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Research Article

State Of Art Review For Transmittance Material For Solar Roadways

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ABSTRACT

Transparent concrete is a modern type of concrete that is gaining popularity in the construction industry. Today transparent concrete is in queue with the finding solution for environmental and sustainable development. It has been observed that despite of several efforts given for proper conservation of solar energy, lot of energy is wasted. Even the use of conventional solar panels on roof top is not utilizing solar energy as required. The present study is based on utilization of transparent concrete in the road. It has been found that the material used in transparent concrete is mostly plastic optical fiber for the transmission of light. Other material used for light transmission are glass fibers and epoxy resin. Plastic Optical Fiber (POF) is not costly material and the workmanship used in POF for transparent concrete is slightly tedious task. This study is an effort to study the transparent concrete that can be used in roadways. The scope of this review is to find a new material having light transmittance properties that can be used in concrete with easy workmanship and must be economical. Contemporary literature shows that epoxy based transparent concrete and plastic optical fibers may be a good option for transparent concrete in solar roadways.

Keywords: Transparent concrete, optical fiber, epoxy polymer, light transmittance.

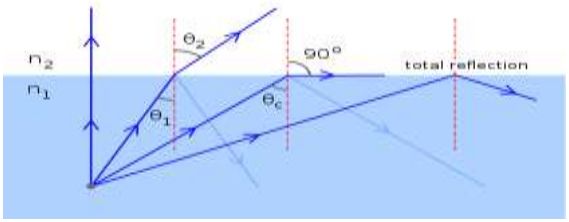
Introduction

The overuse of fossil fuels is causing environmental degradation, a growing energy deficit, and threats to human life. [(Martins, et al., 2019), (Abas, et al., 2015)]. Their use presents a number of issues, many of which have been examined and resolved in several research (Martins, et al., 2019). These problem cause lot of negative environmental impact for example air pollution and global warming, scarcity, supply risk and instability of prices and markets. Researchers have been attempting to gather and transform various sorts of energy from the road into power over the past few decades [(Gholikhani, et al., 2020) (Ahmad, et al., 2019)] encompassing sun, wind, geothermal, mechanical, and aural energy sources. As a type of inexhaustible and infinite energy source [(Bhowmik, et al., 2017)] solar energy plays a major role in the energy system around the universe. Large areas are dedicated to road and since most roads receive sunshine, there is a high degree of between solar energy harvesting and the road network system. One of the biggest problem is that how maximum amount of solar energy can be harvested. The idea is solar roadways. Numerous land resources are occupied by the worldwide road network system. China's total road length by the end of 2020 was 5.198 million kilometres [(Strano, et al., 2017)]. The majority of commercial solar panels typically have 10-12% conversion efficiency, which is relatively low [(Abas, et al., 2015)]. To meet the growing energy demand with the current available efficiencies, Photovoltaic panels need a lot of open space in order to match the present possible efficiency and the expanding energy demand. Because they are easily accessible and frequently left unattended, pavements produce a significant quantity of energy. Solar power is inexpensive and environmentally benign. In addition to providing green power for urban and rural residents utilizing the power grid, generation via pavements might even directly supply power for automobiles on the pavement. With this strategy, carbon emissions might be drastically decreased, global warming could be slowed, and

better use of (paved) land resources could have a positive influence on the economy, society, and ecology [(Li, 2008), (Strano, et al., 2017)]. The concept of solar pavement emerged in 2006 when Scott and Julie founded Solar Roadways (SR), a novel kind of pavement [(Min)]. The first solar parking lot prototype in history was constructed in 2014. It is made up of three layers: an antifuge (at the bottom), a solar power generation layer, and a transparent, non-sliding protective layer [(Min)]. In Netherland (2014), Amsterdam, a 90 m long and 3.5m wide bike path is the world's first solar road [(Johnston, et al., 2017)]. In China (2017), Jinan city, Shandong province 2km of the first solar road pavement highway was constructed. In Idaho, USA, the solar roadways project is being developed [(Zhi-gang, et al., 2018)]. The idea behind this project is the potential for solar panels to be mounted on a variety of surfaces. The solar radiations are directly converted into electricity by using single crystalline silicon or cadmium telluride based solar cell. The transparent concrete is used for paving the surface of solar roads. One of the newest sustainable and green building materials to emerge is light transmitting concrete (LiTraCon), also known as transparent concrete or translucent concrete (TC), which was found by Hungarian architect Aron Losonczi. architect responsible for creating the first LiTraCon, like a panel or block. Several kinds of optical fibre wire, including polymethylmethacrylate (PMMA) polymer fibre, are employed in this application [(Martins, et al., 2019), (Abas, et al., 2015)] or plastic optical fibre (POF) and glass optical fibre (GOF). Its function is to guide the light wave transmits from one end of fibre to the other end. It was demonstrated that 50% of daylight should be transmitted into the green buildings, according to Indian green building council, and this conditions cannot be attained without the fabrication of Litracon [(Gholikhani, et al., 2020)]. At the Technical University of Budapest in 2001, a Hungarian architect used optical fibres to create translucent concrete for the first time. The first translucent concrete block, called Litracon, was created in 2003 with the use of optical fibres. Transparent concrete is currently produced and manufactured by a number of businesses, such as Luccon, Litracon, Italcementi Group, and LUCEM. A more sophisticated form of transparent concrete, called i. light was unveiled by architect Giampaolo Imbrighi in the Italian Pavilion at Expo 2010 Shanghai, China in 2010.The study of solar roadways in India and elsewhere has been studied little. It requires separate study to develop separate code. In terms of material used as light transmittance, no comparison has been done for better transmissibility and durability. The assessment of strength, durability and light transmittance capacity of plastic optical fibres, epoxy resin and glass fibre used in transparent concrete shall be carried out to access its suitability in construction of solar road way.

2.0 Research Progress in Transparent concrete

2.1 Optical fibre based transparent concrete



Transparent concrete is based on the principle of total internal reflection. In this phenomenon when light travel through when an optically dense medium strikes a boundary at a steep angle that is more than the boundary's critical angle, all of the light is reflected back.

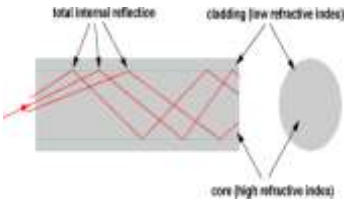


Fig.1 Total internal reflection (Retrieved from New frontiers for design of interior lighting products pg-114 by Andrea Siniscalco)

Hence, when Light travels through such type of material which surface layer is dense, it can able to travel through it even that medium is bent or curved. The best example is optical fibre. Unless the fibre is severely bent or stretched, no light can escape until it reaches the end of the fibre.
Materials used for making transparent concrete are shown in table: 1

Material	Specification
Cement	OPC 43 or OPC 53 (ASTM)
Fine Aggregate	Fine Sand (ASTM)
Coarse Aggregate	Under 10mm size with cubical shape
Water	It should be free from acid, oil, alkalis, vegetable and other organic impurities
Light emitting materials	Plastic Optical Fiber (POF) or Optical Fiber, Epoxy resin, Glass fiber

Table 1 Transparent concrete materials (Adopted from Juan and Zhi, 2019)

Optical Fibre:

Optical fibre is a thin fibre cylindrical in shape of glass or plastic that can carry light from one end to the other. In the centre it has core. Around the core there is layer called cladding. The core and cladding are made of different material so that light travels slower in core than Cladding. Light can travel inside the core and refracted to the cladding. Outstanding light-guiding and sensing benefits like anti-electromagnetic interference capabilities, short size, and anti-corrosion features are other significant attributes that support the use of optical fibre.

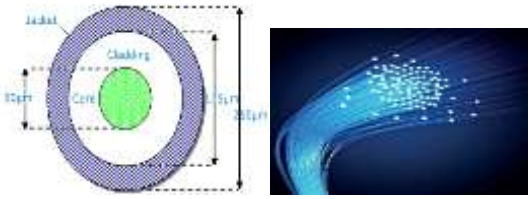


Fig.2 Cross-section of Optical Fibres. (Guo et al.2017)

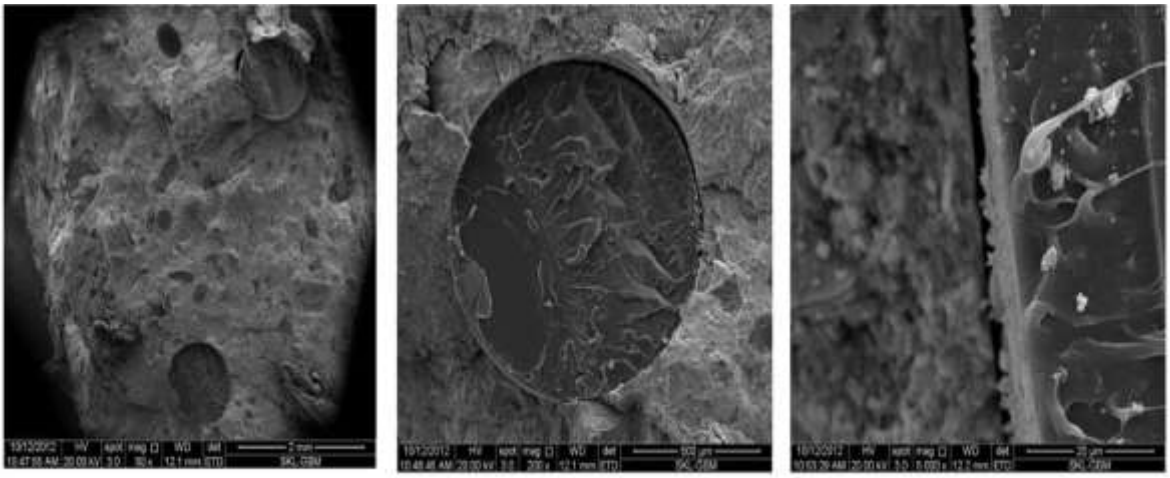
Optical Fibre based Transparent Concrete

In this type of transparent concrete, optical fibers are fixed at certain length throughout the length in mould before casting and prepared concrete mix of cement, sand and aggregate (smaller than 10mm) are poured in the mould without disturbing the optical fibers. Proper compaction is done to remove air voids. After casting all extra fibers are cut.

Fig.3. Process of production of Optical fibre base transparent concrete
(Adopted from Salih, 2014)

(Salih, et al., 2014) Performed computational modelling of translucent concrete panels using software ANSYS. They offer a geometric x-ray tracing algorithm to enhance the translucent concrete panels suggested light transmission qualities. They presented the technique for figuring out how much solar radiation reaches the inside of the structure, how well panels function in various locations, and how big fibre proportional to volume. They found that 30 degree tilt angle for the panel produces maximum amount of light. (Salih, et al., 2014) Studied strength parameter of translucent concrete casted by insertion of optical fibre of different diameter has showed that compressive strength and flexural strength decreases as plastic optical fibre content increased. 2mm diameter optical fiber showed least reduction of compressive strength from 2.8 to 26% and reduction of flexural strength up to 17.14 %. (Sawant et al., 2014) casted transparent concrete, its strength, light transmission and cost were thoroughly studied and found that 10 to 20% reduction in compressive strength due to increment of percentage of optical fiber from 0 to 5%. Light transmission increases with increment in optical fiber content up to 20-23% at 5% optical fiber. Cost of light transmitting concrete was found 12 times higher than conventional concrete, but it can be payback by saving power in 3.5 years of domestic consumption and 2.1 years of commercial or industrial consumption, when a wall of 16 blocks would be casted. They concluded 4 % optical fiber was suggested to get better light transmission and less compressive strength reduction. (Luhar, et al., 2015) Casted concrete cube with plastic optical fibres (1% volume of concrete) and found marginal reduction in compressive strength and found to be effective in light

transmission. (Sunil, et al., 2015) Studied and found that M20 concrete casted with optical fibre gives about 10% reductions in compressive strength. UPV test showed medium range of concrete**.** (V., et al., 2015) Use coir pith as fine aggregate in translucent concrete and found increment in compressive strength, flexural strength and reduction in weight in comparison of ordinary concrete. But compressive strength reduces also with increase of coir pith content. Its behavior is also good in light transmission. (Karandikar, et al., 2015) Casted optical fibre in the centre of concrete cube of dimension 7.5 cm x 7.5 cm x 7.5 cm with volumetric content of 0.00 %, 0.09 %, 0.87 %, 1.05 % and 1.75 %. It was found 30 to 39% reduction in compressive strength and 0.34 to 1.37 % light transmission with increase of optical fiber content up to 1 to 1.75% respectively. (Sunil, et al., 2015) Carried out experiment in which in which optical fibres were inserted during casting of concrete specimen from 0.25% to 4%. Light transmittance result was found up to 5.62% by 4% optical fiber. Coarse aggregate size up to 10 mm used in concrete also prevented the reduction of considerable amount of compressive strength of concrete. (Kadam, 2017) Investigate the behaviour of concrete and mortar with optical fibre and found that the compressive strength of translucent concrete increase with increase in fibre content. The sample with fiber of 4% showed better results in comparison with others. (Mosalam, et al., 2018) introduce a novel building envelope construction solution that can transmit sunlight into the interior of the building. Snells law is followed. They introduced building envelope in two layers. In layer reinforced cement with embedded symmetrical CPC's which are non-imaging concentrators to concentrate maximum sunlight from the outside in a geometrical manner without mechanizing the panel. Layer B was reinforced concrete with embedded optical fiber as a structural sub system to act as a conduit for the natural sunlight from the outside of interior space. (Gulzar, et al., 2019) carried out cost analysis of translucent concrete for a room. They concluded that the initial cost of translucent concrete is much more than the ordinary building but in long term it is economical, energy efficient source and more natural. After going through various literatures it has been found that there is very few or no research has been conducted to quantify the potential or compare the performance of Plastic optical fiber with other light transmitting material.



(a) Matrix with optical fibers (b) cross section of optical fiber (c) fiber/matrix interface

Fig: 4 SEM images of Plastic optical based Transparent concrete
(Adopted from Li.et.al. 2015)

The microscopic morphological properties of transparent concrete were examined using the SEM method. It was discovered that the fibres were uniformly inserted in the compact matrix. The POF fibre's fracture section was rough and round in shape. On the interfaces where the cement matrix and optical fibre met, there were tiny gaps.

2.1 Epoxy based transparent concrete

In some areas, the surface roughness of the concrete material totally dictates its ability to guide light. Because of this, epoxy resin was utilized in place of cement. Since carbon black is utilized to mimic the properties of a concrete environment and epoxy resin is transparent, any light that is detected should be given credit to the POF. Tests on epoxy-based POF transparent concrete have shown that it can generate thermal energy in addition to visual light transmission. It has the ability to lower energy usage for both lighting and heating.

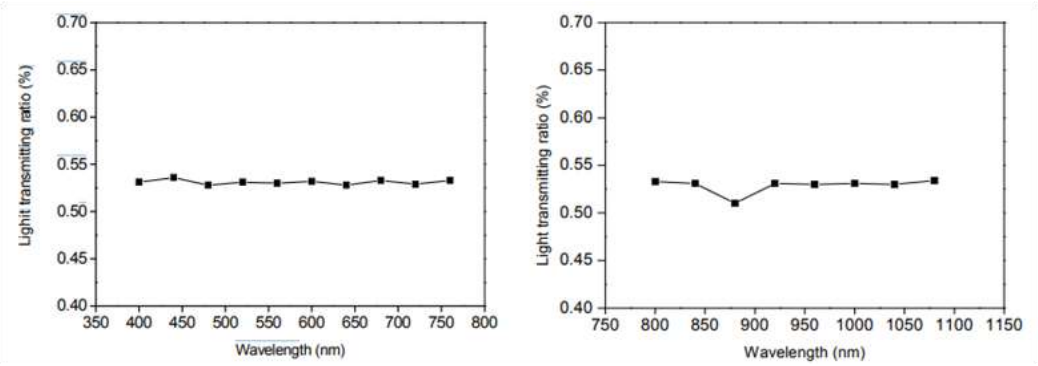


Fig.5. Light transmitting ratio for visible light Light transmitting ratio for infrared rays (Adopted from Zhou et al.2019)

(NOGUEIRA, et al., 2001) Investigated the effect of water absorption on the mechanical properties of epoxy resin and found a gradual reduction in tensile properties with increased in absorbed water**.** (Oussama, et al., 2012) investigated the mechanical properties of epoxy based concrete after exposure to high temperature and they found a significant strength loss at temperature greater than 150 C. (PAUL, et al., 2013) Studied for load bearing transparent concrete and confines reinforcement method in transparent concrete. They formulate transparent concrete mixture using (epoxy matrix 0-90%), (Polycarbonate matrix 0-60%), Fiber Glass (0-10%), colloidal silica solution (0.5-5%), silica (0.5-10%) and for setting agent diethyl tetra mine are used. They also found that the ratio of optical fiber volume to concrete is proportional to transmission. Translucent concrete do not altered to its strength as compared to controlled concrete. (Jiménez-Muñoz, et al., 2014) Observed that reduction in strength due to incorporation of optical fibre can be overcome by addition of 0.5% Glass fibre**.** (Pagliolico, et al., 2015) Carried out experimental work in which flat glass pieces were used in a cement composite panel of size 50 cmx 50 cm x 2.5 cm as inert material and increase translucency. It was concluded that 5% reduction in energy demand can be achieved by these panels and suggested as architectural application in wall. (Spiesz, et al., 2016) Carried out experiential working which glass powder and small pieces up to 60% were utilized as aggregate in concrete to make it translucent. Increment in glass content in concrete reduces compressive strength and flexural strength and increase translucency. Alkali silica reaction can be reduced by using fly ash and ground granulated blast-furnace slag. But its translucency reduces with thickness of specimen. (Raju et al., 2018) studied on light transmitting concrete using POF and epoxy resign and they found that epoxy resin may also be good substitute for the light emitting material used in concrete. (Raju et al., 2018) studied the plastic optical fiber and epoxy resin based translucent concrete in which they constructed light transmitting concrete using POF and epoxy resin and compare all parameter with conventional concrete. They concluded that epoxy resin show better transmissivity compare to plastic optical fiber. Light transmissivity in the the field under sun also have better transmissivity than in laboratory. (Juan, et al., 2019)Studied the mechanical, thermal, and transmittance characteristics of a novel kind of resin-translucent mortar-based concrete (RTMC). Unsaturated polyester resin was selected as the light guide material in this investigation. Resin material show excellent light transmission with thickness of 100mm which can high as 93%. The compressive strength is close to plain concrete if the area of resin material is 5%. They also concluded that RTMC has excellent thermal performance as thermal conductivity of RTMC was 60% lower than that of plain concrete.

Fig.6 Epoxy resin based transparent concrete (Adopted from Juan and Zhi 2019)

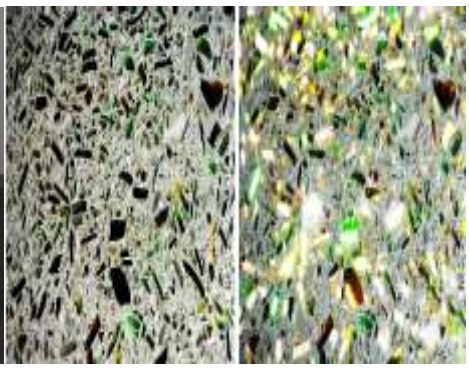


Fig.7 Glass Powder based Transparent Concrete (Adopted from P.Spiesz et.al 2016)

(Bărbuţă, et al., 2009) Investigated the impact of several fillers (silica fume and fly ash) on the mechanical characteristics of polymer concrete and found that adding these fillers enhances the mechanical characteristics.(Ferdous, et al., 2020) In order to optimize the mix design of epoxy-based polymer concrete, the effects of the resin to filler and matrix to aggregate ratios on the material's mechanical and durability qualities were examined. (Baltazar, et al., 2014) Performed an experiment and concluded that epoxy resin may be the best impregnations material for superficial protection of concrete. (Almusallam, et al., 2003) Performed durability study for epoxy resin based concrete. In their work assessment of different parameters is done for example adhesion with concrete, crack propagation study, chloride permeability, water absorption capacity, resistance to sulphuric acid etc. The result showed that epoxy resin coating presented excellent overall performance as surface coating.

Structure of Resin based concrete at micro level

The microstructure of resin based concrete is studied using SEM (Scanning Electron Microscope) and shown in Fig.7.a and Fig.7.b with plain concrete. In the figure mentioned below, filler material such as fly ash is mixed with both concrete. Here fly ash reduce the volume of pore and thus enhance the durability of concrete. It is also shown that the interface of resin and matrix are more closely spaced.

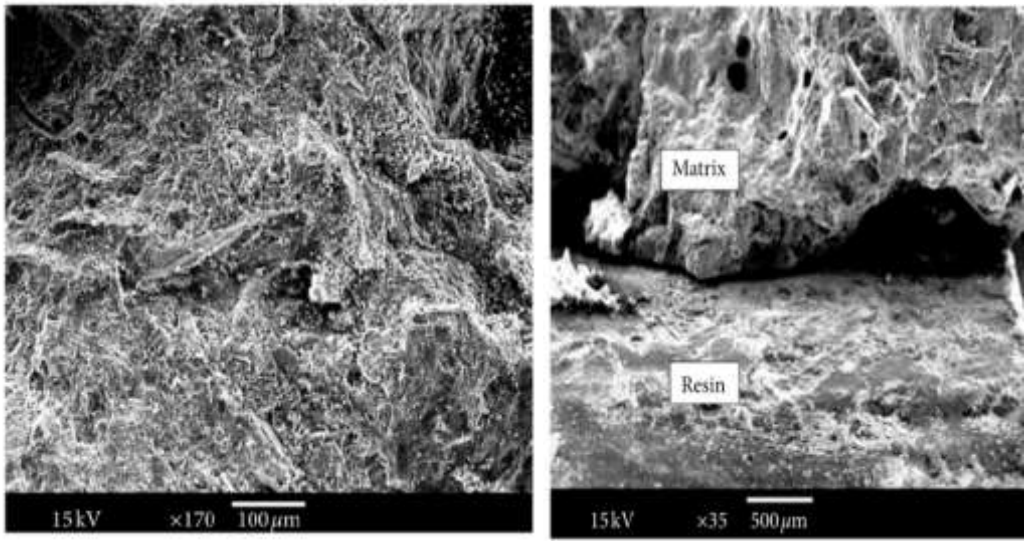


Fig.8.a **Fig.8.b**

Fig.8 SEM images of Plain concrete and Resin based concrete (adopted from Juan and Jhi 2019)

The RTMC SEM showed that the matrix's microstructure was highly dense, with small pores and fewer hazardous ones. The resin's surface was also reasonably rough and could be well-meshed with the matrix.

2.3 Waste Glass based transparent concrete

Waste Glass may also be alternative for light transmission in transparent concrete. Because of its wide range of size fractions, which span from a few micrometres (powder) to a few centimetres, it can be used in place of traditional, mineral concrete fillers and aggregates (fines, sand, and gravel) in concrete [(J.Refined, 1991), (Uchiyama, 1998)]. Glass aggregate has been also used for the light transmission because of exposed glass particle in polished surface. Glass in concrete, however, has the potential to cause some problems. Glass exposed to an extremely alkaline pore solution can experience an expanding alkali-silica reaction (ASR) or an alkali-aggregate reaction (AAR), both of which are harmful goods [(Ling, et al., 2011)- (Park, et al.)]. The smooth texture of glass aggregate decreases the workability and reduces the strength of concrete as aggregates are mostly irregular in shape due to grinding process which makes it difficult to slide between the particles and reduce the flow of mixture [(Limbachiya, 2009), (Kou, et al., 2009)]. The SEM pictures The strength and durability of the mortars are influenced by the interfacial transition zone (ITZ), a broad porous zone that is seen between the cement paste and the glass aggregate in the transparent concrete mix with glass aggregate.[(Lu, et al., 2017), (Lu, et al., 2020)].

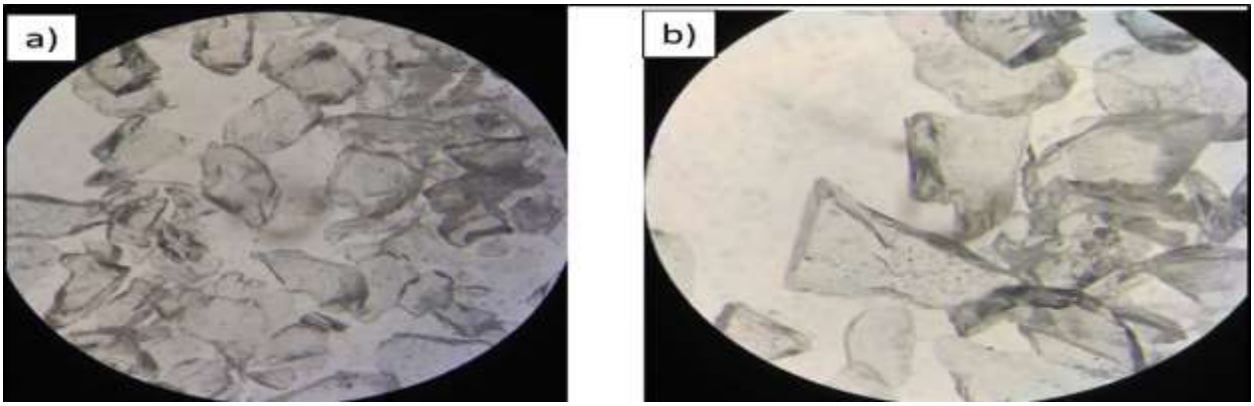


Fig.9 Optical image of glass aggregate in concrete (Adopted from J.Arias-Erazo et al.)

The smooth surface of the glass is thought to be the cause of the weak ITZ that results between glass particles and cement hydration products, which is why there are micro cracks surrounding the glass particles. [(Lu, et al.), (Lu, et al., 2018)].

Light emitting material	Ductility (%)	Mechanical properties
Glass	0	Brittle
POF	>5	Non brittle
Unsaturated polyester Resin	0-5	Less brittle

Table: 2 engineering behaviour of fibres

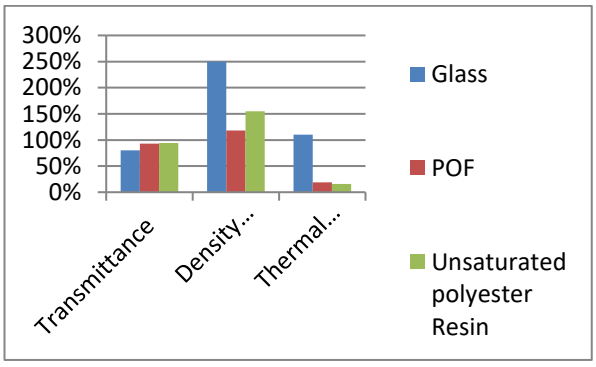


Fig.10 Comparative study between fibres
(Adopted from Juan and Jhi 2019**)**

From table it has been shown that glass is brittle material having greater failure strain than other two fibres. Furthermore addition of optical fibres and epoxy, which act as a reinforcement, allows translucent concrete block to withstand low tensile forces. From table:2 it has been found that unsaturated polyester resin and optical fibres have transmittance rate up to 94% which is more than other as well as thermal conductivity and density is lower which make its scope to be used as better alternative for light emitting material

3. Application in Solar roadways

Solar roadway is a concept, in which road surface is used to lay solar panels. Since Solar energy is a green energy and it is available in large amount all over the world but its power plant requires a large amount of area. Therefore, if roads are used as places to install solar panels then it will be helpful to generate power for road lighting and electric vehicle charging. For this purpose, Transparent concrete is being developed, so that light can pass through it and solar energy can be stored. Solar roadways are in trial in China, France and Canada like countries and they are using tempered glass surface for surface layer and Concrete as base layer in pavement, which is shown in figure below. But, with the help of transparent concrete, it can be achieved in future. Moreover, load-bearing walls, pavement, floors, and speed bump illumination on roads can all be

built with translucent concrete based on POF can also be best used for highway lane markers and night time sidewalk lights. Illumination in dimly lit subway stations and tunnels.

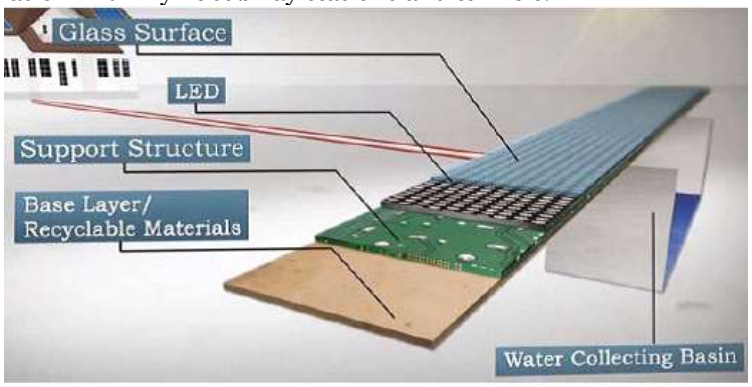


Fig.11 Solar roadway structure

4. Conclusions and future work

There is a large inherent benefit associated with the use of transparent concrete. It is employed to produce brilliant, environmentally friendly building materials. In order to minimize the use of non-renewable energy sources and electrical energy, it may be possible to harness the enormous quantity of potential energy found in sunshine. amount of fuel used. Fine concrete and light transmitting material are the two main ingredients used to make light transmitting concrete. Cement, fine aggregate, and water make up fine concrete, whilst glass fiber, epoxy resin, and plastic optical fiber are utilized as light-transmitting components. Many of the researcher used plastic optical fiber as a light emitting source in concrete and it has also been found that plastic optical fiber give better result in terms of strength and light transmissibility. It has been observed that the rate of light transmission in glass and in optical fiber can reach up to 80 % and 93% respectively. Although light transmission in glass is adequate but due to its high density, high thermal conductivity and poor ductility it is not feasible to use as a light transmitting material in transparent concrete for important structure. POF has adequate transmission rate and density is also low but there is slightly tedious workmanship. Performance of resin in terms of density, mechanical properties and thermal performance are also better. Epoxy resin act as surface coating in the concrete. It solidifies through a chemical reaction or drying inside the concrete's pores and capillaries, forming a barrier on the surface that stops additional surface reactions and extending the concrete's longevity. Influence of moisture content may also be less on resin based concrete and there is excellent bonding between resin and concrete. The flexibility of the resin translucent body allows for the surface to be roughened, improving the adhesion of the resin to the matrix and extending the life of the concrete. It may act as pore blocker. Epoxy based resin can be easily used in transparent concrete, but when quantity of resin is increased for better light transmissibility, strength of concrete is reduced. As epoxy is expensive compared to byproducts, it may be partially replaced with filler for example fly ash. Low filler content mixes exhibit severe segregation and result in layered epoxy concrete with an aggregate-rich bottom layer and a resin-rich top layer, which is bad from a strength and durability standpoint. observe. Thus appropriate quantity of filler may be used with epoxy based resin concrete. Mechanical properties on epoxy based transparent concrete cannot transmit only visible light but also produce thermal energy. It can reduce the consumption of both illumination and thermal based energy consumption. Epoxy based transparent concrete can be widely used in office, multistoried buildings, roadway etc. The only issue with epoxy is health risk. Exposure to epoxy resin poses a health risk that includes dermatitis, allergic responses, and respiratory issues from breathing in vapour and sanding dust, particularly in cases when the resin is not entirely set. Also problem with epoxy is that it provides little more frictionless surface compared to pavement surface. Hence it generally used in building floor. Therefore in pavement, POF may occupy better space for light transmissibility. There may be other option of using epoxy with POF, for this detail study is needed. The use of POF is more suitable in lane separator, median, kerb etc. rather than use directly in pavement because POF is slightly costlier and tedious workmanship. The investigation of the mechanical qualities, durability, and transmittance characteristics of POF-based transparent concrete is presently ongoing.

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