

Research Article

Enhancing the Mechanical and Moisture Resistance Properties of Plaster of Paris Using Nano-Silica, Glass Fibres, and Polyvinyl Alcohol

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Article Info	Abstract
Article History	Plaster of Paris (POP) is widely utilised in construction and artistic applications, yet its limited mechanical strength and sensitivity to moisture remain significant technical challenges. This study investigates the effects of incorporating nanosilica, glass fibres, and polyvinyl alcohol (PVA) on the performance of POP-based composites. Various formulations were evaluated for compressive, flexural, and hardness strengths, as well as water absorption. The experimental protocol distinguished between two immersion conditions: a 2 h immersion period was employed specifically for water absorption testing, while mechanical properties (compressive, flexural, and hardness) were evaluated under wet conditions following a 6 h immersion period. Results demonstrate that integrating nano-silica, glass fibres, and PVA increases mechanical resistance and reduces water uptake. Microscopic analysis indicates that nano-silica particles densify the POP matrix through a microfiller effect. These findings suggest that the modified POP composites exhibit improved performance for short-term moisture exposure, although further research is required to assess long-term durability in aqueous environments.
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1. Introduction

The inherent features of Paris plaster, which is commonly used in construction, significantly affect its utilisation. When plaster of Paris is exposed to water, it deteriorates rapidly, affecting its physical and mechanical strength. When calcium sulfate hemihydrate contacts water, it transforms into the dihydrate form, which deteriorates the crystalline structure and, hence, the strength when compressed. Deterioration can occur through several mechanisms, including swelling, dissolution, fungal processes (specifically in fibrous plaster), and the formation of microcracks, which occur when the material gets wet and dries. The deterioration mechanisms significantly reduce the material's flexural strength; hence, there is a need for effective protective strategies, especially for the conservation of historical materials [1-3]. When exposed to these problems for an extended period, the material's tensile strength decreases, and the rate of failure

increases, resembling patterns observed in plastics and other legacy materials [4]. Comparing fresh plaster to aged plaster reveals that, while fresh plaster of Paris performs well owing to its low porosity and high strength, aged plaster becomes brittle and less effective at managing indoor humidity. This is because aged plaster loses its ability to absorb moisture. Although additives such as biomass can enhance moisture buffering, they remain less effective than clay-based options [5, 6]. Moisture can cause degradation, as reported for heritage structures and other applications of plaster of Paris, resulting in aesthetic and structural damage [7]. Even today, POP remains highly sensitive to moisture, despite its use in construction, conservation, and other medical purposes.

New additives are required to prevent the breakdown of POPs [8, 9]. This is despite plaster being widely used in the building industry. To fill this void, this study investigates the effectiveness of integrating nano-silica, polyvinyl alcohol (PVA), and fibreglass as modifying agents in plaster to significantly reduce water absorption and strengthen the material's mechanical properties [10].

This study aimed to provide a comparative analysis of selected additives and their use in the construction of plaster-of-Paris formulations [11, 12]. Experimental research was conducted to evaluate the effect of each additive on the mechanical strength and water uptake. Beyond academic input, this research addresses practical problems in enhancing the stability of building materials in a moisture-prone environment, as presented in recent studies on gypsum-based composites and sustainable building materials [13, 14]. Therefore, current study was conducted to compare the efficacy of nano-silica, glass fibres, and polyvinyl alcohol in improving the strength and temporary water resistance of Plaster of Paris in both dry and wet environments, thereby helping to create more durable and economical construction materials [15].

2. Literature Review

Previous studies have shown that the addition of nano-silica, glass fibres, and polyvinyl alcohol can enhance the mechanical properties and moisture resistance of gypsum-based composites through matrix densification, crack bridging, and polymer film formation [9, 10, 16, 17]. However, a definitive comparative assessment of these additives under brief water exposure conditions is still lacking.

Research on gypsum and plaster-of-Paris composites has shown that nano-silica can refine pore structure and densify the matrix, improving compressive strength and reducing water uptake through a microfiller/nucleation effect [18, 19]. Fibre reinforcement (including short glass fibres) is widely reported

to improve flexural performance by bridging cracks and delaying brittle fracture, although fibre–matrix interfacial degradation may occur under wet conditions [20]. Polymer modifiers such as PVA can form films within the matrix and partially block capillary pores, providing moderate improvements in moisture resistance and strength retention. Despite these reported benefits, many prior studies have investigated these additives individually under different curing regimes or with different immersion durations and testing protocols, making direct comparison difficult. Therefore, a controlled comparative evaluation using a consistent water-to-gypsum ratio, defined additive dosages, and a clear wet-testing protocol is needed to clarify the relative effectiveness of nano-silica, glass fibres, and PVA under short-term moisture exposure.

Accordingly, the present study applies a consistent test framework to compare nano-silica, glass fibres, and PVA in POP composites under dry conditions and after short-term water immersion.

3. Methodology

This study aims to determine the effects of glass fibres (GF), PVA, and nano-silica (NS) on the mechanical and physical properties of plaster of Paris (POP). Nine different mixtures, each with various additives and their contents, and one reference mixture were prepared and tested under both dry and wet conditions after curing in the laboratory. Various tests were conducted on the specimens, including water absorption, compressive and flexural strength, surface hardness, and SEM tests. Further information on the materials used, mixing ratio, specimen preparation, and curing process is provided in the following sections.

3.1. Materials

Throughout this research, several different materials were utilised to evaluate their impact on the water absorption of Plaster of Paris (POP).

A. Plaster of Paris (also known as POP)

A gypsum production factory in Iraq was used as the source of POP in this study. It is classified as "Al-Borq" in the commercial sector and has a local provenance. Obtaining it in powder form allows it to be used without any additional chemical treatment.

B. Nano-silica, also known as SiO₂ nanoparticles

High-purity nanosilica powder with a specific surface area of approximately 200 m²/g and an average particle size of 20–30 nm was acquired from Sigma-Aldrich (Germany). Nano-silica was used to enhance the microstructure and reduce the capillary porosity of the gypsum matrix.

C. Glass Fibres

Short, chopped glass fibres with an average length of 6 mm and a nominal diameter of approximately 13 μm were used as the reinforcing material for the plaster. This helped bridge the cracks while maintaining workability.

D. Polyvinyl Alcohol (also known as PVA)

Polyvinyl alcohol with a molecular weight of 89,000-98,000 and a degree of hydrolysis of 99% was obtained from Merck (Germany). To enhance bonding and reduce water infiltration, the polymers were dissolved in distilled water and added to the mixture.

E. Water

Potable tap water was used at room temperature for each mixing step. In addition to acting as a solvent for the PVA solution, it also served as a medium for POP hydration. A constant water-to-gypsum ratio of 0.5 was used for all mixes to isolate the impact of the additives and guarantee complete comparability across the mixtures.

All materials were stored in hermetically sealed containers at room temperature. They were used under the same conditions in which they were received.

3.2. Mix Proportions and Sample Codes

Before incorporating water, the dry ingredients in each mixture were mixed to ensure uniform distribution. To commence mixing, measured quantities of Plaster of Paris, along with a measured amount of either nano-silica, glass fibres, or polyvinyl alcohol powder, were measured in accordance with the mix proportions indicated in Table 1. To obtain a homogeneous mixture without any tendency to form lumps, the dry ingredients were mixed for approximately two to three minutes in a fresh, clean, dry vessel using a spatula/trowel. To ensure additional care was taken when mixing samples with fibrous reinforcements, the glass fibres were gradually dispersed during the initial mixing of the dry ingredients to achieve an even distribution of fibres in a homogeneous mixture. After dry mixing, the water was metered out gradually as mixing continued, creating a consistent paste. The mixing process was continued for an additional 2 minutes to achieve a consistent, workable combination. The levels of the additives were chosen based on relevant research and early tests, which showed that higher amounts reduced workability and matrix integrity. Nano-silica (0.5–1.5 wt%), glass fibres (1–3 wt%), and PVA (1–3 wt%) were selected as useful ranges for

comparison. To separate the impact of the additives on the mechanical performance and water resistance, a constant water-to-gypsum ratio of 0.5 was employed for all mixtures. Table 1 lists the additive contents as weight percentages relative to the dry mass of plaster of Paris.

Table 1. Mixed proportions of POP composites (additives expressed as wt.% of dry POP)

Mixed Code	POP (kg)	Water (kg)	Nano-Silica wt% of POP	Glass Fibre wt% of POP	PVA wt% of POP
RP	1	0.5	0	0	0
PSa	1	0.5	0.5	0	0
PSb	1	0.5	1.0	0	0
PSc	1	0.5	1.5	0	0
PG1	1	0.5	0	1	0
PG2	1	0.5	0	2	0
PG3	1	0.5	0	3	0
PP1	1	0.5	0	0	1
PP2	1	0.5	0	0	2
PP3	1	0.5	0	0	3

3.3. Test Methods

To evaluate the performance of the modified Paris plaster composites, a series of physical and mechanical tests was conducted in accordance with the Iraqi Standard Specification for Gypsum-Based Materials (IQS No. 1105/2018) [21]. A set of mechanical tests was performed 3 times ($n=3$), with the results reported as averages and standard deviations. This ensured that all the results were reproducible. The tests were performed as follows:

3.3.1. Absorption of Water

IQS No. 1105/2018 was used to determine the water absorption of the hardened gypsum samples. To determine the dry mass (M_d) of the samples, they were heated to 50 °C in an oven until the mass reached a constant value, that is, the difference in mass was less than 0.1%. After determining the dry mass of the samples, they were submerged in water at room temperature for 2 h. After immersing the samples in water for the required time, they were removed from the water container, and the surface water on the samples was gently wiped using a moist cloth. Subsequently, the saturated mass (M_s) was determined using the following formula to calculate the percentage of water absorbed by the samples:

$$\text{Water absorption (\%)} = (M_s - M_d) / M_d \times 100$$

3.3.2. Compressive Strength

Following the standard test procedure in Iraq, compressive strength tests were performed on cubic samples measuring 50 mm × 50 mm × 50 mm. The test was performed using a universal testing machine, and all specimens were subjected to uniaxial compressive loading at a constant rate of 1mm/min. The tests were performed under two different conditions.

- Dry condition: when samples are air-dried.
- Wet condition (samples that have been submerged in water for around six hours before being analysed)

Three samples per condition were used to assess reproducibility.

3.3.3. Flexural Strength

To determine the flexural strength, prismatic samples with dimensions of 160 mm × 40 mm × 40 mm were used and subjected to a three-point bending test at a constant rate of [1mm/min]. The flexural test was performed under both dry and wet conditions, similar to the compressive strength test. Three replicates were used for each experiment.

3.3.4. Hardness of Gypsum

The surface hardness of the gypsum specimens was determined in accordance with Iraqi Standard Specification IQS No. 1105/2018. The notch diameter formed on the surface when a steel ball dropped from a height of 1.82 m was estimated. The ball had a diameter of 12.7 mm and weighed 8.33 g. The device's tube is 1.72 m in length and 16 mm in diameter. The distance between the end of the tube and the surface of the specimen is 10 cm. The hardness is expressed as the average notch diameter. The test was carried out on air-dried and water-submerged samples for 6 hours at room temperature. Each condition was evaluated based on the average value of three specimens, as previously reported.

To clarify, the setting time was not variable in this study, as the POP specimens were tested after complete hardening, not during the initial setting. Owing to the behaviour of gypsum when it has not solidified, mechanical testing is applied to gypsum only after it has solidified. Therefore, the specimens were cast and left to dry in the laboratory for seven days before the dry-state mechanical tests.

Under wet conditions, the tests were performed during the same 7-day curing period. The samples were immersed in water for 6 h before testing. The immersion duration was intended to be brief and rapid, to detect early moisture-related damage to the item. Long-term immersion consequences were identified

as a limitation and are recommended for use in future studies.

3.3.5. Scanning Electron Microscope

The microstructural morphology of the specimens was examined using a Scanning Electron Microscope (SEM), Model VEGA3, manufactured by TESCAN (Czech Republic). The imaging conditions were as follows: accelerating voltage of 30.00 kV, magnification of 120,000 $\times$ and working distance of 7.0 mm. Electron detection was performed using an Everhart-Thornley Detector (ETD) in a chamber at 1.10×10^{-3} Pa. The specimens were then oven-dried to remove any residual moisture. Small fragments were removed from the inside of the specimens and crushed to expose fresh surfaces. A thin layer of gold was applied to the fragments to prevent charging.

4. Results and Discussions

This study investigated the impact of three different additives, nano-silica (NS), glass fibre (GF), and polyvinyl alcohol (PVA), on the physical and mechanical properties of composites made from plaster of Paris (POP). The results were obtained for samples that were either dry or submerged in water.

4.1. Water Absorption and Dry-State Properties

Table 2 lists the physical and mechanical properties of the mixtures studied. The results indicate that glass fibres (GF), polyvinyl alcohol (PVA), and nano-silica (NS) can be used to improve the performance of Plaster of Paris (POP) composites. The water absorption results showed that the incorporation of nanosilica significantly decreased water absorption, from 11.58% to 8.76%, representing an approximate 24% decrease in the PSc mixture compared to the reference mixture (RP). This has been explained in earlier studies on gypsum and mineral-based matrices [3, 22, 23], which ascribe the effect mainly to the micro-filler effect and the high specific surface area of nano-silica, which leads to pore refinement, better particle packing, and the minimisation of capillary voids, thus reducing water ingress.

The mechanical characterisation of the dry specimens of all modified mixtures exhibited a certain enhancement in their compressive and flexural abilities. The PSc mixture was superior to the reference mix, achieving the highest compressive strength of 8.26 MPa. This increase, as in previous experiments on nano-modified gypsum systems [3, 9, 23], occurred because the nano-silica particles (micro-fillers and nucleation sites) physically densified the gypsum matrix, resulting in a more compact and homogeneous microstructure, enhanced interparticle bonding, and no chemical reaction.

The reinforcing property of fibre-reinforced composites, as is well known in fibre-reinforced gypsum and cementitious composites [24, 25], is largely related to the ability of the fibres to act as a crack-bridging material, thereby increasing stress redistribution and preventing crack propagation in brittle matrices.

The findings indicate that fibre-based composites are highly effective at increasing flexural strength, with the PG2 mixture recording the highest value of 2.51 MPa. This enhancement is attributed to the fibres' ability to improve post-cracking behaviour and seal microcracks, as expected from the widely recognised reinforcement effect of short fibres in brittle matrices [24, 25].

The surface hardness results confirmed these observations. The indentation diameter of the PSc mixture was significantly lower (1.7 mm compared to 2.4 mm of the reference mixture), indicating a higher resistance to localised deformation. As observed in related gypsum and mineral binder structures [3, 26], this enhancement is attributed to the densification and optimisation of the surface microstructure induced by the presence of nano-silica particles. The GF- and PVA-blended mixtures exhibited intermediate properties.

The solution to the problem of PVA-modified mixtures lies in the fact that polyvinyl alcohol can create films in the gypsum matrix. The polymer enhances particle bonding, partially seals pores, and limits the initiation and propagation of microcracks during mechanical loading by forming a thin, continuous or semi-continuous film around gypsum crystals and across microvoids. This physical process has been reported for cementitious composites and polymer-modified gypsum [27, 28].

Table 2. The results of all tests in this study on dry samples (mean $\pm$ SD, $n = 3$)

Mixed Code	Water Absorption %	Compressive strength MPa	Flexural strength MPa	Hardness (indentation diameter) mm
RP	11.58 $\pm$ 0.38	7.08 $\pm$ 0.09	1.83 $\pm$ 0.06	2.40 $\pm$ 0.10
PSa	9.62 $\pm$ 0.28	7.82 $\pm$ 0.08	2.04 $\pm$ 0.09	2.00 $\pm$ 0.05
PSb	8.81 $\pm$ 0.24	8.09 $\pm$ 0.11	2.21 $\pm$ 0.05	1.90 $\pm$ 0.05
PSc	8.76 $\pm$ 0.22	8.26 $\pm$ 0.08	2.28 $\pm$ 0.08	1.70 $\pm$ 0.05
PG1	10.27 $\pm$ 0.32	7.27 $\pm$ 0.16	2.38 $\pm$ 0.09	2.60 $\pm$ 0.10
PG2	9.80 $\pm$ 0.26	7.36 $\pm$ 0.15	2.51 $\pm$ 0.11	2.40 $\pm$ 0.05
PG3	10.39 $\pm$ 0.36	7.31 $\pm$ 0.10	2.48 $\pm$ 0.07	2.50 $\pm$ 0.10
PP1	9.41 $\pm$ 0.18	7.58 $\pm$ 0.12	2.16 $\pm$ 0.08	2.30 $\pm$ 0.05
PP2	9.05 $\pm$ 0.15	7.91 $\pm$ 0.09	2.32 $\pm$ 0.04	2.20 $\pm$ 0.05
PP3	9.38 $\pm$ 0.22	7.50 $\pm$ 0.14	2.25 $\pm$ 0.10	2.40 $\pm$ 0.05

4.2. Effect of Water Immersion on Mechanical Properties

To develop short-term, intensive exposure to moisture, the mechanical properties discussed in this section were measured on samples immersed in water for 6 hours before testing. Since Plaster of Paris (POP) is known to decay easily in water, this immersion time was used to assess any damage caused by moisture in the initial stages. The importance of a longer immersion time is to determine long-term durability, which cannot be observed in this study and may be proposed for future studies.

The high moisture sensitivity of the POP-based materials is confirmed in Table 3, which shows that all mixtures exhibited a significant decline in mechanical properties after immersion in water. However, the type of additive played a significant role in the extent of degradation. Gypsum has a very high solubility in water and is not microstructurally stable, which is why the reference mixture (RP) exhibited a drastic loss of compressive and flexural strength of 31.07% and 38.25%, respectively [1, 2].

The most dominant factor in this degradation was gypsum matrix rehydration. With relatively high porosity, calcium sulfate hemihydrate may partially revert to the dihydrate form in the presence of water, leading to internal volumetric variations, microcracking, and a reduction in interparticle strength [1, 7]. These microstructural changes (which are usually irreversible) can be attributed to limited strength recovery after drying. In addition, because tensile microbonds are more susceptible to moisture penetration and swelling-induced stresses, the flexural strength is more adversely affected than the compressive strength.

The compressive and flexural strengths of the nano-silica-modified mixtures (particularly PSc) decreased by only 18.04% and 19.29%, respectively, indicating that they were much more resistant to moisture degradation. This improved performance is due to the refinement of the pore structure, densification of the matrix, and reduction in capillary connectivity, caused by the nanosilica particles, which restrict water infiltration and delay microstructural disintegration [3, 23, 29]. The results of surface hardness indicate better surface integrity under wet conditions, as the indentation diameter increases for PSc is only 10.52% compared to 22.58% for the reference mixture [30]. With a 20.85% reduction in compressive strength, the PVA-modified mixtures, specifically PP2, also exhibited moderate moisture degradation resistance. This effect can be ascribed to PVA's ability to form films and networks, which slows water penetration and reduces interfacial damage by partially closing capillary pores and forming a protective layer around gypsum crystals [22, 27, 28]. This polymer varnish inhibits surface failure during short microstructural exposure to water, even though PVA is not entirely hydrophobic.

The glass-fibre-reinforced mixtures, however, did not significantly enhance strength under wet conditions and lost approximately 25-27% of their strength. The main reason for this behaviour is interfacial debonding between the fibres and the gypsum matrix under wet conditions, which accelerates microstructural degradation and allows water to permeate along the fibre-matrix interface, as observed in similar gypsum-based composites [24, 25].

The flexural strength outcomes exhibited the same overall trend, with the largest loss (38.25%) in the RP mixture and smaller losses (up to 19.29%) in mixtures modified with nano-silica. This demonstrates the significant role of nano-silica in preventing the development of microcracks and retaining the integrity of the matrix when subjected to moisture [23].

Overall, the evidence above shows that nano-silica is the most suitable additive in POP composites to provide improved short-term moisture resistance owing to its strong ability to increase the microstructure density and reduce the permeability. Glass fibres are also useful in increasing the mechanical performance of the wet state, but not the moist state, owing to failure at the interface. PVA provides a secondary level of protection by forming physical films on the surface and blocking pores.

Table 3. The results of mechanical properties after immersion of samples in water for 6 hours (mean $\pm$ SD, n = 3)

Mixed Code	Compressive strength MPa	Percent change (%)	Flexural strength MPa	Percent change (%)	Hardness (indentation diameter) (mm)	Percent change (%)
RP	4.88 $\pm$ 0.09	-31.07	1.13 $\pm$ 0.03	-38.25	3.10 $\pm$ 0.05	29.16
PSa	6.20 $\pm$ 0.09	-20.72	1.58 $\pm$ 0.06	-22.54	2.40 $\pm$ 0.10	20
PSb	6.61 $\pm$ 0.11	-18.30	1.77 $\pm$ 0.04	-19.90	2.20 $\pm$ 0.10	15.78
PSc	6.77 $\pm$ 0.10	-18.04	1.84 $\pm$ 0.03	-19.29	1.90 $\pm$ 0.05	11.76
PG1	5.34 $\pm$ 0.07	-26.55	1.67 $\pm$ 0.05	-29.83	3.00 $\pm$ 0.05	15.38
PG2	5.51 $\pm$ 0.05	-25.14	1.79 $\pm$ 0.06	-28.68	2.80 $\pm$ 0.10	16.66
PG3	5.34 $\pm$ 0.06	-26.95	1.73 $\pm$ 0.03	-30.24	3.00 $\pm$ 0.10	20
PP1	5.88 $\pm$ 0.08	-22.42	1.65 $\pm$ 0.06	-23.61	2.70 $\pm$ 0.05	17.39
PP2	6.26 $\pm$ 0.09	-20.85	1.80 $\pm$ 0.05	-22.41	2.50 $\pm$ 0.10	13.63
PP3	5.83 $\pm$ 0.08	-22.26	1.73 $\pm$ 0.07	-23.11	2.80 $\pm$ 0.10	16.66

4.3. Results of Scanning Electron Microscope

The SEM micrographs can be used to directly explain the observed mechanical and durability performance because they reveal the specific microstructural distinctions among the discussed mixtures. Figure 1 shows the reference POP sample in dry form, with the gypsum crystals appearing well-formed, though with evident intracrystalline pores. The reference matrix showed severe microstructural damage

after water immersion (Figure 2), including rounded and partially dissolved crystal edges, enlarged pores, and the formation of loose, discontinuous areas. This microstructural degradation is characterised by pronounced reductions in compressive and flexural strengths, and by significant surface softening of the RP mixture after exposure to water [1, 2].

The fibres are embedded in the gypsum matrix of the glass fibre-reinforced composite (Figure 3) and help bridge cracks when the material is in its dry state. However, some fibres had detectable interfacial gaps. These interfaces are favourable pathways for water penetration in wet environments, thereby enhancing microstructural degradation and stimulating interfacial debonding. This finding is consistent with previous observations on fibre-reinforced gypsum composites [24, 25] and mechanical outcomes, which showed that GF-modified mixes maintained moderate strength after immersion.

Among all the mixtures, the nano-silica-modified composite (Figure 4) exhibited the densest and most compact microstructure. Fine nanosilica particles promoted the formation of a much more uniform, densely packed network of gypsum crystals, effectively filling microvoids. The resulting reduction in pore size and connectivity explains both the reduced water absorption and the enhanced compressive, flexural, and surface hardness observed in the PSc mixture. Similar to what has been reported for nano-modified gypsum and mineral-based systems [3, 9, 23, 29], this indicates that the effect of nano-silica in this system is the densification of the microstructure and the refinement of the pores, rather than a chemical reaction.

The PVA-modified composite (Figure 5) was partially coated with a thin polymer film and attached and bound between gypsum crystals. This polymer network forms a continuous protective framework within the matrix, connecting the crystals and locally sealing pores. This microstructural feature, when compared to the reference mixture, justifies the relatively enhanced mechanical performance and the superiority of surface softening and loss of strength after immersion in water. Earlier studies on polymer-modified gypsum systems [27, 28] suggest that the mechanism of protection is mainly physical, involving the formation of films and partial pore blockage.

Overall, the SEM observations supported the mechanical and durability results. A denser, more refined microstructure, decreased permeability, and increased strength retention were observed in mixtures modified with nanosilica [3, 23, 29]. Conversely, microstructural discontinuities and interfacial weakness accelerate degradation when exposed to moisture, as shown in the reference and glass-fibre-reinforced mixtures [24, 31]. The PVA-modified system has an intermediate nature owing to the presence of a partially

protective polymer network [27, 28].

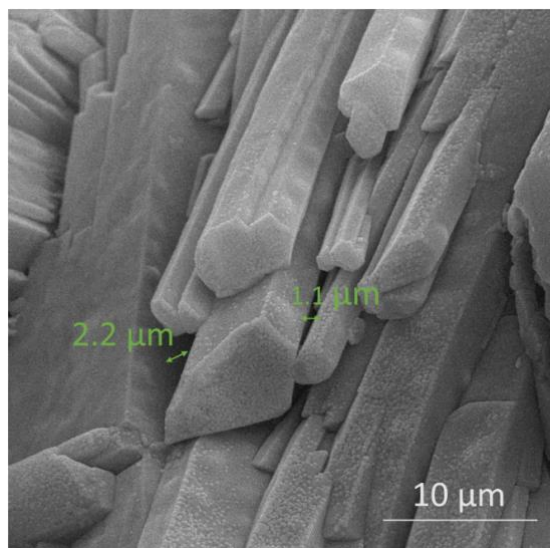


Figure 1. SEM for POP in dry conditions

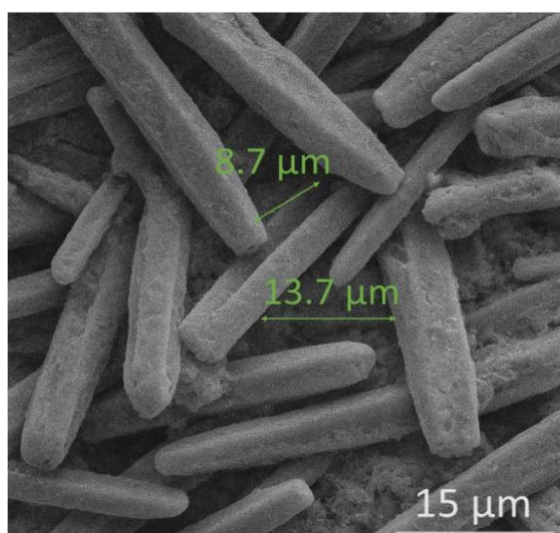


Figure 2. SEM for POP after immersion in water for 6 hours

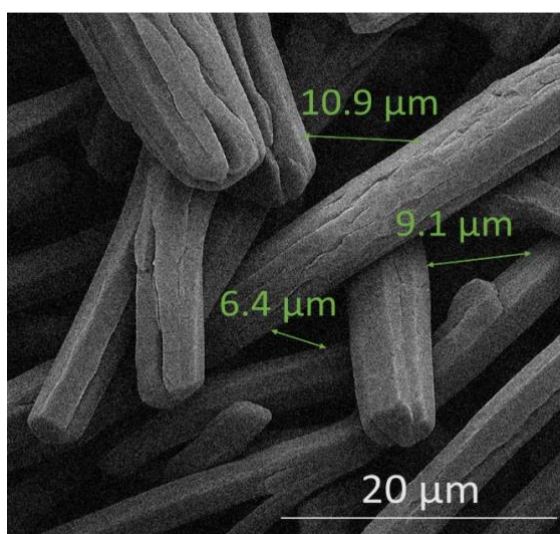


Figure 3. SEM of the POP reinforced with glass fibre after immersion in water for 6 hours

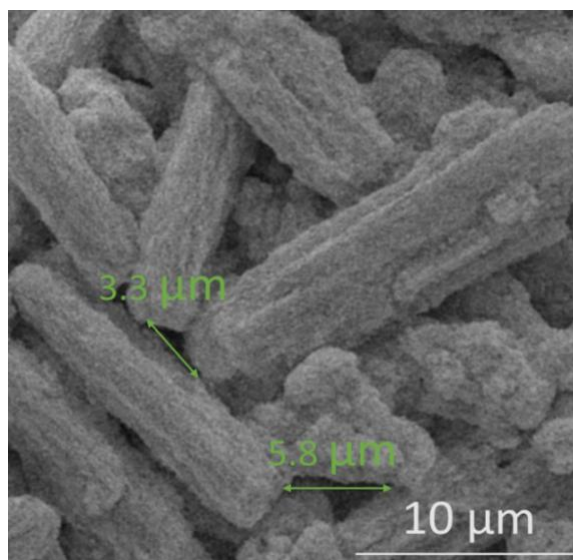


Figure 4. SEM of POP with nano-silica after immersion in water for 6 hours

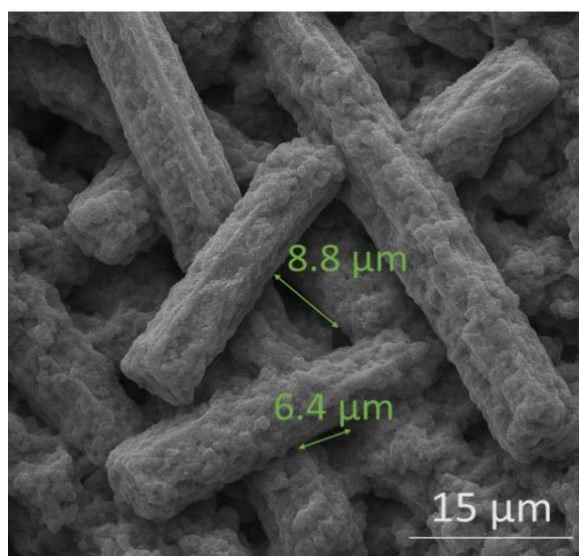


Figure 5. SEM for POP with PVA after immersion in water for 6 hours

5. Conclusions

The cost-performance analysis revealed that adding nano-silica is an effective way to enhance the performance of Plaster of Paris (POP) composite materials, particularly when the amount of the additive is small. The experiments verified that adding nano-silica, glass fibres, and polyvinyl alcohol enhances the mechanical properties and moisture resistance of the POP composite materials to varying degrees. Among the added materials, nano-silica resulted in the greatest improvement in compressive, flexural, and surface hardness of the POP composite materials, whether dry or subjected to short periods of water exposure, and also reduced water absorption. The improvement in the properties of the POP composite materials can be attributed to the ability of nano-silica to densify the materials by filling small holes, thereby enhancing their moisture resistance and strength. Although the addition of PVA also improved the properties of the POP

composite materials, the improvement was moderate compared to that with nano-silica. However, the addition of glass fibres primarily improved the flexural properties of the POP composite materials, whether dry or subjected to short-term water exposure. The experiments verified the effectiveness of adding nano-silica in enhancing the properties of the POP composite materials. However, the present study focused on the short-term exposure of the POP composite materials to water, and further research is recommended to assess their durability.

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Research Involving Human/Animal Participants: This article does not involve any studies conducted by the authors on animals or human participants.

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