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Design of ecological masonry piece for non-structural walls

Diseño de pieza de mampostería ecológica para muros no estructurales

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Abstract

In the research work in the methodological aspect, the tongue and groove Block was designed (geometry) in AutoCad, based on the NMX-C-038-ONNCCE-2004 standard; It was included in the material with which the Block was manufactured, crushed polypropylene plastic (PP) to reuse materials that are polluting, and in this way an ecological Block was made, later it was manufactured complying with the NMX-X-159 standard. ONNCCE-2004 the steel mold for the Block. For the analysis and results, a press was used to test the compression pieces established by the NMX-C-441-ONNCCE-2013 Standard for non-structural blocks. In the laboratory, the initial water absorption test was carried out with the NMX-C-037-ONNCCE-2005 in three pieces of blocks, in addition, the MATLAB software was used to obtain the effort-time graphs of the pieces of block with the different dosages of recycled plastic material. The research concludes that the reuse of polypropylene plastic to make blocks will help reduce environmental pollution. The results of the compression tests were satisfactory for non-structural blocks. The initial maximum water absorption tests to which the blocks were subjected, comply for exterior and interior walls.

Masonry, Ecological, Assemble

Resumen

En el trabajo de investigación en el aspecto metodológico se diseñó (la geometría) en AutoCad del Block machihembrado, con base en la normativa NMX-C-038-ONNCCE-2004; se incluyó en el material con el que se fabricó el Block, plástico de polipropileno (PP) triturado para reutilizar materiales que son contaminantes, y de esta manera se hizo un Block ecológico, posteriormente se elaboró cumpliendo con la norma NMX-X-159-ONNCCE-2004 el molde de acero para el Block. Para los análisis y resultados, se utilizó una prensa para ensayar las piezas a compresión que establece la Norma NMX-C-441-ONNCCE-2013 para blocks no estructurales. En el laboratorio se realizó la prueba de absorción inicial de agua con la NMX-C-037-ONNCCE-2005 en tres piezas de block, adicionalmente se utilizó el software MATLAB para obtener la gráfica esfuerzo – tiempo, de las piezas de block con las diferentes dosificaciones de material de plástico reciclado. En la investigación se concluye que la reutilización del plástico de polipropileno para fabricar los blocks, ayudara a disminuir la contaminación del medio ambiente. Los resultados de los ensayos a la compresión fueron satisfactorios para blocks no estructurales. Las pruebas de absorción máxima inicial de agua a la que se sometieron los blocks, cumplen para muros exteriores e interiores.

Mampostería, Ecológica, Machihembrado

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Introduction

For many years the structural or non-structural walls in buildings have been made of solid block, hollow block of concrete, hollow block of annealed clay, adobe, etc., which must be joined together with mortar made with mortar-sand-water or cement-sand-water, this makes that at the time of joining a block with another generates an increase in time and cost due to the preparation of mortar to join these pieces.

Also, more time is required to join the mortar with the blocks, as well as its leveling and accommodation, when building the masonry walls.

This research will present another way of building non-structural walls, which will be made with ecological block masonry and in turn these will be assembled, which aims to reduce time and costs, in which part of this significant reduction will also get a contribution to the environment by using recycled material such as plastic, which is the largest pollutant worldwide, environmental pollution by plastics is causing irreparable damage to our planet, and increasingly increases, the Greenpeace (2020) states that "The total production of plastic in 2015 reached 380 million tons. To date, some 8.3 billion tons of plastic have been manufactured since production began around 1950," so instead of this plastic being deposited in sanitary landfills or contaminating city streets, fields, rivers or seas, it will be used for construction purposes.

The different types of masonry are described, including the ecological and tongue-and-groove masonry that exist today. Beginning the investigation with the design of the piece in its dimensions and shape, once defined the block was manufactured the steel mold, and blocks were developed to determine that dosage in the mixture met the resistance, to define the dosage are manufactured 8 blocks, of these, 5 are tested to simple compression, and 3 are made the test of maximum initial absorption, the blocks tested to compression is obtained in MATLAB the graph of effort and time.

Types of masonry, ecological bricks and tongue and groove

Hollow mortar block

They are those that have a net area of at least 50 percent of the gross area; the most common being 40x20x20 cm, the thickness of their exterior walls is not less than 15 mm. The hollow brick is a type of brick that has the characteristic of having passing holes in its interior in a longitudinal sense. For hollow pieces with two to four cells, the minimum thickness of the interior walls must be 13 mm (cgservicios, n.d.).

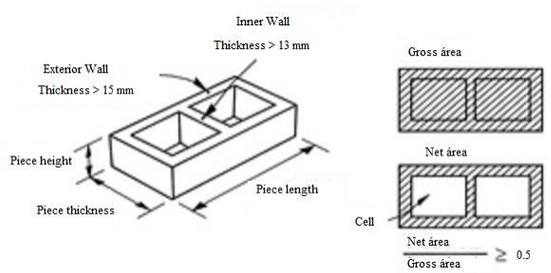

Figure 1 Hollow block
Source: NTC-For design and construction of masonry structures

Multi-perforated parts

For this piece its perforations must be of the same dimensions and with uniform distribution, the minimum thickness of the interior walls will be ≥ 7 mm, and as for the exterior ones ≥15mm. Multi-perforated pieces are understood to be those with more than seven perforations. (cgservicios, n.d.).

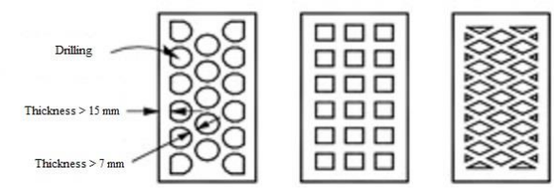

Figure 2 Multi-drilled block
Source: NTC-For design and construction of masonry structures

Normal or solid block

The traditional brick is solid of dense aggregate and responds to the formats DIN (29x14x5cm) or metric (24x11,5x5cm), although it can have some perforations.

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It is considered solid those that have in their most unfavorable cross section a net area of at least 75 percent of the gross area, and whose exterior walls are not less than 20 mm thick (cgservicios, n.d.).

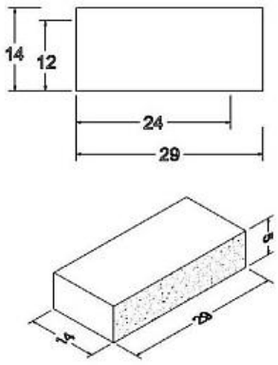

Figure 3 Normal or solid block
Source: Construmatica

Red annealed clay partition.

The red brick is a ceramic piece, usually rectangular in shape, obtained by molding, drying and firing at high temperatures, from a clay paste, the dimensions of the wall are usually around 24 x12 x6 cm. The use of the annealed partition is very extensive in all masonry work: the red partition is found in walls, walls and houses. (Materials for construction, n.d.).

Figure 4 Red annealed clay partition
Fountain: Construrama.com

Ecological brick based on construction waste

At the UNAM Engineering Institute, an ecological brick was created through a sustainable process; construction waste is used as raw material and solar energy is used for drying, instead of the traditional brick kiln firing. (Gazette, 2016)

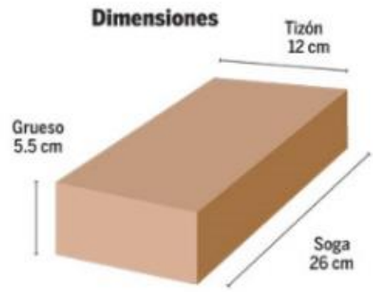

Figure 5 Dimensions
Source: UNAM Gazette, January 11, 2016

Ecological brick based on plastic waste (pet) and concrete

The manufacturing process of these bricks begins with the crushing of the plastics and then mixing it with portland cement as a binder to give cohesion to the mixture, and a chemical additive that improves the adhesion of the plastic particles. This mixture is placed in molds as if it were a prefabricated concrete piece and is left to set. (Science and Cement, 2015).

Figure 6 PET bricks and concrete
Source: Science and Cement, September 28th, 2015

Ecological brick based on plastic waste (pet)

These bricks can be manufactured with the help of a machine that can recycle all types of plastic following a series of steps, to finally compress the plastic paste to produce a 10 kilogram brick. (Ecologiaverde, 2017).

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Figure 7 PET bricks
Source: Ecologiaverde, November 22nd, 2017

Ecological brick based on concrete and rice husks

It is necessary to replace part of the sand aggregates with rice husks, in order to take advantage of the agro-industrial waste produced in high volumes in the places where the rice plant is planted and processed, since they generate environmental pollution in order to prevent such waste from being deposited in the rivers or burned causing pollution. This type is made with the combination of sand, rice husk, cement and water, similar to the conventional block. (Wordpress, 2016)

Figure 8 Rice husk-based bricks
Fountain: WordPress, October 2016

Ecological brick based on coal ash

The ash generated in coal-fired power stations is used, a waste with a high environmental impact and a high cost associated with its disposal. The method developed by "Calstar" (an American company) allows the transformation of such ashes into bricks with only 10 hours of cooking at a maximum temperature of 212 degrees, as opposed to the 24 hours and 2,000 degrees required by the raw materials usually used to produce this construction material. (Ecoticias, 2009).

Figure 9 Bricks based on coal ash
Source: Ecoticias, September 25, 2009

Ecological brick based on hemp

The block is made of industrial hemp fibres, natural hydraulic lime and a mixture of minerals. The components are mixed, solid blocks are pressed and air-dried, so the energy consumption in production is very low. Measures from 30 x 14,5 x 10,5 centimeters. (Elmundo, 2008).

Figure 10 Hemp-based bricks
Source: The World, March 19th, 2008

Ecological brick made from peanut shells

Previously and currently, peanut shells have been a contaminating residue that if stored in large quantities generates a radiation process that absorbs the soil, returning it sterile after a certain time. "Because of this, the ecoladrillos were created, which are made from a mixture of peanut shells, cement, lime and sand; having many benefits besides the already mentioned of reducing waste". (Expoknews, 2015)

Figure 11 Peanut shell-based bricks
Fountain: Expoknews, January 13, 2015

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Adobe brick

This brick is made without "firing", which results from a mass of mud (clay and sand), if needed, straw is added to the mixture, a brick-shaped mold is made and it is left to dry. These bricks can be used to build walls and arches. (Ecured, 2018).

Figure 12 Adobe bricks
Source: ecocosas.com, July 16, 2012

Tongue and groove block.

The tongue and groove block is a block with a system of inputs (female) and outputs (male) which makes your construction method easier, saving time and costs.

If tongue and groove building blocks are used, it is not necessary to be a professional mason to build plumbed walls. The blocks can be made from a variety of materials, including charcoal, slag, and pumice. Each block has a shoulder at the top and an undercut groove at the bottom. Steel rods can be inserted through the holes to reinforce the wall. In order to form a seal around the blocks, mortar is injected into the holes in the blocks. Only a thin line between the blocks is visible on the wall surface. For this type of block there can be as many types as desired, provided they have adequate resistance.

Figure 13 *Tongue and groove block*
Fountain: Architecture Link

Methodology

Type of Geometry

The design of the masonry piece is started with the help of the program "AutoCAD", with which it is intended to produce a block with a different geometry and aggregates to the pieces that are on the market.

Different investigations were carried out on existing pieces, of which we have those already mentioned in the ecological bricks, and on tongue and groove block".

According to the information obtained, we began to design the piece with the (NMX-C-038-ONNCE-2004, 2004).

The conventional measures are chosen for a common block, which are 40 cm long, 15 cm wide, and 20 cm high, with the difference that this piece is added outputs and inputs (male-female) for its tongue and groove design, the inputs and side outputs have 2 cm radius located from the lateral centers, throughout the thickness or height of the block, the left side inward and right outward, as the bottom and top have 4 cm in diameter and 1. The upper part is 5 cm high and the lower part is 1.5 cm inwards.

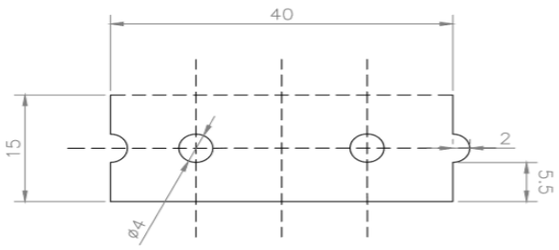

Figure 14 Geometry of the ecological tongue and groove block for non-structural walls

Figure 15 Eco-friendly masonry piece for non-structural walls

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Shredding or cutting of polypropylene (PP) plastic

Polypropylene plastic from yogurt containers, sorbets and bottle caps is shredded to obtain smaller parts of it, to favor mixing with the concrete, and to have better adhesion.

Figure 16 Crushed plastic (PP)

Mould making

A special steel mold is elaborated with the measures designed to manufacture the pieces, since it will not be of the conventional ones because it has a different geometry, this mold will have a thickness of the plates adapted so that it is not deformed at the time of casting the concrete mixture, the (NMX-C-159-ONNCCE-2004, 2004) indicates that "The molds and the accessories to elaborate the concrete specimens must be of steel, fused iron, or any other nonabsorbent and nonreactive material with the portland cement or other hydraulic cementants" (p. 6).

Manufacture of ecological masonry parts for non-structural walls

To make our piece of masonry will need the appropriate tools, equipment and materials for this, whose measures will be 40 cm long with 15 cm wide and 20 cm high, with 14 days old, the blocks were made in the laboratory of soil mechanics and concrete at the University of Veracruz, Coatzacoalcos Campus.

Team:

- Mold for the masonry piece.
- Compacting rod.
- Rubber hammer for compacting.
- Wooden hammer for compacting.
- Racer.

Auxiliary tools:

- Pala.
- Container.
- Spoon.
- Water Meter.

Materials:

- Gravilla.
- CPC 20R cement.
- Agua.
- Recycled crushed plastic.
- Accepted to descend.

According to the specifications provided by the CEMEX company, for non-structural blocks with approximately 40 kg/cm2 of resistance, and measures of 40x20x15 cm the dosage is:

- One 50kg cement bundle.
- 19 cans of 19 kg aggregate (gravel).

For the production of 23 to 25 pieces.

The dosage for a block of masonry with the measures described above is made, and it is obtained that for a piece you need: 15.5 kg of gravel, 2.64 kg of cement and 1 to 1.2 liters of water, approximately.

To determine the dosage for the ecological masonry piece, three proportions of recycled plastic (PP) will be used, until a resistance for non-structural masonry is achieved, one with 25% plastic and 75% stone aggregate, another with 15% recycled material and 85% stone aggregate, and a last one with 10% plastic and 90% gravel.

ISSN 2531-2162

Material	25%PP (kg)	15%PP (kg)	10%PP (kg)
Gravel	11.55	13.09	13.86
Plastic (PP)	3.85	2.31	1.54
Cement	2.13	2.13	2.13
Water	1-1.1 L	1-1.1 L	1-1.1 L

Table 1 Non-structural ecological block dosage

The procedure for making the blocks is explained briefly below, before pouring the mixture into the mold, this should be applied inside, oil with a brush to prevent the masonry piece is stuck to the steel mold when removed; The materials are mixed starting with the gravel and the crushed plastic, then the cement is added and it is homogenized again, and at last water is added gradually, it is mixed until it is a little thick for a better workability in the mold, the mixture will stop adding water until when taking it with the hand and squeezing it it does not disintegrate, the concrete is poured little by little with the help of a bucket so as not to drop it abruptly, this procedure is done in two equal layers, the standard for the elaboration and curing of specimens (NMX-C-159-ONNCCE-2004, 2004) is taken as a reference "for pieces with a surface area of 320 mm or more, a 16mm rod will be used and a penetration per layer of one for every 10 cm2 of surface will be done".

Since the piece will be 600 cm2, a penetration of 60 times will have to be done in the whole layer to eliminate the air holes, as well as it will have to be hit around the mold with a neoprene hammer about 25 times, later the compaction will be completed with a wooden mallet to tamp each layer. Afterwards, the piece is covered, leaving a weight on it, and it is left to dry for 20-30 minutes, in order to properly unmold it. Finally, the mold is unscrewed since it is dismountable and all its faces are removed to take out the masonry piece. This procedure will be done six times to manufacture six blocks to which the compression test will be done.

Two pieces for each one of the plastic dosages (PP), and they will be tested at 14 days of age, to determine which of the dosages complies with the resistance for non-structural blocks.

Simple compressive strength test

We start the test with the pieces with 25% of plastic.

First, a grout is placed on the top and bottom of the specimen, so that the sulfur that will serve to head the block does not remain adhered to it when it is removed due to the not 100% smooth surface, this in order to be able to reuse the sulfur. Later the sulfur is heated to make the pitch of the element, the universal pitcher is prepared based on the NMX-C-036-ONNCCE-2004-"INDUSTRY OF THE CONSTRUCTION-BLOCKS OR BRICKS, TABICONS AND ADOQUINES-RESISTANCE TO THE COMPRESSION-METHOD OF TEST", is not placed as it is commonly done, since the longest length of the header brackets is 40 cm, and our piece due to its protrusions measures 43cm, so an arrangement is made according to the size of our piece. Once the sulphur and the pitching plates are ready, the sulphur is poured into the base of the plates and without letting more than 10 seconds pass (so that the sulphur does not dry out) the block is placed to achieve a uniform pitch. It is worth mentioning that when this procedure is carried out the blocks should not have the upper projections so that our test can be carried out successfully, once the pitch is carried out in the upper and lower part of the block, the sulphur is left to set for approximately 30 minutes.

The block is placed in the press to perform the compression test. The 6 pieces will be tested at 14 days of age, once the results are obtained, the dosage of the elements that manage to be in the range of non-structural blocks will be chosen.

Figure 17 Testing the ecological piece to simple understanding

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The chosen dosage that obtained the best result to the compression was with 10% of shredded plastic.

Block	Plastic (PP) (%)	Resistance f'c (kg/cm^2)
1	25	22.18
2	25	19.21
3	15	25.85
4	15	23.65
5	10	44.93
6	10	42.62

Table 2 Compressive strength of the blocks

Manufacturing 5 blocks with 10% PP to comply with the standard "NMX - C - 441 - ONNCCE - 2013 - INDUSTRIA DE LA CONSTRUCCIÓN-MAMPOSTERIA-BLOQUES, TABIQUES O LADRILLOS Y TABICONES PARA USO NO ESTRUCTURAL-ESPECIFICACIONES Y METODOS DE ENSAYO"

Initial maximum absorption test

Once our dosage of the ecological blocks is obtained (10% PP), we proceed to make another batch of 3 pieces, of measures, 40 cm long, 15 cm wide and 20 cm high, with 14 days of age, made in the laboratory of soil mechanics and concrete of the Universidad Veracruzana Campus Coatzacoalcos. For the test of maximum initial absorption according to the "NMX - C - 037 - ONNCCE - 2005 - "INDUSTRIA DE LA CONSTRUCCION-BLOQUES, LADRILLOS O TABIQUES Y TABICONES - DETERMINACON DE LA ABSOCION DE AGUA Y ABSORCIÓN INICIAL DE AGUA", section 2.7 Determination of water absorption and initial water absorption.

A metal container with a minimum interior depth of 1.3 cm must be used. Two supports are placed on this container so that the block is placed on them and in this way the lower face is in contact with the water, as well as the sides of the piece. The blocks must be submerged in the water up to 5 mm high on the lower face of the piece. The blocks must be left submerged for a period of 10 minutes, counting the time from the moment the piece touches the water surface. It is important to note that during this time the water must be kept at a constant level, so water will be added gradually as the water level in the container decreases.

After 10 minutes the block will be removed, removing the excess water from the saturated surfaces with a damp cloth, without letting this time pass 10 seconds. The block will be weighed again without letting more than 2 minutes pass after having removed the water from the piece, and the algorithm is used to calculate the maximum initial absorption in g/min.

Figure 18 Maximum initial absorption test of the ecological part

Graphic (effort - time)

In the Table are presented the blocks with dosage of the three proportions of crushed plastic, the graph was made with the program MATLAB.

Time (s)	Effort block 1 (10%PP)	Effort block 2 (15%PP)	Effort block 3 (25%PP)
0	0	0	0
5	0.217	0.833	0.217
10	0.333	0.917	0.367
15	0.333	1.3	1.21
20	0.35	3.517	3.41
25	0.70	7.867	7.01
30	1.10	9.65	9.05
35	2.15	11.65	10.75
40	4.533	13.983	15.183
45	9.50	16.283	18.433
50	14.15	18.43	19.05
55	21.083	20.583	19.21
60	27.317	21.817	0
65	32.517	22.85	0
70	37.233	23.657	0
75	41.033	0	0
80	42.62	0	0
85	0	0	0

Table 3 Resistances (effort-time) 10, 15, 25% Polypropylene

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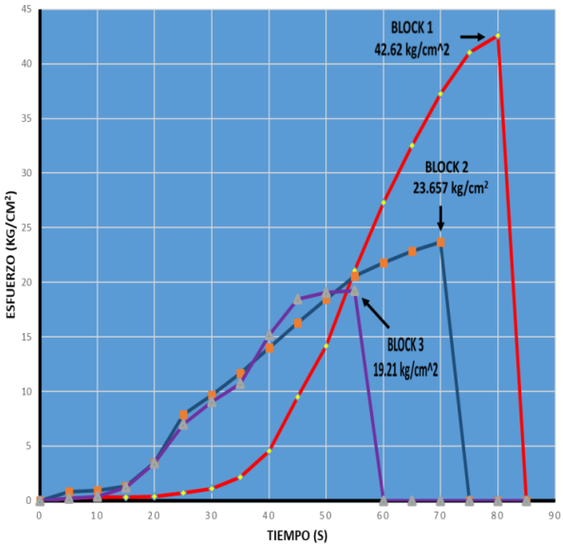

Graphic 1 Resistances (effort-time) 10, 15, 25% Polypropylene

The graphic shows the simple compression tests, performed with the three percentages of shredded plastic, these load parameters were taken every 5s, the block #1 has a compressive strength of 42.62 kg/cm^2, the #2 with a result of 23.657 kg/cm^2, and the #3 with a strength of 19.21 kg/cm^2.

Results

The 5 blocks that were made with 10% PP, were subjected to compression in the press at 15 days of age, obtaining the following results.

Part	P (kg)	A (cm^2)	Resistance f'c (kg/cm^2)
1	26080	600	43.46
2	25850	600	43.08
3	24700	600	41.16
4	24390	600	40.65
5	23090	600	38.48

Table 4 *Resistances of the 5 pieces*

The resistance f'c of each piece is calculated with the following equation

$$f'c = P/A \quad (1)$$

Where:

P is the load at which the part fails in kg

A is the area of the section that receives the load in cm^2

And for the average resistance, the equation

$$f'c\ average = \frac{\Sigma f'c}{\text{Nº Parts}} \quad (2)$$

$$f'c\ average = 41.36\ kg/cm^2$$

Adequate resistance for non-structural walls, according to the standard "NMX-C-441-ONNCCE-2013-INDUSTRY OF CONSTRUCTION-MAMPORY - BLOCKS, STUDS OR BRICKS AND SHEETS FOR NON-STRUCTURAL USE - SPECIFICATIONS AND TESTING METHODS", which indicates that the average resistance is 35 kg/cm2, and the minimum individual resistance is 28 kg/cm2.

At 3 blocks with 10% PP, they were tested at initial water absorption, with an age of 14 days, obtaining the following results.

Part	Weight seco P0(g)	Wet weight P1(g)
1	19,163	19,232
2	18,286	18,358
3	19,486	19,528

Table 5 Dry and wet weights of the 3 pieces

The maximum initial absorption in g/min is calculated by applying the following algorithm

$$Cb = \frac{100M}{S\sqrt{t}} = \frac{100(P1-P0)}{S\sqrt{10}} \quad (3)$$

Where:

Cb is the initial maximum absorption in g/min

M is the weight of water absorbed by the block during the test in grams

S is the surface of the submerged face in cm^2

t is the dive time in minutes.

Part #1

$$Cb = \frac{100M}{S\sqrt{t}} = \frac{100(19{,}232g - 19{,}163g)}{600\ cm^2\sqrt{10}\ min}$$

$$Cb = 3.63\ \text{g/min}$$

Part #2

$$Cb = \frac{100M}{S\sqrt{t}} = \frac{100(18{,}358g - 18{,}286g)}{600\ cm^2\sqrt{10}\ min}$$

$Cb =$ 3.79 g/min

Part #3

$$Cb = \frac{100M}{S\sqrt{t}} = \frac{100(19{,}528g - 19{,}486g)}{600\ cm^2\sqrt{10}\ min}$$

$Cb =$ 2.21 g/min

The results of the blocks for non-structural use comply with the NMX-C-441-ONNCCE-2013-BUILDING INDUSTRY - MAMPOSTERY - BLOCKS, STOPS OR BRICKS AND TABICONES FOR NON-STRUCTURAL USE - SPECIFICATIONS AND TESTING METHODS, which are acceptable for exterior walls as they do not exceed 5 g/min, as well as for interior walls or with 7 tolerance coating. 5 g/min, then the average absorption of the parts was determined.

$$Cbprom = \frac{\Sigma Cb}{Nº\ Parts} \quad (4)$$

$$Cbprom = \frac{3.63 + 3.79 + 2.21}{3} = 3.21 g/min$$

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Conclusions

In the research, different types of dosages were made, 25% (3.85 kg), 15% (2.31 kg), and finally 10% equivalent to 1.54 kg of Plastic in the masonry piece, which were tested for their resistance to compression, giving satisfactory results with an aggregate of 10% PP, with an average resistance of 41.36 kg/cm2 in the test of 5 pieces, so they comply with the NMX-C-441-ONNCCE-2013 for non-structural blocks.

With that same 10% PP dosage, three more pieces were manufactured, which were subjected to the initial maximum absorption test, leaving the blocks submerged for 5mm for 10min, at the end of the test the calculations show favorable results, an average is obtained to determine the initial maximum absorption, with a result of 3.21g/min, therefore they comply with the NMX-C-441-ONNCCE-2013.

It is concluded that the ecological masonry piece with its strength is suitable for use only as non-structural blocks.

It will also be acceptable for use in the construction of interior walls and exterior walls that will be exposed to the weather.

The ecological masonry pieces will make a great contribution to the environment, since for example, if a 4x3m wall is built, 150 blocks of 40cm long x 20cm high will be needed. If 1.54 kg of plastic is used to make an ecological block, 231 kg of polypropylene plastic will be needed to build the wall, thus reusing the plastic that could contaminate the environment.

The design of the ecological masonry piece can be improved if the upper projections and lower circular entrances are modified, by a prismatic geometry, as well as in the sides (projection and entrance) of the block, to increase the moment of inertia in those sections, achieving a greater coupling between the pieces.

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