

Characterization Of Nano-Silica Material as An Insulating Brick for Enhancing Thermal Comfort in Buildings

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Abstract

The study investigates the application of nano-silica as a thermal insulating material in brick construction, aiming to improve building thermal comfort. Nano-silica, recognized for its thermal resistance and mechanical stability, was incorporated in varying proportions into cement bricks to evaluate its influence on the physical, mechanical, and thermal properties of the resulting bricks. A total of 60 samples were prepared and subjected to water absorption, density, ultrasonic pulse velocity, compressive strength, and thermal conductivity tests. The results indicate a positive correlation between nano-silica content and improved thermal insulation, though excessive nano-silica led to a decrease in compressive strength due to particle agglomeration. The optimal nano-silica content, 5%, provided a balance, enhancing thermal insulation without compromising structural integrity. The findings suggest that nano-silica bricks offer potential as a sustainable construction material, aligning with energy efficiency goals in building design. Further research is recommended to optimize nano-silica content for practical applications in varied climatic conditions.

1. Introduction

The impact of buildings on our planet is undeniable. It accounts for an astounding 40% of global energy consumption, even surpassing the entire transportation sector. This makes finding ways to improve their energy efficiency a top priority. Luckily, thermal insulation offers a powerful solution [1].

Thermal insulation is not just a fancy addition to modern buildings; it is a crucial element in reducing our energy footprints and building a more sustainable future. By trapping heat in during cool weather and blocking it out when it's hot, effective insulation minimizes dependence on energy-guzzling HVAC systems. This not only translates to lower energy bills for building owners but also plays a significant role in combating climate change by minimizing greenhouse gas emissions.

Traditionally, insulation materials like fiberglass and rockwool have served us well. However, the emergence of nanoscale materials like nano-silica opens exciting new possibilities. With their exceptional thermal properties, nano-silica-based materials offer the potential to create revolutionary insulation bricks with vastly improved performance. Results show that these nanomaterials improve the structural, thermal, and functional qualities of building materials, resulting in increased mechanical strength of more than 20%, decreased thermal conductivity, self-cleaning properties, and improved durability. As a result, using nanomaterials in housing construction can greatly improve its efficiency and sustainability [2].

Imagine buildings incorporating these cutting-edge nano-silica bricks. Such structures would experience significantly reduced heat loss in winters and minimized heat gain during summers, leading to dramatically reduced energy consumption for heating and cooling. This not only enhances comfort for occupants but also translates to substantial financial savings and a smaller carbon footprint for the building.

1.1 Objectives and Scope

There are three objectives of this research. The first objective is to determine the physical and mechanical properties of nano-silica based material as a partial replacement of cement in brick. The second objective is to investigate the thermal properties of nano-silica based brick. The third objective is to verify the nano-silica brick for thermal performance of brick.

Total number of 60 samples of cement bricks with a standard experimental size of 215mm × 102.5mm × 65mm. The brick will be made of a mixture of cement, water, sand, and nano-silica material. This study will evaluate the thermal, physical, and mechanical performance of the insulating brick that is produced with nano-silica material. The sample will be undergoing several tests with the likes of water absorption test, density test, ultrasonic pulse velocity test, compression test and thermal conductivity test. All tables should be numbered with Arabic numerals. Every table should have a caption. Headings should be placed above tables. Only horizontal lines should be used within a table, to distinguish the column headings from the body of the table, and immediately above and below the table. Tables must be embedded into the text and not supplied separately. Below is an example which the authors may find useful.

2. Materials and Methods

The material setup is a vital stage before beginning work by determining the appropriate and standardized materials. Cement, sand, water, and nano-silica material will be used in this experiment. To get the desired effect, all these materials will be mixed in the appropriate proportions and steps to produce samples of nano-silica based bricks.

60 brick samples, 12 control and 48 with nano-silica replacing cement, were fabricated as per MS 76:1972 (215x102.5x65mm). Each percentage of nano-silica (0%, 5%, 10%, 15%, 20%) used 3 samples for compressive strength, density, UPV, and water absorption, with the rest dedicated to thermal conductivity testing. All samples cured for 7 and 28 days.

This chapter goes into the sample preparation, laboratory testing, and experimental technique used in this study in significant detail. The following topics have been covered in this chapter: sample preparation, laboratory testing for alternative nano-silica bricks, and experimental protocols for all tests. This study and test were prepared in the Concrete Laboratory and Building Services Laboratory at Universiti Tun Hussein Onn Malaysia, Pagoh Campus. All the data collected in this investigation was then analysed.

2.1 Material

Water acts as the key component used in concrete mixing in building to combine all the materials. The water must be pure and come from a reputable source, such as the state government. Furthermore, pollutants such as floating particulates and organic matter should be avoided while using water. This investigation will make use of clean tap water. Water constitutes one of the main components utilized in this study to bind all the ingredients once they have been mixed. The tap water provided by Syarikat Air Johor (SAJ) is utilized throughout the cement brick mixing process

2.1.1 Nano-Silica

In order to achieve energy and climate goals, boosting the energy efficiency of buildings is critically important. Researchers from both academic and industrial sectors are investigating novel materials that could significantly enhance thermal insulation within structures. Nano-silica have emerged as a potential replacement for conventional insulation materials, due to its performance as low heat conductivity, light weight, and soundproofing abilities. Along with their well-known optical and electrical characteristics, nano-silica has been found to have size-dependent thermal properties that have been extensively researched and used in a variety of optoelectronic device applications. However, because the factors influencing thermal transport are unknown, the impact of nanoscale particles in nanostructured materials is still unknown. Good agreement and minimal deviation with the estimated thermal boundary resistance were found in the results of the thermal conductivity models. $m^2K/W = 4 \times 10^{-7}$ [3].

Rice husk, which is typically discarded waste, contains a surprise treasure: silica. This important mineral, which has several industrial applications, may be obtained through an intriguing procedure. After rigorous washing and drying to eliminate contaminants, the husks are subjected to pyrolysis, which is a controlled burning in low oxygen environments. This converts organic materials into charcoal and emits gases. The biochar is

separated by carefully regulating the temperature, leaving silica-rich ash behind. This ash is then purified and isolated using techniques such as acid leaching or alkaline extraction.

The extraordinary extraction mechanism is like the rice plant's capability to "mine" metals from the soil. The plant methodically accumulates silica, treating it like a valuable metal, just as it absorbs critical nutrients and minerals. This silica is absorbed by the root system and transmitted via its vascular network before being stored in the rice husk - nature's own storage container. This process demonstrates the plant's extraordinary flexibility, as it uses the qualities of silica for its own growth and development.

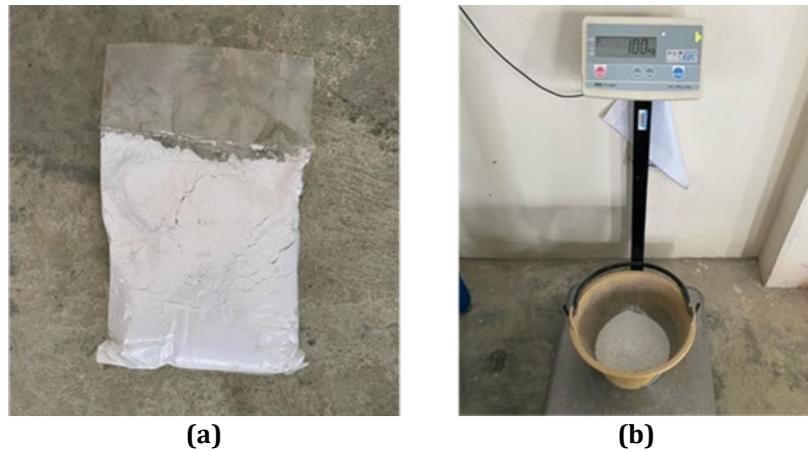


Fig. 1 Nano-silica (a) Nano-silica powder retrieved in packaging; (b) Nano-silica preparation

2.1.2 Cement

Cement is an ingredient that is most used in the building industry to bond other materials by setting, hardening, and adhering to them. Cement is an essential substance that is widely used in building, and there are several varieties of cement in business depending on their use. It has changed the amounts of the elements in the cement and introduced other types of ingredients. The cement utilized in this study is Ordinary Portland Cement, which is a standard cement. This cement is typically used in ordinary construction and most masonry projects. Portland cement is made from limestone, chalk, or marl, as well as clay. The components are combined, heated in a kiln, and the resultant clinker is ground to a fine powder

2.1.3 Sand

In this study, sand or fine aggregate was used in the manufacturing of cement bricks. The gradation of the sand should meet the requirements by passing 6.3 mm sieve. The determined standard of sand for this investigation is 5 mm. Before usage, the sand should be free of impurities and clean.

2.1.4 Water

Water acts as the key component used in concrete mixing in building to combine all the materials. The water must be pure and come from a reputable source, such as the state government. Furthermore, pollutants such as floating particulates and organic matter should be avoided while using water. This investigation will make use of clean tap water. Water constitutes one of the main components utilized in this study to bind all the ingredients once they have been mixed. The tap water provided by Syarikat Air Johor (SAJ) is utilized throughout the cement brick mixing process.

2.2 Sample Preparation

Based on the most prevalent brick size used in the building sector, referring to MS 76:1972 which has dimensions of 215mm in length, 102.5mm in height, and 65mm in width. Table 1 below shows the number of brick samples that will be used for each type of testing that will be carried out

Table 1 Number of brick samples that for the test

Type of Test	Number of Brick for 7 days	Number of Brick for 28 days
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Compressive Strength		
Density		
Water Absorption	3	3
Ultrasonic Pulse Velocity		
Thermal Conductivity	3	3
Total of Samples	6	6
Total for One Batch		12
Total Overall		60

2.2.1 Mix Design for The Sample

Before all the components in this study were combined, the materials were weighed according to the mix design calculation. The cement-sand ratio in the mix design will be 1:3, and the water-cement ratio in the mixture is 0.6. This study employs four different proportions: 5%, 10%, 15% and 20%. According to the mix design calculation, different types of proportions have different types of mass of materials. The volume of the bricks is used to compute the mix design. The mix design utilised in this investigation is shown in Table 2 below.

Table 2 Number of brick samples that for the test

Samples	Percentages of Nano-silica Material (%)	Nano-silica Material (kg)	Cement (kg)	Sand (kg)	Water (kg)
Control	-	0.0	9.7	35.5	1.95
NS 5%	5	0.5	9.2	35.5	1.95
NS 10%	10	1.0	8.7	35.5	1.95
NS 15%	15	1.5	8.2	35.5	1.95
NS 20%	20	2.5	7.7	35.5	1.95

2.2.2 Brick Casting

Prior to brick casting, the materials were weighed corresponding to the mix design calculation. The cement-sand ratio in the mix design is 1:3, and the water-cement ratio in the mixture is 0.6. The procedure of brick casting are shown in Fig. 2. A tray of 1000 mm × 1000 mm was used as a platform for blending the material; sand is placed into the tray first, followed by cement, then nano-silica material. Following that, the mixture is then gradually poured with water and mixed until all elements of the dry mixture mix with water altogether. Before taking the mixture into the mould, the prepared mould was coated with grease on all its surfaces. Next, the fresh mixture is then progressively placed into the prepared mould. A tamping rod is used to compact the mixture. Layer by layer for three layers, the mixture is ground down to ensure that it is compressed, dense, and entirely fills the mould area. The assortments in the mould are depicted in Fig. 1(c). For finalization, the surface of the cast brick mixture is levelled and smoothed with flat trowel and brick trowel. The resulting mixture was then left for 24 hours to dry before remoulding.



Fig. 2 (a) Preparation of dry mixture; (b) Brick mixture; (c) Compacting; (d) Finalization; (e) Brick was air-cured for 24 hours before remoulding

3. Result and Discussion

The experimental findings are the results of investigations for density, water absorption, ultrasonic pulse velocity (UPV), compressive strength, and thermal conductivity. To ensure reliable data representation, three samples were rigorously tested within each batch, generating three distinct result values. The average of these values was subsequently calculated to establish a more robust and representative dataset. The findings are presented in a suitable medium, such as graphs and tables.

3.1 Density Test

Based on Fig. 3, bricks with 5% and 10% nano-silica that had been cured for 7 days had the lowest density, whereas bricks with 20% nano-silica had the maximum density. The non-linear density trend indicates a complicated interplay between void filling and densification, agglomeration, restricted calcium silicate hydrate (CSH) production, and reactive site saturation. The microstructure and strength of high-performance concrete are affected by nano-silica, which fills holes between bigger cement particles, while aggregation causes new spaces at greater concentrations. Brick samples containing 20% nano-silica indicate a significant reduction in density, most likely owing to prolonged curing time and water loss.

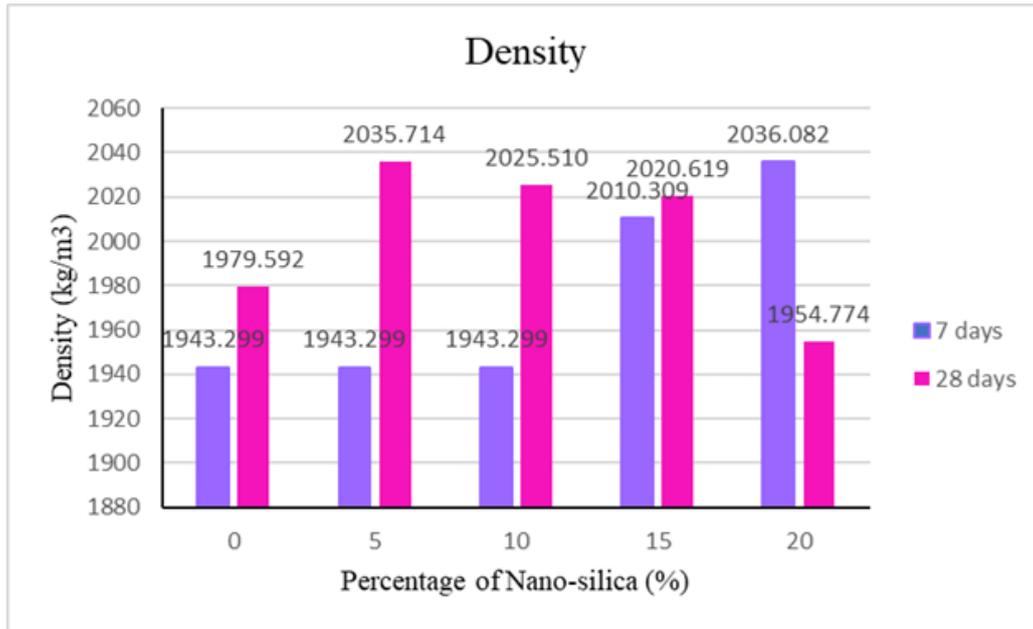


Fig. 3 Density of brick at 7 and 28 days

3.2 Water Absorption Test

The study found that greater nano-silica percentages improve water absorption, with a peak at 10% after 7 days (as shown in Fig. 4). This is due to the attraction of nanosilica particles to water molecules, resulting in enhanced water absorption [4]. Smaller particles (30 nm) absorbed more water due to their larger surface area. Water absorption diminishes at larger doses owing to particle agglomeration. The study also discovered that cement brick samples containing nanosilica absorb much more water than the 4.5% limit imposed by BS EN 771-1. This raises questions regarding their fitness for building.

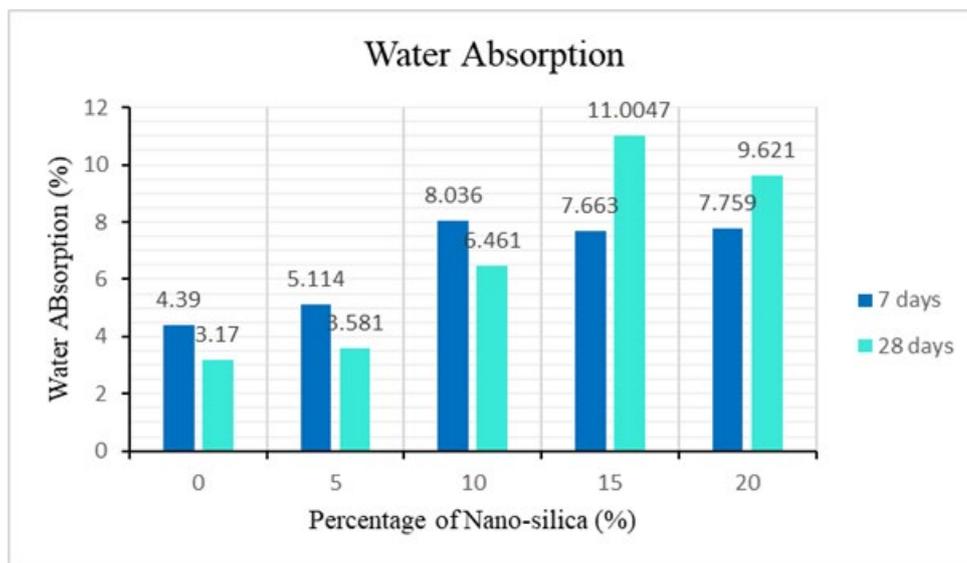


Fig. 4 Density of brick at 7 and 28 days

3.3 Compressive Strength

The study reveals that nano-silica content in cement-sand bricks can lead to a decline in compressive strength, as NS particles agglomerate, weakening the microstructure and reducing strength [5]. The optimal outcome is found in NS5, which surpasses the prescribed 20.5 MPa compressive strength requirement after 28 days of curing (as shown in Fig. 5). All other samples fail to meet load-bearing characteristics, with NS20 having the lowest

compressive strength at 9.13 MPa. The study highlights the time-dependent aspect of strength development, with longer curing duration resulting in higher compressive strength.

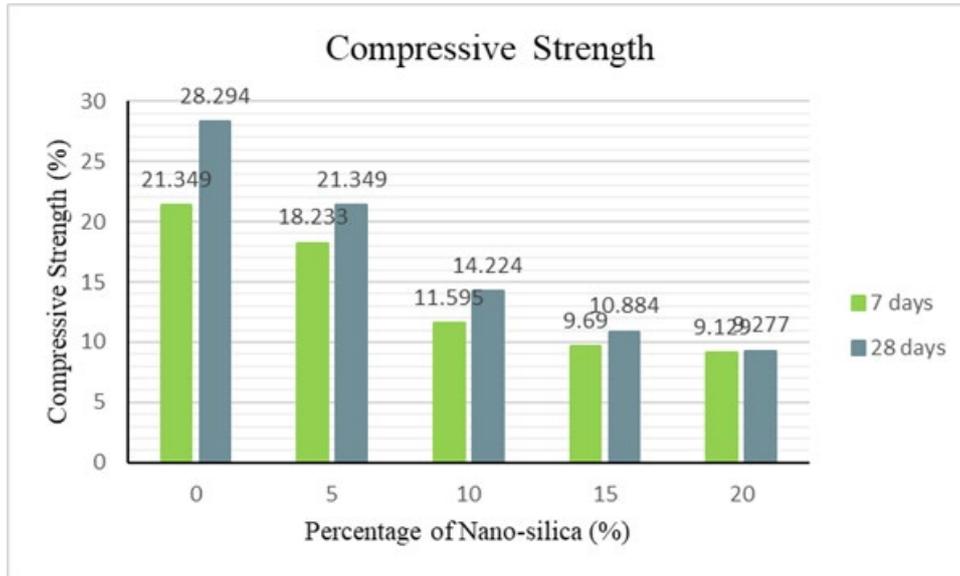


Fig. 5 Density of brick at 7 and 28 days

3.4 Ultrasonic Pulse Velocity

The bar chart in Fig. 6 shows that pulse velocity decreases with increasing nano-silica presence in brick composition, reaching its nadir with samples containing the maximum 20% nano-silica. However, some brick samples exhibit a lower pulse velocity range, categorized as doubtful quality [6]. High nano-silica dosages cause NS particles to clump together, forming agglomerates, which reduce the effective surface area for water interaction, resulting in a less dense microstructure and decreased wave propagation speed. Excessive nano-silica can also introduce micro-cracks, weakening the material and disrupting ultrasonic wave paths [7].

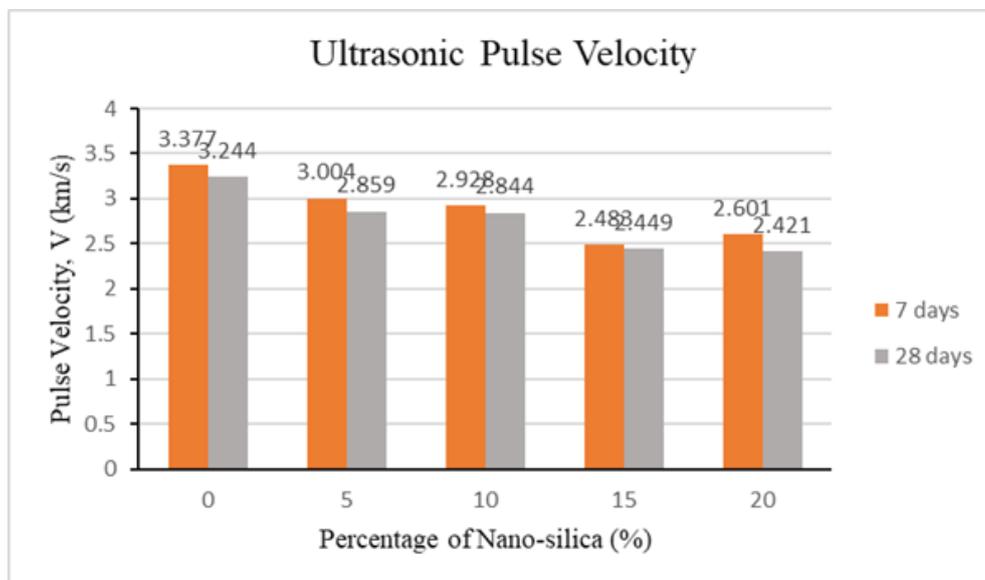


Fig. 6 Ultrasonic pulse velocity for brick sample

3.5 Thermal Conductivity

The K-value decreased with an increase in nano-silica content in bricks at 7 and 28 curing years (as shown in Fig. 7). This is due to the disruption of heat conduction pathways, reducing efficiency. Nano-silica's amorphous

structure limits phonon propagation, reducing thermal conductivity at low concentrations. However, at higher concentrations, interfacial resistance increases, leading to better heat flow and increased thermal conductivity. Particle agglomeration can also facilitate heat flow, further increasing thermal conductivity [8,9].

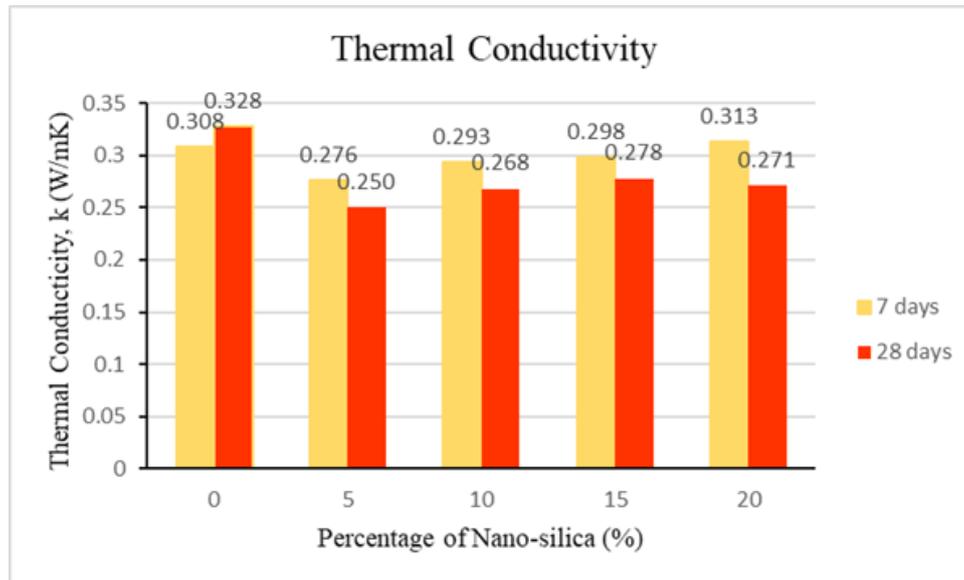


Fig. 7 Ultrasonic pulse velocity for brick sample

4. Conclusion

This study examines the physical and mechanical properties of nano-silica bricks, revealing that all brick samples fall within the normal weight and standard-dense materials classification. The water absorption rate increases with nano-silica content, with a marginal decrease in NS20. The bricks exhibit an average pulse velocity ranging from 2.45 m/s to 3.00 m/s, which aligns with their ability to lower thermal conductivity. The mechanical properties show a diminishing compressive strength as nano-silica (NS) percentage increases. NS5 achieves a compressive strength comparable to the control sample, while NS20 reaches its nadir at 9.28 MPa. The optimal percentage for superior compressive strength is identified as 5% nano-silica replacement. The thermal properties and performance of nano-silica bricks are compared to conventional cement bricks, with NS5 showing higher performance with lower heat conductivity.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: **study conception and planning trial:** Wan Amizah Wan Jusoh, Noor Ain Najihah Che Rosli; **data collection:** Wan Amizah Wan Jusoh, Muhammad Faheem Mahmudin; **analysis and interpretation of results:** Nurul Hidayah Roslan, Syed Mohd Fareed Syed Zin, Loke Kok Foong; **draft manuscript preparation:** Wan Amizah Wan Jusoh, Syed Mohd Fareed, Nurul Hidayah Roslan, Loke Kok Foong. All authors reviewed the results and approved the final version of the manuscript.

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