



Eco-engineered mortar: exploring the multifunctional benefits of nano glass in cement replacement

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ABSTRACT

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The increasing environmental impact of cement production has led to growing interest in using industrial solid waste as a partial cement replacement to reduce CO₂ emissions and landfill accumulation. Nano glass waste, derived from recycled glass, presents a promising alternative due to its fine particle size and pozzolanic properties. This study evaluates the effects of incorporating nano glass waste into mortar on its fresh, mechanical, durability, and thermal characteristics. Mortar mixes were prepared with 0–50% nano glass replacement, and tests were conducted to assess flowability, compressive and flexural strength, acid resistance, and thermal conductivity. The results showed a 39.8% reduction in flowability at 50% replacement. Compressive strength increased by 10.1% at 10% replacement, while flexural strength dropped by up to 25.5% at 50%. Notably, thermal conductivity decreased by 40.31% at 50% replacement, indicating enhanced insulation. These findings suggest that nano glass waste can improve the performance and sustainability of mortar when used at optimal levels based on the intended application. Nano glass waste improves strength at 10% and insulation at 50% replacement in mortar.

Highlights

- Nano glass waste reduces cement use, CO₂ emissions, and solid waste.
- Flow drops 39.8% at 50%; strength peaks +10.1% at 10%, then declines.
- Thermal conductivity falls 40.3% at 50%, boosting insulation.
- Optimal use: 10% for strength (joints), 50% for insulation (plaster).



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1. Introduction

The main composition of the concrete and mortar, which act as binder material is cement (Lu et al., 2017). Due to the high effect of the cement industry on the environmental pollution, researcher interest increase to prepare alternative material which can serve same function of the cement with zero or lower effect on the environment (Ali, 2015, Abu-Bakr et al., 2024). Using waste materials generally progressed in the concrete and mortar, which has been check by many experimental researches (Arivalagan and Sethuraman, 2021; Madandoust and Ghavidel, 2013; Ahmad and Rafiq; 2022). Producing binder material especially which has pozzolanic properties from waste materials will be great obtaining since can reduce the cement production also reduce the waste

quantity in the same time (Saribiyik et al., 2013, Althoey et al., 2023).

Through the researches that done in this field many materials have been found that can act as pozzolanic materials such as rice husk ash, fly ash, ground granulated blast furnace slag, silica fume (Al-Ahdal et al., 2018; Czapik et al., 2021). Also one of these materials that take the interest of researchers to be used as partial replacement of cement and has the pozzolanic reaction is waste glass powder (Hasan et al., 2020, Ahmad & Rafiq, 2024). Glass is non-biodegradable material that has high rate of application in all field in the human life due to the low cost and easy formability (Al Goody et al., 2025; Ahmad et al., 2025). Based on the collected data by the central public health and environmental engineering organization the waste glass quantity estimated by 600 gr/person in each day. Only in

United States, the produced waste glass annually passed twelve million tons (Ahmad et al., 2024b), while its quantity passed 32 million tons in china (Hou et al., 2020, Patel et al., 2019). In Hong Kong, the daily production of waste glass reached to 220000 tons in one day (Guo et al., 2015, Shen et al., 2020). Glass has been used as coarse aggregate, fine aggregate, and also as partial replacement of cement in both concrete and mortar but due to its pozzolanic activity more performable to be used as partial replacement of cement (Ahmad et al., 2023a, Ahmad et al., 2023b, Ahmad et al., 2024a).

The newest direction that researchers have been worked on is to change this pozzolanic material to nano size which makes them to be more attractive and reactive in the cement place. Using waste glass in a nano size as partial replacement of cement is one of the direction that takes lower light by researchers (Arowojolu et al., 2019, Onaizi et al., 2022, Ahmad et al., 2024d). Improving the mechanical properties of mortar is essential to improve the properties of masonry wall sine the mortar used to jointing the masonry units together (Pascual et al., 2014, Tan and Du., 2013, Ahmad et al., 2024c). Arowojolu et al. (2019) investigate the usage of Nano glass as partial replacement of cement with class F-fly ash by three different rate which include 0, 12.5, and 25% when the water to cement ratio was constant. The target was to investigate its effect with fly ash on the fresh, mechanical, and durability of concrete. The obtained result showed that with the increase of the Nano glass usage decrease the flow ability value, while using 12.5% of Nano glass with 12.5% of fly ash decrease the mechanical properties of concrete, but the value of alkali silica reaction still remain the accepted range for normal situation. Onaizi et al, (2022) used Nano glass as additive in concrete with three different rate including 0, 5, 10% in two group of mix. At the result obtained that with the adding of Nano glass decrease the workability of the mix but the performance of the mix will increase especially with the usage of 5% of Nano glass. Huseien et al., 2020, investigate the usage of the nano glass powder as partial replacement of ground granulated blast furnace slag in alkali activated based fly ash to find its effect in the energy usage, durability, mechanical properties of the mortar. The result obtained that the usage of the 5% of Nano glass powder as partial replacement of ground granulated blast furnace slag increase the compressive strength by sixteen percent compare to control mix while reduce the carbon dioxide submission to the air by more than seven percent compare to control mix.

While various studies have investigated the incorporation of nanomaterial in cement-based composites, limited research has focused specifically on nano-sized waste glass and its impact on mortar properties. Nano glass, due to its high surface area and pozzolanic activity, holds significant promise as a sustainable alternative to traditional cement. Its use not only contributes to improved mechanical and thermal performance but also addresses environmental concerns by reducing CO₂ emissions and reusing industrial waste. This aligns with circular economy principles and the global push toward greener construction materials. The primary objective of this study is to evaluate the effects of nano-sized waste glass as a partial cement replacement in mortar, with a focus on optimizing mechanical strength, durability, and thermal

insulation. The research further aims to determine the optimal replacement ratio that balances performance with sustainability and to explore the underlying microstructural mechanisms through XRD and SEM analyses.

2. Materials and Methods

For finding that target, at the first the properties of the used material have been investigated including the properties of water, cement, sand, and Nano glass. At the second step, the mix design of the control mix have been done, after that the used rate of each materials with changing the used rate of cement and nano glass have been calculated and recorded. Finally at the last step the required samples for the investigating of the mortar properties have been prepared which will be tested after the curing time.

2.1 Experimental Work

The experimental work section consists of two main parts which are investigating the usage materials properties, and investigating the properties of mortars.

2.2 Used materials in mortar preparations

2.2.1 Cement

The cement used in this article was ordinary Portland cement (OPC), that obtained from Taslwja Cement Company. The properties of his type of cement have fall in the provided limitation by American Society for Testing and Materials in section 150 (ASTM, C150). Based on the given procedure in ASTM, C115 the value of finances has been measured which was 3535 cm²/gram while the value of normal consistency was 26.9% based on the given procedure in ASTM, C187. Initial and final setting time of the used cement were 140, and 190 minute based on the given procedure in ASTM, C191, also the density with specific gravity were measured which were 1440 kg/m³, and 3.14 based on the given procedure in ASTM, C188.

2.2.2 Nano Glass

The obtained glass in this article was obtained by collecting the waste bottles that putted in the land as a waste, and the collected glasses were broken up to the Nano size by using large crusher by measuring its particle size distribution. Obtained Nano glass particle texture has been shown in Fig. 1. While it's chemical composition has been found using the X-ray diffraction test as shown in Table 1. The physical properties of used Nano glass have been investigated when based on the given procedure in ASTM, C115, the fineness value was 6770 cm²/gr while the specific gravity was 2.88 based on the used procedure in the ASTM, C188.

2.2.3 Water

The used water in this research has been passed through two important tests which are turbidity and pH value. In the turbidity test which has the value equal to 0.73 NTU that describe the rate of solid content in the water. The second test which was pH test describes the rate of alkalinity and acidity of the water based on the given procedure in ASTM, D1293. The obtained value was 7.3 which describe the middle rate of the water between alkaline and acidity which make it acceptable for the usage in the mortar preparations.

Fig. 1 Nano glass particle texture

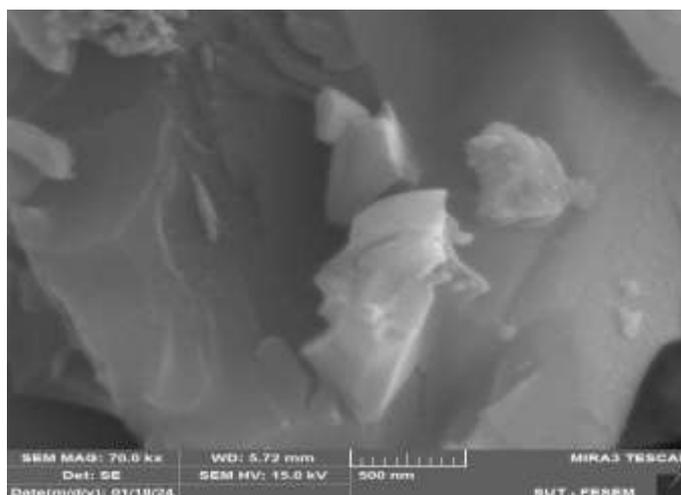


Table 1 Chemical composition of the used Nano glass (XRD Test)

Composition Name	Composition
Silicon dioxide	58.22
Aluminum oxide	2.609
Iron (III) oxide	1.1
Calcium oxide	2.482
Magnesium oxide	0.868
Sulfur trioxide	0.533
Potassium oxide	6.779
Sodium oxide	6.697

Table 2 Fine aggregate physical properties

Properties	Obtained Sand	Standards
Oven-dry specific	2.4	ASTM, C128
Bulk density	1810 kg/m ³	ASTM, C29
Water absorption	5.8%	ASTM, C128

2.2.4 Sand

The fine aggregate obtained from crushed aggregate brought into the laboratory, subsequently passing through the sieve analysis test, and meeting the specifications given in ASTM, C136, C117, and C33. The physical properties of fine aggregate have been determined and expressed in Table 2, and the sieve analysis has been expressed in Table 3.

Table 3 Sieve analysis of sand used in this study according to the ASTM C33 sieve requirements

Sieve Size	Sieve Opening (mm)	Passing (%)	ASTM C33 Lower limit (%)	ASTM C33 Upper limit (%)
3/8 in	9.5	100	100	100
No. 4	4.75	97	95	100
No. 8	2.36	90	80	100
No. 16	1.18	70	50	85
No. 30	0.600	50	25	60
No. 50	0.300	20	5	30
No. 100	0.150	8	0	10
Pan	-	2	0	3

2.3 Mix design of mortar

The mix proportion for the mortar was selected based on the condition provided in ASTM, C109, for that reason the

selected mix proportion for cement; sand was 1; 2.75 with a water-to-cement ratio equal to 0.5. The mix proportion based on the volume of the required sample for each mix with the replacement ratio is described in Table 4.

Table 4 Mortar mix proportions

Replacement Rate (%)	w/c	Water (g)	Cement (g)	Nano Glass (g)	Sand (g)
0	0.5	786.5	1573	0	4460
5	0.5	786.5	1494.5	72.3	4460
10	0.5	786.5	1415.7	144.2	4460
15	0.5	786.5	1337	216.5	4460
20	0.5	786.5	1258.5	288.5	4460
30	0.5	786.5	1101.1	433	4460
40	0.5	786.5	944	577	4460
50	0.5	786.5	786.5	721.4	4460

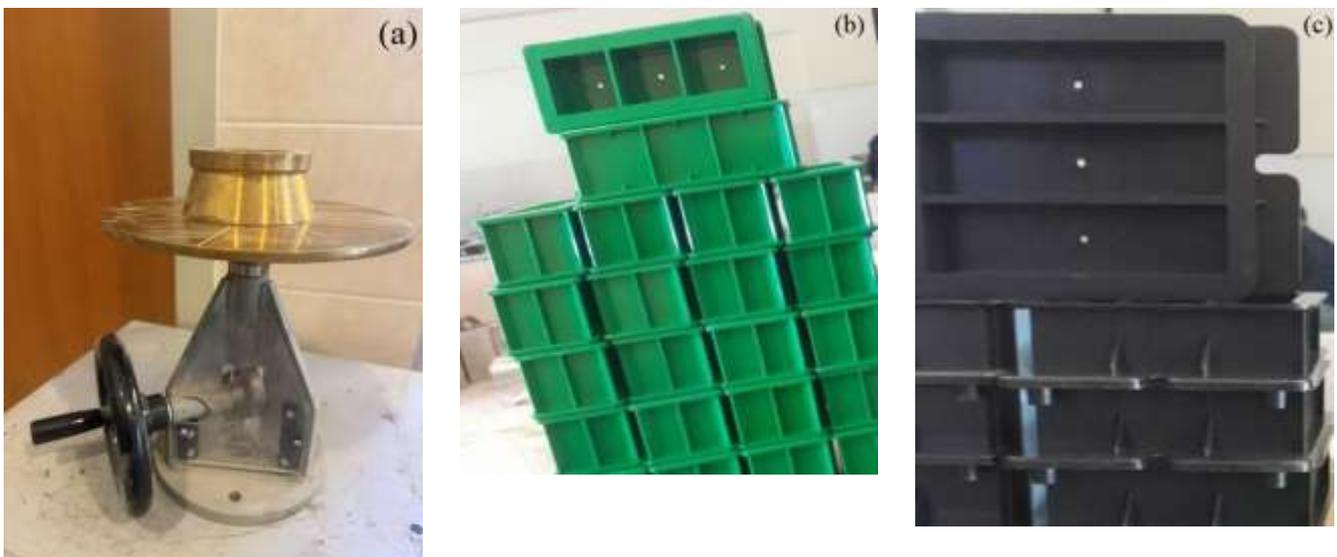
2.4 Investigated properties of mortar

2.4.1 Flow

Flow is one of the workability indicators, after mixing the mortar compositions with using the mixer as specified in ASTM, C305. The flow is measured base on the procedure given in ASTM, C1437 by using the instrument in the Fig 2a. Based on the given procedure, the mold will putted in the center of the flow table, the mold will fill with the mortar by two layer after compacting each layer with twenty rode, after that the extra mortar available in the top of the mold will removed, the mold will removed and the table will rotated 25 time in 15 S, the procedure will be finished by measuring the diameter of the mortar that expand over the mold in four direction and using them in the calculation process as described in ASTM, C1437 to find the flow

2.4.2 Compressive strength

Fig. 2 Flowability and strength test: a) Flow table and mold, b) Compressive strength testing mold, and c) Flexural strength mold



2.4.4 Thermal conductivity

In case of using the modified mortar as plastering in the external surface of the wall, thermal conductivity considers as one of the most important properties that must be investigated.

Fig. 3 Thermal conductivity testing setup for measuring heat transfer across mortar samples

The measurement of the compressive strength will be based on the given procedure in the ASTM, C109, which specified the usage of mortar cube with dimension of 5 cm³ as shown in Fig. 2b, that must be tested under compressive machine load using 900 to 1800 N/s as load rate.

2.4.3 Flexural strength

The modified mortar has different application which is usage as binder material between masonry units or the usage as cement plastering, or for placing finishing units like tile. During the usage of the modified mortar in the placing masonry units, the flexural strength will be important tools that must be investigated sine the placed unit and used mortar will continuously subject to the flexural stress. Based on the provided detail in the ASTM, C348, the usage of the mortar mold for flexural strength test will be with dimension of 4×4×16 cm as shown in Fig. 2c, that subjected to the load rate of 2640 ±110 N.

The samples are prepared as in Fig. 3 with 15×15×1.5 cm dimension, which subjected to the heat wave in the one surface and measured the output wave in the other surface using two sensors in each surface



2.4.5 Acid attack

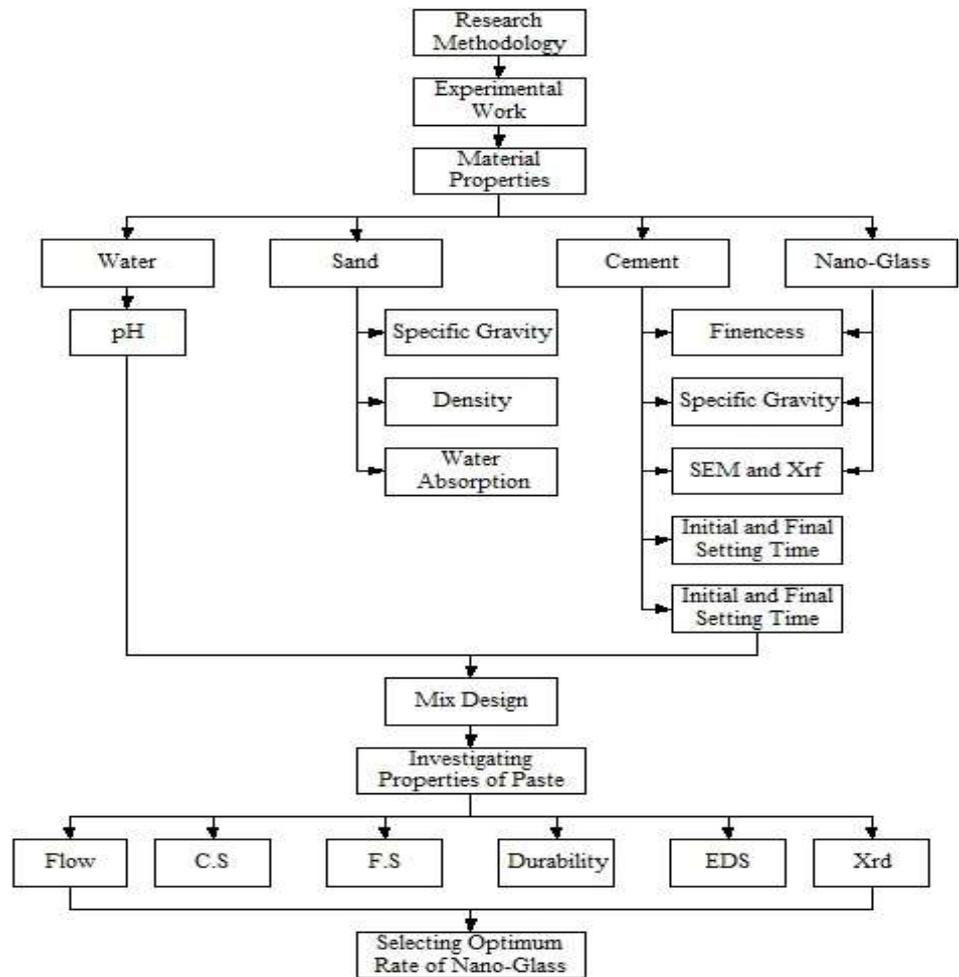
In the case of using prepared or modified mortar as the binding mixture between masonry units or using as cement plastering material, the mortar will have subjected to the attack of the available salt in the ground or during the raining time, for that for each mix six samples with 5 cm cube have been prepared for this test. These six samples have been cured up to 28 days after that three of these samples will be taken to out from water bath, cleaned and putted in the bath which contain the acid as in the Fig. 4 using H₂SO₄ with concentration of 98%. Each

100 liter of the mix was consisting of 95 liter of water and 5 l of H₂SO₄, other three samples will remain in water bath. After another 28 days the samples will be subjected to the compressive load up to failure. At the result obtained data will be analyses and compare to each other to explain the effect of the acid attack on the capacity of the used samples and showing the rate of the decrease in the capacity of the prepared samples compare to the samples which cured in the water bath. To achieve the target outlined in this study, the experimental work followed a structured flow, as illustrated in Fig. 5.

Fig. 4 Mortar samples in the acid bath



Fig. 5 Methodology flow chart

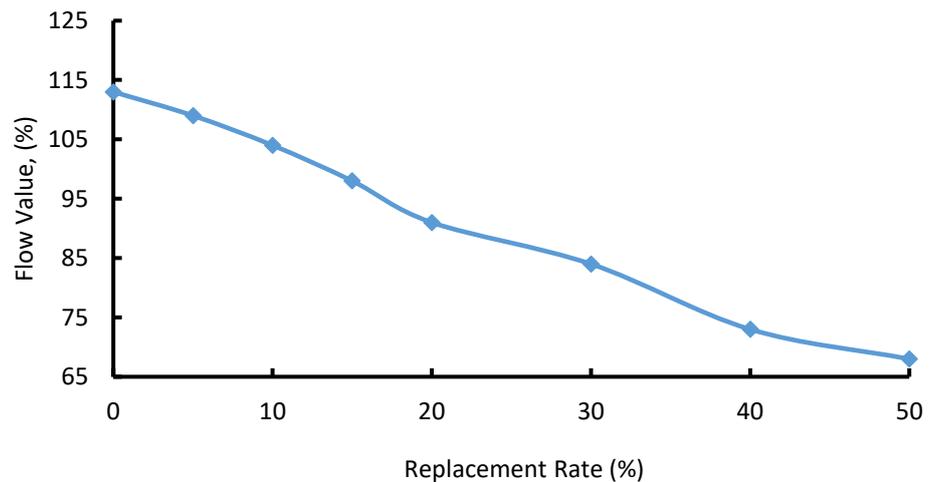


3. Results and Discussions

3.1 Flow

Fig. 6 shows the eight different rates of Nano glass used as partial replacement of cement. The mortar mixes were only modified with Nano glass as a replacement of cement to clearly observe its influence. The effect comes from the very large surface area of Nano glass due to its tiny size. In the first mix, the flow rate with 0% Nano glass (control sample) was 113%. In the second mix, with 5% Nano glass, the flow rate decreased by 3.53% and became 109%. With 10% Nano glass, the flow rate decreased by 7.96% compared to the control, reaching 104%. When the mix contained 15% Nano glass, the flow rate decreased by 13.27% and became 98%.

Fig. 6 Flow value of the mortar based on the used rate of Nano glass



3.2 Compressive strength

The compressive strength of mortar was influenced by the partial replacement of cement with different rates of nano glass (0, 5, 10, 15, 20, 30, 40, and 50%), as illustrated in Fig. 7. For each mix, six cubes were prepared and tested at two ages: 28 days and 56 days. This is important since glass acts as a pozzolanic material, and its effect becomes more visible at later ages.

For the control mix (0% nano glass), the average compressive strength after 28 days was 32.5 MPa. In the first modified mix with 5% nano glass, the average compressive strength increased to 34.1 MPa, which is 4.92% higher than the control. In the mix with 10% nano glass, the compressive strength reached 35.8 MPa, an increase of 10.1% compared with the control. This improvement is due to the high silica content in nano glass, which reacts with calcium hydroxide (Ca(OH)_2) from cement hydration to produce additional calcium silicate hydrate (C–S–H) gel. Since C–S–H is the main strength-giving product in cement paste, this pozzolanic reaction enhances strength. The nano scale size of the glass particles further accelerates this reaction. However, a higher replacement of cement with nano glass reduces the calcium hydroxide content, which may accelerate carbonation, although the refined pore structure can partly counteract this effect.

In the other mixes with higher replacement levels (15, 20, 30, 40, and 50%), the compressive strength decreased compared to the control, with reductions of 11.7, 18.46, 25.5, 26.7, and 31.38%, respectively. These results indicate that the

compressive strength drops significantly once the optimum replacement level is exceeded. When the nano glass content is greater than 10%, the production of C–S–H gel surpasses the available voids in the mortar. At the same time, the cement content and hydration rate decrease, leading to weaker bonding between mortar particles. At 56 days, the compressive strength again reached its maximum at the 10% replacement level, confirming this as the optimum rate. Similar to the 28-day results, the compressive strength decreased sharply with higher replacement levels (15–50%). The 56-day compressive strength at the optimum rate was 15.56% higher than the 28-day value, which confirms the strong pozzolanic activity of nano glass at later ages.

The effect of nano glass differs from that of waste glass powder. For example, Šimonová et al. (2017) found that using waste glass powder as partial replacement of cement produced varying increases and decreases in compressive strength at different ages (7, 28, 56, and 90 days). In contrast, in this study, the changes in compressive strength of mortar modified with nano glass were less variable, showing a clearer and more stable trend.

3.3 Flexural strength

Flexural strength is an important property of hardened mortar and was tested according to ASTM C348. This property plays a key role in the equilibrium of walls, especially under lateral forces. The results of flexural strength for different rates of partial replacement of cement with nano glass at 28 days are shown in Fig. 8. The results indicate that flexural strength

decreases with increasing nano glass content compared to the control mix. For the control mix, the flexural strength was 5.88 MPa. When 5% nano glass was used, the flexural strength decreased to 5.32 MPa, which is 9.52% lower than the control. At 10% replacement, the value further decreased to 5.24 MPa, corresponding to a 10.9% reduction. When the replacement increased to 15%, the flexural strength dropped to 5.08 MPa, which is 13.67% lower than the control. For higher replacement levels (20, 30, 40, and 50%), the recorded flexural strength values were 4.78, 4.61, 4.55, and 4.38 MPa, respectively. These values represent reductions of 18.5%, 21.5%, 22.6%, and 25.5% compared with the control mix. The observed decrease in flexural strength with increasing nano glass content can be attributed to the weaker bonding between particles at 28 days. The low bond strength between nano glass particles reduces the overall cohesion of the mortar, leading to lower flexural strength.

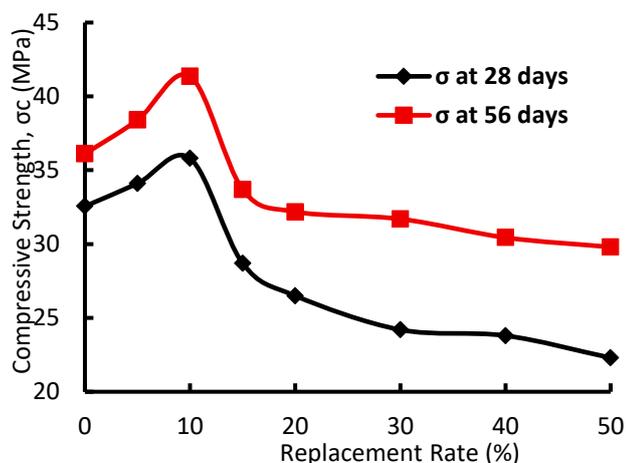


Fig. 7 Compressive value of the mortar based on the used rate of Nano glass

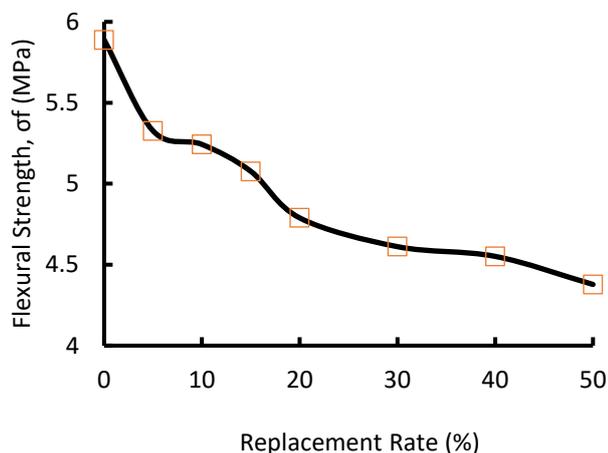


Fig. 8 Flexural value of the mortar based on the used rate of Nano glass

3.4 Thermal conductivity

Thermal conductivity is the ability of a material to conduct heat. When thermal conductivity is low, thermal insulation improves, which enhances the energy efficiency of structures. Cement is generally classified as a material with high thermal conductivity, but the use of fillers can reduce this rate. Thermal conductivity was tested according to ASTM C177, and the

results are presented in Fig. 9. For the control mix (0% nano glass), the thermal conductivity was 0.887 W/m·K. In the mix with 5% nano glass, the thermal conductivity decreased to 0.868 W/m·K, which is a reduction of 2.14% compared with the control. In the mix containing 10% nano glass, the thermal conductivity decreased by 11.83%, and with 15% nano glass the reduction reached 15.67%.

In the other mixes with higher replacement levels (20, 30, 40, and 50%), the thermal conductivity continued to decrease, with reductions of 22.09%, 23.9%, 39.4%, and 40.31%, respectively, compared to the control. These results confirm that nano glass significantly decreases the thermal conductivity of mortar. This effect can be explained by the microstructure of the material. A dense macrostructure typically increases thermal conductivity, but in this case nano glass counterbalances this effect due to its insulating nature. Nano glass has inherently lower thermal conductivity than cement because it is produced from waste glass, which has a high capacity to absorb heat waves. As a result, it takes longer for heat to transfer through nano glass particles compared with cement, providing better thermal insulation.

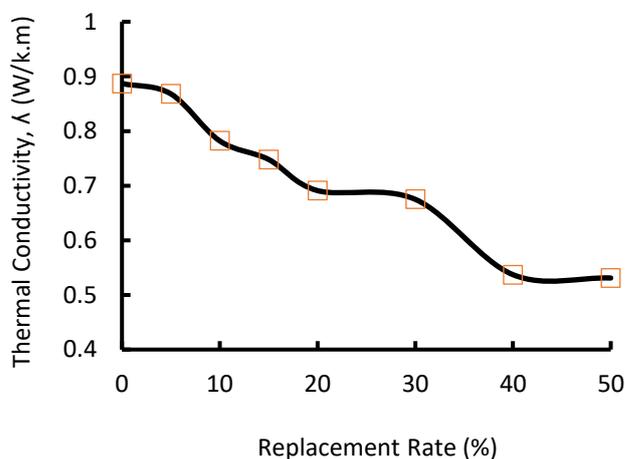


Fig. 9 Thermal Conductivity value of mortar based on the used rate of Nano glass

3.5 Durability

Durability can be measured as the ability of the mortar to withstand the deterioration caused by environmental conditions affecting the physical and chemical properties of the mortar with time. According to ASTM, C267, when samples of mortar after 28 days cured in water bath then placed these samples in acid bath for another 28 days after 56 days these samples have been tested then obtained the results as expressed in the Fig. 10. When the rate of nano glass as partial replacement of cement equal to zero the compressive strength showed be 35 MPa which identified as control mix at 56 days, while when the cement will be replaced by 5% of nano glass the observed compressive strength of mortar increased to 5.7% compared to the control, when the used rate become 10% of nano glass as partial replacement of cement the result showed to be the optimum which is 14.28% related with the control. When the used rate of nano glass as a partial replacement of cement becomes 15% the rate of increase in the compressive strength value will be lower, which is 8.5% compared to the control. when the used rates of nano glass

changed to 20, 30, 40, and 50% as partial replacement of cement, eventually observed the amount of compressive strength dramatically decreased related to strength of control mix by 11.42, 14.28, 20, and 25% respectively. The obtained results of the compressive strength of the mortar samples the cured samples in the bath that contain five percent in H₂SO₄, provide lower compressive strength compare to the control mix that cured in the water bath with total time. The decreases rate of the cured sample in the bath that contain acids, will be same rate as obtained in the normal curing as shown in the Fig. 10.

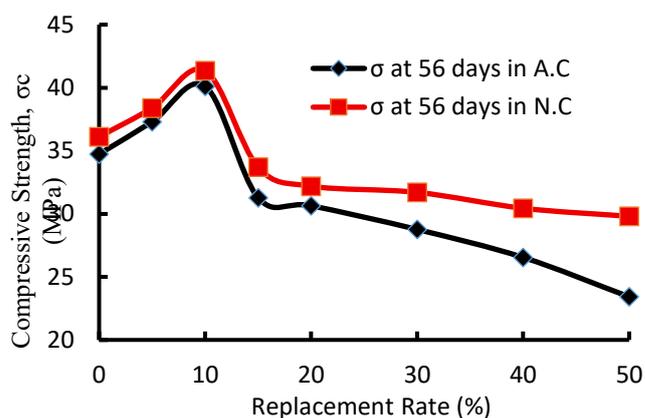


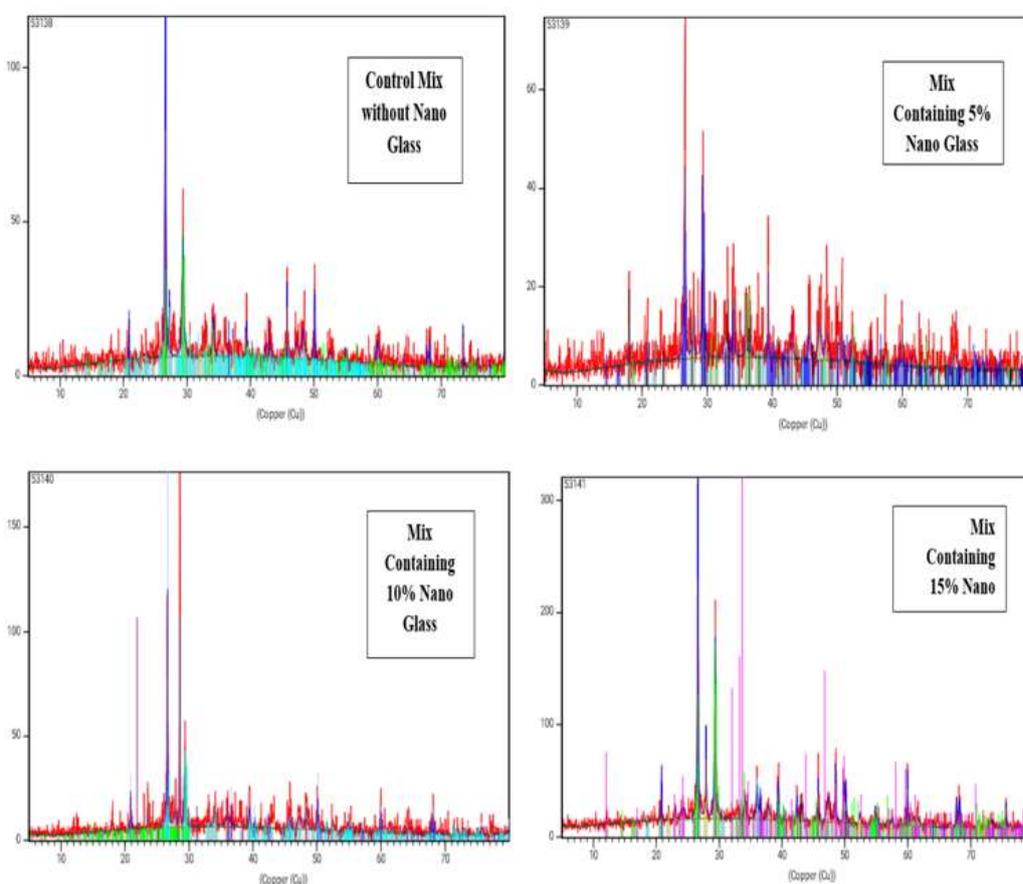
Fig. 10 Decrease rate in samples compressive strength based on used rate of Nano glass in acid bath

Table 5 Identified crystalline phases in mortar mixes with varying nano glass content based on XRD Analysis after 28 days of curing

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
XRD-Based Chemical Composition of the Control Mortar						
*	96-901-2601	39	Quartz	0.000	0.961	Si3.00 O6.00
*	96-900-7169	23	Coesite	0.000	0.353	Si16.00 O32.00
*	96-901-2708	24	Iron	0.000	0.106	Fe4.00
*	96-900-6716	5	Lime	0.000	0.040	Ca4.00 O4.00
*	96-210-3317	5	dicalcium silicate	0.000	0.138	Ca16.00 Si8.00 O32.00
Mortar Mix with 5% Nano Glass Identified by XRD						
*	96-900-7169	36	Coesite	0.000	0.499	Si16.00 O32.00
*	96-900-6710	12	Lime	0.000	0.182	Ca4.00 O4.00
*	96-901-2709	9	Iron	0.000	0.118	Fe4.00
*	96-901-0942	6	Magnetite	0.000	0.168	Fe24.00 O32.00
*	96-901-1496	4	Quartz	0.000	0.113	Si6.00 O6.00
*	96-901-1340	7	Mayenite	0.000	0.203	Ca24.00 Al28.00 O65.80
Mortar Mix with 10% Nano Glass Identified by XRD						
*	00-046-1045	39	Silicon Oxide	0.000	0.648	Si O2
*	96-900-8367	25	Hatrurite	0.000	0.177	Ca108.00 Si36.00 O180.00
*	96-900-8228	2	Cristobalite	0.000	0.575	Si4.00 O8.00
*	96-900-7171	23	Coesite	0.000	0.206	Si16.00 O32.00
Mortar Mix with 15% Nano Glass Identified by XRD						

Visible	Ref. Code	Score	Compound Name	Displacement [°2Th.]	Scale Factor	Chemical Formula
*	00-046-1045	49	Silicon Oxide	0.000	0.965	Si O2
*	96-900-7170	27	Coesite	0.000	0.491	Si16.00 O32.00
*	96-901-0942	10	Magnetite	0.000	0.112	Fe24.00 O32.00
*	96-901-2708	14	Iron	0.000	0.071	Fe4.00
*	96-900-3344	3	Brownmillerite	0.000	1.481	Ca8.00 Fe6.16 Al1.84 O20.00
*	96-901-1496	7	Quartz	0.000	0.046	Si6.00 O6.00

Fig. 5 XRD patterns of mortar samples with 0, 5, 10, and 15% nano glass replacement after 28 days of curing



3.6 X-ray Diffraction (XRD) Analysis

XRD was conducted on mortar samples incorporating nano glass at varying replacement levels of 5, 10, and 15%, and the results were compared to a control mix, all evaluated after 28 days of curing. The control mix exhibited dominant crystalline peaks corresponding primarily to Quartz and Coesite, with minor peaks from Lime and Dicalcium Silicate as in the Table 5. This pattern indicates a matrix primarily composed of silicate phases, with limited evidence of hydration product formation. Introducing 5% nano glass led to noticeable changes

in the diffraction profile, including the appearance of new crystalline phases and variations in peak intensities. The emergence of Mayenite and Magnetite, along with increased Lime content as in the Table 5, points to enhanced pozzolanic activity and improved reactivity involving aluminosilicate and iron-rich compounds. At a 10% nano glass replacement, the XRD spectrum demonstrated a more significant shift, marked by intensified Silicon Oxide peaks and the formation of additional crystalline phases such as Cristobalite and Hatrurite, as in Table 5. This shows a more stable and crystalline matrix, with an increased presence of calcium-

silicate-hydrate (C-S-H) and related products. A corresponding reduction in Lime peaks also indicates more extensive consumption of calcium hydroxide due to pozzolanic reactions.

The sample containing 15% nano glass showed the highest intensity for Silicon Oxide peaks and the formation of new phases like Brownmillerite. This reflects the development of complex calcium-alumina-ferrite structures. The continued detection of Coesite and Magnetite further confirms ongoing mineralogical evolution with increasing nano glass content.

XRD analysis confirms a steady increase in stable silicate and aluminate phases as nano glass content rises from 5% to 15%. The formation of phases like C-S-H, Brownmillerite, Mayenite, and Hatrurite becomes more evident, indicating enhanced pozzolanic activity and mineralogical changes within the mortar matrix. These developments result in a denser, less porous structure, contributing to improved durability. This refined matrix enhances both compressive strength and long-term resistance to chemical degradation. Increased C-S-H formation and reduced free Lime content help minimize risks such as leaching, shrinkage, and chemical attack.

Overall, the results highlight the potential of nano glass as a sustainable supplementary cementitious material. Its use not

4. Conclusion

Based on the use of nano glass waste as a partial replacement for cement in mortar and the investigation of its effects on fresh properties, mechanical performance, thermal conductivity, and durability, the following conclusions were drawn:

1. The addition of nano glass powder reduced the flowability of the mortar, with greater reductions observed at higher replacement levels. For instance, replacing 5% of cement with nano glass resulted in a 3.53% decrease in flow compared to the control mix, while a 50% replacement led to a 39.8% reduction.
2. Compressive strength increased with nano glass replacement up to 10%, reaching a maximum improvement of 10.1% over the control mix. However, further increases in the replacement level led to a decline in compressive strength. Flexural strength consistently decreased with the addition of nano glass. At a 5% replacement, the flexural strength dropped by 9.52%, and at 50%, the decrease reached 25.5% compared to the control mix.
3. Nano glass enhanced the insulation properties of the mortar due to its heat absorption capability. As the replacement level increased, thermal conductivity decreased. A 50% replacement of cement with nano glass resulted in a 40.31% reduction in thermal conductivity compared to the control mix.
4. Exposure to acidic environments negatively affected the mechanical properties of the modified mortar. The severity of strength reduction increased with both higher acid concentration and higher nano glass content, indicating that durability under acidic conditions diminishes with increased nano glass substitution.
5. The used rate of the nano glass in the mortar based on the obtained result from experimental based on its application will

only valorizes waste but also improves mortar performance through optimized phase development and mix design. These phase transformations and trends are clearly illustrated in Fig. 5.

Based on TGA analysis results, it is evident that the adsorption capacity of CJS and $\text{TiO}(\text{OH})_2$ adsorbents decreases with increasing temperature, while increasing with higher carbon dioxide concentrations. For instance, the average carbon dioxide adsorption for CJS at a 90% volumetric concentration reaches 2.31 mmol/g, which is approximately 1.54 mmol/g higher than that of $\text{TiO}(\text{OH})_2$ at 0.77 mmol/g. A comparison of the adsorption results and SEM images indicates that AC adsorbents exhibit superior performance compared to $\text{TiO}(\text{OH})_2$ due to their developed pore structure. Previous studies have demonstrated that $\text{TiO}(\text{OH})_2$ forms strong hydrogen bonds and interparticle forces such as van der Waals interactions due to its polar structure and the presence of O and H atoms. These predominant internal forces lead to particle agglomeration, consequently significantly diminishing the carbon dioxide adsorption performance of this adsorbent.

change. If the mortar has been used for plastering and its target was insulation, it will be better to use nano glass up to 50% as partial replacement of cement since decrease the thermal conductivity up to 40.31% while if the application was to joint masonry unit it will be better to used nano glass as partial replacement of cement not more than 10% since increase compressive strength up to 10.1%.

Statements and Declarations

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors of this paper declared no conflict of interest regarding the authorship or publication of this article

Author contribution

S. S. Shkur and S. K. Rafiq: Conceptualization, writing-original draft preparation, methodology, data curation, writing original draft preparation, writing- Reviewing and editing.

AI Use Declaration

This work did not include AI-assisted content. All outputs were write and edited by the authors.

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