Influence of a Multifunctional Admixture on the Workability and Mechanical Properties of Gypsum-Sand Mortar

Achraf Bouhayek[1*], *Khalid* Cherkaoui[1]

[1]Moulay Ismail University, National Graduate School of Arts and Crafts (ENSAM), Meknes, Morocco

Abstract. Gypsum-based mortars are common building materials, but their use is limited by low mechanical strength and an exceptionally rapid setting time. This study investigates the effects of a multifunctional, calcium carbonate-based powder admixture on a gypsum-sand mortar. A reference mortar was compared against a modified mortar, with fresh and hardened properties evaluated according to EN 13279-2:2014. The results show the admixture acts as a powerful plasticizer and retarder, reducing water demand for standard consistency by over 20% and extending the final setting time from 5 to 56 minutes. However, this significant improvement in workability was accompanied by a reduction in mechanical performance. At 28 days, the modified mortar exhibited a 51% decrease in flexural strength and a 17% decrease in compressive strength compared to the reference. The strength loss is attributed to the admixture's retarding action and a slight increase in air content, which likely alter the gypsum crystal matrix. The findings highlight a clear trade-off between enhanced workability and mechanical strength.

Keywords: ADMIXTURE, CALCIUM CARBONATE, GYPSUM MORTAR, MECHANICAL STRENGTH, SETTING TIME, WORKABILITY.

1 Introduction

Gypsum ($CaSO_4 \cdot 2H_2O$) has been a cornerstone of building materials for millennia, valued for its smooth finish, ease of use, and excellent fire-resistant properties, which stem from the endothermic release of its chemically bound water [1,2]. In modern construction, gypsum-based mortars are ubiquitous for interior plastering, jointing compounds, and manufacturing prefabricated elements [3]. However, the inherent characteristics of conventional gypsum mortars namely low mechanical strength, poor water resistance, and an extremely rapid setting time significantly limit their application in more demanding structural or exterior contexts [4,5].

* Corresponding author: ac.bouhayek@edu.umi.ac.ma

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The performance of these mortars is governed by their microstructure, a network of interlocking, needle-like dihydrate crystals formed during the hydration of calcium sulfate hemihydrate ($CaSO_4 \cdot 0.5H_2O$) [6]. This crystallization process is typically very fast, leading to a setting time of only a few minutes, which presents a major challenge for workability and can result in considerable material waste on-site [7]. The final strength is a function of the density and integrity of this crystalline matrix [8].

To overcome these limitations, a wide array of additives has been investigated. The inclusion of lightweight fillers like expanded perlite or vermiculite can improve thermal insulation but often at the expense of mechanical strength [9,10]. Reinforcement with various fibers (e.g., glass, polypropylene) has been shown to enhance toughness and flexural behavior [11,12] . Furthermore, chemical admixtures such as superplasticizers and retarders are employed to control hydration kinetics, extend workability, and reduce water demand [13,14]. Fine mineral powders like silica fume or fly ash can act as fillers, densifying the microstructure and improving particle packing, which in turn enhances strength and durability [15,16] .

While the use of retarders and fillers like calcium carbonate ($CaCO_3$) is known [7,17], previous research has often focused on their individual effects. The novelty of this study lies in the characterization of a multifunctional admixture based on calcium carbonate and its comprehensive impact on gypsum-sand mortar. Specifically, this work addresses a gap in the literature by explicitly quantifying the trade-off between the significant improvement in workability and the resulting decrease in mechanical strength. This paper aims to clarify how this admixture alters the balance of fresh and hardened properties, providing critical data for its practical application.

2 Materials and Methods

2.1 Materials

- Binder: Commercial "ATLASS Plaster" from a Moroccan company, primarily composed of beta-calcium sulfate hemihydrate (β $CaSO_4 \cdot 0.5H_2O$).
- Aggregate: Standardized siliceous sand compliant with EN 196-1[18].
- Admixture: A proprietary fine white powder based on calcium carbonate, formulated with chemical retarders.
- Water: Potable tap water was used for all mixtures.

2.2 Mortar Compositions and Mixing

Two primary mortar compositions were investigated: a reference mortar [GM-Ref] and a modified mortar containing the admixture [GM-CC]. The base formulation was binder-rich, with a sand-to-plaster ratio of 1/3 by weight. For the GM-CC mixture, the admixture was added at a dosage of 0.08% by weight of the plaster.

The detailed mix proportions are given in Table 1.

Table 1. Mortar Mix Proportions.

Component	Plaster (g)	Sand (g)	Water (g)	Admixture (g)
GM-Ref	1000	333	470	0
GM-CC	1000	333	470	0.8

After several preliminary trials, a manual mixing protocol was adopted. It was observed that mechanical mixing led to insufficient homogenization, with the formation of unincorporated powder deposits at the bottom of the mixing vessel. Therefore, the mixing protocol was performed manually to ensure consistency. For GM-Ref, the plaster and sand were dry-mixed for one minute. Water was then added, and the mortar was mixed for an additional two minutes. For GM-CC, the admixture was first pre-mixed with the gauging water for two minutes before being added to the dry-blended plaster and sand, followed by two minutes of mixing. The mixing was performed by hand while wearing plastic gloves to prevent any water absorption by the skin that could alter the fixed water/plaster ratio.

2.3 Specimen Preparation and Curing

The mechanical performance was assessed by preparing prismatic specimens (40×40×160 mm). Molds were filled and compacted in accordance with EN 13279-2:2014, section 4.5.2[19]. After the final set, surplus material was screeded off, and the prisms were demolded after approximately 4 hours. The demolded prisms were stored for 7 days under standard laboratory atmospheric conditions. Following this, they were dried to a constant mass in a ventilated oven at 40±2°C and subsequently cooled to room temperature within a desiccator prior to testing, adhering to the protocol in EN 13279-2:2014, section 4.5.2[19].

2.4 Testing Methods

2.4.1 Consistency

The consistency of the fresh mortars was evaluated using the flow table method as described in EN 13279-2:2014[19]. The test was conducted by varying the water/plaster (W/P) ratio for each formulation to determine the water demand required to achieve a target flow diameter of 160–170 mm after 15 strokes. This initial test served to quantify the water-reducing effect of the admixture. However, to isolate the admixture's effect on hardened properties and ensure fair comparison, a fixed W/P ratio of 0.47 was used for all subsequent tests. This specific ratio was chosen as it provided sufficient workability to properly fill the molds without segregation, even for the reference mix.

2.4.2 Air Content

The entrained air content of the fresh plaster was determined for both formulations at a W/P ratio of 0.47. Measurements were taken immediately after mixing using a manual pressure-type air meter, employing a method analogous to that described in NF EN 1015-7 (Method A)[20].

2.4.3 Setting Time

Setting time characteristics were evaluated for the reference and modified mixtures, both prepared at a W/P ratio of 0.47. An automatic Vicat apparatus (Figure 1), configured according to EN 13279-2:2014, section 4.4.2[19], was used to record the penetration depth over time and determine the initial set. The final setting time was subsequently calculated from the penetration data using the formula specified in ASTM C191[21]:

$$E+(((H-E/C-D))\ x\ (C-25)) \quad (1)$$

where:

E = time of the last penetration reading > 25 mm (min)

H = time of the first penetration reading < 25 mm (min)

C = penetration reading at time E (mm)

D = penetration reading at time H (mm)

2.4.4 Mechanical Strength

Mechanical tests were performed at 7, 14, and 28 days post-casting.

- Flexural Strength: A three-point bending test was conducted on three prismatic specimens for each mixture and age, as per EN 13279-2:2014, section 4.5.4[19]. A loading rate of 50 N/s was applied.
- Compressive Strength: Following flexural testing, the compressive strength was determined on the six resulting prism halves for each mixture and age, in accordance with EN 13279-2:2014, section 4.5.5[19]. The load was applied to the 40×40 mm side faces at a constant rate of 200 N/s.

3 Results and Discussion

3.1 Fresh Mortar Properties

The consistency test highlighted the significant water-reducing effect of the admixture. To achieve the target flow of ~165 mm, the reference mortar [GM-Ref] required a W/P ratio of 0.49 (flow = 168 mm), whereas the modified mortar [GM-CC] required a W/P ratio of only 0.39 (flow = 165 mm). This represents a water reduction of over 20%, demonstrating that the admixture acts as a powerful plasticizer, greatly improving the fluidity of the paste.

The air content for the GM-Ref and GM-CC mortars, tested at a fixed W/P ratio of 0.47, was 3.1% and 3.5%, respectively. The slight increase in air content for the modified mortar is a common side effect of some plasticizing and retarding agents and is a contributing factor to the observed reduction in mechanical strength.

The admixture's most profound impact was on the setting time. The GM-Ref mortar had a final setting time of approximately 5 minutes, typical for unmodified plaster, which severely limits its practical application time. The addition of the admixture in GM-CC extended the final setting time to 56 minutes. This dramatic, more than tenfold increase transforms the material into a highly workable mortar, providing ample time for application, tooling, and finishing. This retardation is attributed to chemical agents within the admixture that adsorb onto the hemihydrate grains, inhibiting their dissolution and slowing the nucleation and growth of dihydrate crystals [7,14].

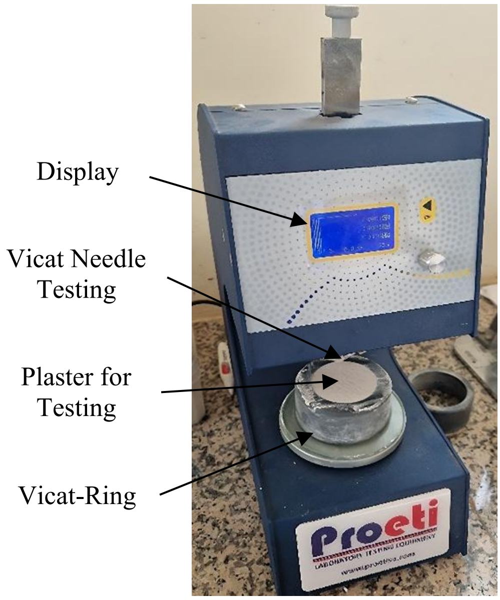

Fig. 1. Automatic Vicat apparatus used for determining the setting time of the mortar pastes.

3.2 Mechanical Strength

The development of flexural and compressive strength over 28 days is presented in Table 2 and illustrated in Figure 2.

Table 2. Mechanical Strength Development (MPa).

Age (days)	Mixture	Flexural Strength (MPa)	Compressive Strength (MPa)
7	GM-Ref	2.88	21.02
7	GM-CC	1.50	18.04
14	GM-Ref	3.02	22.05
14	GM-CC	1.51	18.50
28	GM-Ref	3.20	22.44
28	GM-CC	1.56	18.60

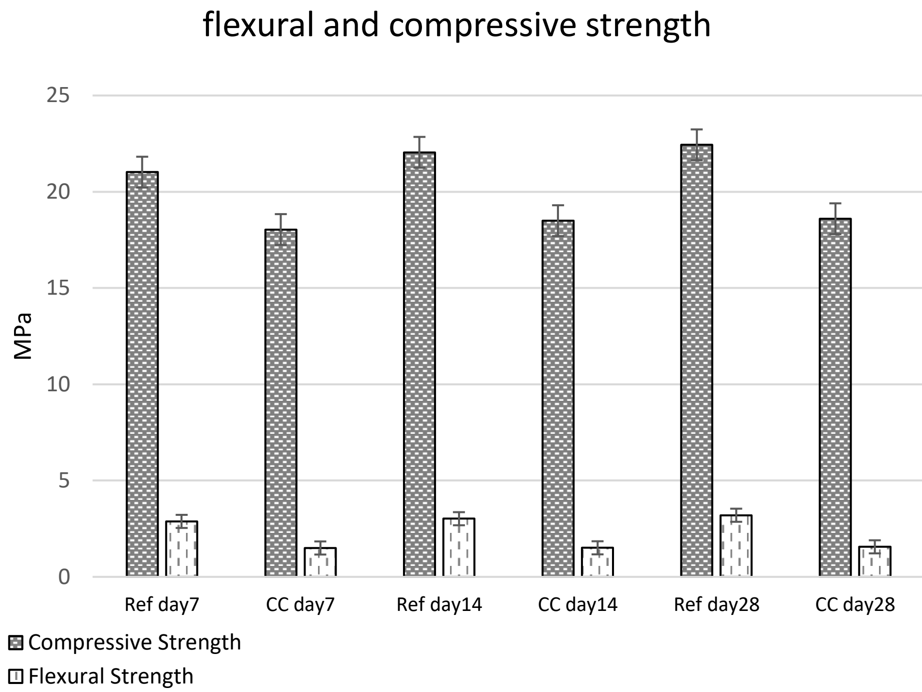

Fig. 2. Development of flexural and compressive strength for reference [GM-Ref] and modified [GM-CC] mortars over 28 days.

Contrary to what might be expected from a water-reducing admixture, the incorporation of the modifier led to a significant decrease in mechanical strength at all ages. At 28 days, the GM-CC mortar exhibited a flexural strength of 1.56 MPa and a compressive strength of 18.60 MPa. These values represent a reduction of approximately 51% in flexural strength and 17% in compressive strength compared to the GM-Ref mortar.

This reduction in strength represents a more complex phenomenon than a simple consequence of increased air content. The primary cause is likely the interference of the chemical retarders with the gypsum crystallization process. While retardation provides excellent workability, it disrupts the formation of a dense, interlocking network of dihydrate crystals, which is crucial for strength. The delayed hydration may lead to the formation of smaller, less acicular (needle-like) crystals or a less organized crystalline structure, resulting in a weaker overall matrix with lower internal cohesion [7,14]. This interpretation is strongly supported by the data: the flexural strength, which is highly sensitive to matrix flaws and micro-cracks, suffers a much greater loss (51%) than the compressive strength (17%), which is more dependent on the bulk density of the material.

4 Conclusions

This study demonstrates that the multifunctional calcium carbonate-based admixture has a profound but complex influence on the properties of gypsum-sand mortars. The admixture acts as a powerful water reducer and retarder, improving workability significantly by reducing water demand by over 20% and extending the final setting time from 5 minutes to a highly practical 56 minutes. However, this enhanced workability comes at the cost of mechanical strength. The modified mortar showed a 51% reduction in flexural strength and a 17% reduction in compressive strength at 28 days. This strength loss is primarily attributed to the chemical retarders altering the gypsum crystal matrix formation, with a secondary contribution from a slight increase in air content. The use of this admixture presents a clear engineering trade-off. For applications where ease of use and a long open time are paramount such as plastering large wall surfaces, creating decorative moldings, or repairing historical elements the gain in workability can be more valuable than achieving maximum mechanical strength. The rapid set of standard plaster often leads to significant material waste and application difficulties. This admixture mitigates those issues, and the resulting mechanical strengths, while lower, can be controlled by adjusting the admixture dosage and remain sufficient for many non-structural interior applications. The key is to select the material based on whether workability or absolute mechanical performance is the priority for a specific construction task.

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