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Use of Textile Waste as an Addition in the *elaboration of an Ecological* Concrete Block

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Abstract. The textile industry has grown significantly in recent years, reaching a global fiber production of 53 million tons which 12 % are recycled; Construction sector has been using more and more recycled materials from different industrial sources, to apply them in their constructions and to reduce CO_2 emissions and final energy consumption. The present study aims to study the behavior of concrete blocks of $f'_c = 210$ kg/cm^2 adding polyester textile waste with 3 %, 6 %, 9 %, 12 % and 15 %; void content, compressive strength and thermal conductivity decrease, and water absorption, acoustic insulation and unit price increase by 3 %, 34 % and 16 % compared to conventional concrete block.

1. Introduction

The accelerated growth of the textile industry has caused problems for environment, in 2015 the emissions of Greenhouse Gases (GHG) totaled 1200 million tons of CO_2 equivalent, this due to the fact that in its production per 1 Tn of textile is produced 17 Tn of CO_2 [1]. Similarly, its textile waste, whose level of contamination varies depending on the type of fiber used, originate methane gas and ammonia [2], [3]. There are some initiatives within the circular economy to minimize this waste, which are oriented towards its reuse in the textile industry or in other sectors such as construction [4], which is considered one of the most polluting due to its high level of CO_2 emissions [5], [6], being buildings responsible for the third part [7], [8].

In order to reduce these emissions, materials can be used in their construction that reduce the energy consumption used in the exploitation of the aggregates as natural resources [9], and that making use of traditional techniques updated with locally available materials [10] , improve their thermal conductivity and are more insulating; In this line, we can propose the need to change the composition of the 0.12 m and 0.15 m conventional concrete blocks used in the walls of the buildings, because with these an average thermal insulation of 0.159 m^{2}K/W and 0.171 m^{2}K/W is achieved [11]. In this regard, [12] carried out an investigation in a masonry system composed of concrete blocks coated with cement mortar and brick coated, also with cement, both materials separated by an air chamber, to compare the thermal conductivity with 2 types of 100 % acrylic fabric; first, with woven fabric residues and the other, with woven fabric sub-residues, finding a higher thermal conductivity for the mortar equal to 1.3 W/m ℃, and lower values for the woven fabric and woven fabric with sub-residues, these being 0.044 W/m℃ and 0.103 W/m℃ respectively; these values coincide with investigations carried out by [13], [14]; In this sense, an alternative for improvement would be to elaborate a concrete block with polyester textile residue. Polyester is a synthetic polymer, whose main source of raw material is petroleum, it can be used in the form of fiber or filament, it is strong and dimensionally stable; it has high resistance to humidity and biotic attacks, it does not contain insecticides or glues [15]. It has good thermal and acoustic insulation, its resistance to fire is good and it is less degradable in humid conditions [15], [16], and it is used in industrial and technical applications such as woven and non-woven fabrics [17].

In this regard, we can mention some referenced investigations on the characterization of textile waste: Water absorption is measured in [18] for concretes with additions of 0.5 %, 1.0 % and 2.0 % of carpet, linen and sisal fibers; finding that it is 4.3 %, 7.1 % and 7.8 % higher than the control sample. [19] found the same trend when studying lightweight concrete blocks with banana fiber additions of 2.5 %, 5.0 % and 7.5 % for different amounts of cement, finding that the water absorption at 28 days was maximum for 7.5 % and equals 201.6 % with respect to the standard block. Regarding the voids content and cost, we can indicate that similar investigations have not been found, but we can mention [20] who finds that the lightweight concrete blocks of 14 cm x 39 cm x 19 cm with the addition of polystyrene beads are 8 % more expensive than conventional concrete blocks, and this is due to the acquisition of the added material.

Regarding the compressive strength, [3] states that the compressive strength at 7 days of concrete blocks with a 25 % replacement of fabric increases by 19 %; and for the age of 28 days, [21], [18] indicate that the increase is between 12.5 % - 21.0 % when varying the percentage of cloth (linen) from 0.5 % - 40 %, and then decreases from 40 % - 94 % with respect to standard concrete. Regarding acoustic insulation, [22] tested fabrics with recycled polyester waste and wool waste, finding that the acoustic coefficient increases with the increase in the frequency range of 50 - 5700 Hz, with the acoustic coefficient being lower in 13.1 % for waste with 100 % recycled polyester fiber compared to waste with 100 % wool; on the other hand, [15] studied the fibers of polyester waste for different mass densities, indicating that the acoustic absorption coefficient increases with increasing mass from 65 - 95 K/gm^3 for frequencies of 100 - 5000 Hz.

With regard to thermal conductivity, [22] after testing fabrics with recycled polyester waste and wool waste, found that the thermal conductivity of waste with 100 % recycled polyester fiber is 9.4 % more than waste with 100 % woollen; Similarly, [15], [23] study fibers of polyester waste for different mass densities, indicating that the thermal conductivity decreases from 13.7 - 29.3 % when the mass of the fabric increases from 65 - 396 Kg/m^3.

This research addresses the low thermal conductivity of conventional concrete blocks in building walls. For this, the percentage of water absorption, the percentage of voids, the cost of manufacturing, the resistance to compression, and the acoustic and thermal insulation and unit cost of the concrete block with polyester have been studied.

2. Materials and methods

2.1. Materials

Portland cement Type I was used according [24]; fine and coarse natural aggregates with a maximum size of Ø ¾ ” comply with [25]; Polyester Fabric (PF) was used in sizes of 30 mm x 60 mm and thickness of 2mm, whose characteristics are: density = 0.16 g/cm^3, elongation = 50 - 70, colour = variety; and image are shown in figure 1, drinking water was used to prepare the mixture according [26].

2.2. Methods

2.2.1. Laboratory testing

The mixtures of the concrete blocks with PF were designed for an f'c = 210 Kg/cm^2 with the method [27], Table 1 and Table 2 show the design of mixtures for a Block with Polyester Fabric (BPF), and the number of blocks, ages and test standards; Blocks were made manually in molds measuring 14 cm wide x 19 cm high x 39 cm long, and compacted on a vibrating table according [27]. Their storage was carried out in a closed environment exposed to room temperature for 24 hours according to [28], then they were cured in water following [28] for 7 and 28 days until the date of the tests. For the case of water absorption and voids content, 3 concrete blocks were used per test with 6 % and 12 % TC and were tested after 56 days according [29], [30].

Table 1. Mix design of concrete blocks.

Materials	BPF-0 (Pattern)	BPF-3 (3%PF)	BPF-6 (6%PF)	BPF-9 (9%PF)	BPF-12 (12%PF)	BPF-15 (15%PF)
Proportion (C:F:C)	1:2:3	1:2:3	1:2:3	1:2:3	1:2:3	1:2:3
Cement (Kg)	2.05	1.99	1.93	1.87	1.80	1.74
Fine Aggregate (Kg)	4.592	4.582	4.574	4.565	4.555	4.546
Coarse Aggregate (Kg)	7.319	7.303	7.291	7.276	7.261	7.245
Water (Kg)	1.44	1.39	1.35	1.31	1.26	1.22
Polyester Fabric (Kg)	0.00	0.25	0.49	0.74	0.98	0.12

Table 2. Number of blocks, ages and standards according to tests.

Tests type	BPF-0 28 days	BPF-3 28 days	BPF-6 28 days	BPF-9 28 days	BPF-12 28 days	BPF-15 28 days	Methods
Compressive Strength	3	3	3	3	3	3	[31]
Acoustic isolation	2	2	2	2	2	2	[32]
Thermal isolation	2	2	2	2	2	2	[33]

2.2.2. Unit price

The analysis of unit prices of the conventional concrete block and concrete block with fabric was made with the studies of [34], [35], having considered the price of polyester as the sale price in Lima of S/. 0.50 / Kg and the dimensions of the polyester of 3 cm x 6 cm.

3. Fresh concrete

3.1. Water absorption

Figure 2 shows the influence of PF on the water absorption of the concrete block, the behavior increases when moving from BPF - 6 block to BPF - 12 block, reaching the values of 3.93 % and 4.03 % respectively, which represents a 2.48 % increase in absorption with respect to the BPF - 6. [36] studied the effect of PF on the water absorption of the concrete block for the age of 56 days, finding that there is an increase when going from 20 gr to 60 gr, reaching the values of 14.01 % and 18.76 % respectively, which represents a 25.27 % increase in absorption compared to block with 20 gr. [37] evaluated the incidence of the cotton fabric fiber on the water absorption of the limestone block for the age of 28 days, finding that there is an increase when going from 32 gr to 130 gr, reaching the values of 12.6 % and 27.2 %, which represents an increase of 53.7 % of absorption with respect to block of 32 gr. [38] indicates that this behavior is due to the presence of a more porous structure in the concrete.

3.2. Void content

Figure 3 shows the influence of PF on the void content in the concrete block, the behavior decreases when moving from the BPF - 0 block to the BPF - 12 block, reaching the values of 42 % and 39.6 %, which represents a 5.71 % decrease in absorption in relation to BPF - 0. [39] studied the effect of the fly ash on the void content of a polymeric concrete block for the age of 28 days, finding a decrease from 6 % to 9 % of addition, reaching values of 22 % and 13 % respectively, which represents a lower void content of 40.91 % compared to the 6 % block. [40] evaluated the incidence of the density of the polypropylene fiber on the void content of a permeable concrete block for the age of 28 days, finding a decrease when going from a density of 1710.23 kg/m^3 to 1837.92 kg/m^3, reaching values of 32.38 % and 25.27 % respectively, which represents a lower void content of 28.14 % in relation to block with 1710.23 kg/m^3. [41] indicates that this behavior may be due to the filling of the concrete voids.

Figure 1. PF sample.

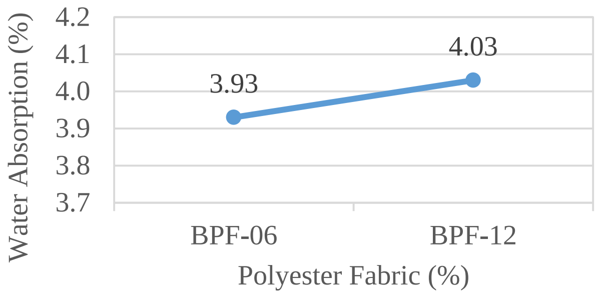

Figure 2: Water absorption.

4. Hardened concrete

4.1. Compressive strength

Figure 4 shows the influence of PF on the compressive strength of the concrete block at the age of 28 days. Resistance decreases, reaching the value of 24.23 Kg/cm^2 for the BPF - 15 block, which represents 49 % less than BPF - 0 block (standard). [42] studied the effect of the percentage of fabric on the compressive strength of the concrete block at the age of 28 days for two mixtures with 1 % and 2 % addition of 4 types of fabrics: polyester, cotton, silk and rayon, and block dimensions of 40 mm x 40 mm x 160 mm, finding a lower resistance value of 183.96 Kg/cm^2 for 2 %, which represents 43.09 % less with respect to the 0 % block (standard). [43] evaluated the incidence of the percentage of polyester fabric on the compressive strength of the concrete block at the age of 28 days, for mixtures with 0.2 %, 0.4 %, 0.6 %, 0.8 %, 1 %, 1.2 %, 1.4 % and 1.6 %, and block dimensions of 150 mm x 150 mm x 150 mm, finding that the resistance decreases, reaching a lower value of 183.96 Kg/cm^2 for 1.2 %, which represents 34.25 % less with respect to the 0.2 % block (standard). [44] indicates that this behavior may be because the materials with polymeric origin resist less to compression forces, their deformation is low and they present a weak bond between them compared to fine aggregates; which produces cracks around it and the existence of voids inside the concrete.

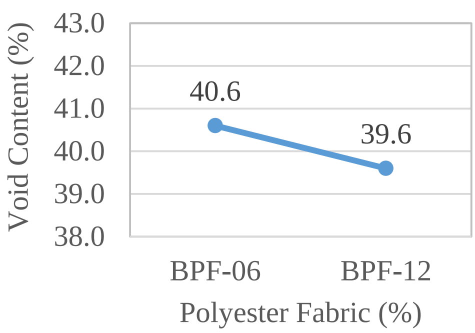

Figure 3. Void content.

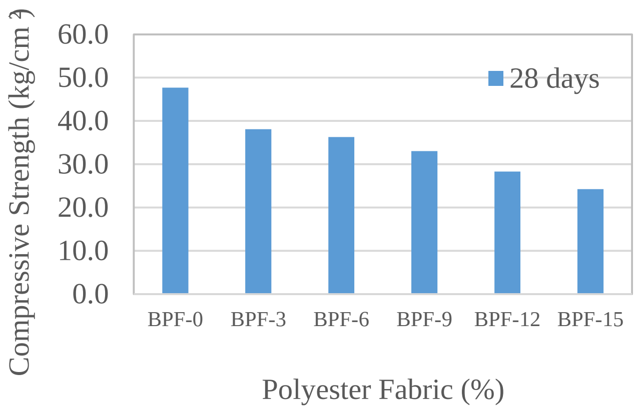

Figure 4. Influence of PF on the compressive strength.

4.2. Acoustic isolation

Figure 5 shows the influence of PF on the sound pressure difference of the concrete block at the age of 28 days. The sound pressure difference increases, reaching the value of 34.76 dB for BPF - 15 block, which represents 34.3 % more than BPF - 0 block (standard). [45] studied the effect of the amount of polyester fabric on the sound pressure difference in a 3.55 m x 2.85 m x 0.06 m drywall plate at 28 days, for mixtures with 20 % and 35 %, finding that the sound pressure difference increases, reaching the highest value for 35 %, this being 43 dB, which represents 2.4 % more with respect to the standard amount of 20 g/m^2(standard). [46] evaluated the incidence of polyester fabric on the sound pressure level, for samples of 21.0 kg/m^3, 34.3 kg/m^{3}and 65.5 kg/m^{3}of 400 mm x 200 mm x 18 mm polyester, finding that the pressure level noise decreases with the increase in the amount of polyester, obtaining the lowest value for the sample of 65.5 kg/m^3, this being 56 dB(A), which represents 12.5 % less compared to the sample of 21.0 kg/m^3, which means that better insulation is thus achieved. [47] indicates that this behavior is due to greater friction between the fibers and the air.

4.3. Thermal conductivity

Figure 6 shows the influence of PF on the coefficient of thermal conductivity of the concrete block at the age of 28 days. In it, it is seen that the coefficient decreases, reaching the value of 1.54 for BPF - 15 mixture, which represents 5.5 % less than the BPF - 0 block (standard). [46] studied the effect of the fabric on the coefficient of thermal conductivity at 28 days for 2 samples with 100 % polyester and 95 % polyester plus 5 % addition lycra on a cylindrical sample with dimensions of 10 cm x 12 cm in diameter, finding that there is a decrease in the coefficient of thermal conductivity when the percentage of fabric varies, reaching the lowest value for the sample with 100 % being 0.0543 W/mK, which represents 11.05 % less than the sample with 95 % polyester. [48] evaluated the incidence of the percentage of polyester fabric on thermal conductivity in fabric samples of 200 mm x 200 mm x variable widths of 5 %, 15 %, 20 %, 25 % and 30 % with respect to the length, finding that the Thermal conductivity coefficient decreases as the percentage of polyester varies, reaching the lowest value for the sample of 30 %, this being 36.3 W/mK, which represents 1.65 % less than the standard sample with a width of 5 %. [49] indicates that this behavior is due to the strong interaction that exists in heat transfer between fibers and air; likewise [50] states that the amount of air trapped in the matrix also reduces the thermal conductivity.

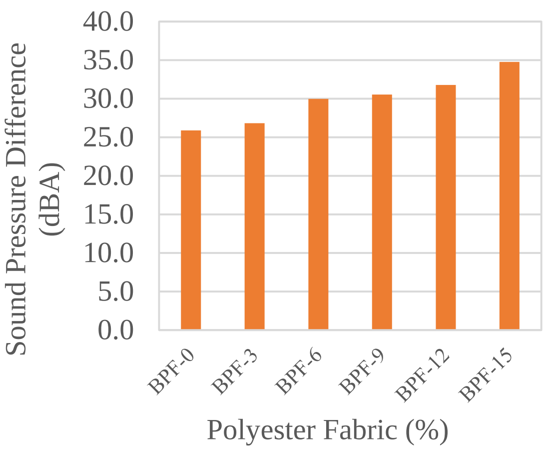

Figure 5. Influence of PF on the sound pressure difference.

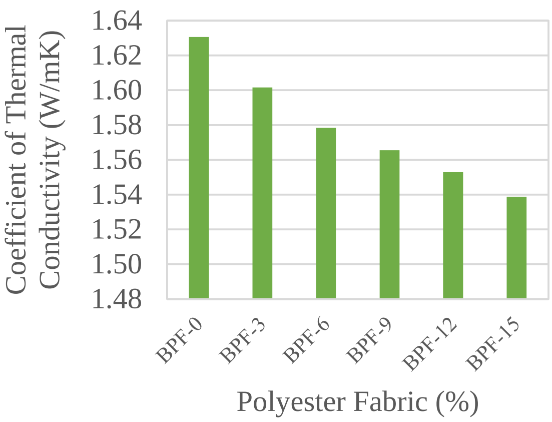

Figure 6. Influence of PF on the coefficient of thermal conductivity.

5. Unit price

Tables 3 and 4 show the analysis of unit prices per m^3 of a conventional concrete block and a concrete block with PF. In them the unit price per m^3 is S/. 3.75 ($ 1.05 USD) for the conventional concrete block and S/. 4.41 ($ 1.21 USD) for block with 15 % polyester, this being 16 % more than the conventional concrete block due to the cost incurred and associated with the production and the added material [51], [52], [53].

Table 3. Analysis of the unit price per m^3 of conventional concrete block.

Performance 120 block/day		Conventional concrete block 39 cm*19cm*14cm			S/.3.75
Description	Unit	Quadrille	Quantity	Price (S/.)	Partial (S/.)
Materials					
Cement	Kg		2.6797	0.42	1.13
Sand	m ³		0.0033	56.00	0.18
Gravel	m ³		0.0065	45.00	0.29
Water			0.0014	4.82	0.01
					1.61
Workforce					
Laborer	HH	1.0000	0.0667	14.33	0.96
					0.96
Equipment					
Rosa Cometa	HM	1	0.0533	20.00	1.07
Manual tools	%MO		0.0478	2.55	0.12
					1.19

Table 4. Analysis of the unit price per m^3 of concrete block with PF.

Performance 120 block/day		Concrete block with PF 39cm*19cm*14cm			S/.4.41
Description	Unit	Quadrille	Quantity	Price (S/.)	Partial (S/.)
Materials					
Cement	Kg		2.6797	0.42	1.13
Sand	m ³		0.0033	56.00	0.18
Gravel	m ³		0.0065	45.00	0.29
Water			0.0014	4.82	0.01
Polyester	Kg		0.1200	1.00	0.12
					1.73
Workforce					
Laborer	HH	1.5000	0.1000	14.33	1.43
					1.43
Equipments					
Rosa Cometa	HM	1	0.0533	20.00	1.07
Manual tools	%MO		0.0717	2.55	0.18
					1.25

6. Conclusions

The high thermal conductivity of conventional concrete is due to the fact that, with its current composition, the coefficient of thermal conductivity, the apparent density and the porosity, necessary to manufacture a block with thermal characteristics, are not improved.

Increased water absorption due to the increase in polyester is because fibers needs more water to mix with the concrete.

Void content decreases as the amount of polyester increases because the fibers cover the voids generated in the concrete slab.

Compressive strength decreases because when polyester is added, fibers increase air bubbles and voids inside the concrete slab.

Increase in acoustic insulation is because the apparent density increases and influences the acoustic absorption coefficient, making the concrete block with polyester a better acoustic insulator.

By decreasing the thermal conductivity by increasing the porosity of the concrete, a polyester block is produced that is a better thermal insulator.

Polyester concrete block is 16 % more expensive than conventional concrete block due to the cost for the recycled material and for the payment of personnel who cut the recycled polyester into small dimensions.

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