J Ther Eng, Vol. 10, No. 3, pp. 746–755, May, 2024

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.14744/thermal.0000831

Research Article

Impact of nano-silica (SiO_2) on thermic properties of concrete

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ARTICLE INFO

Article history
Received: 15 July 2021
Revised: 21 August 2021
Accepted: 21 September 2021

Keywords:
Concrete; Nano-Silica; Specific Heat; Thermal Conductivity; Thermal Properties

ABSTRACT

The application of nanotechnology in the field of Buildings and concrete Build is one of the main goals of this article because of the technology's role in enhances the properties of concrete and increasing the efficiency of building materials, as well as in preserving natural resources, reducing environmental pollutants, and increasing the attention that nanotechnology is currently receiving in various fields of science and engineering applications. By partially replacing cement with silica nanoparticles, the current research is focused on investigate the impact of silica nanoparticles (SiO_2) on the concrete thermic properties, including specific heat capacity (SHC), thermic conductivity, and thermic diffusivity, in order to produce lightweight concrete with good thermal insulation capabilities. In order to replace a portion of the concrete's weight, nano-silica (NS) was added in percentages of 1%, 2%, and 3%. The results showed that the mixtures including nano-silica had lower thermic conductivity coefficient values, ranging from 0.5 to 0.92 W/m.°C. This indicates that the thermic insulation capacity of nano-concrete increased by 41.8 percent, 53.15 percent, and 65.57 percent, respectively. Furthermore, based on the data, Thermal conductivity coefficient's can be lowest value at a ratio of (3%). As a result, replacing concrete beyond this proportion will result in a reduction in its various qualities. Furthermore, a reduction in the specific thermic ability values was noted in contrast to traditional concrete.

Cite this article as: Saleh AN, Ahmed OK, Attar AA, Abdullah AA. Impact of nano-silica (SiO_2) on thermic properties of concrete. J Ther Eng 2024;10(3):746–755.

INTRODUCTION

Global population growth has resulted in an unparalleled surge in the usage of conventional fuels, along with a notable rise in environmental contamination stemming from industrial and human endeavors [1]. According to statistics, activities carried out by people within buildings account for one-third of the world›s energy usage [2]. Given that humans spend 90% of their time indoors, it is crucial to provide these inhabitants with comfortable living environments [3]. Human comfort within structures depends on a number of variables, the most significant of which is temperature since the building›s ability to cool and heat depends on the speed and the heat›s direction transmission through its walls [4]. The movement of heat between a building›s roof and walls is influenced by thermal

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This paper was recommended for publication in revised form by Regional Editor Mustafa Kılıç

Published by Yıldız Technical University Press, İstanbul, Turkey

conductivity. Consequently, thermal insulators are a vital and important tool that help to lessen heat transfer and a portion of the operating energy of equipment utilized for cooling and heating. Because the fuel and electricity needed for this purpose are extremely costly, it is well known that insulation is necessary to reduce heat load, lower the need for heating and cooling devices, and lower emissions of carbon dioxide and other gases that contribute to environmental pollution and global warming [5]. When building homes, apartments, and commercial buildings, concrete with a large heat capacity and low coefficient of thermal conductivity is a wise choice [6].

Recently, heat transfer [7-9], fluid mechanics [10-13] and other technical applications have made use of nanotechnology. Furthermore, a lot of papers have lately been published in this topic on the application of nanotechnology, a contemporary technology, to enhance the thermal properties of concrete [14]. Sikora et al. [15], for instance, employed Nano-silica material and waste glass (WG) to replace regular river sand with WG 100% of the time in addition to adding NS in the appropriate amounts to enhance cement mortar›s mechanical and thermal properties (1, 2 and 3 percent). Furthermore, empirical research demonstrated that WG lowers the absorption coefficient and thermal conductivity. Additionally, it was observed that the addition of Nano-silica substantially reduced thermic conductivity, particularly at the greatest ratio (3 percent). Jittabut [16] investigated the mechanical and thermal characteristics of compounds of concrete and thermic power storage materials. By combining particles of various sizes (12, 50, and 150 nm) with NS (1–5% by weight), the researcher was able to ascertain the impact of the size and condensation of NS particles. The performance of Nano-silica in terms of thermic diffusivity, volume thermic capacity, compressive strength, bulk density and thermic conductivity was examined as well as the degree to which it affected the performance. Over the course of 28 days, the samples were exposed to nano-silica at temperatures between 350 and 900 oC with a particle size of 50 nm. along with a decline in volume heat capacity and thermic conductivity.

The impacts of several storage techniques on the mechanical and thermic properties of cement mortar were examined by Al Zaidi et al. [17]. Initially, samples were made by substituting 50% of the fly ash and 60% of the cement size with air gel. After that, the samples were added to varying weight ratios of Nano-silica to be stored under various atmospheric conditions (1-3 percent). Given that the samples' he results for thermal conductivity were the lowest, it was possible to conclude that the samples' capacity for thermal insulation had improved. Using the curing approach, It required soaking the samples for seven days in water and then air-curing them for the remaining 28 days, the range was (0.865 to 0.762 W/m.K). However, after the samples were cured for 28 days in water, the greatest sample values came from the curing procedure, which ranged from 0.918 to 1.051 W/m.K. By examining the effects of the contents of the glazed hollow beads and the coal gangue CG replacement ratio, Zhang et al. [18] experiments were conducted to develop a new type of concrete with excellent thermal insulation and good bearing capacity. The concrete's compressive strength and thermal conductivity coefficient improved, according to the results. with values of 37.7 MPa and 0.41 (W/m.K) respectively.

Wang [19] replaced part of the cement with weights between 0.1 to 0.5 percent in order to look into how nanoparticles affect concrete's compressive strength and thermal conductivity at different high temperatures. The findings demonstrated that, at temperatures not exceeding 300 °C, nanoparticles increase compressive strength. However, as temperatures rise, strength and thermal conductivity coefficient decrease when 0.1 percent of cement is substituted with nano-clay cement; on the other hand, when 0.3 percent of cement and 5.0 percent of nano clay are substituted with concrete, the thermal conductivity coefficient increases. Yuan et al. [20] investigation into how Nano-MgO affects the thermal and mechanical characteristics of thermic power storage materials for composites made of alumina was conducted. The samples were heated to 105, 350, and 900 °C by the researchers, and it was found that the use of nanomaterials enhances the samples' thermic characteristics. At the same temperature, the ratio of thermic conductivity values with 1 percent of the Nanomaterial added were 34.8 percent and 23.6 percent more rise than those with pure mortar, and the ideal heat capacity value was attained 19.8 percent and 40.8 percent more rise than that with pure mortar.

Reddy et al. [21] conducted research on how heat is transported during buildings using the thermic conductivity property. For concrete samples where GGBS and nano-silica were largely substituted, the thermal conductivity was studied for varying cement weight ratios between (from 1 - 5 percent). The concrete›s split tensile strength and compressive strength both improved by 10%, according to the data. The intensification of the concrete›s microstructure is responsible for this improvement, and it also demonstrated superior thermal resistance over regular concrete. The concrete loses heat conductivity when nano-silica is added at a rate of up to three percent of the cement weight. In earlier studies, lightweight insulating concrete was created by adding expanded polystyrene (EPS) to concrete mixtures.

The impact of $CaCo_3$, Al_2O_3, and TiO_2 nano additions individually, twice, and three times on the microstructure, thermic, and mechanical properties of cement mold completion with fly ash was investigated by N. Vanitha et al. [22]. The nanomaterials were added in percentages of 2 percent, 4 percent, and 6 percent of the bonding material›s volume. We observe a drop in the thermal conductivity values during the experiments, particularly in binary and ternary mixes. In this investigation, Kaya and Kar [23] employed (EPS) at rates of twenty percent, forty percent, sixty percent, and eighty percent of the total volume.

Thermal testing was performed on the samples. Based on the data, it was determined that the samples› density and thermal conductivity values decreased as the ratios of EPS rose. The thermal conductivity coefficient values varied from 0.061 to 0.390, indicating that minimal values were reached when compared to ordinary concrete. Based on cork and cement mixes intended for building, Boussetoua et al. [24] made their determination by examining the thermic and mechanical properties of cork as a novel physical that was modified within the context of building implementation. Various amounts of cork grains are applied during sample preparation. elevated humidity retention, decreased density, a lower coefficient of thermic conductivity, and a loss in mechanical characteristics are all associated with higher cork proportions. Therefore, thermal insulation can be achieved by using a cork concrete mixture. Reducing the amount of cork used to concrete simultaneously enhances its mechanical qualities and boosts its thermal and structural conductivity.

A examination of the published literature reveals a dearth of research on the impact of nanomaterials on the thermal characteristics of concrete. The purpose of this study is to assess how nano-silica (SiO_2) affects the thermal characteristics of concrete, including its thermal diffusivity, SHC, and thermal conductivity. SiO_2 is used because it is comparatively inexpensive when compared to other nanoparticles and because it improves the mechanical and thermal characteristics of concrete. As a substitute percentage of the cement›s weight, nano-silica was added at percentages of 1%, 2%, and 3%.

MATERIALS AND METHODS

The chemical interaction between water and cement is known as cement hydration. where heat is released during the hardening process, and the concrete›s properties are not stable during this a period and rely on its degree of hydration [25]. The current study made use of a number of materials, as detailed below:

Portland Cement

In line with the Iraqi criterion advantages specified (IQS No. 5 1984), This study used ordinary Portland Cement (OPC), which is produced locally in the cement industry and has been accredited by ISO 9001: 2015 for international quality [26].

Fine River Aggregate

We examined the sieves and all sand classes (IQS NO.45 1984) [27], where the region was cleaned and sieve using sand on a sifted (No. 4 = 0.475 cm) to remove clay and other impurities. Throughout the experiment, Zone 3 gradient number fine river aggregate was utilized.

Coarse Accumulation of Gravel

In addition, coarse accumulation, or gravel, with a volume range of 5 to 1 cm, was included in all cement compositions. To create fine gravel that matched the dimensions of the casting molds that were utilized and the proven Iraqi requirements (IQS No.45 1984), A sieve was used to sort the gravel. (NO.3/811=0.95 cm) [27].

Water

Pure water was utilized to create the time basins for the samples, and all research mixes had a water- bonding proportion of 0.48.

Powder of Silicon Dioxide Nano (SiO_2)

This scentless, white powder has a 20–30 nm diameter. Figure 1 illustrate a specimen of the material. Because of its numerous applications it is regarded as the most abundance substance among the various species of nanomaterials in terms of quantity, the fact that producing it is often less expensive than producing most other nanomaterials, and the fact that it is generally easier to handle than other nanomaterials. Table 1 [28] illustrate the parameters of the NS substance.

How to Mix Nano-Materials with Cement

Each concrete mix has a predetermined ratio, which means that the components are mixed precisely to provide a consistent blend of texture and composition. It›s also important to consider combining the NS substance with the dry components using weight of cement within a thick, to prevent the material from volatilizing through blending, use an pristine nylon bag. Then, move the blending to a bowl with a mechanical stirrer, add the water, and stir until the mixture is homogeneous, about five minutes. For SiO_2, three different ratios were used: 1 percent, 2 percent, and 3 percent. The concrete›s various properties will be reduced by more than this percentage replacement [29], and the findings were compared to ordinary concrete. Table 2 lists the mixture compositions and quantities utilized in cement mortar.

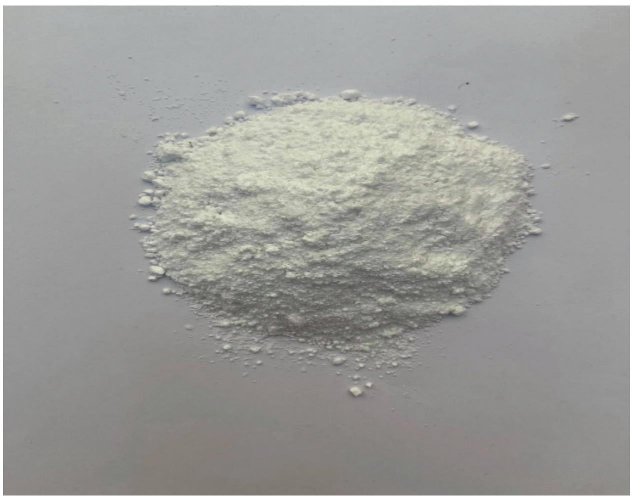

Figure 1. A sample of silicon dioxide nanomaterials (SiO_2).

Table 1. Properties of silicon dioxide nanomaterials (SiO_2) [28]

Parameter	Specification
size of particle	(20-30)*10^{-9} m
Clarity	%99.8
color	White
Fusion degree	1610-1728 Silesian
Boiling degree	2230 Silesian
Density	2533 kg/m^3

Table 2. Blending proportions in cement mortar

Blending no.	Abbreviation	percent of NS in the weight from cement	OPC (g)	WB	Water (g)
1	Ordinary concrete	-	2375	0.48	1141
2	S1	1 percent	2352	0.48	1141
3	S2	2 percent	2328	0.48	1141
4	S3	3 percent	2376	0.48	1141

Experimental Work

The tests were run three times and were carried out in the laboratories of Kirkuk›s Northern Technical University. Each case›s outcomes were documented using the information below:

Formats for thermal conductivity testing

Thermal conductivity test form templates were created utilizing locally manufactured square molds built from (10*10*2) centimeter billets. The molds were cleaned and lightly oiled, and then an iron cable was put at the lowest of each casting so thermocouples could measure the temperature underneath the model. To prevent the concrete mixture from adhering to the moulds, lubricate the motors.

Particular templates for heat capacity testing

When casting models, 10*10*10 centimeter cubic iron molds are used to specific the models› determine thermic capacity. We meticulously cleaned, prepared, and used engine lubricating oil to coat the interior of the molds to prevent from being adhered to by the concrete mixture.

Stacking and casting

The molds are carefully cleaned, ready, and have motor lubricant applied to the internal surfaces in order so as not to cause the concrete mixture to adhere to the molds. After that, the necessary materials are prepared for mixing in varying proportions, where the percentage of gravel is 4, the percentage of sand is 2, and the percentage of cement is 1. These materials are weighed using a sensitive balance and water is added at a rate of = 0.48, then added utilizing a graduated cylinder. Finally, the mixture is placed in a mechanical mixer to achieve a consistent blend. Subsequently, the amalgamation is transferred into the prefabricated molds. After that, the casting is completed in two layers by pouring long crushers into the templates 35 times with an iron rod, until half of the templates are filled. After being poured into the highways thirty-five times to remove all air, reach the maximal density, and the gravitational forces is increased between the Interconnected materials in a homogenous combination, the templates are left in the laboratory atmosphere for an entire day to dry. When the templates are opened and released into the air for an hour, symbols are added to make them stand out. Picture (2-a). They are then stored for 28 days in the ripening tank at room temperature, as obvious in Figure (2-b). Following that, they are removed to carry out the necessary testing, as seen in Figure (2-c).

Thermic conductivity test

Thermic conductivity is the capability of a substance to heat transfer. Conductivity is influenced by substance density, humidity, and ambient temperature; it increases according to increased humidity, density, and temperature [30]. Traditional concrete's heat conductivity is (1.7–2.5) W/m.K. [16]. From the treatment pools, the samples are taken after 28 days and let air dry. After that, the thermal conductivity is measured in compliance with the normative specification (ASTM C177-10) [17] using the hot plate apparatus shown in Figure 3.

Three samples were tested for thermal conductivity for each combination, placing the sample above the plate used for cooling. The thermocouples were attached above and below the sample, which was encircled by holes and insulators in the external and interior water. After that, the sample was screwed onto the heating plate. The water's temperature within and outside the sample, as well as the temperatures above and below it, are measured after the heater is turned on and the equipment has been in a state of thermal stability for 30 minutes. For every sample, three readings were collected on average every thirty minutes. Next, the following computation of the samples' thermal conductivity coefficient was made [31]:

(a) Models after casting

(b) Samples inside the duration tank

(c) Samples after 28 days extracted from the duration tank

Figure 2. Concrete samples used in the tests.

Figure 3. Thermal conductivity device.

$$K=,Q.L-A.\Delta T. \quad (1)$$

K: is the coefficient of thermal conductivity (W/m.°C).
Q: How much heat is exchanged between the sample's two sides? (W).
L: The sample's thickness (m).
A: Area sample (m2).
ΔT: The temperature variation (°C) between the model's two sides.

Test for particular heat capacity

The SHC of a material is defined as the relationship between the power applied to it and the resulting temperature change. The concrete's heat capacity is mostly unaffected by the mineral characteristics. Conventional concrete has a SHC of almost 880 (J /kg.°C), however as temperatures rise and the concrete's moisture content rises, this number increases significantly. In this work, the calorimeter method was utilized to investigate the specific heat capacity models, a tool uutilize to compute the heat capacity and heat interchange rate. The heat capacity of an unknown sample can be found by mixing it with a known substance. Heat is thereby transmitted between these materials. There is an equal amount of heat gained and emitted by the two substances [32]. The specific heat capacity was computed using the following formula [33]:

$$m1.c1.(Teq - T1) = m.c.(T - Teq) \quad (2)$$

m: Substance mass (kg)
c: The substance's SHC (J/kg. °C)
T: Substance temperature (°C)
Teq: Temperature equivalent (°C)
m1: Water mass (kg)
c1: Water's specific heat capacity (J/kg.°C)
T1: The water and calorimeter's initial temperatures (°C)

Test of thermic diffusivity

Thermic diffusion is the relative movement of the mixture components, which occurs when there is a difference in the temperature of the concrete changes. Moreover, the relationship between diffusion (δ) and thermal conductivity (k) is shown by the following formula [34] that follows:

$$v=,v-v.v \quad (3)$$

δ represents thermic diffusivity (m^2/s)
K is the thermic conductivity factor (W/m. °C).
c: SHC expressed as J/kg. °C.
ρ: mass ($grams/m^3$)

RESULTS AND DISCUSSION

Test of Thermoelectricity (K)

A thermic conductivity test of the models was performed on three models of each mixture, and Table 3 displays the results. It is observed that the SiO_2 added to the concrete blend has resulted in a significant increase in the ability of thermic insulation when compared to conventional concrete. The results of ordinary mixture concrete's thermal conductivity, which were attained without the addition of any nanomaterials, also make this clear. The thermal conductivity coefficient varied between 1.22 and 2.05 W/m. °C, according to the measurements. On the other hand, the conductivity coefficient of nano-thermal concrete varied from 0.52 to 0.92 W/m. °C, suggesting that the inclusion of SiO_2 enhances the material's ability to hold onto heat. The combination (S3) had the highest thermal insulation capacity; the greatest percentage we could achieve when the

Table 3. Values of thermal conductivity for various combinations

Mixture I.D	Ordinary concrete	S1	S2	S3
	1.34	0.92	0.77	0.56
(K) value (W/m.°C)	1.32	0.89	0.73	0.52
	1.22	0.86	0.65	0.50

SiO_2 percentage was in the region of (0.5-0.56) W/ m. °C was the thermic conductivity coefficient (3%). The results show that thermic conductivity diminishes as the increase of SiO_2 ratio. Preventing heat transfer due to the creation of a small air space is the main cause of the low thermic conductivity, which is in line with the findings published by Jittabut [16] and Kaya and Kar [23]. Substitute some of the NS with cement provides financial advantages because compared to other nanomaterials, it's good and economical alternative. Figure 4 shows how heat conductivity varies with different nano silica ratios.

Specific Heat Capacity Test (Cp)

One sample per mixture was used to examine the samples› specific heat capacities using the calorie method. The determined heat was emitted using the (CRD C124 – 73) Concrete, aggregate, and other material specific heat test method [19]. Table 4 shows the values for the specific heat capacity. for each of the blends. The concrete specific heat capacity rose as the percentage of SiO_2 added increased, according to a comparison between its specific heat capacity and that of normal concrete. The finding is in accordance with a search by Yuan et al. [20] that employed Nano-MgO and discovered that the optimal heat capacity was also attained, with an increase of 19.8 percent and 40.8 percent above pure mortar; the raise was brought about by the materials› inherent compositions. Concrete›s specific heat capacity, which can be exploited to boost the material›s thermal energy storage capacity, is clearly correlated with the quantity of silica in the material, as Figure 5 shows.

Thermal Diffusivity Test (δ)

The definition of diffusion is the rate at which heat diffuses through a medium. and can be computed by taking the value of specific heat and density and dividing thermal conductivity by that value. A lowering in the thermic diffusivity value leads to an increase in the time that heat travels through the material. Therefore, two essential elements of efficient thermal insulation are thermal diffusivity and thermal conductivity. Consequently, one has to know a material's specific heat, density, and conductivity in order to calculate its diffusivity; these may be found using equation (3) [34]. The values of different thermal diffusivity combinations are shown in Table 5, for ordinary concrete

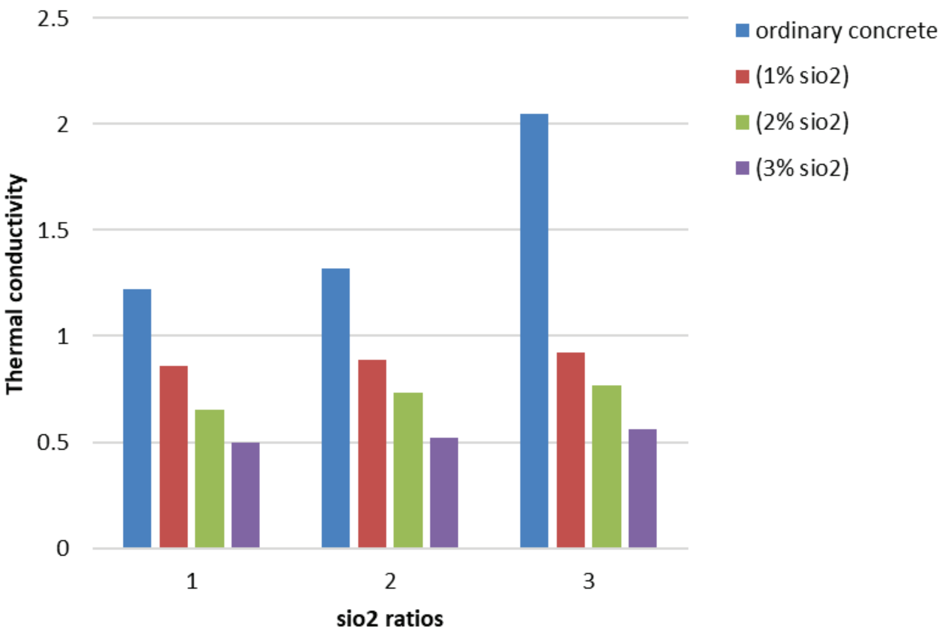

Figure 4. Mixture's thermal conductivity at different SiO_2 ratios.

Table 4. Values of SHC for varied blend

Symbol	Specific heat (J/kg.°C)
Ordinary concrete	832
S1	837
S2	854
S3	896

Table 5. Thermal diffusivity values for different mixtures

Symbol	Thermal diffusivity (m²/s)
Ordinary concrete	$6.38*10^{-7}$
S1	$4.23*10^{-7}$
S2	$3.41*10^{-7}$
S3	$2.38*10^{-7}$

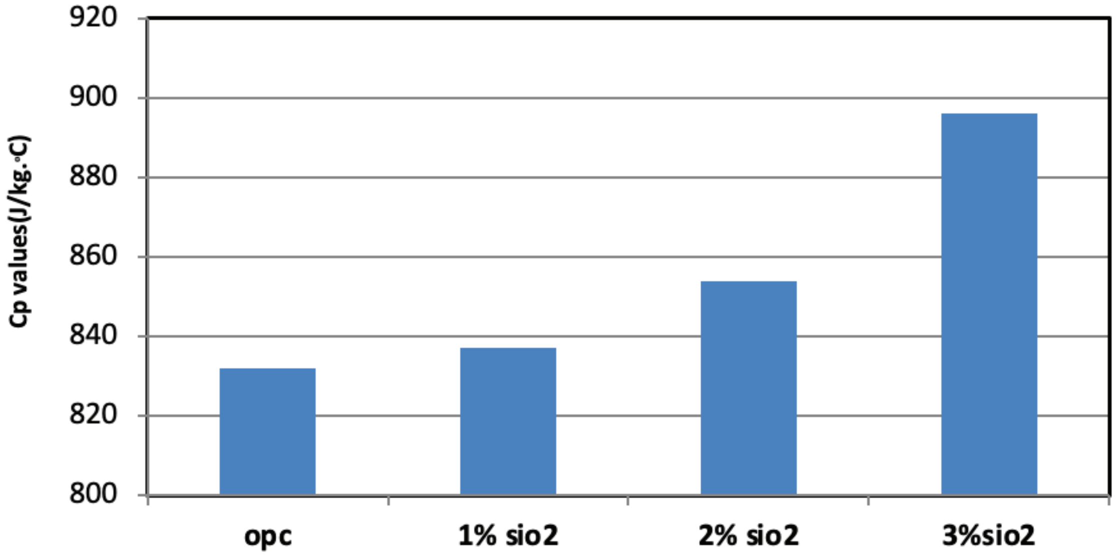

Figure 5. Nano concrete's specific heat capacity values comparable with ordinary concrete.

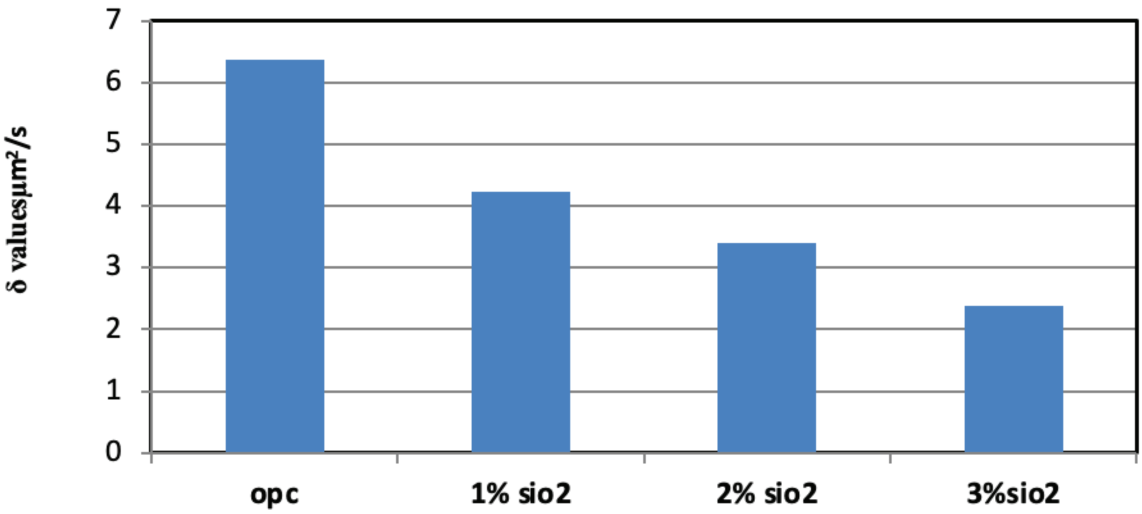

Figure 6. Nano concrete's thermal diffusivity values comparable to ordinary concrete.

the value is 7.5*10-7 μm^2/s [35]. The results showed that the values of thermal diffusivity dropped as the amount of Nano-silica added to the mixture increased (Figure 6). This decrease can be related to relationship between diffusivity and conductivity, as shown by Eq (3).

CONCLUSION

Based on our findings, the following conclusions can be drawn:

1. The findings clearly that the inclusion of NS enhanced concrete's capacity for thermic insulation. Conventional concrete had a thermic conductivity of between 1.22 and 2.05 W/m.°C, whereas nano-concrete had a thermic conductivity of between 0.5 and 0.92 W/m.°C.
2. The mixture (S3) had the optimum thermal insulation capacity when the SiO_2 addition was 3 percent of the cement's weight, and the thermic conductivity coefficient measured between 0.5 and 0.56 W/m.°C.
3. As the amount of NS addition increased, a rise in the SHC values was seen.
4. As the additional percentage of NS increased, a decrease in the thermal diffusivity values was seen.
5. As a result, substituting some of the cement with nano-silica has positive effects on the economy and environment since nano-silica is a good substitute that is reasonably priced when compared to other nano-materials.

NOMENCLATURES

Symbol	Description
OPC	Ordinary Portland cement
WB	water-binder ratio
GGBS	Ground granulated blast-furnace slag
EPS	Expanded polystyrene
SHC	Specific heat capacity
NS	Nano-silica
WG	Waste glass
CG	Coal gangue
S1	1% SiO_2
S2	2% SiO_2
S3	3% SiO_2

ACKNOWLEDGEMENTS

I would want to express my gratitude to all those who have given me valuable information that has helped make this study paper a success. I also express my gratitude to the international publishing houses for compiling important data from studies that were released in foreign publications.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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