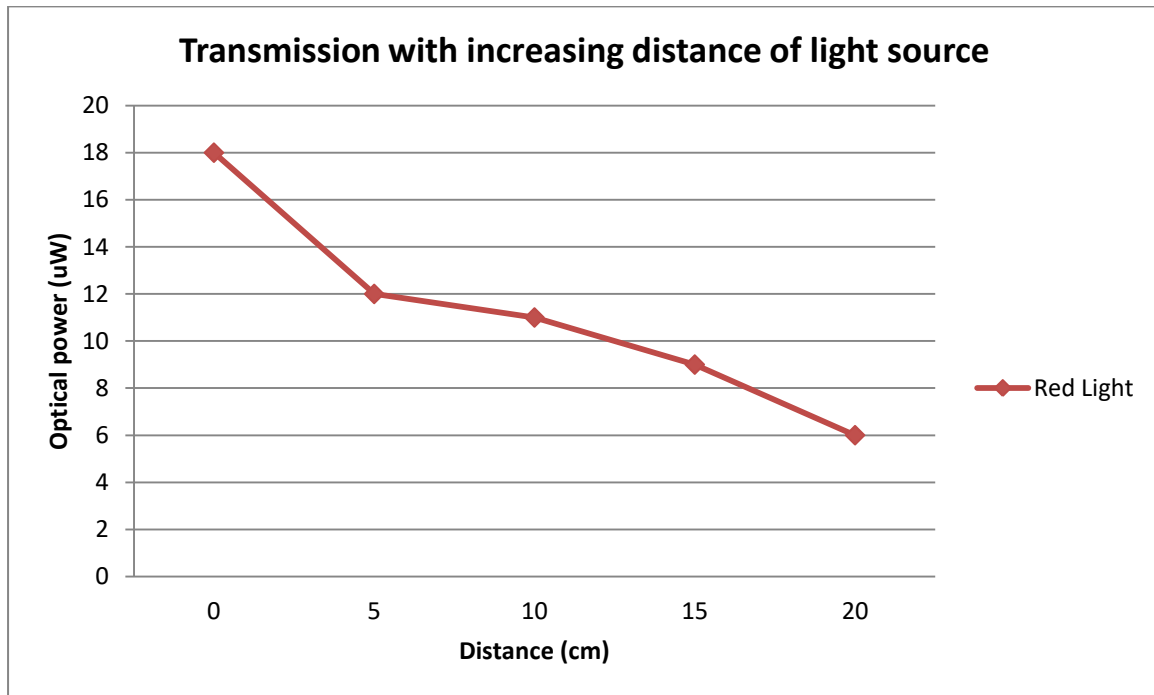


Fig 4.6 Variation of transmission with increasing distance of the light source

Thus in the above curve, it is clear that the transmission changes to a slight extent with increasing distance of the source of the red light from the sample. The reason for this behavior can be concluded due to the change in incident angle and intensity of light falling on the surface of the sample. This also can be attributed to the total internal reflection (TIR) phenomenon occurring in the plastic optical fiber. Red laser focused light was used and as a result there is a gradual loss with increasing distance of the source.

Further, the variation of the light transmission with changing distance of the receiver is been done. In this, the source of the red light and the sample specimen is kept statically fixed to one place and the transmission is observed with increasing distance of the receiver from sample. This explains the intensity of the light at the receiving end with distance from the specimen.

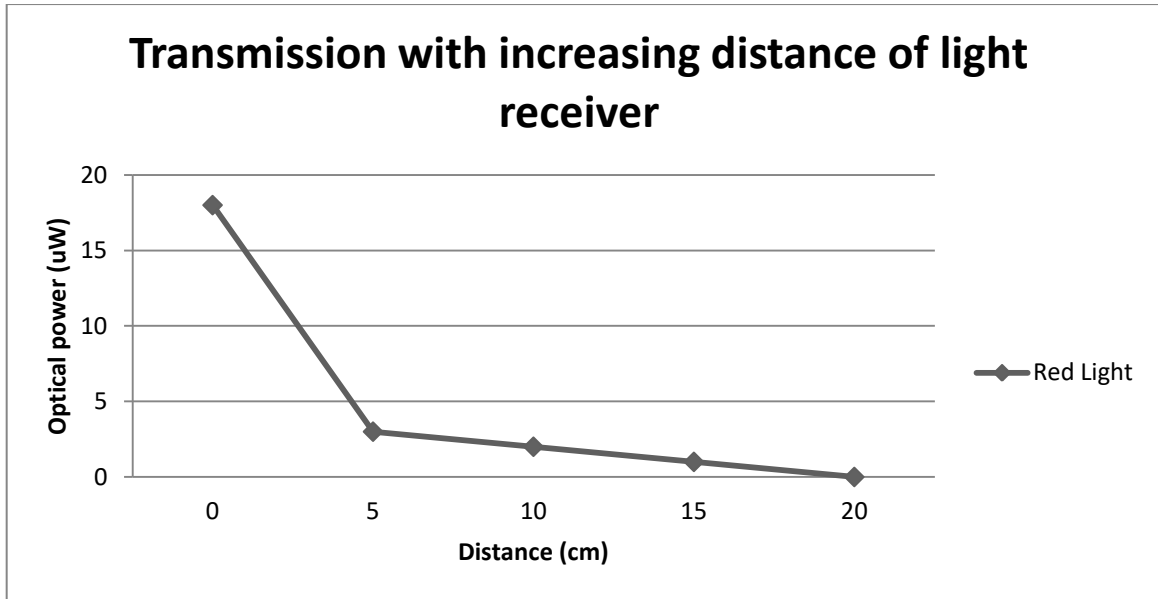


Fig 4.7 Variation of transmission with increasing distance of the receiver from the sample

The curve shows (in Fig 4.7) a sudden decrement in transmission due to the fact the light is received after the TIR (total internal reflection) from within the plastic optical fibers. Thus, after the scattering light can be received maximum at the closest or no distance from fiber end. As the distance increases the scattering tends to expand the light from a point to a growing circle and thus, the intensity decreases at the receiver's end to a large extent. Further, the transmission was also tested with changing horizontal as well as the vertical angle of the source. The observation for the angle change behavior was mostly same for both angle cases with similar trend depicted in Fig 4.8.

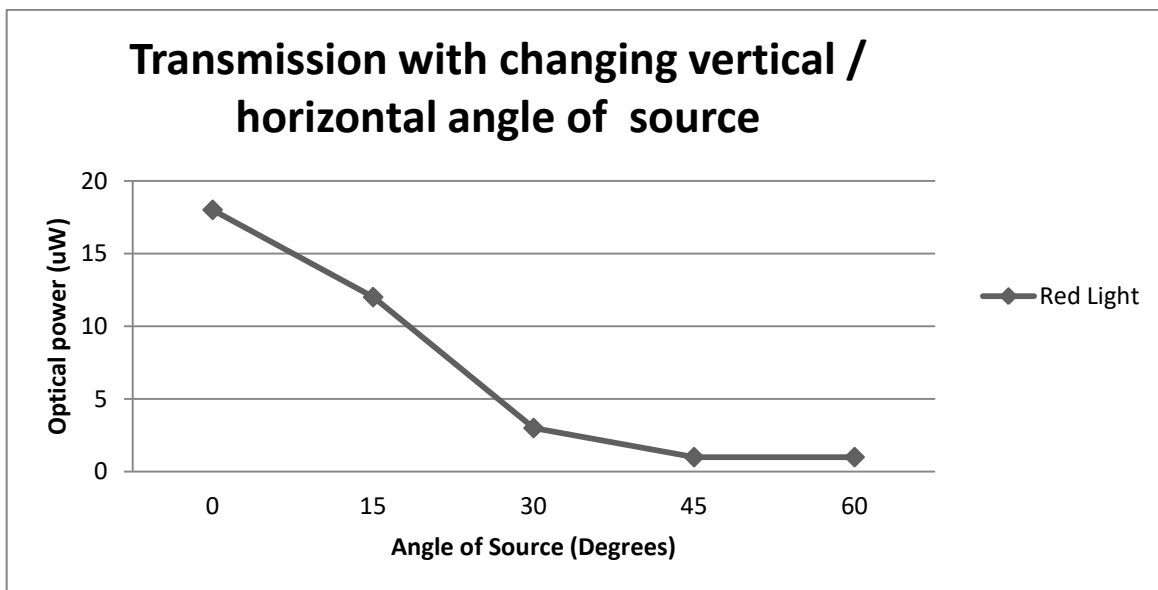


Fig 4.8 Variation of transmission with changing the incident angle of light

As depicted from the curve in Fig 4.8, the transmission shows a similar behavior with a change in angle for vertical and horizontal direction. The reason for the reduction of transmission was due to the acceptance angle of optical fiber for the occurrence of total internal reflection. Hence the transmission gets reduced due to change in incident angle to the fiber. With the further increase in angle, the transmission decreased further citing the same reason.

It must be noted that the transmission for angular incident light was also affected by the angle and orientation of receiver. As the receiver aligns with the direction of light of incident (to whatever angle of the incident may be to the fiber/sample), the transmission tends to increase. In simple words, the direction of receiver or observer was also another factor in the calculation of the transmission for angular incident light.

Further testing was carried out to also determine the reflection of light, from the surface of the sample under consideration. The reflection was calculated due to presence of glass particles in the concrete. As the glass particles (fine and coarse size) with finished surface tends to have a high reflection property, hence with the application as wall brick/block or floor tiles or table top will help to impart a shiny lustrous surface.

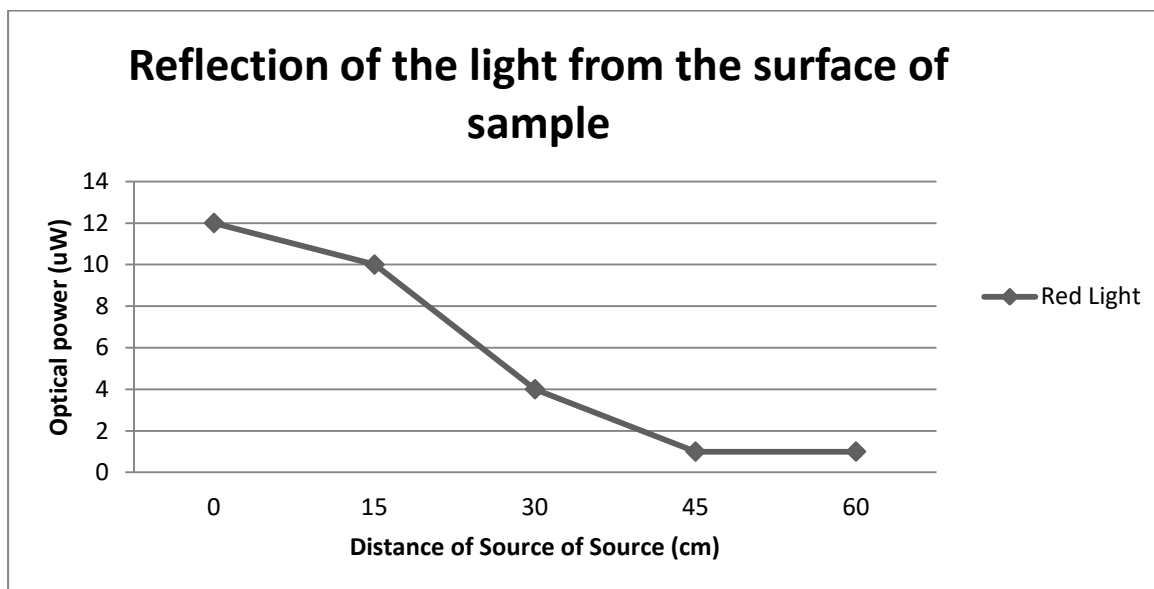


Fig 4.9 Variation of surface reflection with increasing source distance

This curve in Fig 4.9 shows that that the reflection phenomenon from the surface with glass particles, tends to reduce with increasing distance of the source of light. The reason for the decrement is due to the reduction of incident light intensity and the scattering of light with increasing distance and thus less intensity of the light received.

4.6 DRILL & CUT

As application for the bricks and tiles may practically require special size cutting of the product, thus the test was conducted to check the integrity of the sample. The test was performed to see whether the sample shows any signs of cracks or disintegration at the cut section,

Similarly, the drilling was done to check till what depth the hole can be drilled without harming the cross-section, as its basic required property for the bricks/blocks. As shown in the chapter 3, the specimen with cut section (4.11b) and drilled holes (4.10b) in shown in Fig 4.10.

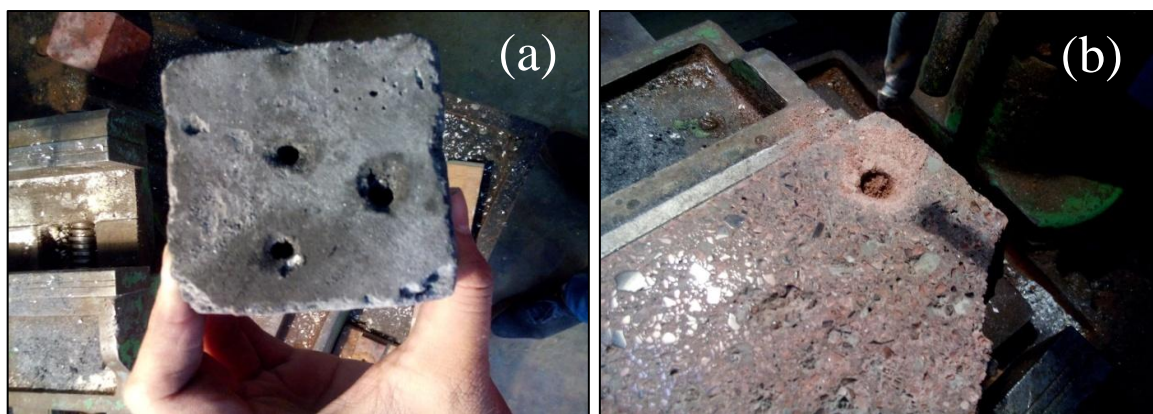


Fig 4.10 Holes drilled in the Cube and a specimen

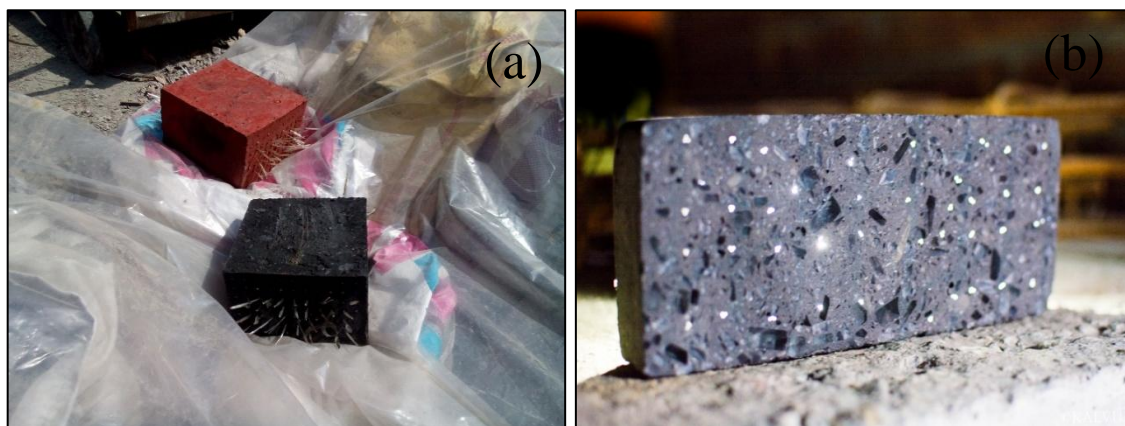


Fig 4.11 Raw cast concrete and finished cut sample

A specimen of 300mm concrete was casted and then the pieces of 25mm were cut from the concrete. This justified the cutting property of the concrete and ability to form any size and shape as per the required. Hence, the cutting was done through any section and tested till 15mm thickness minimum without any deterioration of the sample or its surface/edges.

4.7 SULFURIC ACID ATTACK

The sulfuric acid attack was carried out for the application of floor tiles as well as bricks. There are chances of stains of acid on the concrete, due to the subjection of acid by the rainfall or accidental spills. Hence, the test was carried out to measure the effect of acid on the surface and strength parameter.

As with 28-days immersion in sulfuric acid of 2% solution with pH maintained to be 1 (one). The surface of the concrete got stained as shown in Fig 4.12.



Fig 4.12 Sample with eroded surface and yellowish stains due to acid

- The sample surface was slightly eroded due to subjection to immersion in acid for 28 days.
- The sample did not lose much weight during and after the acid immersion period (as noted: weight before immersion: 775gms / weight after immersion: 781 gms), the slight increment in weight can be attributed to the pozzolanic reaction and further hydration process of concrete.
- Similarly, the compressive strength of sample containing waste glass was observed and noted before immersion as 14 MPa and after immersion period, it was 13.8 MPa. Hence, not much loss in the compressive strength was observed. Hence it may require testing for a longer duration to get conclusive results.

4.8 FIRE TEST

The fire test conducted to check with the transmission behavior with rising temperature and duration of the fire. The fire test was done in two parts i.e. a quickfire where the cube specimen was subjected to a fire from all side from one minute and secondly, the specimen (of practical size and usage thickness) was subjected to fire for one-hour duration (specimen after 1 hour of burning shown in Fig 4.13). This test was done with simultaneous analysis for transmission and spalling or any apparent cracks on the surface.



Fig 4.13 Sample after one-hour fire test

- As with the flash fire test for a minute, the surface of the specimen was dead burnt to black(refer Fig 3.15) and the transmission loss/fiber damage was around 20 % of the total area under influence of fire.
- In case of prolonged fire of one hour, the sample sustained the heating easily and did not show any sign of spalling or surface crack whereas it lost the surface smoothness.
- Also with the prolonged fire, the transmission was completely lost in the subjected is of fire and fibers tends to melt after 40 minutes of exposure to the bunsen burner.
- A fire mark and lightening of color shade occurred due to the fire on the colored sample (shown above).

4.9 MICROSTRUCTURE ANALYSIS

The microstructure of the concrete mix used in the research was analyzed using scanning electron microscopy (SEM). The images observed by the SEM analysis is shown in two parts of Fig 4.14(a & b). The images depict the interfacial zone of the mortar matrix and the glass particles at different magnification level.

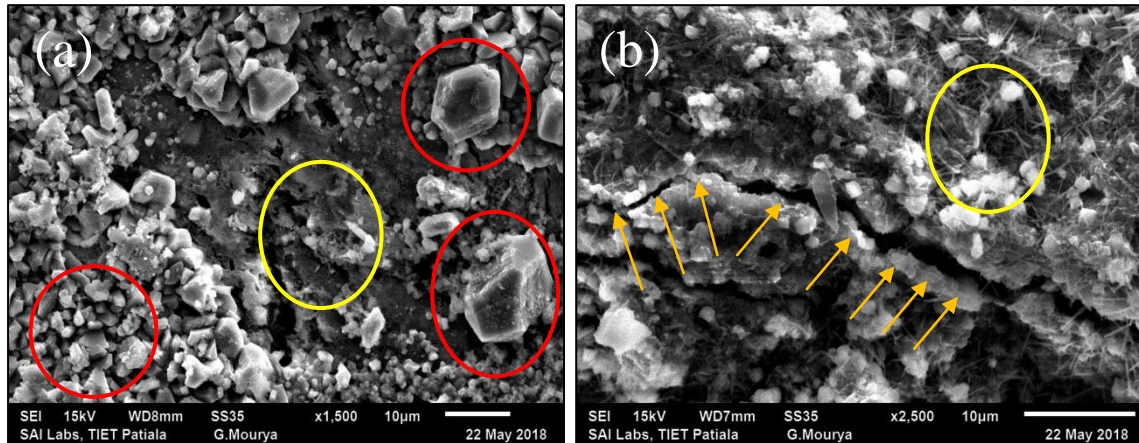


Fig 4.14 Highlights un-reacted glass particles (red), ASR gel (yellow) & voids (arrow)

As observed in the images by the SEM analysis above, the highlighted part in red circles depicts the coarse and fine size glass aggregates, which remains un-reacted to the hydration process and behave as inert aggregates in the concrete mix. Whereas the silica content in the glass also formed a gel (due to alkali-silica reaction) which is highlighted in the yellow circle in the Fig 4.14. Formation of ettringite is visible in Fig 4.14b. Whereas the interfacial zone between the waste glass the cement mortar matrix is clearly visible in Fig 4.14b. The inert glass aggregates due to smooth surface possess a clear interfacial zone, as observed in the analysis.

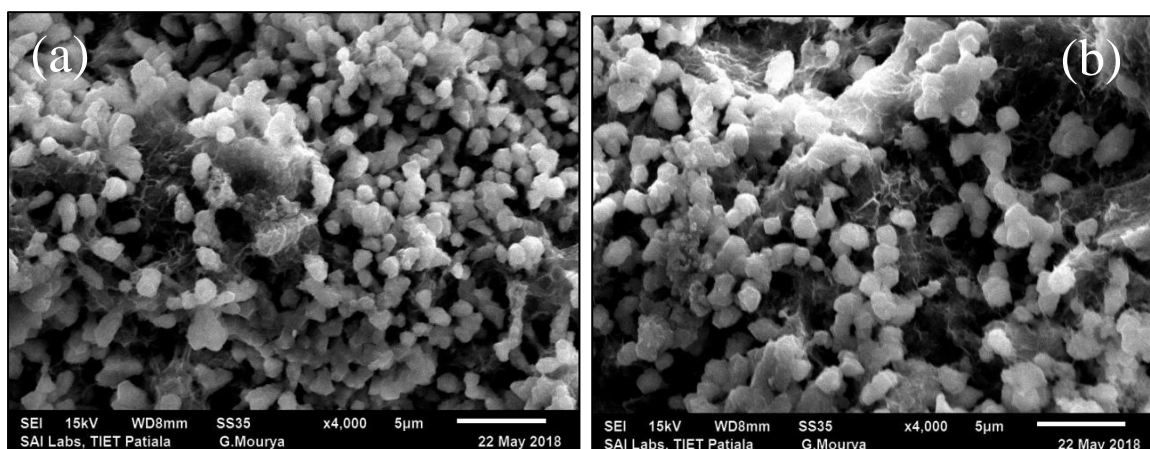


Fig 4.15 Uniform spherical particles of fine waste glass

Smooth surfaced and spherical size fine waste glass particles was observed in the Fig 4.15 (a & b). Similarly, the formation of the gel-like structure was also visible in the Fig 4.15b, which was at 4000x magnification level. Following the SEM analysis of the concrete, the analysis of the plastic optical fibers was done. Careful extraction of the fiber from the concrete was done to avoid any surface alteration of the fiber.

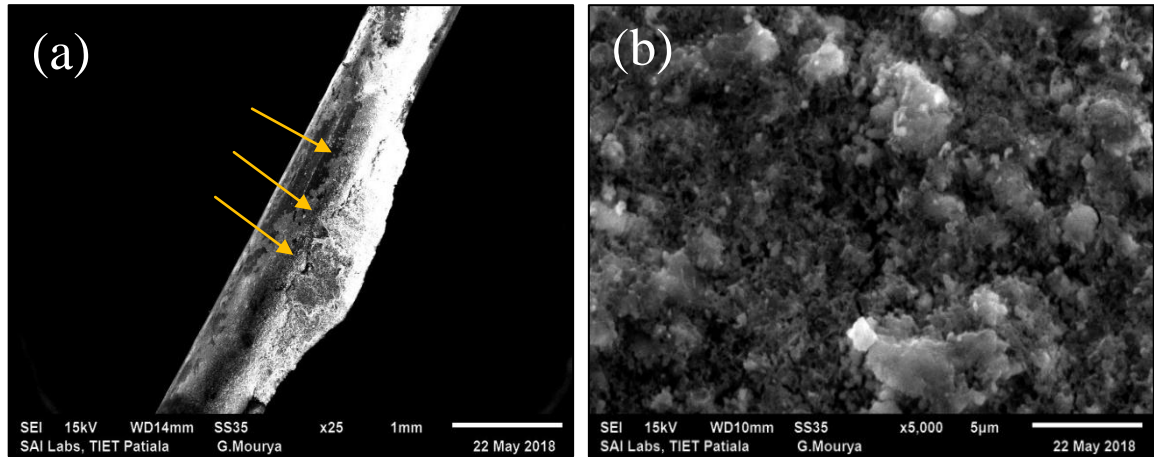


Fig 4.16 Plastic optical fiber and ITZ with cement paste on surface

With the cement paste on the surface of the plastic optical fiber was observed by the SEM analysis (Fig 4.16a). The interfacial zone was also focused and the surface of fibers was observed in clear as well as covered view by the paste. The view of the fiber covered with the C-S-H gel paste is shown Fig 4.16b, whereas the image of the clean fiber depicted in Fig 4.17a. Similarly, the interfacial zone was viewed at 5000x magnification level and the observed image is depicted in Fig 4.17b.

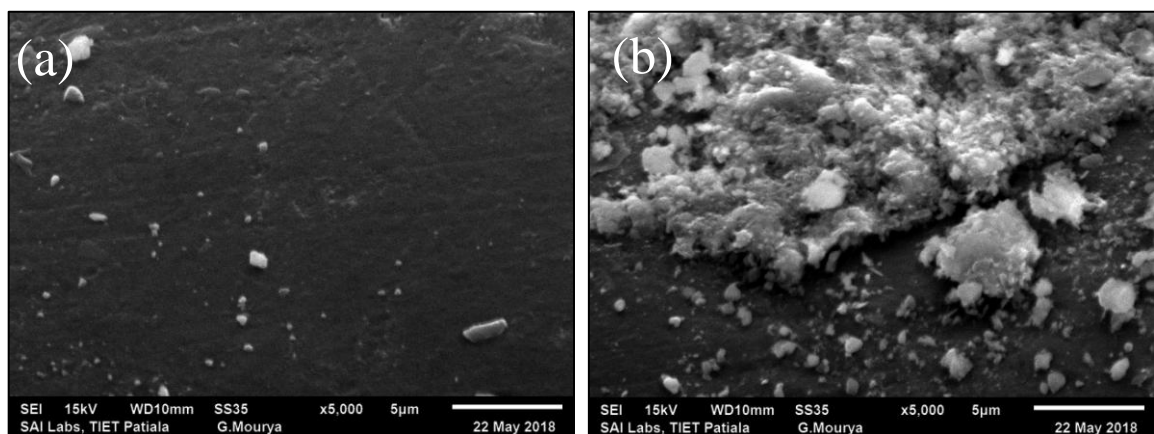


Fig 4.17 Clear surface (left) and interfacial zone of the plastic optical fiber

Thus, it was noted that the cement mortar matrix tends to form slight bond with the smooth surface of the plastic optical fiber. The ITZ of the two materials still had voids, which may be attributed to the smoothness of the surface of the fiber.

4.10 SURFACE PROPERTIES

The finished concrete with glass particles possesses a shiny lustrous surface, hence certain tests were performed to test the properties of the surface and its resistance of various practical parameters like hot plate/ utensil, oil spills, surface absorption due to voids on fiber-mortar interface and testing effects on coloring of the sample (using oxide color in cement). The tests conducted for the surface and results are as follows.

4.10.1 *Hot Plate Test*

In this test, for the application of the concrete as a tabletop, the sample is tested for the exposure to physical contact/touch of hot utensils over the surface. Thus, the damage caused to the surface due to the instant heat of the utensil is determined and it was observed that not much surface was damaged by the touch of the heating metal. Thus, it can be concluded that the surface of the concrete can take the heating effect without affecting the plastic optical fiber and the finishing of the surface. Further, durability can be enhanced with the layering of concrete sealer, which not only improves the finish but also retards the water absorption on the surface. Also, the transmission was not affected by high-temperature exposure of physical touch to the surface.

4.10.2 *Oil Spill Test*

As specified in previous chapter about the oil spill test performed on the sample, it was observed that sample without any coating/layer of (shown in Fig 4.18) absorbed a little



Fig 4.18 Sample after oil spill test

extent due to uneven finished surface, without void filling done after finishing. Also, the oil left a mild spot on the surface which could not be cleaned off with water. Further, a sealant or concrete sealer coat will be preferred to avoid any marks by the spillage absorption.

4.10.3 Surface Absorption

The surface absorption test was performed to determine the absorption on the surface of the concrete containing plastic optical fiber. Hence, the test was performed after 28 days of curing for the concrete containing waste glass and plastic optical fibers at 1.4 % of the total volume. The fibers were evenly spread in the cross-section at 12mm distance from each other throughout the section.

The measured reading for the surface absorption test was as follows:

- The reading for 10 minutes of testing was noted to be: 0.64
- Similarly, the reading for 30 minutes of testing is 0.49
- The reading for 60 minutes of testing is 0.39

Thus, using the formula the value of the flow will be:

- For 10 minutes, $f = 0.064$
- For 30 minutes, $f = 0.049$
- For 60 minutes, $f = 0.039$

Thus the average value of flow rate is = 0.050

The value is quite low and signified a lower surface absorption through the section. Further, by using the concrete sealer, the water absorption can be reduced and the concrete surface durability can be increased.

CHAPTER 5- CONCLUSIONS

5.1 GENERAL

The present investigation was carried out to develop optical fiber incorporated concrete (OFIC) brick and to study its physical and mechanical properties. Waste glass was used as aggregate and the ratio of concrete mix having waste glass as aggregates was limited to 1:2.5 (cement: waste glass). Different sizes of optical fiber were used for development of OFIC brick. The major conclusions drawn from the study are enumerated below:

5.2 DEVELOPMENT OF OFIC BRICKS

Major conclusive remarks for development of OFIC bricks are presented below.

1. The addition of waste glass was useful not just for the purpose of using a waste product but also it helped to form a finished ready to use product in the form of a concrete brick.
2. The density of the concrete was reduced due to lower specific gravity of waste glass as compared to normal aggregates. Uneven edges were formed due to irregular shape of waste glass aggregates.
3. The fine size of the waste glass reduced the flowability and its non-absorption behaviour tends to improved the flowability. This produced a neutralizing behaviour and the flowability was not much affected by the waste glass aggregates in OFIC bricks.
4. Light transmission and reflection depicted inverse behaviour with the distance and angle of source of light. Transmission and reflection reduced on increasing angle and distance of the source and vice-versa.
5. The sample brick formed can be easily cut and drilled without damaging the surface. Hence OFIC Bricks depicted better performance than brittle fly ash bricks which tends to crack / break on being cut or drilled.

5.3 PROPERTIES OF OFIC BRICKS

A comparison of the properties of OFIC and traditional bricks is given in Table 5.1.

Table 5.1 Comparison of properties of OFIC and other bricks

Bricks→ Properties↓	OFIC Brick	Clay Brick	Fly Ash Brick	Concrete Block	Value as per IS Code
Edges	Rough	Rough	Smooth	Smooth	Smooth
Density (kg/m³)	1970	2000	1300	1500	1400-2400
Compressive Strength (MPa)	16-20	10-14	10-30	15-25	12-25
Water Absorption (%)	10-13	10-14	7-10	10-12	< 20 %
Efflorescence	No	Slight	Slight	No	Moderate
Fire Resistance	High	Medium	Medium	High	Not specified
Drill and Cut Test	Yes	Yes	No	Yes	N.A
Surface Texture	Smooth	Rough	Rough	Rough	N,A
Light Transmission	Yes	No	No	No	N.A

Other significant conclusions pertaining to OFIC bricks observed from the research work carried out are listed below:

1. Although acid stains were found on the surface of unfinished OFIC brick sample after sulfuric acid attack but the compressive strength was not much affected.
2. The OFIC brick formed offers good fire resistance and can maintain the light transmission property even after 15-20 minutes of fire exposure.
3. SEM analysis depicted the non-bonding behaviour of fibers with voids on ITZ.
4. The surface of OFIC brick was not affected by heating and the oil spill left faded a mark on it.

From above points and Table 5.1 it is clear that OFIC depicts better characteristics than traditional bricks in certain aspects. Due to the presence of waste glass and finished smooth surface OFIC brick will not require any further surface treatment (plaster / paint) as compared to other traditional bricks.

5.4 SCOPE OF RESEARCH

- *Material base development:* To add other waste materials for enhancing properties as per required
- *Testing base development:* Testing the concrete for different parameters as per specific practical application requirement,
- *Utility-base development:* Developing utility of the product into different from other than brick / blocks. The development can be aesthetical as well as functional.
- *Mass manufacturing development:* Development of easy manufacturing method for mass scale production to reduce cost.

REFERENCES

1. Ali, Efram Emam , Sherif H. Al-Tersawy. *Recycled glass as a partial replacement for fine aggregate in self compacting concrete*. Construction and building materials (2012) (V 35- page 785-791).
2. Basma F. Bashbash et al. *Basics of Light Transmitting Concrete*. Global Advanced Research Journal of Engineering, Technology and Innovation (ISSN: 2315-5124) Vol. 2(3) pp. 076-083, March, 2013.
3. Bekir Topcu*, Mehmet Canbaz. *Properties of concrete containing waste glass*. Cement and Concrete Research 2004. (V 34, 267-274).
4. Bernard K. Baiden, J.K. *Perceptions on Barriers to the Use of Burnt Clay Bricks for Housing Construction*. Journal of construction Engineering (2014),, Hindalwi Publication.
5. Ismail ZZ, Al-Hahsmi EA. *Recycling for waste glass as partial replacement for fine aggregates in concrete*. Journal of Waste Management, 2009 (Feb).
6. Maininia Giovanni Andrea et al. *Spectral light transmission measure and radiance model validation of an innovative transparent concrete panel for façades*. Energy Procedia (2012) (Volume 30, page 1184 – 1194).
7. Product brochure at <https://www.lucem.com>, (Accessed on 12th March,2018)
8. Product specification details from www.frank-ele.com/pro (Accessed on 12th February, 2018)
9. Reference slides on waste materials from www.scribd.com (Accessed on 22nd April, 2018)
10. Reports from <http://www.globalcement.com/reports> (Accessed on 21st March, 2018)
11. S.L. Pagliolico, V.R.M. Lo Verso, A. Torta, M. Giraud. *A preliminary study on light transmittance properties of translucent concrete panels with coarse waste glass inclusions*. 6th International Building Physics Conference. IBCP. Energy Procedia, Elsevier, vol. 78, 2015, pp. 1811–1816.
12. Sadoon Abdallah, Mizi Fan. *Characteristics of concrete with waste glass as fine aggregate replacement*. International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-2, Issue-6, June 2014.

13. Seung Bum Park, Bong Chun Lee, Jeong Hwan Kim. *Studies on mechanical properties of concrete containing waste glass aggregate*, Cement and Concrete Research, 2004.
14. Smith, A.S. *To Demonstrate Commercial Viability of Incorporating Ground Glass in Bricks with Reduced Emissions and Energy Savings*. The Waste and Resource Action Programme, Banbury, Oxon, UK (2014).
15. Technical reference at <http://www.litracon.hu/en/products/litracon-pxl>
16. Thiago dos S. Henriques, Denise C. Dal Molin, Ângela B. Masuero *Study of the influence of sorted polymeric optical fibers (POFs) in samples of a light-transmitting cement-based material (LTCM)*, Construction and Building Materials, 2018 (V 161, page 305-315).
17. Tuncan M.B. Karasu, M. Yalc, *The suitability for using glass and fly ash in Portland cement concrete*. The Proceedings of the Eleventh International Offshore and Polar Engineering Conference (ISOPE 2001), Stavanger, Norway, vol. 4, 2001, pp. 146–152.
18. Yue Li, Jiaqi Li, Yuhong Wan, Zhiyuan Xu. *Experimental study of light transmitting cement-based material (LTCM)*, Construction and Building Materials, 2015 (V 96, page 319-325).
19. Zainab Z. Ismail, Enas A. AL-Hashmi. *Recycling of waste glass as a partial replacement for fine aggregate in concrete*", Waste Management, 2009.