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A TECHNICAL STUDY OF RECYCLED EPS LIGHTWEIGHT CONCRETE PANELS USED IN ROOF SYSTEMS

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— Abstract—

This article presents a technical studio of a lightweight concrete panel prototype for the construction of a modular single-family home. The compressive and flexural strength of the panel is studied. Expanded polystyrene (EPS) recycled is used as a lightweight material. Compression, flexion, and load tests were carried out to determine the strength of the concrete and the panel. The results obtained show that this type of panel meets the minimum requirements for lightweight slab systems specified in the Mexican technical standards.

Keywords

Panels, EPS, Lightweight concrete.

Environmental problems occupy the international agenda, of those we can highlight water pollution and degradation of the ground; being the Expanded Polystyrene (EPS) one of the materials that contaminate the water and ground the most, this due to that they take place in great amounts for packaging of appliances, computer equipment, etc., causing the deterioration of the characteristics of these resources. EPS becomes a material with a highly usable potential, especially for the construction industry, which already covers a large area as a lightweight material for concrete slabs, thermal and acoustic insulation to mention just a few, however, there is no great field of action for it as a truly functional aggregate for structural concrete, which can support large loads, due to its poor mechanical properties, besides, there are even fewer studies that tell us how to use the waste produced by EPS (Lopez, 2013).

In Mexico, there is a type of housing called "Social Interest", which is consigned to groups of people with limited economic resources. These social interest housing units are built in series; they have an approximate area that varies from 30 to 80 square meters, with structural and architectural designs that are similar to each other, based on the minimum conditions of the building regulations in force in the area (Trujillo *et al.*, 2010). However, there are prototypes of housing in marginalized areas that are designed to support slab systems based on sheets, wood, or clay tiles, which, over time, owners switch to reinforced concrete slabs, increasing the weight that such housing can support.

Different types of housing have been proposed, among which are the modular type. Jiménez (2012), describes that a modular house is built industrially, with the characteristic that most of its elements can be assembled and it only needs to be located in space for its correct organization. This type of housing can have one or several sections, being the lightened slabs one of the main slab systems used in this type of housing.

Since its inception, lightweight concrete has been obtained through various methodologies, including the use of lightweight foams or the total and partial replacement of conventional aggregates with low-density aggregates (Liu and Chen, 2014). It is clear that the use of EPS in construction is not new, however, the intention is to implement recycled EPS as a replacement for thick aggregate and thus provide greater lightness to the panels for load-bearing walls and slabs in homes and at the same time, reduce the waste that EPS produces. Several articles are describing how this has been attempted, with unsatisfactory results from a resistance point of view.

The objective of the project is to propose a lightweight concrete panel prototype with recycled aggregates that can be used as floor systems (slabs) that can replace the joist and vault system, with better performance in both compression and bending, for use in modular housing (Image 1).

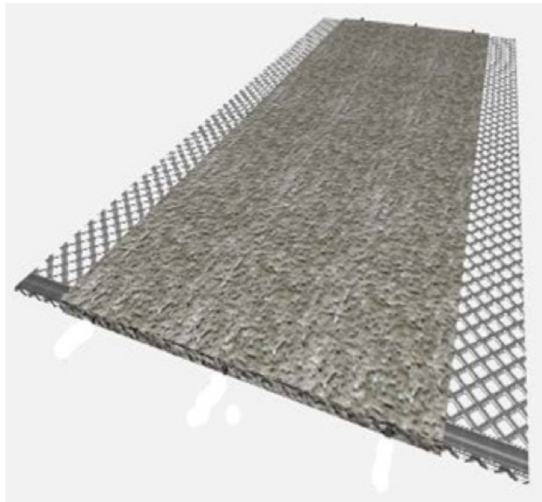

Image 1. Recycled panel prototype. Source: Own elaboration

BACKGROUND

In recent years, in the laboratory of Concrete Technology of the Faculty of Engineering of the Universidad Autónoma de Chiapas, studies have been developed regarding the use of EPS to be used as a light material in the production of mortars and concrete.

Ocaña and Zea (2016), present a study in which they propose the use of crushed EPS, in the shape of pearls, to be used as a lightening agent in lightweight concrete, proposing the use of lightweight concrete plates with dimensions of 122*60*8 cms, as modular elements for building houses. In this study, a block of lightweight concrete with a volumetric weight of 1,100 kg/m^3 was obtained, with very low compressive strength, as shown in Image 2

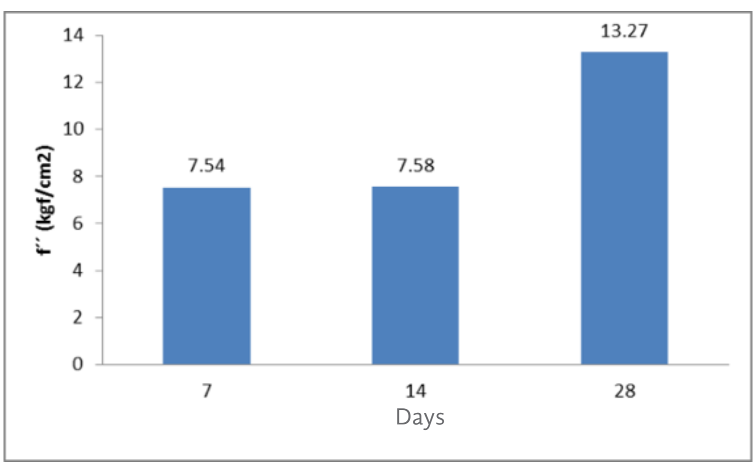

Image 2. Average resistance of the dosage used. Source: Ocaña and Zea (2016)

Romero and Laguna (2017) present a modification to the dosage and type of panels used by Ocaña and Zea (2016) that would allow a better assembly between them and with better mechanical properties, which is shown in images 3, 4, and 5.

Image 3. Recycled concrete panel prototype of 110*60*5 cms, with a bump of 10*2 cms. Source: Romero and Laguna (2017)

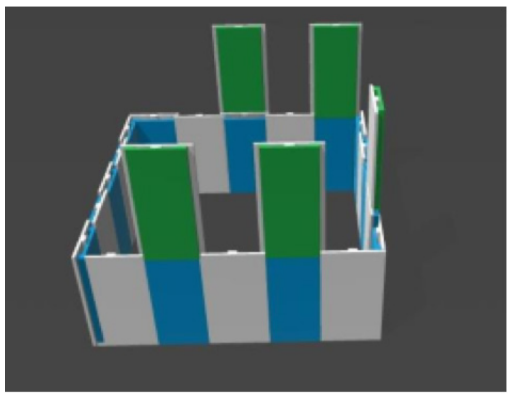

Image 4. Proposal for assembly in modular housing. Source: Romero and Laguna (2017)

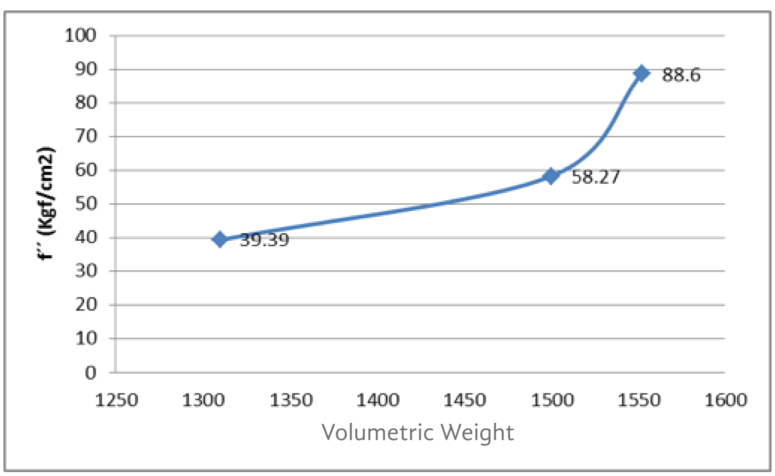

Image 5. The ratio of compressive strength to volumetric weight at 28 days of age. Source: Romero and Laguna (2017)

As can be seen, the dosage with a volumetric weight of 1,550 kg/m^3, gave the highest resistance to compression.

In Albores (2017), the study of light concrete specimens is shown to be used as vaults, with greater thicknesses than those used in the two previous studies, using the same dosages proposed by Romero and Laguna (2017), obtaining the same compressive strengths. The bending tests carried out on the 60*60*7 cm vaults are shown in Table 1.

Table 1
Average results obtained in bending tests

Specimen (60*60*7 cms)	Weight (kg)	Load (kgf)	Resistance (kgf/cm^2)
E1 without wire	66.80	899	15.29
E2 with wire	66.67	1183	20.15
E3 with wire	66.92	1293	21.99

Source: Albores (2017)

Therefore, this article presents the technical study to compression and flexion of a proposed light concrete plate measuring 110*60*4 cms reinforced with chicken wire, as shown in image 6, assembled as shown in image 7, to obtain a modular house according to the architectural project presented in image 8.

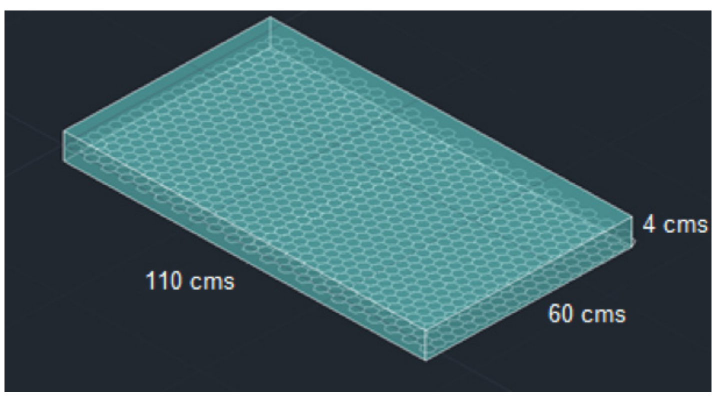

Image 6. Lightweight concrete plate prototype. Source: Own elaboration

Image 7. Panel assembly proposal . Source: Own elaboration

Image 8. Modular housing. Source: Own elaboration

TECHNICAL STUDY DEVELOPMENT

Below are the steps that were taken to achieve the specific objectives set out in this project:

- Collection of expanded polystyrene: EPS waste was collected.
- Selection: From the EPS waste collected, the specimens in the best condition and with the largest particle diameter were selected. Since there are characteristics that make one EPS different from another, i.e. the EPS produced from packaging has a larger particle

diameter than that of disposable containers, in addition to the different degree of compaction of the pieces and the cohesion of their particles; therefore, only the packaging product was chosen, since it is much easier to grind.

- Shredding: Once the EPS was selected, we proceeded to crush it by mechanical means, using the material that passed through the wire number 10 (2 mm).
- Lightweight concrete mix design: To carry out the dosages, a block of concrete with a resistance of 150 kgf/cm² was used as a base, under the IMCYC (2011), making the pertinent adjustments, such as replacing the thick aggregate with recycled EPS. The characterization of the sand properties was carried out (Table 2 and Image 9) according to what is established in the standards NMX-C-073-ONNCCE-2004, NMX-C-077-ONNCCE-1997, NMX-C-165-ONNCCE-2014, NMX-C-166-ONNCCE-2018, and the thick aggregate was replaced in volume by EPS.

Table 2

Characterization of the sand of the Banco de Río Santo Domingo

Thinness module	2.8
The sand rating according to the function of the thinness module	Thick sand
Absorption (%)	6.73
Density (kg/dm³)	2.97
Through wire no. 200 (%)	3
Loose-dry volumetric weight (kg/m³)	1,502
Compact dry volumetric weight (kg/m³)	1,646

Source: Own elaboration

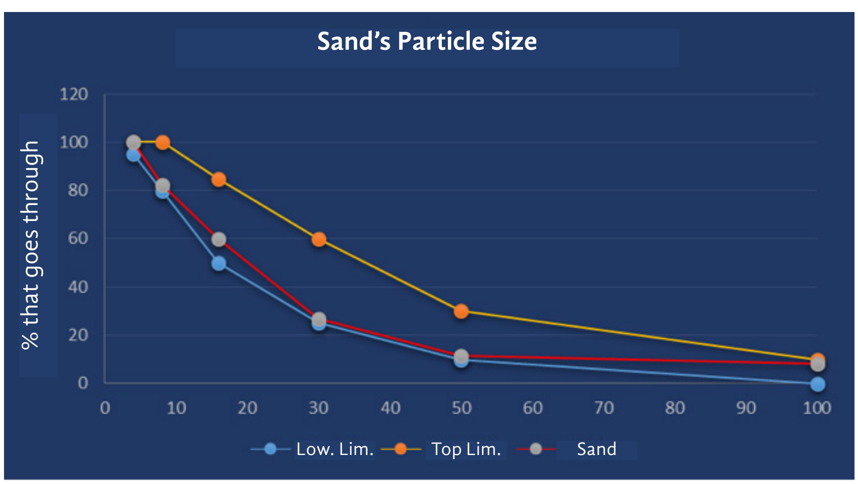

Image 9. Particle size curve of the Santo Domingo bank sand. Source: Own elaboration

- Elaboration and testing of compression and bending specimens: Cylindrical specimens were elaborated to carry out the compression test of each one of the specimens, as it is indicated in the standard NMX-C-159-ONNCCE-2016, which were tested at 7, 14, and 28 days respectively (Image 10), following the processes of the standard NMX-C- 109-ONNCCE-2013 and NMX-C-083 ONNCCE-2014. As well as the realization of beams to determine the resistance to the flexion of the concrete, using a simple beam with load in the thirds of the span, according to the established in the standard NMX-C-191-ONNCCE-2015 (Image 11). In both cases, two experimental campaigns were carried out, 10 compression tests and 3 bending tests per campaign.

Image 10. Uniaxial compression cylinder test. Source: Own elaboration

Image 11. Bending beam test. Source: Own elaboration

- Panel elaboration and testing: Lightweight panels with dimensions 110*60*4 cms reinforced with chicken wire (Image 12) were made and tested by applying cyclic loads, to know their bending performance (Image 13). Only one experimental campaign was conducted using 8 concrete panels and two different types of chicken wire (22 and 23 calibers).

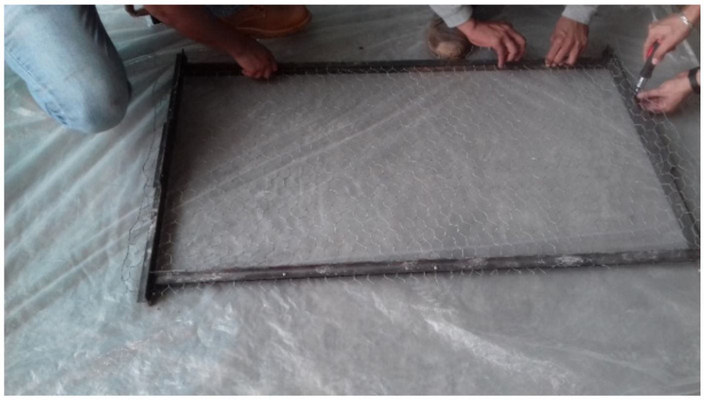

Image 12. Panel elaboration. Source: Own elaboration

Image 13. Loading and unloading test. Source: Own elaboration

RESULTS ANALYSIS

Regarding the resistance to compression, the Student's t-test was performed, obtaining a mean of $f'c=116.93\ kgf/cm^2$, with an $s=6.6476$ with a 95% CI confidence interval (113.708, 120.092), obtaining a statistic $t=76.63$ (Image 14). Also, a comparison study of more than two samples was carried out (one-way ANOVA) obtaining the results shown in Table 3 and Image15.

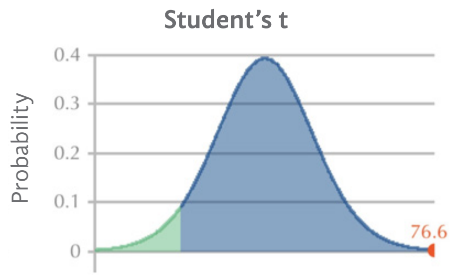

Image 14. Student's t-test result. Source: Own elaboration

Table 3

ANOVA RESULTS

Source of Variation	Ss	Df	Ms	F
Treatment	331.40	3.00	110.4667	3.19996
Error	552.40	16.00	34.5250	
Total	883.80	19.00		

Source: Own elaboration

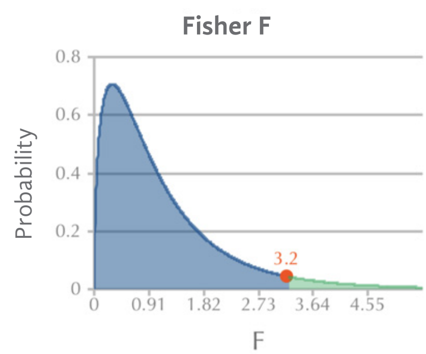

Image 15. Fisher F graphic results. Source: Own elaboration

Therefore, it is considered that a good resistance to compression was obtained, if we compare it with the volumetric weight obtained which was 1,650 Kg/m^3 with that of conventional concrete which is 2,200 kg/m^3; for a proposed mix design of conventional concrete of f'c=150 kgf/cm^2. Image 16 shows the results obtained at 7, 14, and 28 days.

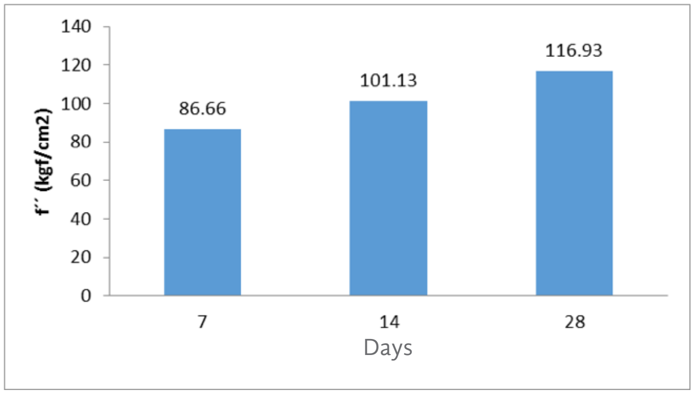

Image 16. Average compressive strength of lightweight concrete. Source: Own elaboration

Concerning the bending resistance, in Table 4 the average results obtained in each campaign of experimentation are shown, it is observed that the use of EPS with dimensions smaller than 2 mm, improves the adhesion of the concrete obtaining a better performance to flexion.

Table 4

Results of the bending test on lightweight plates

Beam (15*15*50 cms)	Weight (kg)	Load (kgf)	Resistance (kgf/cm²)
VC1	18.70	2,137	28.49
VC2	18.64	2,112	28.16

Source: Own elaboration

As for the tests on lightweight concrete panels, the average result obtained with live-loading and unloading cycles was 300 kg/m², which is higher than the 190 kg/m² established by the building regulations for mezzanine slab systems. Table 5 shows the average results obtained with the 22 caliber chicken wire and the 23 caliber chicken wire. In Images 17 and 18, the results of the deformation obtained in the panels are shown.

Table 5

Results obtained from the 3 loading and unloading cycles test

Sample	Length (cm)	Height (cm)	Width (cm)	Weight (kg)	Age (Days)	Deformation (mm)
Panel 22 Cal.	110	3.8	60	46.7	28	0.648
Panel 23 Cal.	109	4.0	60	42.5	28	0.456

Source: Own elaboration

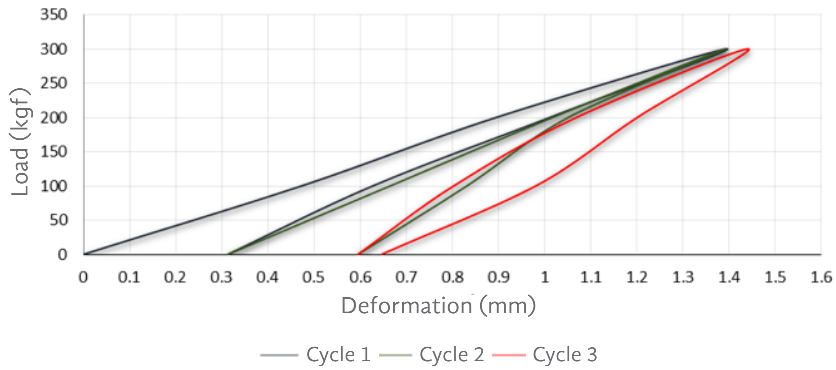

Image 17. Graph of the 3 loading and unloading cycles test in the panel with 22 caliber chicken wire.
Source: Own elaboration

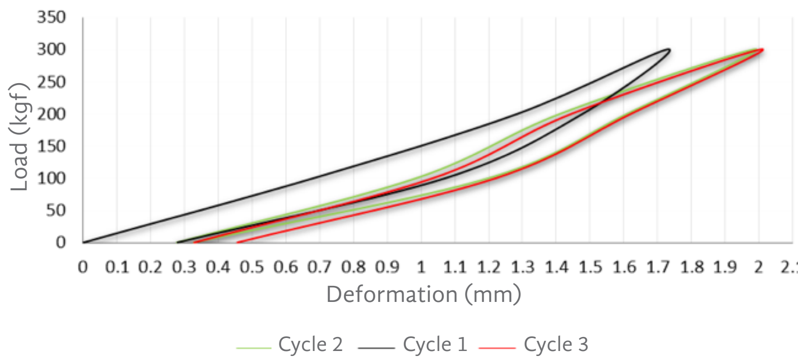

Image 18. Graph of the 3 loading and unloading cycles test in the panel with 23 caliber chicken wire.
Source: Own elaboration

It can be seen that the deformations that occur in the panels are within what is stated as permissible deformations in the literature for reinforced concrete elements.

CONCLUSIONS

The results obtained in the tests carried out on cylindrical specimens, beams, and panels, show that the proposal of a panel made with EPS lightweight concrete, improves the performance of the panel in compression and bending, due to the use of EPS in smaller sizes than those used in previous projects, thus obtaining a lightweight concrete more homogeneous and with greater adhesion in its components.

By obtaining better performance in compression and bending, this panel can be proposed as a slab element for modular homes, guaranteeing its safety and durability. Compared to the joist and vault system, there are economic savings by eliminating a joist due to the size of the panel, because the commercial vault is smaller, and also because of the use of recycled EPS.

The construction of modular homes using lightweight panels is an ecological solution because it uses one of the least recycled materials in Tuxtla Gutierrez, Chiapas, as well as being lightweight elements, reduce the load transmitted to the ground, decreasing the size of the foundation.

REFERENCES

Albores, L. (2017). *Estudio técnico del comportamiento mecánico de bovedillas de concreto ligero. Tesis profesional*. Universidad Autónoma de Chiapas. Diciembre 2017.

IMCYC (2011). *Posibilidades del concreto*. Construcción y Tecnología en Concreto, 13. Instituto Mexicano del Cemento y del Concreto.

Jiménez, G. (2012). *Viviendas prefabricadas modulares con el Sistema Steel Framing para el área metropolitana de la Ciudad de México*. México, D.F.: UNAM.

Liu N. y Chen, B. (2014). Experimental study of the influence of EPS particle size on the mechanical properties of EPS lightight concrete. Science Direct , 227 - 232.

López, M. (2013). E*valuación de los procesos de corrosión en concretos aligerados con EPS expuestos en medios simulados y reales. Evaluación de los procesos de corrosión en concretos aligerados con EPS expuestos en medios simulados y reales. Xalapa, Veracruz, Mexico*.

Ocaña, H. y Zea, F. (2016). *Aplicación del material poliestireno reciclado en la construcción de muros y losas. Tesis profesional*. Universidad Autónoma de Chiapas. Marzo 2016.

Romero, L. y Laguna, C. (2017). *Estudio técnico para la elaboración de paneles de concreto ligero a base de EPS reciclado como agregado grueso para viviendas modulares. Tesis profesional*. Universidad Autónoma de Chiapas. Agosto 2017.

Trujillo, A. Orduña y Licea, R. (2010). *Análisis experimental de un sistema constructivo innovador para vivienda económica en zonas sísmicas*.

CITED STANDARDS

NMX-C-073-ONNCCE-2004 Industria de la Construcción – Agregados – Masa Volumétrica – Método de Prueba.

NMX-C-077-ONNCCE-1997 Industria de la Construcción – Agregados para Concreto – Análisis Granulométrico – Método de Prueba.

NMX-C-083-ONNCCE-2014 Industria de la Construcción – Concreto – Determinación de la Resistencia a la Compresión de Especímenes – Método de Ensayo.

NMX-C-109-ONNCCE-2013 Industria de la Construcción – Concreto – Cabeceo de Especímenes Cilíndricos.

NMX-C-159-ONNCCE-2016 Industria de la Construcción – Concreto – Elaboración y Curado de Especímenes de Ensayo.

NMX-C-165-ONNCCE-2014 Industria de la Construcción – Agregados – Determinación de la Densidad Relativa y Absorción de Agua del Agregado Fino – Método de Prueba.

NMX-C-166-ONNCCE-2018 Industria de la Construcción – Agregados – Contenido de Agua por Secado – Método de Prueba.

NMX-C-191-ONNCCE-2015 Industria de la Construcción – Concreto – Determinación de la Resistencia a Flexión del Concreto Usando una Viga Simple con Carga en los Tercios del Claro.