

# Influence of the shape of the natural aggregates, recycled and silica fume on the mechanical properties of pervious concrete

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**Abstract**— Currently the problems of water quality are increasing; much of the material is rinsed and is dragged into streams, rivers, and groundwater from the contaminated superficial draining, which contains materials that are applied to the soil surface.

Therefore is that the provide the greatest amount of uncontaminated water to the subsurface is of great importance, since it can still potentially solve some important collateral problems, such as the settlement in the soil, which is related largely to levels low capacity of the aquifer. Therefore, use Pervious Concrete (PCo) can help prevent physical barrier between rainwater and underground (especially in urban areas).

For the investigation of the feasibility of PCo three types of aggregate were used: Round Natural Aggregate (RNA), Natural Crushed Aggregate (NCA) and Recycled Aggregate from Concrete crushed (RAC), since the shape of the aggregates generally determines the mechanical properties; and yet very little is known about their correlation with permeability.

Moreover, concrete recycling is an effective way for the elimination of debris from demolition as well as replace part of the cement by waste material as the Silica Fume (SF); in both cases, these actions production decreases and CO<sub>2</sub> emissions associated with their production.

In this work different aggregates with a substitution of SF are evaluated, for know physical and mechanical properties of pervious concrete and in part to contribute to solving the environmental problem of the construction.

**Keywords**—Pervious concrete, silica fume, recycled aggregates.

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## I. Introduction

### A. General context

The concrete permeable term describes to a material with workability between zero and a high void ratio, usually it is constituted by Portland cement, coarse aggregate, little or no fine aggregate, additives and water. The combination of these components will produce a material hardened with connected pores that go from the 2 to 8 mm, which will allow that the water should happen across them from easy form. The void content of these concretes can vary from 10 to 35%, and with resistances to simple compression of the order from 2.8 to 28 MPa. On the other hand, the drainage capacity of a concrete pavement permeable tends to vary depending on the size of aggregate and of the density of his mixture; in general they reach values between 81 to 730 L/min/m<sup>2</sup>[1].

Similarly, it is known that the mechanical properties of concrete depend on several important factors, such as: the water/cement ratio, the degree of compaction and its porosity; existing likewise other factors that emphasize these, such as: the shape, the size and resistance of aggregates, among others [2].

In addition, it is also known that the strength of the concrete in the so-called interfacial zone between the aggregate and the cement pasta depends on the integrity of the cement pasta and on the nature of the thick aggregate [3]. Being so, the form of the aggregate is important, since using the round aggregates in the PCo causes a decrease in mechanical properties due to the adhesion between the aggregate and the paste; for what in the crushed aggregates, on having had major adherence in the pasta of concrete [4-5] can foresee improvement in his properties.

At present, the concrete at the end of his life cycle can be recycled to serve as aggregate in new concrete with new applications [6]; the previous thing contributes with advantages, since this material is not disposed of in landfills that contaminate the environment and likewise these prevent the extraction of natural aggregates that cause harm to ecosystems.

It is known also that SF has properties pozzolanic (capacity of chemical reaction with calcium hydroxide in the presence of water at room temperature), and that is used as partial

replacement of the cement Portland, thus reducing the consumption of cement, diminishing CO<sub>2</sub> emissions produced, thus improving the properties of the concrete [7-9].

In this work were prepared different PCo with the RNA and NCA, the RAC was also used as a replacement for natural aggregates by 50% and adding SF on it, in order to increase its mechanical strength. As parameters of mechanical evaluation, tests of resistance to compression and bending of these concretes were made.

The mechanical results of the PCo obtained, were used to compare and to analyze the importance of the utilization of the RAC, the influence of the form of the aggregates in these concretes, and the mechanical contribution that the SF does in these.

## II. Materials

The materials used, prior to use in the production of mixtures were classed for determining their physical properties (density, humidity and absorption), geometry (shape) and size distribution (granulometric) with the aim of obtain high reliability and minimum variation in results imputable to uncontrolled variables. To continued, the origin of the materials used in the research are provided, and some of its basic characteristics studied.

### A. Natural aggregate

The Natural aggregates (crushed or round) come from the sieving process of an extraction of materials located in the Common Charay, Mochis, Sinaloa, Mexico. The aggregate has a size distribution between 3/4 to 3/8 inch (9.5 mm 19.05). The natural round gravel, also called boulder (see Figure 1A); this aggregate, also is used for be crushed in a machine grinding, in order to change its shape and get an irregular aggregate, which is called crushed gravel (see Figure 1B ).

### B. Recycled aggregate

The RAC (Figure 1C) was obtained from a process of crushing waste concrete slabs, obtained in a storage center for construction debris, fragments of these slabs and before grinding process, some properties of interest were evaluated. Finally, these fragments were crushed by a jaw crusher and they were separated by size with a sieve.

### C. Silica Fume

The Silica Fume (see Figure 1D) was provided by the Research Center for Advanced Materials (CIMAV) of the city of Chihuahua, Mexico, which was physically and chemically characterized for the purpose of compare the known properties by reviewing the literature.



Figure 1. Materials utilized A) RNA, B) NCA, C) RAC y D) SF.

## III. Methodology

The techniques used in this investigation, the preliminary analysis of the materials and tests on a PCo are detailed below.

Control methods of natural aggregates are shown in Table 1, where the property of interest is described and studied the standard used to determine this.

Table 1. Testing developed to natural aggregate.

Property	ASTM Method
Volumetric weight compact	C 29
Density and absorption	C 127 (gravel)
Humidity	C 566

A concrete slabs residue (CO, source of RAC) tests were performed rebound index (Figure 2A) following Mexican standard NMX-C-192 to determine its hardness and induce compressive strength, their porosity, absorption dry and density (ASTM C642). The figure shows some of the works made for these tests, such as the drying in oven, the wet weight and the water saturation.



Figure 2. A) Configuration indirect compression resistance by rebound index, B), C) y D) This pictures shows some of the work done in the ASTM C642 standard.

The mix design included the preparation of six mixtures PCo (see nomenclature in Table 2); all of which had the following design criteria: water/cement ratio of 0.38 and aggregates size of 1/2 inch.

Table 2. Nomenclature of the mix design.

Nomenclature	Composition of Pervious Concrete (PCo)
NCA-C	NCA and 100% of cement
NCA-SF	NCA, 90% of cement and 10% of silica fume
RNA-C	RNA and 100% of cement
RNA-SF	RNA, 90% of cement and 10% of silica fume
RAC50-C	50% of RAC and 50% of NCA with 100% of cement
RAC50-SF	50% of RAC and 50% of NCA with 90% of cement and 10% of HS

For the mixing process of the materials, once the materials were weighed, aggregates along with the rest of the components were placed in a mixer for three minutes, after this period and when observed that aggregates had a shiny surface, the kneading stopped.

Prior to the kneading process, the recycled aggregate was immersed in water for 10 minutes and then to saturate, this is dried superficially to saturate and prevent water affect the design of the cement paste (see Figure 3). Each of the concrete mixtures were deposited into two beams molds of 15x15x50 cm and compacted with a roller weighing 115 kg (see Figure 4A), and then were protected for 24 hours by plastic cover to avoid moisture loss by last they were demolded and placed in a chamber for 28 days immersion (Figure 4B).



Figure 3. A) RAC in saturation process and B) Drying surface of RAC.

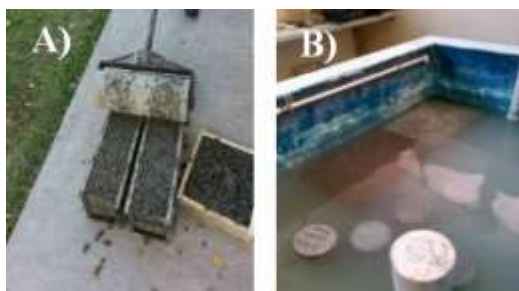


Figure 4. A) Casting mixtures y B) Immersion curing chamber.

After 28 days of curing, the beams were subjected to the test of resistance to bending (M. R, ASTM C293), applying a

point load at the center of the upper surface of the beam and having two supports underneath it (Figure 5A), the formulation used to determine this property is shown in equation (1), in which MR is the bending strength, "P" is the applied load, "L" the length of the sample, "b" is the width and "d" is the height of the specimen.

$$M. R = \frac{3PL}{2bd^2} \quad (1)$$

After the test bending, the surplus material was cut transversely for obtain cubes of 15x15x15 cm (see Figure 5B), of which were tested in compression (ASTM C39, see Figure 5C), the formula used to determine this property is presented in equation (2), where, "fc" is the compressive strength, "c" is the applied load, and "a" is the area of the sample.

$$f_c = c/a \quad (2)$$



Figure 5. A) Test of bending strength, B) Cutting beams and C) Test compressive strength

## iv. Results

The obtained results allow an analysis on the influence of the shape of the aggregate on the mechanical properties of the PCo. These allow us to know the properties of materials and correlate, interpret and predict the behavior in the mechanical strength of these particular.

### A. Physical properties

In Table 3 the characteristics of CO are shown, of which may come to exert influence on the properties of the RAC. Can be highlighted that the absorption and density achieved are lower than those of conventional concrete, which can be explained by its low porosity, being a concrete "old", spite of that, its compressive strength is adequate. All this indicates that CO is a material with high strength and suitable for use in the development of an RAC.

Table 3. Concrete properties of origin.

Property	Value
Absorption (%)	6.28
Density (g/cm <sup>3</sup> )	2.35
Porosity (%)	16.31
Rebound index (MPa)	29.9

The results of tests performed to natural aggregates are presented in Table 4, in which it can be seen that the RNA could be considered as a dense aggregate, closely followed by the NCA, and very distanced from these two by RAC. This

verifies the analysis of CO, where a high absorption, low density and high porosity is shown.

Humidity values for RNA and NCA are equal, while for the absorption is almost doubled for the NCA (possible increase of cracks and increased specific surface area by grinding); Humidity values for RNA and NCA are equal, while for the absorption is almost doubled for the NCA (possible increase of cracks and increased specific surface area by grinding); so that these values will not alter the design of mixes or their relation a/c, mixtures with this item required an adjustment of its mixing water.

Table 4. Properties aggregates.

Gravel	VWCG Kg/m <sup>3</sup>	Humidity %	Absorption %	Size (mm)
ANT	1455.13	1.67	3.28	0.9525
ANR	1502.37	1.67	1.67	0.9525
AR	976.07	Immersed in water		0.9525

VWCG: Volumetric Weight Compact of Gravel

### B. Mechanical properties

Figure 6 presents results obtained from testing of bending strength of the blends of PCo, it is observed that the mixture with the NCA-C reaches the highest resistance of all variables studied (in accordance with the values NCA), and the lower bending strength reached was the one containing 50% of RAC.

This indicates that the strongest PCo (made with ANT), can be correlated to the irregular shape of this aggregate allowing better adhesion between the aggregate and paste. With a difference of 0.84 kg/cm<sup>2</sup> the RNA, and because of its oval shape gets less resistance -not significant-.

Finally the resulting mixture less resistant, is that which containing RAC, this is attributed to the RAC reaches lower mechanical properties than natural aggregate (preliminary deduction of the concrete of origin aforementioned corroborates this information).

With respect to the mixtures PCo with 10% HS, the trends of the curves are similar to those of the mixtures of PCo 100% cement. However, -and surprisingly-, the levels that reaches are always lower than the first. This anomalous behavior is attributed to the loss of calcium hydroxide Ca(OH)<sub>2</sub> in the PCo with 10% SF, since this particular structure, with pores up to 90 mm, which contributes to crystals CH (hydroxide calcium) produced by the hydration of cement with water dissolve in the immersion chamber, and which is not carried out the pozzolanic activity under this component, to wit, the HS does not react with these crystals for CH to form new CSH (calcium silicate hydrate). In this regard, further research is required to confirm these hypotheses.

Finally, it also checks that the effect of the aggregate's shape is correlated with the bending resistance of this PCo with SF.

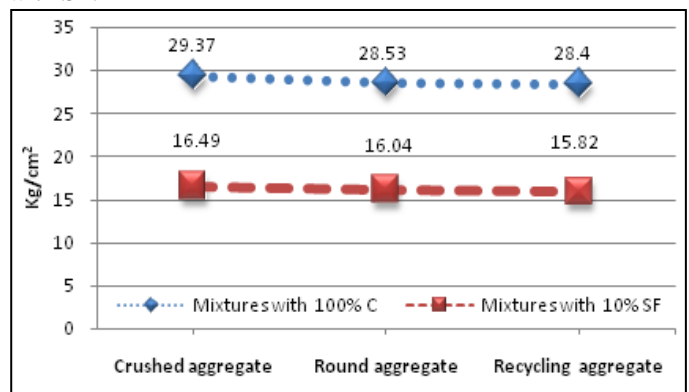


Figure 6. Flexural strength of pervious concrete.

Figure 7 shows that the blends made with Portland cement reached compressive strength higher than the mixtures including SF. The mixture NCA-C reaches the highest resistance of the studied variables, foreseeing that the shape of the aggregate correlates in part this property to increasing the adhesion between the aggregate and the paste; followed it, and by little difference are RNA's mixtures, to stay at the end with a high loss of strength, the mixtures containing 50% substitution of aggregate by RAC. In the latter case, this loss is attributed to than the RAC used in these mixtures is porous and has a lower density (product of the old paste adhered to the gravel and have a greater amount of the call Interfacial Transition Zone [ITZ]).

Regarding the use of the SF, as in the case of bending strength, in compression is resubmitted resistance loss with this component. This is also response of the hypothesized presented before that the structure of the material and loss of Ca (OH)<sub>2</sub> are the causatives.

Analyzing the influence of the shape of the aggregate, it is also noteworthy that the mixture with NCA obtained a higher mechanical strength than the mixtures with RNA and RAC.

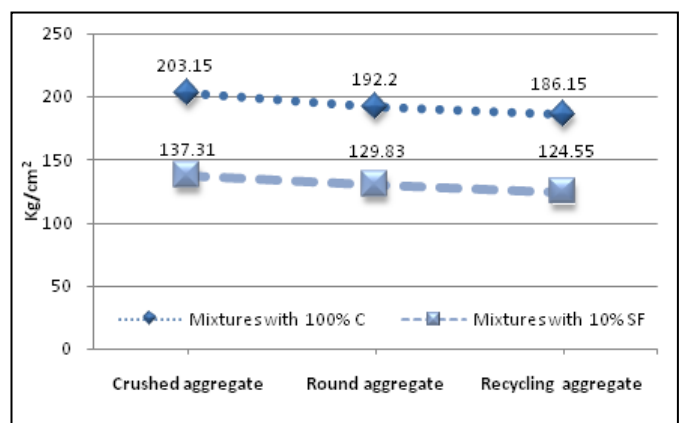


Figure 7. Compressive strength of pervious concrete.

## v. Conclusions

The original concrete achieves compression strengths valid for use as a new resistant aggregate and in good condition; the aging period of this, can be intuited in specific properties such as: absorption, density and porosity, as the direct correlation between age and the latter is valid.

The samples with SF show a decrease in the flexural strength of up to 56% compared to samples produced with 100% of cement, which require more thorough investigations to understand this behavior.

In bending resistance as compression, using crushed aggregate respond to the best alternative to achieve higher mechanical strength due to its irregular shape, producing better adherence and therefore more resistance.

The use of a partial substitution of 50% of RAC in samples of pervious concrete causes low mechanical strength, This is explained by the increase of preferential fault zones, partly by new ITZ formed when mixing aggregate and recycled paste containing ancient ITZ paste and the ITZ containing the old paste and the old aggregate found in the RAC.

In these cases, is recommended to use mix design with a lower ratio of empty, because to exist voids up to 90 mm, is produced less dense materials and less durable. By contrast, the concrete formed from a mixture design containing up to 20% of voids allows high permeability of concrete.

Mixtures with NCA-C with respect to the RNA-C and with RAC50-C, Reported small variations in compressive strength and flexural, however the shape of the aggregate seems to be associated with them and therefore should continue being studied more carefully.

## Acknowledgment

The authors express thanks to: research project S-01117 from CTT-UPC, to EPSEB-UPC, to the Department CAII-EPSEB-UPC, to FIM-UAS and to the scholarships program for Master Degree studies by CONACYT.

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