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Analysis of the Mechanical Properties of Concrete Blocks Reinforced With Glass Particles and Recycled Paper: A Sustainable Approach

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Abstract

The materials to produce concrete blocks (sand, gravel, and cement) are limited resources that are becoming scarce over time due to their increasing demand in construction. On the other hand, the waste of glass and paper is progressively increasing without being fully utilized through recycling. Therefore, the objective of this scientific research is to evaluate the influence on the mechanical properties of masonry concrete blocks made with recycled glass and paper particles. Likewise, the sample was non-probabilistically selected for convenience, consisting of 192 concrete blocks manufactured with additions of 3% (2% glass particles and 1% recycled paper), 6% (4% glass particles and 2% recycled paper), and 9% (6% glass particles and 3% recycled paper), as well as concrete blocks manufactured without additions. According to the results obtained, at 3%, 6%, and 9% addition of glass and paper particles, the absorption decreased by 4.94%, 3.398%, and 3.52% respectively. However, the warping increased between 1.7mm and 1.8mm, while the compressive strength (f'c) increased to 75kg/cm2, 82kg/cm2, and 77kg/cm2, respectively. Similarly, the axial compressive strength (f'm) increased to 91.22kg/cm2, 94.45kg/cm2, and 92.80kg/cm2, and the diagonal compressive strength (V'm) increased by 8.90kg/cm2, 9.70kg/cm2, and 9.70kg/cm2. Nevertheless, the manufacturing cost of masonry units showed a progressive reduction with the amount of glass + paper addition, amounting to 0.57 USD, 0.55 USD, and 0.53 USD. It was also determined that the optimal addition of these materials in the concrete mix in terms of cost and strength is 9% (glass + paper), resulting in compressive strengths of 77kg/cm2, 92.8kg/cm2, and 9.70kg/cm2, with a cost of 0.53 USD per unit. In conclusion, it can be affirmed that adding glass and recycled paper particles in the production of concrete blocks for use in load-bearing masonry walls positively influences the physical and mechanical properties of the blocks. Additionally, it allows for a reduction in manufacturing costs, leading to significant savings for builders.

1. Introduction

Nowadays, humanity is immersed in a process of constant evolution. Therefore, there has been a growing interest in promoting sustainable growth and proper waste management with the aim of mitigating or reducing the environmental impact caused by the accumulation of waste in our surroundings. It is important to highlight that one of the industries that generates a significant amount of waste is the construction industry, due to the need to obtain new materials for the construction of durable spaces with good living conditions for human beings (Mejía, 2019). However, it is worth noting that we currently have a wide variety of materials for use in civil construction, including recycled glass and paper. These materials can not only be used for aesthetic purposes but also as additives to improve the properties of existing construction materials, while reducing production costs and contributing to environmental protection (Almengor, Gutiérrez, Moreno & Caballero, 2019). It is also important to mention that both glass and paper are inert materials that can be recycled multiple times without altering their chemical properties.

There are studies that have shown that glass and paper can be reused as suitable materials in the construction industry. These investigations also mention that using glass and paper in the manufacture of concrete blocks allows them to achieve superior physical and mechanical properties compared to the traditional block.

(Acuña & Quispecondori, 2021). In their analysis, they propose to identify the optimal amount of paper that can be added to the concrete in partial replacement to improve the mechanical properties of the masonry blocks used in the construction of load-bearing walls. The results obtained in terms of compressive strength indicated that, for the designs with additions of 15%, 20% and 25%, the strength decreased significantly with increasing amount of cellulose paper added, while for the designs with additions of 5% and 10% the decrease was slight. In addition, they determined that the optimal amount of paper to add to the mix is 5.05%, which allowed reaching a compressive strength of 75.20 kg/cm2.

(Sandoval, 2020). In their study, they manufactured concrete blocks under the ASTM C-31 standard, replacing the fine aggregate with 25%, 50%, and 75% recycled paper. As a result, they found that the compressive strength at 7, 14, and 28 days for the 25% replacement of paper was 32 kg/cm2, 45 kg/cm2, and 60 kg/cm2, respectively. For the 50% replacement of paper, the values were 10 kg/cm2, 17.5 kg/cm2, and 20 kg/cm2, and for the 75% replacement of paper, they were 7.5 kg/cm2, 12.5 kg/cm2, and 17.5 kg/cm2, respectively. However, according to Ecuadorian regulation INEN 640, the minimum strength should be 60 kg/cm2. On the other hand, the manufacturing price in the Ecuadorian market for solid 12cm blocks is 0.81 USD, and with the use of recycled paper, it decreases to 0.79 USD.

(Burgos, 2020). In their research, it was determined that concrete blocks with partial addition of crushed glass at percentages of 5%, 10%, 15%, and 20% showed a reduction in water absorption of 3.27%, 7.39%, 15.40%, and 19.89%, respectively. Likewise, suction decreased by 11.77%, 22.36%, 27.09%, and 36.50%. On the other hand, an increase in simple compressive strength of 3.01%, 7.75%, 15.94%, and 19.14% was observed, as well as an increase in axial compressive strength in pilasters of 6.66%, 13.38%, 29.11%, and 35.16%. Overall, diagonal compressive strength increased by 11.82%, 20.42%, 24.42%, and 30.97%, respectively.

(Almengor, Gutiérrez, Moreno & Caballero 2017). In their study, they analyzed the mechanical behavior of concrete blocks by replacing all the aggregates with glass and paper. For this purpose, blocks were manufactured with a mixture consisting of 14% water, 14% cement, 24% paper, and 48% glass. Subsequently, they underwent tests according to the Panamanian standard COPANIT 48. They obtained a strength of 334.0 psi compared to the required 600 psi specified by the standard. Therefore, it can be observed that there is a need to produce concrete blocks using aggregates such as sand and stone, and to use less than 48% glass to achieve satisfactory results.

(Rubio & Toscano 2017). En In their descriptive study, they proposed improving the quality of concrete blocks by replacing glass with fine aggregate in proportions of 0%, 10%, 15%, 20%, and 30%. This resulted in blocks with a 28-day strength of 35.38 kg/cm2, 46.91 kg/cm2, 52.62 kg/cm2, 34.26 kg/cm2, and 48.84 kg/cm2, respectively. They also conducted an impact test, which revealed that the blocks with 10%, 15%, and 30% glass exhibited similar fragility to the standard concrete block.

Most previous studies on concrete blocks have focused on the use of recycled glass and paper to enhance their strength. However, compared to blocks made solely with recycled paper, these blocks have been found to be weak and less durable. Moreover, traditional concrete block production is not environmentally friendly, as it requires substantial amounts of sand and gravel, leading to a negative impact on the environment.

Therefore, the present study focused on evaluating the influence on the mechanical properties of masonry concrete blocks made with recycled glass and paper particles.

2. Materials and Methods

2.1 Used Material

2.1.1 Aggregates

To produce concrete blocks in this research, the following materials were used: Sand extracted from La Victoria - Pátapo, Lambayeque, and crushed Stone obtained from Tres Tomas - Ferreñafe, Lambayeque.

Table 1 *Physical Properties*

	MATERIAL		UND
Moisture Content	Sand	1.54	%
	Crushed Stone	0.37	%
Specific weight	Sand	2622	kg/m3
	Crushed Stone	2718	kg/m3
Absorption	Sand	0.92	%
	Crushed Stone	0.69	%
loose unit weight	Sand	1578	kg/m3
	Crushed Stone	1366	kg/m3
Compacted Unit Weight	Sand	1782	kg/m3
	Crushed Stone	1537	kg/m3

2.1.1 Glass Particles and Recycled Paper

The glass and paper used in this study were obtained through recycling processes. For the glass, waste from glassware and discarded bottles was collected without restrictions regarding their shape, size, or color, to have a wide range of options when selecting the material. Similarly, the paper used was collected from waste generated in printing shops, offices, and bookstores.

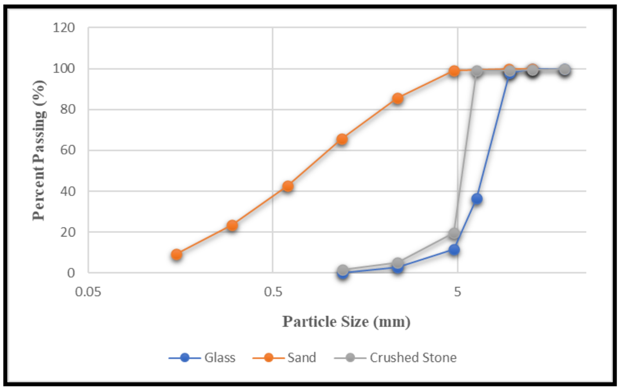

Fig. 1 *Granulometric Distribution*

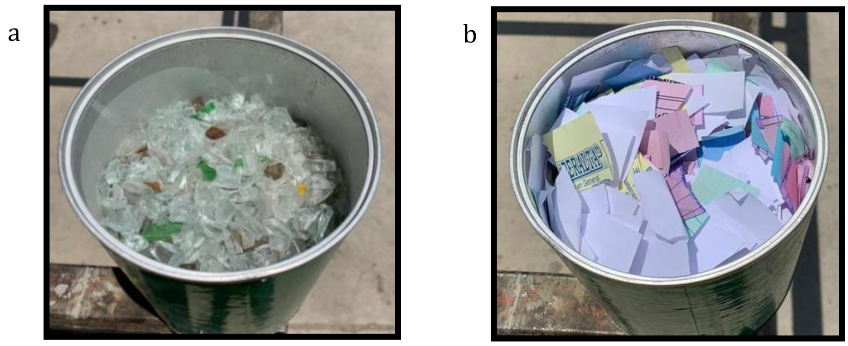

Fig. 2 *Glass particles (a), recycled paper (b)*

2.2 Mix Design

Table 2 *Mix proportion used for specimens*

Material	Quantity	Units
Cement	323	Kg/m3
Sand	708	Kg/m3
Crushed Stone	1067	Kg/m3

Water	263	Lts/m3

Table 3 *Glass and paper additions to the concrete mix*

Additions	Material	Quantity	Units
1% paper + 2% glass	Glass particles	49	Kg/m3
	Recycled paper	8	Kg/m3
2% paper + 4% glass	Glass particles	95	Kg/m3
	Recycled paper	11	Kg/m3
3% paper + 6% glass	Glass particles	141	Kg/m3
	Recycled paper	13	Kg/m3

2.3 Specimen Preparation

The collection of glass and paper was carried out, which were subsequently subjected to washing, ventilation, and drying processes. Then, they were crushed. After that, tests were conducted on the aggregates, and a mix design was developed to produce concrete blocks with additions of 0%, 3%, 6%, and 9% of recycled glass and paper particles.

Subsequently, the manufacturing and curing of the concrete blocks were carried out, along with the creation of test specimens (concrete blocks arranged in stacks and walls) to measure axial and diagonal compression strength. Subsequently, tests for dimensional variation, absorption, and warpage were conducted using 3 blocks from each addition (0%, 3%, 6%, and 9%). Additionally, compression strength tests were performed on the blocks at 7 and 28 days for each percentage used. Furthermore, the compression strength of the blocks arranged in stacks and walls with the same percentages of recycled glass and paper particles was evaluated, but at a 28-day age.

It should be noted that all these tests were conducted in accordance with the corresponding regulations, which are detailed in the following table.

Table 4 *Test standards*

Properties	Testing	ASTM International	Peruvian standard
Physical	Dimensional variation	ASTM C90/C90M	NTP – 399.604
	Absorption	ASTM C140/C140M	NTP – 399.604
	Warpage	ASTM C90/C90M	NTP – 399.604
Mechanical	Compressive Strength (f'b)	ASTM C90/C90M	NTP – 399.613
	Axial compressive strength (f'm)	ASTM C1314-23	NTP – 399.613
	Diagonal compression strength (v'm)		NTP – 399.621

2.4 Specimens

According to ASTM C140 or NTP 399.604 standard, it is stipulated that for conducting tests on concrete blocks, 6 samples should be selected for every 10,000 units, and 12 units for a batch larger than 10,000. In this case, as it is small-scale research it was decided to take 3 units for each age. Therefore, the sampling of the specimens to be tested is detailed in Table 5.

Table 5 *Specimens*

Concrete block properties	Testing	Additions				Number of specimens
		0%	3%	6%	9%	
Physical	Dimensional variation	3	3	3	3	12
	Absorption	3	3	3	3	12
	Warpage	3	3	3	3	12
Mechanical	Compressive Strength (f'b)	6	6	6	6	24
	Axial compressive strength (f'm)	9	9	9	9	36
	Diagonal compression strength (v'm)	24	24	24	24	96
				Total:		**192**

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2.5 Formulas and Equations

2.5.1 Dimensional Variation

Equation 1 - Calculation of dimensional variation $$V\% = \frac{\sigma}{Lp}$$	(1)

Where:

V%: Coefficient of variation [%]

σ: Standard deviation [Kg]

Lp: Average length

2.5.2 Absorption

According to the E 0.70 standard, concrete blocks must contain a maximum absorption value of 12%

Equation 2 - Absorption calculation $$Abs = \frac{P_{sat} - P_{sec}}{P_{sec}} \times 100$$	(2)

Where:

Abs: Absorption percentage [%]

Psat: Saturated weight [Kg]

Psec: Dry weight [Kg]

2.5.3 Compressive Strength (f'b)

Standard E070 states that the minimum strength requirement for concrete blocks is 4.5MPa (50 kg/cm2).

Equation 3 - Compressive strength calculation f'b $$f'b = \frac{F}{A}$$	(3)

Where:

F: Maximum load [Kg]

A: Concrete block area [cm2]

2.5.4 Axial Compressive Strength (f'm)

Standard E070 specifies that the minimum strength requirement for concrete piles is 7.3 MPa (74 kg/cm2).

Equation 4 - Compressive strength calculation f'm $$f'm = \frac{F}{A} \times f$$	(4)

Where:

F: Maximum load [Kg]

A: Concrete block area [cm2]

f: Slenderness correction factor

Esbeltez	2.0	2.5	3.0	4.0	4.5	5.0
Factor (f)	0.73	0.80	0.91	0.95	0.98	1.00

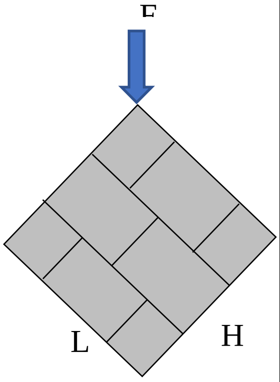
2.5.5 Diagonal Compression Strength (V'm)

Standard E070: According to this standard, the required strength to be achieved is 0.8 MPa (8.6 kg/cm2).

Equation 5 - ***Compressive strength calculation V'm***

$$v'm = \frac{F}{A}$$

$$A = \left(\sqrt{L^2 + H^2}\right) \times t \qquad (5)$$



Where:

F: Maximum load [Kg]
A: Wall area [cm2]
f: Slenderness correction factor

Wall dimensions:

L: long [cm]
H: High [cm]
t: thickness [cm]

3. Results

3.1 Physical Properties of Concrete Masonry Blocks

3.1.1 Dimensional Variation

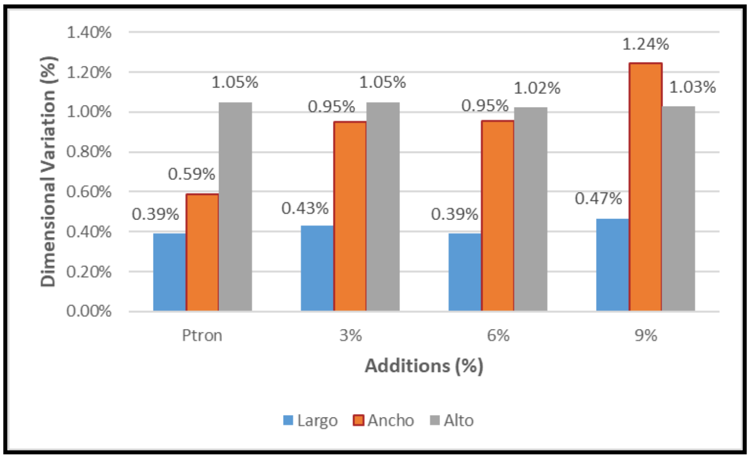


Fig. 2 *Dimensional variation results*

Interpretation

According to standard E070, a concrete block must not exceed the established maximum percentages of ±4 in height, ±3 in width, and ±2 in length. Likewise, the variation values presented in Figure 3 do not exceed the percentages established in the regulations. On the other hand, it can be observed that the width dimensions of the blocks increase as the additions of 3%, 6%, and 9% of glass and paper particles are used, with the 9% addition showing the highest variation (1.24%).

3.1.2 Warpage

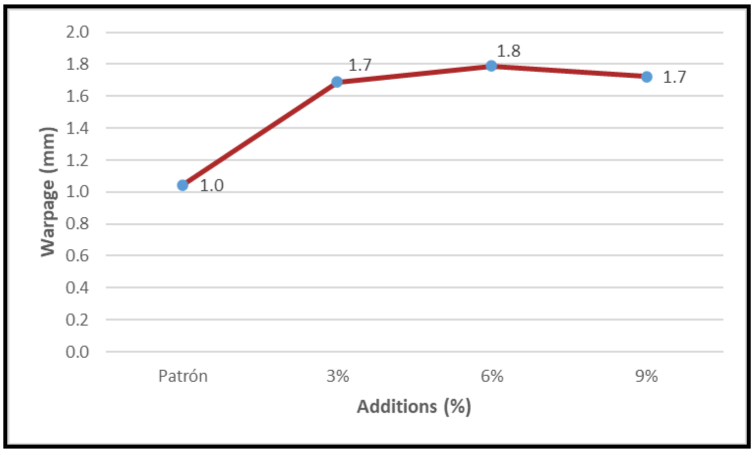


Fig. 3 *Warping results*

Interpretation

According to standard E070, the maximum allowable value for warping is 4mm. Therefore, according to Figure 4, the standard sample has a warping of 1.0mm. Similarly, the samples with additions of 3%, 6%, and 9% of recycled glass and paper have warpings of 1.7mm, 1.8mm, and 1.7mm respectively, all of which are below the maximum value established in the Peruvian regulations. From this, it can be concluded that the warping value increases when glass and paper are added, with the 6% sample having the largest dimension.

3.1.3 Absorption

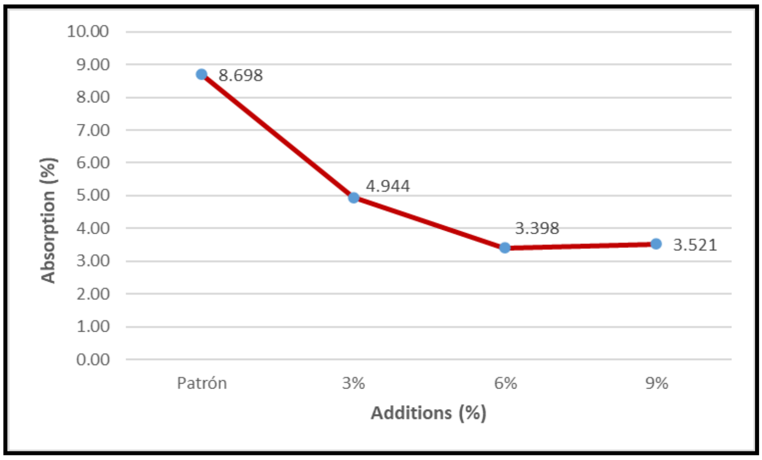


Fig. 4 *Absorption results*

Interpretation

The E070 standard states that the maximum absorption value for masonry concrete blocks is 12%. As a result, Figure 5 shows that none of the presented values exceed the mentioned limit, as the maximum absorption value obtained was from the standard sample (8.698%), while the samples with additions of 3%, 6%, and 9% obtained values of 4.94%, 3.398%, and 3.52% respectively.

3.2 Mechanical Properties of Concrete Masonry Blocks

3.2.1 Compressive Strength (f'b)

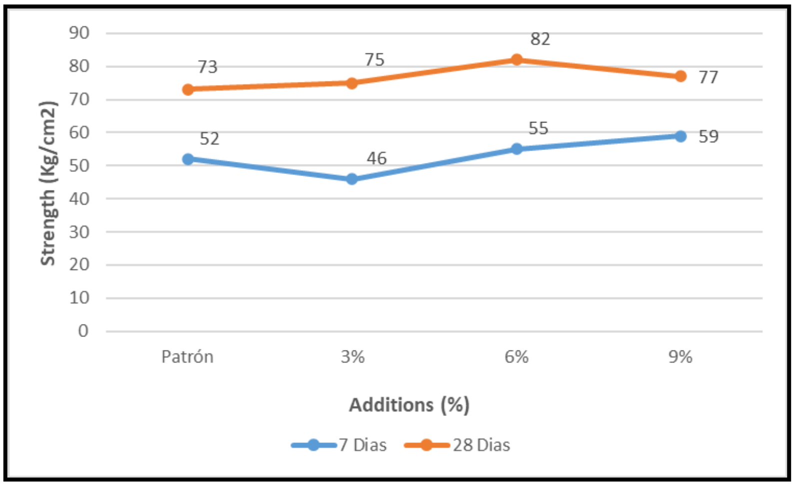


Fig. 5 *Compressive strength results*

Interpretation

The Peruvian Standard E070 states that masonry concrete units must withstand a minimum pressure of 50 kg/cm2. In Figure 6, it is evident that both the standard sample (73 kg/cm2) and the samples with additions of 3%, 6%, and 9% (75 kg/cm2, 82 kg/cm2, 77 kg/cm2) significantly exceed this value. The sample with a 3% addition obtained the highest value, surpassing the minimum value by 64% and the standard sample by 12.33%.

3.2.2 Axial Compressive Strength (f'm)

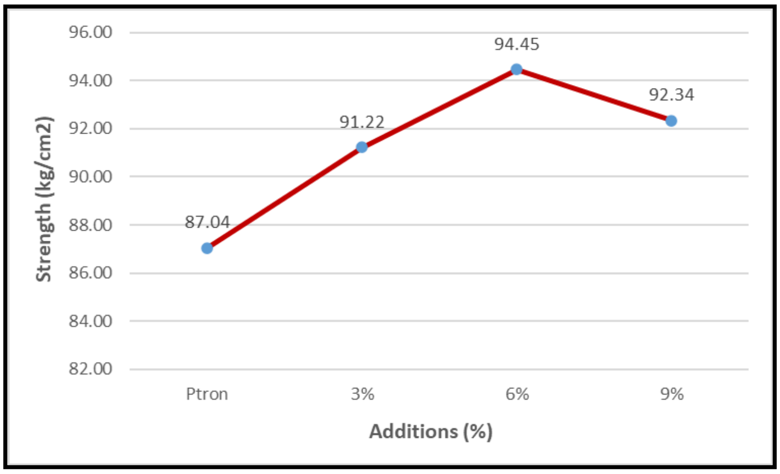


Fig. 6 *Compressive strength results*

Interpretation

According to the Peruvian Standard E070, masonry prisms made of concrete must withstand a minimum pressure of 74 kg/cm2. As shown in Figure 7, both the standard sample (87.04 kg/cm2) and the samples with additions of 3%, 6%, and 9% (91.22 kg/cm2, 94.45 kg/cm2, 92.80 kg/cm2) exceed this value. The sample with a 6% addition achieved the highest value, surpassing the minimum requirement by 27.63% and the standard sample by 8.51%.

3.2.3 Diagonal Compression Strength (v'm)

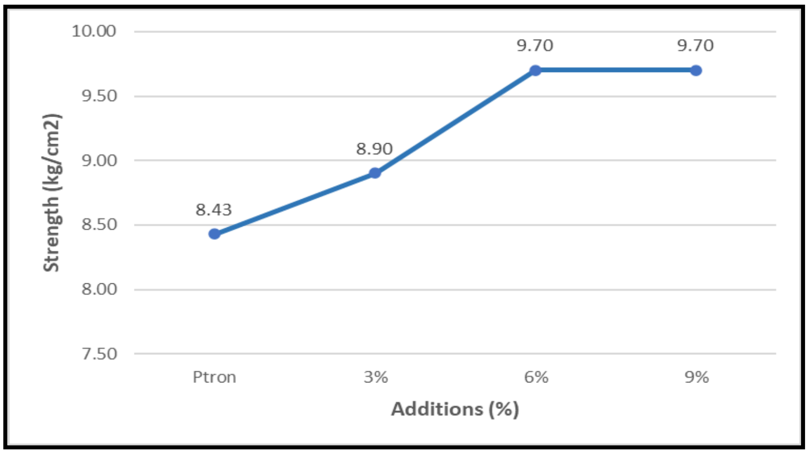


Fig. 7 *Compressive strength results*

Interpretation

The Peruvian Standard E070 states that masonry walls made of concrete must withstand a minimum pressure of 8.6 kg/cm2. Figure 8 shows that the samples with additions of 3%, 6%, and 9% (8.90 kg/cm2, 9.70 kg/cm2, 9.70 kg/cm2) exceed this value. The samples with 6% and 9% addition obtained the highest value, surpassing the minimum requirement by 12.79%.

3.2.4 Block Cost

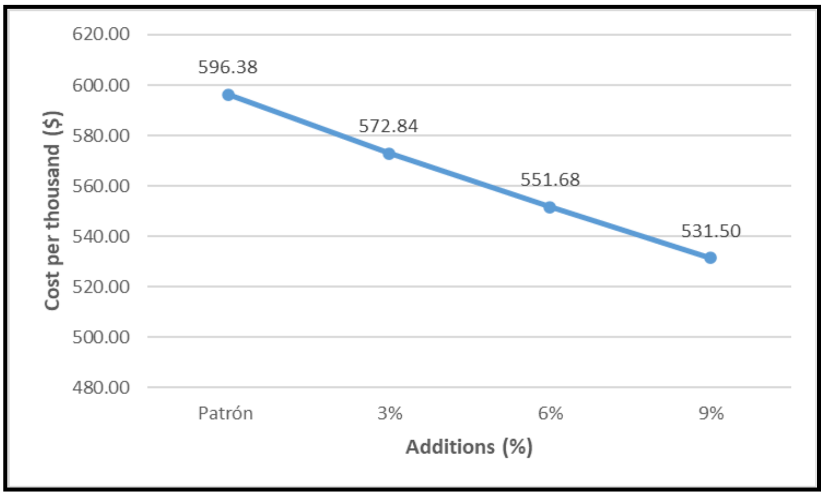


Fig. 8 - *Manufacturing cost of concrete blocks in dollars*

Interpretation

As can be seen in Figure 9, the manufacturing cost of concrete blocks with different additions decreases as the percentage of addition increases. However, the addition of 9% glass + paper has obtained the lowest value, being $64.88 lower than the standard sample.

3.2.5 Optimum Percentage of Addition of Glass Particles and Recycled Paper (3%, 6% Or 9%), With Respect to Manufacturing Cost and Resistance

Table 6 *Optimal percentage*

Strength \ Addition	No addition	3%	6%	9%
F'b	73.00	75.00	82.00	77.00
F'm	87.04	91.22	94.45	92.34
V'm	8.43	8.90	9.70	9.70
Cost ($)	596.38	572.84	551.68	531.50

Interpretation

The three different additions used in this research successfully exceed the established Peruvian regulations for masonry concrete blocks. However, it can be observed that the best percentage of addition in terms of strength is the 9% glass + recycled paper, as it satisfies the parameters of the standard and significantly reduces the manufacturing cost.

4. Discussion

The comparison of the results obtained from the research carried out with the background is presented.

4.1 Physical Properties of Concrete Masonry Blocks

Table 7 *Comparison of physical properties*

Author	Material	Additions (%)	Research data
This investigation	Glass + Paper	0%, 3%, 6% y 9%	**Dimensional variation (%)** L.A.H: 0.39, 0.59, 1.05 L.A.H: 0.43, 0.95, 1.05 L.A.H: 0.39, 0.95, 1.02 L.A.H: 0.47, 1.24, 1.03 **Warpage (mm)** 1.0, 1.7, 1.8, 1.7 **Absorption (%)** 8.7, 4.95, 3.4, 3.52
(Burgos, 2020)	Crushed glass	0%, 5%, 10%, 15% y 20%	**Dimensional variation (%)** L.A.H: 0.15, 0.56, 0.61 L.A.H: 0.11, 0.75, 1.31 L.A.H: 0.11, 0.73, 1.46 L.A.H: 0.10, 0.75, 1.30 L.A.H: 0.11, 0.75, 1.44 **Warpage (mm)** 1.30, 1.43, 1.33, 1.43, 1.58 **Absorption (%)** 8.66, 8.37, 8.02, 7.32, 6.49

In table 7, the dimensional variation results from (Burgos, 2020) show similar values to the results of the current research.

On the other hand, the warping increases when recycled material is added, but this increase is not significantly high, which is consistent with the results as shown in table 7.

The results presented by (Burgos, 2020) in Table 7 reveal a decreasing trend in the absorption values as the amount of recycled glass and paper increases. However, it is important to note that the observed reductions are relatively small. The results of this research align with the decrease in absorption, but in a significant manner, going from 8.7% in the standard sample to a value of 3.52% when a combination of 9% glass and paper is added.

4.2 Mechanical Properties of Concrete Masonry Blocks

Table 8 *Compressive Strength Comparison*

Author	Material	Additions (%)	Research data
This investigation	Glass + Paper	0%, 3%, 6% y 9%	73.00, 75.00, 82.00, 77.00 Kg/cm2
(Almengor, Gutiérrez, Moreno & Caballero, 2017)	Glass + Paper	100%	23.53 Kg/cm2
(Burgos, 2020)	Crushed glass	0%, 5%, 10%, 15% y 20%	60.15, 71.23, 74.50, 80.17, 82.39 Kg/cm2
(Rubio y Toscano, 2021)	Crushed glass	10%, 15%, 20% y 30%	35.38, 46.91, 52.62, 34.26 y 48.84Kg/cm2
(Acuña & Quispecondori 2021).	Recycled paper	0%, 5%, 10%, 15%, 20% y 25%	72.88, 71.03, 58.25, 7.81, 6.39, 5.22 Kg/cm2

(Burgos, 2020) and (Rubio & Toscano, 2017) indicate that the higher the addition of crushed glass, the greater the obtained strength, which is consistent with the results of this research. On the other hand, (Acuña & Quispecondori, 2021) state that when using only recycled paper, the strength decreases, as it would not meet the minimum requirements established in their regulations. Therefore, by using both materials together in proportions of 3%, 6%, and 9%, the strength increases.

In the study conducted by (Almengor, Gutiérrez, Moreno & Caballero, 2017), the traditional aggregates were completely replaced by glass + paper in the mix. However, only 55.6% of the minimum required strength was achieved. Nevertheless, by adding glass + paper in proportions of 3%, 6%, and 9% relative to the total volume, the minimum parameters necessary to be used in load-bearing walls were met, reaching a minimum strength of 75 kg/cm2.

4.2.1 Block Cost

Table 9 *Concrete block manufacturing cost comparison*

Author	Material	Research data (Unit cost)	
		UC. No addition (Block)	UC. Investigation (Block)
This investigation	Glass + Paper	0.68 Usd/und	0.53 Usd/und
(Sandoval, 2020)	Recycled paper	0.81 Usd/und	0.79 Usd/und
(Acuña & Quispecondori 2021).	Recycled paper	0.71 Usd/und	0.62 Usd/und
(Rubio & Toscano, 2017)	Crushed glass	0.35 Usd/und	0.64 Usd/und

In the study conducted by (Sandoval, 2020) and (Acuña & Quispecondori, 2021), as shown in Table 9, it is indicated that the addition of recycled materials to the concrete block mixture reduces the manufacturing cost compared to blocks without additives, which is consistent with the results of this research.

Furthermore, regarding the information presented in Table 9, the study conducted by (Rubio & Toscano, 2017) indicates that the manufacturing cost of concrete blocks with crushed glass addition increases by 82.68% compared to the reference sample. This increase is attributed to the use of specialized machinery for glass crushing. Therefore, this research significantly differs from this finding, showing a manufacturing cost decrease of 22.05% compared to the sample without additives, emphasizing that no specialized machinery was used for glass crushing.

5. Conclusion

After analyzing the physical properties of the concrete blocks, a maximum dimensional variation of 0.47%, 1.24%, and 1.05% was recorded for the length, width, and height dimensions, respectively. Additionally, the warping exhibited a value of 1.0 mm for the reference sample and slightly increased by 0.7 mm, 0.8 mm, and 0.7 mm for the samples with additions of glass and recycled paper particles at 3%, 6%, and 9%, respectively. Regarding the absorption capacity of the masonry units, a value of 8.7% was observed for the sample without additives, progressively decreasing as the amount of added recycled materials increased, obtaining values of 4.95%, 3.4%, and 3.52% for the samples with additions of 3%, 6%, and 9% of glass and recycled paper particles, respectively. In conclusion, it can be stated that the addition of glass and recycled paper particles has had a positive effect on the physical properties of the concrete blocks, as all obtained values fall within acceptable limits.

Regarding the mechanical properties, it was observed that the compressive strength per masonry unit varied significantly depending on the amount of glass and recycled paper particles added. Specifically, the reference sample exhibited a compressive strength of 73 kg/cm2, while the samples with additions of 3%, 6%, and 9% experienced an increase of 2.74%, 12.33%, and 5.48%, respectively. In the case of masonry prisms, the sample without additions displayed a compressive strength of 87.04 kg/cm2, while the samples with additions experienced an increase of 4.80%, 8.51%, and 6.09%, respectively. Lastly, regarding diagonal compressive strength, it was found that the reference sample exhibited a strength of 8.43 kg/cm2, whereas the samples with additions recorded an increase of 5.58%, 15.07%, and 15.07%, respectively. In conclusion, it can be affirmed that the inclusion of glass and recycled paper particles in the concrete mixture for masonry unit production has a positive impact on their mechanical properties.

Regarding the conducted economic analysis, it was determined that the manufacturing cost of a concrete block without additions amounts to 0.60 USD. However, in the case of blocks that incorporate glass and recycled paper particles in the concrete mixture in proportions of 3%, 6%, and 9%, a decrease in production costs of 5%, 8.33%, and 11.67% was observed, respectively. Therefore, it can be concluded that the incorporation of these recycled materials in the production of concrete blocks is economically viable and beneficial for the construction sector.

Upon analyzing the compressive strength and production cost of concrete blocks with different quantities of recycled glass and paper particles, it has been concluded that the optimal addition is 9% (6% glass and 3% paper). This ratio provides a compressive strength, masonry axial compressive strength, and diagonal compressive strength of 77Kg/cm2, 92.34Kg/cm2, and 9.70 Kg/cm2, respectively. Additionally, the manufacturing cost of the blocks is 0.53 USD, resulting in a savings of 11.67% compared to the sample without additions.

In a general conclusion, it can be stated that adding glass and recycled paper particles in the manufacturing of concrete blocks for use in load-bearing masonry walls has a positive influence on the physical and mechanical properties of the blocks. Additionally, it allows for a reduction in manufacturing costs, leading to significant savings for builders.

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