Technobius, 2026, 6(2), 0103, DOI: https://doi.org/10.54355/tbus/27897338.6.2.2026.0103

Technobius

https://technobius.kz/

e-ISSN 2789-7338

Article

Study on the influence of polycarboxylic acid water-reducing agent on the performance of gypsum-modified mud mortar

Sawulet Bekey[1,2,*], Wumeng Liu[3], Qing Wang[1], Wenze Wang[1], Jingzheng Mi[1]

[1]College of Architecture and Engineering, Xinjiang University, Urumqi, China
[2]Xinjiang Key Laboratory of Building Structure and Earthquake, Xinjiang University, Urumqi, China
[3]NO.2 Engineering Co., Ltd. OF CCCC Third Harbor Engineering Co., Ltd., Shanghai, China
*Correspondence: jgxyswlt@xju.edu.cn

Abstract. Masonry mortar, as the primary bonding material in adobe construction, plays a crucial role in the integrity of adobe masonry due to its working properties, compressive strength, and shrinkage rate. Based on the use of industrial by-product gypsum for sustainable material modification, gypsum and polycarboxylate superplasticizer were added to address the defects of the masonry mortar and explore their impact. The effect of gypsum on the compressive strength of the mortar specimens exhibited a trend of initially decreasing, then increasing, and eventually decreasing again within a certain range. The experiment found that a 20% gypsum content led to the greatest improvement in compressive strength, reaching 3.12 MPa, which is 1.49 times that of the plain mortar specimens. However, adding gypsum alone negatively affected the mortar's consistency, water retention, and volume shrinkage. Therefore, a combination of polycarboxylate superplasticizer and gypsum was studied to evaluate the mortar's performance. The experiment showed that polycarboxylate superplasticizer effectively improved the consistency and water retention of the gypsum-modified mortar, enabling it to meet the required consistency for masonry under low water-to-soil ratios. The optimal dosage of the superplasticizer ranged from 0.5% to 1.0%, which significantly improved the consistency and water retention properties, with water retention reaching up to 99%. Polycarboxylate superplasticizer also improved the volume shrinkage of the gypsum-modified mortar. With 1% superplasticizer, the volume shrinkage rate of the mortar specimens was reduced to below 10%, almost half of the shrinkage rate of the unmodified mortar. The compressive strength of the gypsum-modified mortar also showed significant improvement with the addition of the superplasticizer. The compressive strength of the mortar increased with the amount of superplasticizer, and when 20% gypsum and 1.5% superplasticizer were mixed, the compressive strength of the mortar specimens reached 5.96 MPa, which is 2.84 times higher than that of the plain mortar specimens.

Keywords: desulphurization gypsum, polycarboxylate water reducing agent, denseness, water-retaining property, compressive strength.

1. Introduction

As early as the Neolithic period, 8000 years ago, humans began using unfired earth as a building material for the construction of dwellings. As one of the most primitive building materials, raw earth has been utilized in construction worldwide [1]. According to incomplete statistics from UNESCO, approximately two billion people globally still reside in various forms of earthen architecture, including earth-sheltered dwellings, rammed earth structures, and cave dwellings. Compared with conventional building materials, raw earth offers economic advantages such as convenient sourcing, ease of processing, and low cost. Earthen architecture is also highly harmonious and environmentally friendly with the natural surroundings; it can be reused or returned to nature after demolition, generating virtually no pollution, which is of significant importance for environmental protection and the maintenance of ecological balance.

Earthen buildings are predominantly masonry structures constructed from traditional adobe blocks and their corresponding earthen mortar. However, compared with industrial materials such as cement mortar, concrete, and fired bricks, earthen mortar exhibits issues including low strength, substantial volumetric shrinkage, and poor water retention capacity [2], [3]. In response to these existing problems, numerous studies [4] have been conducted to modify earthen mortar, yielding relatively favorable results. In 1895, while investigating the formation mechanisms of saline-alkali soils, European and American scholar Hilgard discovered through experimentation that gypsum exerted a beneficial effect on ameliorating the saline-alkali environment within the soil, thereby initially identifying the potential of natural gypsum for the improvement of sodic saline-alkali soils. Over the subsequent period spanning more than a century, countries including China, the United States, Australia, and India have conducted research on the effects of gypsum on the amelioration of saline-alkali soils, as well as on the workability and mechanical properties of masonry mortars [5], [6], [7], [8], [9], [10], [11], achieving numerous notable advancements. Research indicates that the modification of earthen materials using industrial by-products such as flue gas desulfurization (FGD) gypsum can effectively enhance their compressive strength, water resistance, and weatherability [12]. Concurrently, modification with gypsum constitutes a widely adopted approach for the improvement of earthen mortar. When employed as a modifying agent, gypsum exhibits the characteristic of rapid setting, enabling the formation of a complete skeletal framework that imparts early strength to the mortar and substantially improves the mechanical properties of mortar specimens [13]. Superplasticizers, which are commonly used as admixtures in concrete, have found widespread application, and their utilization in the modification of earthen mortar is currently being investigated by numerous researchers [14], [15]. The incorporation of superplasticizers serves both to enhance the fluidity of the mortar and to reduce the water content required during mixing, thereby mitigating drying shrinkage cracks and salt efflorescence on the surface of mortar specimens caused by moisture evaporation. Qian et al. [16] investigated the influence of polycarboxylate superplasticizer on the workability and mechanical properties of gypsum-fly ash modified earthen mortar, concluding that a superplasticizer dosage of 0.8% was sufficient to enable casting and molding of the mud mortar, and further determining that, within a certain range, the compressive strength of the modified mortar increased with increasing superplasticizer content. Existing research demonstrates that gypsum and superplasticizers can effectively ameliorate the inherent deficiencies of earthen mortar. During the course of investigation, it was observed that while modification with gypsum enhances compressive strength, it may adversely affect volumetric stability and water retention. Based on prior experience, modification using polycarboxylate superplasticizer was undertaken to examine the effects of the superplasticizer on the consistency, volumetric stability, water retention, and compressive strength of the gypsum-modified earthen mortar.

2. Methods

2.1 Experimental Materials

The loess excavated from the Xinjiang region was used as soil material. Before testing, the soil was sieved to remove larger stones, debris, and other extraneous matter. In the Urumqi soil particles, silt particles (4–63μm) constitute the largest proportion, accounting for approximately 46.24%–62.49%; clay particles (<4μm) account for 15.97%–35.02%; and sand particles (>64μm) represent the smallest proportion, ranging from approximately 8.16%–37.71%. The basic composition of the soil is presented in Table 1.

Table 1 – Content of various components in the soil used for testing, mg/kg

Na	K	Ca	Mg	HCO^-_3
1668.82	11.34	94.95	27.70	220

The FGD gypsum used in the experiment was sourced from a cement plant in Urumqi. Similar to natural gypsum, its primary constituent is calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$). It is primarily

derived from the flue gas desulfurization process and is characterized by a fine particle size, stable composition, and low levels of harmful impurities. FGD gypsum powder also contains silicon dioxide, sodium oxide, calcium carbonate, calcium sulfite, limestone, calcium chloride, and magnesium chloride [17], among other components. It is widely utilized in industries such as building materials, which not only vigorously promotes the further development of the national environmental circular economy but also substantially reduces the extraction of mineral gypsum, thereby conserving resources. It is considered an environmentally friendly material. The specific composition is detailed in Table 2.

Table 2 – Main components of FGD gypsum, %

$CaSO_4 \cdot 2H_2O$	CaO	SO_3	Al_2O_3	SiO_2	Fe_2O_3
≥93	30.42	46.38	1.59	5.46	1.11

The polycarboxylate high-performance superplasticizer (water reduction rate: 42.3%) manufactured by Jinan Shanhai Chemical Technology Co., Ltd. (Jinan, China) was selected. This product conforms to the current national standard [18]. The main component content and factory inspection technical specifications for this polycarboxylate superplasticizer are presented in Table 3.

Table 3 – Main inspection indicators of polycarboxylate superplasticizer

Item	Cl^- content, %	Moisture content, %	Water reduction rate, %	Bleeding rate ratio, %
Standard	≤0.1	≤5	≤25	≤60
Result	0.01	2.5	42.3	24.7
Evaluation	Conforming	Conforming	Conforming	Conforming

2.2 Experimental program

The experimental program consisted of several testing procedures, including the consistency test, water retention test, compressive strength test, and volumetric shrinkage rate measurement.

The consistency in this study refers to the property of mortar, indicating its ease of flow under self-weight or external force, serving as a measure of a material's resistance to permanent deformation. Based on construction experience, when the consistency value of earthen mortar is controlled within the range of 40–50 mm, the fluidity is deemed appropriate and convenient for masonry operations. The test procedures were conducted in full accordance with the [19].

The water retention test was conducted immediately following the completion of the consistency test. The water retention rate index refers to the [20], wherein a water retention rate exceeding 88% is considered qualified.

A compressive strength test was performed with reference to the cube compressive strength test specified in [19]. The dimensions of the test specimens were 70.7×70.7×70.7 mm, with three specimens constituting one group. The specimens were subjected to a curing period of 28 days. After specimen molding, they shall be kept at room temperature (20±5) °C and a relative humidity of not less than 90% for (24±2) h before demolding. After demolding, the specimens shall be immediately placed in a standard curing room for curing. The loading rate during testing shall be 0.2 to 1.5 kN per second. The arithmetic mean of the measured values from the three specimens in a group was taken as the average compressive strength for that group. If the difference between the maximum value or the minimum value among the three measurements and the median value exceeded 15% of the median value, both the maximum and minimum values were discarded, and the median value was taken as the compressive strength value for that group of specimens. The test equipment used is a YAW-3000 electro-hydraulic servo compression testing machine (Jinan Xinguang Test Machine Manufacturing Co., Ltd., Jinan, China).

For the volumetric shrinkage rate measurement, the specimens used were identical to those employed in the cube compressive strength test. Measurements of dimensions were taken at 7 days and 28 days, respectively. The degree of shrinkage of the earthen mortar was expressed in terms of the natural shrinkage rate. The volumetric shrinkage rate is calculated according to Eq. (1).

$$\varepsilon = \frac{V_0 - V_i}{V_0}, \quad (1)$$

where: ε – natural drying volumetric shrinkage rate; V_0 – initial volume after 7 days of curing, mm^3; V_i – molded volume after 28 days of curing, mm^3.

The amounts of FGD gypsum and polycarboxylate superplasticizer incorporated in the experiment were both added as a percentage of the soil mass. With the soil mass fixed as 1, gypsum was sequentially added at proportions of 10%, 15%, 20%, 25%, and 30% of the soil mass to investigate the effect of single gypsum addition on various properties of the earthen mortar. Based on the experimental results obtained from the aforementioned tests, three distinct gypsum dosage levels were selected and subsequently combined with polycarboxylate superplasticizer at dosages of 0.5%, 1.0%, and 1.5%, respectively, for further investigation of their combined effects.

3. Results and Discussion

3.1 Effect of a single addition of gypsum on the consistency and water retention of earthen mortar

The experiment was conducted according to the mixed proportions specified above; the data for the single gypsum addition are presented in Table 4 below.

Table 4 – Data of mortar consistency and water-soil ratio with single gypsum addition

Sample ID	Consistency, mm	Soil amount, kg	Water amount, kg	Water-soil ratio
SGT10	48	2	0.50	1:4
SGT15	49	2	0.60	1:3.33
SGT20	48	2	0.75	1:2.67
SGT25	47	2	0.80	1:2.5
SGT30	48	2	0.85	1:2.35

The consistency of the earthen mortar was adjusted within the range of 40 to 50 mm by controlling the water-to-soil ratio to enable the mortar to meet the requirements for masonry work, as well as to avoid a serious reduction in cohesion, bleeding, and segregation effects in fresh mortar.

The consistency values and the corresponding water-to-soil ratios for the gypsum-modified earthen mortars with varying gypsum dosages are presented in Figure 1.

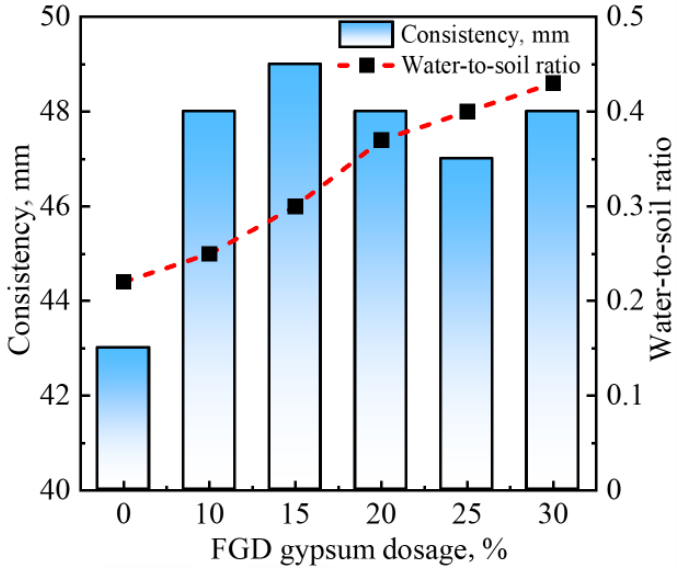


Figure 1 – Effect of a single addition of FGD gypsum on the consistency and water-to-soil ratio of earthen mortar

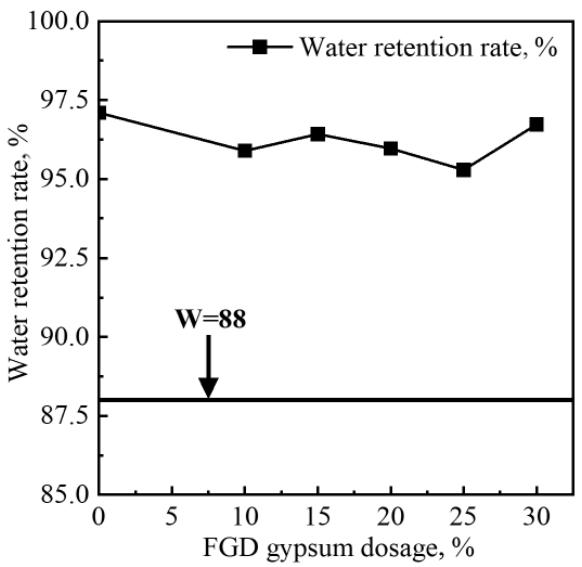


Figure 2 – Effect of a single addition of FGD gypsum on the water retention rate of earthen mortar

It can be observed from the figure that when the consistency of the mortar is controlled within the range of 40 mm to 50 mm, the water-to-soil ratio increases continuously with increasing gypsum content. That is, the addition of gypsum leads to a progressive increase in the amount of water required for mixing. Therefore, a higher water-to-soil ratio is required to maintain the target consistency range. At a gypsum dosage of 30%, the amount of mixing water required is nearly twice that required for mud mortar. The increase in water demand renders the consistency of the mortar difficult to control. Furthermore, the increased water content causes the bonding between soil particles to become looser, and as moisture evaporates, numerous internal pores are left within the set mortar. These factors are collectively detrimental to the proper workability of the earthen mortar.

The phenomenon that the addition of FGD gypsum leads to an increase in the water-to-soil ratio can be explained from three aspects. First, the primary constituent of FGD gypsum is calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), whose crystal structure contains water of crystallization. This crystalline water endows FGD gypsum with a strong affinity for moisture, enabling it to bind with water molecules through hydrogen bonding, thereby exhibiting pronounced hygroscopicity. Under environmental influences, the crystalline water may be released under high-temperature or dry conditions, and reabsorbed in humid environments. Second, FGD gypsum tends to form a porous structure during the production process, containing numerous internal micropores and capillary pores. These pores are capable of adsorbing and retaining moisture, further enhancing their water absorption capacity. In addition, FGD gypsum particles are typically fine and possess a large specific surface area. A larger specific surface area implies a greater number of active surface sites available for the adsorption of water molecules, thus resulting in stronger water absorption.

Water retention refers to the ability of a fresh mortar mixture to retain moisture and resist bleeding, reflecting, to a certain extent, the stability of the mixture. As can be observed from Figure 2, the water retention rates of all groups exceed 88%, meeting the requirements stipulated in the specifications. However, the water retention capacity of the gypsum-modified earthen mortar is slightly decreased compared to that of the unmodified mortar. Poor water retention tends to facilitate the formation of permeable channels within the mortar, leading to severe bleeding. During transportation and construction, rapid moisture loss may cause significant discrepancies in the water content between the upper and lower portions of the mortar, thereby adversely affecting the bond between the mortar and adobe blocks. Concurrently, it can induce non-uniform shrinkage, resulting in shrinkage cracking of the mortar. FGD gypsum is rich in ions that undergo ion exchange with the clay minerals present in the earthen mortar, neutralizing the negative charges on the surfaces of clay particles and disrupting their electrical double-layer structure. This process induces flocculation of the clay particles, reducing their specific surface area and water absorption capacity, and consequently diminishing the water retention of the earthen mortar.

3.2 Effect of gypsum on the volumetric shrinkage rate and compressive strength of earthen mortar

The phenomenon of volumetric shrinkage occurring during the setting process of earthen mortar, also referred to as drying shrinkage, is illustrated in Figure 3.



a) Gap appearing between the specimen and the mold

b) Micro-cracks appearing on the surface of the specimen

Figure 3 – Mud drying shrinkage

The photograph was taken on the third day after casting the specimens. A distinct gap can be observed between the mortar cast in the mold and the mold itself, and some fine cracks have also appeared on the surface of the mortar. Severe drying shrinkage of the mortar is primarily attributed to moisture loss. When traditional earthen mortar hardens in a dry environment, numerous micro-cracks tend to form on the exterior surface. In brick masonry structures, drying shrinkage of the mortar can induce stress concentration, which constitutes a significant factor affecting the overall structural integrity. Concurrently, the shrinkage of the mortar can also adversely affect the quality of the masonry work.

Figure 4 illustrates the volumetric shrinkage rate of earthen mortar modified with a single addition of gypsum and the effect of superplasticizer on the volumetric shrinkage rate of gypsum-modified earthen mortar. As shown in the figure, the volumetric shrinkage rate of the mud mortar specimen is 11.47%, which represents the normal shrinkage behavior of unmodified soil material. With the progressive increase in gypsum content, the volumetric shrinkage rate of the specimens also exhibits a continuous increase. The volumetric shrinkage rate at a gypsum dosage of 30% is 14.49%, representing an increase of 3.07% compared with that of the mud mortar specimen.

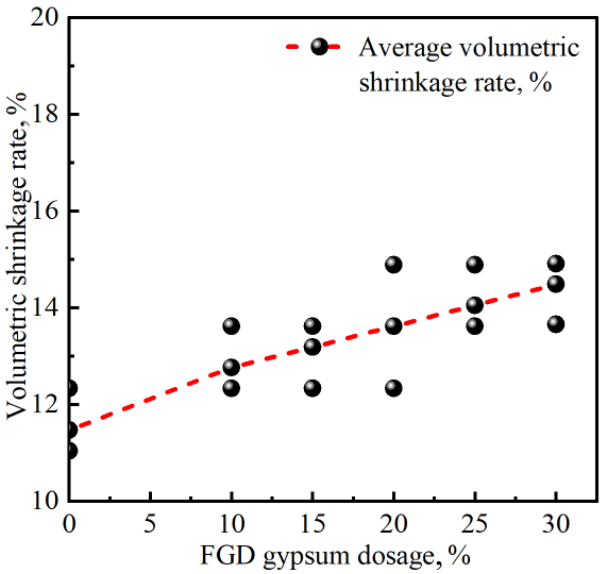
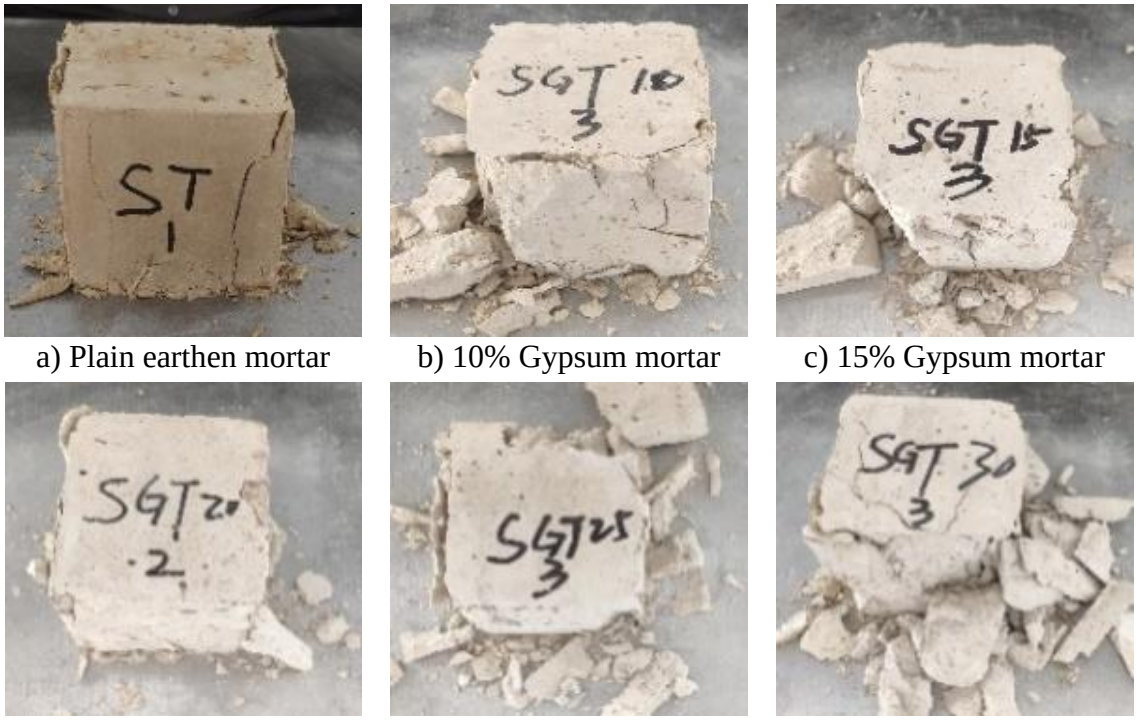


Figure 4 – Volumetric shrinkage rate of specimens with a single addition of gypsum

This observed change may be attributed to the following reasons: First, as established from the relationship between FGD gypsum dosage and the water-to-soil ratio in the preceding experiments, the incorporation of FGD gypsum significantly increases the amount of water required during mixing. During the setting and hardening process of the specimens, the evaporation of this additional moisture induces greater volumetric shrinkage. Second, the chemical composition of FGD gypsum contains two molecules of crystalline water, and the material itself possesses a porous structural characteristic. During the mixing stage, the gypsum absorbs a substantial amount of water to fill its internal pores. In the subsequent drying process, the evaporation of this moisture generates additional voids within the gypsum, providing supplementary space for the overall shrinkage of the specimen. Furthermore, the addition of gypsum may alter the internal microstructure of the earthen mortar, rendering the pathways for moisture migration more unobstructed, thereby accelerating the rate of moisture loss. The combined effect of these factors ultimately results in the gypsum-modified specimens exhibiting a more pronounced volumetric shrinkage phenomenon compared with mud mortar.

The compressive strength of masonry mortar constitutes the most critical performance indicator of the mortar and is also a significant factor influencing the shear resistance of masonry structures. The failure morphology of the mortar specimens is presented in Figure 5.



a) Plain earthen mortar b) 10% Gypsum mortar c) 15% Gypsum mortar

d) 20% Gypsum mortar e) 25% Gypsum mortar f) 30% Gypsum mortar

Figure 5 – Compressive strength test of earthen mortar specimens

From left to right, the specimens shown are a mud mortar specimen and those modified with gypsum at dosages ranging from 10% to 30%. It can be observed from the figure that after failure, the mud mortar specimen remains relatively intact as a whole. In contrast, the five gypsum-modified earthen mortar specimens with varying gypsum dosages disintegrate into numerous fragments upon failure. This phenomenon occurs because FGD gypsum, like natural gypsum, is a brittle material. When subjected to compressive stress, it is prone to brittle fracture, resulting in the fragmentation of the material and the formation of debris.

The variation in compressive strength of the specimens with respect to FGD gypsum dosage is presented in Figure 6.

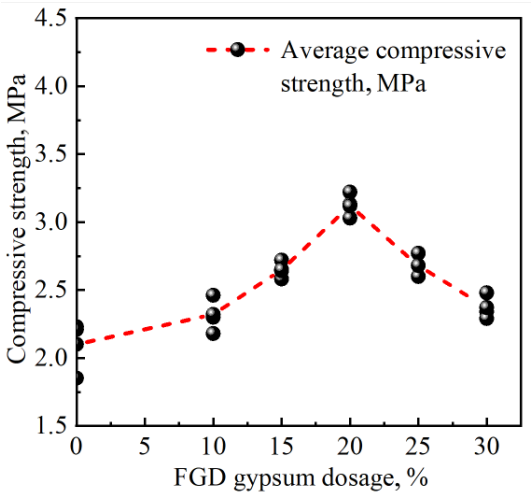


Figure 6 – Compressive strength of specimens with a single addition of gypsum

The compressive strength of the specimens exhibits an initial increasing trend followed by a subsequent decrease as the gypsum dosage increases, reaching a peak value at a gypsum dosage of 20%. The compressive strength of the specimen with a 10% gypsum dosage is 2.32 MPa, representing an increase of approximately 10.5% compared with that of the mud mortar specimen. When the

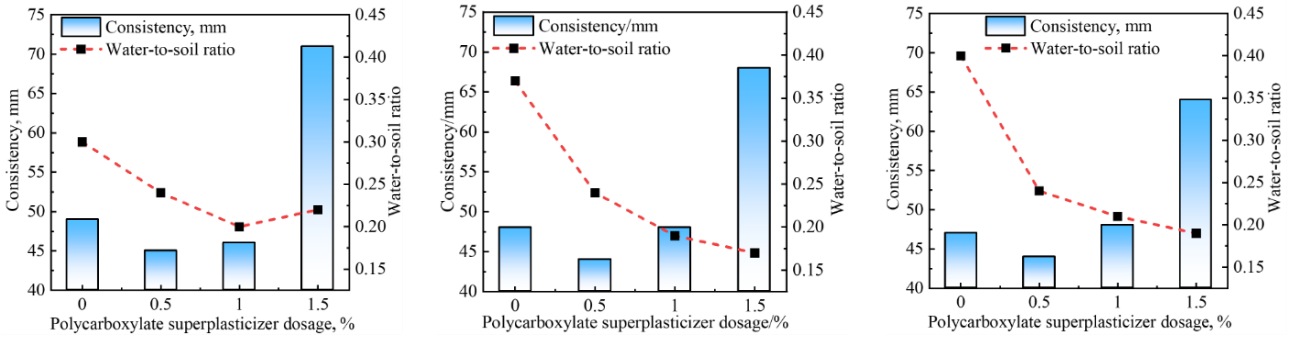
gypsum dosage is increased to 15%, the compressive strength rises to 2.65 MPa, an increase of 0.55 MPa relative to the mud mortar specimen. At a gypsum dosage of 20%, the compressive strength attains the maximum value among the five groups with varying FGD gypsum dosages, reaching 3.12 MPa, which corresponds to a 49.04% improvement compared with the mud mortar specimen. As the gypsum dosage is further increased to 25% and 30%, the compressive strength of the specimens begins to exhibit a declining trend, with values of 2.68 MPa and 2.37 MPa, respectively; nevertheless, these values remain 27.6% and 12.9% higher, respectively, than that of the mud mortar specimen.

The relatively fine particles of FGD gypsum are capable of filling the pores within the specimen. This kind of filling is expected to improve the specimen's density and overall integrity. The crystal structure of FGD gypsum is comparatively stable. When FGD gypsum is incorporated into the soil, a portion of the calcium sulfate dihydrate dissolves in water, releasing Ca^{2+} and SO_4^{2-} ions. These ions can react with other constituents present in the soil to form potential cementitious substances, such as ettringite ($3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}32H_2O$), which is a substance possessing cementitious properties. The formation of ettringite and other cementitious products establishes a rigid skeletal framework within the specimen, thereby further enhancing its compressive strength [15]. However, excessive formation of such products may induce expansive stresses within the specimen, potentially leading to the initiation of microcracks or structural deterioration, consequently resulting in a reduction in compressive strength.

3.3 Effect of polycarboxylate superplasticizer on the consistency and water retention of gypsum-modified earthen mortar

Based on the investigation of the effects of single modification materials on the consistency, water retention rate, volumetric shrinkage rate, and compressive strength of the earthen mortar, three distinct gypsum dosage levels were selected from each modification category for combined incorporation with superplasticizer in the subsequent experimental study on hybrid addition. The experimental results indicate that FGD gypsum results in water demand during mixing and water retention properties that are inferior to those of mud mortar; however, its effect on compressive strength is improved at dosages of 15% and 20%. To check if the water reducer can effectively counteract the negative effects caused by excessive gypsum. Accordingly, the gypsum dosage levels of 15%, 20%, and 25% were selected for the subsequent combined addition experiments.

The influence of polycarboxylate superplasticizer dosage on the consistency and water-to-soil ratio of the three types of gypsum-modified earthen mortar is presented in Figures 7a, 7b, and 7c.



a) 15% FGD gypsum dosage b) 20% FGD gypsum dosage c) 25% FGD gypsum dosage

Figure 7 – Effect of polycarboxylate superplasticizer on the consistency and the water-to-soil ratio of gypsum-modified earthen mortar

The incorporation of polycarboxylate superplasticizer causes the consistency of the three gypsum-modified earthen mortars to exhibit a trend of initially decreasing and subsequently increasing, while also affecting a substantial improvement in the amount of water required for mixing. At superplasticizer dosages of 0.5% and 1.0%, the consistency of all three groups of gypsum-modified mortar was effectively controlled within the range of 40 mm to 50 mm. Moreover, a superplasticizer dosage of 1.0% reduced the mixing water requirement to less than half of the original amount. At a

superplasticizer dosage of 1.5%, the consistency of the mortar increased to values exceeding 60 mm. In the experiment, once mixed to a mortar state, the material exhibited high fluidity, approaching a nearly liquid state, and the consistency could not be maintained within the appropriate range. It can thus be concluded that within a certain range, the dosage of polycarboxylate superplasticizer can reduce the mixing water requirement of the earthen mortar while satisfying workability requirements. Although further increases in superplasticizer dosage can continue to reduce water demand, they readily cause the moisture content to exceed the liquid limit of the soil, rendering the consistency unsuitable for masonry applications.

The incorporation of polycarboxylate superplasticizer also substantially improves the water retention rate of the earthen mortar modified with a single addition of FGD gypsum, as illustrated in Figure 8. Upon the addition of 0.5% superplasticizer, the water retention of the FGD gypsum-modified earthen mortar exhibits an increase, and the water retention performance of the modified mortar continues to improve with increasing superplasticizer dosage. The water retention rate of the 15% FGD gypsum-modified earthen mortar without polycarboxylate superplasticizer is 96.42%, representing a decrease of 0.68% compared with that of mud mortar. After the addition of 0.5% superplasticizer, the water retention rate increases to 98.40%, an improvement of 1.3% relative to the mortar without superplasticizer. Subsequently, as the dosage of polycarboxylate superplasticizer is further increased, the water retention rate continues to exhibit a certain degree of enhancement. Among these several groups of modified mortars, the optimal water retention performance is achieved by the combination of 20% FGD gypsum dosage and 1.5% polycarboxylate superplasticizer, exhibiting a water retention rate of 99.89%. The water retention rates of the remaining two groups, incorporating 0.5% and 1.0% superplasticizer, respectively, also reach 99%.

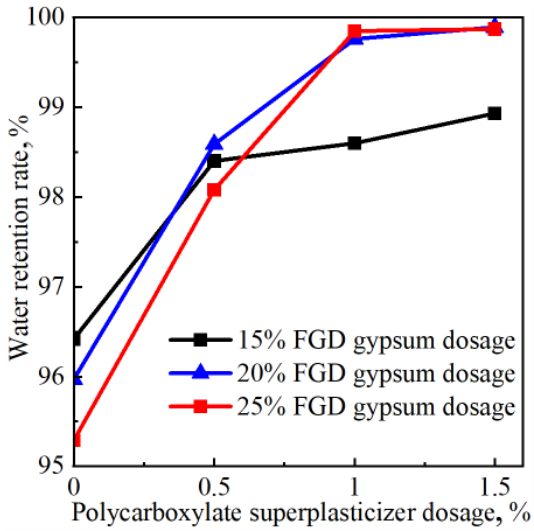


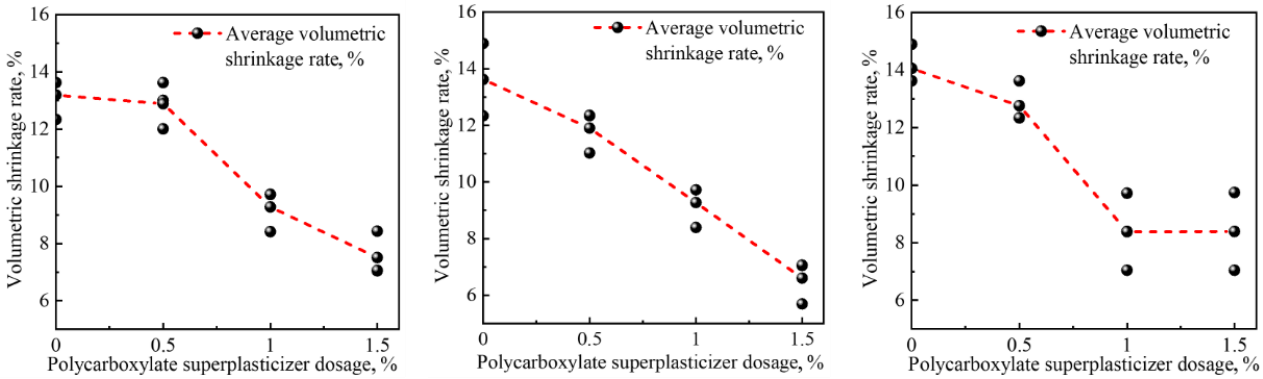
Figure 8 Effect of polycarboxylate superplasticizer on the water retention rate of gypsum-modified earthen mortar

The improvement in water retention of the earthen mortar afforded by the polycarboxylate superplasticizer can be attributed to its ability to regulate the rate of moisture release within the mortar, thereby preserving both the water content and a certain degree of consistency of the mixture [16].

3.4 Effect of polycarboxylate superplasticizer on the volumetric shrinkage rate and compressive strength of gypsum-modified earthen mortar

The volumetric shrinkage rate of the specimens exhibits a marked improvement following the addition of the polycarboxylate superplasticizer. As can be observed from Figure 9, the volumetric shrinkage rate decreases continuously with increasing dosage of the polycarboxylate superplasticizer. At a superplasticizer dosage of 1%, the volumetric shrinkage rates of the three specimens with varying

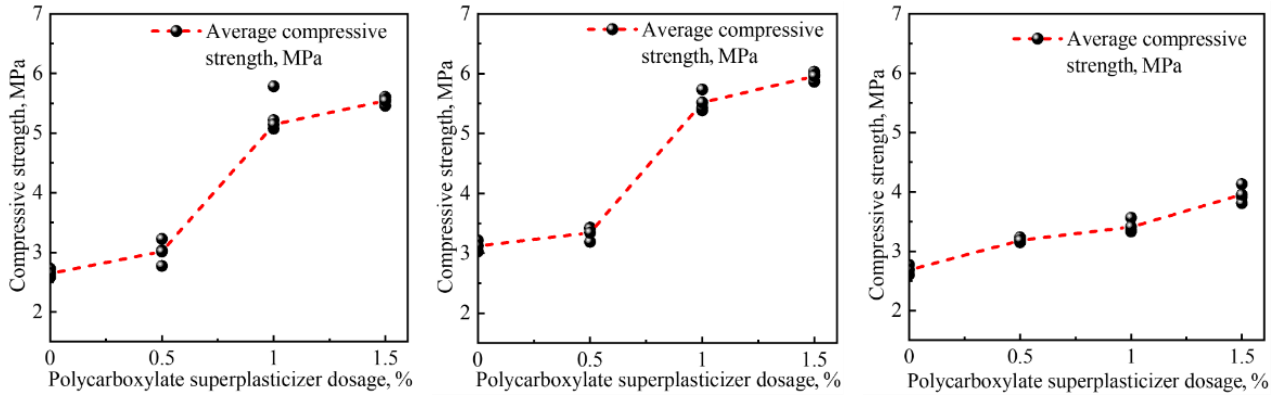
FGD gypsum contents are all reduced to within 10%. Notably, the volumetric shrinkage rate of the specimen containing 25% FGD gypsum is reduced to 8.82%, representing a decrease of 5.23% compared with the specimen without superplasticizer. At a superplasticizer dosage of 1.5%, the volumetric shrinkage rate of the specimen containing 20% FGD gypsum is merely 6.60%, a value approximately half that of the corresponding specimen without superplasticizer. The experimental results demonstrate that the polycarboxylate superplasticizer can effectively enhance the volumetric stability of the earthen mortar specimens. On one hand, it reduces the water demand, thereby lowering the internal moisture content of the mortar and diminishing the amount of water subject to evaporation, which consequently mitigates the impact of drying shrinkage on volumetric stability. On the other hand, the incorporation of the superplasticizer leads to a reduction in internal porosity and a denser microstructure, which significantly ameliorates the volumetric shrinkage rate of the specimens.



a) 15% FGD gypsum dosage b) 20% FGD gypsum dosage c) 25% FGD gypsum dosage

Figure 9 – Effect of polycarboxylate superplasticizer on the volumetric shrinkage rate of gypsum-modified earthen mortar

The incorporation of polycarboxylate superplasticizer further enhances the compressive performance of the FGD gypsum-modified earthen mortar specimens. The effect on the compressive strength of the earthen mortar specimens modified with 15%, 20%, and 25% FGD gypsum is presented in Figure 10. As shown in the figure, the compressive strength of the FGD gypsum-modified earthen mortar specimens increases continuously with increasing dosage of polycarboxylate superplasticizer. The compressive strength of the mud mortar sample is 2.10 MPa. After the incorporation of 0.5% polycarboxylate superplasticizer into the soils modified with the three different contents of FGD gypsum, the average compressive strengths are 3.01 MPa, 3.34 MPa, and 3.18 MPa, respectively, with the most pronounced improvement observed for the mortar modified with 20% FGD gypsum. When the superplasticizer dosage is increased to 1%, the compressive strengths of the earthen mortars modified with 15% and 20% FGD gypsum both exceed 5 MPa, reaching 5.14 MPa and 5.52 MPa, respectively, representing a significant enhancement in compressive strength. It is 2.45 times and 2.63 times the compressive strength of the reference mud mortar samples, and represents improvements of 94% and 77%, respectively, compared with the FGD gypsum-modified specimens without superplasticizer addition. Adding 1% water-reducing agent to the modified mud mortar with 25% desulfurized gypsum boosted its compressive strength to 3.41 MPa, which is 1.62 times that of the mud mortar, 1.27 times higher than the modified mud mortar without the water-reducing agent, and 7.23% higher compared to the sample with 0.5% water-reducing agent. At a polycarboxylate superplasticizer dosage of 1.5%, the compressive strength of the FGD gypsum-modified earthen mortar specimens continues to rise. The compressive strength of the mortar specimen modified with 20% FGD gypsum reaches 5.96 MPa, representing the highest compressive strength among all modified groups. This value is 2.84 times the compressive strength of the mud mortar and corresponds to an 8% increase relative to the modified mortar specimen incorporating 1% superplasticizer.



a) 15% FGD gypsum dosage b) 20% FGD gypsum dosage c) 25% FGD gypsum dosage

Figure 10 – Effect of polycarboxylate superplasticizer on the compressive strength of gypsum-modified earthen mortar

4. Conclusions

The effects of a single addition of FGD gypsum at five different dosage levels on the workability, volumetric stability, and compressive strength of plain earthen mortar were first investigated. Based on a comprehensive analysis of the aforementioned experimental results, FGD gypsum dosages of 15%, 20%, and 25% were selected for combined incorporation with polycarboxylate superplasticizer. Through a similar investigation of the workability, volumetric stability, and compressive strength of the resulting mortar, the following conclusions are drawn:

1. To achieve a consistency suitable for masonry requirements, the earthen mortar modified with a single addition of gypsum requires a relatively large amount of water. Polycarboxylate superplasticizer can substantially reduce the water demand; however, the dosage of the superplasticizer should preferably be controlled within the range of 0.5% to 1.0%. When the superplasticizer dosage is increased to 1.5%, it becomes difficult to control the consistency of the mortar. The water retention test was conducted immediately following the consistency test. The incorporation of polycarboxylate superplasticizer results in a significant improvement in the water retention performance of the earthen mortar. When combined with varying dosages of gypsum, the superplasticizer consistently elevates the water retention rate to above 97%.

2. The addition of gypsum increases the water demand, and excessive water content induces pronounced shrinkage in the test specimens. The incorporation of polycarboxylate superplasticizer can reduce the volumetric shrinkage rate of the specimens to half the value observed before its addition. At polycarboxylate superplasticizer dosages of 1.0% and 1.5%, the volumetric shrinkage rate of the specimens can be reduced to below 10%, thereby playing a crucial role in maintaining the volumetric stability of the specimens.

3. The compressive strength of plain earthen mortar specimens is comparatively low. The addition of gypsum enhances their compressive strength, and the experimental results indicate that a gypsum dosage of 20% yields the greatest improvement in the compressive strength of the earthen mortar specimens. Adding a polycarboxylate superplasticizer later further improved the compressive strength of the gypsum-modified mud mortar test blocks. Mixing 20% desulfurized gypsum with 1.5% superplasticizer can make the specimen's compressive strength reach 5.96 MPa, which is 2.84 times that of the mud mortar specimen.

Acknowledgments

This research was funded by the National Natural Science Foundation of China (Grant No. 52268045: Experiment Research and Mechanism Analysis on Mechanical Properties of Composite Mesh Reinforced Adobe Masonry Structure).

References

[1] J. Liu, K. Yuan, S. Zhang, and N. Chen, "Ecological Modification Formula of Raw Soil Masonry Mud," *Bull. Chin. Ceram. Soc.*, vol. 42, no. 2, p. 496, 2023.

[2] J. Qian, W. Qing, and X. Jia, "Research on preparation of adobe materials with desulfurized wastes from coal-fired power plant," *New Build. Mater.*, no. 2, pp. 28–31, 2009.

[3] H. Su, W. Pan, W. Bai, Y. Bai, and X. Yang, "Seismic behavior of new adobe walls structure," *J. Civ. Environ. Eng.*, vol. 37, no. 6, p. 54, 2015, doi: 10.11835/j.issn.1674-4764.2015.06.008.

[4] J. Liu, L. Zhang, and J. Yang, "Research progress of raw earth materials at home and abroad," *Mater. Rep.*, vol. 26, no. 23, p. 14, 2012, doi: 10.3969/j.issn.1005-023X.2012.23.003.

[5] N. Degirmenci, "The using of waste phosphogypsum and natural gypsum in adobe stabilization," *Constr. Build. Mater.*, vol. 22, no. 6, pp. 1220–1224, 2008, doi: 10.1016/j.conbuildmat.2007.01.027.

[6] C. Jayasinghe and N. Kamaladasa, "Compressive strength characteristics of cement stabilized rammed earth walls," *Constr. Build. Mater.*, vol. 21, no. 11, pp. 1971–1976, 2007, doi: 10.1016/j.conbuildmat.2006.05.049.

[7] F. F. Khorasani and M. Z. Kabir, "Experimental study on the effectiveness of short fiber reinforced clay mortars and plasters on the mechanical behavior of adobe masonry walls," *Case Stud. Constr. Mater.*, vol. 16, p. e00918, 2022, doi: 10.1016/j.cscm.2022.e00918.

[8] O. Ige and H. Danso, "Physico-mechanical and thermal gravimetric analysis of adobe masonry units reinforced with plantain pseudo-stem fibres for sustainable construction," *Constr. Build. Mater.*, vol. 273, p. 121686, Mar. 2021, doi: 10.1016/j.conbuildmat.2020.121686.

[9] K. Stathopoulos, M. Apostolopoulou, and A. Bakolas, "Enhancement of water resistance of earthen mortars through stabilization," *Constr. Build. Mater.*, vol. 289, p. 123180, 2021, doi: 10.1016/j.conbuildmat.2021.123180.

[10] K. A. J. Ouedraogo, J.-E. Aubert, C. Tribout, and G. Escadeillas, "Is stabilization of earth bricks using low cement or lime contents relevant?," *Constr. Build. Mater.*, vol. 236, p. 117578, Mar. 2020, doi: 10.1016/j.conbuildmat.2019.117578.

[11] M. Jin, Y. Zhou, B. Wen, L. Liu, and H. Liu, "Progresses of gypsums for the improvement of saline-alkaline soil," *J. Nanjng For. Univ. Nat. Sci. Ed.*, vol. 47, no. 2, pp. 1–8, 2023, doi: 10.12302/j.issn.1000-2006.202209047.

[12] Y. Wang, F. Liu, L. Liu, K. Guan, and K. Zhang, "Experimental analysis on compressive strength of raw soil material modified by industrial waste," *J. Civ. Environ. Eng.*, vol. 38, no. 6, p. 32, 2016, doi: 10.11835/j.issn.1674-4764.2016.06.005.

[13] J. Qian, J. Yu, H. Sun, and y. Ma, "Formation and Function of Ettringite in Cement Hydrates," *J. Chin. Ceram. Soc.*, vol. 45, no. 11, 2017.

[14] M. Xie, "Research on Material Modification and Structure Optimization of Raw Soil Building," in *Dissertation*, Chongqing, China: Chongqing University, 2020, p. 120.

[15] D. Yin, "Study on Gypsum-based Modified Raw Soil Building Materials," in *Dissertation*, Chongqing, China: Chongqing University, 2019, p. 78.

[16] J. Qian, D. Yin, D. Yu, Y. Fan, and Y. Huang, "The effect of polycarboxylate superplasticizer on the properties of modified raw soil materials," *J. Build. Mater.*, vol. 22, no. 03, p. 378, 2019, doi: 10.3969/j.issn.1007-9629.2019.03.008.

[17] S. Wang, Y. Zhao, and Y. Li, *Research and application of desulfurization gypsum for improving saline-alkali soils*. Beijing, China: Science Press, 2020. [Online]. Available: https://liblsp.neau.edu.cn/space/searchDetailLocal/m9239f61399a5c340ecd0f89a0d24bf66

[18] "GB/T 8077-2023 Methods for testing uniformity of concrete admixtures," Beijing, China: State Administration for Market Regulation, China National Standardization Administration, 2023, p. 42.

[19] "JGJT70-2009 Standard for test method of basic properties of construction mortar," in *Bulletin of the Ministry of Housing and Urban*, Beijing, China: Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2009, p. 71.

[20] "RISN-TG008-2010 Technical Guidelines for Ordinary Building Mortar," in *Series of Technical Guidelines for Engineering Construction Standards*, Beijing, China: Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2010, p. 112.

Information about authors:

Sawulet Bekey – Master, Professor, Doctoral supervisor; 1) College of Architecture and Engineering, Xinjiang University, Urumqi, China; 2) Xinjiang Key Laboratory of Building Structure and Earthquake, Xinjiang University, Urumqi, China; jgxyswlt@xju.edu.cn

Wumeng Liu – Master, Assistant Engineer, NO.2 Engineering Co., Ltd. OF CCCC Third Harbor Engineering Co., Ltd., Shanghai, China, 1296544415@qq.com

Qing Wang – Master Candidate, College of Architecture and Engineering, Xinjiang University, Urumqi, China, 2262881295@qq.com

Wenze Wang – Master Candidate, College of Architecture and Engineering, Xinjiang University, Urumqi, China, 1471983186@qq.com
Jingzheng Mi – Master Candidate, College of Architecture and Engineering, Xinjiang University, Urumqi, China, 1028564380@qq.com

Author Contributions:
Sawulet Bekey – funding acquisition, concept, methodology, resources.
Wumeng Liu – data collection, testing, analysis, visualization, interpretation.
Qing Wang – analysis, interpretation, editing.
Wenze Wang – drafting, analysis, interpretation.
Jingzheng Mi – drafting, analysis, interpretation.

Conflict of Interest: The authors declare no conflict of interest.

Use of Artificial Intelligence (AI): The authors declare that AI was not used.

Received: 06.05.2026
Revised: 18.06.2026
Accepted: 24.06.2026
Published: 25.06.2026

Copyright: © 2026 by the authors. Licensee Technobius, LLP, Astana, Republic of Kazakhstan. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY-NC 4.0) license (https://creativecommons.org/licenses/by-nc/4.0/).