Comparison of the Percentage of Absorption and Voids of Concrete Produced by Incorporating Candelilla Wax as a Coating for the Coarse Aggregate and a Conventional Concrete

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Abstract - Concrete with high permeability results in the decrease of other properties, such as the durability, which it's reduced considerably. The main goal of this research is to compare the percentage of absorption and voids with the incorporation of candelilla wax in the concrete in order to increase the durability in it. This research consisted of the preparation of two concrete mixtures, one was made conventionally, which was designated as the "standard sample", and the second was prepared with a candelilla wax coating on the coarse aggregate, which was designated as the "test mixture".

Thirty-three samples of each mixture were made and tested after twenty-eight days. Each test was carried out in accordance with current standards. A statistical analysis was then done on the standard sample and the sample prepared with candelilla wax.

The results indicate that the test sample reduced the percentage of absorption and voids, thereby increasing the durability of the concrete.

Key words: Durability, absorption, voids, concrete, candelilla.

I. INTRODUCTION

A feasible solution to reduce the environmental impact of the concrete industry is to properly manage the resources that compose it. Likewise, by carrying out the above, in an effective way, concrete improves its properties such as durability or otherwise it will need less energy or materials in its production [2].

Research with non-conventional materials on aggregates and concrete admixtures has diversified, all this because the massive production of concrete has led to an excessive consumption of natural resources. Some research has been carried out with materials added to concrete in production, such as: polypropylene fibers, steel shavings, lechuguilla, coconut tow, bagasse, foundry slag, industrial waste and construction debris or waste [10].

In the past, mechanical strengths, such as compressive strength, were thought to be the most important property, but recent studies show that concrete durability is critical. One condition that leads to low durability of concrete is high permeability, as an example, reinforced concrete is mentioned, the penetration of water and oxygen producing corrosion in the steel, facilitating the appearance of cracks in the concrete. Permeability is not only related to the number of voids in concrete, but also to their size, distribution and continuity. Some parameters that help measure the permeability of concrete are the physical properties of absorption and void ratio [9].

Durability control in concrete provides a lower cost in the maintenance of structures from an economic investment perspective. The deficiency of this property will affect society, the surroundings and the environment, since the impact of reconstruction or repair is negative [9]. The objective of this paper is to compare the percentage of absorption and voids of concrete, incorporating candelilla wax as a coating of the coarse aggregate and a concrete produced in a conventional way.

II. METHODOLOGY AND MATERIALS

A. Candelilla plant description

Candelilla is a plant that ranges in size from 20 to 110 cm tall, grayish in color and leafless. This is because they are covered with wax, but in rainy weather they bloom as shown in Fig. 1 (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2008; Aguilar, Aguirre, Ascacio, Rojas, 2012; Garza., 2015).

Fig. 1.- Candelilla plant in its semi-arid environment. [7]

B. Physical properties

Candelilla wax is brown in its unrefined form and changes to a yellow color (Fig. 2), once this process has been carried out, it has an undefined structure and its hardness is intermediate between the carnauba wax and beeswax.

Fig. 2.- Refined Candelilla. Ávila. (2013).

It is solid at 20°C, reaches a maximum viscosity point at 80°C, is insoluble in water but is soluble in chloroform and toluene and has a specific gravity of about 0.98. Table 1 and 2 show some physical properties of candelilla wax [8].

Table I.- Physical properties of candelilla wax [8].

Melting point (°C)	67 - 79
Acidity value (mg KOH/g)	12 - 22
Iodine content (mg I_2/g)	14 - 27
Saponification value (mg KOH/g)	35 - 87
Thermal diffusivity (cm^2/s)	0.026 ± 0.00095
Thermal conductivity (W/mK)	2.132 ± 0.16
Electrical resistance (Ohm-cm)	5.98 ± 0.19 x 10^{17}

C. Chemical composition

The typical composition of candelilla wax is presented in Table II.

Table II.- Chemical properties of candelilla wax [8].

Hydrocarbons (ca. 98% kerosenes and 2% alkanes)	42.0% (w/w)
Wax, resin and sitosterol esters	39.0% (w/w)
Lactones	6.0% (w/w)
Free wax and resin acids	8.0% (w/w)
Free wax and resin alcohols	5.0% (w/w)
Saponifiable constituents	23.0-29.0% (w/w)
Unsaponifiable constituents	71.0-77.0% (w/w)

III. PREPARATION OF THE MIXTURE

The test specimens for this study were prepared in accordance with Mexican Standard NMX-C-159-ONNCCE-2004, Concreto-Elaboración y Curado de Especímenes en el Laboratorio and the international standard ASTM C-642-13 [3].

A standard sample was made according to the mix design for a f'c = 250 kg/cm2 (water, cement, sand and gravel). Fig. 3a, 3b, 3c and 3d show the preparation of the mix, slump and cylindrical samples.

(a) (b) (c) (d)

Fig. 3- Preparation of the standard mix (a) preparation of materials, (b) mixing of materials, (c) slump test and (d) preparation of cylindrical samples. Own elaboration

A concrete mix was made, with coating of the coarse aggregate with candelilla wax, which is the object of study. The tests are based on ASTM C 642-13 Standard Test Method for Determining Density, Absorption and Void Volume in Hardened Concrete [3].

A. Characteristics of aggregates

The stone aggregates used for the preparation of the research mixtures are those found in the facilities of the materials laboratory of the Facultad de Ingeniería, Ciencias y Arquitectura (UJED). The characteristics of coarse and fine aggregate are presented in Tables III and IV, respectively.

Table III.- Coarse aggregate characteristics. Own elaboration

Coarse aggregate characteristics	
	Gravel
Volumetric weight rodding (Kg/m³)	1512.24
Loose volumetric weight (Kg/m³)	1373.09
Absorption (%)	0.840
Density (g/cm³)	6.544

Table IV.- Fine aggregate characteristics. Own elaboration

Fine aggregate characteristics	
	Sand
Volumetric weight rodding (Kg/m³)	1512.24
Loose volumetric weight (Kg/m³)	1204.37
Absorption (%)	3.093
Density (g/cm³)	2.353

Material dosage design (f'c= 250 kg/cm²) for the standard sample and for the samples with coarse aggregate coated with candelilla wax.

The method used for the design of the mixtures in this research is volumetric weights of the A.C.I., as shown in tables V and VI below, the data for each of the dosages.

Table V.- Dosage for the preparation of the standard sample. Own elaboration

Material	Quantity
Water (l)	5.419
Cement (kg)	7.789
Gravel (kg)	26.879
Sand (kg)	20.879
Water/cement ratio	0.69

Table VI. - Dosage for the preparation of the test sample. Own elaboration

Material	Quantity
Water (l)	5.419
Cement (kg)	7.789
Wax-coated gravel (kg)	26.879
Sand (kg)	20.879
Wax (%) * Included in gravel weight	5.803
Water/cement ratio	0.69

IV. RESULTS AND DISCUSSION

Table VII.- Comparison of the averages of the data obtained in the tests carried out on the standard and candelilla wax mixtures. Own elaboration

Physical properties	Standard mixture	Candelilla wax mixture
Absorption (%)	8.48	6.36
Percentage of voids (%)	16.24	11.32

Comparing the results obtained for each test mixture, a decrease in the amounts of absorption and percentage of voids of the mixture with candelilla wax can be seen, regarding to the data obtained with the standard mixture. Table VII shows the comparison of the averages of each of the physical characteristics of the mixtures in this research.

Fig. 4 and 5 show the behavior of the data of each of the tests for the two mixtures and show the difference between the results in a better way.

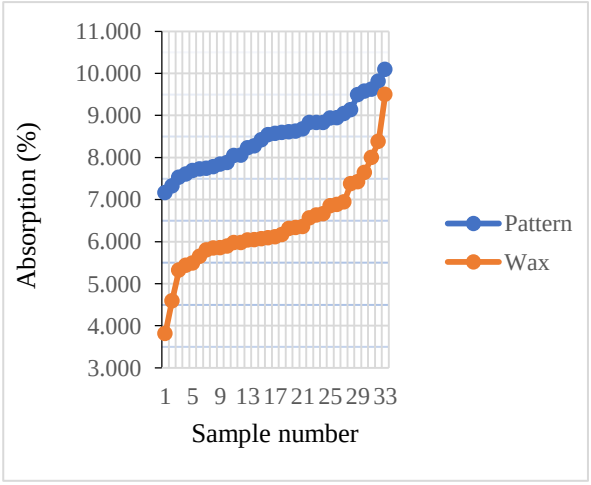

Fig. 4. Comparison between the absorption tests of the standard mixture and the mixture with candelilla wax. Own elaboration

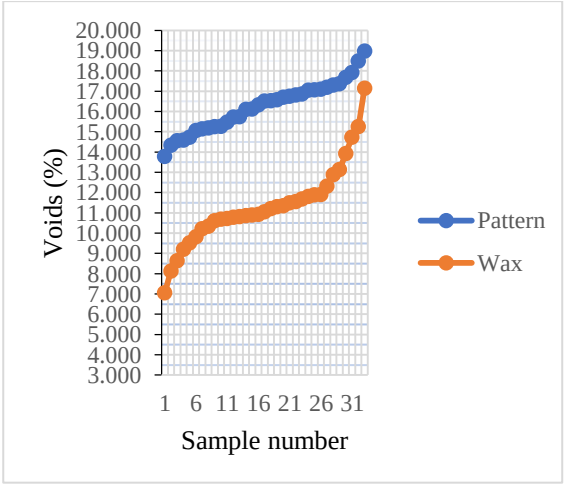

Fig. 5.- Comparison between the void percentage tests of the standard mixture and the mixture with candelilla wax. Own elaboration.

In the document "Durabilidad de la infraestructura de concreto reforzado expuesto a diferente ambientes urbanos de México" from the Secretaría de Comunicaciones y Transportes through the Instituto Mexicano del Transporte establishes the parameters for the evaluation of the quality

of concrete based on the percentage of voids [2]. Table VIII shows the above-mentioned information.

Table VIII.- Porosity evaluation criteria [2].

Porosity percentage	Concrete quality
$\leq 10\ \%$	Concrete of good quality and compactness
$10\ \% - 15\ \%$	Moderate-quality concrete
$> 15\ \%$	Concrete of inadequate durability

With an average value of 16.24%, the standard mix concrete would be a concrete of inadequate durability, while the mix made with candelilla wax with an average of 11.32% gets into the category of moderate quality concrete.

As previously mentioned, the percentage of voids produces a deficiency in the durability of concrete, since oxygen and other agents penetrate it, causing corrosion in the reinforcing steel and cracking in the compression material (concrete).

V. CONCLUSION

This research was aimed at collecting data and tests required to determine the percentage of absorption and the percentage of voids in a standard mixture and a mixture with candelilla wax, in order to perform a descriptive statistical analysis. This was followed by a comparative analysis of the two samples. To coat the coarse aggregate with the wax, it was concluded that the most appropriate way was to use a sieve. With the data obtained, it is possible to deduce that the mixture with candelilla wax decreases the percentage of absorption and voids, which causes the increase of the durability of the concrete and its density to decrease.

It is important to point out that is more common the concrete mixture designs that keep the specifications for some type of construction. Due to the above, it is advisable to continue investigating the behavior of different materials, with the purpose of knowing the behavior of concrete, and in this way, determine whether they are beneficial or not for the mix or provide them with a property that is useful in construction.

Based on these analyses, it can be concluded that the incorporation of wax as a coating for the coarse aggregate positively benefits the concrete mix regarding to its durability, since it decreases the percentage of absorption and the percentage of voids, while decreasing the density.

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