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RESEARCH ARTICLE

Mechanical and Microstructural Performance of Ultrasonically Synthesized Nano-Chitosan/PVA/Corn Cob Ash Hybrid Composite in Cement Mortar

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ABSTRACT

Nanotechnology has emerged recently as a successful technique to enhance cement-based material performances. When nanoparticles, polymers and other material are added to the cement, it changes microstructure of cement composites drastically. This study synthesized a nano chitosan incorporated PVA-Corn Cob Ash (CCA) hybrid composite by using ultrasonic dispersion and incorporated it in the cement mortar. Mortar mixes were made with a cement-to-sand ratio of 1:2.75 and a water-to-cement ratio of 0.485. The hybrid composite was added at one percent by weight of cement. As per ASTM C109, the compressive strength was evaluated at 7 days and water absorption and density were determined as per ASTM C642. The time of setting was measured as per ASTM C191. The findings indicate that the hybrid composite enhances compressive strength and yields a denser cement matrix than the control mixture. The improved properties are due to the nuleation of the nano-chitosan particles, the formation of polymer film by PVA, and the pozzolanic reaction of corn cob ash. The use of agro waste materials in a hybrid system is useful for sustainable construction.

Keywords: Nano-chitosan, Polyvinyl alcohol, Corn cob ash, Cement mortar, Hybrid nanocomposite, Ultrasonic synthesis

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1. Introduction

Concrete is the most widely used building material in the world, mainly due to its high pressure resistance, durability and versatility in construction. However, conventional concrete based on Portland cement suffers from a number of known limitations, most notably the susceptibility to the formation and spread of microcracks under the influence of continuous mechanical and thermal loads, high porosity that facilitates the penetration of moisture and aggressive ions such as chloride ions, as well as biological degradation resulting from microorganisms colonizing the internal pore networks [1].

Together, these factors lead to an early deterioration in structural performance, especially in harsh environments characterized by high temperatures, periodic succession of wetting and dehydration, and exposure to various chemicals [2]. Therefore, recent research has tended to develop advanced mixing techniques aimed at improving the properties of concrete, most notably the integration of polymeric materials and nanomaterials into cement matrices to enhance mechanical properties and resist degradation factors [3].

Chitosan, a natural biopolymer obtained from the acetylating of the chitin complex, has emerged as a promising bioadditive in cement and concrete applications. Its molecular structure is characterized by

containing active functional groups such as amine (–NH_2) and hydroxyl (–OH), which gives it a high adsorption ability on the surfaces of cement particles, thus influencing the wetting kinetics and rheological behavior of cement systems in their fresh state [4].

Baykara et al. (2024) showed that the introduction of chitosan particles extracted from shrimp shells into hydraulic cement slurry in different proportions modified the wetting process and achieved moderate improvements in compressive resistance in middle ages, as well as achieving environmental benefit through the investment of marine industry wastes [5]. The amino (–NH_2) and hydroxyl (–OH) functional groups present on the nano-chitosan surface are capable of complexing with calcium ions (Ca^{2+}) released during cement hydration, potentially modifying C–S–H gel nucleation and growth kinetics and contributing to microstructure densification [6]. A comprehensive review by Fediuk et al. (2025) on nano-enhanced bio-additives in cementitious composites confirmed that chitosan nanomaterials offer multifunctional benefits in concrete, acting simultaneously as crack-healing agents, water barriers, and hydration modulators, while maintaining full biodegradability and environmental safety [7]. Furthermore, Douba et al. demonstrated that nano-chitosan (NC) incorporated into cement mortar at a dosage of 4% accelerated hydration heat release and enhanced 28-day compressive strength, with scanning electron microscopy (SEM) confirming the effective coating of cement particles by nano-chitosan, thereby improving interfacial bonding within the cementitious matrix [8]. According to the analysis, nano- chitosan is a multifunctional admixture that can improve the early-age hydration kinetics, interfacial transition zone (ITZ) quality and antimicrobial performance of concrete simultaneously [9]. The synthetic polymer poly (vinyl alcohol) (PVA) is a water-soluble polymer frequently used to reinforce engineered cementitious composites (ECC) with fiber and polymers. Due to the material's high density of hydroxyl groups, strong hydrogen bonding with the cement hydration products occurs. This allows for better integrity of the matrix and an improved interfacial transition zone between the polymer and the cementitious binder [10]. The inclusion of PVA fibers has been shown to improve tensile ductility, flexural strength, and crack resistance through the action of fiber-bridging, which helps to impede the propagation of cracks at a micro level [11]. Zhao et al. (2023) effectively demonstrated that to enhance the impermeability as well as the chloride ion penetration resistance, and freeze-thaw resistance of cementitious composites under wet-heat-salt coupling conditions, an optimal PVA fiber content of 1.2% will contribute significantly to the service life of the mixture [12]. In addition, Zhang et al. (2024) found that when ultra-high-performance concrete (UHPC) was added with modified PVA fibers it had a better compressive strength and flexural strength of 12% and 6% respectively at the optimum dosage while further surface modification of the fiber enhanced the fiber–matrix interfacial bonding and toughness of the composite [13]. Apart from being used as fiber reinforcement, either in a dissolved or film form, PVA can also refine pores in a cementitious matrix by reducing capillary porosity. It can help with water penetration [14].

Corn cob ash (CCA) is an agricultural by-product formed by the controlled burning of corn cobs which are one of the most widely produced lignocellulosic residues. Chemical analysis of CCA repeatedly show a high concentration of amorphous silica (SiO_2) and the presence of calcium, potassium, aluminum oxides give the material a great pozzolanic reactivity [15]. The reactive siliceous phases of the CCA partake in series of pozzolanic reaction with calcium hydroxide [$Ca(OH)_2$] generated during hydrating of the cement which do result in the formation of further C-S-H gel. The resultant C-S-H gel will packing up the cementitious microstructure and eliminate the capillary porosity [16]. In a study by Sathiparan (2025), CCA's incorporation into cementitious systems was reviewed. It confirmed pozzolanic properties of CCA and mechanical performance contribution. Further, the supplementary cementitious properties of CCA is significantly dependent on combustion temperature and fineness of particles [17]. In a complementary investigation, Oriola et al. (2023) demonstrated that partial cement replacement with CCA at optimized proportions yielded comparable or enhanced compressive strength and improved thermal insulation characteristics relative to control mixes [18]. The dual role of CCA as both a reactive pozzolanic filler—generating supplementary C–S–

H gel through reaction with portlandite—and a passive micro-filler that reduces inter-particle void content renders it a particularly cost-effective and sustainable additive for concrete modification [19].

Silver nanoparticles (AgNPs) are typically synthesized using silver nitrate ($AgNO_3$) as a precursor. Recently, these nanoparticles have been investigated as multifunctional additives for cementitious materials offering improved mechanical performance and antimicrobial protection simultaneously. Microbial colonization of concrete structures, especially sulfur-oxidizing bacteria, nitrifying bacteria, and fungi, is a well-known accelerating agent for the deterioration of wastewater infrastructures and marine structures and structures under constant wetness [20]. At the nanoscale, silver nanoparticles (AgNPs) exhibit powerful broad-spectrum antimicrobial activity. The Ag^+ ions released by AgNPs can inhibit the action of enzymes within bacteria. Furthermore, the ROS produced by AgNPs can damage cellular components of all microbes. Finally, AgNPs can affect the membranes of all microbes [21]. When it comes to mechanical properties, Chen and Xu (2025) found that the simultaneous addition of AgNPs (0.05–1.00 wt%) and nano-silica to the ordinary Portland cement paste led to a 33% enhancement of 28-day compressive strength, two to three orders of magnitude higher charge transfer resistance, as well as a denser C–S–H network via nucleation acceleration and blocking of capillary pores [22]. Sybis et al. (2025) further confirmed through in-situ microbiome analysis that AgNP incorporation into cement composites inhibited complex spatial biofilm formation and induced qualitative changes in the bacterial metapopulation under authentic wastewater environment conditions, validating the practical antimicrobial efficacy of AgNP-modified concrete in service [23].

The ultrasonication technique, based on the principle of acoustic cavitation—the formation, growth, and implosive collapse of microbubbles in liquid media under high-frequency ultrasonic irradiation—has been established as one of the most effective methods for preparing polymer nanocomposites with homogeneous nanofiller dispersion [24]. The transient localized regions of extreme temperature and pressure generated during cavitation events facilitate the deagglomeration of nanoparticles, promote intimate interfacial contact between matrix components and inorganic fillers, and can accelerate reduction reactions involved in in-situ nanoparticle synthesis [25]. Romero-Fierro et al. (2023) have confirmed that in the case of nanomaterial-modified concrete, the nanomaterials produced using ultrasonic dispersion delivered better improvement of compressive strength in concrete compared to conventionally mixed ones. This is explained by the greater homogeneity in the distribution of nanoparticles within the cementitious matrix using a sonochemical process [26]. The functional characteristics of nanomaterial-modified concrete are highly dependent on the quality of the dispersion. Nanoparticle agglomeration creates stress concentration points that weaken the interfacial transition zone ITZ, while well-dispersed nanoparticles uniformly fill micro- and nano-scale voids and provide abundant nucleation sites for C–S–H precipitation [27].

Despite the substantial and growing body of literature addressing individual or binary admixture systems—including nano-chitosan, PVA, agricultural ash-based fillers, and silver nanoparticles—the simultaneous incorporation of all four components in a quaternary hybrid composite form, prepared via ultrasonication, has not been investigated with respect to its effects on concrete performance. The anticipated synergistic interactions among nano-chitosan's hydration-modifying and microstructure-densifying capacity, PVA's crack-bridging and pore-refining effects, the pozzolanic reactivity and micro-filling action of corn cob ash, and the nucleation-accelerating and antimicrobial properties of AgNPs derived from $AgNO_3$, are expected to produce complementary and mutually reinforcing improvements across the full performance spectrum of concrete—encompassing fresh-state workability, early and long-term compressive and flexural strength, water absorption, porosity, and resistance to biological and chemical deterioration. Accordingly, the present study aims to prepare a novel quaternary hybrid composite comprising nano-chitosan, PVA, corn cob ash, and silver nitrate-derived AgNPs via the ultrasonication technique, and to systematically evaluate its influence on the fresh, mechanical, microstructural, and durability properties of concrete at various curing ages.

2. Materials

The materials used in this investigation included ordinary Portland cement, standard sand accordance ASTM C109[28]. , nano-chitosan powder, polyvinyl alcohol (PVA), corn cob ash (CCA)which it is prepared by first washing it by water and drying it at 105℃ for 24 h to facilitate the burning process, then burning it in special ovens at 600-700℃ accordance ASTM C618[29], and silver nitrate solution which it is prepared by solving 0.25gm in 1 litter of water .

3. Preparation

3.1. Preparation of Hybrid Composite

The hybrid composite was synthesized using ultrasonic dispersion. The nano-chitosan is dissolved in glacial acetic acid, and the polyvinyl alcohol(PVA) is dissolved in hot distilled water. Different proportions of these are taken with corn cob ash(CCA), and 10 ml of silver nitrate is added to them, as shown in table (1).

Table 1. shows the ratios of the composites

Chitosan(gm)	PVA(gm)	CCA(gm)	$AgNO_3$(ml)
1.5	1.5	0.75	10
1.5	1.0	0.5	10
1.5	0.5	0.25	10
1.5	0.25	0.125	10

3.2. Preparation of mortars [28]

Cement mortar samples were prepared according to the specification ASTM C109[28], the propotion of materials for the standear mortar shall be one part of cement to 2.75 parts of standerd sand by weight .Use a water –cement ratio of 0.485 for all Portland cements.The molds used are made of stainless steel cubes with dimension 5*5*5cm (50*50*50)mm., (Image 1).The quantities of materials to be mixed at one time in the batch of mortar for making six,nine ,and twelve test specimens shall be as table (2).

Table 2. shows the quantity of materials.

NO. of specimens	6	9	12
Cement (gm.)	500	740	1060
Standard sand(gm.)	1375	2035	2915
Water (ml)	242	359	514

4. Mix Design

Three cubes of cement and sand, without any added composite, were used to prepare a reference sample. Four samples, each consisting of three cubes, were then prepared by adding composites at a rate of 1% of the cement weight.



Image 1. The Cubic Mortar

5. Experimental Program

Compressive strength test according to ASTM C109[28]. Water absorption test according to ASTM C642[30]. Density measurement according to ASTM C642[30]. Setting time measurement according to ASTM C191[31].

6. Application of Composites Z1-Z4 on Concrete

6.1. Compressive strength results at 7 days curing:

Sym. of specimens	Compressive strength
Control	26.9
Z1	27.24
Z2	27.16
Z3	28.82
Z4	24.9

The results show that the hybrid composite improved compressive strength compared with the control mixture. The highest compressive strength was observed for mixture Z3.

This improvement can be attributed to the combined effects of nano-chitosan, PVA, and corn cob ash. Nano-chitosan particles act as nucleation sites that accelerate the formation of hydration products. PVA forms polymer films within the cement matrix that improve bonding and reduce microcrack formation.

Corn cob ash contributes to pozzolanic reactions that consume calcium hydroxide and generate additional C-S-H gel, leading to a denser microstructure.

6.2. Water absorption and density results at 7 days curing:

Sym. Of specimens	Absorption %	Density(kgm./m^3)
Control	4.8	2224.32
Z1	4.1	2265.04
Z2	3.8	2273.6
Z3	2.9	2285.2
Z4	4.5	2279.8

The reduced water absorption in modified slurry mixtures is attributed to the synergistic interaction between three main components: nano-chitosan, polyvinyl alcohol (PVA), and corn cob ash. Nano-chitosan molecules act as nucleation sites that accelerate rehydration reactions and promote the formation of aqueous calcium silicate gel (C-S-H), while polyvinyl alcohol contributes to the formation of polymeric membranes that partially close the capillary pores and limit the spread of micro-fissures. Corn cobs ash is involved in pozzolan reactions with calcium hydroxide, generating additional amounts of C-S-H gel that condenses the microstructure of the cement matrix. The synergy of these mechanisms results in reduced pore bonding, and thus a noticeable reduction in water absorption compared to a standard mixture.In terms of density, measurements recorded after seven days indicate that the addition of the hybrid compound (nano-chitosan/PVA/maize coaxon ash) resulted in a slight increase in the density of the modified slurry mixtures compared to the standard mixture, which can be attributed to improved pore structure and the accumulation of rehydration products within the cement matrix. Z3 is expected to record the highest density values, as the mixture that has demonstrated the highest pressure resistance and the lowest water absorption, reinforcing the close relationship between these properties on the one hand, and improving the microstructure of the cement materials on the other.

6.3. Setting time by Vicat Needle

Sym. Of specimens	Initial time(minute)	Final time(minute)
Control	170	285
Z1	180	300
Z2	185	305
Z3	190	315
Z4	175	295

The setting time results indicate that the incorporation of the nano-chitosan/PVA/corn cob ash hybrid composite slightly delayed both the initial and final setting times compared with the control mixture. However, the delay remained within acceptable limits according to ASTM C191[31]. This behavior can be attributed to the presence of polymeric and biopolymeric components that partially coat cement particles and regulate the hydration process, resulting in a more controlled development of the cement matrix.

7. Results and Discussion:

7.1. SEM Morphological Analysis of the Composite

The SEM analysis confirms, which presents in figure (1), that the ultrasonication-assisted synthesis produced a structurally integrated composite exhibiting three distinct morphological features: (i) angular plate-like CCA fragments providing micro-scale reinforcement and pozzolanic reactivity; (ii) well-dispersed AgNPs contributing antimicrobial functionality and nano-pore-filling capacity; and (iii) a continuous PVA/nano-chitosan matrix ensuring cohesion and interfacial compatibility between all components. The surface roughness, angular particle geometry, and abundant active surface sites collectively suggest high potential for mechanical interlocking and chemical interaction within the cementitious matrix, expected to translate into measurable improvements in compressive strength, water absorption resistance, and microstructural densification of the resulting concrete.

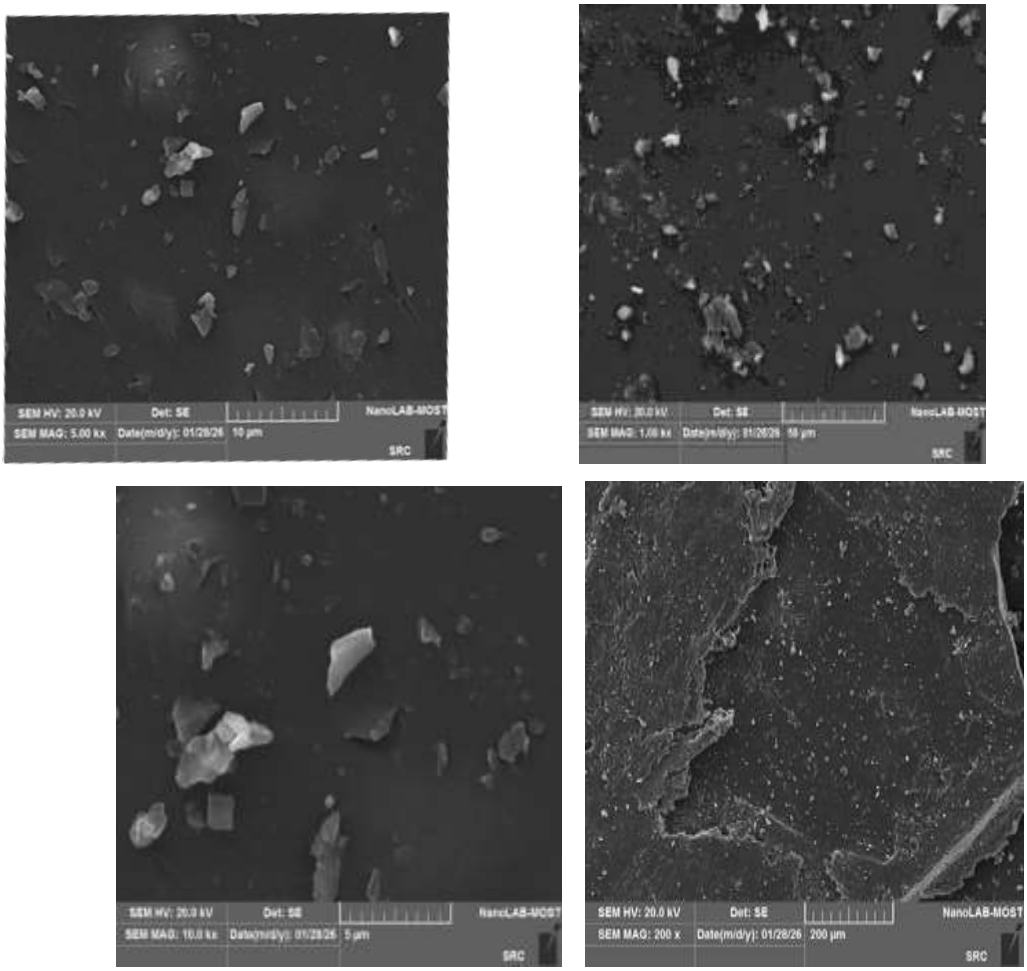


Figure 1. Scanning Electron Microscopy (SEM)

7.2. XRD Analysis of the copmosite

The XRD analysis presented in figure (2,3) collectively confirms that the synthesized nano-chitosan/PVA/corn cob ash/AgNPs hybrid composite (AM6046-2 Z2) possesses a predominantly amorphous microstructure, characterized by the absence of sharp long-range crystalline order and the dominance of broad diffuse scattering attributable to the amorphous polymeric matrix and amorphous siliceous phases of CCA. This amorphous structural character is of direct and significant relevance to the intended application of the composite as a concrete admixture. Amorphous siliceous materials are inherently more chemically reactive than their crystalline counterparts, as the disordered SiO_4 network presents a greater density of unsatisfied surface bonds and reactive silanol (Si–OH) groups available for participation in secondary pozzolanic reactions with calcium hydroxide [$Ca(OH)_2$] produced during Portland cement hydration [4]. These pozzolanic reactions generate supplementary calcium silicate hydrate (C–S–H) gel, which densifies the cementitious microstructure, reduces capillary porosity, and refines the interfacial transition zone (ITZ)—the weakest structural domain in conventional concrete [5]. Furthermore, the amorphous character of nano-chitosan within the composite implies a higher surface reactivity and greater availability of amino ($–NH_2$) and hydroxyl (–OH) functional groups for interaction with cement particle surfaces and hydration products, thereby enhancing the polymeric admixture–cement matrix compatibility. Consequently, the XRD results provide a robust crystallographic basis for anticipating measurable improvements in compressive strength, water absorption resistance, and long-term durability in concrete incorporating the synthesized hybrid composite.

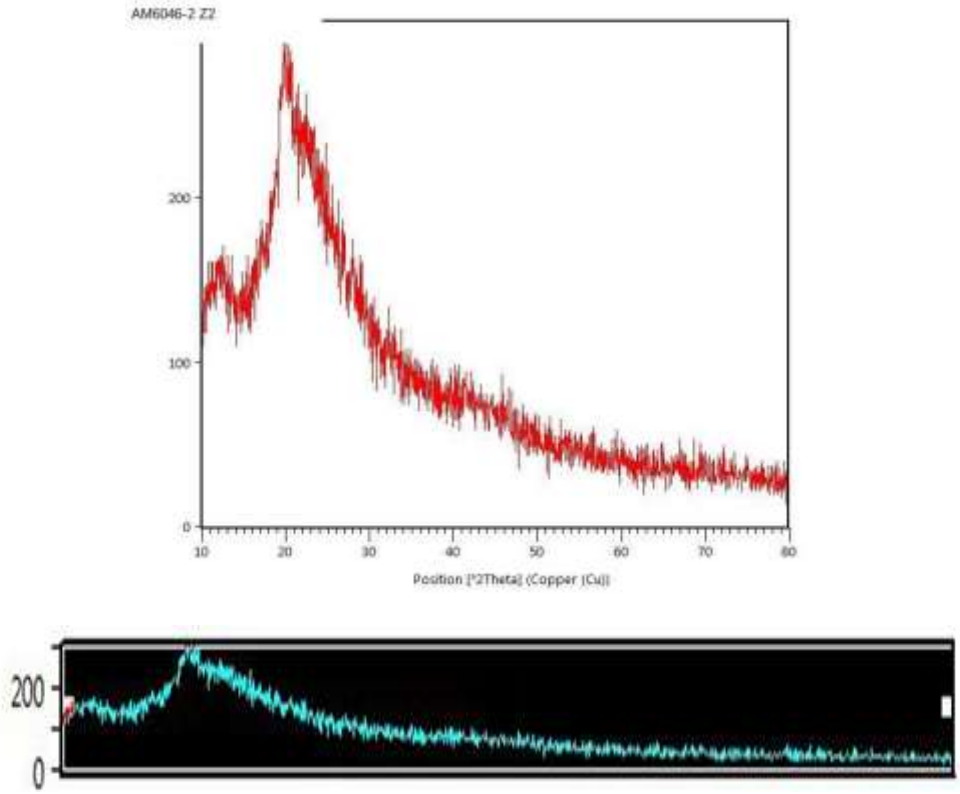


Figure 2. Xrd analysis composite

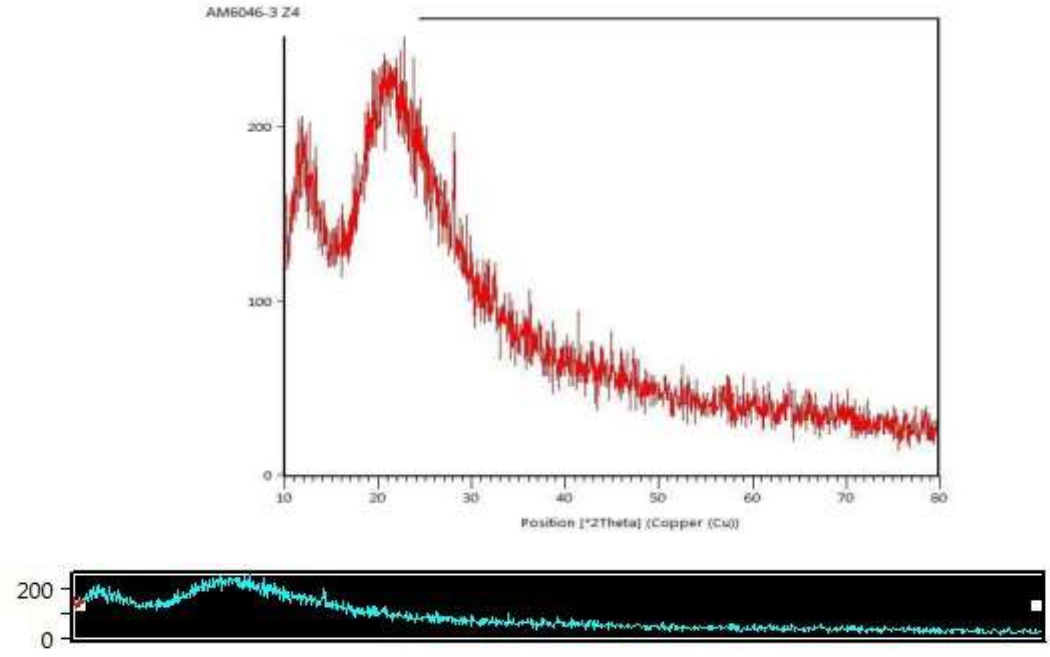
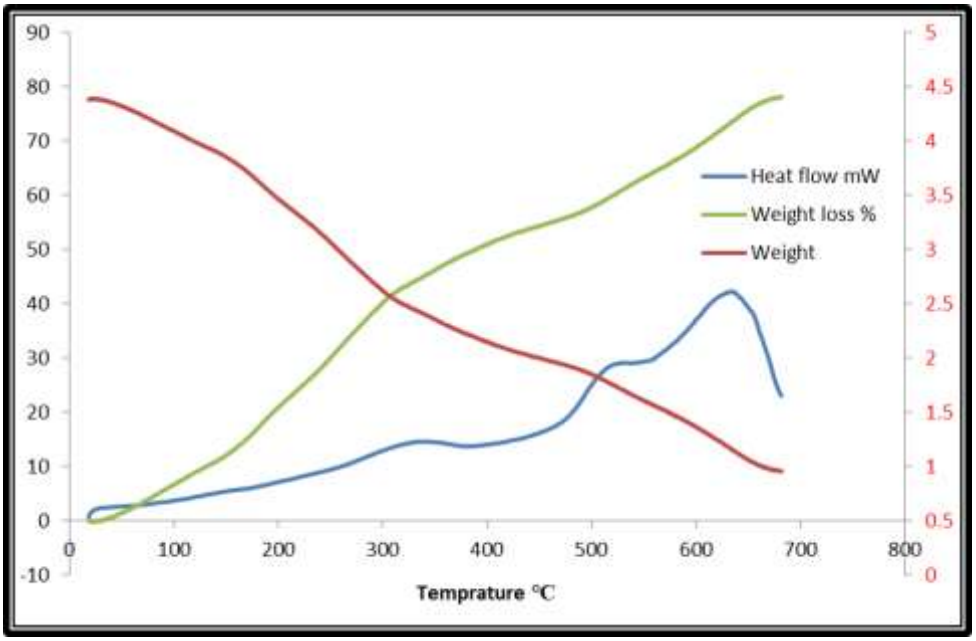


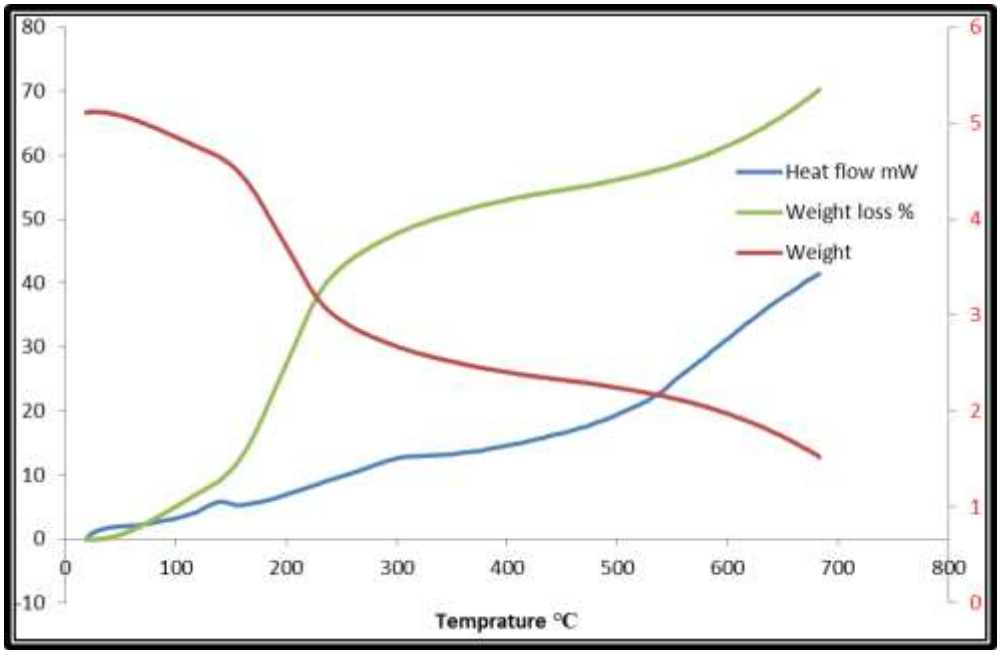
Figure 3. Xrd analysis composite

7.3. Thermal Gravimetric Analysis (TGA)

The TGA shows that the course of the thermal decomposition of the four composites (Z1, Z2, Z3, Z4) differs significantly. As figures (4,5,6). First step started at (17.7 - 150)℃ and at (20-250)℃ respectively corresponding to evaporation of water (Dominika, K. et. al., 2016), second step began at (150 -350)℃ and at (250-550)℃ for the two previous complexes match with release of gases like (CO, Cl) and decomposition of

the main chains for the synthesized polymer, while the third step corresponding with decomposition of the main chain of chitosan and natural polymer main chains and it started at (350-831 oC) and (550-700oC) (Lutfor, R., et. al., 2022).





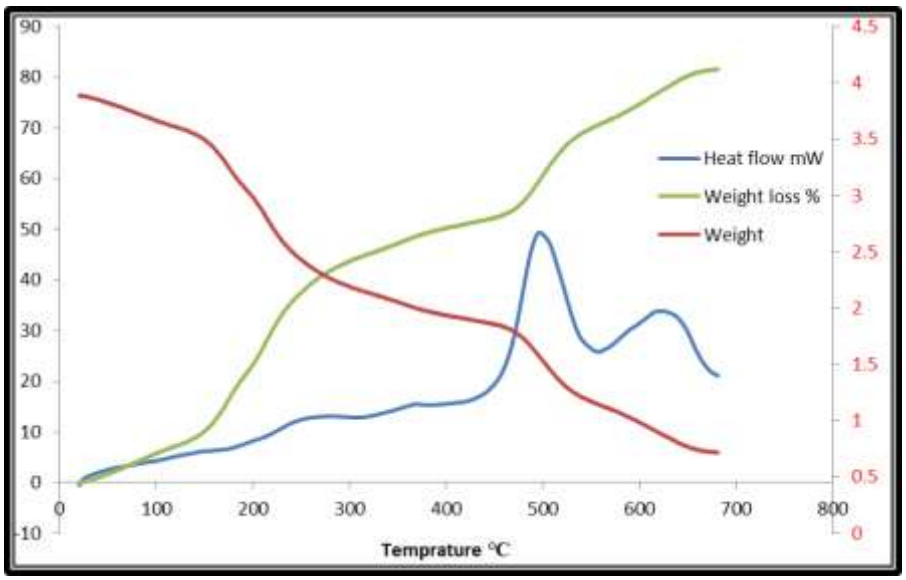


Figure 4,5,6. TGA Analysis

Table 3. Thermal analyses data for complexes (1-4)

Comp.	Dissociation steps	Temp. range in °C	Weight loss found %	Weight loss (Cal.)%	Estimated phase	Final Weight loss found %	Final Weight loss (cal.)%	Final Weight residue %
Z1	StepI StepII StepIII	17.7-150 150-350 350-831	12.29 43 42	12 42.85 42	Dehydration Synthesized polymer main chains Chitosan and natural polymer chain residues	85	84.85	15 % it represent residue of polymer and metal oxide
Z2	StepI StepII StepIII	20-250 250-550 550-700	37.54 32.35 11.11	37 32 10.5	Dehydration Synthesized polymer main chains Chitosan main chains and Natural polymer chain residues	81	79.5	19 % it represent residue of polymer and metal oxide
Z3	StepI StepII	18-300 300-681	40.17 38.06	39 38.5	Dehydration and release of gases like and decomposition of the main chains for the synthesized polymer Chitosan main chains and Natural polymer chain residues	78.23	77.5	21.8 % it represent residue of polymer and metal oxide
Z4	StepI StepII	18-250 250-781	42.471 41.03	42 41	Dehydration and release of gases like and decomposition of the main chains for the synthesized polymer Chitosan main chains and Natural polymer chain residues	83.58	83	16.5 % it represent residue of polymer and metal oxide

8. Conclusions

The present study investigated the effect of an ultrasonically synthesized nano-chitosan/PVA/corn cob ash hybrid composite on the mechanical and durability properties of cement mortar. Based on the experimental results obtained in this work, several important conclusions can be drawn.

The incorporation of the hybrid composite into cement mortar improved the mechanical performance of the mortar mixtures compared with the control mixture. The compressive strength results obtained at 7 days showed that the modified mixtures exhibited higher strength values, indicating that the hybrid composite contributed to improving the structural integrity of the cement matrix.

The reduction in water absorption observed in the modified mixtures indicates that the hybrid composite improved the compactness of the cement matrix. The lowest water absorption value was recorded for mixture M3, which suggests that the selected proportion of nano-chitosan, PVA, and corn cob ash provided an optimal balance for refining the pore structure of the mortar.

The improvement in both compressive strength and water absorption can be attributed to the synergistic interaction between nano-chitosan particles, polymer film formation by PVA, and the pozzolanic activity of corn cob ash. Nano-chitosan particles act as nucleation sites that accelerate hydration reactions and promote the formation of additional C-S-H gel, while PVA forms polymer films that reduce pore connectivity and improve bonding between hydration products. In addition, corn cob ash reacts with calcium hydroxide to produce additional hydration products, contributing to the densification of the microstructure.

Overall, the results demonstrate that the use of nano-chitosan/PVA/corn cob ash hybrid composites can significantly improve the mechanical and durability properties of cement mortar. The utilization of corn cob ash also contributes to sustainable construction by recycling agricultural waste materials and reducing environmental impact.

References

1. Mehta, P.K., & Monteiro, P.J.M. (2014). Concrete: Microstructure, Properties, and Materials (4th ed.). McGraw-Hill Education.
2. Imbabi, M.S., Carrigan, C., & McKenna, S. (2012). Trends and developments in green cement and concrete technology. International Journal of Sustainable Built Environment, 1(2), 194–216. https://doi.org/10.1016/j.ijsbe.2013.05.001
3. Reches, Y. (2018). Nanoparticles as concrete additives: Review and perspectives. Construction and Building Materials, 175, 483–495. https://doi.org/10.1016/j.conbuildmat.2018.04.214
4. Fediuk, R., Amran, M., Vatin, N., et al. (2025). Reinforcing concrete with nano-enhanced bio-additives: A path toward sustainable construction materials. Discover Concrete and Cement, 2, 22. https://doi.org/10.1007/s44416-025-00022-8
5. Ke, C.L., Deng, F.S., Chuang, C.Y., & Lin, C.H. (2021). Antimicrobial actions and applications of chitosan. Polymers, 13(6), 904. https://doi.org/10.3390/polym13060904
6. Wang, L., Ju, S., Wang, L., Wang, F., Sui, S., Yang, Z., Liu, Z., Chu, H., & Jiang, J. (2023). Effect of citric acid-modified chitosan on the hydration and microstructure of Portland cement paste. Journal of Sustainable Cement-Based Materials, 12(1), 83–96. https://doi.org/10.1080/21650373.2021.2016515
7. Fediuk, R., Amran, M., Vatin, N., et al. (2025). Reinforcing concrete with nano-enhanced bio-additives: A path toward sustainable construction materials. Discover Concrete and Cement, 2, 22. https://doi.org/10.1007/s44416-025-00022-8
8. Douba, A., Emiroglu, M., Gebregziabiher, B., Kawashima, S., & Ulm, F.J. (2022). Nano-chitosan as a cement composite: Effect on mechanical properties and hydration. Cement and Concrete Composites, 134, 104722. https://doi.org/10.1016/j.cemconcomp.2022.104722
9. Qin, Z., Wu, J., Hei, Z., Wang, L., Lei, D., Liu, K., & Li, Y. (2024). Study on the effect of citric acid-modified chitosan on the mechanical properties, shrinkage properties, and durability of concrete. Materials, 17(9), 2053. https://doi.org/10.3390/ma17092053
10. Wang, C., Zhang, P., Guo, J., Wang, J., & Zhang, T. (2023). Durability and microstructure of cementitious composites under the complex environment: Synergistic effects of nano-SiO_2 and polyvinyl alcohol fiber. Construction and Building Materials, 400, 132621. https://doi.org/10.1016/j.conbuildmat.2023.132621

11. Sabapathy, L., Mohammed, B., et al. (2024). Evaluating bulky PVA-ECC mortar developed with river sand, silica fume, and high-volume fly ash. Arabian Journal for Science and Engineering, 49, 5307–5323. https://doi.org/10.1007/s13369-023-08653-4
12. Zhao, H., Liu, J., & Zhang, P. (2023). Influence of PVA fibers on the durability of cementitious composites under wet-heat-salt coupling environment. Reviews on Advanced Materials Science, 62(1), 20230155. https://doi.org/10.1515/rams-2023-0155
13. Zhang, W., Zheng, H., Ma, Y., et al. (2024). Influence of modified PVA fiber on ultra-high performance concrete and its enhancing mechanism. Polymers, 16(23), 3449. https://doi.org/10.3390/polym16233449
14. Al-Sulaiman, M.A., Abid, S.R., & Abbood, I.S. (2023). The impact of using natural waste biopolymer cement on the properties of traditional/fibrous concrete. Innovative Infrastructure Solutions, 8, 302. https://doi.org/10.1007/s41062-023-01253-z
15. Shakouri, M., Exstrom, C.L., Ramanathan, S., & Suraneni, P. (2020). Hydration, strength, and durability of cementitious materials incorporating untreated corn cob ash. Construction and Building Materials, 243, 118171. https://doi.org/10.1016/j.conbuildmat.2020.118171
16. Ofuyatan, O.M., Olutoge, F.A., Olowofoyeku, A.A., Olofinnade, O.M., & Chukwuemeka Eze, E. (2021). Influence of corn cob ash on the properties of self-compacting concrete. Materials Today: Proceedings, 44, 2119–2124. https://doi.org/10.1016/j.matpr.2020.12.324
17. Sathiparan, N. (2025). Sustainability applications of corncob ash in construction materials: A review. Jurnal Inovasi Teknologi dan Edukasi Teknik, 5(1), 1–18.
18. Oriola, K.O., Raheem, A.A., & Ogundele, A.B. (2023). Investigation of compressive strength and thermal properties of corn cob ash cement concrete. Materials Today: Proceedings, 86, 128–133. https://doi.org/10.1016/j.matpr.2023.04.520
19. Umer, U., Khan, M.Z.N., & Khan, H.A. (2023). Mechanical properties and life cycle assessment of sugarcane bagasse and corn cob ashes-based geopolymer concrete. Structural Concrete, 24(6), 7214–7227. https://doi.org/10.1002/suco.202300119
20. Sybis, M., Stanińska-Pięta, J., & Paluch, E. (2025). Microbiome analysis of novel cement composites admixed with biopolymer and silver nanoparticles. International Biodeterioration & Biodegradation, 196, 106014. https://doi.org/10.1016/j.ibiod.2025.106014
21. Eker, F., Duman, H., Akdaşcı, E., Witkowska, A.M., Bechelany, M., & Karav, S. (2024). Silver nanoparticles in therapeutics and beyond: A review of mechanism insights and applications. Nanomaterials, 14(20), 1618. https://doi.org/10.3390/nano14201618
22. Chen, B., & Xu, J. (2025). Synergistic effects of nano-silver and nano-silica on strength, electrical conductivity and corrosion resistance of Portland cement paste. Construction and Building Materials, 467, 140293. https://doi.org/10.1016/j.conbuildmat.2025.140293
23. Sybis, M., Stanińska-Pięta, J., & Paluch, E. (2025). Microbiome analysis of novel cement composites admixed with biopolymer and silver nanoparticles. International Biodeterioration & Biodegradation, 196, 106014. https://doi.org/10.1016/j.ibiod.2025.106014
24. Abdulhameed, M.A., & Salim, M. (2023). Ultrasound assisted synthesis of polymer nanocomposites: A review. Journal of Polymer Research, 30, 412. https://doi.org/10.1007/s10965-023-03786-4
25. Taurozzi, J.S., Hackley, V.A., & Wiesner, M.R. (2011). Ultrasonic dispersion of nanoparticles for environmental, health and safety assessment—issues and recommendations. Nanotoxicology, 5(4), 711–729. https://doi.org/10.3109/17435390.2010.528846
26. Romero-Fierro, D., Bustamante-Torres, M., Hidalgo-Bonilla, S., & Bucio, E. (2023). Comparison of nanocomposites groups performance in cements: A review. Journal of Composites Science, 8(12), 503. https://doi.org/10.3390/jcs8120503
27. Lavagna, L., Musso, S., Ferro, G., & Pavese, M. (2023). An elucidative review of the nanomaterial effect on the durability and calcium-silicate-hydrate (C-S-H) gel development of concrete. Gels, 9(8), 613. https://doi.org/10.3390/gels9080613
28. ASTM C109/C109M-16a Standard Test Method for Compressive Strength of Hydraulic Cement Mortar (Using 2-in. or [50-mm] Cube Specimens).
29. ASTM C618 Standard Specification for Coal Fly Ash and Calcined Natural Pozzolan for Use in Concrete.
30. ASTM C642-21 Standard Test Method for Density,Absorption, and Voids in Hardned Concrete.
31. ASTM C191-21 Standard Methods for Time of Setting of Hydraulic Cement by Vicat Needle.