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Mathematical model of Concrete water penetration with recycled aggregate replacement

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Abstract :- The environmental impact generated by the use of natural aggregates in the manufacture of concrete has led to the search for alternative alternatives. The use of recycled aggregates produced from crushed waste concrete reduces the environmental effect of the exploitation of aggregates. However, physical and mechanical properties are demerited in most cases. For this reason, the need to develop a mathematical model that predicts the behavior generated by the use of these waste materials arises. In this paper, we propose a mathematical model to predict water penetration in concrete made with recycled aggregate replacements, using the results of absorbed water in Pipette Absorption Test (RILEM II.4) and the effective porosities.

Keywords:-Granulometry, particle size, sands, aggregates.

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I. INTRODUCTION

The inadequate use of concrete has led to a reduction in the useful life of the structures, causing extensive repairs or else its total replacement. This has had an impact on the increase in the extraction of natural resources, thus affecting the environment**[1]**. However, today, simple or reinforced concrete remains the most commonly used materials in the construction industry. For its elaboration, it is mainly required of: water, cement, aggregates (fines and coarse) and sometimes additives. Of these, it is cement and the coarse aggregates that have contributed to the deterioration of the environment in greater proportion.On the other hand, the coarse aggregate constitutes the major component of concrete, it is extracted from the bed of rivers or by demolition of rocks. This practice, of course, leads to the deterioration of natural environments and / or their disappearance. In order to solve this problem, the demolition concrete is being reused to manufacture AR and to use it in the elaboration of concrete for new constructions. In this sense, there are no research papers that point to AR as an element to be discarded in constructions for structural uses. However, due to the great experimental shortage of the structural and durability characteristics of this material, its use has been limited to certain types of structures and environments**[2]**. To contribute to sustainability, the concrete industry has to apply a variety of strategies, such as improving the durability of concrete and the reuse of waste materials. **[3]**. As far as durability is concerned, it is important to mention that water is the main cause of degradation of building materials. It penetrates porous media, transports harmful substances and freezes inside **[4]**. Permeability controls deterioration of concrete in the aggressive environment since the penetration of water, chlorides and other aggressive ions in the concrete are the most important factor in the process of its deterioration, both physical and chemical and it is the microstructure of the concrete that mainly controls the physical-chemical phenomena associated with water movement and ion migration in concrete **[5]**. The penetration of species that cause alterations such as chloride, oxygen and water ions in concrete, is governed by the quality of the coating of the concrete**[6].**Two aspects on the water absorption characteristics of porous building materials are of particular interest and practical importance. These are: water absorption and capillary suction property of materials**[7]**. In this paper, we propose a mathematical model to predict water penetration in concrete made with recycled aggregate replacements, using the results of absorbed water in Pipette Absorption Test (RILEM II.4) and the effective porosities.

II. EXPERIMENTAL PROCEDURE

2.1. Pipette absorption test**(RILEM II.4).**

Test tubes made of recycled aggregate with different percentages of 10.0 cm diameter and 5.0 cm high were used. The test specimens were oven dried at 50 ° C to constant dry mass. Figure 1 shows how a pipette was attached using silicone and allowed to dry for 1 h, water was added with a column height applied in the concrete surface.13.4 cm (1314 Pa) The volume of water absorbed was measured as a function of time for 24 hours, taking hourly readings of the volume absorbed. The recommendations of RILEM II.4 for the pipette indicate dimensions a diameter of 0.84 cm and 2.5 cm in the contact zone, this being an area of 0.55 cm^2. and 4.91 cm^2., respectively. In the present work, a pipette with a diameter of 2.8 cm and of 8.35 cm in the contact area was used, being areas of 6.16 cm^2. and 54.76 cm^2., respectively. The above with the intention of maintaining the relationship between the areas of recommendation of RILEM II.4 and obtaining a larger contact area, thus achieving more representative results, since a small area has a high probability of being invaded by thick aggregates. It was plotted with the absorption in cm^3 on the vertical axis against the time in s on the horizontal axis. Water absorption rate was determined with the time intervals of one hour and its absorption, results that were used for the calculation of the water penetration in the test slices.

Figure 1. Test specimens with fixed pipette.

2.2. Modeling development.

With the volumes absorbed by the test slices in the pipette absorption test (RILEM II.4) and the effective porosity of the capillary absorption and effective porosity test (ASTM C-158), the calculation of water penetration was performed for the various replacement factors r, taking into account the effective velocity **[8]**calculated with equation (3) and together with equations (1), (2) and (4), to conclude with the calculation of water penetration in the test slices of hardened concrete (10 cm in diameter and 3 cm of height) with substitutions r of 0.0, 0.25, 0.50, 0.75 and 1.0, by equation (5).

For the calculation of water penetrations of test slices with substitution factors r different from 0.0 and 1.0, starting from the penetrations obtained from these substitution factors r limits, a model was proposed whereby the results of only these two substitutions (r = 0.0 and r = 1.0) can be determined for the rest of the r, even without having manufactured the specimens with factors of intermediate replacement.

$$Q_i = \frac{\Delta \, Vol}{\Delta \, t} \tag{1}$$

$$q_i = \frac{Q_i}{A} \tag{2}$$

$$Ve_i = \frac{q_i}{\varepsilon_e} \tag{3}$$

$$X_i = Ve_i * \Delta \, t \tag{4}$$

$$X_n = \sum_{1}^{n} X_i \tag{5}$$

Where:

Q_i= Spent over a time interval of one hour(cm^3/s).

q_i = Unit expenditure or average speed in cross-section, in a time interval of one hour (cm/s).
A= Cross-sectional area of the test slice(cm^2).
Ve_i = Effective flow rate in the specimen mass(cm/s).
Δ Vol = Volume of water absorbed in one hour(cm^3).
Δ t = One hour time interval(s.).
X_i = Penetration of the water in a direction parallel to the longitudinal axis of the slicein a time interval of one hour(cm).
n= contador que va de 1 a 24, corresponde al total de horas del día.
X_n = Penetration of the water in a direction parallel to the longitudinal axis of the slice at a given time "t"(cm).

A graph was drawn with water penetration X_n (en cm) on the vertical axis versus time (in s) on the horizontal axis. This for each r substitution, all represented on the same graph. In addition, a second graph was made, in which the proposed model was compared against the calculated values of water penetration in the parallel direction of the longitudinal axis of the slice.

III. RESULTS AND DISCUSSIONS

3.1.Calculation of water penetration

With the results of figure 2 and the equation (1), Qi was calculated for intervals of 1.0 hr, then Qi was determined with equation (2) and a value of A = 78.54 cm^2, then with the results of figure 2 and the equation (3) Ve_i was calcultated, which is the average velocity of water in the concrete mass. It was calculated, with equations (4) and (5), the penetration of unidirectional water X parallel to the longitudinal axis of the specimen. These results are shown in Figure 4, where it can be seen that the increase in r produces a decreasing nonlinear increase, having as upper limit the penetrations of r = 1.0. The position of the curves for the different r of 0.25, 0.50 and 0.75 are located at 47.3, 78.3 and 95.1% of the region bounded by the curves of r = 0.0 and 1.0, respectively.

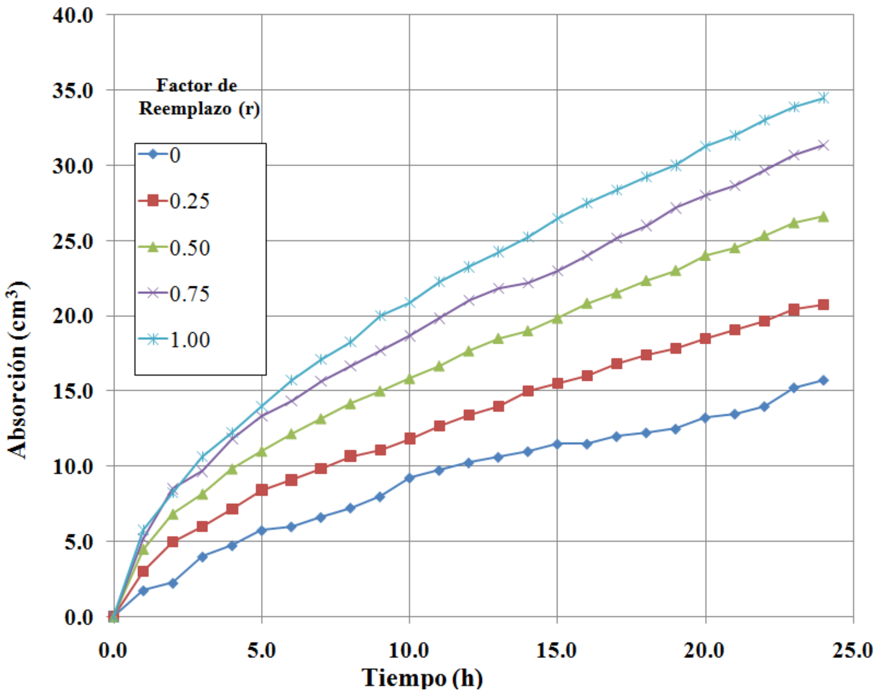


Figure 2. Results of the pipette absorption test.

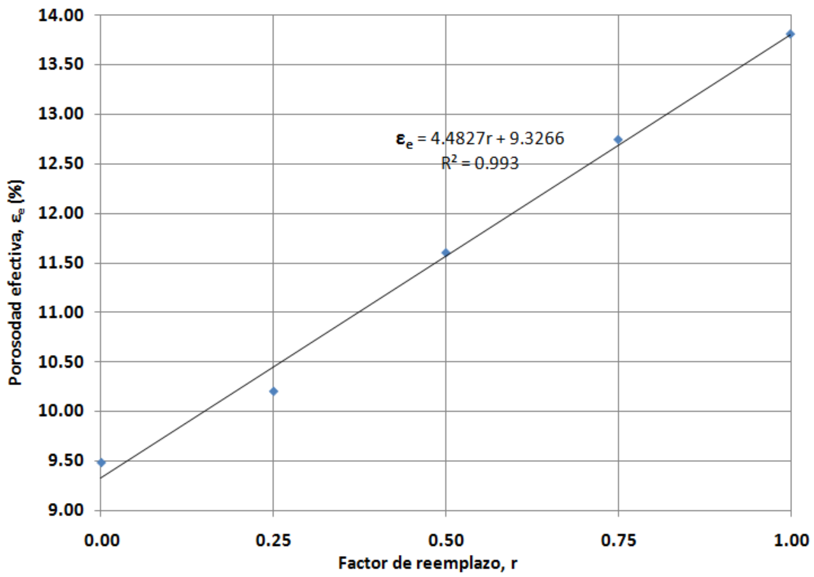


Figure 3. Effective porosity vs. replacement factor.

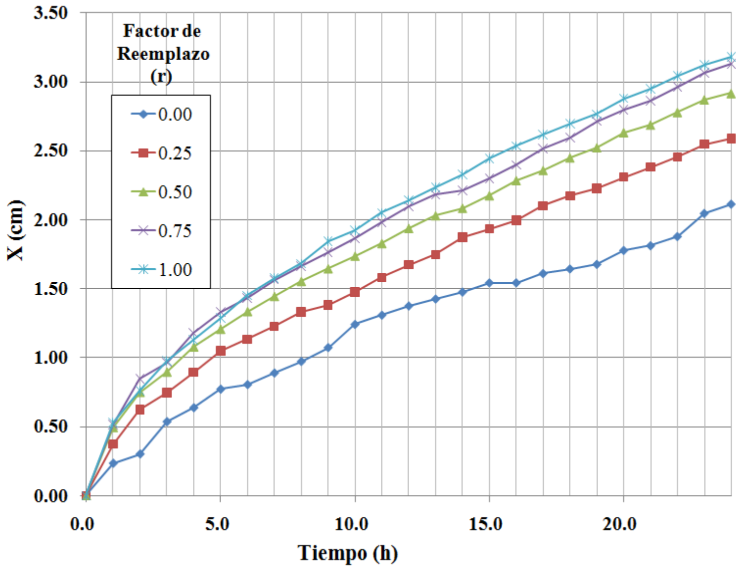


Figure 4.Calculated penetration of water into the concrete in the direction of the longitudinal axis of the specimen.

3.2. Model of water penetration respect tor=0.00 y r=1.00.

These results can be represented in a graph by placing on the horizontal axis the root of the time in $s^{1/2}$ and in the vertical axis the penetration of water in cm, as shown in figure 5. In addition, idealization has an equation in the form of "a t $^{b/2}$". The coefficient of R^2determination shown in figure 5 have values in the range 0.9862 and 0.9997 for a direct nonlinear correlation of the variables replacement factor and water penetration, for being very close to 1.00 they imply a very marked causal relationship almost perfect, being, therefore, a strong direct correlation between the variables, manifesting a tendency own and particular.

Based on the above, a model is proposed in which the water penetrations are determined as a function of the concrete characteristics with r = 0.0 and r = 1.0.This model is described by equations (6) and (7).

$$X(t) = a_0 t^{\frac{b_0}{2}} + F\left(a_1 t^{\frac{b_1}{2}} - a_0 t^{\frac{b_0}{2}}\right) \quad (6)$$

$$F(r) = \frac{r}{3}\left(4r^2 - 9r + 8\right) \quad (7)$$

Where:

X(t)= (cm). Penetration of water in a direction parallel to the longitudinal axis of the specimen (cm).
t= Time elapsed(s.).
a_0, b_0= Specificparameters of the concrete with r = 0.0, are determined by making a potential adjustment of the curves of **Error! Reference source not found.**.
a_1, b_1= Specific parameters specific to the concrete with r = 1.0, are determined by making a potential adjustment of the curves of **Error! Reference source not found.**.
F(r)= Factor of adjustment, in which it positions the curve within the region delimited by the curves of r = 0 and r = 1, which depends only on the replacement factor.

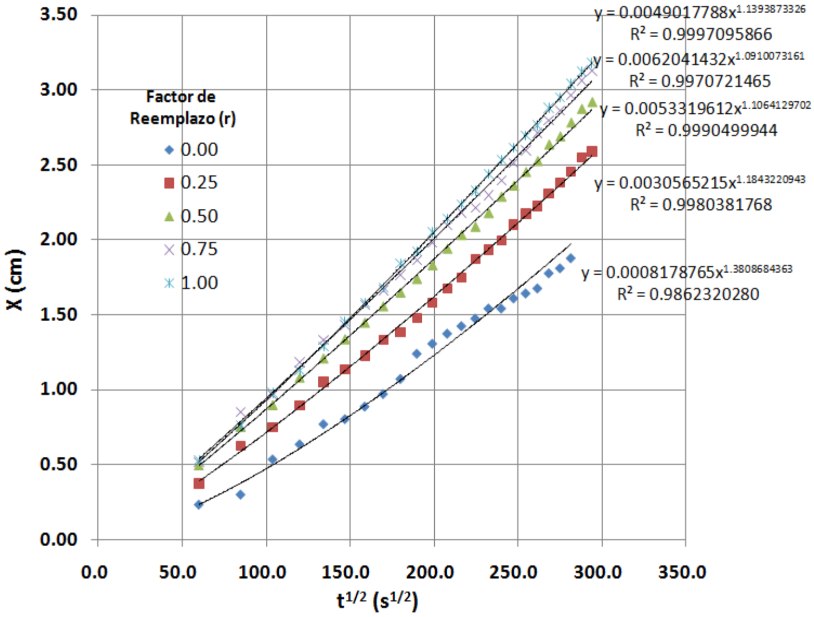
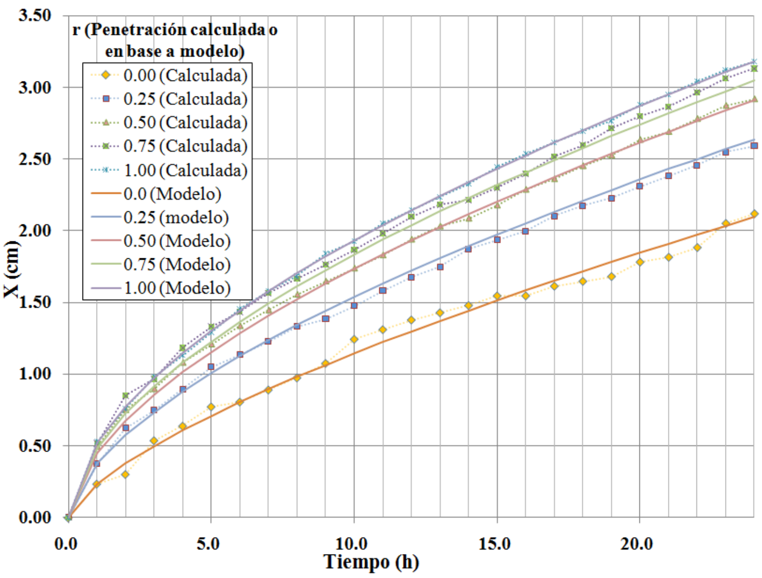


Figure 5. Water penetration vs. time root.

In the present work, the parameters a_0, b_0, a_1 and b_1 are 8.178765×10^{-04}, 1.380868, 4.901779×10^{-03} y 1.139387, respectively. In figure 6, they are shown with a dashed line and discrete points the calculated penetrations and with solid line the ones corresponding to the model, which are adjusted acceptably to the calculated penetrations. The errors presented by the model penetrations based on the calculated penetrations of figure 4 are of 4.5, 2.4, 2.2, 3.5 and 0.6% for r of 0.00, 0.25, 0.50, 0.75 and 1.00, respectively. These are low errors considering that the penetrations for any value of r can be estimated and the unidirectional flow is studied.



FigureIII-1. Penetration of water in concrete in the direction of the longitudinal axis of the specimen based on the proposed model.

IV. CONCLUSION

It was verified that it is possible to perform water penetration modeling on concrete made with recycled aggregate replacements, using the results of absorbed water in Pipette Absorption Test (RILEM II.4) and effective porosities.

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