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Evaluation of the Physical and Mechanical Properties of Concrete Blocks Prepared with Partial Replacement of the Aggregate by Sand and Silica Powder

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Abstract: This study aimed to evaluate the influence of silica sand and dust on the concrete mix used to make blocks. Fourteen blocks were manufactured with 20% silica sand replacing the natural aggregate and 15% silica dust, in addition to 14 blocks using a standard mix. Each sample underwent tests established in COVENIN 42-82 Standard at 28 and 90 days to evaluate its physical and mechanical properties. One of the physical properties evaluated was dimensional stability; the results were similar for both samples, since they were manufactured under the same conditions and the silica did not affect their dimensions. The other physical property is the absorption capacity of the blocks, which gave similar results at 28 days between the two samples and at 90 days registering an increase in the Pattern sample with an average of 8.54% and a decrease in the silica sample with an average of 7.05%, all complying with the range established by the Venezuelan COVENIN 42-82 Standard. The mechanical property evaluated was compressive strength, at 28 days the Pattern sample did not reach the minimum accepted strength while the sample with silica did reach said standard, and at 90 days the Pattern sample maintained the recorded strength while the sample with silica increased its values.

Key words: concrete; reinforced concrete; concrete blocks; silica sand; silica powder

1. Introduction

The construction industry has been incorporating various types of products, seeking to improve the properties of construction elements, most of which come from nature with the premise of taking advantage of available resources and achieving a balance of using the already established with the new, thus seeking to innovate with new products without neglecting the concept of sustainable design. Silica sand is a by-product of industries, so it is obtained at low cost and when mixed with cement, it provides greater resistance to the mixture. Although it meets the requirements, it remains for the researchers to evaluate its dosage in the mix, as well as its advantages and disadvantages in the mechanical and physical properties. To this effect, this research sought to determine the influence on the mechanical and physical properties of concrete blocks by introducing sand and silica powder in the mixture, carrying out a series of tests pre-established in the COVENIN 42-82 Standard [1], such as dimensional stability, compressive strength and absorption.

2. Development

It is essential to consider the efficient use of available resources as one of the key principles when developing materials used in construction. This raises the need to investigate the true technological and expressive possibilities of construction systems, in order to ensure their proper management, both in terms of resilience and comfort and maintenance. Likewise, it is important to consider cultural variables for the acceptance of the technologies used, since resistance to change has been one of the main factors in the failure to implement proposals that are not yet very efficient, and have failed to be included in popular construction techniques [2].

2.1 Hollow concrete blocks according to COVENIN 42-82 Standard

A hollow block is a simple element in the shape of an orthogonal parallelepiped, with perforations parallel to some of the edges, obtained by molding the concrete, for use in construction as masonry. On the other hand, the design must be based on sustainability, noting that this means creating physical objects from the micro to the macro level, based on the idea of economic, social, and ecological sustainability [3]. The blocks are classified according to the COVENIN 42-82 Standard as specified in Table 1.

Table 1. Classification of concrete blocks according to COVENIN 42-82 Standard(Source: [1])

According to	Types	Identification
Aggregates	Heavy	Manufactured with normal aggregates. The unit weight of dry concrete is greater than 2000 kg/m^3.
	Medium-heavy	Manufactured with lightweight and normal aggregates. The unit weight of dry concrete is between 1400 kg/m^3 and 2000 kg/m^3.
	Light	Manufactured with lightweight aggregates. The unit weight of dry concrete is less than 1400 kg/m^3.
Use	Type A	Concrete blocks for load-bearing walls, whether or not exposed to moisture. Class A1: For exterior walls, below or above ground level and exposed to moisture. Class A2: For exterior walls, below or above ground level and not exposed to moisture.
	Type B	Blocks for non-load-bearing walls or partition walls. Class B1: For walls exposed to moisture. Class B2: For walls not exposed to moisture.

2.2 Requirements for blocks according to COVENIN 42-82 Standard

According to their appearance and finish, they must be solid and free of cracks, except for those listed below:

For type A blocks: They must not present cracks parallel to the load. If imperfections appear, they must not exceed 5% of the order, as long as the cracks perpendicular to the load that appear are no longer than 2.5 cm.

For type B blocks: Minor cracks produced during manufacturing or fragments produced during handling may be present.

According to their dimensions, they are specified in Table 2.

Table 2. Classification of concrete blocks according to their dimensions (Source: [1])

Ordinary denomination (cm)	Normal dimensions (cm^3)	Modular dimensions (cm^3)
10	39 ×19 × 9	40 × 20 × 10
15	39 × 19 × 14	40 × 20 × 15
20	39 × 19 × 19	40 × 20 × 20
25	39 × 19 × 24	40 × 20 × 25
30	39 × 19 × 29	40 × 20 × 30

The minimum thickness that blocks must have is specified as shown in Table 3, where the maximum tolerance in any dimension is 0.3 cm.

Table 3. Classification of concrete blocks according to their thickness (Source: [1])

Type	Denomination (cm)	Wall thickness (cm)	Thickness of ribs (cm)
A	10	1.9	1.9
	15	2.2	2.2
	20	2.5	2.5
	25	2.8	2.8
	30	3.2	2.8
B	10	1.3	1.3
	15	1.5	1.5
	20	1.7	1.7
	25	1.9	1.9
	30	2.2	1.9

Now, based on the maximum water absorption determined in the test for each type of block, the values are specified in Table 4.

Table 4. Classification of concrete blocks according to water absorption (Source: [1])

Block type	Heavy %	Light heavyweight %	Light %
A1 – A2 and B1	14	16	12
B2	It does not have an absorption test		20

According to the minimum compressive strength at 28 days after manufacture, it is indicated in Table 5.

Table 5. Classification of concrete blocks according to compressive strength (Source: [1])

Block Type	Average 3 blocks (kg/cm^2)	Minimum 1 block (kg/cm^2)
A1	70	55
A2	50	40
B1 – B2	30	25

The blocks, after being cured using approved methods, have a compressive strength equal to or greater than 80% of the values indicated in the table.

3. Methodology

The purpose of this research was to determine the influence of adding sand and silica powder to the concrete block preparation mix. This was done in order to analyze the mechanical and physical properties of the concrete blocks. These tests were performed according to the COVENIN 42-82 Standard, such as dimensional stability, compressive strength, and absorption. The sample consisted of 28 hollow concrete blocks with a thickness (e) of 15 cm; 14 samples were made with the standard mix and 14 with the addition of silica.

3.1 Block manufacturing process

Type I Portland cement, washed sand, 20% silica sand, silica powder, and 15% silica powder, and water were used to make the concrete blocks. To manufacture the blocks, the concrete mix is initially prepared with the respective dosages. Then, using a vibro-compactor, also known as a block layer, the mixture is poured into the mold. A lever is used to remove the mold and obtain the blocks. This process takes approximately 25 seconds per demolding. The machine makes approximately 6 batches for a 0.45 m^3 mix, which would be approximately 48 blocks. Approximately 6,500 blocks are produced in an 8-hour workday.

The machine has two 2HP electric motors to move the vibratory process, one 7HP motor that drives the hydraulic pump to move the hydraulic jacks of the mold and one 7HP motor to move the machine, it uses 220 three-phase current.

Figure 1. Concrete block manufacturing process. (Source: the authors)

3.2 Test methods

For the dimensional stability test, all block dimensions established in COVENIN 42-82 Standard were measured using a vernier caliper. These dimensions were length, height, width, and thickness. The method for determining compressive strength was established in the same standard, which indicates that the testing machine must have sufficient load application capacity to cause the specimens to break. It must have two steel plates with a smooth surface and a diameter of 15 cm. "Additional steel plates with a hardness of not less than 60 rc, with a thickness of 1/3 of the distance between the edge of the load plate and the farthest corner of the test block" [1]. The blocks are placed so that the loads are applied in the same direction as the loads or dead weight to which they will be subjected in the construction.

They were also subjected to the absorption test according to the parameters established by the standard, requiring equipment such as: a furnace, scale, containers, and supports, as well as the materials necessary to carry out the test according to routine procedures. The samples were immersed in water for 24 hours at a temperature ranging from 15°C to 27°C. The samples were then extracted, dried, and immediately weighed. They were then placed in the oven where they remained for a minimum of 24 hours at a temperature of 100°C to 115°C. They were then weighed until two successive weighings at 2-hour intervals showed no weight loss greater than 0.2% of the previous weight.

4. Results and Discussion

4.1 Block dosing

The blocks were prepared following the procedures outlined in COVENIN 42-82 Standard. 28 blocks were manufactured, 14 based on the Pattern mix, and the rest with the incorporation of silica sand replacing the natural sand by 20% and the addition of 15% silica powder, taking into account that it is based on the original dosage of the La Bloquera block factory located in the city of Barquisimeto, provided by them, Table 6 shows the dosages of each of the materials in the mix.

Table 6. Block dosage

Sample	Arena natural (kg)	Cement (kg)	Silica powder (kg)	Silica sand (kg)	Water (lt)
Standard sample (Silica-free)	320	20	0	0	12
Sample with the addition of 15% silica powder and 20% replacement of natural sand with silica sand	256	20	3	64	12

4.2 Determination of dimensional stability

The graph in Figure 2 shows that the difference between the two samples is minimal in terms of their dimensions. Compared to the standard tolerance of 0.3 cm, the length and height dimensions comply with the standard, excluding the width, which does not. Therefore, it can be said that silica does not affect the volumetric change and, consequently, its dimensional stability.

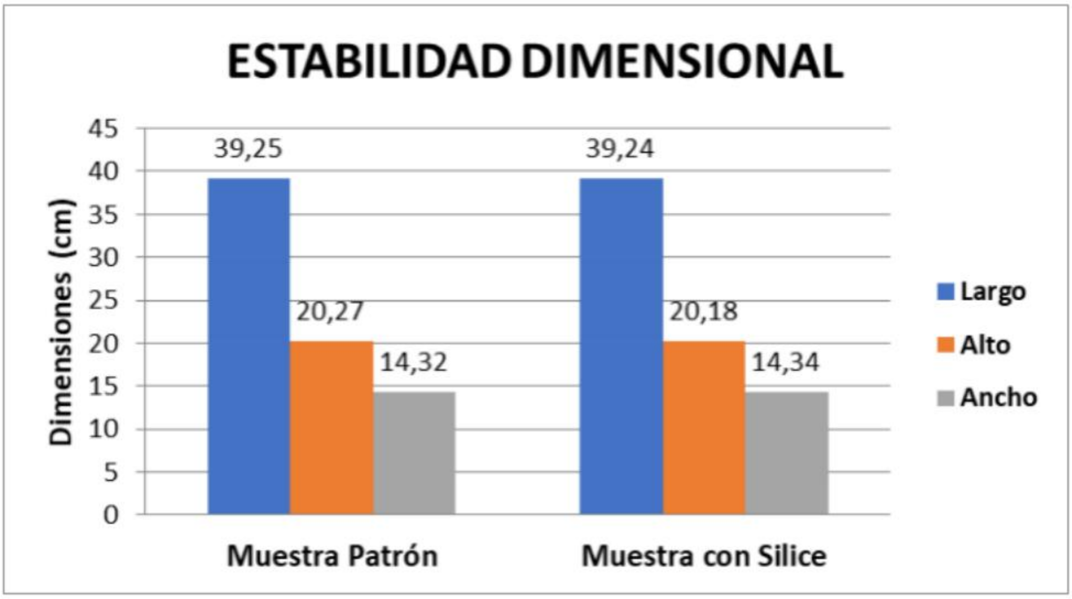

Figure 2. Comparison of the dimensional stability of the block samples. (Source: the authors)

4.3 Evaluation of compressive strength in blocks

The compressive strength test was performed in the Laboratory of the Dean's Office of Civil Engineering at the Universidad Centroccidental Lisandro Alvarado, using a hydraulic press to determine the ultimate compressive load supported. The test was performed on seven blocks of each sample after 28 days, since the concrete is expected to develop 100% of its strength within that period, and after 90 days because silica reacts more slowly to improve strength during that period. The compressive strength is determined according to expression (1) as established by COVENIN 42-82 Standard.

$$\text{Rc} = \frac{\text{Ultimate load (kg)}}{\text{Gross section (cm}^2\text{)}} \quad (1)$$

The comparison of the results obtained is reflected in the graph represented in Figure 3. It is observed that the maximum value obtained was 20.78 kg/cm^2 and the minimum was 10.64 kg/cm^2, obtaining an average of 15.20 kg/cm^2, so that only one of the samples complies with the range accepted by the COVENIN 42-82 Standard.

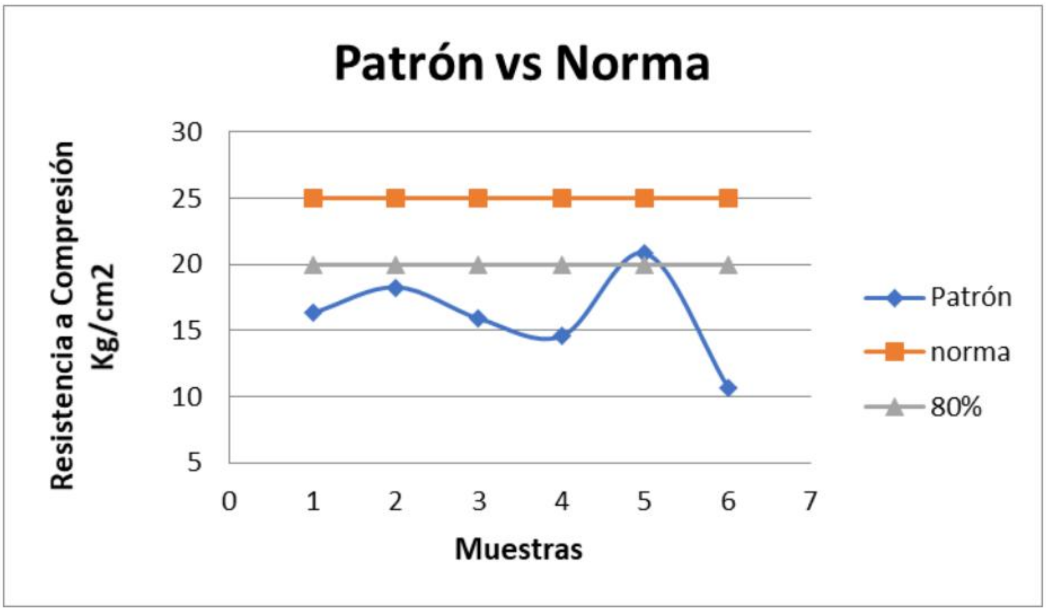

Figure 3. Comparison of the 28-day compressive strength of the Pattern vs Normal samples.
(Source: the authors)

In the graph shown in Figure 4, it can be seen that, for compressive strength at 28 days for the sample with silica incorporation, a peak of 31.63 kg/cm^2 and a minimum of 19.47 kg/cm^2 were obtained, obtaining an average of 21.63 kg/cm^2.

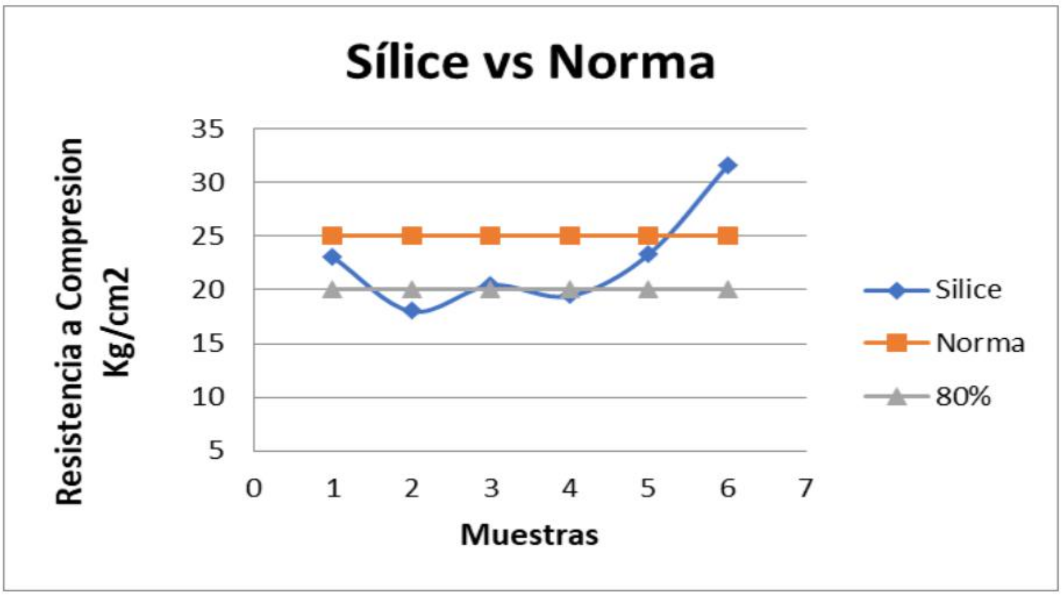

Figure 4. Comparison of the 28-day compressive strength of silica-coated samples versus standard samples.
(Source: the authors).

Unlike the standard sample, in the sample with silica incorporation, four values met the range established by the COVENIN 42-82 Standard, and three samples did not, although the average of all samples did. This is because silica sand is harder and the powder is more absorbent, making the mix more compact, filling in the voids, and resulting in stronger blocks.

4.4 Average compressive strength comparison at 28 and 90 days

The graph in Figure 5 compares the compressive strength of the samples at 28 days. It can be seen that the Pattern sample was quite far from the value accepted by the Standard, unlike the silica sample, which exceeded the minimum value. The high strength values achieved with the addition of sand and silica powder are due to the fact that these grains are finer and harder than cement, filling the empty spaces in the mixture and achieving greater compaction, as well as the contribution of silica powder with its pozzolanic properties.

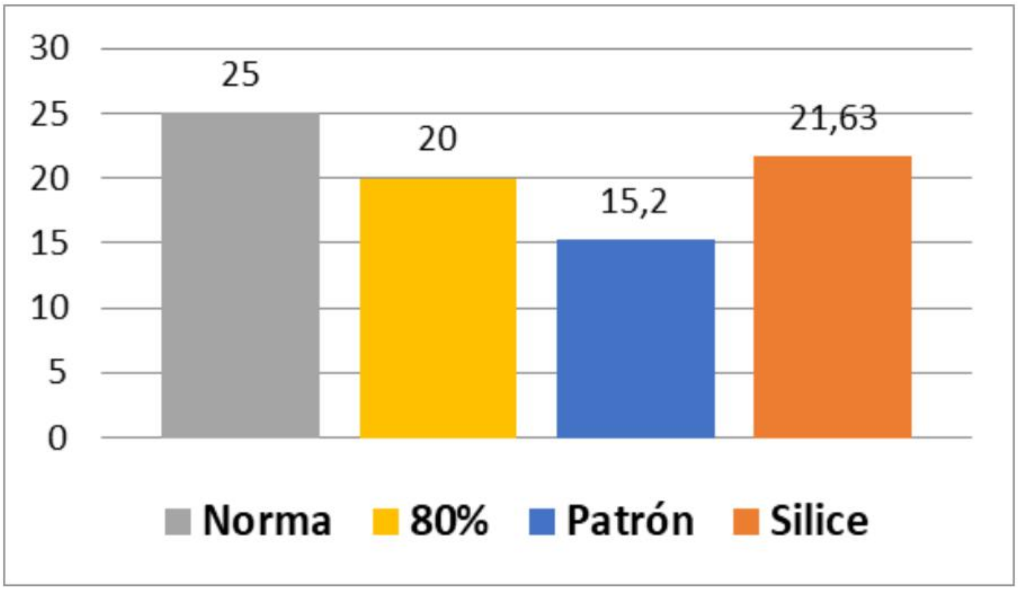

Figure 5. Comparison of the compressive strength of the samples at 28 days. (Source: the authors)

Below are the results of compressive strength at 90 days (see Figures 6 and 7). The values shown indicate that the compressive strength in the Pattern sample remained below 20 kg/cm^2, failing to comply with the provisions of the COVENIN 42-82 Standard. While the blocks with silica incorporation showed a considerable increase in compressive strength due to slower reactions, registering an average of 22.46 kg/cm^2, all values except two meet the minimum value accepted by the COVENIN 42-82 Standard.

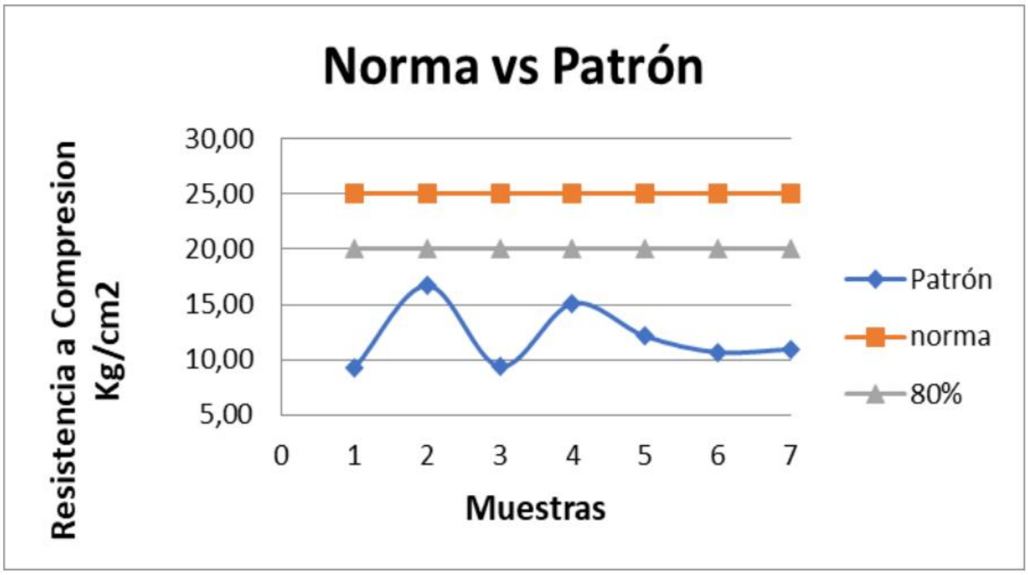

Figure 6. Comparison of the 90-day compressive strength of the Pattern vs. Standard samples. (Source: the authors).

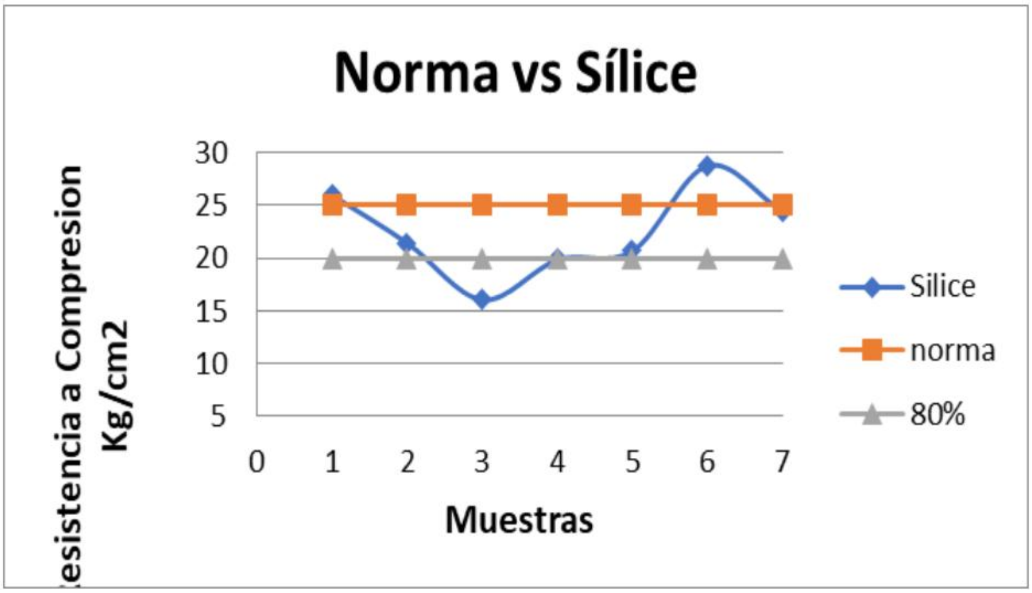

Figure 7. Comparison of 90-day compressive strength of silica-coated samples versus standard samples. (Source: the authors).

The comparisons at 90 days shown in Figure 8, record that the compressive strength values of the Pattern sample remained below the range established by the COVENIN 42-82 Standard. Unlike the sample with the incorporation of silica, the performance of this sample has increased beyond the value specified in the standard and meets the requirements. The reason for this situation is that the reactivity of silica is slow, the shape of silica sand particles is irregular and harder, and silica powder absorbs more water, thereby delaying the solidification process. Therefore, it takes longer to reach its maximum strength, which is why the strength increases within 90 days.

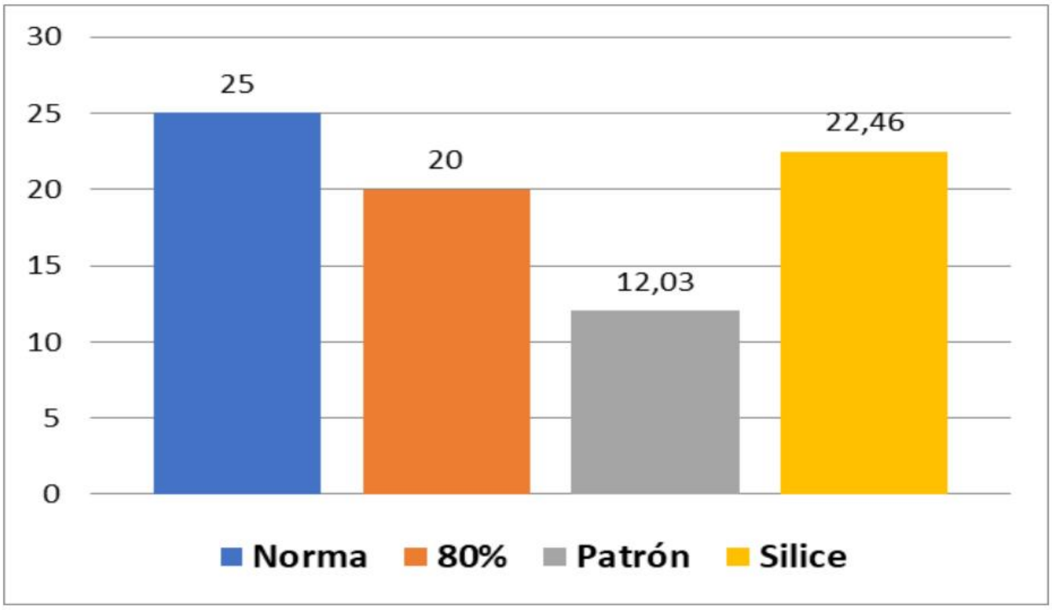

Figure 8. Comparison of the 90-day compressive strength of the samples. (Source: the authors).

4.5 Evaluation of the absorption capacity of the blocks

The blocks subjected to the absorption capacity test were weighed according to the instructions in section 5.1 of COVENIN 42-82 Standard. The tests were conducted in the UCLA Civil Engineering Laboratory using the oven and the pool. Three pieces of blocks from each sample were immersed in the pool for 24 hours at a temperature of approximately 20°C. After this period, they were removed and dried. Their weight was recorded. They were then placed in an oven at a temperature of approximately 100°C for 24 hours, and their dry weight was subsequently recorded, as established by COVENIN 42-82 Standard. The values obtained for the samples after 28 days are shown below (see Figure 9). There was little difference between the absorption values of both samples, demonstrating that the addition of silica does not significantly affect this property, as they maintain almost the same absorption characteristics.

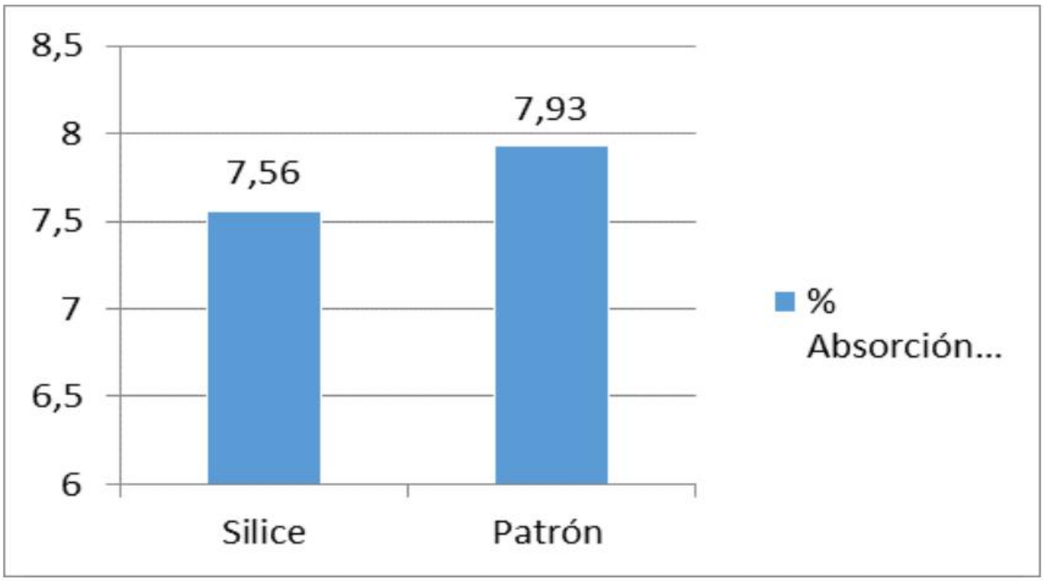

Figure 9. Comparison of the absorption capacity of the samples at 28 days. (Source: the authors)

At 90 days, however, there was little difference between the absorption of both samples, demonstrating that the addition of silica did not significantly affect this property, as it maintained almost the same absorption characteristics (see Figure 10). The comparison shown shows the small difference between the two samples, representing a difference of 1.49% absorption.

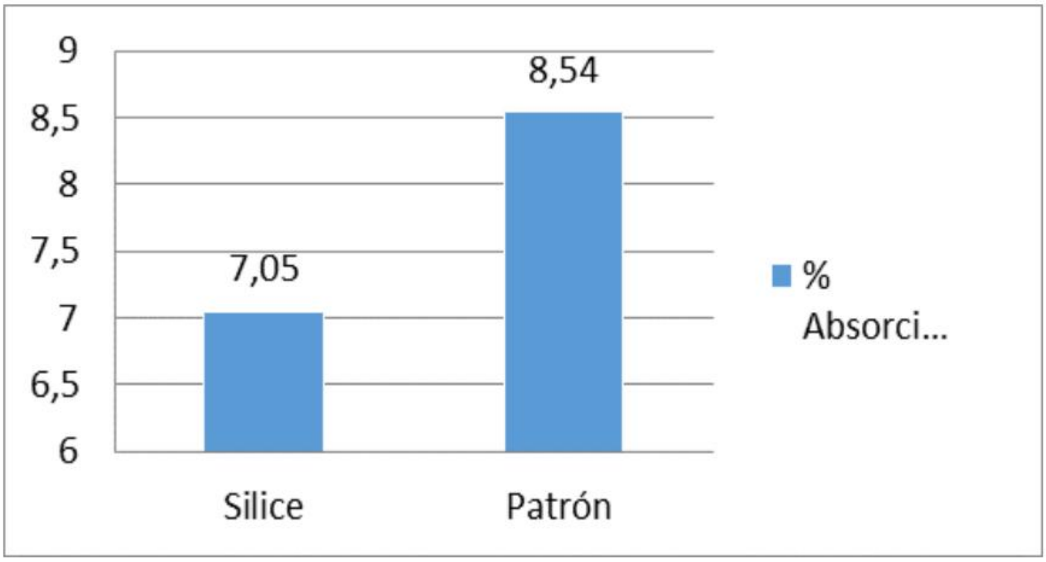

Figure 10. Comparison of the absorption capacity of the samples at 90 days. (Source: the authors).

It can be said that silica did not have a major impact on the absorption capacity property, as it acts as a water repellent, functioning as an impermeable material, since the silica sand grain is harder.

5. Conclusions

For the dimensional stability test, the results recorded were quite similar between the standard sample and the sample with silica. Regarding the other physical property, absorption capacity, tests were conducted after 28 days, which showed average results for the standard sample of 7.93% and for the silica sample of 7.56%. A rather small difference of 0.37% was noted between them, with no evidence of any impact from the silica. Furthermore, both comply with the range accepted by the COVENIN 42-82 Standard, which establishes a maximum absorption of 14% for heavy type B1 blocks. After 90 days, similar results were recorded, showing a 0.61% increase in the standard sample compared to the 28-day sample, and a 0.51% decrease in the silica sample, both remaining within the range established by the standard.

Regarding the mechanical property, compressive strength, the standard sample at 28 days recorded an average of 15.2 kg/cm^2, below the established range and not complying with COVENIN 42-82 Standard. This standard establishes a compressive strength equal to or greater than 80% of that specified in the table, which for type B blocks is 25 kg/cm^2; therefore, the minimum will be 20 kg/cm^2. The sample with 15% silica powder incorporated and 20% of the natural aggregate replaced by silica sand recorded an average of 21.63 kg/cm^2, complying with the range accepted by the standard. At 90 days, the standard sample continued to maintain the trend, even dropping the average compressive strength to 12.03 kg/cm^2, which did not meet the standard. The silica sample, unlike the standard, increased its average compressive strength to 22.46 kg/cm^2, confirming it was within the acceptable range of the standard.

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Contribution of the Authors

During the research, the main activities of analysis, conceptualization, and conclusions were carried out by A.G., while the testing and theoretical foundations were carried out by L.D.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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