ENGLISH VERSION...

Optimization of the concrete through the addition of nanosilice, using aggregates of the cantera de Añashuayco de Arequipa

Optimización del concreto mediante la adición de nanosílice, empleando agregados de la cantera de Añashuayco de Arequipa

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Abstract

The present research work is carried out using the experimental study to evaluate the concrete made with Aggregates of the Quarry with Addition of Nanosilica containing micro-fine nanoparticles of amorphous silica dioxide (Si O^2). Nanosilica has pozzolanic properties that, upon contact with water, reacts with hydrated cement to form more particles of C-S-H (gel), which reduces porosity by partially filling the pores to refine the structure and therefore gives us greater compressive strength. The recommendation of this study is to implement low-cost, low-rise housing construction.
The microstructure properties of the cement paste are improved with the addition of Nanosilica. Nanoparticles have high specific surface areas, and their surfaces are very active; an intense pozzolanic reaction between Nanosilica and CH, would accelerate the pozzolanic reactions between SIO^2 and water molecules. Therefore, the smaller the pore volume, the higher the compressive strength and water absorption capacity of Nanosilica-modified pastes results.
The volume of the pores was reduced along with the increase of the Nanosilica dose. The cement and sand mixture without Nanosilica after 7 days of curing, shows a porous structure.

Keywords: *Nanosilica, strength, sompression, permeability*

Resumen

El presente trabajo de investigación se desarrolla haciendo uso del estudio experimental para evaluar el concreto elaborado con agregados de la cantera de Añashuayco (Perú) con adición de Nanosílice que contiene nanopartículas micro finas de dióxido de sílice amorfa (Si O^2).
La Nanosílice posee propiedades puzolanicas que al contacto con agua reacciona con el cemento hidratado para formar más partículas de C-S-H (GEL), el cual reduce la porosidad rellenado parcialmente los poros para refinar la estructura y por consiguiente nos da una mayor resistencia a la compresión. Las recomendaciones de este estudio es implementar la construcción de viviendas de baja altura y bajo costo.
Las propiedades de microestructura de la pasta de cemento se mejoran con la adición de nanosílice. Las nanopartículas tienen áreas superficiales especificas elevadas, y sus superficies son muy activas; una reacción puzolanica intensa entre la nanosílice y el CH, acelerarían las reacciones puzolanas entre SIO^2 y moléculas de agua. Por lo tanto, a menor volumen de poros, resulta en una mayor resistencia a la comprensión y una capacidad de absorción de agua de las pastas modificadas con nanosílice.
El volumen de los poros se redujo junto con el aumento de la dosis de Nanosílice. La mezcla de cemento y arena sin nanosílice después de 7 días de curado, muestra una estructura porosa.

Palabras clave: Nanosílice, resistencia, compresión, permeabilidad

1. Introduction

In the last decade, Arequipa has been experiencing an accelerated growth of its urban expansion, as well as its infrastructure and other activities related to the construction industry.

High-performance concretes, which for the remaining of this research will be referred as CAD, are made of essentially the same materials as conventional concrete. The objective of this research is to improve the quality of a concrete with natural aggregates from the Añashuayco quarry (see (Figure 1)), by adding Nanosilica. With this we intend to improve the properties of the concrete, considering what is indicated by the NTP. Then compare and determine the influence of the addition of Nanosilica in the final strength of the concrete. It will contribute to a greater knowledge in the material and will constitute a contribution to the community. A new ecological material will be available, which will implement the environmental Public Policy in Peru, using more economical local resources, and producing safer constructions.

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Figure 1. *Natural Aggregate from Añashuayco Quarry*
Source: (Road Infrastructure, Arequipa News)

Nanosilica, due to its high silica (SiO2) content and the fineness of its particles, increases the compressive strength of concrete, in addition to its environmentally friendly manufacture.

According to the author's research (Fuentes et al., 2014) to obtain a high-performance concrete (HPC) that exceeds the compressive strength of a conventional standard concrete, it requires: (1) a cementitious material presenting particles smaller than 0.5μm, high SiO2 contents and the use of water-reducing admixtures. Such is the case of the addition of Nanosilica in concrete with Añashuayco aggregates. This material with a high chemical content of silica SiO2 and fineness, increases the compressive strength of the concrete.

Nanosilica reacts with portlandite to produce additional C-S-H gel, for this reason, the bonding of nanosilica refined the pores and decreased the pore volume of the pastes. (Huang et al., 2021). It was also revealed that the addition of nanosilica refined the pore structure of concrete and improved the chloride penetration resistance of concrete. (Zhang et al., 2011); porosity and pore diameter decrease with the inclusion of nanosilica. (Lim et al., 2018)

In other studies, it can be observed that the incorporation of nanosilica in cemented soil increases the intensity of calcium hydroxide (CH). The increase in the maximum dry density of cemented sand mixed with nanosilica, can be demonstrated by the fact that the void within the aggregate, becomes occupied by nanosilica nanoparticles in the cemented soil, (Choobbasti and Kutanaei, 2017). The use of nanosilica can shorten the cement expenditure by preventing it from releasing CO2.The effects of Nanosilica on concrete are comparable, due to its ultrafine size and high chemical reactivity, its performance is much better with less amount of admixture required, (Varghese et al.,2019) (Lincy et al., 2018).

We can say that the improvement in concrete is attributed to the acceleration of cement hydration, rapid pozzolanic reaction, as well as optimized packing of particles in the cement matrix, (Wang et al., 2018) (Kotsay, G., 2017) (El-Feky et al., 2019), resulting in a high probability of segregation in concrete. A much lower dosage of nanosilica can also be used to produce a lightweight concrete with comparable or better mechanical performance than one incorporating silica fumem, (Sikora et al., 2020); although exceeding the optimum nanosilica dosage resulted in a decrease of the beneficial effect of this mixture on water accessible porosity, (Meng et al., 2020) (Quercia et al., 2014) (Tobon et al., 2018).

Nanosilica improves the characteristics of the transition zone and strengthens the bond between the aggregate and the cement paste; therefore, its addition hinders water movement in concrete to some extent. (Du and Pang, 2019); on the other hand, the incorporation of nanosilica in smaller doses produces lightweight concretes with a much more robust microstructure and better mechanical and transport properties. (Sikora et al., *2020); Nanosilica influences the improving transport properties of concretes by refining the pore structure in the capillary range, thus originating a much more impermeable cement matrix. (Sikora et al., 2020).*

1.1 Nanosilica

Nanosilica is a liquid additive derived from micro-fine particles of amorphous silicon dioxide (SiO2). Nanosilica particles present smaller size (see (Figure 2)), high purity and reactivity, a crystalline structure similar to silica fume, therefore, it is expected to achieve superior results with its use. It is a nano additive in liquid state, of cloudy and slightly viscous appearance, composed of silica with nanometer-sized particles. It is a great water reducer, with high activity and pozzolanity. (Technical Data Sheet for Gaia nanosilica additive, Cognoscible Technologies, n.d.).

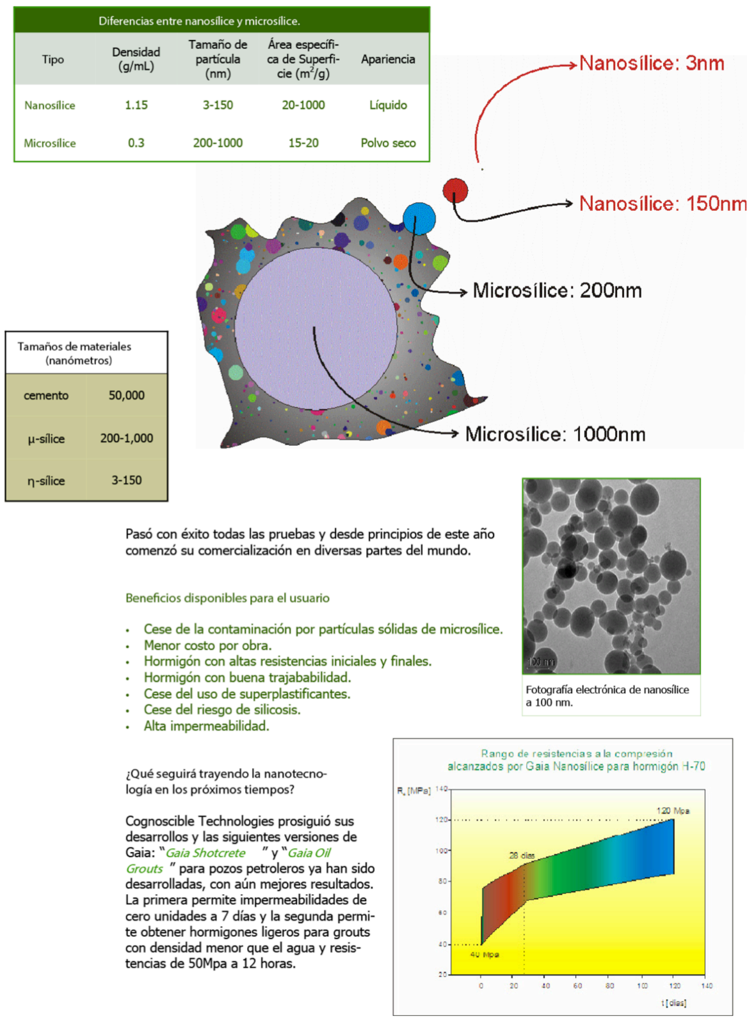

Figure 2. Nanosilica
Source: Concrete Construction and Technology

According to studies, colloidal silica nanoparticles theoretically react with calcium ions created during cement hydration periods (1), forming a calcium silicate gel (C-S-H) (2), (Mehta and Monteiro, 2001). In different words, the chemical mechanism is similar to the pozzolanic reaction, however, with a high purity element, a very high specific surface area (about 50 000 m2/kg) and dynamics as shown in the following expressions, (Equation 1) and (Equation 2) (Dobson, 1988); (Brough ,1994).

$$C_3S + H_2O = \text{gel C-S-H} + Ca\,(OH)_2 \qquad (1)$$

$$Si\,O_2\,(nSA) + Ca\,(OH)_2 = \text{gel C-S-H} \qquad (2)$$

2. Experimental Program

The present investigation will be developed using the experimental study. In the experimental study, the compressive behavior of concrete is evaluated, using aggregates from the Añashuayco quarry and the addition of Nanosilica.

Finally, the evaluation and contrast of experimental results will allow for the understanding of the studied phenomenon, and therefore, based on the results, the growth of suggestions and recommendations in the design of concrete. These will intend to achieve concretes capable of withstanding stresses in their components without degrading their earthquake resistance.

2.1 Pozzolanic cement IP

It is a cement made from Clinker, with pozzolan and (Plaster o Gypsum); resistant to sulfates attack; the calcium hydroxide, released during cement hydration, reacts with sulfates.

The pozzolanic portland cement IP produces more silicates, produced in the cement hydration, decreasing the capillary porosity, so the concrete becomes more impermeable and protects the steel from corrosion. Reduces the harmful alkali-aggregate reaction; lowers hydration heat; the reaction between calcium hydroxide, released during cement hydration, with the tricalcium aluminate (C3A) present in the cement, generates high hydration heat. This prevents shrinkage and cracking which affect the concrete quality, especially in large volume projects.

2.2 Aggregates

2.2.1 Geological characterization of Añashuayco Creek

Añashuayco is the name given to the ravine located in the northwestern part of the city of Arequipa (Peru). It has an extension of several square miles and occupies part of the glacis made up of ignimbrites and alluvial deposits. In the northern cone sector there are excellent outcrops, well exposed by the Chachani streams that descend from the Andean slopes.

The geomorphology of the area has a transverse volcanic gorge coming from the Chachani and culminating on the right bank of the Chili River near the Caldera batholith in the Uchumayo district.

2.2.2 Location

The study area is located at the following UTM coordinates: 8 192 365 m North and 223 806 m East, at an altitude of 2 545 m above sea level. In the Villa Salvador human settlement; and; 8 182 237 m North and 214 495 m East, at an altitude of 1969 m above sea level in the Añashuayco ravine. Comprising the Cerro Colorado and Uchumayo districts, in the province and department of Arequipa.

2.2.3 Types of Aggregates and Characteristics

The material of the area of the torrentera and surroundings will be studied, in the same way exploitation of stone materials for construction that correspond to alluvial fan deposits, has been seen, the alluvial cone deposits correspond to detrital sediments with sands and clays - silts.

Consequently, the characteristics of the fine aggregate are the presence of large amounts of silts and clays. The coarse aggregate is irregular in shape and presents crystals (which may be quartz) and some porosity.

2.2.4 Physical Properties of the Aggregate

In (Figure 3) you can see the three samples of the coarse aggregate granulometry; in (Figure 4) we see the three samples of the fine aggregate.

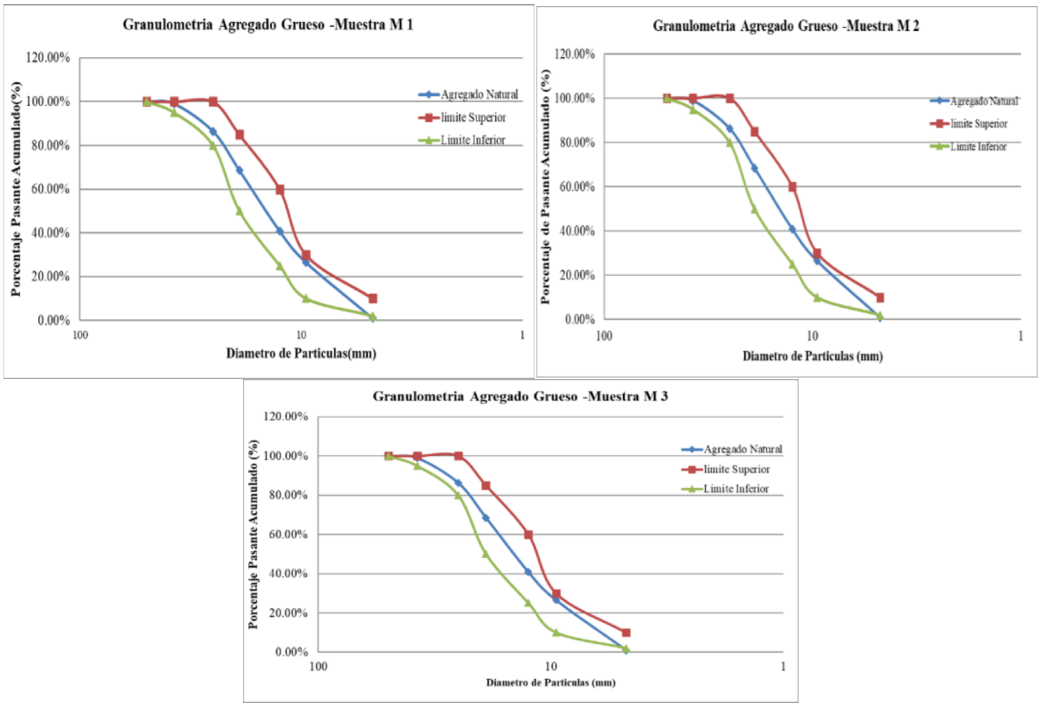

Figure 3. Coarse Aggregate particle size
Source: Own

Results: *The particle size of the coarse aggregate was determined. Once the aggregate was sieved, the particle size curves obtained from the three samples tested were within the particle size range indicated in NTP 400.037.*

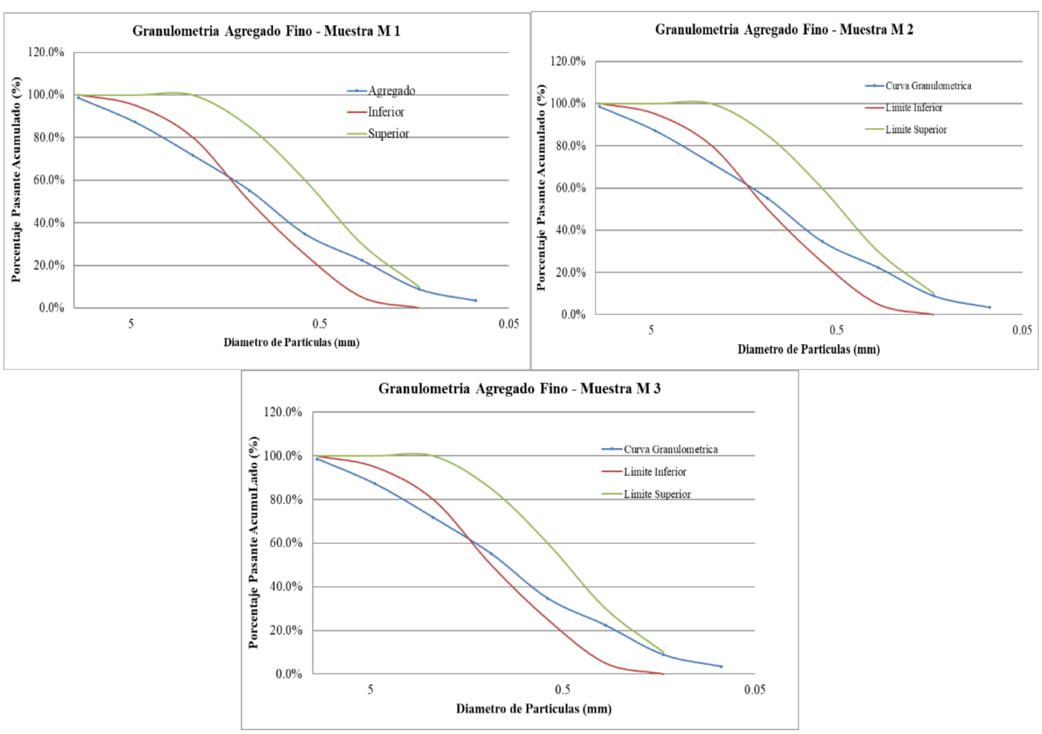

Figure 4. Granulometry of Fine Aggregate
Source: Own

Results: *Part of the granulometric graph of the fine aggregate is below the lower limit of the curve established in the Peruvian Technical Standard (NTP 400.037), therefore, it is not a recommended material for mix design; but through a process of improvement, it can be optimized for use.*

The properties of cement, water, and aggregates used for concrete mix design are shown in (Table 1).

Table 1. *Properties of cement, water, and aggregates*

Cement		
Type	Type Yura IP	
Origin	Arequipa-Cono Norte	
Specific weight (kg/cm3)	2810	
Drinking Water		
Specific weight (kg/cm3)	1000	
Aggregates		
PROPERTIES	**Fine**	**Coarse**
Quarry	**Añashuayco**	**Añashuayco**
Maximum Nominal Size	-	1"
Moisture Content	0.25%	0.09%
Absorption	0.80%	3.21%
Modulus of fineness	2.54	7.16
Mass P.E. (kg/cm3)	2627	2424
P.U. of rod (kg/cm3)	1677	1402
P.U. Loose dry (kg/cm3)	1453.7	1295.2

2.3 Water

The water comes from Arequipa's public drinking water system.

2.4 Gaia Nanosilica Addition

It is a producer of nanocement. The silica produces C-S-H particles, which is the "glue" of concrete and what keeps all its CSH particles cohesive with a size between 5mm and 250mm (Technical Data Sheet of Gaia nanosilica additive. Cognoscible Tecnologies, n.d.).

2.5 Mix design

For the design of the standard concrete (conventional concrete) and for the design of the non-conventional concrete (with the addition of Nanosilica) the following sequence was applied; the amount of water is maintained according to the design, also the proportion of aggregates and cement that was used was maintained; the only percentage that changes is the Nanosilica in percentages of 0.6%, 0.8%, 1.0% and 1.4% for the respective resistances. The representation of these data can be seen in Table 2.
Water was continuously added to the mixture, until a well-mixed paste was obtained, then the specimens were placed in a curing well under the same humidity and temperature conditions.

Table 2. *Results of the proportions of the materials*

Material	175 kg/cm2	210 kg/cm2	280 kg/cm2	350 kg/cm2	Unidad
Cement	326,433	367,12	439,914	517,68	kg/cm3
Fine aggregate	751,004	713,798	645,478	572,495	kg/cm3
Coarse aggregate	906,198	906,578	906,578	906,578	kg/cm3
Effective water	238,638	237,121	236,843	236,547	kg/cm3
Nanosilica 0.6%	1,908	1,999	2,570	3,024	kg/cm3
Nanosilica 0.8%	2,542	2,665	3,426	4,032	kg/cm3
Nanosilica 1%	3,332	3,574	4,283	5,041	kg/cm3
Nanosilica 1.4%	4,664	5,005	5,997	7,056	kg/cm3

3. Results and discussion

3.1 Slump

(Table 3) shows the results of the slump for 4 established dosages of simple compressive strength in structural concrete (175,210,280 and 350 Kg/cm2) and different percentages of nanosilica in weight of cement. In (Figure 5) you can see the results of Slump for the established situation. From the results analysis of the table, it was observed that for dosage increases in the Nanosilica admixture (0.6%;0.8%;1% and 1.4% with respect to the weight of cement), the slump of the concrete is in the range of 2 to 4 inches. In addition, it is observed that the minimum Slump value for each concrete dosage is: for 175 Kg/cm2 is 2 ¾ inches, for 210 Kg/cm2 is 3 ¾ inches, for 280 Kg/cm2 is 2 inches and for 350 Kg/ cm2 is 2 ½ inches.

Table 3. *Slump results -Aci's method (Own source)*

MIXTURE ID	STRUCTURAL CONCRETE F'c (Kg/cm2)	NANOSILIC ADDITIVE DOSAGE (% of cement weight)	MAXIMUM SLUMP (inches)
1	175	0	4
2		0.60	3 ½
3		0.80	2 ¾
4		1.00	3 ¼
5		1.40	4 ⅛
1	210	0	4
2		0.60	4
3		0.80	4 ½
4		1.00	4
5		1.40	3 ¾
1	280	0	2 ¼
2		0.60	3
3		0.80	3
4		1.00	2
5		1.40	2 ½
1	350	0	2 ¾
2		0.60	2 ¼
3		0.80	3
4		1.00	2 ½
5		1.40	4 ½

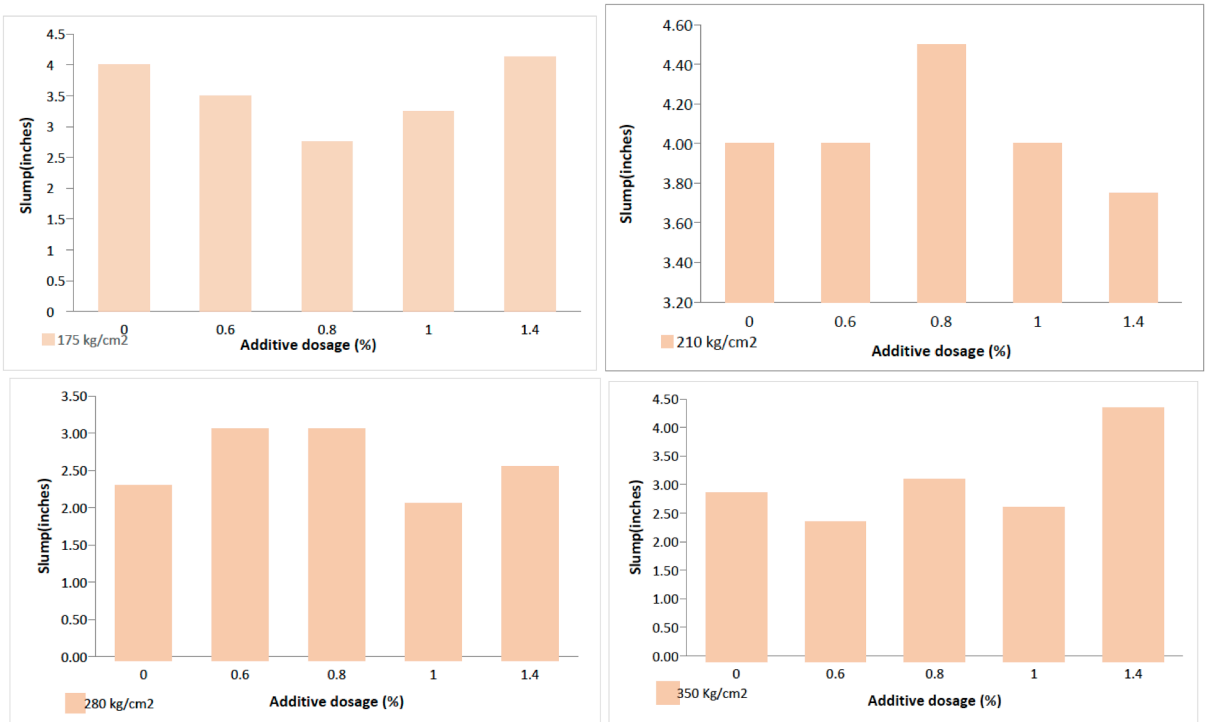

Figure 5. Slump test for a strength of 175,120,280,350 kg/cm2.
Source: Own

3.2 Air Content

According to the results obtained for air content, they are less than or equal to 3.5% for the different concrete designs with and without Nanosilica, see (Figure 6) and (Table 4).

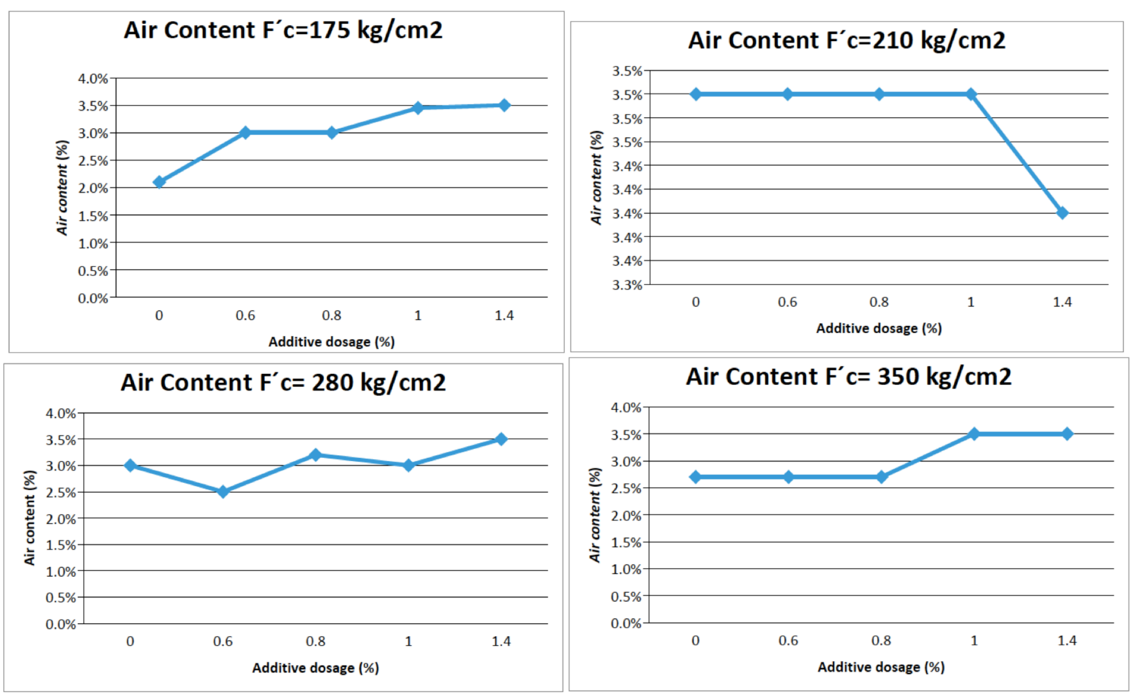

Figure 6. Air content test for F'C=175,210,280,350 kg/cm2.
Source: Own

Table 4. *Results of Fresh Concrete Air Content - Aci's Method (Own source)*

ID CEMENT	STRUCTURAL CONCRETE F'c (Kg/cm2)	DOSAGE OF NANOSILIC ADDITIVE (% weight of cement)	AIR CONTENT (%)	% VARIATION IN RESPECT TO CONCRETE WITHOUT ADMIXTURE
1	175	0	2.1%	100%
2		0.60	3.0%	142.86
3		0.80	3.0%	142.86
4		1.00	3.5%	164.29
5		1.40	3.4%	166.67
1	210	0	3.5%	100%
2		0.60	2.2%	62.86
3		0.80	3.3%	100.00
4		1.00	2.2%	62.86
5		1.40	3.4%	97.14
1	280	0	3.0%	100%
2		0.60	2.5%	83.33
3		0.80	3.2%	106.67
4		1.00	3.0%	100.00
5		1.40	3.4%	116.67
1	350	0	2.7%	100%
2		0.60	2.7%	100.00
3		0.80	2.7%	100.00
4		1.00	3.5%	129.63
5		1.40	3.4%	129.63

3.3 Unit weight

The unit weights obtained for the designs are in the range between 2201.503 and 2283.655 kg/m3. However, the values obtained from the tests correspond to that of a normal concrete, for all designs with and without addition of Nanosilica, see (Table 5) and (Figure 7).

Table 5. *Concrete Unit Weight Test Results (Own source)*

MIXTURE ID	STRUCTURAL CONCRETE F'c (Kg/cm2)	DOSAGE OF NANOSILICA ADDITIVE (% of cement weight) (kgf)	MOULD WEIGHT (kgf)	MOULD WEIGHT + CONCRETE (kgf)	CONCRETE WEIGHT (kgf)	VOL. MOLD (cm3)	UNIT WEIGHT(kgf/m3)
1		0	4.3	11.450	7.150	3152.84	2267.797
2		0.60	4.3	11.340	7.040	3152.84	2232.907
3	175	0.80	4.3	11.340	7.040	3152.84	2232.907
4		1.00	4.3	11.200	6.900	3152.84	2201.503
5		1.40	4.3	11.445	7.145	3152.84	2266.211
1		0	4.3	11.210	6.910	3152.84	2211.675
2		0.60	4.3	11.250	6.950	3152.84	2204.362
3	210	0.80	4.3	11.200	6.900	3152.84	2201.503
4		1.00	4.3	11.300	7.000	3152.84	2220.220
5		1.40	4.3	11.400	7.100	3152.84	2251.938
1		0	4.3	11.300	7.000	3152.84	2220.220
2		0.60	4.3	11.300	7.000	3152.84	2220.220
3	280	0.80	4.3	11.340	7.040	3152.84	2232.907
4		1.00	4.3	11.500	7.200	3152.84	2283.655
5		1.40	4.3	11.300	7.000	3152.84	2220.220
1		0	4.3	11.250	6.950	3152.84	2204.362
2		0.60	4.3	11.350	7.050	3152.84	2236.079
3	350	0.80	4.3	11.355	7.055	3152.84	2237.665
4		1.00	4.3	11.200	6.900	3152.84	2201.503
5		1.40	4.3	11.350	7.050	3152.84	2236.079

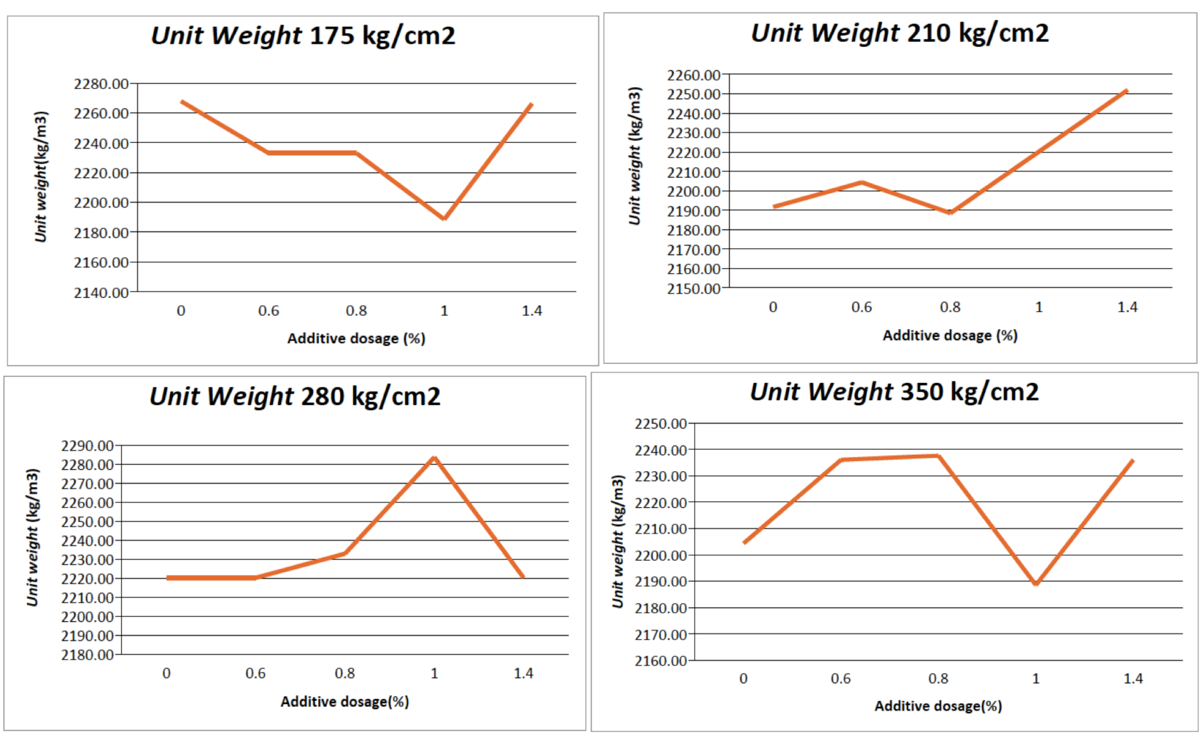

Figure 7. *Unit Weight for a Resistance of 175,210,280,350 kg/cm2.*
Source: own

3.4 Compressive Strength

As it can be seen in (Figure 8), the growth of compressive strength given by the additive with Nanosilica, consequently, as previously mentioned Mehta and Monteiro determined that the presence of Silica (Nanosilica) reduces the thickness of the transition zone between paste and aggregate resulting in the reduction of exudation. This is due to two important reasons, the first is pore refinement associated mainly with the nano-filling effect where it partially fills large voids and capillary pores to refine the pore structure of the cement paste. The second reason is the pozzolanic reaction of NS can consume portadite, which not only reduces the calcium hydroxide of the cement paste, but also causes the calcium hydration products of the paste to become more homogeneous (C-S-H).

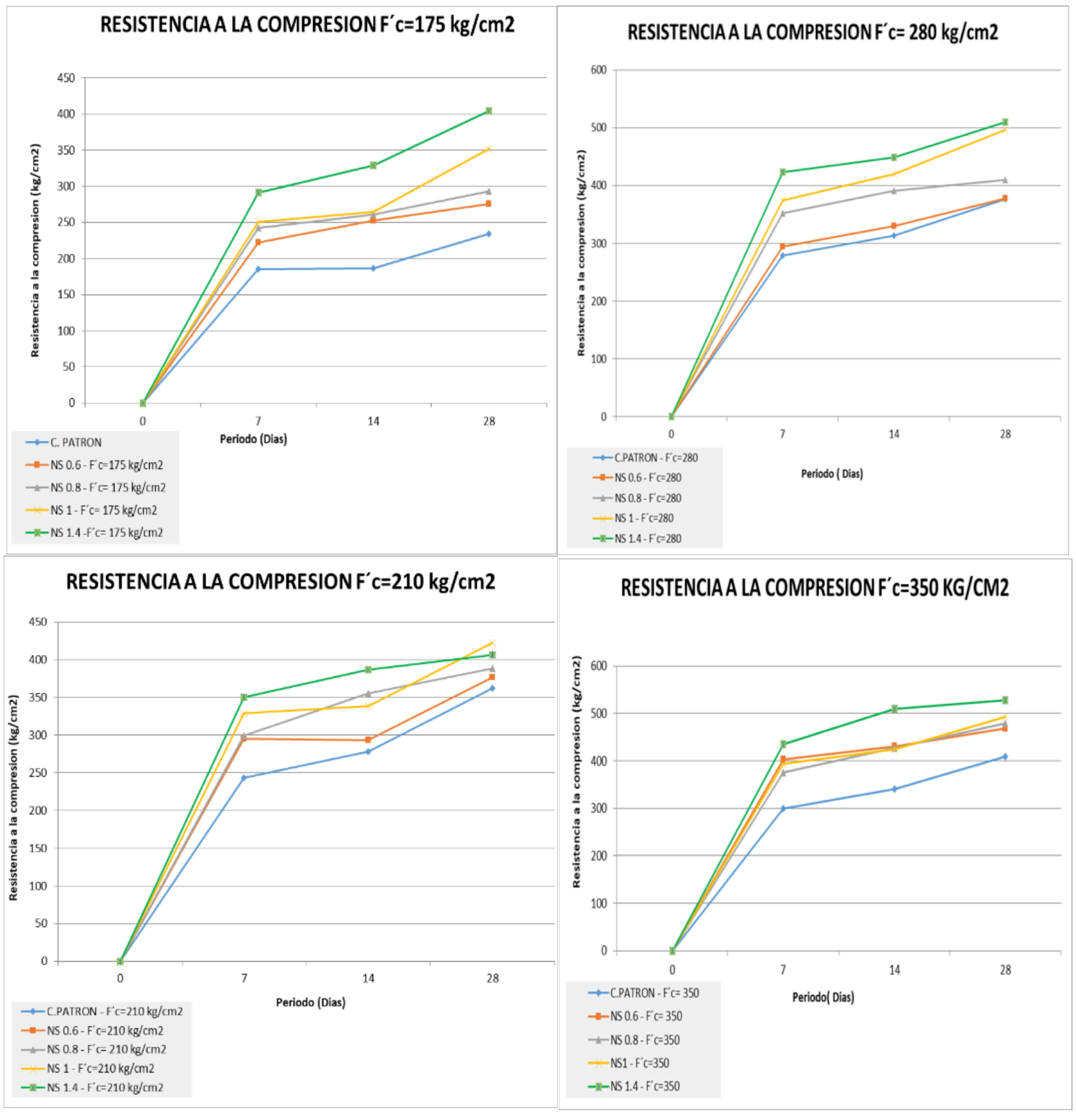

Figure 8. *Compressive Strength Test for a Resistance of 175 kg/cm2.*
Source: own

We can notice in (Figure 8) the increase in strength of the concretes with Nanosilica; for example, the specimens with NS 0.6, NS 0.8, NS 1, and NS 1.4 had a compressive strength of 175 kg/cm2 at 7 days. This meant an increase in ratios of 20.24%, 31.19%, 35.63% and 57.29% compared to the reference groups (concrete - standard). Meanwhile, NS also contributed to the compressive strength at 28 days, which had increase ratios of 17.33%, 24.89%, 49.84% and 72.38% for NS 0.6, NS 0.8, NS 1, and NS 1.4, compared to the specimens with standard concrete. In (Figure 9) it can be observed the breakage of the concrete specimen.

Figure 9. *Compressive Strength Test*
Source: own

3.5 Permeability (D.I.N. 1045, D.I.N. 1048)

As can be observed in (Table 6) and (Figure 10), a normal concrete without addition of Nanosilica has higher penetration than concretes with addition of Nanosilica. We can also see in (Table 6) that the penetration is very high in a standard concrete, unlike some concretes with admixture where it is observed that penetration decreases by 50%. The permeability test can be seen in (Figure 11).

Table 6. *Penetration test results for strengths of 210 kg/cm2*

STRENGTH OF STUDY (Kg/cm2)	DOSAGE OF NANOSILIC ADDITIVE (% of cement weight)	AGE (days)	Penetration 1- (mm)	Penetration 2 -(mm)	Penetration 3 -(mm)	AVERAGE PENETRATION (mm)
210	0,0	28	24,9	25,4	25,6	25,30
210	0,6	28	14,2	8,9	8,2	10,43
210	1,0	28	10,4	9,6	8,0	9,33
210	1,4	28	7,5	15,4	8,5	10,47

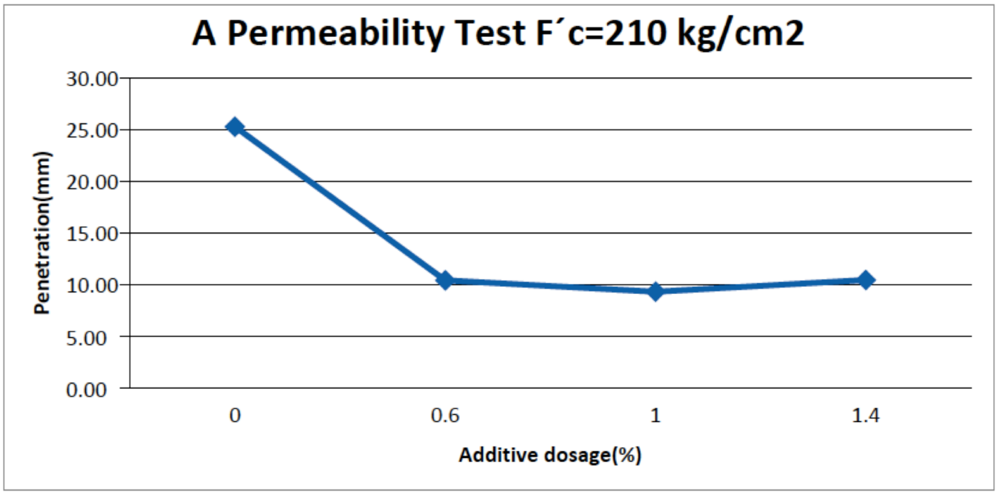

Figure 10. *A permeability test. Source: own*

Figure 11. *Permeability test for a resistance of 210 kg/cm2*
Source: own

3.6 Comparative costs analysis of concrete with Nanosilica compared to concrete without Nanosilica and concrete with the powerful aggregate.

The composition of the new concrete was designed based on the concept of Mehta and Monteiro; the amount of material used, defined in costs, is shown in (Table 7) and (Figure 12).

Table 7. *Cost comparison for strengths of 175,210,280 and 350 kg/cm2*

Name	Cost(s/.)
C.Poderosa	208.761
C.Patron 175	172.601
NS 0.6 -175	202.195
NS 0.8 -175	212.059
NS 1 -175	231.687
NS 1.4 -175	252.381
Name	**Cost(s/.)**
C.Poderosa	254.43
C.Patron 210	191.763
NS 0.6 -210	210.992
NS 0.8 -210	221.339
NS 1 -210	245.914
NS 1.4 -210	269.485
Name	**Cost(s/.)**
C.Poderosa	345.52
C.Patron 350	265.086
NS 0.6 -350	312.049
NS 0.8 -350	327.698
NS 1 -350	343.362
NS 1.4 -350	374.661
Name	**Cost(s/.)**
C. Poderosa	304,590
C. Patron 280	227,216
NS 0,6 - 280	267,123
NS 0,8 - 280	280,408
NS 1,0 - 280	293,729
NS 1,4 - 280	320,340

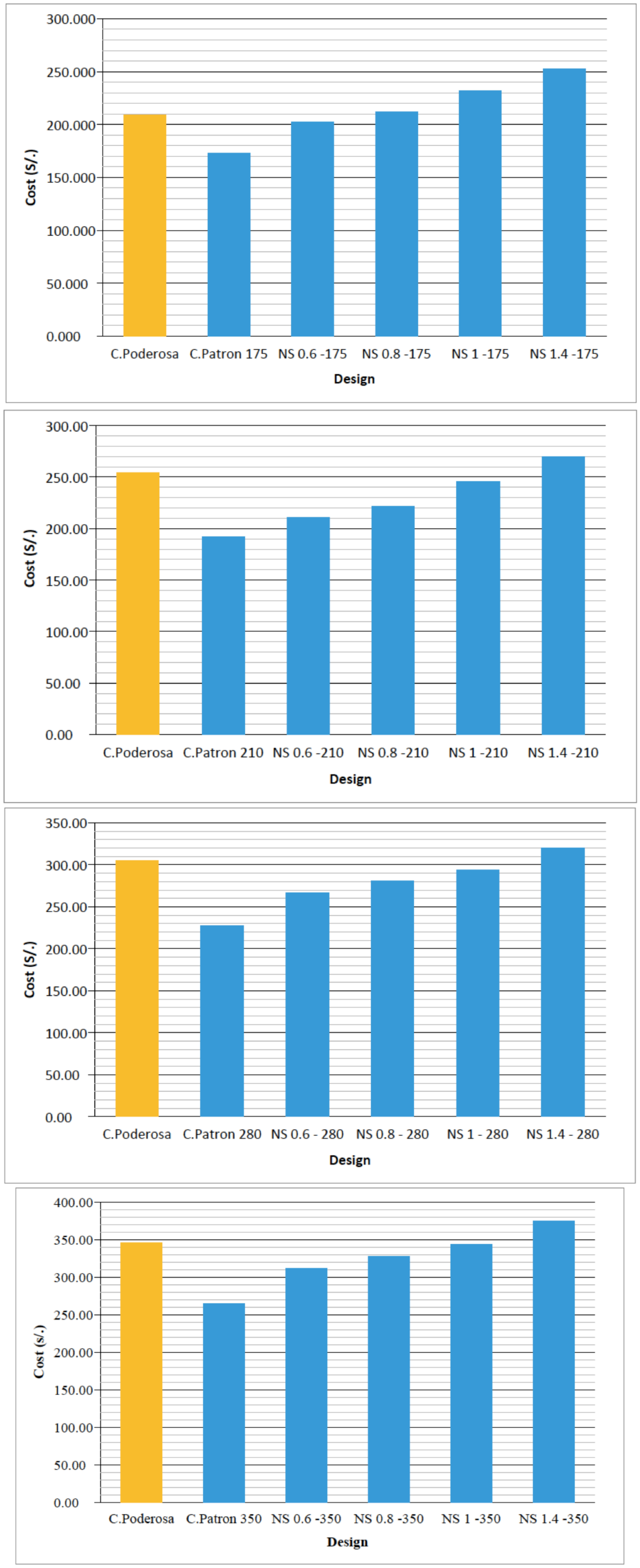

Figure 12. Cost Comparison.
Source: Own

We can conclude that the designs with Añashuayco aggregates, and with the addition of Nanosilica between the range of 0.8 to 1.4 %, reach the resistances of a design with aggregate from la ponderosa. But in terms of costs, the designs with Añashuayco aggregates are cheaper. But we must consider that the cost, of concrete with Nanosilica additions higher than 1%, is higher than concrete using aggregates from the La poderosa quarry.

4. Conclusions

This study analyzed the benefit of incorporating fine and coarse aggregates from the Añashuayco quarry to an optimum mix with Nanosilica, with respect to standard concrete obtained at 28 days of age. To be able to develop a type of concrete with high CAD performance:

It is concluded that the compressive strength improved substantially, thanks to the pozzolanic reaction of Nanosilica, with portlandite quickly produce C-S-H gel, which reduces the porosity of the structures. In addition, the nanometer size of nanosilica particles can partially fill the capillary pores to refine the pore structure of the cement paste.

The aggregates from Añashuayco quarry are not of good quality, limiting their strength. The use of Nanosilica addition for similar aggregates will favor the strength and optimization of concrete.

The standard deviation values of the compression tests vary between 4.3 kg/cm2 to 21 kg/cm2, this result compared with the quality control table for specimens provides a qualification of good and excellent in its majority. The quality and reliability of the results can be established according to the procedures given by the ACI 214 committee.

The permeability of the concrete with admixture is progressively reduced according to the percentage of admixture, providing greater compactness to the concrete, it is observed that it decreases 50% in penetration. It makes the concrete more compact, to the point that the elements that cause corrosion cannot penetrate the concrete.

It can be observed that the concrete samples for designs of 280 kg/cm2 with aggregates of the powerful one is very expensive, with an approximate price of S/. 304.59 (without considering the freight of the aggregate). The concrete obtained has an approximate cost of S/. 267,123 being 15% cheaper. It can be concluded that concrete with Añashuayco aggregate adding the percentage of Nanosilica reaches the strength requirements for a structural concrete and also generates an economic benefit by being a concrete very accessible in costs to the population of the northern cone.

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