

Eco-Concrete for *Hydraulic Structures* with Addition of Colloidal Nano-Silica

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Abstract. In the construction of buildings and infrastructures, high resistance materials are used due to current design requirements, concrete being one of the main materials used in the execution of these projects whose cement content is limited to obtaining an economic concrete and of minimum retraction. This limitation requires the use of new additions such as Nano Silica (NS), which due to its nanometric structure is used as a partial replacement for cement, producing an increase in strength in concrete. The present investigation studies the partial replacement of the NS in the cement to determine its behavior in compressive strength, diametric compressive strength, water permeability coefficient. The results indicate that with an addition of 0.225% of NS the compressive strength and splitting tensile strength are increased and the water permeability coefficient decreases, all of them compared to a conventional concrete.

1. Introduction

The conventional concrete is a material that has been developed approximately 150 years ago to imitate natural stone while providing less labor-intensive methods of shaping the material (casting rather than hewing and carving) [1], its components are Portland cement, sand, stone and water [2]. Cement is the main element that contributes to its durability and strength; it must be designed with an economical amount because it is more expensive than aggregates [3]. Important studies have been carried out in recent years on the use of mineral additions in concrete, ranging from natural pozzolans, through fly ash and blast furnace slags to micro silica; the latter being used, in one of its forms, as a partial replacement for Portland cement [4]. Pozzolans have had extensive uses as a component of Portland cement concrete, particularly for marine and hydraulic structures [5]. The hydraulic structures have different pathologies caused by the presence of external agents, with sulphates causing the greatest damage when they come into contact with the concrete, because they react with the cement components, expanding the hardened mixture and causing its progressive detachment. The canals are responsible for transporting large amounts of water, which causes damage by abrasion, erosion and cavitation on its surface; because the liquid they carry carries sediments and particularly sulphates, which wear away the concrete [6]. On the other hand, the wetting of the soils by irrigation or rain seepage can activate the soluble salts that would produce a chemical attack on the concrete of the foundations or of the structure that is in direct contact with the ground, such as the canals [7].

Recent advances in the field of Nanotechnology and cement indicate that the NS as a partial replacement of cement produces an increase in the density of its microstructure in the concrete mix [8]. This NS in low percentages increases the speed of the hydration process from its chemical



reaction and fills the empty spaces of the mixture by its size [9]. Today, the NS is an attractive cement replacement solution because it reduces the greenhouse effect and CO₂ emission, and because its high specific surface area / volume ratio provides efficient chemical reactivity. [10] studying the compressive strength of concrete for different ages from 3 to 180 days, obtaining that with 10% replacement of NS the compressive strength is greater than the CS, indicating that the NS acts as a filler which increases the density of the microstructure and as an activator in the hydration reaction. On the other hand, [11] studying mortar mixtures at the age of 28 days for a 3% and 6% replacement of NS, finding that the compressive strength increases 19% and 44% with respect to the conventional mortar. Similarly, [12] evaluates different properties of the mortar, finding that with 1% replacement of NS the compressive strength and diametric compressive strength at 28 days, increase by 12% and 25% compared to the mortar conventional, and the water absorption coefficient evaluated 38.5% compared to the standard mortar. In the present work, study the effect of the addition of 0.225% of nanoparticles as a replacement for cement in compressive strength, splitting tensile strength and water permeability coefficient in order to elaborate an eco-concrete to be used in the construction of hydraulic channels.

2. Materials and Methods

2.1. Materials

The cements used are Portland Type I and Portland Type HS; the aggregates were from the quarry of Cieneguilla, the sand particles of 0.15-9.50 mm and the stone particles of 2.36-12.50 mm; the water was drinkable; and the additives used were Gaia Nanosilica and the Sika CEM superplasticizer.

2.2. Method

The present work has been developed in the Laboratory of Concrete Technology of the UPC-Monterrico. The mix design was made for a concrete $f'_c = 280 \text{ Kg} / \text{cm}^2$ and according to [13]. Table 1 shows the mixing designs made for Conventional Concrete (CS) and Concrete with Nano Silica (CNS), with Superplasticizer (SP) and Nano Silica (NS) and in Table 2 the tests and numbers of specimens used in the experimental development of the present investigation. The specimens for the tests of compressive strength, splitting tensile strength were cylindrical 6"x12" and for the test of water permeability also cylindrical 4 "x 8", both specimens shown I Figure 1 y Figure 2; which were cured in the laboratory until 28 days according to [14], then they were demoulded and tested. As a previous part of the investigation, a CS with slump of 3" to 4" was designed and since the slump values for the CNS1 and CNS3 mixtures were outside the allowed range, the mixtures were discarded and the CNS2 mixture was considered with a percentage of addition of NS of 0.225% in relation to the weight of the cement, which is called CNS.

Table 1. Mix design for concrete $f'_c = 280 \text{ Kg/cm}^2$ units Kg/m^3

Code	Cement	Water	Aggregate	Sand	SP	NS	Slump (in.)
CS	480 ¹	216	954.38	615.44	5.65	0	3.20 ¹
CNS 1	480 ¹	216	954.38	613.12	5.65	0.96	2.70 ¹
CNS 2	480 ¹	216	954.38	612.86	5.65	1.08	3.30 ¹
CNS 3	480 ¹	216	954.38	612.54	5.65	1.20	5.50 ¹
CS-HS	480 ²	216	954.38	615.44	5.65	0	3.40 ²
CNS-HS	480 ²	216	954.38	612.86	5.65	1.08	3.10 ²

¹ Portland Cement Type I

² Portland Cement Type HS

Table 2. Tests performed

Concrete Tests	Methods	N ^o Specimens		Age (days)
		CS ^a	CNS ^a	
Compression strength Splitting tensile	ASTM C39[15] ASTM	3	3	7, 28



Figure 1. Specimens concrete 6"x12"



Figure 2. Specimen in water permeability test

3. Analysis and Results

3.1. Compression strength

Figure 3 shows the effect of curing time on the compressive strength of concrete with addition of 0.225% nanosilica. It shows that the compressive strength increases with the cure time, obtaining the values of 424.14 and 487.41 kg / cm² at the ages of 7 and 28 days for the CNS that represent an increase of 5.79% and 6.28% with respect to the CS. [18] studies the compressive strength at 28 days with an addition of 0.25% nanosilica, and obtains a 20-25% increase over conventional cement paste. Similarly, [19] for an addition of 2% of NS finds that the compressive strength increases at 28 days by 7.30% with respect to the CS. These growth trends are similar to those obtained in the present study. [20] indicates that this behavior is due to the good dispersion of the silica nanoparticles in the concrete, which generates a denser microstructure and produces a decrease in voids and weak areas, which can be cracking points.

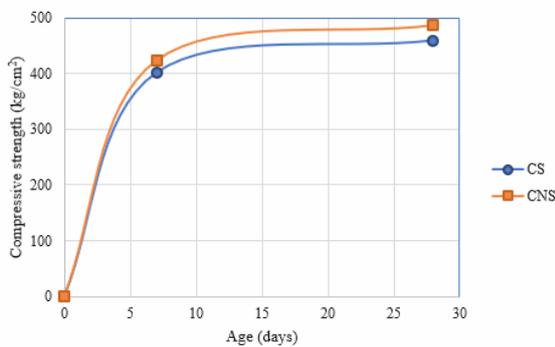


Figure 3. Effect of the test age on the compressive strength

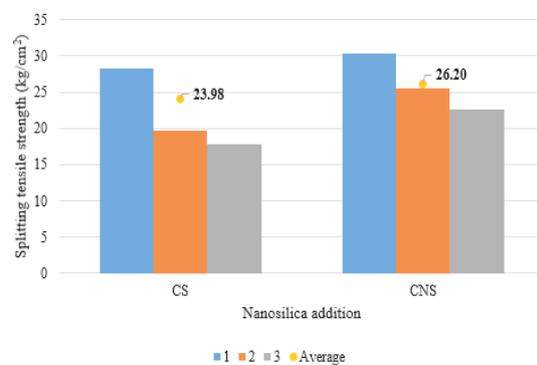


Figure 4. Effect of the addition of 0.225% on the splitting tensile strength

3.2 Splitting tensile strength

Figure 4 shows the effect of the addition of 0.225% nanosilica on splitting tensile strength at the age of 28 days. It shows that the individual values and the average obtained for the CNS are greater than the values reached by the CS, the average value being 26.20 Kg / cm² 19.47% more than the 21.93 Kg / cm² of the CS. [18] studies the increase in splitting tensile strength for an addition of 1% and 2% NS with cure at 28 days; from this investigation it obtains a 17% and 24% increase, respectively, compared to the CS. [21] in his research, he made concrete mixtures with additions of NS of 1.5% and 3% in concrete mixtures with different water-cement ratios (0.412, 0.435 and 0.44 for 1.5% of NS; and 0.374, 0.42 and 0.434 for 3% of NS), obtaining that with 1.5% of NS and water-cement ratio of 0.44 the average resistance by splitting tensile strength reached at 28 days is 3.83 MPa, this being lower than the CS in 8.8%, which can be due to poor particle dispersion. [20] indicates that this behavior is due to the existence of a greater specific surface area in the concrete, which causes a dispersion of nanoparticles in the matrix that produces a denser and more homogeneous CSH gel, promoting a better zone of interfacial transition between aggregates and cement paste.

3.3 Water Permeability Coefficient

Table 3 shows the coefficient of permeability (K) at 28 days for an addition of 0.225% nanosilica. It shows that the water permeability coefficient for CNS reaches a value of 8.47×10^{-12} which gives it a low permeability level [17] and represents 50.12% more than the CS that has a medium permeability level [17]. [18] in their study, considering a 0.30% percentage of NS addition, the CNS water permeability coefficient increases 56% more than the CS. Likewise, as noted [22] in his investigation, he obtained a water permeability coefficient of 2.65×10^{-13} for an addition of 9% nanosilica, which compared to CS decreased by 69.60%. These K growth trends are similar to those obtained in the present study. [23] indicates that this behavior is due to the fact that the pozzolanic reaction between silica (of NS) with calcium hydroxide in solution forms a super saturated CSH gel, producing a reduction in the pore structure of the CSH microstructure that decreases the fibril and the porous structure of CSH to a denser gel. It should be noted, as mentioned [22] in his research, the lower the water permeability coefficient of the concrete, the greater the compressive strength, this relationship indicates that the addition of nanosilica improves the microstructure of the concrete and, together with it, the mechanical properties.

Table 3. Water permeability coefficient at 28 days with 0.225% nanosilica

Type	CS	CNS
K	$1.69E^{-11}$	$8.47E^{-12}$
Level	Medium	Low

4. Conclusions

- The partial replacement of cement with the addition of 0.225% of NS allows the development of an eco-concrete that contributes to the reduction of greenhouse gases.
- The compressive and splitting tensile strength improved with the addition of NS because its nanoparticles fill the voids of the cement microstructure producing a more resistant concrete
- The water permeability coefficient decreases because the pores in the cement matrix are reduced, contributing to the development of a less porous and durable concrete.

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