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Physical and mechanical study of sustainable repair mortar incorporated with maguey juice

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Physical and Mechanical Study of Sustainable Repair Mortar Incorporated with Maguey Juice

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Abstract The objective of the project is to evaluate the physical and mechanical properties of the repair mortar incorporated with maguey juice for the repair of structural pathologies in the city of Huancayo. The construction sector has been growing over the years, but natural phenomena such as earthquakes and seismic events also occur daily, causing destruction and structural damage, and their repairs are becoming more and more costly. For this reason, the use of maguey juice as a natural additive in mortar was proposed to find out if it improves or worsens the properties of the mortar. To fulfill the objective of the research, an experimental study was carried out to find the physical and mechanical properties of the mortar. Tests of fluidity, air content, setting time, compressive strength, flexural strength, and mortar shrinkage test were carried out at 7, 14 and 28 days of curing with dosages of 0%, 3%, 5% and 7% of maguey juice based on a standard mix design of 260 kg/cm² with the ACI method. It was recommended to apply the 5% percentage of maguey juice, since that dosage was the one that provided the highest compressive strength reaching a value of 280.56 kg/cm²; also a higher flexural strength was achieved having a value of 77.49 kg/cm². Additionally, with the dosage of 5% maguey juice, optimal values were obtained in relation to the physical properties of the mortar in its fresh state. Finally, it was concluded that by using dosages higher than 5% maguey juice, the physical and mechanical properties of the mortar tend to worsen.

Keywords Maguey Juice, Strength, Properties, Cement, Repair, Mix Design

1. Introduction and Background

Between 1969 and 2009, Peru was shaken by five earthquakes that exceeded 7 ° on the Moment Magnitude (Mw) scale, causing more than 70,000 deaths and considerable material damage. Peru is located in the so-called Pacific Ring of Fire, which concentrates 90% of the planet's seismic activity [1], which causes several collapses and structural damage to buildings throughout the Peruvian territory; that is why solutions to these structural damages began to be sought. On the other hand, it is known that concrete is the most used construction material in the world and its production increases annually, the construction sector consumes 40% of the world's energy and is responsible for 23 to 40% of the emission of greenhouse gases [2]; taking into account this environmental pollution problem, we sought to improve the physical and mechanical properties of mortar in a sustainable way to achieve durable buildings, thus reducing the use of industrial additives and in extreme cases avoiding the destruction and total replacement of damaged structures. The use of natural additives in the production of high-performance concrete or mortar represents an alternative to replace toxic commercial additives and supplementary materials, which are harmful

to the environment and costly due to their absence in the local market.

Additives are used individually either in fresh or hardened concrete; their dosage can be administered independently according to the requirement. For the case of structural damage to buildings in Peru, it was decided to evaluate the incorporation of maguey juice as an organic additive to the mix design of a conventional repair mortar, in which the maguey juice was obtained from the distillation process of the maguey plant as shown in Figure 1. This research also seeks to contribute to environmental engineering by providing an added value to the residues from the distillation process of the maguey plant, as well as to know if this residue contributes beneficially to improve the physical and mechanical properties of the repair mortar.

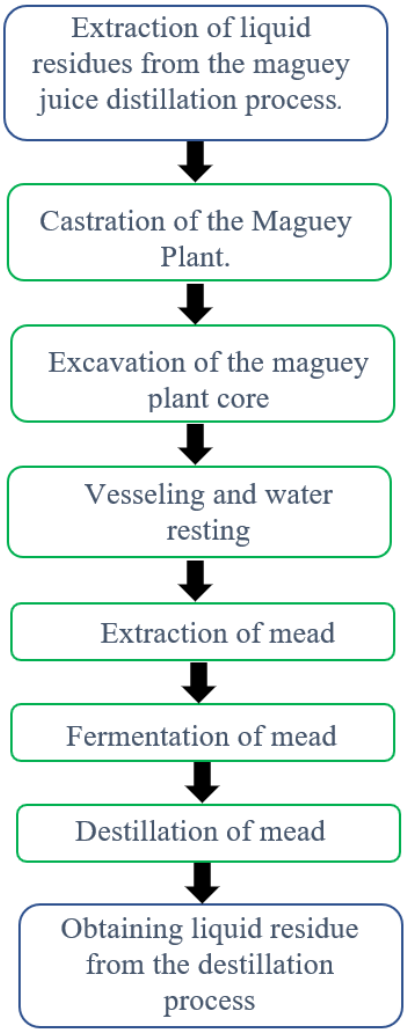

Figure 1. Flow diagram of the extraction of liquid residues from the maguey juice distillation process

Among the studies related to the improvement of mortar properties is the one carried out in Spain by Ochoa [3], who studied the use of liquor from agave plants as an additive in mortars and concretes. The author concludes that with the lower incorporation of the organic additive, the cohesion of the mixture is greater, and as the dose of the organic additive increases, it behaves as a plasticizer, so that when the setting time is carried out with this component, it tends to behave as a retardant compared to the American agave.

Another research carried out in Colombia by Porras and Guzmán [4], who studied the use of alternative materials to improve the resistance of structural masonry mortar, concluded that the mortar used to set bricks when incorporating fique fiber in its elaboration sets faster, and in its compressive strength, it presents greater resistance compared to other materials.

Orbegoso and Quezada [5] who studied the comparative analysis of the use of traditional mortar and pre-dosed mortar for the repair of structural pathologies in the city of Trujillo located in Peru, used alternative materials to improve the resistance of structural masonry mortar in which they concluded that pre-dosed mortar increases its compressive strength by 23.05%, decreases its permeability by 6.87%, absorption decreases by 45% and is economically accessible.

A study carried out in Mexico by Hernández, Cano and Torres [6], who added nopal mucilage and seaweed extract to concrete with high and low water/cement (w/c) ratios, improved the compressive strength of the concrete significantly with respect to the standard sample, and also reduced the diffusion rate of chloride ions and the depth of carbonation.

A study in Brazil by Mayara [7] analyzed the efficiency of adding silica fume, glass powder, Amazon chestnuts and biopolymer to mortars made with a binder. It was found that the residues contribute to the concept of technological innovation and sustainable development, as they bring benefits to the performance of lime mortars.

Unlike previous studies, in this research the liquid residues of the distillation process from the maguey juice will be used, evaluating in this study percentages of 3%, 5% and 7% to determine the optimum percentage of its application and analyze whether it is beneficial or not. It is expected that the incorporation of the maguey juice residue will be a good option and will contribute to improve the physical and mechanical properties of the repair mortar, which will provide both economic and environmental benefits.

2. Materials and Methods

The physical and mechanical analysis of the repair mortar with Maguey juice presents a scientific research methodology, a type of applied research, an explanatory research level and an experimental research design. First, the study area was defined, and the district of Viques was chosen as shown in Figure 2, which belongs to the Junín region in Peru. The district of Viques was chosen because according to Chávez [8], there are abundant crops of the maguey plant in that area. A land located in Jr. San Martín

was used as shown in Figure 3, where the samples were taken for the research.

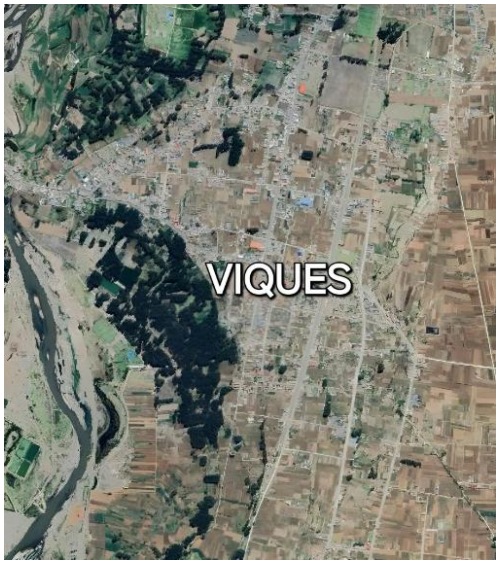

Figure 2. Geographic location of the study area

Figure 3. Land in the District of Viques

2.1. Materials

2.1.1. Fine Aggregate

They are called sands, which have their own resistance so as not to impair the properties and characteristics of the mortar, generating greater adherence with the cement paste and water [9]. According to ASTM C33 [10], fine aggregate is classified with particle sizes no larger than 4.75 mm and with a minimum size of 75 microns. Fine aggregate extracted from the Huamancaca quarry was used for the manufacture of the mortar specimens, which quarry is located 30 minutes from the city of Huancayo, the fine aggregate was taken to the laboratory to identify its physical characteristics which are shown in Table 1, these data were used to develop the mortar mix design; the presence of silt and clay in the fine aggregate was not evidenced, which means that it is an ideal material in the region.

Table 1. Fine aggregates characteristics

HUAMANCACA QUARRY	
FINENESS MODULUS	2.53
UNIT WEIGHT (kg/m ^{3})	1421
SPECIFIC WEIGHT (g/cm^3)	2.48
MOISTURE CONTENT (%)	0.39
ABSORPTION CAPACITY (%)	2.86
SUCS CLASSIFICATION	Well graded sand (SW)

2.1.2. Maguey Juice

It is also known as agave americana; this plant is of Mexican origin, normally growing in the mountains, or cliffs at more than 1000 or 2000 meters above sea level [11]. They are commonly used for the manufacture of textile fibers, sugar, and alcoholic beverages. The juice of this maguey plant has a density of 1.00 g/ml, and a pH of 4 to 5, inside it has 85% moisture, 6% cellulose, 8% organic matter, proteins, nitrogen, phosphorus, calcium, potassium, saponins and 1% minerals [12]. The taxonomy of the maguey plant is shown in Table 2. For the study carried out, dosages of 3%, 5% and 7% of the maguey plant juice were considered.

Table 2. Taxonomy of the maguey plant

KINGDOM	PLANTAE
DIVISION	MAGNOLIOPHYTA
CLASS	LILIOPSIDA
SUBCLASS	LILIIDAE
ORDER	ASPARAGALES
FAMILY	ASPARAGACEAE
SUBFAMILY	AGAVOIDEAE
GENUS	AGAVE L.

2.1.3. Water

Water is a substance composed of two hydrogen atoms and one oxygen atom (H_2O) and can be found in solid, gaseous, and liquid states. It has a density of 1g/cm^3, a boiling point of 100 ℃ and a freezing point of 0 ℃ [13]. Water is essential for the preparation of mortar, since with this the mixture is prepared and serves to perform the curing, and it must be free of acids, alkalis, salts and any harmful substance [14]. The magnitude of this element determines the consistency or fluidity of the mortar and when it comes into contact with the cement it generates a series of reactions that influence the physical and mechanical properties of the concrete [15]. The amount of this value shall be calculated according to the water/cement ratio established by Gutierrez [16].

2.1.4. Cement

It is a material with adhesive properties which can bind mineral fragments to make it compact, it is manufactured from calcareous materials such as limestone, alumina, and silica [15], it is essential to identify the use that will be given to the cement to ensure its durability to the aggressive agents to which it will be exposed when used. Portland Andino Type I cement was used, which meets the requirements of ASTM C-1157 [17], is resistant to contact with sulfate soils and saline substances, and is ideal for all types of structures, floors, and foundations. It was used in the preparation of the standard mortar and in the mortar incorporated with maguey juice. Table 3 shows the cement properties indicated by the manufacturer.

Table 3. Cement Properties

PORTLAND CEMENT TYPE I	
NAME	Andean Type I
MATERIAL	Cement
PRESENTATION	Bag (42,5 kg)
CHARACTERISTICS	Obtained from the co-milling of type I clinker.
STANDARD	NTP-334.009 / ASTM-150

2.2. Dosing Method

According to the European Standard UNE-EN 1504-3 [18], it indicates that structural mortars should have a compressive strength between 255 kg/cm^2 and 459 kg/cm^2, on the other hand, non-structural mortars have a strength between 102 kg/cm^2 and 153 kg/cm^2. There is no American standard for structural mortars. ASTM C270 - 10 [19] only establishes four types of mortar for masonry according to their resistance: Type "O", Type "N", Type "S" and Type "M" with minimum values of 25 kg/cm2, 55 kg/cm^2, 125 kg/cm^2 and 175 kg/cm^2 respectively. For this research, a mix design was made for a structural mortar with a compressive strength of 260 kg/cm^2 being a mortar type “M” according to [18]. The standard mix design was carried out according to the ACI Method [20] considering the characteristics of the materials shown in Table 4. First, the water/cement ratio was determined according to the design strength of 260kg/cm^2, then the volume of water, cement, and sand for 1 m^3 of mortar was found; finally, the final quantities of each material for 1 m^3 of mortar were found considering the percentage of sand absorption for the correction of water quantity. Table 5 shows the final weights of the materials for 1 m^3 of repair mortar for a mix design of 260 kg/cm^2. To meet the research objective, 12 samples were prepared for the flowability test, 12 samples for the air content test, 12 samples for the setting time test, 72 samples for the compressive strength test and 36 samples for the flexural strength test.

Table 4. Characteristics of Materials for Mixing Design

CHARACTERISTICS OF MATERIALS	
Specific Weight (sand) kg/m^3	1421
Specific Gravity (sand)	2.48
Specific Weight (cement) kg/m^3	1310
Specific Gravity (cement)	3.15
Specific Weight (water) kg/m^3	1000
Specific Gravity (water)	1
Water / Cement	0.48

Table 5. Mix design for the standard sample

MATERIALS	QUANTITY (kg)	VOLUME (m^3/m^3)
Cement	535.50	0.170
Fine Aggregate	1421.00	0.573
Water	297.70	0.257

For the mix design of the repair mortar incorporated with maguey juice, the same procedure was performed according to the ACI Method [20], with the difference that in this case percentages of 3%, 5% and 7% of maguey juice were incorporated in relation to the amount of cement; these obtained amounts of maguey juice were proportionally replaced with the water content of the standard mix design with the objective of not altering the water/cement ratio of 0.48 of the mix design. Table 6 shows the final weights for the repair mortar with f'c 260kg/cm^2 incorporating the maguey juice.

Table 6. Mortar mix design incorporated with Maguey Juice

MATERIALS	**3%**	**5%**	**7%**
Cement (kg)	535.5	535.5	535.5
Fine Aggregate (kg)	1421	1421	1421
Water (l)	281.6	270.9	260.2
Maguey Juice (l)	16.1	26.8	37.5

2.2.1. Flow Test

It was carried out using ASTM C1437 - 07 [21], this test was necessary to determine the characteristics of the mortar in terms of consistency and workability, this value also influences the compressive strength and adhesion between masonry units if applicable. For the elaboration of the test, a metallic trunk mold was installed on the shaking table, then it was filled with the standard mortar and the mortar with dosages of 3%, 5% and 7% of maguey juice in two layers of 25 mm of height, tamped with 20 blows at a pressure that ensures the uniform filling of the mold; after removing the mold vertically, a slight rotating movement was made at the base of the shaking table, giving 25 blows during 15 seconds and letting it fall from a height of about 12.70 mm. Next, the diametrical measurements formed by the mortar on the table were taken to obtain a final average,

three samples were taken for each dosage for this test. The materials and equipment used were flow table, compactor, conical log, vernier, balance, tares, spatulas, gloves, and test tubes. Figure 4 shows the mortar flow test performed.

Figure 4. Mortar Flow Test

2.2.2. Air Content

This test was performed as specified in ASTM C185-08 [22]. First, a metallic cylinder-shaped container with an inner diameter (Di) of 76 mm ± 2 mm and an approximate depth of 88 mm was used to contain 400 ml ± 1 ml of water, then to eliminate voids within the mix, the mold was filled with mortar in 3 equal layers compacted 20 times using the tamper and lightly tapping the sides of the container to eliminate the unconsidered air. Subsequently, the excess mortar was excluded and leveled with the spatula so that finally the container and its contents could be weighed. For this test, three samples were prepared for each dosage of 3%, 5% and 7% of maguey juice. The materials and equipment used were mortar mixer, metal container, compactor, scale, graduated test tube, tares, spatula, and gloves. Figure 5 shows the Mortar Air Content Test performed.

Figure 5. Mortar Air Content Test

2.2.3. Time of Setting of Cement Mortar

This test was done according to ASTM C403 [23], to perform the test, the ambient temperature between 20 and 25 ℃ was considered, then the needle of the loading apparatus began to penetrate to a depth of 25 ± 2 millimeters in a time span of 10 ± 2 seconds, then the required force was recorded to find the resistance to penetration. The initial and final setting times were recorded when a given strength was reached, it is worth mentioning that six penetrations were made for each setting time test at regular time intervals such as to provide a satisfactory curve of penetration resistance versus elapsed time. The materials and equipment used were Compression Machine, Specimen Mold, Penetration Needle, Tamping Rod, Pipettes and Thermometer. Figure 6 shows the Mortar Setting Time Test performed.

Figure 6. Mortar Setting Time Test

2.2.4. Compressive Strength

This method establishes the way to determine the compressive strength of cement mortars using 50 mm cubes, which will be prepared and cured according to the procedures indicated in ASTM C109M-16 [24]. Having readied the standard mix and the mixes with 3%, 5% and 7% of maguey juice, they were poured into the previously greased metal molds, the pouring of the mix was in 2 layers compacted in four stages of 8 blows each during 10 seconds for each layer. The metal molds were covered with a damp cloth for a period of 24 hours to prevent moisture loss. The compression test was performed using 3 samples for each percentage at 7, 14 and 28 days. The materials and equipment used were compression machine, specimen mold, compacting rammer, tares, scales, spatula, lubricant, gloves, and test tubes. Figure 7 shows the Compressive Strength Test of Mortar performed.

Figure 7. Compressive Strength Test of Mortar

2.2.5. Flexural Strength

ASTM C348-21 [25] establishes the way to determine the flexural strength of the mortar when it is subjected to loads at the center of the span. Having readied the standard mixture and the mixtures with 3%, 5% and 7% of maguey juice, they were poured into the previously greased metallic molds with dimensions of 40x40x160 mm, they were poured in 2 compacted layers with 60 blows in 60 seconds per layer, leveling the last one with the edge of a metallic ruler until it was leveled. To demold and cure the molds, they were first covered with a damp cloth for 24 hours. For this flexural test, three specimens were made for each percentage of maguey juice dosage to test at 7, 14 and 28 days. The materials and equipment used were compression machine, specimen mold, compacting rammer, tares, scales, spatula, lubricant, gloves, and test tubes. Figure 8 shows the Mortar Flexural Strength Test performed.

Figure 8. Mortar Flexural Strength Test

2.2.6. Length Change of Hardened Cement Mortar

ASTM C157-17 [26] establishes the way to determine the way to determine the changes in length during the hardening stage of the mortar produced by the loss of moisture that it experiences under environmental conditions of temperature and humidity. Having readied the standard mixture and the mixtures with 3%, 5% and 7% of maguey juice, they were poured into the previously greased metallic molds with dimensions of 25x25x285 mm, they were poured in 2 compacted layers, leveling the last one with the edge of a metallic ruler until it was leveled. The specimens were cured in a humid room, then these were taken out of their molds at an age of 23 ½ ± ½h, finally the initial comparison of the specimens was read at an age of 24h ± ½h. After the initial comparison reading, the specimens were stored in the drying room at a temperature of 23 ± 2 ℃ (73 ± 3 ℉) until they reached an age of 7, 14 and 28 days to take their readings as described above. For this shrinkage test, three specimens were made for each percentage of maguey juice dosage. The materials and equipment used were molds, length comparator, tamper, tamping rod, and filter paper. Figure 9 shows the Mortar shrinkage test performed.

Figure 9. Mortar shrinkage test

3. Results and Discussions

The results of the physical properties of the fresh mortar are shown, such as the test of fluidity, air content and setting time; likewise, the results of the mechanical tests of the hardened mortar are shown, such as the compressive strength, flexural strength, and shrinkage test at 7, 14 and 28 days of curing with the percentages of 0%, 3%, 5% and 7% of maguey juice. The results obtained were analyzed to determine the viability of the study.

3.1. Flow Test

Table 7 shows the results obtained from the flowability test of the mortar incorporated with 0%, 3%, 5% and 7% maguey juice; it is worth mentioning that three samples were tested for each dosage according to ASTM C1437 - 07 [21].

Table 7. Flow of Cement Mortar

Specimen	0% (%)	3% (%)	5% (%)	7% (%)
M-01	105.54	99.26	100.69	98.13
M-02	100.37	104.42	97.55	99.21
M-03	103.20	102.95	101.25	103.82
Average	103.04	102.21	99.83	100.39
Standard Deviation	2.59	2.66	1.99	3.02
Avg - Sd	100.45	99.55	97.84	97.36

Pico [27] defines the flowability of mortar in three consistencies: Dry (0%-90%), Plastic (90%-110%) and Fluid (110%-130%); and according to Table 7 it was determined that all mortars tested have a Plastic consistency. ASTM C1437 [21] indicates that the optimum fluidity should be in the range of 100±5%, and it is observed that all the samples tested with 0%, 3%, 5%, 5%, 7% of maguey juice are within the optimum range.

According to Figure 10, it is observed that the bar diagrams have a decreasing behavior, i.e., the higher the percentage of maguey juice dosage, the % flowability of the mortar tends to decrease, with 7% being the dosage that has the lowest % flowability than the rest. In addition, mortars with 3%, 5% and 7% of maguey juice present a decrease in flowability of 0.89%, 2.59% and 3.07% respectively in relation to the standard mortar.

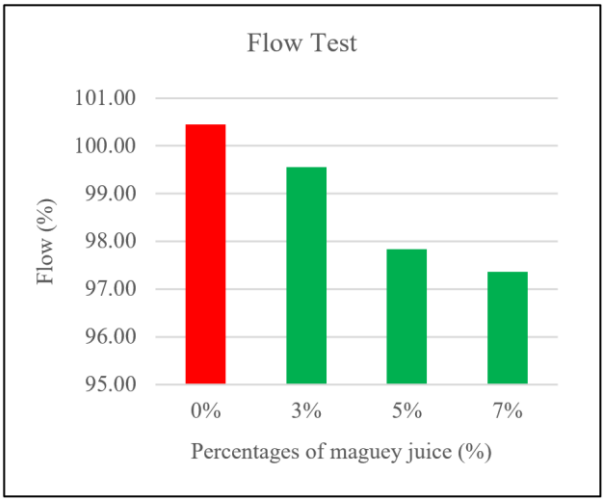

Figure 10. Fluidity Test Bar Graph

3.2. Air Content

Table 8 shows the results obtained from the air content test of the mortar incorporated with 0%, 3%, 5% and 7% maguey juice; it is worth mentioning that three samples were tested for each dosage according to ASTM C185 [22].

There is no specific Peruvian standard on air content parameters in high-strength repair mortars; only NTP 399.610 [28] establishes the specifications for mortars used in the construction of reinforced and non-reinforced masonry works.

According to ASTM C270-10 [19], this indicates that the maximum air content is 12%. with respect to the volume of the mortar, then according to Table 8, it is observed that all the samples tested with 0%, 3% , 5% and 7% of maguey juice comply with the recommendations of the American Standard.

Table 8. Air content per dosage

Specimen	0% (%)	3% (%)	5% (%)	7% (%)
M-01	3.80	4.10	4.40	5.20
M-02	3.60	4.50	5.10	5.50
M-03	3.90	4.00	4.80	5.30
Average	3.77	4.20	4.77	5.33
Standard Deviation	0.15	0.26	0.35	0.15
Avg - Sd	3.61	3.94	4.42	5.18

According to Figure 11, it is observed that the bar diagrams have an increasing behavior, i.e., the higher the percentage of maguey juice dosage, the higher the percentage of air content of the mortar tends to increase, with 7% being the maguey juice dosage that presents the highest percentage of air content. In addition, mortars with 3%, 5% and 7% of maguey juice present an increase in air content of 9.14%, 22.43% and 43.49% respectively in relation to the air content of the standard mortar.

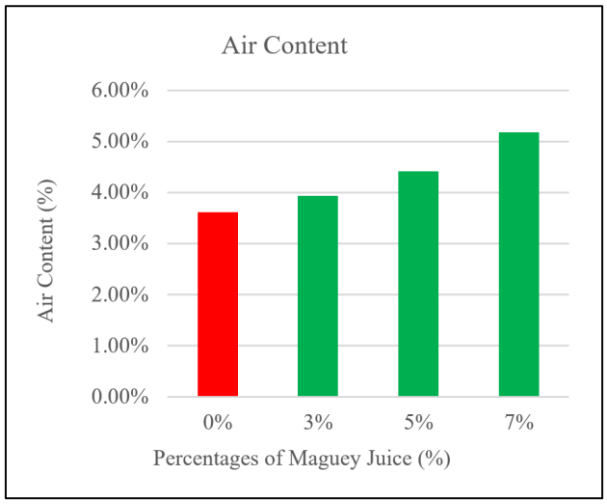

Figure 11. Air Content Test Bar Chart

3.3. Time of Setting of Cement Mortar

Table 9 shows the results obtained from the setting time test on average of the mortar incorporated with 0%, 3%, 5% and 7% maguey juice, it is worth mentioning that six penetrations were made for each setting time test at regular time intervals according to ASTM C403 [23].

According to the normative parameters of ASTM C403 [23], the range of initial setting time and final setting time is between 210.5 minutes and 501 minutes respectively,

then according to Table 9 the mortars with 0%, 3%, 5% and 7% of maguey juice meet the requirements of the standard.

Table 9. Setting time for each dosage

Specimen	Initial setting time		Final setting time	
	Minutes	Hours	Minutes	Hours
0%	345.60	5.76	496.40	8.27
3%	342.80	5.71	485.60	8.09
5%	341.30	5.69	472.30	7.87
7%	335.50	5.59	456.20	7.60

According to Figure 12, it is observed that the bar diagrams have a decreasing behavior, i.e., the higher the percentage of maguey juice dosage, the setting time of the mortar tends to decrease, being 7% the dosage that achieves a lower initial and final setting time. In addition, mortars with 3%, 5% and 7% of maguey juice present a decrease in the final setting time of 2.17%, 4.85% and 8.10% respectively in relation to the final setting time of the standard mortar. Therefore, it can be said that maguey juice behaves as a setting accelerator.

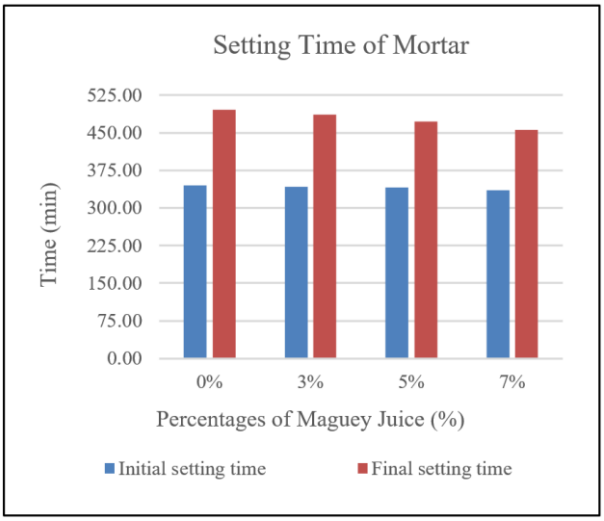

Figure 12. Setting Time Test Bar Graph

3.4. Compressive Strength

Table 10 shows the results obtained from the Compressive Strength test of the mortar at 7 days of curing incorporated with 0%, 3%, 5% and 7% of maguey juice, it is worth mentioning that six samples were tested for each dosage according to ASTM C109M [24].

Table 11 shows the results obtained from the Compressive Strength test of the mortar at 14 days of curing incorporated with 0%, 3%, 5% and 7% of maguey juice, with 7% being the dosage that achieves the highest compressive strength. It is worth mentioning that six samples were tested for each dosage according to ASTM C109M [24].

Table 10. Compressive Strength after 7 days of curing

Specimen	0%	3%	5%	7%
C-01 (kg/cm^2)	83.63	92.02	98.76	106.80
C-02 (kg/cm^2)	97.36	105.32	112.57	108.46
C-03 (kg/cm^2)	80.65	100.28	102.20	111.55
C-04 (kg/cm^2)	91.10	90.05	101.69	97.53
C-05 (kg/cm^2)	97.38	101.10	113.51	106.21
C-06 (kg/cm^2)	85.62	98.45	101.36	101.59
Average	89.29	97.87	105.02	105.36
Standard Deviation	7.13	5.79	6.34	5.02
Avg - Sd	82.16	92.08	98.68	100.33

Table 11. Compressive Strength after 14 days of curing

Specimen	0%	3%	5%	7%
C-01 (kg/cm^2)	237.36	240.37	255.65	254.19
C-02 (kg/cm^2)	233.32	243.85	244.49	255.14
C-03 (kg/cm^2)	238.39	250.49	246.61	262.50
C-04 (kg/cm^2)	225.27	243.95	254.46	264.63
C-05 (kg/cm^2)	239.96	257.26	255.35	253.56
C-06 (kg/cm^2)	232.44	244.42	253.17	261.98
Average	234.46	246.72	251.62	258.67
Standard Deviation	5.37	6.11	4.83	4.89
Avg - Sd	229.09	240.61	246.79	253.77

Table 12 shows the results obtained from the Compressive Strength test of the mortar at 28 days of curing incorporated with 0%, 3%, 5% and 7% of maguey juice, with 7% being the dosage that achieves the highest compressive strength. It is worth mentioning that six samples were tested for each dosage according to ASTM C109M [24].

Table 12. Compressive Strength after 28 days of curing

Specimen	0%	3%	5%	7%
C-01 (kg/cm^2)	271.05	277.31	285.46	280.57
C-02 (kg/cm^2)	275.32	277.62	283.61	281.68
C-03 (kg/cm^2)	262.18	289.71	292.08	273.85
C-04 (kg/cm^2)	261.23	281.97	279.11	274.66
C-05 (kg/cm^2)	276.31	290.58	286.84	277.40
C-06 (kg/cm^2)	274.57	291.10	282.59	288.17
Average	270.11	284.72	284.95	279.39
Standard Deviation	6.75	6.52	4.38	5.31
Avg - Sd	263.36	278.19	280.56	274.08

According to the results of Table 12, it is verified that the compressive strength of the mortars with dosages of 0%, 3%, 5% and 7% of maguey juice are higher and comply

with the proposed mix design of 260 kg/cm^2. It is also observed that with the 7% maguey juice dosage, a compressive strength of 274.08 kg/cm^2 was achieved, and with the 5% maguey juice dosage, a compressive strength of 280.56 kg/cm^2 was achieved, the latter value having a 2.36% higher strength with respect to the 7% maguey juice; this indicates that when using a dosage higher than 5% maguey juice, the compressive strength begins to decrease. Additionally, it is verified that with all the dosages of 0%, 3%, 5% and 7% of maguey juice, a high-strength structural mortar of R3 classification is achieved.

According to Figure 13, it is observed that the Compressive Strength vs. Setting Time Curve has an increasing behavior, i.e., the higher the percentage of maguey juice dosage, the compressive strength of the mortar tends to increase, but this is only true up to 5% maguey juice. In addition, it is observed that at 28 days of curing, mortars with 3%, 5% and 7% maguey juice present an increase in compressive strength of 4.07%, 6.53% and 5.63% respectively, in relation to the compressive strength of the standard mortar.

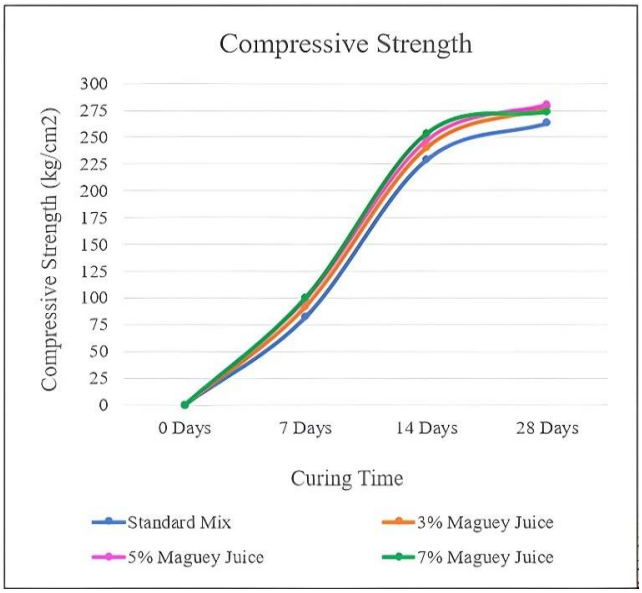

Figure 13. Compressive Strength vs. Setting Time Curve

3.5. Flexural Strength

Table 13 shows the results obtained from the Flexural Strength test of the mortar at 7 days of curing incorporated with 0%, 3%, 5% and 7% of maguey juice, it is worth mentioning that three samples were tested for each dosage according to ASTM C348 [25].

Table 14 shows the results obtained from the Flexural Strength test of the mortar at 14 days of curing incorporated with 0%, 3%, 5% and 7% of maguey juice, with 7% being the dosage that achieves the highest compressive strength. It is worth mentioning that three samples were tested for each dosage according to ASTM C348 [25].

Table 13. Flexural Strength after 7 days of curing

Specimen	0%	3%	5%	7%
F-01 (kg/cm^2)	62.75	60.31	63.14	60.36
F-02 (kg/cm^2)	57.97	57.97	60.36	63.75
F-03 (kg/cm^2)	59.88	62.75	58.97	65.21
Average	60.20	60.34	60.82	63.11
Standard Deviation	2.41	2.39	2.12	2.49
Avg - Sd	57.79	57.95	58.70	60.62

Table 14. Flexural Strength after 14 days of curing

Specimen	0%	3%	5%	7%
F-01 (kg/cm^2)	63.52	66.14	69.23	67.53
F-02 (kg/cm^2)	64.03	64.98	66.14	74.14
F-03 (kg/cm^2)	66.14	68.53	72.78	70.92
Average	64.56	66.55	69.38	70.86
Standard Deviation	1.39	1.81	3.32	3.31
Avg - Sd	63.17	64.74	66.06	67.56

Table 15 shows the results obtained from the Flexural Strength test of the mortar at 28 days of curing incorporated with 0%, 3%, 5% and 7% of maguey juice, with 7% being the dosage that achieves the highest compressive strength. It is worth mentioning that three samples were tested for each dosage according to ASTM C348 [25].

Table 15. Flexural Strength after 28 days of curing

Specimen	0%	3%	5%	7%
F-01 (kg/cm^2)	74.70	78.09	77.70	77.13
F-02 (kg/cm^2)	77.09	80.48	79.05	78.47
F-03 (kg/cm^2)	77.20	76.70	81.48	75.22
Average	76.33	78.42	79.41	76.94
Standard Deviation	1.41	1.91	1.92	1.63
Avg - Sd	74.92	76.51	77.49	75.31

According to the results of Table 15, it is verified that the flexural strength of the standard mortar at 28 days of curing was 74.92 kg/cm^2, which is higher than expected, since normally the flexural strength ranges between 10 to 15% in relation to the compressive strength according to Gianfranco [29]. It is also observed that with the dosage of 5% maguey juice a flexural strength of 77.49 kg/cm^2 was achieved and with the dosage of 7% maguey juice a flexural strength of 75.31 kg/cm^2 was achieved, the latter having a lower strength by 2.81 % with respect to the 7% maguey juice; this loss of resistance was expected because previously there was a higher compressive strength with 5% maguey juice, and it is known that normally the flexural strength is directly proportional to the compressive strength. Therefore, when using in the mortar a dosage

higher than 5% of maguey juice, the flexural strength begins to decrease as well as the compressive strength.

According to Figure 14, it is observed that the Flexural Strength vs. Setting Time Curve has an increasing behavior, i.e., the higher the percentage of maguey juice dosage, the mortar flexural strength tends to increase, but this is only true up to 5% maguey juice. In addition, it is observed that, at 28 days of curing, mortars with 3%, 5% and 7% maguey juice present an increase in flexural strength of 2.12%, 3.43% and 0.52%, respectively, based on the flexural strength of the standard mortar.

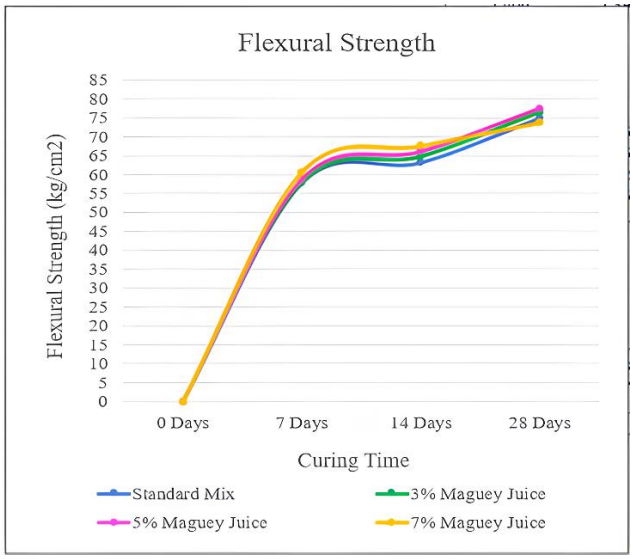

Figure 14. Flexural Strength vs Setting Time Curve

Additionally, Table 16 shows that all the mortar samples with dosages of 0%, 3%, 5% and 7% of maguey juice have a f'f/f'c ratio of 28.45%, 27.50%, 27.62% and 27.47% respectively, all of them exceed the ratio between 10% and 15%, which indicates that all mortars have a good structural behavior, being the 5% dosage of maguey juice the one that achieves the highest flexural strength.

Table 16. Ratio of flexural strength to compressive strength after 28 days of curing

Percentage (%)	Flexural Strength (kg/cm²)	Compressive Strength (kg/cm²)	f'_f/f'_c
0	74.92	263.36	28.45%
3	76.51	278.19	27.50%
5	77.49	280.56	27.62%
7	75.31	274.08	27.47%

3.6. Length Change of Hardened Cement Mortar

Table 17 shows the results obtained from the mortar shrinkage test at 7 days of curing incorporated with 0%, 3%, 5% and 7% of maguey juice, it is worth mentioning that three samples were tested for each dosage according to ASTM C157-17 [26].

Table 17. Length change of specimen at 7 days

Specimen	0%	3%	5%	7%
R-01 (kg/cm²)	-0.0324	-0.0270	-0.0252	-0.0214
R-02 (kg/cm²)	-0.0322	-0.0263	-0.0246	-0.0210
R-03 (kg/cm²)	-0.0329	-0.0255	-0.0257	-0.0221
Average	-0.0325	-0.0263	-0.0252	-0.0215
Standard Deviation	0.0004	0.0008	0.0006	0.0006
Avg - Sd	-0.0329	-0.0270	-0.0257	-0.0221

Table 18 shows the results obtained from the mortar shrinkage test at 14 days of curing incorporated with 0%, 3%, 5% and 7% of maguey juice, it is worth mentioning that three samples were tested for each dosage according to ASTM C157-17 [26].

Table 18. Length change of specimen at 14 days

Specimen	0%	3%	5%	7%
R-01 (kg/cm²)	-0.0557	-0.0451	-0.0406	-0.0359
R-02 (kg/cm²)	-0.0549	-0.0454	-0.0395	-0.0365
R-03 (kg/cm²)	-0.0555	-0.0461	-0.0409	-0.0367
Average	-0.0554	-0.0455	-0.0403	-0.0364
Standard Deviation	0.0004	0.0005	0.0007	0.0004
Avg - Sd	-0.0558	-0.0460	-0.0411	-0.0368

Table 19 shows the results obtained from the mortar shrinkage test at 28 days of curing incorporated with 0%, 3%, 5% and 7% of maguey juice, it is worth mentioning that three samples were tested for each dosage according to ASTM C157-17 [26].

Table 19. Length change of specimen at 28 days

Specimen	0%	3%	5%	7%
R-01 (kg/cm²)	-0.0685	-0.0588	-0.0576	-0.0532
R-02 (kg/cm²)	-0.0675	-0.0595	-0.0571	-0.0543
F-03 (kg/cm²)	-0.0676	-0.0602	-0.0582	-0.0540
Average	-0.0679	-0.0595	-0.0576	-0.0538
Standard Deviation	0.0006	0.0007	0.0006	0.0006
Avg - Sd	-0.0684	-0.0602	-0.0582	-0.0544

According to Figure 15, it can be observed that the higher the dosage of maguey juice, the shrinkage of the mortar tends to decrease, having a decrease of 20.46% with 7% dosage in relation to the standard sample. It can also be seen that the longer the curing time, the mortar shrinkage tends to increase, the most unfavorable dosage was the standard sample, since it had a shrinkage of -0.0684% and the dosage that suffered the least shrinkage was that of 7% maguey juice with -0.0544%.

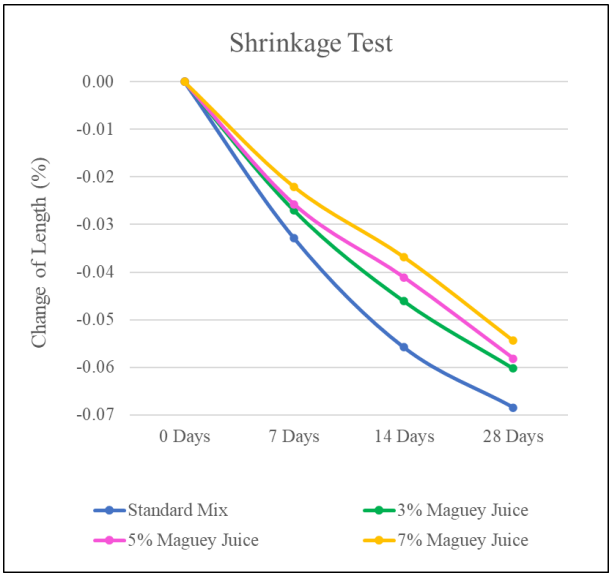

Figure 15. Length Change vs Curing Time

According to Kosmatka [30], the typical value of shrinkage due to drying that concrete experiences is between 0.04% to 0.08% at 28 days of curing, and it is observed that the dosages of 3%, 5% and 7% of maguey juice achieved to be within the typical range of shrinkage of the mortar. Maguey juice does not behave as a shrinkage controlling additive because according to ASTM C157-17 [26], controlled shrinkage mortars (CRC) achieve values lower than 0.032% at 28 days (60-70% RH and 22 ℃±2 ℃).

4. Conclusions

The incorporation of maguey juice extracted from the district of Viques to improve the physical and mechanical properties of the repair mortar is a good option, since good results were obtained in the studies carried out with the three dosages. In the physical properties of the mortar in its fresh state, a fluidity of plastic consistency was obtained with the dosages of 3%, 5% and 7% of maguey juice; the higher the dosage of maguey juice, the percentage of fluidity tended to decrease, and all of these were within the optimum fluidity of 100 ± 5%. On the other hand, it was possible to increase the air content with the three dosages of 3%, 5% and 7% of maguey juice; the higher the maguey juice dosage, the higher the percentage of air content tended to increase; a maximum range of air content of up to 12% was achieved. The setting time of the repair mortar tended to decrease with a higher dosage of maguey juice, with the dosages of 3%, 5% and 7% within the permissible range of 210.5 minutes and 501 minutes corresponding to the initial and final setting, respectively.

Regarding the mechanical properties of the repair mortar in the hardened state, with the three dosages, higher strengths were achieved than the proposed mix design of 260 kg/cm^2; it should be noted that a higher compressive strength was achieved with the 5% maguey juice dosage after 28 days of curing, reaching a value of 280.56 kg/cm^2. According to the results of the flexural test, the flexural strength was slightly improved with the 3% and 5% maguey juice dosages, reaching a maximum strength of 77.49 kg/cm^2 with the 5% dosage at 28 days of curing. In the case of the hardened mortar length change test, 7% was the dosage that achieved the lowest volumetric shrinkage of the mortar with a value of 0.0538%. It was concluded that when using dosages higher than 5% maguey juice, the mechanical properties of the mortar tend to worsen; likewise, in the physical properties of the mortar, when using dosages higher than 5% maguey juice, results outside the optimum parameters were obtained.

The optimum dosage is the one that achieves the best behavior of the cement mortar in fresh and hardened state, so in this research for the application of this repair mortar for structural purposes, it is recommended to use the dosage of 5% of maguey juice since with that dosage better results were obtained complying with the regulations.

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