# An Experimental Investigation on the Fresh and Hardened Properties of Cement-Based Plaster Containing Barium Sulfate

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*Received: 5 February 2026 | Revised: 13 March 2026 | Accepted: 23 March 2026*

 *DOI: https://doi.org/10.48084/etasr.17980*

## ABSTRACT

**Although cement-based plaster is widely used as a finishing material for building envelopes, its role is generally limited to surface protection and appearance. This study examines how barium sulfate ($BaSO_4$) affects the fresh and hardened properties of cement-based plaster when used as a partial replacement for fine aggregate. The cement content and water-to-cement ratio were kept constant while $BaSO_4$ was introduced at different replacement levels so that the observed changes could be discussed mainly in relation to the presence of the filler. Flowability, setting time, and water retention were measured in the fresh state, while density, water absorption, and compressive strength were evaluated after hardening. The results showed a gradual reduction in flowability and setting time as $BaSO_4$ content increased, whereas density and water retention increased. Water absorption decreased progressively, and compressive strength increased at both tested stages. Overall, these results suggest that $BaSO_4$ can modify cement-based plaster in a beneficial way, with an overall trend consistent with filler-related improvement in matrix compactness.**

***Keywords-cement-based plaster; barium sulfate; compressive strength; fresh properties***

## I. INTRODUCTION

Cement-based plaster is a popular finishing material for building envelopes in modern construction, due to its cost-effectiveness, compatibility with conventional substrates, and ease of application. However, it is mainly used for aesthetic and protective purposes, with limited contribution to advanced performance requirements such as improved durability, crack resistance, and moisture control [1, 2]. In response to the growing demand for durable, multifunctional finishing materials, authors in [3, 4] used mineral fillers in cementitious systems to improve their mechanical and microstructural properties. Barium sulfate ($BaSO_4$) has gained interest as a filler due to its high density, chemical stability, and small particle size [2, 5]. As an inert mineral filler, $BaSO_4$ is expected to influence primarily through physical interactions rather than chemical ones. Its addition could enhance particle packing and diminish internal voids, potentially augmenting density and compressive strength [6-11]. Concurrently, the presence of fine particles may increase interparticle friction in the fresh state, consequently reducing flowability and accelerating setting due to a faster structural buildup [12, 13]. Additionally, $BaSO_4$'s dense, low-porosity characteristics may contribute to a more compact matrix and reduced water transport. This could lead to decreased water absorption and improved water retention, both of which are relevant to plaster performance and longevity [3, 9]. Plaster materials require satisfactory hardened performance and appropriate fresh-state characteristics for surface application, particularly with respect to flowability, setting behavior, and water retention. Therefore, findings from mortar and concrete systems cannot be directly applied to cement-based plaster without investigation. The use of barium sulfate ($BaSO_4$) as a partial substitute for fine aggregate in cement-based plaster must be further examined, especially with regard to its synergistic effects on the properties of the fresh and hardened materials, along with a systematic evaluation of its impact on the density, water absorption, compressive strength, flowability, setting time, and water retention of plaster systems. This study aims to evaluate the feasibility of using barium sulfate ($BaSO_4$) as a partial replacement for fine aggregate in cement-based plaster and to examine its effects on interrelated properties under a unified experimental framework, providing experimental data specific to the application of $BaSO_4$ within a plaster matrix. This extends the existing understanding of how fillers affect performance beyond the established contexts of mortar and concrete. Consequently, the study offers practical insights into the potential application of $BaSO_4$ as an inert mineral filler in plaster compositions.

## II. MATERIALS AND METHODS

### A. *Materials*

- The primary binder used in this study was Ordinary Portland Cement (OPC), which met the ASTM C150 requirements.
- Natural river sand, sieved to a maximum particle size of 2.36 mm, was utilized as the fine aggregate for cement plaster. The grading met the standards set by ASTM C144.
- Potable tap water was used for all mixtures and curing processes.

Barium sulfate ($BaSO_4$) powder, shown in Figure 1, was employed as a mineral additive in the cement plaster. The barium sulfate, obtained from a commercial source, was found to be very pure and chemically stable. Due to its high specific gravity and low solubility, it was selected to examine its impact on the unit weight and mechanical performance of cement-based plaster. Before mixing, the barium sulfate powder was dried in an oven at 105 ± 5 °C for 24 h. This step was taken to remove any remaining moisture and ensure consistent mixing.

Fig. 1. Barium sulfate ($BaSO_4$) powder.

### B. *Mix Proportions and Specimen Preparation*

#### 1) *Mix Proportions*

As depicted in Table I, barium sulfate ($BaSO_4$) was used as an inert mineral filler. It was added to the mixture by partially replacing the natural sand, at levels ranging from 2.5% to 10% of the total weight. The cement-to-sand ratio was fixed at 1:3, and a constant water-to-cement ratio of 0.50 was used for all mixtures to isolate the effects of incorporating $BaSO_4$ on the performance of cement-based plaster.

TABLE I. MIX PROPORTIONS

| **Mix proportions (kg/m³)** | | | | |
|---|---|---|---|---|
| Mixture ID | Cement | Fine aggregate | $BaSO_4$ | Water |
| OM | 500 | 1500 | 0 | 250 |
| BS2.5 | 500 | 1462.5 | 37.5 | 250 |
| BS5.0 | 500 | 1425 | 75 | 250 |
| BS7.5 | 500 | 1387.5 | 112.5 | 250 |
| BS10 | 500 | 1350 | 150 | 250 |

#### 2) *Specimen Preparation*

The dry materials were first mixed for 2 min in a laboratory mortar mixer to ensure the uniform dispersion of $BaSO_4$, and then water was gradually added while mixing continued for an additional 3 min until a homogeneous plaster was obtained. Fresh plaster was used immediately for fresh-state tests. For hardened state tests, specimens were cast into steel molds and compacted to minimize entrapped air. The specimens were then covered with plastic sheets for 24 h, demolded, and cured in water at 27 ± 2 °C until testing.

## III. TESTING METHOD

### A. *Flowability*

The flowability of the fresh cement plaster, illustrated in Figure 2, was determined using a flow table test according to ASTM C1437. Fresh plaster was placed in a truncated cone mold on the flow table and compacted according to the standard procedure. After lifting the mold, the table was dropped a specified number of times, and the spread diameter was measured in two perpendicular directions. The flow value was calculated by averaging the percentage increase in diameter compared to the initial diameter.

Fig. 2. The flowability of cement plaster containing $BaSO_4$.

### *B. Setting Time*

The initial and final setting times were measured using a Vicat apparatus according to the ASTM C191 guidelines, as displayed in Figure 3. The setting time was recorded as the elapsed time from initial contact between the cement and water until penetration resistance reached the limits specified for the initial and final settings.

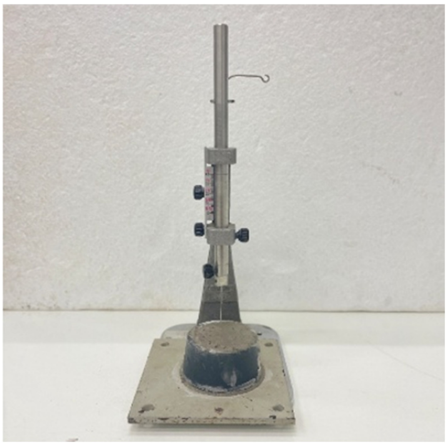

Fig. 3. Vicat apparatus for setting time test.

### *C. Water Retention*

The water retention of the fresh plaster was evaluated in accordance with ASTM C1506, as shown in Figure 4. This test involved applying a standardized suction to the plaster. The percentage of water remaining in the sample after suction was calculated. This measurement indicates the plaster's ability to resist losing water during application.

Fig. 4. Water retention test setup.

### *D. Unit Weight*

The unit weight of the fresh cement plaster was determined according to ASTM C138. The plaster was placed in a calibrated container in layers and compacted to ensure full consolidation. Then, the mass of the filled container was measured, and the unit weight was calculated by dividing the mass by the volume, showing the averages of three separate measurements.

### *E. Water Absorption*

The water absorption of hardened plaster specimens was measured according to ASTM C642. The specimens were oven-dried to a constant mass, immersed in water for a specified duration, and then weighed again. Water absorption was calculated based on the mass difference before and after immersion, and was expressed as a percentage of the dry mass.

### *F. Compressive Strength*

Compressive strength tests were conducted in accordance with ASTM C109 using 50 mm × 50 mm × 50 mm cube specimens, as depicted in Figure 5. The specimens were tested at 7- and 28-day curing ages using a universal testing machine at a constant loading rate. Compressive strength was calculated by dividing the maximum applied load by the cross-sectional area, and the average value of three specimens was reported for each mixture.

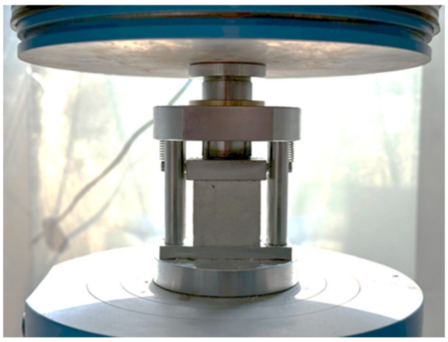

Fig. 5. Compressive strength test.

## IV. RESULTS

### *A. Water Absorption*

Figure 6 presents the water absorption results for cement plaster with various levels of barium sulfate ($BaSO_4$) replacement. The control plaster (OM) exhibited the highest water absorption, at 3.16%. In contrast, all $BaSO_4$-modified plasters showed a pronounced, monotonic reduction in water absorption as the $BaSO_4$ content increased. Water absorption decreased to 2.80%, 2.28%, 2.02%, and 1.87% for BS2.5, BS5.0, BS7.5, and BS10, respectively.

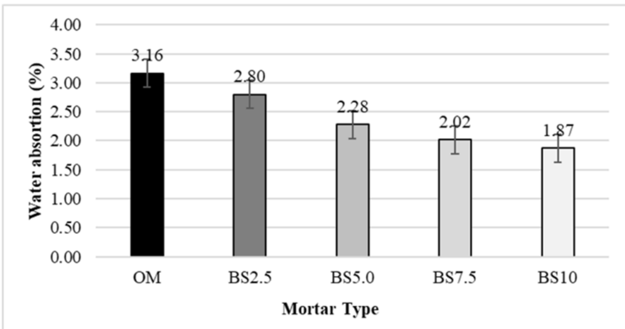


Fig. 6. Water absorption.

This reduction in water absorption is consistent with $BaSO_4$'s role as a physical filler in the plaster matrix [3, 6]. Due to its dense, inert nature, barium sulfate may contribute to a denser, more compact solid structure and reduced water transport through the hardened material, as is commonly reported for fine mineral fillers. However, since the present study did not conduct direct pore-structure or microstructural analyses, the observed decrease in water absorption is interpreted as consistent with filler-assisted densification rather than as direct evidence of pore refinement or a specific transport mechanism [3, 12].

### *B. Density*

Figure 7 demonstrates the density of cement plaster mixtures that include barium sulfate ($BaSO_4$) with various amounts of sulfate. The control plaster (OM) had the lowest density at 1,813.3 kg/m³. As the $BaSO_4$ content increased, so did the measured density, reaching 1,906.7, 1,932.0, 1,984.0, and 2,068.0 kg/m³ for BS2.5, BS5.0, BS7.5, and BS10, respectively. This trend is related to the relatively high specific gravity of barium sulfate compared with the original plaster constituents [2, 10]. Replacing some of the fine aggregate with $BaSO_4$ increased the total mass of the mixture and made the hardened plaster denser. Authors in [4, 11] reported similar trends, particularly when dense particles are introduced into cementitious matrices. In the present study, the increase in density is mainly interpreted as a consequence of material substitution and filler-related compactness rather than as evidence of a distinct chemical effect [14].

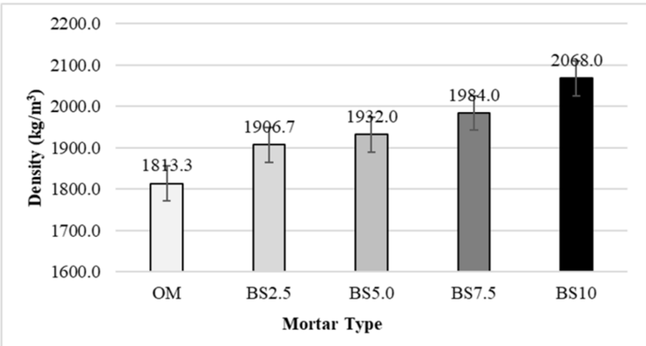


Fig. 7. Density.

### *C. Flowability*

Figure 8 shows the flow values of fresh cement plaster mixtures containing barium sulfate ($BaSO_4$). The control mixture (OM) exhibited the greatest flowability at 120.3%. As the $BaSO_4$ content increased, a steady decrease in flow was observed, with values of 105.8%, 96.8%, 78.3%, and 69.0% for BS2.5, BS5.0, BS7.5, and BS10, respectively. This reduction in flowability is likely related to the physical characteristics of barium sulfate, especially its fine particle size and relatively high density [11]. As the replacement level increased, the fresh mixture became less mobile during the flow table test. This behavior may be associated with increased particle interaction and a lower proportion of water contributing to the paste's free movement [15]. Nevertheless, all mixtures remained workable for plastering applications. Taken together with the density and water absorption results, the flow trend suggests that the addition of $BaSO_4$ primarily affects the fresh-state response through physical filler-related effects rather than through chemical interaction with cement hydration [11].

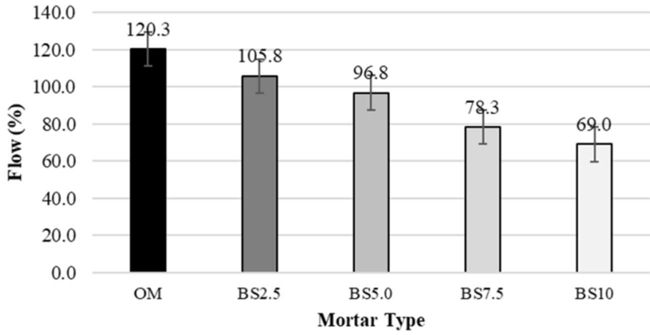


Fig. 8. Flowability.

### *D. Setting Time*

Figure 9 exhibits the initial and final setting times of cement plaster containing barium sulfate ($BaSO_4$). The control mixture (OM) had initial and final setting times of 182 min and 297 min, respectively. As the amount of barium sulfate increased, the setting times decreased steadily and consistently. This decrease appears to be mainly due to the physical effects of $BaSO_4$ rather than the direct chemical interaction with cement hydration. Due to its high density and fine particle size, barium sulfate may influence setting through filler-related effects, such as closer particle packing and faster structural development in the fresh matrix. Additionally, based on previous studies of inert fine fillers, a nucleation-related contribution may be possible. Therefore, the shortened setting times observed here are more appropriately interpreted as consistent with filler-assisted early stiffening rather than as direct evidence of enhanced nucleation.

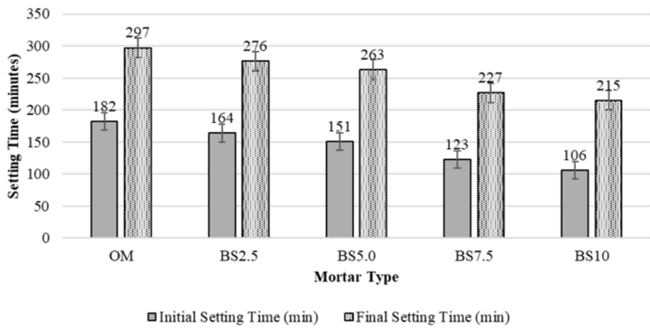


Fig. 9. Setting time.

### *E. Water Retention*

Figure 10 illustrates the water retention capacity of cement plaster mixtures containing barium sulfate ($BaSO_4$). The control mixture (OM) had the lowest water retention at 75%. In contrast, the mixtures with $BaSO_4$ showed an increase in water retention as the amount of $BaSO_4$ increased. This pattern appears to correlate with the physical filler function of $BaSO_4$ within the newly mixed matrix. The compact, fine particles of barium sulfate could facilitate a denser particle configuration and decrease initial water evaporation [3, 17-19]. Consequently, the enhanced water retention documented here is indicative of filler-mediated water retention rather than direct evidence of a particular microstructural process. Additionally, retained water may contribute to maintaining fresh-state cohesiveness and promoting early hydration; however, these specific effects were not investigated in this study [12, 20].

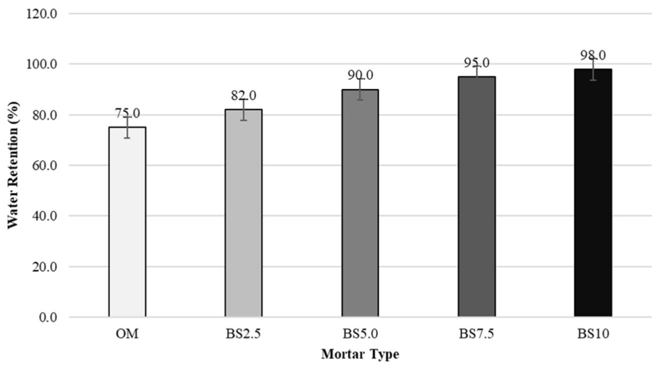


Fig. 10. Water retention.

### *F. Compressive Strength*

Figure 11 presents the change in compressive strength of cement plaster with barium sulfate ($BaSO_4$) over 7 and 28 days.

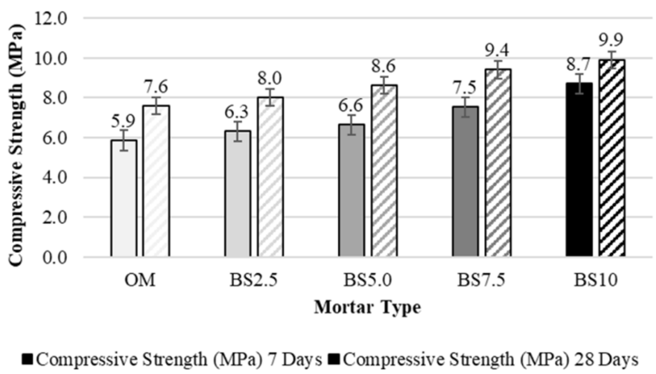


Fig. 11. Compressive strength.

The control mixture (OM) had compressive strengths of 5.9 and 7.6 MPa at 7 and 28 days, respectively. In contrast, adding $BaSO_4$ increased the compressive strength at both curing times. This increase appears to be primarily due to the physical filler effect resulting from the addition of $BaSO_4$. $BaSO_4$ is a dense, inert mineral filler that could facilitate a more compact solid matrix and reduce internal voids. This aligns with prior research on filler-modified cementitious materials [3, 11]. Consequently, this behavior may foster the formation of a denser, hardened structure, enabling it to withstand greater compressive loads. Authors in [16] indicated that fine particles may facilitate early hydration through nucleation-related effects. However, this mechanism was not examined directly in the present study and is referred to only as a possible contributing factor. The strength gain trend also corresponds well with the observed increase in density and decrease in water absorption. This suggests that the improved compressive performance is consistent with a filler-related densification effect rather than chemical reactivity [3, 21].

## V. DISCUSSION

The results show a consistent shift in fresh and hardened properties when using $BaSO_4$ to replace some of the fine aggregate in cement plaster. As the replacement level increased, the density and compressive strength of the plaster increased, while its water absorption decreased. At the same time, flowability decreased, setting occurred earlier, and water retention increased. Taken together, these results indicate that the addition of $BaSO_4$ changed the general behavior of the plaster system across both fresh and hardened stages, affecting more than one property in isolation. From a material performance standpoint, the hardened state results suggest that the plaster matrix became less permeable and stronger as the $BaSO_4$ level increased. However, the fresh-state results show that these gains were accompanied by lower mobility and shorter working time. A mixture that performs better after hardening may not be the easiest to apply on site, particularly for plastering work, where consistency, spreadability, and water retention are all important during placement. The present findings are compared with previously reported filler-based cementitious systems, as shown in Table II. The present study contributes to the literature by documenting this combined behavior in a plaster system. While the filler effects in mortar or concrete were studied, plaster applications place greater emphasis on fresh-state handling and surface application. This study provides a clearer picture of how $BaSO_4$ changes plaster performance by examining the increase in density from 1813.3 to 2068.0 kg/m³, the decrease in water absorption from 3.16% to 1.87%, and the reduction in flowability from 120.3% to 69.0%. Therefore, the findings enable understanding material behavior and selecting a replacement level that balances application requirements with hardened-state improvement.

## VI. CONCLUSIONS

This study demonstrated that barium sulfate ($BaSO_4$) can effectively replace fine aggregates in cement-based plaster and improve its hardened performance. Within the investigated replacement range, $BaSO_4$ increased density and compressive strength while reducing water absorption. This demonstrates the development of a denser, less permeable plaster matrix. These improvements are mainly attributed to filler-related densification and improved particle packing. However, changes in fresh properties indicate that practical mixture design must balance improvements in the hardened state with workability and setting requirements. The main contribution of this work is its application-specific evaluation of $BaSO_4$ in a cement-based plaster system. While previous studies have demonstrated that dense mineral fillers can enhance the compactness and strength of mortar and concrete, the evidence for plaster applications is limited. Therefore, the present study provides application-specific experimental data indicating that $BaSO_4$ can function as a promising inert mineral filler for improving plaster performance. In this respect, the observed trends are consistent with previous literature on filler effects and extend their relevance to plaster materials. The conclusions of this study should be interpreted within the scope of the experimental program.

TABLE II. COMPARISON OF $BASO_4$-MODIFIED PLASTER WITH REPRESENTATIVE FILLER-BASED CEMENTITIOUS SYSTEMS REPORTED IN PREVIOUS STUDIES

| Study | Filler / fine addition | System | Main reported trend(s) | Relevance to the present study |
|---|---|---|---|---|
| Present study | $BaSO_4$ | Cement-based plaster | Density increased from 1813.3 to 2068.0 kg/m³; water absorption decreased from 3.16% to 1.87%; flowability decreased from 120.3% to 69.0%; compressive strength increased at both 7 and 28 days. | Shows that $BaSO_4$ improves hardened performance in plaster, but with a trade-off in fresh-state workability. |
| [22] | Limestone powder | Cement-based materials / mass concrete | Limestone powder was reported to improve compactness and reduce porosity through filler-related and microstructure-modifying effects. | Supports the general filler-effect framework; the novelty of the present study lies in applying a dense inert filler specifically to a plaster system. |
| [23] | Waste marble as sand substitution | Self-compacting mortar | Waste marble substitution altered fresh flow, strength, and durability behavior of self-compacting mortar. | Relevant as a mineral fine replacement system showing that dense mineral additions can change both fresh and hardened properties. |
| [24] | Carbonate filler | Cementitious mixtures / mortar | The best performance was obtained at 25% filler substitution, with compressive strength of 40.72 MPa and water absorption around 7% at w/c = 0.42. | Confirms that dense mineral fillers can improve compactness and strength, but the present study contributes a plaster-focused dataset including workability, setting time, and water retention. |
| [25] | Fillers from construction by-products | Sustainable mortars | Mortars containing by-product fillers showed acceptable physical performance; compressive strength decreased in some mixtures, while adhesive strength improved and durability-related properties were largely maintained. | Highlights that filler systems do not always improve all properties simultaneously; this helps position $BaSO_4$ as a plaster filler with a different performance balance. |
| [26] | Granite residue filler | Mortar | Granite residue affected fresh-state applicability and technological behavior, with filler incorporation influencing mortar rheology and overall performance. | Useful comparison showing that filler systems may improve application behavior, whereas $BaSO_4$ in the present study reduced flowability while improving hardened performance. |

Microstructural, interfacial, adhesion-related, and long-term durability analyses were not performed and are necessary to clarify the governing mechanisms and practical reliability of $BaSO_4$-modified plaster. From a practical perspective, the addition of barium sulfate ($BaSO_4$) may be more suitable for applications where improved compactness, lower water absorption, and higher compressive strength are prioritized over maximum workability and minimum cost. Since a full economic analysis was not conducted, the feasibility of implementing $BaSO_4$ will depend on the price and availability of local materials and the target application. Future studies should include a cost-performance assessment, a microstructural investigation, an evaluation of adhesion behavior, and a long-term durability evaluation to determine the most suitable replacement level for practical use.

## DECLARATION OF COMPETING INTERESTS

The authors declare that they have no competing interests.


## ACKNOWLEDGMENT

The authors would like to sincerely acknowledge "Rajamangala University of Technology Phra Nakhon (RMUTP)" for its support. The facilities, technical assistance, and institutional resources provided by the university were essential to the successful completion of this research.


## .DATA AVAILABILITY

The data supporting the findings of this study are available within this paper.

## AI USE AND DECLARATION OF GENERATIVE AI USE

The authors used generative AI solely for language improvement and editorial assistance during the preparation of this manuscript. All generated output was carefully reviewed and edited by the authors, who take full responsibility for the content of the final manuscript.

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