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Compressive Behavior of Mortar Mixtures Including Marble Waste (Dust) and Nopal Mucilage

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***Abstract*— The exploitation of natural resources has been a frequent activity in the history of society. This activity has generated great benefits; however, its negative effects are obvious, just look at the large amount of waste that is produced and that generally has no use. Such is the case of the marble industry which generates thousands of tons of waste, highlighting the dust for its negative effect, since it contains very fine particles that contaminate the air causing health problems. In this work, it is shown how marble dust in combination with cactus mucilage can be used in mortar mixtures. Mixtures were made by replacing marble dust and mucilage with sand and cement in various percentages, and then their behavior under compression was evaluated, observing that these mixtures have similar characteristics to traditional mortar, some even exceed their resistance.**

***Keywords*— Mortars; marble waste; cactus mucilage; cementitious mixtures.**

I. INTRODUCTION

Sustainable development has had a great boom in recent decades, various sectors of the scientific and research community have tried to mitigate the negative effects of the exploitation of natural resources through the development of new production techniques, new materials, recycling of materials, etc. Over the years, society has modified its lifestyles without leaving behind architectural evolution. Natural aesthetic elements such as marble have not stopped being used.
Unquestionably, the construction industry is very important for the growth of the infrastructure of cities, however, this situation causes it to be one of the industries that consume the most natural resources (Kibert et al 2000), coupled with high consumption of energy, causing a strong negative impact on the environment. This problem is evident in the marble industry, affecting society, mainly the inhabitants surrounding the marble production and processing areas, due to the large dispersions of dust (Betancourt et al. 2015), which is usually a substance that tends to be too absorbent in terms of its physical characteristics.
Fine dusts are usually very light, so they are easily combined with air, and, in the presence of dust storms, they can reach the immune systems of the population near the area of influence, causing a high rate of allergic diseases such as rhinitis, conjunctivitis and bronchial asthma (Barrientos and Holguín 2009).
Thus, many researchers are focusing their work on improving construction materials (Cabrera et al. 2017, Medina 2000, Suescum-Morales et al. 2022, Visairo-Méndez et al. 2021). Work can be observed in which solid waste and organic materials are used in the creation of modified materials such as bricks, blocks, concrete and mortar, among others. (Aukour 2009, Hernández et al. 2016, Kavas and Olgun 2008, Kazim et al. 2023, Sung-Ching et al. 2024,).

Marble
Marble is a carbonated sedimentary rock (mainly limestone) that has reached a high degree of crystallization through the process of metamorphism. For centuries, it has been associated with the topic of construction, mainly in countries with the largest deposits, such as Italy, Spain, Portugal, Turkey and Greece. Likewise, in America, countries such as the United States of America, Canada, Mexico and Brazil stand out.
As mentioned above, various investigations around the world are experimenting to develop construction elements that are sustainable and environmentally friendly, including studies on mortar and concrete mixtures. In India, Singh and Nanda (2013) experimented with concrete and mortar mixtures replacing cement with marble dust in various percentages (0%,

5%, 10%, 15%, 20%) obtaining compression and flexural similar results acording with control mixtures, observing that the development of this type of mixtures is viable.
Likewise, in Turkey they found that the addition of marble dust as a filler does not affect workability, however, its compressive strength is affected in mixtures above f¨c=200 kg/cm^2 (Topcu, et al., 2009).
At the Hashemite University of Jordan, a project was carried out to develop cement blocks with marble sludge, which was monitored for three years with very encouraging results. The results showed that by appropriately incorporating waste, an element with favorable characteristics in terms of compressive strength can be produced, as resistances of 91 kg/cm2 were obtained after 28 days. This use is very attractive, since the waste has no cost, as companies seek to get rid of it (Aukuor, 2009).

Nopal
Nopal is available in many arid and semi-arid regions of Mexico, 874,000 tons are produced per year, with an average yield of 67 tons/inhabitant. In addition, the use of nopal mucilage in cement-based materials can have a social impact, providing added value to the production of this plant, and improving its profitability. It should be mentioned that not all species of nopal are used as food, so those that are not used for human or animal consumption can be used for industrial applications (Hernández, 2008).
Mexico is one of the countries in which the implementation of organic materials has been growing, nopal mucilage is one of the most common, taking advantage of its properties to modify the characteristics of construction materials. Aranda and Suárez (2013) experimented with the inclusion of mucilage in various percentages (0, 1, 2, 3, 4, 10, 20, 30, 40 and 50) in compressed earth blocks (CEB), concluiding that it can improve compressive strength, porosity decreases as the mucilage concentration increases, improving impermeability.
Noriega (2005) demonstrated that nopal works as an additive for construction, even using all of it, that is, mucilage and shell of the nopal through drying at high temperatures. The indigenous people ancestrally used the mucilage of the nopal to glue adobe for the coating of walls, they used mixtures of lime with mucilage (Granados, 1997).
Hernández (2008) used nopal powder (dehydrated nopal) to improve the mortar, he made various mixtures. The results obtained from their resistance to compression were favorable, since the mortars with nopal additive showed greater resistance than the reference mortars, the only drawback is that it requires a longer period to achieve its final setting. In the research carried out by Ramírez-Arellanes (2008), it is shown that the mucilage increases the viscosity and acts as a retardant. Likewise, depending on the amount of nopal mucilage, its resistance to axial compression and its modulus of elasticity increases or decreases.
Based on this characteristic, De León Castillo (2012) investigated nopal as a retarding additive in self-compacting concrete. In this case, the nopal used was in liquid form (nopal mucilage) and it was found that depending on the amount of additive, it improves some properties of the concrete.
Since nopal has been used as an additive in liquid form, it is necessary to know the best method to obtain nopal mucilage (additive), producing the least amount of CO_2 possible. In this regard, Pérez et al. (2015) explain three extraction methods, they experimented in the elaboration of mortars with mucilage and using as aggregate: marble dust, brick dust and yellow sand. These were studied and compared in the contraction, hardness and maximum stress tests with different amounts of aggregates and additives. The mortar that gave the best results in terms of stress-strain was the mixture with a 1:3 proportion of lime-marble dust with a maximum value of 11.73 kg/cm^2.
To identify whether the characteristics of mucilage and its performance as a material depend on the extraction method, three processes were analyzed: In each method, the characteristics of the mucilage were measured in Brix degree, the most relevant method was the method called two, in which the nopal leaves were cut into small pieces and left to rest for 24 hours in distilled water, then they were pressed, to try to obtain the largest amount of mucilage possible and finally they were filtered.
Using extraction method 2, lime mortars were made, and two variables, load and proportions, were considered as part of the test, mainly evaluating their mechanical resistance. The aggregates used were yellow sand, brick dust and marble dust, each prepared in two lime-load proportions: 1:1 and 3:1. Various control mixtures were used, some were added with only water and others with cactus mucilage as an additive. In the results obtained, the 1:3 proportions of marble dust and yellow sand showed greater compatibility with cactus mucilage. In this proportion, the mucilage considerably increased the mechanical properties of the mortars: presenting less contraction, greater hardness and resistance to maximum effort. These results are directly related to the material and proportion used.
Despite the countless tests carried out on cactus mucilage, it has not been possible to carry out an evaluation that measures its effectiveness in detail, there are many variables in both the preparation and the application conditions. To this we must add the methods of extraction of the mucilage, since the difference between the methods of obtaining and preparing it can have a subsequent effect on its properties.
Considering the problems caused by this type of waste (marble dust), a sustainable product is being developed that uses the waste in combination with nopal mucilage, particularly mortars, trying to achieve better mechanical performance of the new product. The use of these materials could consequently help reduce the large amounts of waste, protect material banks and reduce the use of cement.

II. MATERIALS AND METHODS

The materials used in this research were the following:

• Marble dust (waste) produced by cutting and polishing slabs of the same material, from the company “Mármoles Parra”, located in Ciudad Lerdo, Durango.
• Nopal mucilage (Opuntia ficus-indica) from the region.
• River sand.
• Portland cement CPC R30

Tests were carried out on the aggregates (dust and sand) to determine their physical characteristics such as: volumetric weight, density, granulometry, percentage of humidity and absorption.

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The nopal mucilage was obtained by the resting and filtering method, that is, the nopal was cut into square pieces of 1 cm approximately and left to rest for 24 hours, then strained to remove solid particles.
Once the materials to be used were characterized, exploration mixtures were prepared with a dosage of 1 part cement and 2.75 parts aggregate (1:2.75). Four mixtures were established as an exploratory experiment, MC1, which is the control mixture, and mixtures M1, M2 and M3, which have a percentage of replacement of cement and sand by cactus mucilage and marble dust (see Table 1).

Table 1. Dosage of exploratory mixtures.

Mix	Base material	Replacement percentage	Material replaced
MC1	Sand	0%	Marble dust
	Cement	0%	Mucílage
M1	Sand	10%	Marble dust
	Cement	5%	Mucílage
M2	Sand	10%	Marble dust
	Cement	10%	Mucílage
M3	Sand	15%	Marble dust
	Cement	5%	Mucílage

After specifying the dosage of the mixtures, cylinders were made for each test age (28 and 90 days), three for the control mixture and three cylinders for each of the mixtures with substitution, the mixing was done dry manually and later the water with the mucilage was added. The cylinders were made and tested according to the current regulations (NMX-C-486-ONNCCE-2014), as well as the compression tests (NMX-C-061-ONNCCE-2015), see Figure 1.

Figure 1. Preparation and testing of exploration samples.

Taking the results of the exploration experiment as a reference and trying to use a smaller amount of cement, a second experiment was carried out which was called the base experiment. For this stage, 5x5x5 cm cubes were used to prepare the compression test specimens. Three mixtures were made: MC2, ME1 and ME2 (see Table 2). Where: 50% of the sand in the ME1 mixture was replaced by marble dust and the amount of cement was reduced by 30% with respect to that used in the control mixture (MC2). In addition, the nopal mucilage was diluted in water at a rate of 15%. 10% of the sand in the ME2 mixture was replaced by marble dust and the amount of cement was also reduced by 30% with respect to that used in the control mixture (MC2). Likewise, the nopal mucilage was diluted in water at a rate of 15%.

Table 2. Dosage of base experiment mixtures.

Mix	Base material	Remplacement percentage	Material remplaced
MC2	Sand	0 %	Marble dust
	Cement	0 %	Mucílage
ME1	Sand	50 %	Marble dust
	Cement	-30 %	Cement of control
	Water	15 %	Diluted mucilage
ME2	Sand	10 %	Marble dust
	Cement	-30 %	Cement of control
	Water	15 %	Diluted mucilage

It should be noted that these dosages were prepared with the purpose of observing whether the compressive strength is maintained despite reducing the amount of cement, since as Arguelles-Hernández (2013) points out, cement is one of the materials most produced in the world and therefore generates large amounts of CO2 for each ton produced, which is why reducing the use of cement directly influences the production of less polluting materials.

III. RESULTS

Although the results of the exploratory stage could be considered good, they are not those expected for a type I mortar that has an average strength of 180 kg/cm² (see Table 3). However, with this strength it could be used as a type II mortar, which is also used for structural purposes according to the structural design (NMX-C-486-ONNCCE-2014). It is important to note that the amount of water used for mixtures M1 and M3 (10-5% and 15-5%) of marble dust and cactus mucilage respectively, was 183.33 ml/cylinder, while in the control and M2 mixtures (10-10%), the amount of water increased to 250 ml/cylinder, that is, the mixtures with mucilage require less water.
On the other hand, in the compression results of the base experiment, it can be observed that the resistance (see Table 4) is within the parameters established in the Mexican regulations for type I mortar, so it is considered feasible to use it for this purpose.

Table 3. Average compressive strength, exploratory experiment.

Mix	28 days (kg/cm²)	90 days (kg/cm²)
MC1	138	219
M1	135	**288**
M2	129	204
M3	139	162

Table 4. Average compressive strength, base experiment.

Mix	7 days (kg/cm²)	28 days (kg/cm²)
MC2	124	178
ME1	125	177
ME2	142	202

IV. CONCLUTIONS

Based on this research, it can be determined that it is possible to use marble waste (dust) and cactus mucilage in mixtures for hydraulic mortar, obtaining similar and even better compressive strengths than traditional or common mortars.

• The workability of the mixtures with marble dust and cactus mucilage compared to the control mixtures was lower, since their consistency is denser.
• The mixtures with marble dust require a longer time for homogenization.
• The mixtures with cactus mucilage require less water than those that do not use mucilage.
• Cactus mucilage acts as a retarding additive and contributes in some way to improving the compressive strength in mortars.
• Cactus mucilage helps improve the workability of the mixtures.
• The compressive strength of the mixtures of the base experiment that used marble dust and cactus mucilage showed good compressive performance compared to the control mixtures.

Recommendations

It is recommended to carry out a chemical and mineralogical characterization of the elements that make up the mortars, to have a better overview of their composition.

Further studies should be carried out, experimenting with other dosages, varying the percentages of marble, mucilage and cement residues.

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