Revista Ingeniería de Construcción RIC
Vol 38 Nº2 2023
www.ricuc.cl
DOI: 10.7764/RIC.00067.21

ENGLISH VERSION...

Analysis and comparison of improved concrete with the addition of different types of materials

Análisis y comparación de hormigón mejorado con la adición de distintos tipos de materiales

D. Benel Ramírez* [1] https://orcid.org/0000-0002-7659-6993

* Santo Toribio de Mogrovejo Catholic University. Chiclayo, PERU

Fecha de Recepción: 16/10/2022
Fecha de Aceptación: 31/01/2023
Fecha de Publicación: 02/08/2023
PAG: 255-264

Abstract
The present analysis was developed by creating a detailed analysis of each article selected for the corroboration of the information and the subsequent comparison between them in order to encourage research of alternative methods of concrete production that will allow the reduction of pollution and will improve the quality and efficiency of concrete. The materials used were nanosilica, pozzolana, and recycled crushed brick that were subjected to laboratory studies with the goal of knowing their properties and of developing mix designs with different content percentages to have a broad study population and achieve representative results. These mix designs were used to create specimens that were tested in different periods to analyze their behavior in various situations. After testing, it was possible to determined that the addition of these materials are effective, in creating concrete of greater strength in the case with the addition of nanosilica, in the case of pozzolana, greater strength can be obtained at a reduced cost due to it being a natural material with various deposits where the material can be obtained in this country and throughout the world, and in the case of the addition of crushed brick, concrete with a similar strength to a conventional type can be obtained at a reduced cost of fabrication due to being a recycled material.
Keywords*:nanosilica; pozzolanic; crushed brick; concrete; compression.*

Resumen
El presente análisis se desarrolla haciendo un análisis minucioso de cada artículo escogido para la corroboración la corroboración de sus Datos y posterior comparación entre ellas con la finalidad de incentivar la investigación en alternativas en el Uso de elaboración de concreto que permitan reducir la contaminación y mejorar la calidad y eficiencia del concreto. Los materiales a utilizar fueron el nanosílice, la puzolana y el ladrillo triturado reciclado y fueron sometidos a estudios de laboratorio con la finalidad conocer sus propiedades y poder elaborar diseños de mezcla con distintos porcentajes de contenido para tener una población de estudio amplia y lograr resultados representativos, estos diseños de mezcla sirvieron para la elaboración de probetas que fueron ensayadas en distintos periodos para analizar su comportamiento en diversas situaciones. Y luego de estos ensayos se pudo determinar que la adición de estos materiales son efectivos para obtener concretos de mayor resistencia en el caso de la adición de nanosílice, en el caso de la puzolana se pueden obtener mayores resistencias disminuyendo el costo de fabricación al ser éste un material natural y con diversos depósitos de obtención en este país y en el mundo y en el caso de la adición de ladrillo triturado se puede obtener concretos de muy parecida resistencia al convencional disminuyendo el costo de fabricación al ser este material un material reciclado.
Palabras clave: nanosílice; puzolana; triturado de ladrillo; concreto; compresión.

[1] ***Corresponding author:***
Universidad Católica Santo Toribio de Mogrovejo
author: danielbenelramirez@gmail.com

Revista Ingeniería de Construcción RIC
Vol 38 Nº2 2023
www.ricuc.cl
DOI: 10.7764/RIC.00067.21

1. Introduction

In sight of the vast amount of pollution and emissions of CO_2 that are present in the various economic productive sectors, including the construction sector, various researchers have taken on the task of searching for alternatives that will improve the environmental crisis, in which the construction sector takes part by searching for a material that can be added to the traditional concrete mixtures that will partially reduce the amount of concrete and/or can aid the production of concrete since this is the material most used on a worldwide level thanks to the high demand for this product due to how quickly and easily it can be prepared, its great versatility, and the exponential economic and social growth in various nations and sectors throughout the world.

In this article, there will be a review and comparison of four innovative options in regards to concrete production, the first option includes an optimization of concrete through the addition of Nanosilica (Caballero et al., 2021), the second option that we will review will be the production of concrete that considers producing concrete with recycled crushed brick as a replacement for course aggregate (Perez, 2012), and as a third option, we will see the creation of concrete that adds volcanic pozzolana (Cerna and Quiliche 2020), in order to compare the strength achieved by each of these mixtures, as well as the cost, with a basis for reference of the strength, the curing time, and the costs achieved by the conventional concrete mix.

2. Concepts and Materials

2.1 Nanosilica

Nanosilica is an additive that has similar characteristics to silica fume. This material having a pozzolanic-type behavior contributes to the increase in strength of the concrete mix by significantly reducing the porosity present in this mix, going into detail about its structure, it can be stated that it is crystalline, it is found in a liquid state, and its particles vary in size between 3 and 150 nanometers, thus differentiating and surpassing microsilica particles whose particles range from 200 and 1000 nanometers in size, and they do not have a liquid appearance, rather having an appearance of dry powder. It is also worth noting that the nanosilica has its origin in microfine particles of amorphous silicon dioxide (Galeote, 2012) (Caballero et al., 2021).

2.2 Pozzolana

The pozzolanic material has been of vital importance in the creation of cementitious material since the time of ancient Rome to the present day. In the pozzolanic cement, which is a combination of plaster, pozzolana, and cement, which generally is in portions of 2 to 4% of plaster, 30 to 45% of pozzolana, and of 55 to 70% of Clinker. The pozzolana can be of natural origin or artificial. Pozzolana of natural origin comes from volcanic rocks that are formed of glass that is obtained by the sudden change of temperature of the lava when it cools. It is also worth noting that the origin of artificial pozzolans, which can be obtained from the ashes of agricultural scraps, such as rice husks or sugar cane, can also be obtained from furnace slag, from thermally activated or calcined clay, or from fly ash (Snelling and Elsen 2012).

2.3 Clay blocks

Nowadays, we can see that the clay block, also known as fired brick, is frequently used in the construction process. However, there are qualities or characteristics of the clay that must be met in order to be suitable for the creation of these fired bricks for construction purposes. The material known as clay is composed of alumina silicate, whose particles have a diameter equal to or less than 0.005 mm. This microscopic grain has the particular characteristic of having the shape of a scale, which allows it to have a larger surface and when it comes into contact with water, it obtains plastic characteristics, malleable and ductile, thus becoming able to adopt almost any shape, and when it goes through a calcination process, it hardens and remains with the shape that it was given. This material is found in nature in large quantities and its ease of procurement and workability make this material the favorite for the production of construction blocks (Zea, 2005).

3. Methods

Next, we will detail one by one the methods indicating percentages, composition, and design of the concrete mixtures or concrete that have been elaborated in the analyzed studies.

3.1 Article 1 - (Caballero et al., 2021)

As we will see in the (Table 1) below, the material that will vary in each of the specimens under study will only be the percentage of nanosilica used. It should also be clarified that the procedure of the addition of water was continuous in order to obtain a homogenous paste. The other materials, both cement as well as aggregates, in all cases maintained the same amounts and each specimen went through a curing process under the same conditions.

Table 1. *Amount of material for the design of concrete according to strength*

Material	175 kg/cm2	210 kg/cm2	280 kg/cm2	350 kg/cm2	Units
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

Source: (Caballero Arredondo, 2021)

3.2 Article 2 - (Cerna and Quiliche, 2020)

In this investigation, tests were carried out to determine the properties of the aggregates to be used in these tests, in the same way that researchers ensured that both the fine aggregates and the coarse aggregates were suitable according to the standard for the production of concrete.

Once this was clarified, the design mixture was carried out for a compressive strength of 210 kg/cm^2 in order to prepare specimens that will correspond or will be composed of batch quantities designed for the standard sample. The same method, which used the same design mixture was used to make the specimens that included volcanic pozzolan, with the difference that these new batch quantities were obtained by replacing the cement in different percentages of weight (4, 8, 12, and 15%) with pozzolan. It should be noted that in order to have a larger sample and prevent any errors, 18 specimens were made for both the standard sample as well as for each of the four different batch quantities, for a total of 90 specimens which were tested. Below is a compilation of the quantities and the materials that were used by type.

Table 2. *Quantities of material for the concrete design*

Material	Sample	4%	8%	12%	15%	Unit
Cement	32.98	31.66	30.34	29.02	28.03	Kg
Fine Aggregate	81.26	81.26	81.26	81.26	81.26	Kg
Coarse Aggregate	97.42	97.42	97.42	97.42	97.42	Kg
Effective Water	27.83	27.83	27.83	27.83	27.83	Lt.
Volcanic Pozzolana	-	1.32	2.64	3.92	4.95	Kg

Source: (Cerna & Quiliche, 2020)

As can be seen in the (Table 2), the quantities in kilograms of fine and coarse aggregate do not vary in any of the sample types, likewise the liters of effective water do not change either. However, the amount of cement does, as this is the only material with respect to the standard sample that is replaced by the volcanic pozzolana in the percentage specified in each of the types of specimens produced.

3.3 Article 3 - (Pérez, 2012)

In this study Perez uses natural aggregates from quarries in the town of Sogamoso in Boyaca, Colombia, for his normal mixture (without additions), also known as the standard mixture. The brick residue was obtained by ovens that produced brick and tile based on fired clay that was later crushed. The cement, as in the other two articles that were previously reviewed, was Portland cement type one.

The recycled crushed material was submitted in order to determine its physical properties, such as apparent density (gr/cm^3), the absorption of water (%), and the unit mass (gr/cm^3). Perez, as well as Caballero and company, carried out a mix design and a quantity per batch of the materials for his standard sample, and based on this, he replaced the coarse aggregate with crushed recycled brick in percentages of 10, 20, and 30%. It should be noted that the material, due to the high absorption that it presented in the aforementioned tests, had, for practical purposes of this study, to be saturated one day before the preparation of the specimens to avoid variations in the amount of water in the mixture of concrete.

Perez, for his standard sample and for his other three types, demonstrated that he made three specimens with a total of 12 specimens intended for compression rupture. The (Table 3) will be presented graphically detailing the nomenclatures and the different quantities that were used in this trial.

Table 3. *Quantities of materials for the design of concrete*

Materials	M0	M1	M2	M3	Unit
Cement	5.12	5.12	5.12	5.12	Kg
Fine Aggregate	9.91	9.72	9.54	9.36	Kg
Coarse Aggregate	12.11	10.7	9.32	8.01	Kg
Effective Water	0.5	0.5	0.5	0.5	w/c
Crushed Brick	-	1.19	2.33	3.43	Kg

Source: (Pérez Rojas, 2012)

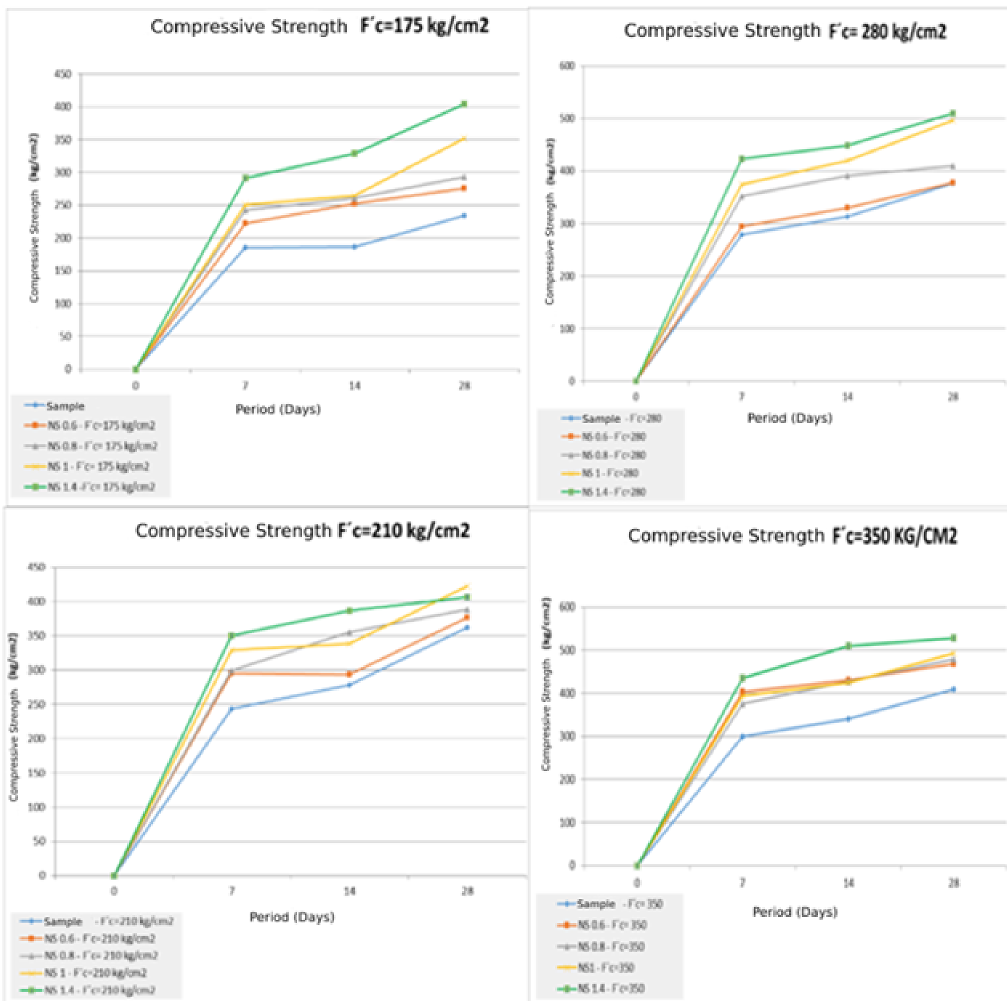
Where:
M0= standard mixture
M1= mixture which replaces the 10% of coarse aggregate with crushed recycled brick
M2= mixture which replaces the 20% of coarse aggregate with crushed recycled brick
M3= mixture which replaces the 30% of coarse aggregate with crushed recycled brick

Revista Ingeniería de Construcción RIC
Vol 38 Nº2 2023
www.ricuc.cl
DOI: 10.7764/RIC.00067.21

4. Results

4.1 Trial 1 - (Caballero et al., 2021)

In the present study it becomes evident that as a result of the addition of the nanosilica, the compressive strength of the specimens increases proportionally to the degree of the percentage added, as mentioned in this study. This is due to the effect of the nano filler, which fills, in large part, the pores of the cementitious paste. It also reduces the exudation by reducing the contact area between the aggregate and the cementitious paste.



Source: (Caballero Arredondo, 2021)

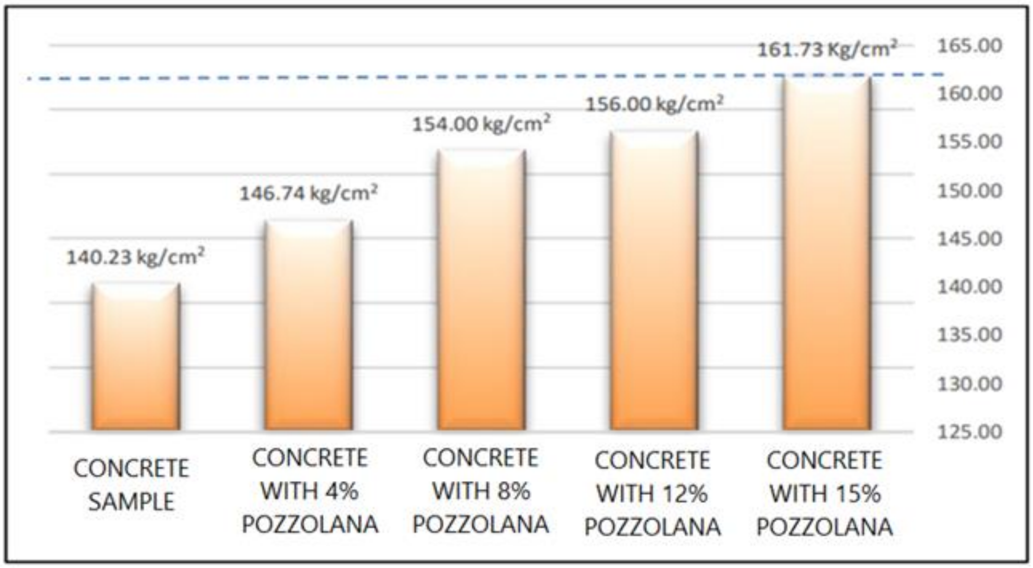
Figure 1. *Compressive strength of concrete for different strengths and percentages of added nanosilica*

As we can see in the (Figure 1), if you notice a clear increase in the percentage of compressive strength, we see that the higher the percentage of nanosilica that was added to the sample, the greater the compressive strength obtained in the specimens, reaching increases of up to 57.29% compared to the standard sample during a period of 7 days, and at the end of 28 days, values were observed from an increase in strength of 17.33% for a content of 0.6% of nanosilica up to an increase of 72.38% for a percentage of 1.4% of nanosilica, therefore we can say that this material is effective in improving the concrete mixture in terms of compressive strength.

DOI: 10.7764/RIC.00067.21

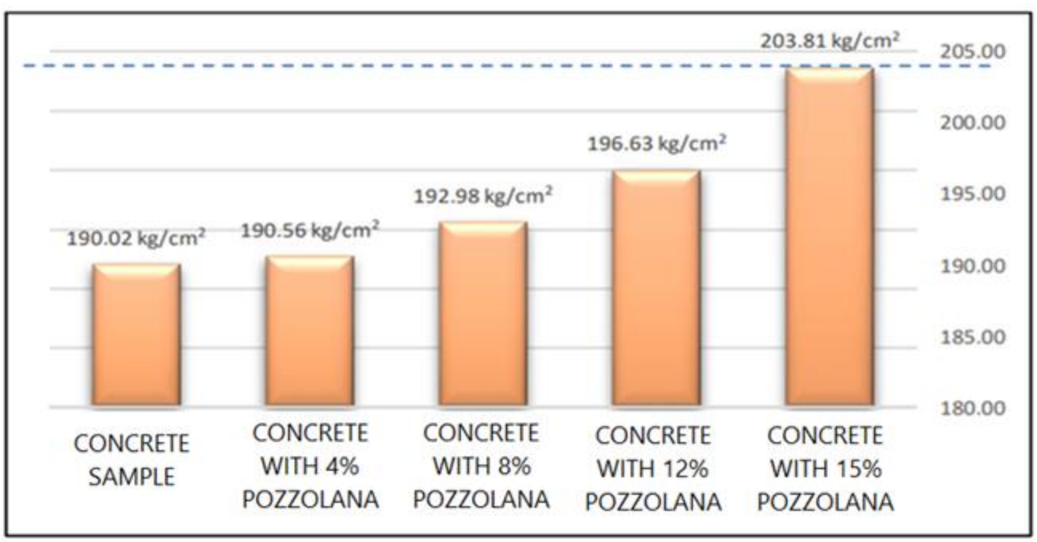
4.2 Trial 2 - (Cerna and Quiliche, 2020)

As in the previous article, the proposed hypothesis is also fulfilled here, since in all cases, an increase in the compressive strength of the specimens is obtained in comparison with the standard concrete sample. The increases in strength obtained are given over a period of 7, 14, and 28 days, and it is shown that in addition to their easy access in Peru, the natural pozzolans are of great importance and impact for the production of concrete and could be used for a great change for the good of the construction sector of this country, as well as the production of concrete of higher quality. (Figure 2), (Figure 3), (Figure 4) and (Figure 5).



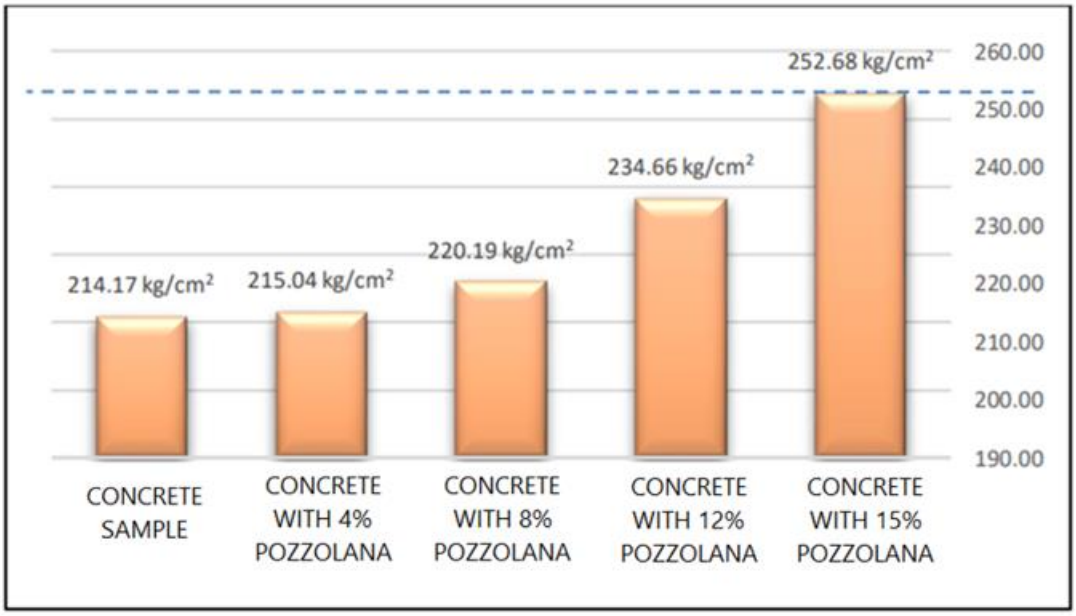
Source: (Cerna & Quiliche, 2020)

Figure 2. *Compressive strength obtained during a period of 7 days*



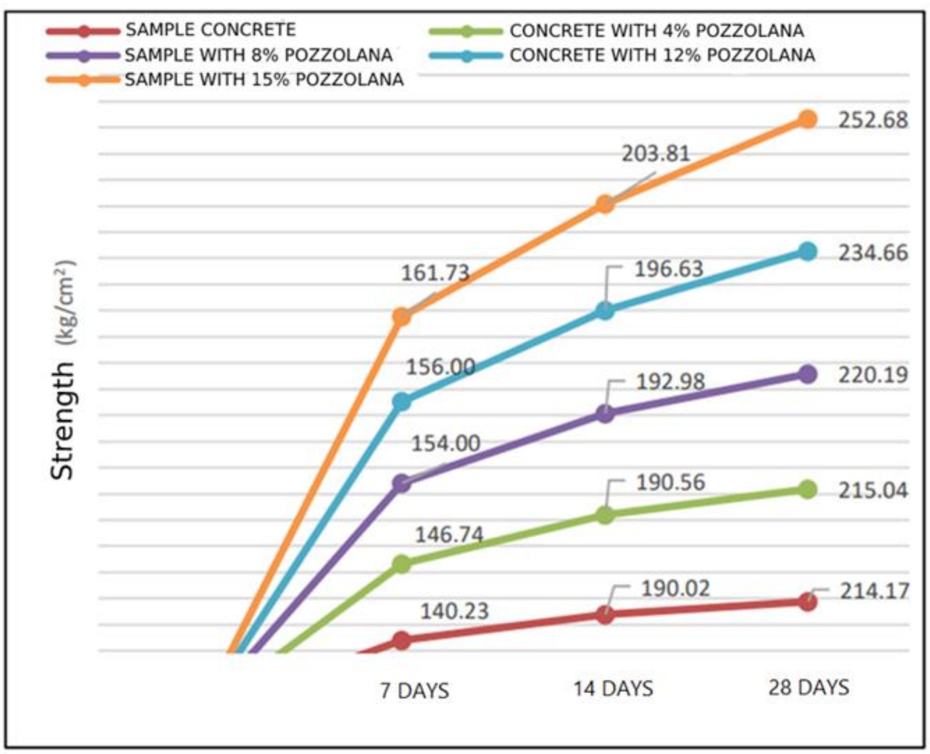
Source: (Cerna & Quiliche, 2020)

Figure 3. *Compressive strength obtained during a period of 14 days*



Fuente: (Cerna & Quiliche, 2020)

Figure 4. *Compressive strength obtained during a period of 28 days*



Source: (Cerna & Quiliche, 2020)

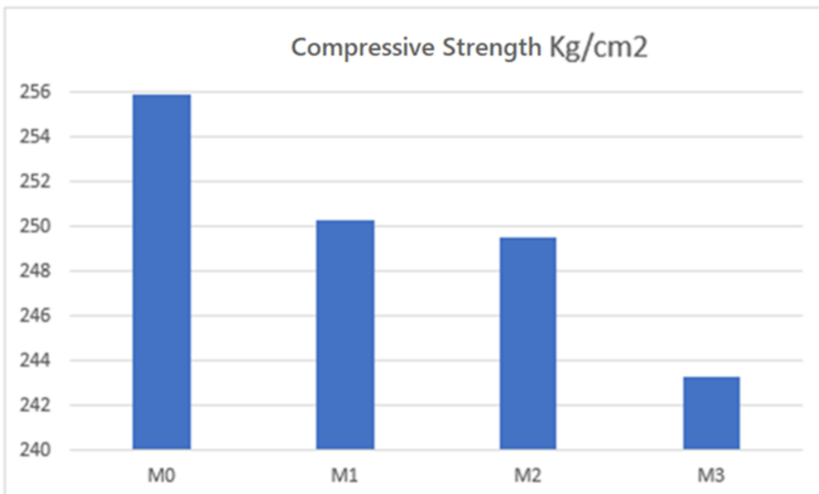
Figure 5. *Increases in compressive strength in different periods.*

Revista Ingeniería de Construcción RIC
Vol 38 Nº2 2023
www.ricuc.cl
DOI: 10.7764/RIC.00067.21

4.3 Trial 3 - (Pérez, 2012)

The results presented here comprise a period of 28 days, in which we can see that although it is true that there is a decrease with respect to the strength obtained, which is directly proportional to the quantity or percentage of coarse aggregate replaces, we can state that this decrease is minimal, as we only see a maximum decrease of only 5% of the final strength, and in this mixture that replaced 30% of the coarse natural aggregate with recycled brick crushed aggregate.

Therefore, according to this study, it is recommended only as long as the 30% replacement is not exceeded, the use of brick from a defective manufacturing and that which does not pass quality control, for the production of conventional concrete up to a strength of 210 kg/cm^3. It should also be noted that since brick is a material that varies in terms of origin and composition, whenever it is desired to be used in concrete production, it will be imperative to carry out the corresponding studies in order to determine the physical and chemical characteristics it presents. (Figure 6).



Source: (Pérez Rojas, 2012)

Figure 6. *Compressive strength in a period of 28 days.*

5. Discussion

In the research analyzed and compared in this article, we can see that it is feasible to replace or add natural materials, new or recycled, to the common or usual composition which is given to the design mixture of a concrete for construction purposes. Of course, this is subject to consideration that must be taken for each particular case. However, when these considerations are given correctly, and are carried out in compliance with all regulations and details, the use of these innovative materials is correct because we can make improvements in the manufacturing processes, both in the environmental aspect as well as the economic aspect when using recycled aggregates.

Through statistical approximations, the values found in each investigation were taken to a base average range of 210 in order to compare the behavior of each of these materials. We can observe that the standard samples are very similar as a result of this statistical approximation carried out, and from there, we can point out that the addition of nanosilca presents a better performance in the different percentages or type samples than the pozzolanic material as well as the crushed recycled brick, of course. This could be due to the fact that the nanosilica was added to the mixture without replacing the pre-existing materials, in this case, cement, unlike the test tubes made with pozzolana, where a percentage of the weight of the cement was replaced by this material. Additionally, we point out that in the specimens made with the crushed brick, the material

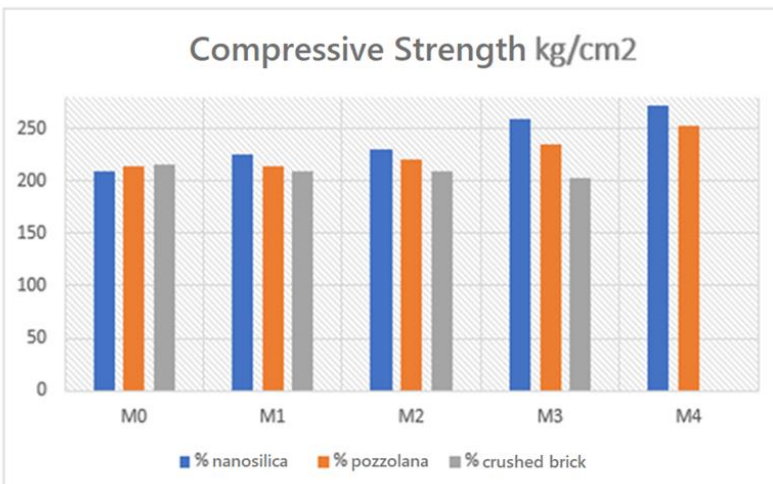
Revista Ingeniería de Construcción RIC
Vol 38 Nº2 2023
www.ricuc.cl
DOI: 10.7764/RIC.00067.21

replaced was not the cementitious material. In this case, the crushed brick replaced the coarse aggregate component in the mixture, therefore a decrease in the final strength of the mixture is obvious, as it is a recycled product of a lower quality.

In the (Figure 7) presented below, we can see that for a period of 28 days, the samples containing crushed brick begin to decrease in strength from the first sample which contains 10% of crushed brick per coarse aggregate. However, we can also see that the difference between the 10 and 20% in this sample does not decrease significantly. It does, however, when the sample shows 30% crushed brick. Regarding the results of the samples with nanosilica content, we cannot see a significant increase between the samples with 0.6 and 0.8% content, however from 1% of added nanosilica, we can see a significant increase in the compressive strength obtained, strength which is even more significant when we observe the strength reached by the specimen with a content of 1.4%. Finally, in the sample of pozzolana , it can be seen that samples of 4 and 8% are similar to the standard sample, while the samples of 12 and 15% demonstrate an increase in strength, though it is not as significant as in the case of nanosilica.

In sample number four, only two types of materials can be seen. This is because the study of the replacement of crushed brick for coarse aggregate was only carried out for three types of samples, unlike the other two studies reviewed in this article, who present four sample types each.

It should be clarified that in all of the investigations that comprise this article, the procedures and characteristics of the materials used comply with the current corresponding regulations, for which external factors should not be a reason to object to the comparisons in the compressive strengths obtained.



Source: Self created.

Figure 7. *Compressive strength in a period of 28 days.*

6. Conclusions

Referring to the three articles studied, we can conclude that a readjustment can be made in the chemical elements that compose the concrete mixture in order to obtain a reduction in environmental pollution by opting for natural alternatives, without affecting the quality of the product that is sought.

In the first article, we observed that the presence of nanosilica in the concrete increases the compressive strength notably, filling the capillary voids to refine the pore structure of the cement paste, bringing us to the conclusion that the use of nanosilica is entirely recommended since it increases the strength and from the economic standpoint, it is a lower cost by 15%.

In the second article, we conclude that the replacement of volcanic pozzolana increases the strength by 17.98%, thus being completely recommendable, helping to make the construction more resistant.

Finally, in the third article, the use of crushed clay block material as a coarse aggregate in concrete is detailed, where it is shown that it reduces the mechanical characteristics as well as the durability of concrete, compared to natural aggregates and is therefore not as recommended for use, being worse for coastal areas where the concentration of chlorides is high in the environment

7. References

Caballero Arredondo, P. W.; Damiani Lazo, C. A.; Ruiz Pico, Á. A. (2021). Optimization of the concrete through the addition of nanosilice, using aggregates of the cantera de Añashuayco de Arequipa. Revista ingeniería de construcción, 36(1), 71-87. https://doi.org/10.4067/S0718-50732021000100071

Cerna, G. C.; Quiliche, J. (2020). Resistance to axial compression of the concrete f'c=210 Kg/cm^2, adding pozzolana volcanic. 18th LACCEI International Multi-Conference for Engineering, Education, and Technology: "Engineering, Integration, and Alliances for a Sustainable Development" "Hemispheric Cooperation for Competitiveness and Prosperity on a Knowledge-Based Economy", July 27-31, 2020, Virtual Edition.

Galeote M., E. (2012) Influencia de la nanosílice sobre las características de un microhormigón de ultra alta resistencia. Trabajo Final de Grado, Grau en Engineyria de la Construcció. Universitat Politécnica de Catalunya, Barcelona Tech.

Parth Harkishan, J.; Parekh, D. N. (2022). Assessment of utilization of ceramic waste as a substitute to concrete constituents – A review. Revista Ingenieria de Construccion, 37(1), 69-78. Scopus. https://doi.org/10.7764/RIC.00019.21

Pérez Rojas, Á. V. (2012). Uso de triturado de ladrillo reciclado como agregado grueso en la elaboración de concreto. Ingenium, 13(26), 116-125.

Snelling, R.; Mertens, G.; Elsen, J. (2012). Supplementary Cementitious Materials. Reviews in Mineralogy and Geochemistry. 74(1), 211-278. https://doi.org/10.2138/rmg.2012.74.6

Zea Osorio, N. L. (20o5). Caracterización de las arcillas para la fabricación de ladrillos artesanales. Universidad de San Carlos de Guatemala. http://biblioteca.usac.edu.gt/tesis/08/08_2549_C.pdf

Zschimmer & Schwarz (2021). Propiedades físicas y químicas de la cerámica. (2021, noviembre 11). ZS España. https://www.zschimmer-schwarz.es/noticias/propiedades-fisicas-y-quimicas-de-la-ceramica/