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Determination of Compression Stress and Volumetric Weight of Lightened Concrete Blocks, with the Use of Recycled Polymers and Nanoadditives

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Abstract— **The current study describes the development and evaluation of hollow concrete blocks using recycled polymers and a waterproof, resistance improver nanoadditive together with cement, sand, and pumice to search for an ecological building material capable of reducing the environmental pollution. Three phases were performed; in which the first, we characterized petrous aggregates, polyethylene terephthalate (PET) and the nanoadditive. In the second one, several dosages were established with different percentages of crushed PET that represented to the sand. Additionally, a nanoadditive's part was placed in relation to the total water of the mixture. In the third phase, the compressive stress, volumetric weight, and absorption of the elaborated specimens were determined according to the national standard. The resulting optimal dosage was about 25% PET in replacement of sand + 0.0087 kg of nanoadditive, able to generate a better quality material, obtaining a compressive strength of 36.5 kg/cm^{2,} very close to the normative (40 kg/cm^2) and superior to the of commercial blocks (14.35 kg/cm^2). Regarding the volumetric weights, the plastic had a good performance as it managed to reduce the weight by 20%, while the use of the nanoadditive waterproofing decreased by 25% of water absorption. The block of the current research was twice as expensive as the traditional, even if production is tripled, as it was reduced to only $ 0.06 (8%). However, in comparison with the industrially elaborated procedure, the costs are very similar.**

Keywords—**Masonry; copolymer; PET; resistance; nanoadditive.**

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I. INTRODUCTION

Traditionally in masonry construction, materials from alluvial deposits are used, such as rocks and mud, obtained from areas close to settlements for ease of transport [1]-[3]. However, the environment is being negatively affected with time, as raw materials during their life cycle may leave irreparable ecological traces [4], [5]. The rate of extraction of aggregates in the quarries increases every year. Therefore, researchers have seen the need to create new raw materials that, in addition to being friendly to the environment, are resistant and relieve structures, creating sustainable and sustainable development [6]-[8]. Mixtures of polyethylene terephthalate (PET) and cement for the production of blocks have been developed, tested, and characterized [9]-[11]. As a result of this, an obtained final result is a stable block with characteristics and functionalities similar to traditional blocks but replacing the materials extracted from the earth's crust [12], [13]. Furthermore, an economical alternative with recycled materials for masonry elements has been presented to reduce environmental pollution and increase the strength of concrete blocks, concluding that the PET used in construction elements partially replaces the aggregates of conventional concrete, obtaining advantages such as the reduction of the specific weight and better thermal insulation [14]-[16].

In Ecuador, there has been little research on the use of PET as an alternative material in construction. Nonetheless, a study has proposed an innovative and ecological technology in the elaboration of aggregate for cobblestones in the city of Quito due to a large number of PET plastic bottles [17], [18]. The construction of construction materials whose mixing composition contains recycled PET, saves costs and generates durability benefits compared to traditionally prepared materials [19]-[21]. In addition, being a pollutant residue of a greater amount on the planet generates a great environmental impact, so recycling should become a habit [22]. The use of this recycled polymer generates new products that favor the construction sector, where the possibility of replacing crushed plastic with aggregates that are commonly used in the construction of construction materials is notable [23]-[25].

A recent study demonstrated that the non-structural masonry concrete blocks used in several buildings in Ecuador do not meet quality standards because they presented compressive strengths below the minimum required by the regulations used [26]. Therefore, the main objective of the current study has been to create a new material in which a percentage of polyethylene terephthalate and nanoadditive is added over the original mixture, to improve the properties of the masonry.

II. Materials and Method

A. *Characterization of Materials Used in the Preparation of Concrete Blocks*

In the norm NTE INEN 3066, about concrete blocks, within the requirements and test methods, it has been defined that the concrete blocks must be made with hydraulic cement, fine and coarse aggregates, such as sand, gravel, split stone, volcanic granules, pumice, slags or other suitable inert inorganic materials [27]. The characteristics of the sand (size, shape, granulometric distribution, and texture) must guarantee a uniform mixture preventing the materials from segregating [28], for which the fineness module must be in the range of 2, 3, and 3.1 allowing the processed concrete to be manageable. Therefore, it is fundamental to control the amount of fine aggregate; if the sand is insufficient, the mixture becomes rough, or in the opposite case, when there is more, the mixture has a dry consistency; therefore, more water will be required [29].

Pumice rock is used to produce lightweight and low-strength concrete depending on the degree of crushing of the material. Its porous texture causes the material to have a low density (0.4 to 0.9 g / cm3), although it has values between 2.1 to 2.5 g / cm3 of specific gravity. It is commonly used in residential masonry construction because it insulates heat easily [30]. In the current study, the stone material that was used in the manufacture of hollow concrete blocks was acquired from a block located in the Santa Teresa-Sanqolquí suburb, which receives the aggregates of Lasso-Latacunga, north-central Ecuador. The characterization obtained from the aggregates is presented in Table 1.

TABLE I
CHARACTERIZATION OF STONE MATERIALS USED IN THE ELABORATION OF HOLLOW CONCRETE BLOCKS

Properties	Normative NTE-INEN	Unit	Aggregates	
			Pumice	Fine
Specific gravity of the impermeable material of the particles	856:2010	kg/m^3	2170,62	2602,30
Specific weight of saturated particles with dry surface		kg/m^3	1835,06	2469,90
Specific weight of dry particles		kg/m^3	1549,31	2387,50
Water absorption		%	18,44	3,45
Fineness module	696:2011			2,68
Natural humidity	862:2011	%	18,88	14,03
Nominal maximum size	696:2011	pulg.	1/2"	
Weight vol. Loose	858:2010	kg/m^3	777,74	1324,06
Weight vol. Compact		kg/m^3	860,00	1570,88

The type of plastic that was analyzed is PET, a material that is easily found but generates a high level of pollution on the planet as it is composed of 64% petroleum, 23% of liquid derivatives of natural gas, and 13% air [31], is a chemical composition that does not allow to degrade rapidly, so it is advisable to recycle it. It was obtained from the Enkador industrial plant, a company located in Sangolquí, and is a material that goes through a washing process, preventing the placement of polluting chemicals [32]. Table 2 lists the characterization of the PET plastic. This project also used a nanomolecular additive responsible for adhering to the particles correctly, generating new functionalities, such as a high level of resistance to the presence of UV rays and water. It also provides stability when the material is exposed to high temperatures [33].

TABLE II
CHARACTERIZATION OF POLYETHYLENE TEREPHTHALATE (PET) USED IN THE ELABORATION OF HOLLOW CONCRETE BLOCKS

Properties	Normative NTE-INEN	Normative ASTM	Unit	Amount	Range
Density of PET plastic		D 792:2013	Kg/m^3	1298,41	min 1200,00
Water absorption		D 570:2010	%	0,26	0,10 - 0,70
Fineness module	696:2011			3,10	2,30 - 3,10
Weight vol. Loose	858:2010		Kg/m^3	469,06	430,00 - 482,00
Traction strength		D 638:2014	MPa	119,02	108,00±15,00
Module of elasticity			MPa	2054,44	2000,00-4000,00

B. *Dosage Determination*

In his report, Kuster et al. [34] indicate that there are several methods for calculating the dosage of concrete to encounter the optimum method A.C.I., as it allows to obtain the quantities of the materials based on the required strength. The A.C.I. (American Concrete Institute) is through tables to determine the proportions that meet certain characteristics [29]. The concrete blocks were manufactured in this investigation had the dimensions detailed in Fig. 1.

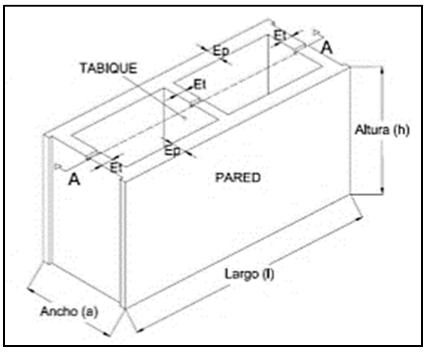


Fig. 1 Dimensions of a hollow concrete block (Servicio Ecuatoriano de Normalization, 2016). The parameters and sizes are Length (l) 400mm; Width (a) 150mm, Height (h) 200mm; Partition thickness (Et) 25mm; Wall thickness (Ep) 25mm.

Different dosages were performed to generate a concrete of dry consistency and the ability to comply with the compressive strength requirements established in the NTE INEN 3066 standard (Table 3). Pilot tests were conducted in order to reach an acceptable resistance before introducing plastic and additives into the mixture. The compression test applied at seven days allows to obtain 70% of the resistance, to make adjustments in the mixture if necessary [35].

TABLE III
MINIMUM NET COMPRESSIVE STRENGTH IN CONCRETE BLOCKS [27]

Description	Minimum net resistance to simple compression (MPa)*		
	Class A	Class B	Class C
Average of 3 blocks	13,8	4,0	1,7
Per block	12,4	3,5	1,4

*1 MPa=10,2 kg/cm^2

Once the dosage was corrected, 9 block samples were prepared for each dosage. In total there were 126 specimens, where in the first test the amount corresponding to 10, 20, 30, 40 and 50% of PET was replaced, replacing the same percentage of sand. The amount of nanoadditive was determined by the ratio 1/300 of the total volume of water. Subsequently, a new dosage was generated with 0, 10, 15, 20, 25 and 30% PET in replacement of the same percentage of sand, due to the graph in Figure 8 where the percentage of optimal PET is within 10% at 30% PET. Here cement was increased 35% and the ratio 1/250 was used, meaning 1 kg of additive on 250 l of water. Finally, a test was performed where the quantity by volume of the pumice stone was replaced by crushed PET plastic. In this mixture no nanoadditive was applied in order to analyze the effect of PET plastic on the concrete of block-type masonry

C. *Concrete Block Building*

The blocks were made in the materials testing laboratory of the University of the Armed Forces ESPE, and according to Tang et al. [36], the techniques used should be similar to those used in a block. Therefore, the fine, coarse and crushed PET aggregates and cement were first placed in the concrete, according to Hu et al. [37], until visually a homogeneous color is obtained. Subsequently, water was added in two equal parts, where the first was to hydrate the paste and the second to control the workability and consistency of the mixture [38].

The amount of nanoparticle additive corresponding to each dosage was dissolved in the first part of the water that was separated. According to Sapronova et al. [39], concrete mixing needs to be performed for a period of 4 to 5 minutes, verifying that the union of all materials forms a uniform mixture and controlling the amount of water applied since this may vary when placing additives in the concrete mix, causing the block to crumble or crack [35]. Subsequently, the mold was filled in three layers verifying that the concrete disperses completely without leaving empty spaces and is compacted (Fig. 2a). Finally, the mold was turned and removed with slight upward movements, ensuring that the block was perfectly demoulded (Fig. 2b). Once the metal mold was removed, a visual evaluation was conducted. If the specimen showed large cracks in its walls, the material had to be placed back in the truck to proceed to the elaboration of a new block [40]. Similar procedures have been applied elsewhere [48].

Fig. 2 Placing the concrete inside the mold (left); process to demould the concrete blocks (right).

According to Shi et al [41], the blocks need to be cured immediately after their elaboration, so that the immobile specimens were left in the place where they were demoulded for a day until they hardened. Then they are moved to a storage place where the climatic conditions are adequate for the blocks to maintain their humidity and achieve maximum resistance. Redha [40] mentioned that they were placed with a maximum separation of 2 cm between each specimen to ensure air circulation (Figure 3).

Fig. 3 Curing and storage process of hollow concrete blocks.

III. RESULTS AND DISCUSSION

The NTE INEN 3066 standard was used to determine the compressive stress of the concrete blocks. Therefore, whole samples were tested, which were countersigned according to the NTE INEN 2619 standard to generate a flat surface. Prior to refraining, the blocks were submerged in water for a period of 2 hours so that the 1: 1 dosing mortar may adhere properly. This was placed in a 6 mm distributed layer on the masonry's upper and lower face, controlling its leveling (Fig. 4). In order to finish, the mortar of the restraint was moistened to prevent cracking and to keep its moisture plastic covers were placed for a day (Fig. 5) [27].

Fig. 4 Placing mortar on the upper face of the block (left); leveling the mortar placed on the lower part of the block (right).

Fig. 5 Moistening of the facing placed in the hollow concrete blocks.

After 24 hours of curing of the restraint, the elements were preceded to be tested, which were placed on the compression machine according to the position they were placed in the construction of the masonry. In addition the vertical alignment was verified so that the applied load. It is distributed throughout the contact area (Figure 6) [27].

Fig. 6 Placing hollow concrete block in compression machine.

Figure 7 illustrates the results of compression resistance presented by the hollow concrete blocks of the first test, where it is observed that it increases favorably until reaching 20% of PET. However, by placing more percentage of crushed plastic the resistances decrease, and they are even lower than the compressive effort obtained when testing the blocks without plastic. According to Tian et al. [42], by adding recycled materials to the concrete mixture, its resistance is reduced to compression, which is even less than the designed resistance due to the presence of low-quality aggregates.

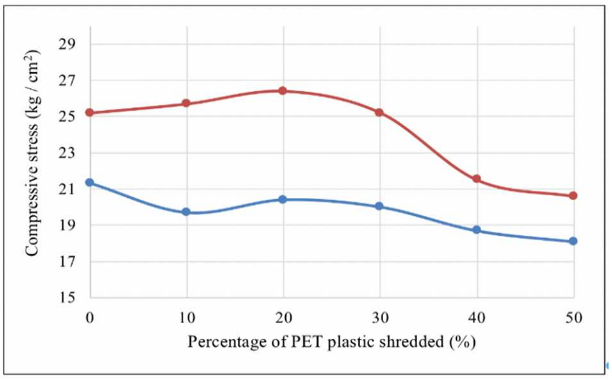


Fig. 7 Compressive stress vs. % PET plastic (10%, 20%, 30%, 40%, 50%) in replacement of sand + nanoadditive, Age of cure 7 days (blue) and 28 days (red).

The greatest resistance was encountered in the blocks that contain a percentage between 10% to 30% of crushed PET plastic (Fig. 8). This is consistent with that expressed by Ryu et al. [22], who mention that increasing the amount of polyethylene terephthalate in block making increases the resistance.

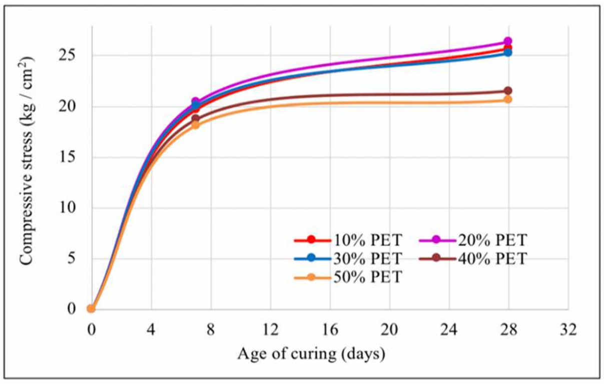


Fig. 8 Compressive stress vs. age of curing of hollow concrete blocks. 10%, 20%, 30%, 40%, 50% PET replacement sand + nanoadditive.

The resistance results of the blocks containing a percentage between 10% and 30% of plastic in their mixture are shown below, where the efforts are increasing up to 25% of PET (Fig. 9). These values indicate an increase of 20% compared to the previous results, as the dosage used had an increase in cement and nanoparticle additive [22]. It is advisable to add a few amounts of cement so that the concrete has the appropriate consistency for the preparation of blocks.

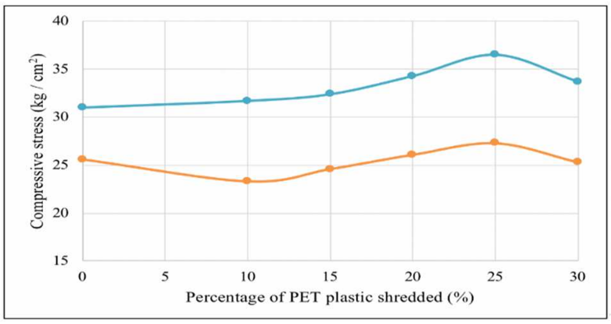


Fig. 9 Compressive stress vs. % PET plastic (10%, 15%, 20%, 25%, 30%) in replacement of sand + nanoadditive. Curing age 7 days (yellow) and 28 days (blue).

In Figure 10 the optimal dosage is that which contains 25% PET + nanoadditive, as it presented the highest resistance result. According to Krasna et al. [17], the resistance of the blocks with 25% plastic is suitable for these masonry to be used in the elaboration of exterior and interior partition walls.

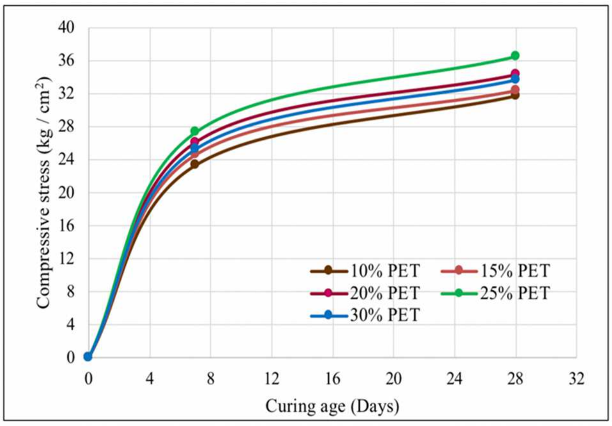
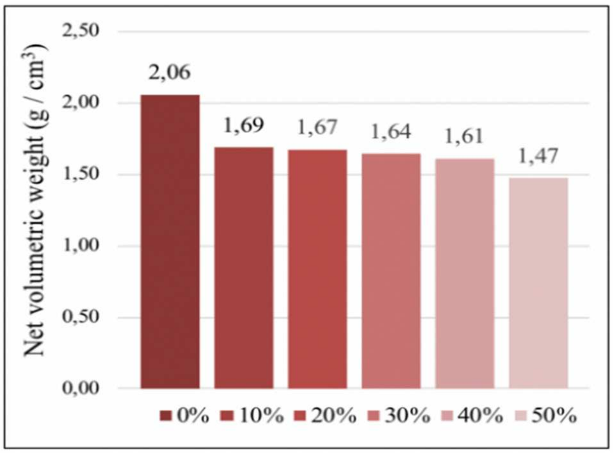
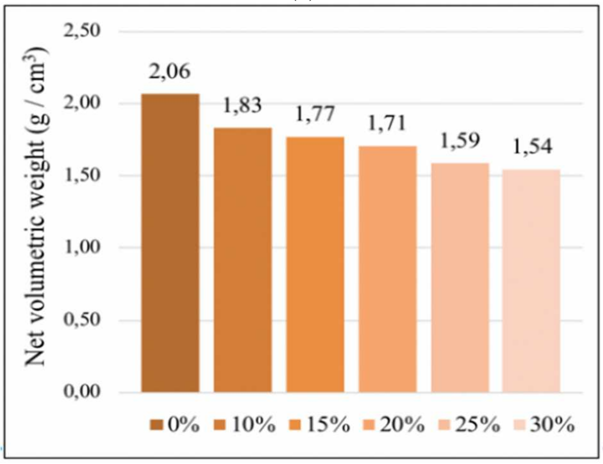


Fig. 10 Compressive stress vs. age of curing of hollow concrete blocks. 10%, 15%, 20%, 25%, 30% PET replacement sand + nanoadditive.



(a)



(b)

Fig. 11 Graph of volumetric weights of hollow concrete blocks with% PET and nanoadditive. a) 10%, 20%, 30%, 40%, 50% PET, b) 10%, 15%, 20%, 25%, 30% PET

As Pincheira et al. [43] indicated, recycled PET can be used to manufacture concrete with superior mechanical properties. With the compression results obtained in the current study it can be defined that by introducing different percentages of PET plastic and a certain amount of nanoadditive the resistance exceeds that of traditional blocks. In the case of volumetric weight, the specimens of the first test yielded a certain similarity between the percentages of 10%, 20% and 30% of PET (Fig. 11a). Hereby, we obtained values that are reduced while increasing the amount of PET plastic. The lowest values correspond to the blocks whose mixture contained 25% and 30% PET + nanoadditive compared to the volumetric weight obtained in the blocks made without plastic or additive (see Figure 11b).

Figure 12 illustrates that introducing a low-density material such as plastic into the block concrete mix influences the reduction of volumetric weights as the results obtained are lower than the value presented by the traditional blocks. Olofinnade et al. [44] expressed that the decrease in weight is evident in blocks containing PET, which generates a reduction in the weight of the structures.

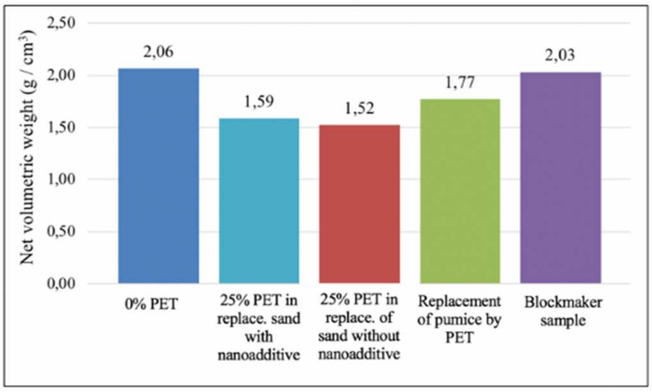


Fig. 12 Comparative graph of volumetric weights with 0% PET, 25% PET in replacement of sand + nanoadditive, 25% PET in replacement of sand and without nanoadditive, blocks replacement of pumice by PET, samples of blockmaker

The results obtained also agree with the one described by [14], who indicates that using plastic waste in cement mixtures generates materials with properties whose volumetric weight is low [12]. This is because PET has a lower weight compared to the aggregates used in the manufacture of blocks. In order to obtain the absorption results, the NTE INEN 3066 standard was used, where first the whole blocks were immersed in water for 24 h (Figure 13a), then the mass of each specimen was recorded while it was submerged in the water with the support of a metal mesh held with a wire (Figure 13b) [47].

The visible water was removed as shown in Figure 13c to verify the dry surface mass. All the specimens were placed inside the oven 24 hours to end the test. After that period of time the dry mass of each sample was recorded [27]. Light-weight blocks must have an average maximum absorption of 288 kg / m^3. Figures 14 and 15 illustrate a bar graph with the absorption in kg / m3 and a scatter plot with the absorption in%. In the two conducted studies, it has been demonstrated that the absorption values tend to decrease while introducing more percentage of plastic in the mix, coinciding with [44], which indicates that the absorption and humidity decrease while the proportion of PET increases, as the plastic, is composed by non-absorbent particles.

(a) (b) (c)

Fig. 13 a) Blocks submerged for 24 hours, b) Determination of the submerged mass of a hollow concrete block, c) Surface drying of concrete blocks

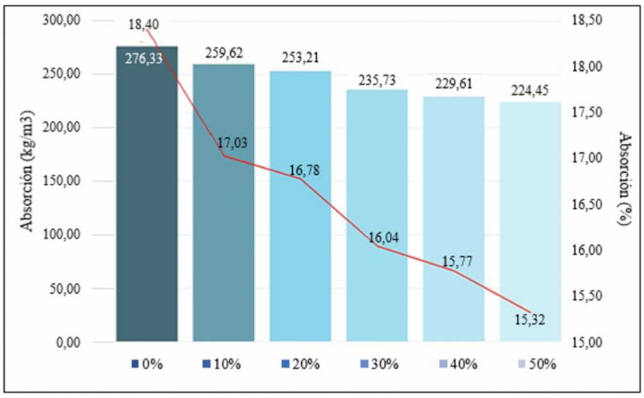


Fig. 14 Graph of water absorption in hollow blocks of concrete with 0%, 10%, 20%, 30%, 40%, 50% PET and nanoadditive.

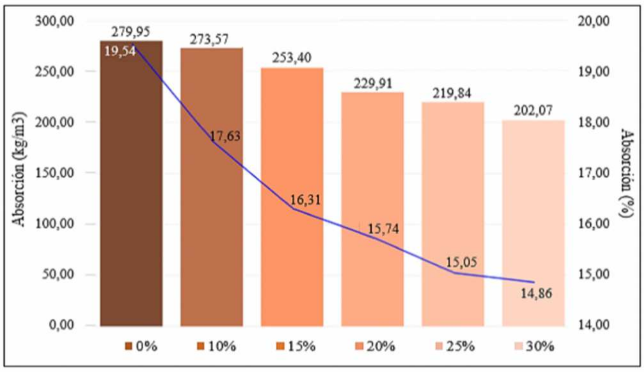


Fig. 15 Graph of water absorption in hollow concrete blocks with 0%, 10%, 15%, 20%, 25%, 30% PET and nanoadditive

For comparison purposes, compression and absorption tests were conducted on specimens that were made with only 25% PET in sand replacement, being samples in which the total amount of pumice was replaced by PET plastic and hollow concrete blocks purchased in a distributor of construction materials located in Sangolquí. The bar graph of Figure 16 illustrates that the concrete blocks for commercial use have low resistance compared to the blocks that were generated. It can even be determined that specimens with PET that do not contain additives and those that do not have pumice could be used in construction, coinciding with studies where blocks containing plastic, due to their resistance, cannot be used in structural masonry [44]. However, they could be used in non-bearing masonry. It may also be determined that placing a percentage of PET + nanoadditive in the mixture reduces the amount absorbed. Nonetheless, the blocks that only contained plastic also had a lower absorption than the traditional blocks as seen in the line graph of Figure 16.

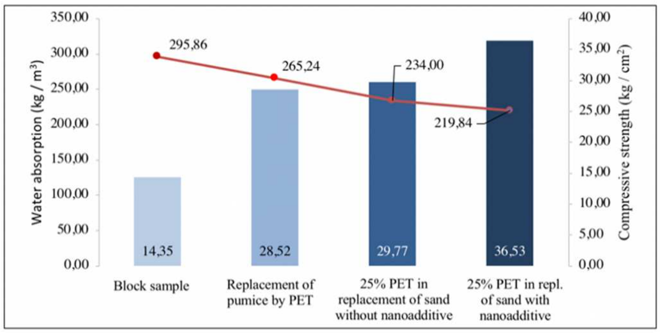


Fig. 16 Comparison of the increase in resistance and reduction of water absorption in hollow concrete blocks

Several studies mention that using recycled plastic as aggregate in concrete reduces costs [19]. However, in the current study, the unit price analysis indicated that those blocks containing PET are more expensive (Fig. 17), as there may be an increase, especially when there is a need to add more cement or new materials are introduced in order to obtain superior strength. Table 4 lists the costs of the block unit without considering indirect costs.

TABLE IV
COSTS PER UNIT OF THE HOLLOW CONCRETE BLOCK WITHOUT CONSIDERING INDIRECT COSTS

Type of block	Cost per block unit			
	Equipment	Workforce	Materials	Total
0% PET without nanoadditive	$0,03	$0,06	$0,49	$0,58
25% PET without nanoadditive	$0,03	$0,06	$0,53	$0,62
25% PET with nanoadditive	$0,03	$0,06	$0,60	$0,69
PET without pumice	$0,03	$0,06	$0,62	$0,71

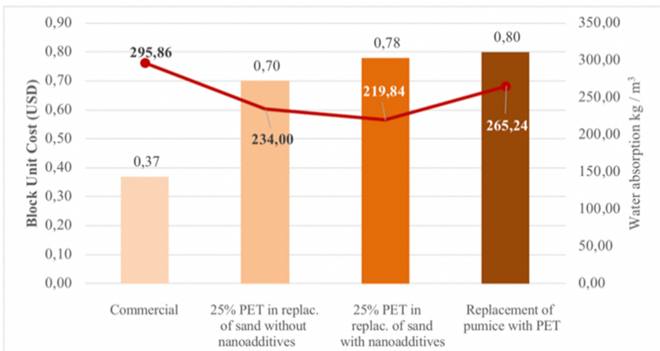


Fig. 17 Cost and water absorption comparison of hollow concrete blocks

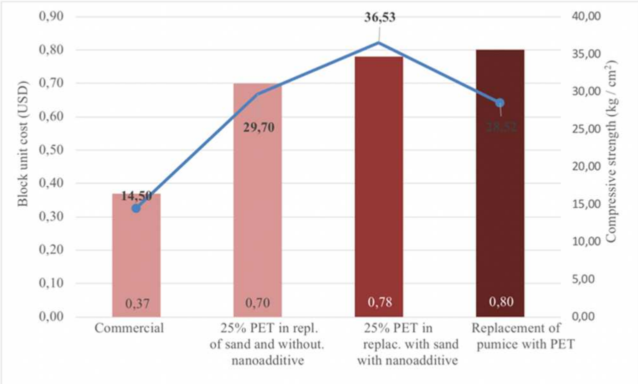


Fig. 18 Comparison of costs and compressive strength of hollow concrete blocks

In Figures 17 and 18 a comparison was performed between compressive strength, water absorption, and costs to relate them to each other and determine the optimal dosage. This contains 25% PET in sand replacement + nanoadditive and although its cost is high, it generated the best results in both compression and absorption. However, it could also be considered the dosage with 25% PET in replacement of sand without nanoadditive, as its results are acceptable, and the cost is lower [49]-[55].

In order to generate a reduction in the cost of the masonry a daily production of 6000 blocks was established considering the labor capacity of a worker, which implies an increase in both machinery and labor. However, when performing the new cost analysis, a maximum of $ 0.06 per block was reduced as listed in Table 5.

TABLE V
COST PER UNIT OF PROPOSED HOLLOW CONCRETE BLOCK

Type of block	Cost per block unit				
	Equipm.	Workf.	Mater.	Total	Total + indirect costs
0% PET without nanoadditive	$0,02	$0,03	$0,49	0,54	$0,59
25% PET without nanoadditive	$0,02	$0,03	$0,53	0,58	$0,64
25% PET with nanoadditive	$0,02	$0,03	$0,60	0,65	$0,72
PET without pumice	$0,02	$0,03	$0,62	0,67	$0,74

The 15 x 20 x 40 blocks in the market vary in cost depending on their manufacture, handmade or industrial. Craft blocks range around $ 0.37, but industrial blocks, as they are fabricated with better quality aggregates, increase their prices, like in the case of the company DISENSA which distributes blocks whose cost is around $ 0.64 [45]. In the case of the blocks elaborated in the current study the competition is directed only to the industrial part.

IV. CONCLUSION

In all the compression tests performed in the hollow concrete blocks, resistance was obtained lower than the minimum value of 40 kg / cm^2, while the best result being 36.5 kg / cm^2 belongs to the dosage of 25% PET in sand replacement + 1/250 of waterproofing and resistance improver nanoadditive, whose resistance compared to the blocks that are sold is very good, because these usually have an average 14.3 kg / cm^2, being well below the minimum value.

The volumetric weights belonging to the percentages of plastic used were excellent, as all were light. Even considering the dosage of 25% PET in sand replacement + 1/250 of waterproofing and resistance improver nanoadditive, whose resistance was the best, a value of 1.59 g / cm^3 lower than the blocks sold is obtained whose average value is 2.03 g / cm^3. The volumetric weight is not significantly affected in the block if pumice is used or PET instead, but it could vary with the nanoadditive. However, as noted, the ratio between both (PET + nanoparticle additive) maintained the light characteristic that was expected to be obtained.

It was demonstrated that plastic in quantities greater than 15% prevent water absorption, therefore the dosage with 25% PET had a water absorption value of 234 kg / m^3 less than the traditional 295.9 kg / m^3 and less also to the value stated in the standard which is 288 kg / m^3. If it is considered to use PET next to the nanoadditive that is optimal, even less water is absorbed (219, 84 kg / m^3) as its combination allows a waterproof structure without pores. The hollow concrete blocks with the optimum dosage, of 25% PET in replacement of sand + nanoadditive, compared to the traditional blocks made in a block demonstrated an increase in compressive strength by more than 100% and a reduction in water absorption approximately 25%.

The price of the experimental block is higher than the traditional block with or without additive. However, it should be considered that when proposing a material with recycled polymers it has reduced environmental pollution and the masonry will have better characteristics that will avoid the costs that come hand in hand with the blocks of lower price and of poor quality, such as humidity control in masonry. Increasing production does not represent a significant cost reduction, as the number of workers needs to be increased and considering their work capacity

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