

## Effect of drying conditions on the shear strength and deformation behavior of MICP-treated soil



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### ABSTRACT

Improving the strength and deformation behavior of soils is an important challenge in civil engineering and requires reliable and sustainable ground improvement methods. Microbially induced calcite precipitation (MICP) is a bio-mediated soil improvement technique; however, the effect of drying conditions on the mechanical behavior of biocemented soils has not been fully investigated. This study experimentally evaluates the influence of different drying regimes on the strength and deformation response of MICP-treated soil. Soil specimens were biocemented and cured for 0, 7, 14, 28, and 35 days under two drying regimes: mechanical drying and natural drying. Direct shear tests were performed to determine cohesion and internal friction angle at all curing stages, while deformation behavior was evaluated using shear stress–displacement responses. Microstructural characteristics were qualitatively analyzed using scanning electron microscopy (SEM) for untreated soil and treated specimens cured for 7, 14, and 28 days. SEM results showed the formation of carbonate bridges and partial pore filling, and complementary energy-dispersive spectroscopy (EDS) analysis indicated that the calcium content in MICP-treated specimens was approximately twice that of untreated soil, confirming successful calcite precipitation. The results demonstrate that drying conditions have a stage-dependent effect on the mechanical behavior of MICP-treated soils and mainly influence the rate of strength and deformation development rather than the final stabilized mechanical properties. These findings provide experimental insight into the relationship between curing conditions and biocementation efficiency and support the practical application of MICP in geotechnical ground improvement.

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### 1. Introduction

Soil improvement is a fundamental requirement in civil engineering practice to ensure sufficient strength, stiffness, and durability of geomaterials under service loading and environmental exposure. A wide range of ground improvement methods has been developed, including chemical stabilization, physical densification techniques, and structural reinforcement using piles. Microbially induced calcite precipitation (MICP) is a bio-mediated ground improvement technique that enhances soil

performance through biologically driven carbonate precipitation (Soon et al., 2013). The process relies on microbial activity to promote the formation of calcite at particle contacts, leading to improved intergranular bonding and reduced pore connectivity. Unlike conventional chemical stabilizers, MICP operates under relatively mild conditions and can be regulated by controlling biological, chemical, and environmental parameters (Khalaj et al., 2024).

Several recent studies, such as Zhang et al. (2023), have focused on the durability and environmental performance of soils treated by microbially induced calcite precipitation (MICP), highlighting the sensitivity of biocemented systems to moisture variations, ageing, and cyclic loading conditions. Sharma and Satyam (2021) investigated poorly graded liquefiable sand treated in polyvinyl chloride (PVC) columns using bioaugmentation with *Sporosarcina pasteurii*, *Bacillus sphaericus*, and their

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mixed culture to explore potential synergistic effects of hybrid bacterial activity. The biotreatment was conducted using a 0.50 M cementation solution with controlled injection frequencies of 12 and 24 hours and varying injection pore volumes over a treatment period of up to 18 days. Post-treatment characterization included permeability measurements and calcite content determination, followed by an extensive durability assessment involving up to 20 wetting–drying cycles and ageing periods of up to six months under uncontrolled temperature conditions. Mechanical performance was evaluated using ultrasonic pulse velocity, shear modulus, unconfined compressive strength, and split tensile strength, while mass-loss rates were quantified to assess material degradation. The results demonstrated that MICP-treated sand retained notable resistance to wetting–drying cycles, with ageing leading to more than a twofold increase in mechanical properties, and dynamic cyclic simple shear tests further confirmed improved liquefaction resistance, as excess pore pressure ratios remained below unity even after 100 loading cycles.

The influence of drying–wetting cycles has also been examined in reinforced biocemented systems incorporating additional sustainable materials. Kou et al. (2023) studied calcareous sand reinforced by a combination of MICP and recycled shredded coconut coir, revealing that cyclic drying–wetting conditions significantly affect long-term durability. With an increasing number of cycles, specimens exhibited elevated mass-loss rates and critical void ratios, accompanied by a pronounced reduction in maximum shear modulus, peak strength, and overall toughness. These findings indicate that while fiber-based or bio-based reinforcements may enhance initial performance, cyclic moisture variations can progressively deteriorate the mechanical integrity of MICP-treated soils.

Beyond granular soils, the application of MICP to fine-grained and expansive soils has also received growing attention. Jiang et al. (2025) investigated the effects of cementation solution concentration on swelling behavior and mechanical degradation in expansive soils subjected to repeated wet–dry cycles. The results showed that higher cementation concentrations significantly reduced free swell and unconfined swell ratios while markedly increasing unconfined compressive strength, cohesion, and internal friction angle. However, prolonged exposure to wet–dry cycling led to substantial performance degradation, with compressive strength reductions exceeding 60%, underscoring the vulnerability of MICP-treated expansive soils to cyclic environmental actions despite their improved initial properties.

Environmental durability has been further explored in the context of erosion resistance and climatic exposure. Hang et al. (2022) conducted a parametric study on MICP-treated desert sand, demonstrating that higher treatment temperatures and increased biocement solution concentrations enhanced resistance to wind-induced erosion. Nevertheless, the resistance of biocemented sand

decreased with an increasing number of drying–wetting cycles, as well as with prolonged exposure time and freeze–thaw cycling, although the latter effects were less pronounced. Similar conclusions were reported by Liu et al. (2019), who observed severe reductions in unconfined compressive strength of MICP-treated soils after wet–dry cycles, freeze–thaw cycles, and acidic immersion. The findings showed that fiber reinforcement primarily improved ductility rather than strength retention, while multiple MICP treatments significantly enhanced durability and mitigated strength loss under adverse environmental conditions.

At the microstructural scale, several studies emphasize that the effectiveness and durability of MICP-treated soils are governed by the distribution, continuity, and bonding quality of calcium carbonate precipitation. Tang et al. (2024) demonstrated that CaCO<sub>3</sub> content and spatial distribution play a dominant role in controlling the resilience of biocemented clayey soils under climatic wetting–drying cycles, highlighting the potential of MICP as a low-carbon and environmentally friendly soil improvement technique.

Complementing these results, critical state–based investigations by Hora et al. (2026) revealed that MICP treatment alters the shearing and consolidation behavior of sand, influencing brittleness, dilatancy, and instability characteristics. The results indicate that under high confining stresses, localized failure and partial strength loss may occur, suggesting that moisture-induced microstructural changes could further affect deformation mechanisms in treated soils.

Overall, the reviewed studies demonstrate that while MICP can significantly enhance the mechanical performance and environmental resistance of soils, its long-term durability is strongly influenced by drying–wetting cycles, ageing, treatment strategy, and microstructural characteristics (Erdmann and Strieth, 2023; Gao et al., 2019; Ren et al., 2026). These findings underline the necessity of systematically examining moisture-related effects and deformation behavior to ensure the reliable application of MICP under realistic environmental conditions.

In continuation of previous research, this study examines the combined influence of drying regimes on the development of strength, deformation, and microstructural characteristics of MICP-treated soil at different curing stages. Attention is paid to the influence of natural and mechanical drying on the evolution of shear strength parameters and the associated deformation behavior of biocemented soil. The experimental program is complemented by microstructural analysis, enabling interpretation of the observed mechanical responses in terms of the formation and redistribution of interparticle carbonate. To achieve a deeper understanding of the deformation response under different drying regimes, numerical modeling is employed, providing a consistent and mutually supportive assessment of experimental and computational results.

## 2. Methods and materials

The experimental program was carried out in the «ENU-Lab» laboratory at L.N. Gumilyov Eurasian National University. A natural sand with fine friction characteristics, collected in the Astana region (Kazakhstan), was used as the test material. Prior to specimen preparation, all testing equipment was configured and calibrated in accordance with standard laboratory procedures. The soil was classified based on sieve analysis, hydrometer analysis, and Atterberg limit tests, which were performed to evaluate grain-size distribution, consistency, and plasticity characteristics.

### 2.1. Soil material and biocementation procedure

The tested soil exhibited a heterogeneous grain-size composition, consisting predominantly of sand with a notable proportion of fines. The sand-sized fraction (75  $\mu\text{m}$ –2 mm) accounted for approximately 61% of the material, while silt-sized particles (5 – 75  $\mu\text{m}$ ) and clay-sized particles (< 5  $\mu\text{m}$ ) constituted about 19% and 16%, respectively. The soil showed low plasticity behavior, with a liquid limit of approximately 23% and a plasticity index of about 8%, indicating limited clay activity. The specific gravity of soil solids was close to 2.54, while the maximum dry density and optimum water content were approximately 2.03  $\text{g}/\text{cm}^3$  and 10.2%, respectively. The soil was classified as a sand with fines, exhibiting moderate density and low plasticity, which makes it suitable for investigating the effects of MICP treatment and drying regimes on strength and deformation behavior.

For microbial treatment, the soil specimens were inoculated with the ureolytic bacterium *Sporosarcina pasteurii*, selected due to its well-documented effectiveness in MICP applications. The suitability of the bacterial culture for biocementation was confirmed through a urease activity test conducted on Christensen agar supplemented with urea. The observed color response indicated active enzymatic hydrolysis, confirming the capability of the strain to induce carbonate precipitation.

The bacterial strain *Sporosarcina pasteurii* was cultivated on a nutrient agar medium formulated to support ureolytic activity. The cultivation medium contained sodium chloride (5.0 g/L), peptone (1.0 g/L), glucose (1.0 g/L), potassium dihydrogen phosphate (2.0 g/L), phenol red (0.0012 g/L) as a pH indicator, and agar (15.0 g/L), with the initial pH adjusted to 7.0. To activate bacterial metabolism, the culture was first incubated at 37 °C for 24 h. Sterilized urea was subsequently added to the medium to obtain a final concentration of 4% (w/v) per 100 mL. The medium was dispensed into sterile test tubes, solidified in an inclined position to form agar slants, inoculated with *Sporosarcina pasteurii*, and incubated at 28 °C for 48 h to ensure active bacterial growth. The ureolytic activity of the bacterial culture was qualitatively verified prior to soil treatment by a visible color change of the

cultivation medium. Soil specimens with an average mass of approximately 231.48 g were prepared and placed in individual containers. In total, 81 containers were used, including untreated reference specimens and samples subjected to microbial treatment. The biocemented specimens were distributed among curing durations of 0, 7, 14, 28, and 35 days to capture different stages of strength development during the MICP process. Control specimens without bacterial inoculation were maintained to confirm the absence of native ureolytic activity in the natural soil.

For microbial treatment, a bacterial suspension with a concentration of approximately  $1 \times 10^8$  CFU/mL was introduced into the soil samples. The treated specimens were incubated at 28 °C for the selected curing periods. During the biocementation stage, 8 mL of a cementation solution prepared by mixing equal volumes of 1.0 M calcium chloride ( $\text{CaCl}_2$ ) and 1.0 M urea was added daily to each specimen. To sustain bacterial activity, supplementary injections consisting of 4 mL of bacterial suspension and 4 mL of peptone solution were applied on days 4, 8, 12, 16, 20, and 24. Owing to the aerobic nature of *Sporosarcina pasteurii*, the soil mixture was gently mixed once per day following bacterial addition to ensure sufficient oxygen availability.

After completion of the biocementation stage corresponding to each curing duration, the treated specimens were divided into two groups according to the applied drying regime. A total of 36 specimens were subjected to mechanical drying at 70 °C, while the remaining 36 specimens were allowed to dry naturally under ambient laboratory conditions. This experimental design enabled a systematic assessment of the influence of drying regimes on the evolution of shear strength parameters and deformation behavior of MICP-treated soils at different curing stages. For clarity, the following abbreviations are used: US denotes untreated soil; MICP-ND indicates specimens subjected to natural drying, while mechanically dried specimens are denoted as MICP-MD.

### 2.2. Microstructural analysis by scanning electron microscopy

To investigate surface morphology and microstructural changes induced by biocementation, scanning electron microscopy (SEM) was conducted using a TM4000Plus scanning electron microscope at the ENU Laboratory of L.N. Gumilyov Eurasian National University. SEM observations were performed exclusively on specimens cured for 0, 7, 14, and 28 days, corresponding to the stabilized stage of strength development, at which the most pronounced effects of calcium carbonate precipitation are expected. Prior to SEM examination, representative fragments were carefully extracted from the interior of the specimens to minimize surface disturbance and edge effects. The samples were air-dried and mounted on

aluminum stubs using conductive carbon tape. SEM imaging was carried out under high-vacuum conditions at appropriate accelerating voltages to ensure clear visualization of particle contacts and cementation features. The microstructural analysis focused on identifying the morphology, distribution, and continuity of calcium carbonate precipitates formed during the MICP process. Particular attention was given to the presence of interparticle carbonate bridges, partial pore filling, and changes in contact geometry between soil grains. Comparisons were made between untreated soil and biocemented specimens to qualitatively assess the role of biocementation in modifying soil fabric. The SEM observations were used to support the interpretation of mechanical test results by linking microstructural features to the observed evolution of strength and deformation behavior.

### 2.3. Direct shear testing

To characterize the shear behavior of the investigated soil and to quantify the effect of microbially induced calcite precipitation (MICP) using *Sporosarcina pasteurii*, a comprehensive series of direct shear tests was conducted using a Wykeham Farrance DIGISHEAR system (model 27CWF2060, UK). The testing program included both untreated reference specimens and MICP-treated samples, allowing a systematic assessment of changes in shear resistance associated with microbial carbonate precipitation.

Direct shear tests were performed on specimens corresponding to curing durations of 0, 7, 14, 28, and 35 days. For each curing stage, samples were subjected to either mechanical drying or natural drying prior to testing, enabling evaluation of the influence of drying regime on the stage-dependent development of shear strength during the MICP process. Normal stresses of 50, 75, and 100 kPa were applied, representing stress levels typical of near-surface soil layers under common engineering conditions. For each combination of curing duration, drying condition, and applied normal stress, three independent replicate tests were conducted to ensure reproducibility and statistical reliability of the results.

Specimen preparation followed a standardized and uniform procedure to minimize experimental variability across all test series. After placement in the shear box, specimens were allowed to stabilize under the applied normal load before the initiation of shearing. Shear loading was applied under displacement-controlled conditions at a constant

rate, while shear force and horizontal displacement were continuously recorded throughout the test. Each test was continued until a distinct peak in shear resistance was observed, ensuring consistent identification of the failure condition.

The peak shear stresses obtained at different normal stress levels were interpreted using the Mohr–Coulomb failure criterion, expressed as:

$$\tau = c + \sigma \cdot \tan \varphi \quad (1)$$

where,  $\tau$  is the peak shear stress at failure,  $\sigma$  is the applied normal stress,  $c$  is the cohesion, and  $\varphi$  is the internal friction angle.

The values of cohesion and internal friction angle were determined from the linear regression of the peak shear stress data obtained under the three applied normal stress levels for each test condition. All direct shear tests were conducted under controlled laboratory conditions with stable temperature and humidity to minimize the influence of external environmental factors. For each test series, mean values of the shear strength parameters were calculated from replicate measurements, while the observed scatter was used as an indicator of experimental repeatability and data consistency. This testing protocol ensured reliable comparison of shear behavior across different curing stages and drying regimes.

## 3. Results and discussions

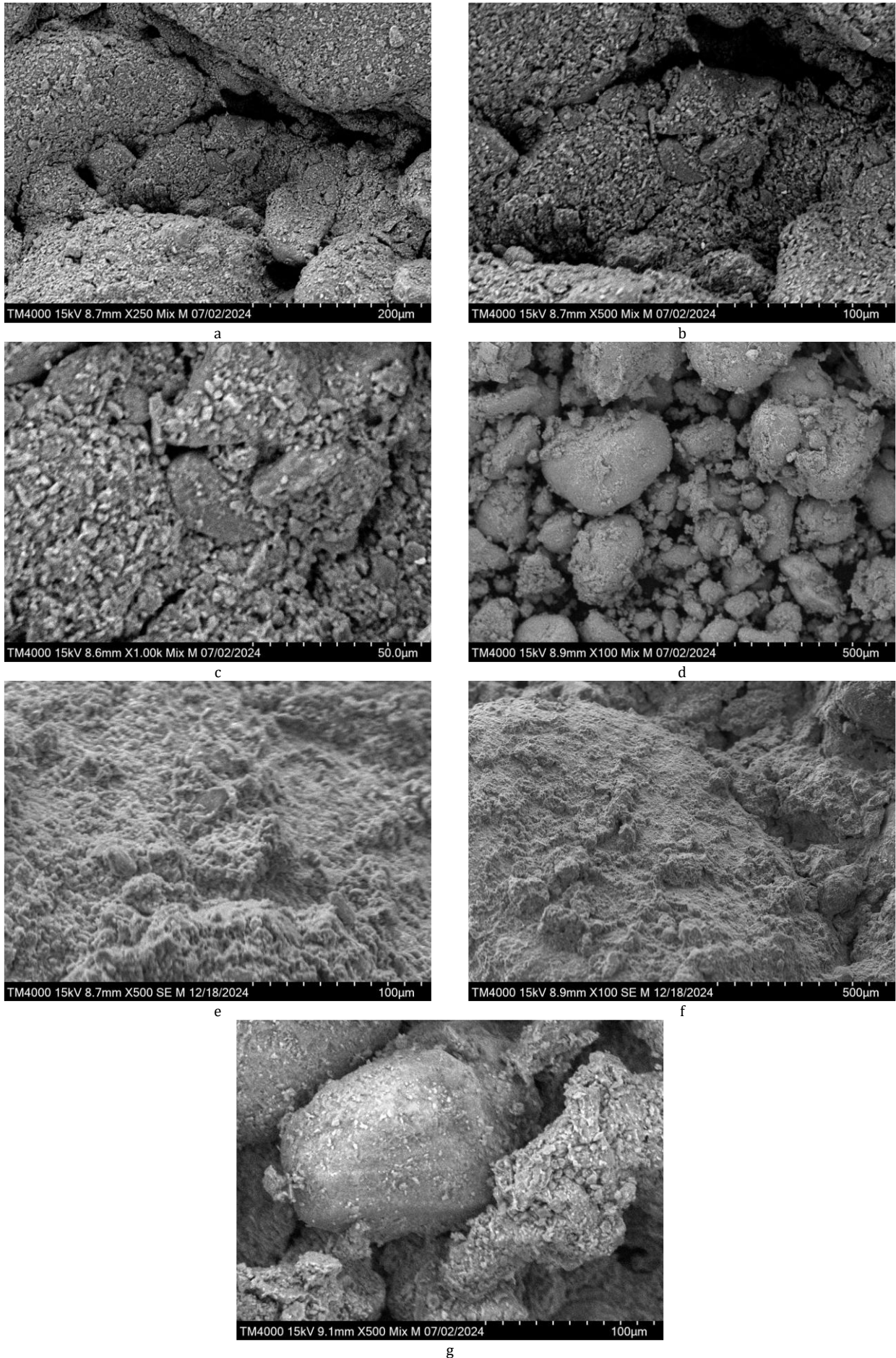
### 3.1. SEM results

SEM images illustrating the microstructural features of untreated soil and MICP-treated specimens after 7, 14, and 28 days of curing are presented in Fig.1.

SEM images of the untreated soil reveal a loose granular structure with clearly distinguishable particle boundaries and the absence of interparticle bonding. After 28 days of biocementation, pronounced microstructural changes are observed for both drying regimes, characterized by the formation of calcium carbonate bridges between soil particles and partial pore filling. Comparison between mechanically and naturally dried specimens at 28 days indicates that mechanical drying results in a more compact and locally cemented microstructure, whereas natural drying leads to a more uniform and less localized cementation pattern. The results of the EDS analysis are summarized in Table 1.

**Table 1:** Elemental composition of soil samples

Soil	Mass, %										Total, %
	C	O	Na	Mg	Al	Si	K	Ca	Ti	Fe	
US	6.26	51.51	0.65	1.59	7.8	18.83	2.58	5.54	0.88	4.36	100
MICP-MD 28d	3.44	42.9	0.83	2.12	8.55	22.82	2.12	11.98	0	5.24	100
MICP-ND 28d	3.44	44.1	0.90	2.12	8.52	22.74	2.02	10.92	0	5.24	100



**Fig. 1:** SEM images a) MICP-MD 7d; b) MICP-ND 7d; c) MICP-MD 14d; d) MICP-ND 14d; e) MICP-MD 28d; f) MICP-ND 28d; g) US

The untreated soil is primarily composed of oxygen and silicon, reflecting its silicate-based mineralogy, with moderate contributions from aluminum, calcium, and iron. Calcium detected in the untreated soil reflects naturally occurring mineral phases. The untreated soil also exhibits a relatively higher carbon content, consistent with the presence of natural organic matter in the soil matrix.

After 28 days of MICP treatment, an increase in calcium content was observed for both drying regimes. Compared with the untreated soil, the calcium mass fraction increased from 5.54 % to 11.98 % for mechanically dried specimens and to 10.92 % for naturally dried specimens, indicating the formation of calcium-based cementation products during MICP treatment.

The increase in calcium content was accompanied by a relative decrease in carbon content compared with the untreated soil. For specimens subjected to natural drying, the calcium content remained elevated after 28 days of curing, indicating that elevated calcium levels were maintained under ambient drying conditions. Minor differences in oxygen and silicon contents between mechanically and naturally dried samples indicate that the drying regime mainly affects moisture removal and the spatial distribution of cementation products rather than the overall elemental composition. The EDS results support the SEM observations by confirming the occurrence and stabilization of calcium-based phases in MICP-treated soils.

### 3.2. Results of direct shear test

For the untreated soil, the cohesion value was approximately 8 kPa, which served as the reference state for assessing the influence of biocementation. At the initial stage of MICP treatment (0 days), the cohesion of treated specimens remained close to that of the untreated soil under both drying conditions, indicating that the contribution of microbially induced cementation to shear resistance was still limited at this stage (Fig. 2).

As curing time increased, a clear and progressive increase in cohesion was observed for all MICP-treated specimens. Under mechanical drying conditions, cohesion increased steadily from the initial value to approximately 14 kPa at 28 days of curing, after which the cohesion values remained approximately constant up to 35 days of curing. Specimens subjected to natural drying exhibited a more gradual increase in cohesion, with lower mean values observed at intermediate curing stages. The variability of cohesion values, represented by the error bars ( $\pm$ SD) in Fig. 2, remained limited across all curing times, indicating good repeatability of the direct shear tests. However, by 35 days of curing, the cohesion values under natural drying approached those obtained under mechanical drying, suggesting a convergence of shear resistance at later stages of biocementation. A similar curing-dependent trend was observed for the internal friction angle (Fig. 3).

The internal friction angle of the untreated soil was approximately 29°, reflecting the initial frictional resistance of the soil matrix. At the initial stage of MICP treatment (0 days), only minor changes in the friction angle were observed under both drying conditions, indicating that the contribution of biocementation to frictional resistance was still limited.

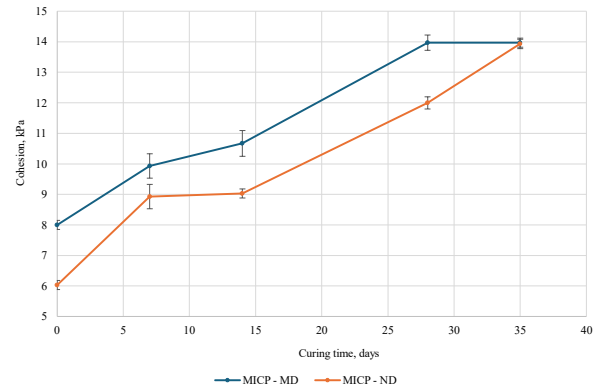


Fig. 2: Evolution of cohesion with curing time under MICP-MD and MICP-ND conditions

With increasing curing time, a gradual increase in the internal friction angle was observed for all MICP-treated specimens. Under mechanical drying conditions, the friction angle increased more rapidly during the early and intermediate curing stages, reaching mean values of approximately 35° by 28 days of curing, after which the values remained nearly constant up to 35 days. In contrast, specimens subjected to natural drying exhibited a more gradual increase in friction angle, with lower mean values observed at intermediate curing stages. The variability of friction angle values, represented by the error bars ( $\pm$ SD) in Fig. 3, remained limited across all curing times, indicating good repeatability of the measurements.

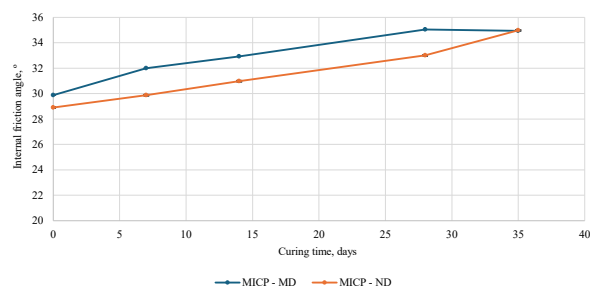


Fig. 3: Evolution of internal friction angle with curing time under MICP-MD and MICP-ND conditions

The results obtained in this study are generally consistent with previously published research on the application of microbially induced calcite precipitation (MICP) for improving the mechanical properties of soils. Numerous studies have demonstrated that the enhancement of shear strength in MICP-treated soils is primarily associated with the formation of carbonate bridges between soil particles, which improve interparticle bonding and load transfer efficiency. The direct shear test results

presented in this study confirm these established trends, showing a systematic increase in cohesion and internal friction angle with increasing curing time.

In addition to these well-recognized mechanisms, the present results indicate that drying regimes exert a noticeable influence on the rate of strength development in biocemented soils. Specimens subjected to mechanical drying exhibited a more rapid increase in shear strength parameters at early and intermediate curing stages compared with naturally dried specimens. This behavior is primarily attributed to accelerated moisture removal, which promotes earlier supersaturation of pore water and precipitation of calcium carbonate at particle contacts. As a result, interparticle cementation bridges form more rapidly, leading to faster strength gain during the initial stages of treatment. Furthermore, elevated drying temperatures may influence residual microbial activity and biochemical reaction rates, accelerating the transition from biologically mediated processes to physicochemical cementation mechanisms.

As curing time increases, the differences between mechanical and natural drying regimes gradually diminish. At later stages of biocementation, both drying conditions yield comparable cohesion and friction angle values, indicating structural stabilization of the cemented soil matrix. This observation supports the concept of MICP as a staged process, in which external technological factors such as drying conditions play a dominant role during early and intermediate phases of structure formation, while their influence becomes limited once a continuous and stable cementation network has developed.

Microstructural observations obtained through scanning electron microscopy provide further insight into the mechanisms governing strength evolution. SEM images confirm the presence of carbonate bridges and partial pore filling, which increase contact density and enhance intergranular bonding. A comparison between specimens prepared under different drying regimes suggests that mechanical drying promotes earlier formation of localized interparticle bonds, whereas natural drying results in a more gradual and spatially uniform development of cementation structures. These observations are consistent with the experimentally observed differences in the kinetics of shear strength development. Energy-dispersive spectroscopy results further support the microstructural interpretation. The untreated soil exhibited a relatively higher carbon content, consistent with the presence of natural organic matter contributing to the baseline carbon signal. Following MICP treatment, a relative decrease in carbon content accompanied by an increase in calcium content was observed. This trend reflects the increasing contribution of calcium-based cementation products within the soil matrix as biocementation progresses. It should be noted that EDS provides semi-quantitative elemental information and is sensitive

to local compositional heterogeneity; therefore, the reported elemental proportions should be interpreted as indicative trends rather than absolute values. The consistent increase in calcium content across treated specimens, together with SEM observations, provides complementary evidence of effective calcite precipitation induced by MICP.

It should also be acknowledged that the direct shear tests were conducted using three normal stress levels. While this stress range is commonly applied in laboratory-scale investigations and was sufficient to identify comparative trends between drying regimes and curing stages, the limited number of stress levels may affect the precision of the derived shear strength envelopes. The inclusion of additional normal stress levels would enhance the robustness of cohesion and friction angle determination and allow a more detailed assessment of stress-dependent behavior. This limitation should be considered when extrapolating the present results to higher stress conditions relevant to field-scale applications.

Overall, the findings demonstrate that drying conditions primarily influence the kinetics of strength development in MICP-treated soils rather than their ultimate stabilized mechanical state.

#### 4. Conclusions

The findings of this study confirm the effectiveness of MICP as a soil improvement technique and demonstrate that drying conditions play a significant, stage-dependent role in governing the strength and deformation behavior of biocemented soils.

1. Direct shear testing showed that MICP treatment leads to a substantial enhancement of shear strength parameters. At advanced curing stages, cohesion increased by approximately 1.7 times compared to untreated soil, while the internal friction angle increased from initial values of about 29° to more than 35°. Mechanical drying promoted a faster development of both cohesion and friction angles during early and intermediate curing stages, whereas under natural drying, comparable strength levels were reached at later stages.
2. SEM and EDS analyses confirmed the formation of interparticle carbonate bridges and an increase in calcium content from 5.54 % in untreated soil to 10.92–11.98 % in MICP-treated specimens after 28 days, indicating effective calcite precipitation. Variations in the spatial distribution of carbonate phases under mechanical and natural drying conditions explain the observed differences in the rate of shear strength development.
3. The experimental results indicate that drying conditions primarily influence the deformation response of MICP-treated soils during early and intermediate curing stages. As curing progresses and cementation becomes structurally stabilized, the influence of drying regime on deformation behavior diminishes, and both regimes exhibit

comparable mechanical responses at advanced curing stages.

Treating the drying regime as a controlled experimental parameter improves the consistency and comparability of laboratory MICP studies and provides a more reliable basis for transferring biocementation techniques to practical engineering applications.

### List of abbreviations

CFU	Colony-forming units
EDS	Energy-dispersive spectroscopy
IoT	Internet of Things
MICP	Microbially induced calcite precipitation
MICP-MD	Mechanically dried MICP-treated specimens
MICP-ND	Naturally dried MICP-treated specimens
PVC	Polyvinyl chloride
SD	Standard deviation
SEM	Scanning electron microscopy
US	Untreated soil

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### Compliance with ethical standards

### Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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