JARTE
Journal of Applied Research in
Technology & Engineering

1(1): 9-14, 2020
https://doi.org/10.4995/jarte.2020.13832

Received: June 10, 2020; Accepted: June 18, 2020; Published: July 31, 2020

LIGHT TRANSMITTING CEMENT-BASED MATERIAL (LTCM) AS A GREEN MATERIAL FOR BUILDING

Agustina Robles[a], Gustavo F. Arenas [b], Pablo M. Stefani [c*]

[a] Facultad de Ingeniería, Universidad Nacional de Mar del Plata (UNMdP), Av. Juan B. Justo 4302, 7600 Mar del Plata, Argentina.
juliagustinarobles@gmail.com

[b] Instituto de Investigaciones Científicas y Tecnológicas en Electrónica (ICYTE), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Universidad Nacional de Mar del Plata (UNMdP), Av. Juan B. Justo 4302, 7600 Mar del Plata, Argentina.
garenas@fi.mdp.edu.ar

[b] Instituto de Investigaciones en Ciencia y Tecnología de Materiales (INTEMA), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Universidad Nacional de Mar del Plata (UNMdP), Av. Colon 10800, 7600 Mar del Plata, Argentina.
pmstefan@fi.mdp.edu.ar

Abstract:
In recent years, light-transmitting cement-based materials (LTCM) have become important in the construction of green buildings because these reduce energy consumption for lighting. LTCMs were prepared by adding polymeric optical fibers (POFs) in a high strength self-compacting mortar (SCM). SCM was formulated from Portland cement, fine sand and water reducing admixture following the EFNARC criteria. LTCMs with a constant fiber content (5%) and three fiber diameter (0.75, 1 and 1.5 mm) were prepared by casting fresh SCM into a formwork designed ad hoc to keep the fibers fixed and aligned. Light transmitting performance of LTCM was tested by optical power measures. The effects of fiber diameter and distance between sample and detector on the optical power were evaluated. The compressive strength of hardened SCM reached a value of 69 MPa at an age of 28 days, while the LTCMs maintained sufficient strength for structural purposes. LTCMs are suitable to produce precast blocks and wall panels for application in building facades, signage and decorative art.

Keywords: self-compacting mortars; polymeric optical fibers; translucent concrete; optical properties; mechanical properties; water reducing admixture.

Cite as: Robles, A., Arenas, G., Stefani, P. (2020). Light Transmitting Cement-based Material (LTCM) as a green material for building. *J Appl Res Eng Technol & Eng., 1*(1), 9-14. https://doi.org/10.4995/jarte.2020.13832

1. Introduction

Green buildings are designed, built and operated in such a way that the impact on the environment is minimized. Lighting consumes a considerable amount of energy in buildings, so it is necessary to look for alternative that depends mainly on sunlight (Ahuja & Mosalam, 2017; Kamdi, 2013; Berli et al., 2018). Traditional glass and organic composites allow light to pass through the building facades, but these are not structural materials. Building designers must decide between transparent or strength materials, limiting in some cases the available surface for lighting in residential or industrial buildings (Altlomate et al., 2016; Hoyos Montilla, 2012; Li et al. 2015a).

Light transmitting cement-based material (LTCM) is a new type of structural material that allows light transmission without the need to limit the thickness of the wall (Henriques et al., 2018; Li et al., 2015a; Li et al., 2015b). Basically, LCTM consists of a high-strength cement mortar and optical fibers placed with a specific spatial arrangement. Optical fibers act as a real "light pipe" between indoor and outer surface of wall. In 2001, Hungarian architect Aron Losonczi invented LiTraCon, the first commercially available LTCM (Li et al., 2015a). In this product, optical fibers are arranged in the required pattern before the mortar is cast. The optical properties of LCTM depend on fiber type, diameter, volumetric fraction as well as particular spatial arrangement pattern. By adjusting these parameters and mortar composition, different textures, colors and original optical effects can be achieved (Henriques et al., 2018; Li et al., 2015b; Yadav et al., 2018). On the other hand, the fiber volumetric fraction would be less than 6%, to achieve an adequate balance between transparency and strength. In this way, the LCTM can be used as a supporting structure in homes (Li et al. 2015a; Yadav et al., 2018).

Another advantage of this material is its ability to produce soft, subdued light without the need for curtains or blinds. It is a "smart", non-invasive light, which gives warmth to the rooms and allows permanent interaction between outdoor and indoor environment. Different applications have been proposed for LTCM, for example, in emergency exits of buildings, hospitals and prisons, as well as in metro stations and underground parking lots. It can also

---

*Corresponding author: P.M. Stefani, pmstefan@fi.mdp.edu.ar be incorporated into pavements to highlight areas with color indications lighting them below which contributes to the road safety of a “smart cities” (Henriques et al., 2018).

Despite the potential of LCTM to be used in many applications, some aspects related to optical behavior and optimization of manufacturing processes have not been fully explored. Liu & Liu (2010) patented a preparation method for LCMT, using parallel distributed optical fibers. Another patent proposed the use of optical fiber fabrics whose versatility allowed unique designs with good light transmission properties (Li et al., 2012). However, the same authors reported some drawbacks associated with contraction cracking processes, high cost and the complexity of the preparation method. It is clear that the main drawback of both patented systems is related to the positioning of the fibers and the filled process of formwork with mortar. Even for low fiber contents, and even more so when using a fabric, low viscosity mortars are required (Yadav et al., 2018).

In this sense, a self-compacting mortar (SCM) is a plausible alternative for the production of LTCM. The SCMs are specifically designed so that these can be placed in the formwork without applying internal or external compaction (Fornasier et al., 2003; Okamura & Ouchi, 2003). Cement based mortars behave like a Bingham fluid. Thus, the rheological parameters that characterize its workability are the threshold shear stress that corresponds to the stress required to start the flow and the viscosity. To achieve the self-compacting condition, very low threshold stress values must be achieved without significant loss of viscosity in order to provide adequate segregation resistance (Faccin et al., 2017; Schiopetto & Stefani, 2015). In this way, the mortar can easily flow between the optical fibers without altering its spatial distribution in the matrix.

In the present work, we study the effect of processing conditions on the mechanical and optical properties of LTCM based on polymeric optical fiber (POF) and a self-compacting mortar (SCM).

2. Experimental

2.1. Materials and characterization

Portland cement fillerized (CPF40, Cemento Avellaneda, Argentina) that complies with the Argentinean standard IRAM 50001 (2019) was used. Table 1 shows the physical, chemical and mechanical characteristics of the cement.

The sand was provided by Arenas Verdes (Necochea, Argentina). The sand fraction retained by the sieve with nominal size of 0.59 mm was discarded. The properties of fine sand measured according to IRAM 1512 (2013), IRAM 1505 (2019) and IRAM 1520 (2002) argentinian standards are summarized in Table 2.

Two water reducing admixtures were used in this work: ADVA® 567 (GCP, Argentina) and MIRA® 57 (GCP, Argentina). ADVA® 567 is a polycarboxlate-based high-range water-reducing admixture while MIRA® 57 is mid-range water-reducing admixture based on polymers. Both admixtures were formulated to comply with specifications of ASTM C494 as a Type A and F and IRAM 1663 (2002) Argentinian standard. Both admixtures do not contain calcium chloride.

Table 1: Cement properties and IRAM 50001 requirement.

Test	Unit	Result	Requirement
Specific area (Blaine)	m^2/kg	389	≥250
Specific weight	g/cm^3	3.1	---
Initial setting time	min	159	≥60
Final setting time	min	207	---
Soundness to heat	%	-0.03	≤0.8
Insoluble residue	%	2.33	≤10
Fire loss	%	8.14	≤13.5
Magnesium oxide	%	0.74	≤7
Sulfur anhydride	%	2.39	≤3.5
Comp.Strenght- day 1	MPa	13	---
Comp.Strenght- day 2	MPa	24	≥10
Comp.Strenght- day 7	MPa	39	---
Comp.Strenght-day 28	MPa	52	≥40

Table 2: Physical characteristics of sand.

Sieve (aperture)	Weight retained (g)	% By weight	
		Retained	Accumulated
0.59 mm	0	0	0
0.30 mm	303.46	30.5	30.5
0.15 mm	566.07	57.2	87.7
0.08 mm	111.76	11.2	98.9
<0.08 mm	9.12	2.1	100
Total	990.41	100	
Fineness modulus			1.18
Maximum characteristic dimension (mm)			0.30
Specific weight			2.67 (g/cm^3)
% Absorption			0.92

Polymeric optical fibers based on PMMA (POF, Huanuomei®, China) with diameters of 0.75, 1.0 and 1.5 mm were used in this study. The loss rate of fiber at 650 nm wavelength was less than 250 dB/km. The operating temperature was from -50 to 70 °C. Furthermore, the glass transition temperature (Tg) was determined by differential scanning calorimetry (DSC50 Shimadzu) at 10 °C/min and under N_2 stream (20 ml/min). The measured value of Tg was 84 °C. This is the maximum temperature which the POF can be used without affecting its mechanical and optical behavior.

2.2. Preparation and characterization of SCM

The mixture design and tests were carried out in the fresh state following the EFNARC (2005) recommendations. About 5 min after the start of each mixing, the spread flow was measured using the mini-cone, and then the flow time was evaluated using the mini V-funnel (Fig. 1). An initial formulation was prepared based on our previous works and the method of Okamura & Ouchi (2003): water-cement weight ratio (w/c) equal to 0.4, volumetric fraction of sand in mortar (f_a) equal to 0.5 and the dosage of the MIRA®57 admixture equal to 0.4% with respect to cement mass. Self-compacting condition was obtained by varying the superplasticizer content (ADVA® 567), w/c ratio, and f_a. Self-compacting conditions were reached when the values of mini-cone and mini-funnel V tests were D=25±1 cm and t=9±2 s, respectively, and there was no visual evidence of segregation. The air content in the mortar was measured according to IRAM 1634 (1963) standard. After that, the filling of the prismatic test specimens of dimensions 40 × 40 × 160 mm was carried out in the absence of any vibration. After 24 h, they were unmolded and stored in environmental chamber at 23 °C and 95% RH according to IRAM 1534 (1985) standard. After 7 and 28 days of curing, destructive tests were carried out in order to examine the evolution of the compressive and flexural strengths according to IRAM 1622 (2002) standard. Mechanical tests were carried out in a universal machine INSTRON EMIC 23-50 (Brasil).

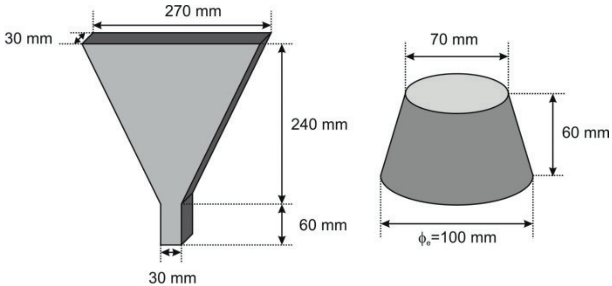

Figure 1: mini-cone and mini V-funnel apparatus according EFNARC requirements.

2.3. Preparation and characterization of LCTM

POFs were passed through the holes of two plastic sheets which were fixed on the slots of plywood formwork (Fig. 2.) LTCMs with a constant POF content (5%) and three fiber diameters (0.75, 1 and 1.5 mm) were prepared by casting fresh SCM into a formwork. No vibration instrument was used for compacting the mix, because SCM mix flows under its own weight.

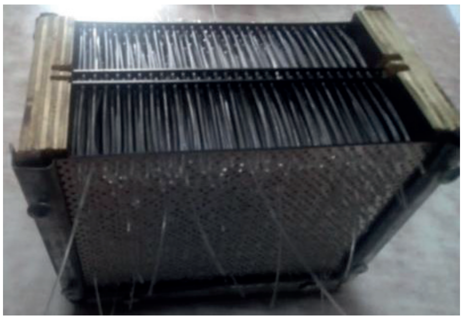

Figure 2: Formwork for LCTM

After 24 h the sample was unmolded and cured in the same way that pure mortar. A plastic sheet was used in order to minimize the risk of surface crusting and shrinkage cracks caused by early age moisture evaporation. After that, the blocks of 120 × 160 × 40 mm were curing for 28 days and the fiber edges were cut flush with a hot knife according to a procedure before reported (Li et al., 2015b). Specimens of 40 × 40 × 160 mm were prepared and the flexural and compressive strength were evaluated in the same way as the SCM. Fig. 3 shows as the load was applied during tests.

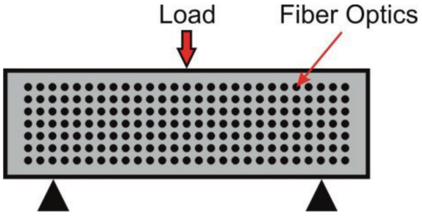

Figure 3: Schematic diagram of flexural test for LTCM.

Light transmitting performance of LTCM was tested by optical power meter. Figure 4 shows a scheme of the measurement setup. This includes a white light source (LED lamp - 7W warm light) and an optical power meter with a silicon detector (Ophir PD-200, Israel) of 1 cm diameter inside a dark box. The optical power meter was used to measure the optical power as function of distance between sample and detector (d in Fig 4.).

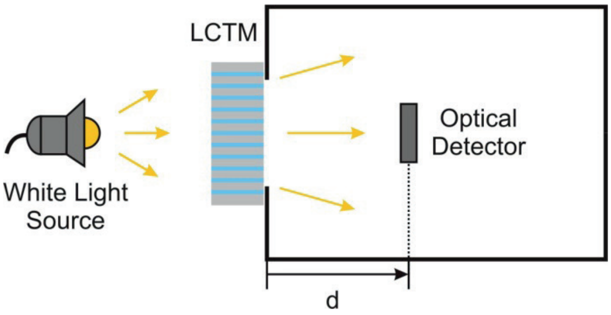

Figure 4: Scheme of testing optical path

3. Results and discussion

3.1. Self- compacting mortar (SCM)

Based on the design method, six mixes were tested until finding one that fulfilled the self-compatibility conditions. Table 3 summarizes the dosage for 1 m^3 of SCM with the sand in saturated surface dry (SSD) state.

Table 3: SCM formulation.

	Weight (kg)	Volume (l)
CPF40	645	208.1
Sand*	1257	472.2
Water	295	295
MIRA®57	2.57	2.2
ADVA® 567	2.67	2.5
Air	-	20
w/c	0.457	
% MIRA®57	0.40	
% ADVA® 567	0.414	
f_a	0.472	

* Saturated surface dry (SSD) state.

An air content close to 2% was determined for preliminary mixes. So, that value was used in order to design the SCM. The moisture content of the sand was measured and water content was corrected in the formulation before preparation. The continuous evaluation of the humidity in the aggregate is a key factor when formulating SCMs due to its rheological behavior are very sensitive to slight changes in the humidity, even more if the sand is stored without weather protection (Faccin et al., 2017). It should be noted that the values of w/c and f_a were within the ranges proposed by Okamura & Ouchi (2003).

Table 4 summarizes the properties in fresh and hardened state of the SCMs. The properties in the fresh state were those expected due to the mortar was designed to achieve these target values. Additionally, Figure 5 shows the image of the spread flow where there was no evidence of segregation process. Regarding hardened state, the compressive and flexural values at 7 days reached 75% of the strength at 28 days. Furthermore, the strength values measured at 28 days were similar to those reported for other mortars used for the production of LCTM. Li et al (2015a) reported values of compressive strength equal to 69.1 MPa, while Henriques et al. (2018) reported a value of compressive strength equal to 56.2 MPa. High-strength mortars are required in order to design LCTM with mechanical strength enough for structural use.

Table 4: SCM properties.

hardened state			
σ_F (MPa)*		σ_C (MPa)*	
7 d	28 d	7 d	28 d
8.9±1.3	12.1±2.1	58.2±2.1	69.3±1.6

fresh state	
D (cm)	t (s)
24.5	8

* compressive (σ_C) and flexural (σ_F) strengths.

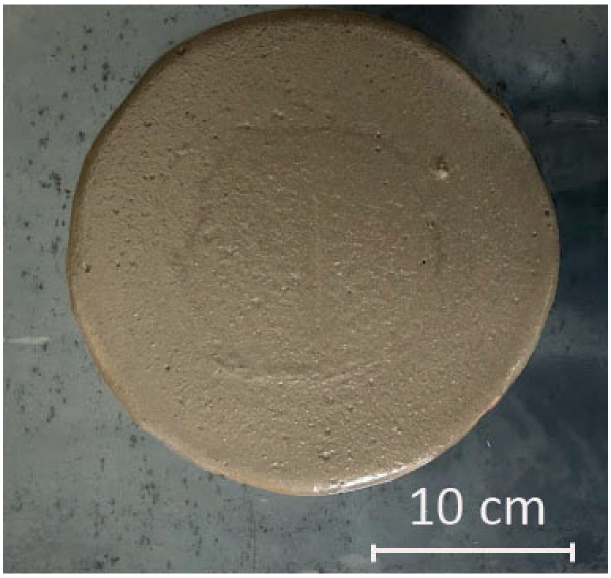

Figure 5: Image of mini-cone test.

3.2. Light transmission cement-based materials (LCTM)

LCTMs requires a suitable balance between the ability to transmit light and mechanical strength. Many authors had reported that a POF volumetric fraction equal to 5% allowed an adequate compromise between mechanical and optical behavior (Li et al., 2015b; Salih et al., 2014; Sangshetty & Dhawale, 2017). For POF volume fractions higher than 5%, light transmission would increase, but it would also increase the probability of cavities or defects appearing that would impair the mechanical behavior of LCTM. Therefore, LTCMs with a constant POF content equal to 5% and sand with maximum size of 0.59 mm were used in this study. The latter is particularly critical as the POF diameter is reduced, the number of fibers increases and, consequently, the free space between them decreases.

Figure 6 shows an image of the surface of the LCTM block with POFs of 0.75 mm. A smooth surface is observed without defects like bubbles and with an excellent surface finish which is directly associated with the fluidity and high content of fines in the mortar. It is important to highlight that contrary to what was observed by Li et al. (2015a), the presence of macroscopic cracks as a consequence of the contraction of the mortar around the POF was not evidenced. This behavior would be associated with a low contraction of the mortar and the curing conditions selected (Henriques et al., 2018).

Table 4 summarizes the values measured for compressive (σ_C) and bending (σ_F) strength of LCTMs. As expected, all LCTMs showed lower resistance values than pure mortar, although these kept a considerable percentage of its strength. It was also observed that both σ_F and σ_C grew as the fiber diameter increased. The failure began in the transition zone of the interface between the POF and the mortar as evidenced in Figure 7. Interface was mechanically weak due to the low surface roughness of the POF. In addition, σ_F and σ_C values were higher as fiber diameter increased, which would be associated with a decrease in the interface area (Li et al., 2015a; Salih et al., 2014; Sangshetty & Dhawale, 2017).

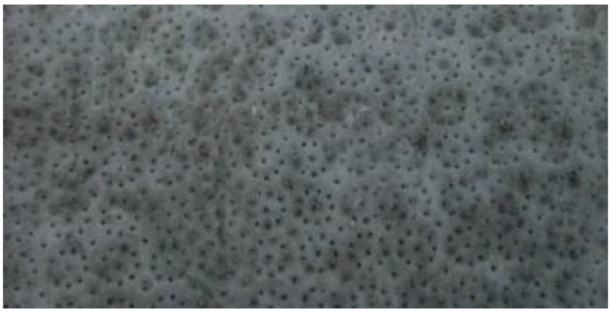

Figure 6: LCTM block surface (fiber diameter=0.75 mm).

Figure 7: Image of LCTM failure (fiber diameter=1.5 mm).

Table 5: LCTMs mechanical properties.

D_{POF} (mm)	σ_F (MPa)	% σ_F *	σ_C (MPa)	% σ_C *
1.5	5.8±0.9	48	42.3±3.1	61
1	4.5±1.1	37	29.2±2.2	43
0.75	3.7±2.2	31	25.4±2.9	37

*reference pure mortar (SCM).

Regarding the optical behavior, Figure 8 shows the variation of the optical power as a function of the distance to the detector for the LCTM with the three fiber diameters. It can be seen that as the distance between the detector and the sample increases (d in scheme of Figure 4) the optical power gradually decreases (Li et al., 2015a). When d increased, the effect of the fiber diameter disappeared, converging all the curves to the same value. This occurred because the detector received light overlap from the solid angles of all individual fibers according to its numerical aperture (Bass & Van Stryland, 2002), as if fibers were a single source, losing its individual effect (Henriques et al., 2018; Li et al., 2015b).

Finally, from the architectural point of view it is very important to observe the effect of the fiber diameter on the definition of the shadow of an image. As seen in Figure 9, better image contour precision was achieved by decreasing the fiber diameter. This type of effects should be considered for its application in signage systems or architectural design.

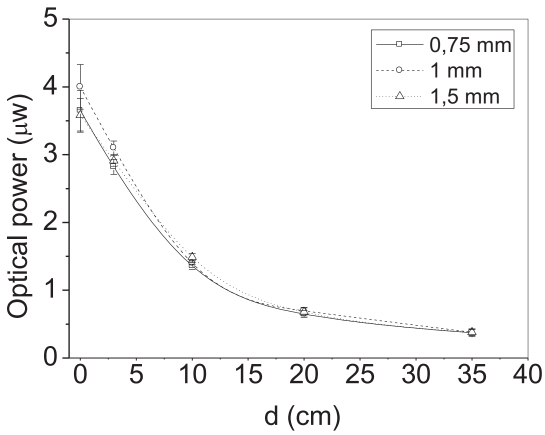

Figure 8: Optical power as a function of distance.

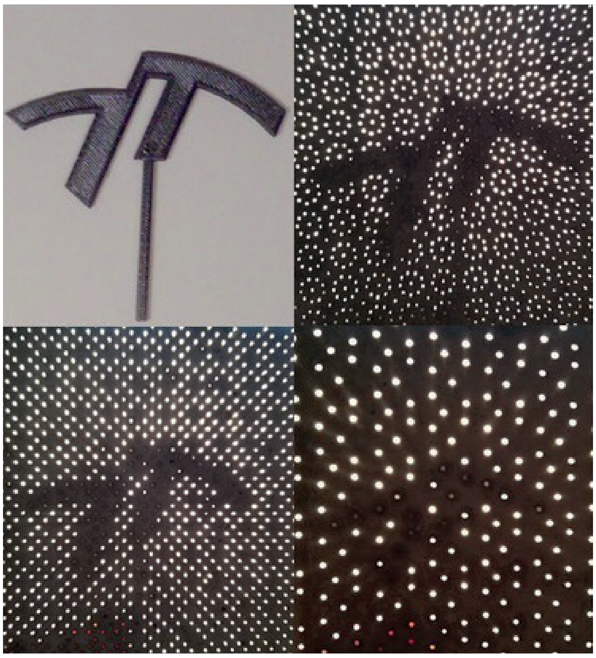

Figure 9: Effect of fiber diameter on shadow contour.

4. Conclusions

LCTMs were obtained by incorporating polymeric optical fibers into a high strength SCM. The rheological and mechanical behavior of the SCM allowed to obtain, through a simple process, LCTM samples with a good surface finish, without defects and with enough mechanical properties for structural use.

It is interesting to note that LCTMs with fiber optic diameter equal to 1.5 mm combined the best balance between lighting and strength.

The control of the distribution and size of the fibers allowed to obtain original designs with different optical effects for construction, signage and artistic applications.

Acknowledgements

This work was supported by the Agencia Nacional de Promoción Científica y Tecnológica (ANPCyT) under Grant PICT 2016 0445; Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) Argentina. Special thanks to Ing. Juan Belmonte and Lic Andres Torres for their assistance in mechanical tests.

References

Ahuja, A., & Mosalam, K.M. (2017). Evaluating energy consumption saving from translucent concrete building envelope. Energy and Buildings, 153, 448-460. https://doi.org/10.1016/j.enbuild.2017.06.062

Altlomate, A., Alatshan, F., Mashiri, F., & Jadan, M. (2016). Experimental study of light-transmitting concrete. *International Journal of Sustainable Building Technology and Urban Development*, *7*(3-4),133–139. https://doi.org/10.1080/2093761X.2016.1237396

Bass, M., & Van Stryland, E.W. (2002). *Fiber Optic Handbook - Fiber, Devices, and Systems for Optical Communications*. McGraw-Hill.

Berli, M.E., Brondino, A., & Di Paolo, J. (2018). Prediction of thermal impact reduction in a double wall building. *Ingenius. Revista de Ciencia y Tecnología*, (20), 38–47.

EFNARC (2005). *The European Guidelines for Self-Compacting Concrete Specification, Production and Use "The European Guidelines for Self Compacting Concrete."* http://www.efnarc.org

Faccin, F., Pascuzzi, N., Alvarez, G., Belmonte, J., & Stefani, P.M. (2017). Diseño de hormigones autocompactantes (hac) con agregados de la región sudeste de la provincia de buenos aires. *CAIQ 2017*.

Fornasier, G., Fava, C., Luco, L.F., & Zitzer, L. (2003). Design of Self Compacting Concrete for Durability of Prescriptive *vs*. Performance-Based Specifications. *ACI Symposium*, *Special Publication*, *212*, 197–210.

Henriques, T., Dal Molin, D.C., & Masuero, Â.B. (2018). Study of the influence of sorted polymeric optical fibers (POFs) in samples of a light-transmitting cement-based material (LTCM). *Construction and Building Materials*, *161*, 305–315. https://doi.org/10.1016/j.conbuildmat.2017.11.137

Hoyos Montilla, A.A. (2012). *Concreto translúcido transmisión de luz visible a través de morteros con fluorita como agregado fino*. Maestría thesis, Universidad Nacional de Colombia, Sede Medellín.

IRAM 1505 - Agregados. Análisis granulométrico., IRAM (2019).

IRAM 1512 - Agregado fino para hormigón de cemento. Requisitos. IRAM (2013).

IRAM 1520 - Agregados finos. Métodos de laboratorio para la determinación de la densidad relativa real, de la densidad relativa aparente y de la absorción de agua, IRAM (2002).

IRAM 1534 - Hormigón de cemento pórtland. Preparación y curado de probetas para ensayos en laboratorios, IRAM (1985).

IRAM 1622 -Determinación de resistencias mecánicas IRAM (2002).

IRAM 1634 - Método para la determinación del contenido de aire en morteros, IRAM (1963).

IRAM 1663 - Hormigón de cemento. Aditivos químicos, IRAM (2002).

IRAM 50001 - Cementos. Cementos para uso general. Composición y requisitos, IRAM (2019).

Kamdi, A.B. (2013). Transparent concrete as a green material for building. *International Journal of Structural and Civil Engineering Research, 2*(3), 172-175.

Li, Y., & Xu, Z. (2012). Preparation method of light transmitting concrete using optical fiber fabrics. *China Patent No. ZL201110022019*.

Li, Y., Li, J., & Guo, H. (2015a). Preparation and study of light transmitting properties of sulfoaluminate cement-based materials. *Materials and Design*, *83*, 185–192. https://doi.org/10.1016/j.matdes.2015.06.021

Li, Y., Li, J., Wan, Y., & Xu, Z. (2015b). Experimental study of light transmitting cement-based material (LTCM). *Construction and Building Materials*, *96*, 319–325. https://doi.org/10.1016/j.conbuildmat.2015.08.055

Liu, X., Liu, L. (2010). A light transmitting concrete component and its manufacturing process. *CN101906836A, 2010 (China Patent).*

Okamura, H., & Ouchi, M. (2003). Self-Compacting Concrete. *Journal of Advanced Concrete Technology*, *1*(1), 5–15. https://doi.org/10.3151/jact.1.5

Salih, S.A., Joni, H.H., & Mohamed, S.A. (2014). Effect of Plastic Optical Fiber on Some Properties of Translucent Concrete. *Engineering and Technology Journal, 32*(12 Part (A) Engineering), 2846–2861.

Sangshetty, P.R., & Dhawale, A.. (2017). An Overview of energy Efficiency of Translucent Concrete. *IJAIEM*, *6*(2), 37–40.

Schiopetto, F., & Stefani, P.M. (2015). Self-compacting concrete containing silica fume: evaluation of mortar properties. *COMAT 2015*.

Yadav, A., Shekhar, S., Anand, A., & Badal, A. (2018). An Investigating Study on a new Innovative Material: Transparent Concrete. *International Journal of Engineering Research and Advanced Development*, *4*(1), 64–72. http://www.ijerad.redmac.in