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Organic addition for mortar mixtures based on pitahaya cactus

Adición orgánica para mezclas de mortero basado en cactus de pitahaya

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Abstract

In the field of construction, and specifically regarding cement-based mixtures such as concrete, endless alternative materials have been implemented aiming at improving the physical, mechanical and chemical properties, reducing cement usage through the use of materials from an organic origin. In this sense, cacti species have gained ground in the construction industry, therefore, in this research work, the pitahaya species was studied. Pitahaya powder was characterized to replace cement in the mortar mix in percentages of 1% and 2%, evaluating the compressive strength at 28 days. Results showed that characteristics similar to those of nopal were obtained, such as the ability to store water within the pores, which leads to improvements in compressive strength with respect to the control mixture.

Cement-based mixtures, Cacti, Mortar, Organic additive, Concrete

Resumen

En el ramo de la construcción y específicamente en las mezclas base cemento como el concreto, se implementan un sinfín de materiales alternativos, con el propósito de mejorar las propiedades físicas, mecánicas y químicas disminuyendo el uso de cemento, mediante el uso de materiales de origen orgánicos. En este sentido, la especie de las cactáceas ha ganado terreno en el área de la construcción, por lo que, en este trabajo de investigación, la pitahaya se eligió como especie estudiada. Se caracterizó el polvo de pitahaya para sustituir el cemento en el mortero en porcentajes del 1% y 2%, evaluando su resistencia a la compresión a los 28 días. Los resultados muestran que se obtienen características similares al nopal, como la capacidad de almacenar agua dentro de sus poros, la cual que propicia mejoras en la resistencia a la compresión con respecto a la mezcla control.

Pitahaya, Mezclas Base Cemento, Aditivos Orgánicos

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Introduction

On a global scale, cement is one of the most widely used materials in the construction industry and will continue to be so unless there is a revolution in the materials industry. This is reflected in a high demand of it and, being the most used material in construction, it also becomes the biggest polluter due to its production process, which generates large amounts of greenhouse gases, since the manufacture of a ton of cement requires approximately 4 GJ (Giga Joules) of energy and the production of Portland cement clinker emits about a ton of carbon dioxide (CO_2) into the atmosphere [1,2]. Initially, it was thought that the cement mixture produced could withstand any climate or condition and it was assumed that this material did not require maintenance throughout its life span, which was relegated when durability problems arose in concrete structures, which deteriorate mainly in aggressive environments or due to the use of inappropriate materials as well as poor handling of construction processes, however, the greatest damage to structures is generally caused by the reinforcement steel corrosion and attack by chlorides [3,4].

This has evolved over the years, implementing new technologies to meet the demands of the concrete industry through the activation and development of special concretes in which mineral additions are used [5]. Most of the countries' infrastructure is built with this material, so it is very important to gain knowledge of the production process. Bad practices in construction result in deficiencies in concrete in terms of its properties, since once these problems arise, most of these structures cease to be functional, limiting their projected life span. From this perspective and taking into account that Mexico is a country with climatic diversity and aggressive environments, it is essential to know and control this issue [6,7]. In this sense, concretes are designed for different durability requirements; depending on the desirable properties, the components of the mixture, proportions and the way in which they interact with each other determine the concrete's useful life span [8]. Based on this, the use of organic materials as an addition in the concrete mixture, known mostly as organic additions, which are often available locally and are inexpensive, has improved the concrete's durability [9].

This is where Mexico plays an important role, since the use of these organic materials, such as cacti, of which there are more than 670 species, has gained ground in the area of construction and several authors [10] report that the most studied one is nopal, which presents favorable results in terms of physical, mechanical and durability properties when applied to mortar and concrete mixtures and compared to the implementation of some mineral additions made with materials such as fly ash and blast furnace slag, among others, or to additions of imported materials, which make their use more expensive and, although they improve their properties, they are not viable for large-scale application [11,12].

For this reason, cacti species, with a great diversity of species to study, have been widely implemented in the field of construction. Among the cacti are those of the genus *Hylocereus*, of which the most known species are *Selenicereus megalanthus*, or yellow pitahaya, and *Hylocereus undatus*, or red pitahaya [7,11]. Specifically, pitahaya is a plant that grows wild, whether on stones, living trees or walls. Pitahaya, like most cacti, is characteristically succulent, with many thorns and highly adapted to arid and semi-arid regions [13]. The pitahaya plant, and the parts that make it up, are used for different forms of purposes: ornamental, protective barriers, food and medicinal purposes, all of this can be made compatible with its productive function, which opens up a wide range of opportunities to implement its use in other areas. Therefore, the main objective of this work was to evaluate the effect of the addition of pitahaya cactus in a dehydrated form on the physical, chemical and mechanical properties (compressive strength) of a masonry mortar.

Experimental Section

Material procurement

The amount of material needed was estimated for the assessment of the physical and mechanical properties in the mortar mixture with the addition of pitahaya cactus in percentages of 1% and 2% and continue with the location of local suppliers to obtain the materials.

Regarding the obtaining of the pitahaya, this was achieved through family crops suppliers, that is, they themselves produce the fruit, located in the Mayan region called “Los Chunes” route in the municipality of Felipe Carrillo Puerto, Quintana Roo, Mexico, Figure1.

Figure 1. Location map of the *Chunes* region

Physical characterization of fine aggregate

The materials were sampled according to the NMX-C-030 standard, which establishes "the sampling of the aggregates that are used in the investigation of potential sources of supplies”. The aggregate used corresponds to the bank called "El 21", according to the list of material warehouses in Quintana Roo, corresponding to the collection of warehouse No. 1, with coordinates 18°30'57.75” N - 88°29'04.79” W, being of the alluvial type of Qhoal category; this material contains weathered limestone, laterite clay and silt [14]. Equal portions of the aggregates from a mound (gravel or sand) were taken. Once the portions were obtained, they were mixed to obtain a representative sample of the total amount of material, as shown in Figure 2a. Subsequently, they were sampled according to the NMX-170 method, which explains the correct way of reducing the materials obtained in the field to the appropriate size for the test.

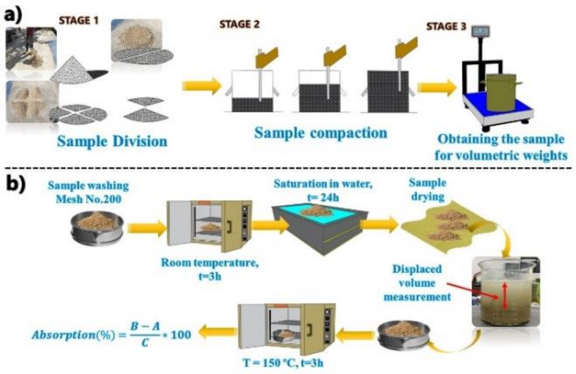


Figure 2 a) Process diagram for obtaining and reducing the sample and b) Scheme for the determination of density and absorption in fines

Volumetric weight of the aggregates

Dry Compacted Volumetric Weight (DCVW). 55 kg of fine aggregate were taken and, in accordance with NMX-030, they were reduced to a volume of approximately 1.5 times the capacity of the container. The container, with a volume of 5.05 liters, was filled up to one third of its volume and then the surface was flattened. The material was firmly mixed with a rod, applying 25 evenly distributed penetrations on the surface. Finally, the container was filled until the material exceeded the upper edge to obtain the final weight using Equation 1.

$$DCVW = \frac{W_m}{V_c} \tag{1}$$

Where, $\boldsymbol{W_m}$= Material weight /kg [$\boldsymbol{W_m}$ = $(W_{container} + W_{material}) - W_{container})$], $\boldsymbol{V_c}$ = Container volume / m^3.

Dry Loose Volumetric Weight (DLVW). As for the DCVW test, the NMX-C-073 standard was used, which briefly consists of the "determination of the volumetric mass of fine and coarse aggregates or a combination of both". This method is applicable to aggregates whose maximum nominal size does not exceed 150 mm. The test procedure consisted of homogenizing the material by means of a correct mixing in dry conditions to continue with the filling of the container as shown in Figure 2a. Dropping the material from a height of 5 cm, trying to rearrange the material due to improper movements, scratching the excess. Subsequently, the container is weighed and the data is recorded, to finish with the calculation of the volumetric weight of the dry and loose material, through Equation 1.

Fine aggregate grading analysis and fineness modulus. The granulometric analysis was carried out in accordance with the provisions of NMX-C-077, using the sample obtained in the sampling of the aggregates, after its reduction. The granulometric limits of the fine aggregate were used according to the NMX-C-111 standard with respect to the size of the sieves, as indicated in Table 1

Sieve Number	% Passing the Sieve
9.5 mm (3/8")	100
4.75 mm (No. 4)	95 - 100
2.36 mm (No. 8)	80 - 100
1.18 mm (No. 16)	50 - 85
0.60 mm (No. 30)	25 - 60
0.30 mm (No. 50)	10 - 30
0.15 mm (No. 100)	2 - 10

Table 1 Fine aggregate grading limits

The fineness modulus (FM) of the fine aggregate was obtained in accordance with the NMX-C-111-ONNCCE standard, which was obtained by adding the accumulated percentages (by weight) of the aggregates retained in a specific series of sieves and dividing the sum by 100. On the other hand, to determine the density of the fine aggregate, the volume difference method was used (Equation 2); while, for absorption, the process described in NMX-C-165 was used.

$$D = \frac{MSSD}{DVD} \qquad (2)$$

Where, $\boldsymbol{D}$ = aggregate's density; ***SDSS***= surface dry saturated sample and ***DVD*** = displaced volume difference. For the obtention of the absorption percentage, Equation 3 was used with the data obtained from the process of saturation and drying of the fine aggregate:

$$\%Absorption = \frac{B-A}{C} * 100 \qquad (3)$$

Where, ***B***= dry sample weight, ***A***= saturated sample weight, ***C***= surface dry weight. The sample obtained was subjected to the washing process in accordance with the standard [1] to remove excess fines from the aggregate. The sample was divided into two equal portions of 1 kg and, subsequently, sieved through sieve number 200 to eliminate the fines within it, until the water did not present turbidity. Once the sample was washed, it was placed on the electric grill to dry, allowing it to cool to room temperature in a period of t=1h - 3h. Once the time had elapsed, the material to be saturated in water (700 ml) was placed for a period of t=24 h inside a covered metal container to prevent moisture loss. After 24 h, the fine aggregate density was determined by means of the water displacement method in conjunction with the NMX-C-165 standard, the process is summarized in Figure 2b.

Physicochemical characterization of Pitahaya

For a correct workability, a pre-grinding was carried out on the pitahaya stems, which allowed obtaining better results in the dehydration of the material. For this, a manual mill with an iron body and a capacity of 2 kg was used. Grinding was carried out until a smaller material was obtained. It is worth mentioning that this pre-grinding was done with fresh pitahaya stems, just as they are obtained from pruning. The dehydration process consisted of placing the collected and ground material in a muffle at a T_{max} = 175°C for t = 2 h to subsequently continue with the dehydration, which was carried out with a thermal process starting at room T until reaching T = 175 °C in a period of t = 3 h, as shown in Figure 3. Once the material was dehydrated, the sample was subjected to a mechanical grinding process, using a blender equipment with blades until obtaining a fine powder of 0.2 mm size.

Figure 3 Dehydration process

Thermogravimetric Analysis (TGA). The powder decomposition process during thermal heating was characterized by thermogravimetric analysis using a MOM – Budapest OD – 103 equipment in a temperature range of T= 0°C to 800°C with a heating rate of 10°C/ min.

Determination of the chemical composition, through X-Ray Fluorescence analysis (XRF). XRF data were obtained with a Philips PW – 1050 X´ diffractometer using radiation of Cu Kα = 1.5487 Å. The diffraction patterns were run over a range of 2θ = 10 – 100° with a step of 0.02 in 2θº.

Determination of the morphology, through an analysis of Scanning Electron Microscopy and Dispersive Energy Spectroscopy (SEM-EDS).

The morphology and microstructure of the materials were performed using a SEM (JEOL, model JSM-6510LV) equipped with an energy dispersion spectrometer (EDS, BrukerXFlash 6I10).

Mix Design and mechanical characterization

The mix design was determined with respect to the number of variables available, which are shown in Table 3. Where, Vc is the volume of cement, Vsd the volume of sand and Vw the volume of water. Three types of mixture were made, the first one was the control mixture (MC_0), another mixture with 1% addition of pitahaya cactus (MP_1) and the third one with 2% addition of pitahaya cactus (MP_2). The volumes' method was used with the data shown in Table 3.por paso, que se estimó mediante calculo y mediante las pruebas de flujo en secciones posteriores.

	CONTROL MIX			
	% Fluidity	110.0%	**Ratio a/c**	0.54
Real Volume	0.00050	**m^3**		
Vc	0.331	**kg**	331.5	**gr**
Vsd	0.655	**kg**	687.75	**gr**
Vw	0.179	**lts**	178.9	**ml**
	MIX WITH 1% ADDITION			
	% Fluidity	112.3%	**Ratio a/c**	0.57
Real Volume	0.00050	**m^3**		
Vc		344.58		**gr**
Vsd		687.75		**gr**
Vw		200.01		**ml**
	MEZCLA CON ADICION 2%			
	% Fluidity	113.5%	**Ratio a/c**	0.59
Real Volume	0.00050	**m^3**		
Vc		344.58		**gr**
Vsd		687.75		**gr**
Vw		206.07		**ml**

Table 3 Mix design

Fluidity in Mortar. This test was carried out in accordance with NMX-C-486 to obtain a workable concrete mix; briefly, for a mix to be considered workable, it must be within the limits of 110 ± 5% for CPC 30R cement, starting with a percentage of water calculated in the mix design and varying its volume. For each one of the volumes, the diameters were measured, and the fluidity was calculated with Equation 4. This procedure was repeated for the mixtures with 1% and 2% addition of dehydrated pitahaya, until the necessary fluidity was found.

$$\% \, Fluidity = \frac{(Average\ diameter - Initial\ diameter)}{Initial\ diameter} * 100 \qquad (4)$$

Compressive Strength. Cubes with dimensions of 5 cm x 5 cm were made, which were pre-conditioned and cleaned, avoiding previous residues. The elaborated specimens, after 28 days of curing, were tested to determine their compressive strength. These specimens, once taken to failure in the aforementioned test, were crushed and the obtained powder was characterized by SEM to know its morphology.

Results and Discussion

Physical characterization of fine aggregate

Regarding the characterization, this turned out to be within the lower (LL) and upper (UL) limits established in accordance with the NMX-C11 standard, as it can be seen in Figure 4. From this, an FM of 2.83 was obtained.

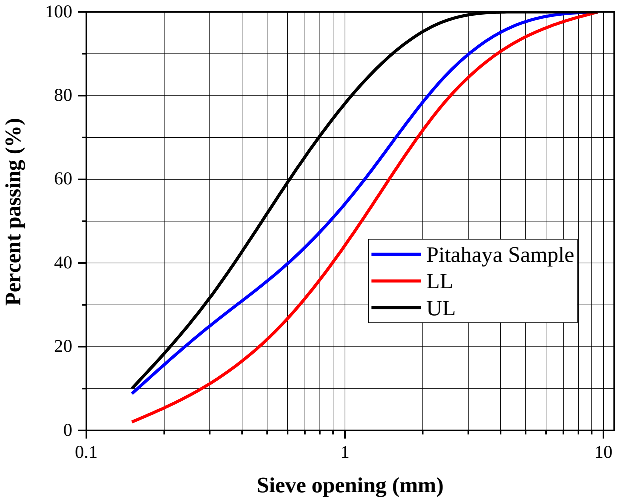


Figure 4 Fine aggregate grading graphic

Similarly, results of the characterization, described in Table 4, show a high percentage of absorption, which is why, according to the literature, they are classified as high absorption aggregates [14]. Due to this, the mix design required a higher percentage of water, since, being a material with high absorption, it will need more of it, so that, otherwise, in the hydration process, the water consumed will leave spaces, causing pores and fissures and consequently, the quality of the mix will be affected [17].

Aggregate	DLVW (kg/m^3)	DCVW (kg/m^3)	Absorption (%)	Relative Density	Wear (%)	Fineness Modulus
Fine aggregate	1.31	1.76	5.26	2.86		2.83

Table 4 Fine aggregate characterization

TGA Analysis. TGA analysis allowed to determine the thermal conditions at which the pitahaya powder begins to decompose. The TGA curve showed a behavior of mass loss with the increase in temperature, as shown in Figure 5. The TGA graph showed a rapid weight loss in a range of 25°C - 126°C (I) of at least 7% of the initial weight, associated to water loss [3]. A second weight loss of about 10.96% in a range of 126 °C – 177 °C (II). A third more pronounced loss of 75.08%, in a range of 177 °C -323 °C (III), which is related to the decomposition of polysaccharides [18,19], stage that does not produce the best properties in the pitahaya powder for its implementation in the mortar mix. These components help to improve the properties in the mixtures, so, according to the results and the literature, the optimal range would be between T=126°C – 177°C (II) [20]. In sections III and IV, the loss of elements corresponds to the polysaccharides [3].

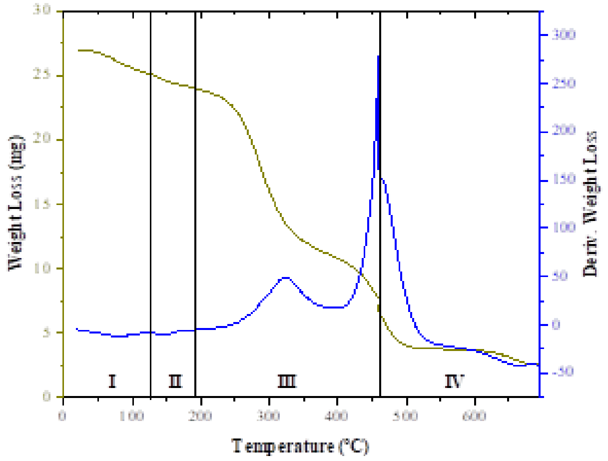


Figure 5 TGA curve for pitahaya powder

XRF Analysis. To identify the presence of elements that favor the implementation of the powder in the mixture, an XRF analysis was performed. Results, shown in Figure 6, exhibit the presence of calcium in a higher concentration percentage of 70.15%, Manganese (Mn) of 0.61%, Iron (Fe) of 1.96%, which is characteristic of this type of species such as nopal [4,8,12,20]. This element (Ca), which is found as Calcium Oxide (CaO), together with those of the cement, can accelerate the hydration process in the mixtures, due to the higher percentage of calcium, which is present in the main phase (Alite) responsible for the initiation of setting and early strength [21].

The pitahaya powder presented mostly Ca elements, so, as mentioned in previous lines, it can be beneficial for the initial phase of hydration and resistance [2].

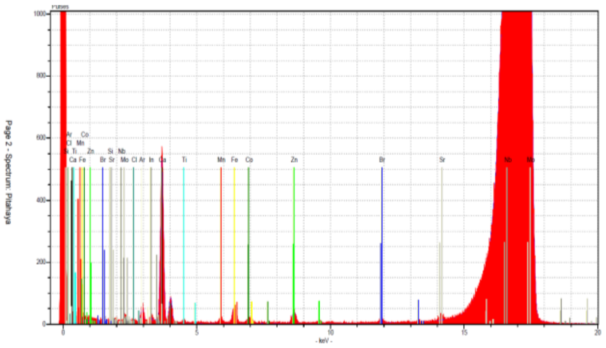
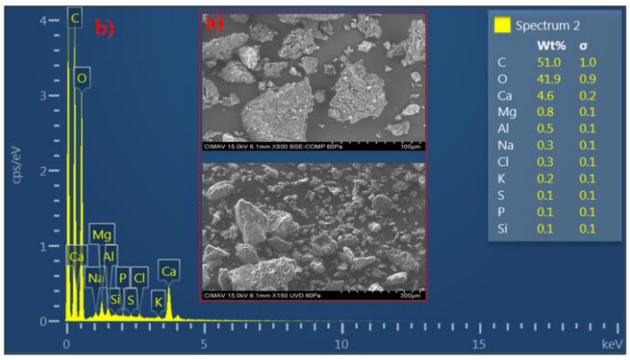


Figure 6 XRF analysis of the pitahaya powder

SEM-EDS. Results of the SEM analysis for the pitahaya powder are shown in Figure 7, where a polygonal structure can be observed due to particle size as reported in [22][22]. It is also possible to observe the surface of the particles, which tends to have a rough shape [23]. Some reports also indicate that this kind of structure can be associated with the drying conditions and the extraction method [24]. The EDS analysis shows the presence of elements such as Carbon (C), Oxygen (O) and Calcium (Ca), belonging to this type of species such as nopal [25]. As for these elements found, they tend to the molecular structures of sugars where these elements predominate [26]. As shown in Figure 8a, these elements correspond to the formation of some crystals corresponding to calcium oxalates, which is the most common in this type of material [27]. When these components come into contact with water and cement, they react favorably, improving in the curing stages, causing these particles to store large amounts of water, covering the network of interconnected pores and acting as an additive for a good hydration of the mixture [20].



Spectrum 2

	Wt%	σ
C	51.0	1.0
O	41.9	0.9
Ca	4.6	0.2
Mg	0.8	0.1
Al	0.5	0.1
Na	0.3	0.1
Cl	0.3	0.1
K	0.2	0.1
S	0.1	0.1
P	0.1	0.1
Si	0.1	0.1

Figure 7 a) SEM images at 500x and 150; b) ESD of dehydrated pitahaya powder

Fluidity in mortar

Once the volumes of cement, water and sand were obtained, the fluidity test was carried out to determine the correct volume of water. The data obtained is shown in Table 3. It is possible to observe that the correct amount of water to comply with the standard was 155 ml, with which the w/c ratio was modified. Subsequently, two tests were carried out with an established volume of water, the first one with a volume of 150 ml, in which the lack of workability was noticed because of the high density of the mixture, which reached a fluidity of 85.55% and the second one with a volume of 155 ml, where the fluidity was optimal with 110%, as it can be seen in Table 3.

Implementing the same procedure of the NMX-C-486, the volume of water was increased from 150 ml to 155 ml for the control samples, in this case, the mixture showed greater workability when it was emptied into the cone. At the end of the process, the diameters were measured to verify that the mixture complied with the appropriate percentage. The mixture with 155 ml of water was adequate to meet the standard. In the case of the mixtures with addition of pitahaya powder of 1%, the mixture was made with the parameters established in the NMX-C-061 standard, which complied with the percentage of fluidity in the control mixture. The mixing process was similar to that of the control sample with the difference that, at the time of pouring the cement, the pitahaya powder was added too. For this test, the volume of water needed to add to the mortar mix for the cubes was obtained. After having carried out the same procedure for the mixtures with the addition of 2%, no inconvenience was noted at the time of the mixing process. Similarly, the volume of water (Table 3) for the mixtures with 1% pitahaya powder was obtained by increasing 5 ml of water. For the volume of 165 ml, the mixture did not meet the standard, so the volume was increased by 5 ml. The optimal volume of water for the mixture with the 2% addition was 170 ml, which complied with the percentage established in the standard.

At the end of each of the mixtures, it was observed that the samples with the addition of pitahaya needed a greater amount of water to obtain the appropriate fluidity percentage, since these materials tend to store water inside their pores. Table 3 shows that, as the addition percentage of pitahaya powder increases, and the percentage of cement decreases, the w/c ratio increases. These results were similar to those described in several research works where they have implemented cacti such as nopal and dehydrated aloe and the authors agree with the increase in the volume of water in the mixtures, due to the type of organic material which has properties of storing water in the pores [20].

Preparation of specimens

After obtaining the parameters for the adequate workability of the mixtures, the mortar cubes were made, as shown in Figure 8, according to NMX-C-061. Obtaining a total of 3 mixtures (0%, 1% and 2%), with 4 samples each, at the age of 28 days. During the elaboration process, no change in the color of the mixture was noted, which could be related to the low percentage of addition; in contrast, a characteristic odor was perceived at the time of mixing due to the addition of pitahaya powder.

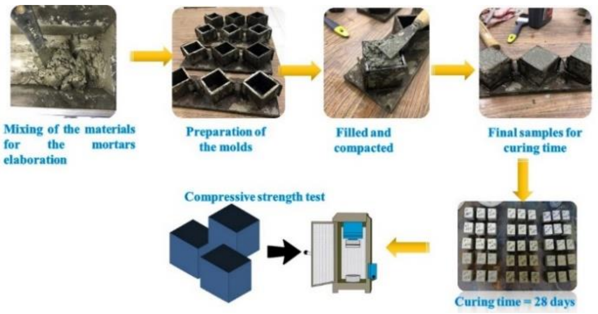


Figure 8 Elaboration process of the mortar mixtures for the different addition percentages

Mechanical and structural Characterization of mortars

Compressive strength. Figure 9a shows the results of the compression test evaluated at 28 days, in which it is possible to appreciate that this mechanical property improved significantly; in the case of the sample with 2% addition, it presented a decrease in resistance with respect to that of 1% addition, this is due to the higher percentage of pitahaya powder, since this material, as mentioned above, has the ability to store water within its structure [20].

So that those spaces left by the water particles within the matrix were not occupied by the cement particles [7,28]. Another behavior that is noted in Figure 10b is that the increase in resistance values improves as the percentage of fluidity increases, making these mixtures more workable. These results agree with what was found in other investigations, where the addition of a cactus species improved this property in percentages lower than 2% [29].

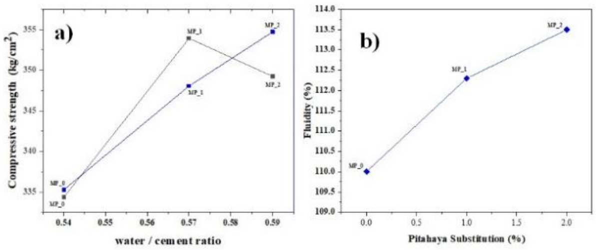


Figure 9 a) Compressive strength of mortar cubes and b) relationship between fluidity and percentage of pitahaya powder

It is important to mention that, in research works where nopal powder was implemented, the optimum amount was less than 1% since, when that amount is exceeded, the compressive strength decreases, due to the fact that the material absorbs more water and, in the hydration, process generates voids that affect the quality of the mixture [11]. For the case of the addition of dehydrated pitahaya, the proportions of 1% and 2% significantly exceeded the resistance of the control sample, even though they presented an increase in the w/c ratio.

SEM analysis in mortar mixtures. SEM images taken from the mortar cubes were analyzed, which were crushed in order to extract the powder from it.

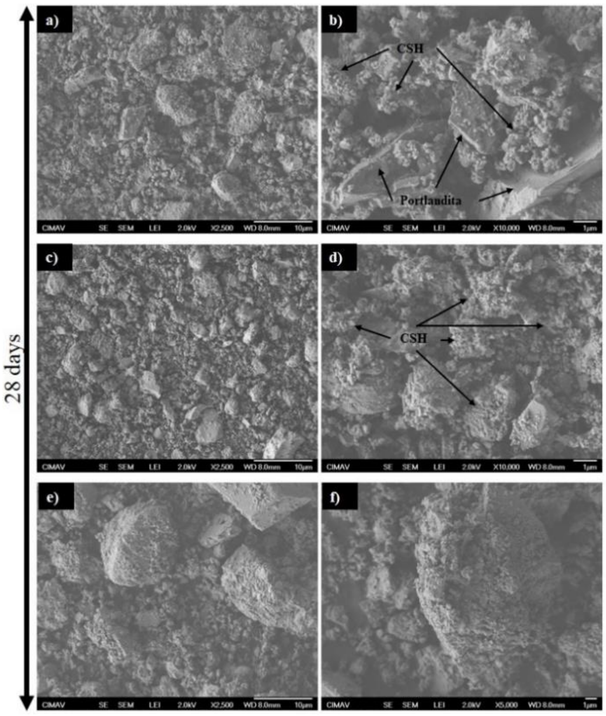


Figure 10 SEM micrograph of 0% (a and b), 1% (c and d) and 2% (e and f) at 28 days of curing

Figure 10a and b show images of the control mixture (0%) and the presence of portlandite crystals and calcium silicate hydrate (CSH), product of the hydration of the mixture [5]. For the sample with 1% addition of pitahaya powder, Figure 10d shows more hydration products due to the implementation of pitahaya powder and, as a result, the increase in compressive strength [4]. In the case of the mixture with 2% addition, it was possible to see small sponges that were not found in the control mixture, which may be particles of pitahaya powder and, like PM_1, it is possible to see hydration products. as CSH around said particles. These elements favor the hydration of the mixture, making it less permeable.

Conclusion

It was possible to observe that, during the characterization of the pitahaya powder, it has elements such as Carbon (C), Oxygen (O) and Calcium (Ca), which make it compatible for the implementation of this material in mortar mixtures. Likewise, the presence of portlandite crystals and hydrated calcium silicate (CSH) was noted, product of the hydration of the mixture in the additions of 1% and 2%. In the characterization, the optimum decomposition range of the material was also obtained, showing values similar to those obtained for nopal.

For the particular case of pitahaya, values between T=126 °C – 177 °C would be appropriate according to the dehydration method implemented in this research work. The implementation of this material, like its close relative the nopal, showed water storage capacity, a peculiar property of this species and a fundamental part for the improvement of the characteristics of the mortar mixtures. This property was reflected in the compressive strength, since the addition of pitahaya powder improved the strength values for MP_1 (353.93 kg/cm^2) and MP_2 (349.24 kg/cm^2), with respect to the control sample (MP_0) of 334.5 kg/cm^2, achieving in the same way the reduction of cement. It was noted that this increase in resistance is related to the percentage of substitution even when the percentages of fluidity increased, acting as an ecological alternative for this type of mixture. The values of these mixtures exceeded the control mixture in percentages of 5.80% for PM_1 and 3.93% for PM_2 due to the development of hydration products and a more compact morphology that possibly reduced permeability due to the implementation of pitahaya powder and, as a result of this, the compressive strength increased by 5-10% on average for the 1% and 2% additions. The use of cacti in cement-based mixtures is still under study, so this research work has only focused on the Hylocereus undatus species, however, it is necessary to expand the research on applications for the construction industry.

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