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# Evaluation of Shear Strength of Soil Stabilized by Microbiological Method

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**Article**

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**Abstract**

Biological soil stabilization is a new method in soil resilience against erosion. In this study, a bacterium producing urease enzyme with the scientific name of (Sporosarcina pasteurii) with the ability to precipitate in soil pores was used. To evaluate the effectiveness of bacteria, soil shear strength with a vane cutting machine was used. Treatments included soil type, bacterial concentration, storage time, re-injection with an interval of six days and the effect of environmental conditions on bacterial yield and the amount of shear strength. The results show that the shear strength of soils improves significantly over time. The highest shear strength in carbonate sand and then silica sand with a more proper grain size distribution, 0.64 and 0.39 kg / cm2, were obtained. The best state of equilibrium between nutrients and the number of bacteria in this study was observed at a light density of 1.5. The results showed re-injection has an increasing effect on the strength of samples, especially in silica sand, by 55% compared to a single injection.

## Introduction

Soil is a vital resource for food production and other necessities of human life, but it is produced so slowly that it is considered a non-renewable resource. In general, soil formation and evolution take place over several thousand years [1].

It takes about 200-1000 years to form 2.5 cm of topsoil in tropical and temperate regions. Wind erosion is one of the leading causes of soil degradation in arid and semi-arid regions. The desert and semi desertification of about two-thirds of the country's area provides the conditions for the movement of soil particles under the influence of wind. Due to the climatic conditions of Iran, many parts of central, southern and eastern Iran are affected by wind erosion, and14 provinces located in arid and semi-arid regions are facing the problem of wind erosion. This type of erosion causes the loss of about 500 million hectares of land every year and produces between 500 and 5000 teragrams of dust. Due to wind erosion, about one thousand billion rials of damage is directly and indirectly caused to the country's natural resources annually [2, 3]. Therefore, due to the growing population and the need to produce more food, this type of erosion is essential and the need for further research to increase the existing knowledge and awareness in the direction of proper planning and reduce the damage caused by this type of erosion and makes it necessary to minimize costs. Different methods for Soil stabilization and wind erosion control have been proposed by various researchers, including mechanical, chemical, managerial and biological processes. This is while the application of each of these methods has several specific limitations [4]. One of the new methods and techniques in controlling erosion is using microorganisms in the soil that effect they do not cause undesirable. This method is widely used in geotechnical engineering and includes increasing the strength and firmness of soil characteristics through microbial activity. Bacteria are one of the most abundant soil microorganisms on average, and there are more than 10 to the power of 9 bacterial cells per gram of soil at a depth of one meter, which decreases with increasing depth. These microorganisms are estimated to be more than 1.5 billion years old and have followed the sedimentation process for most of this period [5]. The method used in this research is called microbial deposition of calcium carbonate, which is a completely environmentally friendly method and a particular species of a spore-bearing bacterium called Sporosarsina Pasteurii, which belongs to the Bacillus family and lives naturally in the soil and also has sedimentation ability, has been used [6]. This bacterium causes bonding and adhesion between soil particles. This process uses urease-producing microorganisms that are naturally present in soil deposits. This process takes place spontaneously and very slowly in nature and causes sandstones, limestones, and the phenomenon of stromatolites for millions of years. Figure (1) schematically shows how calcium carbonate precipitates during a biological process using the *Sporosarcina Pasteurii* microorganism as a source of urease enzyme production. The enzyme urease acts as a catalyst and breaks down urea present or added to the environment and converts it to ammonium, bicarbonates and carbonate ions.

In the presence of calcium ions in the soil (in the laboratory, calcium carbonate is added to the soil), they bind to carbonate ions and cause calcium carbonate deposition, creating cementation between the soil grains. This process raises the pH of the soil, which provides ideal conditions for bacterial nutrition and more calcite deposition in the soil. Chemical hydrolysis of urea in the absence of catalytic is a prolonged process in which the enzyme urease accelerates this reaction 10 to 16 times faster [7]. Many researchers have studied this phenomenon, and on various applications, many studies have been done on the phenomenon of bio-blockage, bio-cementation and bio-purification, etc. Good results have also been reported; that can be attributed to the work of increasing soil shear strength, reducing soil hydraulic conductivity, reducing the potential of soil liquefaction, and improving concrete in increasing resistance to wind erosion. They also used a fin-cutting machine to evaluate the effect of microalgae on the soil to evaluate the parameters affecting the biological stabilization of fine-grained soils using Microalgae Chlorella Vulgaris microalgae. In the present study, three types of sandy soils of siliceous and carbonate origin and with different grain distribution has been used to investigate and compare the effectiveness of microorganisms in soils and thus combat wind erosion and desertification. One of the methods to deal with soil erosion is to add a force resistant to wind-driving detail. As the adhesion between soil particles and the formation of aggregates increases, the resistance to rupture and displacement of soil particles against the erosive force increases. In this study, the mentioned bacterium increases soil resistance by producing calcium carbonate adhesive between soil particles and increasing the particle movement threshold; therefore, shear strength has been studied by spraying this species of bacteria on the soil surface. In this regard, by examining the effective parameters of storage time, bacterial concentration, soil type, moisture, injection method and environmental conditions, the effectiveness of microorganisms in soil surface strengthening has been studied and by quantifying and estimating the shear strength of the soil surface stabilized using a feather cutting machine, its stability has been reviewed, which has not been addressed in previous studies [8].

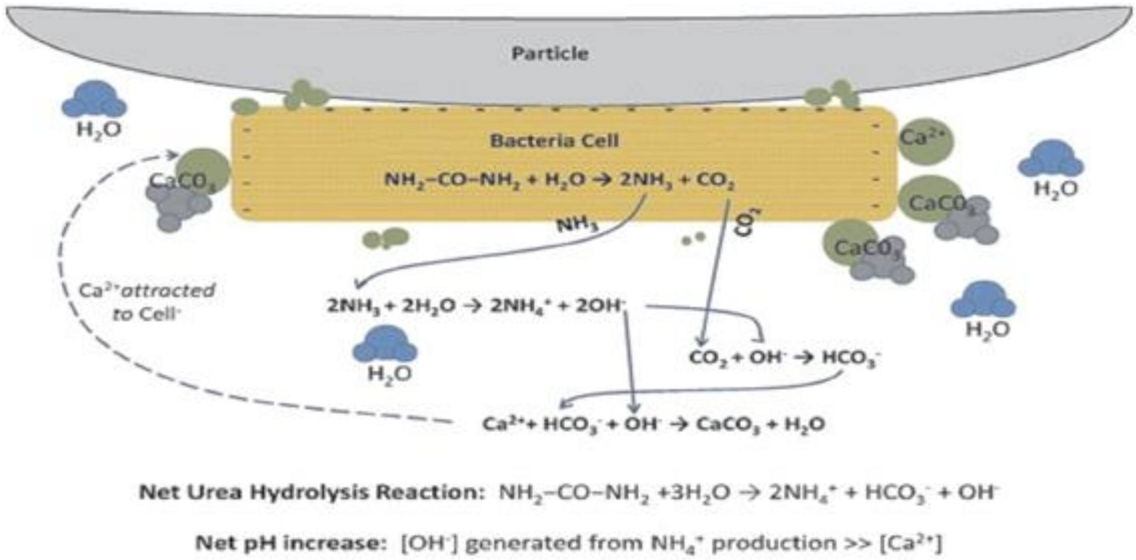


Figure (1) Microbial deposition process of calcite with urea hydrolysis mechanism

## Materials and Methods

### Microorganism used

The bacterium used in this study belongs to the Basilas family and has the scientific name of *Sporosarsina Pasteurii*. The strain of this bacterium has been purchased from the centre of Iran Mushroom Collection as lyophilized. The bacterial strain had to be activated in the laboratory first. For this purpose, a liquid culture medium containing 20 g / l yeast extract and 10 g / l ammonium chloride was formed by adding distilled water and then, to optimize the activity of urease, by adding potassium hydroxide to the solution, its pH was adjusted at 8.5 [9]. After sterilizing the culture medium in an autoclave for 20 minutes at a temperature of 120 ° C, the desired bacteria were first added to about 20 cm3 of the culture medium. For optimal aeration and growth, it was kept in an incubator shaker device at a speed of 150 rpm and a temperature of 28.5 ° C for 48 hours. After ensuring bacterial growth using a spectrophotometer, it was stored in the refrigerator until use. For use in soil, the grown bacteria were transferred to the culture medium in larger containers, and It was added to the soil surface immediately after reaching the desired concentration. Bacterial concentrations were read using a spectrophotometer. The amount of optical density, a dimensionless number, is read at a wavelength of 580 to 600 nm. In this study, ODs equal to 1, 1.5, 2 and 2.5 were used.

To provide a favourable environment and nutrients for bacterial growth in soil and cementation, urea with calcium chloride, sodium bicarbonate, ammonium chloride, and the nutrient broth were diluted. In this way, the urea dilution was first sterilized using a filter with a spring diameter of 0.22 microns(Urea is decomposed in an autoclave). Then, by preparing a dilution of the rest of the materials and sterilizing them in the autoclave, urea was added to the desired dilution and kept in the refrigerator as a cement solution until use. The concentrations of the substances listed in Table 1 are based on Whiffin *et al.* (2007)work. It is noteworthy that based on the relation of Ramachandran et al. given in relation 1, the number of live bacterial cells in ODs 1, 1.5, 2 and 2.5 is equal to 8.59 × 10^7,1.49 × 10^8, 2.21 ×10^8 and three ×10^8 cells per millilitre.

Relation(1): $Y = 8.59 \times 10^7 \times OD600^{1.3627}$

Table 1 Concentration of chemicals in cementation solution and bacterial culture medium

| Amount (grams per litre) | Cement solution | Bacterial culture medium |
|---|---|---|
| **20.00** | | Yeast extract |
| **10.00** | Ammonium chloride | Ammonium chloride |
| **20.00** | Urea | |
| **45.50** | Calcium chloride | |
| **3.00** | Nutrition Broth | |
| **2.12** | Sodium bicarbonate | |

## Soils Used

The primary purpose of this study is to investigate the application of the calcite microbial deposition method in stabilizing quicksand in desert areas that have the highest potential for fine dust production. Therefore, two types of sandy soils with silica and carbonate origin have been used. The effect of solutes in the soil on the efficiency of this method has been investigated. Also, to examine the distribution of soil particles on the efficiency of this method, two soil types of t60 siliceous sand and t90 silica sand have been used. Specifications for all three soil types are given in Table (2). It is one of the uses of silica sand in foundry factories, prepared from Chirok sand mines. One of the reasons for using this type of soil is to ensure the absence of any chemicals in the soil, the lack of adhesion, and its uniform granulation. The difference between these two siliceous areas of sand is in their granulation and distribution of particles, and t60 silica sand has a more exemplary grain distribution than t90 silica sand. The carbonate sand used belongs to the Khormoj region of Bushehr and has 60% calcium carbonate. The reason for using carbonate soil is to evaluate the efficiency of the biosementation method in the presence of calcium in the ground and the possibility of using this method in the desertification of the region. Clay and sticky soils, if moisture is added to them, depending on the type of mineral in them after drying, their strength will increase, and at the soil surface, a tubercle is created that can be used as a solution to the dust phenomenon; Therefore, if they are used due to the relatively low accuracy of the shear strength measuring device, it is not possible to observe the effect of bacteria. Another reason for not using this type of soil is distribution unevenly dissolved in soil due to soil adhesion, which reduces soil resistance to sandy soil. Of course, in clay with low plasticity, we have conducted studies and observed favourable results.

Table 2 Characteristics of soils used in research

| Parameter | T60 silica sand | T90 silica sand | Carbonated sand |
|---|---|---|---|
| $D_{50}$ (mm) | 0.28 | 0.25 | 0.2 |
| $\rho_{dmax}$ ( $g/m3$ ) | 1661 | 1632.00 | 1685 |
| $\rho_{d\,min}$ ( $kg/m3$ ) | 1401 | 1432.00 | 1463 |
| $G_s$ | 2.65 | 2.64 | 2.67 |
| $C_u$ | 1.7 | 1.75 | 2.96 |
| $C_c$ | 0.98 | 0.81 | 1.01 |

**Preparation of test samples**

The experiments were performed as factorial and in a completely randomized statistical design with three replications. To test trays with dimensions, two × 30 × 50 cm was used, and the soil sample was transferred to the trays after sterilization in an autoclave, and its surface was levelled. Then approximately 1/5 times the porosity of 3 mm thick surface soil where the blade of the feather cutting machine penetrated the volume of the mixture bacterial solution, and cementation solution are added to the soil in a ratio of 1: 1 and in ODs 1, 1.5, 2 and 2.5. The method of adding is by spraying and through a spray container evenly on the soil surface. The samples were then stored in a germinator at 28.5 ° C for 3, 7, 14, 20 and 28 days.

To evaluate the effect of bacteria in soil, the shear strength of the soil surface was used, which was measured using a fin cutter with five replications (figure 2). Because in this study, the shear strength of the soil surface has been investigated to combat wind erosion, and the bacterial solution has been sprayed on the soil surface. Therefore, a pocket or Torvin blade cutting machine has been used and inspired by the ASTM D 46 48 standards. This test can be used for loose to relatively hard soils, for which three blades with different shear strength ranges are used. When large blades (Sensitive) and small blades (high capacity) are used, coefficients of 0.2 to 2.5 are used. The steps of the experiments are as follows: First, the effect of storage time on the shear strength of three soil samples of t60 silica sand, t90 silica sand and carbonate sand was investigated, and the impact of ODs 1, 1.5, 2 and 2.5 on the shear strength of two silica sand soils t60 and t90 was investigated and after obtaining the optimal concentration of the bacterial solution, the shear strength of carbonate sand at the optimal concentration of bacterial solution over time was investigated. The second stage of experiments investigates the effect of re-injection of bacterial solution and cement solution with a time interval of 6 days on the shear strength of two soils of silica sand t60 and carbonate sand in the optimal concentration of bacterial solution over time. The third step is to investigate the effect of adding moisture to the soil on the shear strength. Also, the impact of environmental conditions on a sample of t60 siliceous sand soil was investigated. Statistical analysis of data was performed using SPSS software. An example of a ridge formed on the soil surface after the experiment is shown in Figure (3).

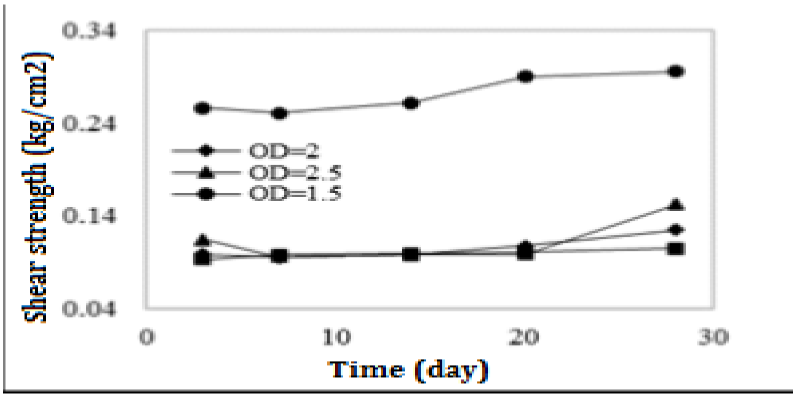
Figure (2): Blade cutting machine (Torvin)

Figure(3): Soil formed in the soil (after testing)

## Discussion and results

Investigation of the effect of retention time and bacterial concentration on shear strength and t60 silica sand T90 silica sand effect of storage time and attention of the bacterial solution on shear strength in both soils t60 silica sand, and t90 silica sand were significant at 1% level. The interaction effects of time and concentration in t60 silica sand were not significant, which shows that the effect of these two factors on the shear strength of soil is independent of each other. In comparison, in t90 silica sand, 1% has become significant (Table 3). Based on the results obtained in Figures 4 and 5, the shear strength has increased over time from 3 days to 28 days, which has been observed in all ODs, indicating bacterial activity and cementation in This period is when it has not stopped and as long as the environmental conditions are favourable and the nutrient is available to the microorganism this activity has continued. In t60 silica sand soil, the shear strength after 28 days in ODs 1, 1.5, 2 and 2.5 is 0.181, 0.393, 0.2 and 0.3 kg / cm2, respectively, while all three soils are treated with distilled water and treated with cement solution did not show any resistance; [10].

The distribution of soil particles should be such that bacteria with a size of 0.5 to 3 micrometres can quickly move and move in the soil. The best soil granulation range for bacterial growth and activity is reported to be between 50 and 400 μm [11]. The moving space will also allow the bacterium to spread evenly in the soil environment while trapped in the space between cavities; Therefore, the comparison between soil granulation properties and bacterial size is a significant factor in the process of micro calcite deposition. Here, t90 sand, which has a more acceptable grain size than t60 sand, has shown a more significant increase in shear strength, which due to the fineness of both soil types can be due to the proper contact of soil particles with each other and therefore better dispersion of calcite sediment in this species The soil is relative to t60 sand, which confirms the previous results. The results also show that in both soils, t60 silica sand and t90 silica sand in OD equal to 1.5 has the highest shear strength; Therefore, the optimal concentration of bacteria in the conditions of this study in OD was equal to 1.5. A high concentration of bacterial solution means more bacterias cells are in the solution. And with the increase in the number of bacterial cells, more urease enzyme is produced. Therefore, the area in the environment decomposes more, leading to more calcite deposition; But if the environmental conditions and materials nutrient is limited and constant. Increasing the concentration of bacteria does not guarantee more calcite deposition because the bacteria to perform the metabolic activity needs more favourable environmental conditions and more nutrients; Therefore, according to what has been said, the best balance between the amount of material present and the number of bacteria in this study in OD is equal to1.5 was obtained. The results of comparing the mean in both silica sand soils t60 and t90 show a significant difference in OD of 1.5 times compared to other ODs and a time of 28 days compared to other times (table 4). Shahrokhi-Shahraki *et al.* (2014), by investigating the effect of the biological method of calcite microbial deposition on compressive strength as well as hydraulic conductivity of two types of sand with two different granulations, observed a 3.5 to 5-fold increase in soil strength and a 10^-2 per cent decrease in permeability compared to the control sample and also concluded that this method it was more effective in fine-grained soil and also observed an optimal bacterial concentration in OD of 1 [12].




Figure(4): Shear strength changes of t60 silica sand at different concentrations over time

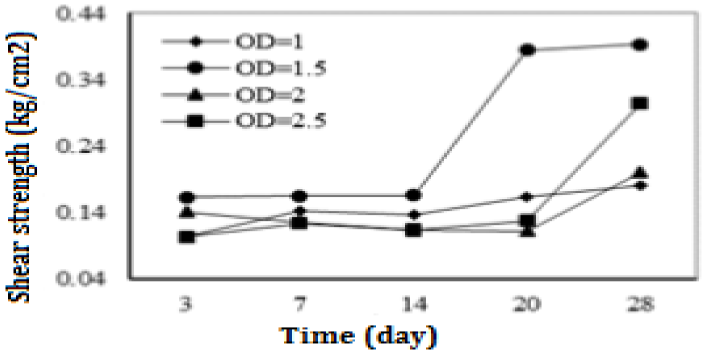



Figure (5): Shear strength changes of t90 silica sand at different concentrations over time

Effect of retention time on shear strength of carbonate sand at optimal concentration given that OD of 1.5 was obtained as the optimal concentration of bacteria, carbonate sand was studied in OD of 1.5. In the optimal OD in carbonate sand, the effect of time on shear strength is significant at the level of 1%(table3). Carbonate sand according to the routine observed in the two siliceous areas of sand t60 and t90, over time, the shear strength of the soil has increased, except for the two times of 7 and 14 days, in other times is a significant difference (Table 3). Compared to the two types of siliceous sand soils, the shear strength of carbonate sand has increased at a higher rate. So that for 28 days, its shear strength has risen from zero to 0.64 kg / cm2, i.e. compared to Similar conditions show a 38% increase over t90 silica sand and a 54% increase over t60 silica sand; Therefore, the phenomenon of cementation in soils of carbonate origin, as expected due to the presence of calcium, has occurred more than soils of siliceous origin; Hence the phenomenon of cementation as a biological process can occur in all soils, but the amount varies depending on the source of the soil under study.

Table 3 Results of analysis of variance the effect of concentration and time on shear strength of silica sand t90, t60 and carbonate sand

| **Carbonated sand** | | | **Siliceous sand t90** | | | **Siliceous sand t60** | | |
|---|---|---|---|---|---|---|---|---|
| **Sources of changes** | Degrees of freedom | average of squares | Sources of changes | Degrees of freedom | average of squares | Sources of changes | Degrees of freedom | average of squares |
| | | | Density | 3 | 0.03 | Density | 3 | 0.0691 |
| **Time** | 4 | 0.035 | Time | 4 | 0.03 | Time | 4 | 0.0014 |
| | | | Density * Time | 12 | 0.006 | Density * Time | 12 | 0.0002 |
| **error** | 5 | 0.000 | error | 20 | 0.000 | error | 20 | 0.0002 |

Table4 Results of comparing the mean effect of concentration and time on shear strength of silica sand t90, t60 and carbonate sand

| **Carbonated sand** | | | | **Siliceous sand t90** | | | **Siliceous sand t60** | | |
|---|---|---|---|---|---|---|---|---|---|
| **average** | time | average | time | average | Density | average | time | average | Density |
| **0.64** | 28 | 0.2699 | 28 | 0.2543 | 1.5 | 0.7 | 28 | 0.272 | 1.5 |
| **0.5067** | 20 | 0.1967 | 20 | 0.1542 | 2.5 | 0.15 | 20 | 0.112 | 2.5 |
| **0.474** | 7 | 0.1388 | 7 | 0.1382 | 2 | 0.14 | 14 | 0.106 | 2 |
| **0.3787** | 4 | 0.1318 | 14.000 | 0.1448 | 1 | 0.140 | 3 | 0.1 | 1 |
| **0.29** | 3 | 0.1272 | 3 | | | 0.13 | 7 | | |

Investigation of the effect of re-injection of bacterial solution and cementation on soil shear strength. In this case, the bacterial solution and cementation in OD are optimal and in two stages with an interval of 6 days from the first injection to two soils of t60 silica sand and carbonate sand have been added. The impact on time shear strength in both soil types was significant at the level of 1 % (Table 5). Comparison of the mean in both carbonate sand and silica t60 soils showed that the shear strength increased over time, significantly different in carbonate sand at all times. Still, in t60 sand in 14 days, there is a statistically significant difference compared to the two times. There are 3 and 7 days that can be caused by errors in the test (Table 6). As shown in Figure 6, re-injection of the bacterium increased the shear strength in both t60 silica sand and carbonate sand soils compared to the one-time injection, so that in the carbonate sand, it increased the shear strength by 29% over time. It has been 28 days that this in t60 silica sand showed a 55% increase compared to a single injection at 28 days.

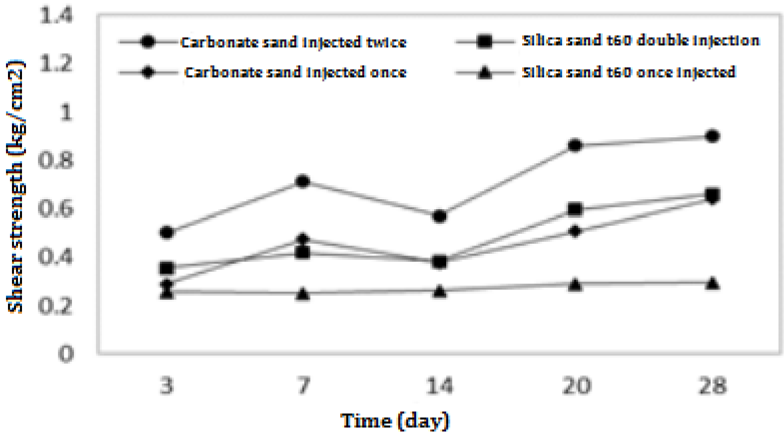



Figure 6 Changes in shear strength of carbonate sand at optimum concentration over time

Some authors investigating the effect of micro calcite deposition biological method on erodibility of sandy soil with erosion function device, to this It was concluded that re-injection of bacterial solution and cementation within six days from the first injection causes better performance of bacterial injection in reducing sand erodibility; Therefore, the distribution and injection of bacteria into the soil are essential factors in the process Microbial sediment is calcite, which is a two-stage injection of bacterial solution and cementation, if added to the soil at an optimal time interval, increases the biological stabilization efficiency of the soil, which was also observed in this study. Also, as mentioned, the rate of resistance by re-injection compared to one injection in silica sand t60 soil is higher than the soil with carbonate origin because bacteria need freedom of movement and access to food to perform their metabolic activity [13].

In carbonate sand in the first injection, due to the formation of more calcite deposit in the space between the particles, so by re-injection, the bacteria do not move freely.

The increase in strength is less than silica sand (29%), but the final strength in carbonate sand is higher; therefore, re-injection of bacteria and cement solution with an interval of 6 days has a more significant effect on increasing the strength of silica sand than carbonate sand.

Table 5 Results of analysis of variance of the effect of time on shear strength of carbonate sand and t60 in the case of double injection

| | Sand t60 | | | Carbonated sand | |
|---|---|---|---|---|---|
| **average of squares** | Degrees of freedom | Sources of changes | average of squares | Degrees of freedom | Sources of changes |
| **0.037** | 4 | Time | 0.061 | 4 | Time |
| **0.000** | 5 | ERROR | 0.000 | 5 | ERROR |

Table 6 Results of comparing the mean effect of time on shear strength of carbonated t60 silicate sand in double injection mode

| **Sand t60** | | **Carbonated sand** | |
|---|---|---|---|
| **average** | time | average | time |
| **0.66** | 28 | 0.9 | 28 |
| **0.595** | 20 | 0.861 | 20 |
| **0.419** | 7 | 0.712 | 7 |
| **0.384** | 14 | 0.57 | 14 |
| **0.3545** | 3 | 0.5033 | 3 |

## Investigating the effect of adding moisture on soil shear strength

To investigate the effect of excess moisture on bacterial activity, experiments for this purpose in silica sand soil t60 and t90 and half of the initial moisture in the bacterial solution and cementation was added to the soil moisture. The analysis of variance shows that the effect of storage time and concentration on shear strength in the case of adding moisture to the soil in both silica sand t60 and t90 soils was significant at the level of 1%. The results show a more substantial increase in bacterial activity and shear strength in added moisture in both soil types than in conditions where moisture is not added to the soil.

Figures 7 are shown. As specified, Within 14 days after adding moisture, soil resistance has an increasing trend due to the greater access of microorganisms to nutrients and more excellent metabolic activity. Still, after 14 days, the soil resistance decreased sharply due to the washing of salts and food and bacteria are in the lower depths of the soil, which causes the cementation phenomenon in the lower depths of the soil and the bottom of the container.

ODs. Comparison of average in t60 sand shows that in the available times and in the ODs used, the statistical difference in the amount of resistance is significant and the highest resistance created in OD is 1.5, which is statistically significant compared to the rest. In sand t60, also in OD equal to 1.5, the difference is statistically significant. There is also a difference between the time of 14 days and all test times significantly; this is not observed in other times.

Comparing the two soils of t60 siliceous sand and t90 silica sand in the presence of moisture addition, t90 sand, which has a finer granulation, has increased more resistance; therefore, the presence of moisture in the soil causes more bacterial activity and increased calcite deposition.

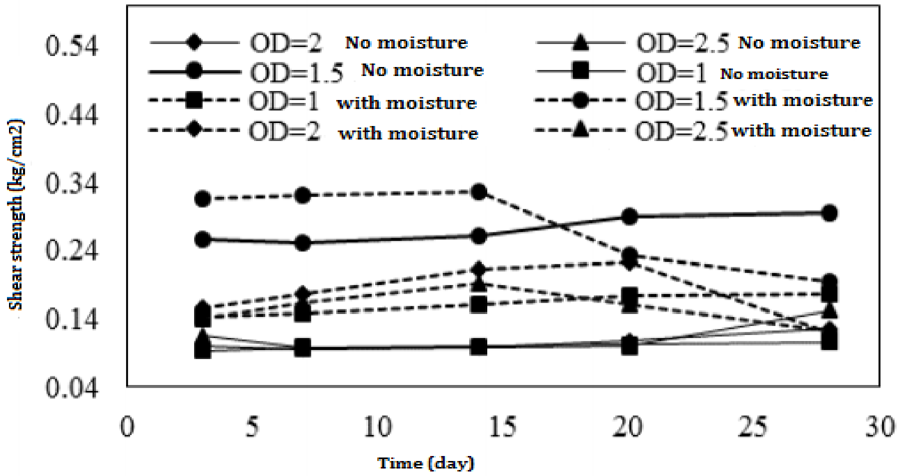



Figure 7 The effect of moisture addition on the shear strength of sand t60

Table 7 Results of analysis of variance Effect of concentration and time on shear strength of silica sand t90 and t60 in the presence of moisture

| **Silica sand t60** | | | **Silica sand t90** | | |
|---|---|---|---|---|---|
| **Sources of changes** | Degrees of freedom | average of squares | Sources of changes | Degrees of freedom | average of squares |
| **Density** | 3 | 0.038 | Density | 3 | 0.106 |
| **time** | 4 | 0.006 | time | 4 | 0.011 |
| **Density*time** | 12 | 0.002 | Density*time | 12 | 0.004 |
| **error** | 20 | 0.000 | error | 20 | 0.000 |

Table 8 Results of comparing the mean effect of concentration and time on shear strength of silica sand t90 and t60 in the presence of moisture

| **Siliceous sand t90** | | | | **Siliceous sand t60** | | | |
|---|---|---|---|---|---|---|---|
| **Density** | time | average | Density | Density | time | average | Density |
| **0.2233** | 14 | 0.2855 | 1.5 | 0.305 | 14 | 0.3871 | 1.5 |
| **0.2065** | 20 | 0.1774 | 2 | 0.2803 | 7 | 0.2865 | 2 |
| **0.2025** | 7 | 0.1602 | 1 | 0.2498 | 20 | 0.1828 | 2.5 |
| **0.1885** | 3 | 0.1556 | 2.5 | 0.2235 | 3 | 0.1651 | 1 |
| **0.1527** | 28 | - | - | 0.2185 | 28 | - | - |

## Investigation of the effect of environmental conditions on bacterial activity

To evaluate the bacterial activity and cementation action in actual conditions outside the laboratory, the bacterial solution and cementation in the optimal OD equal to 1.5 were sprayed on unsterilized t60 silica sand soil and outside the laboratory and in the shade, under variable temperature and humidity conditions were maintained for 110 days with the onset of storage in December.

Statistical analysis shows that time on shear strength is significant at a 1% level (Table 9). As shown in Figure 11, in the cold season of the year, the shear strength increases at a relatively low rate due to the low temperature. Still, with the favourable temperature, the soil resistance increases at a higher rate than 28-day shear strength; less was obtained in vitro.

The formation of dew droplets in these conditions is a positive point for a more bacterial activity to provide moisture; therefore, the results show the excellent performance of the biosementation phenomenon in natural conditions, so that after 110 days, soil resistance has reached 0.38 kg / cm2. The average comparison shows the amount of resistance obtained after 110 days, there is a statistically significant difference compared to other times, but most of the time, there is no significant difference that can be due to errors in the test and temperature fluctuations in this period when in

Table 9 can be seen. It should be noted that soil samples in the wind tunnel with a maximum wind speed limit of 10 m / s were studied that the erosion threshold of the control sample without bacteria was 3.5 m / s, and models stabilized with bacteria at the maximum wind tunnel speed Used did not suffer from erosion. If the wind speed in the desert is 8 meters per second, depending on surface roughness, moisture, vegetation, soil texture, etc., erosion occurs and leads to dust production. Therefore, considering that the standard wind speed is 8 meters per second, therefore

Biological stabilization of soil through microbial deposition process of calcite using bacteria, suitable options for desert control - Degassing and moving of quicksand is suggested. It can be a convenient alternative for all types of mulches and other stabilization methods with environmental, operational, and economic impacts. There are a series of limitations and problems. It is recommended to evaluate the degree of soil erodibility stabilized by this type of dissemination method in different resistances in wind tunnels with higher speed and the relationship between resistance and erodibility. Also, field studies to identify and review most of this method and simulation of desert temperature, which has been reported as a maximum of 60 ° C, are recommended for bacterial activity and soil resistance.

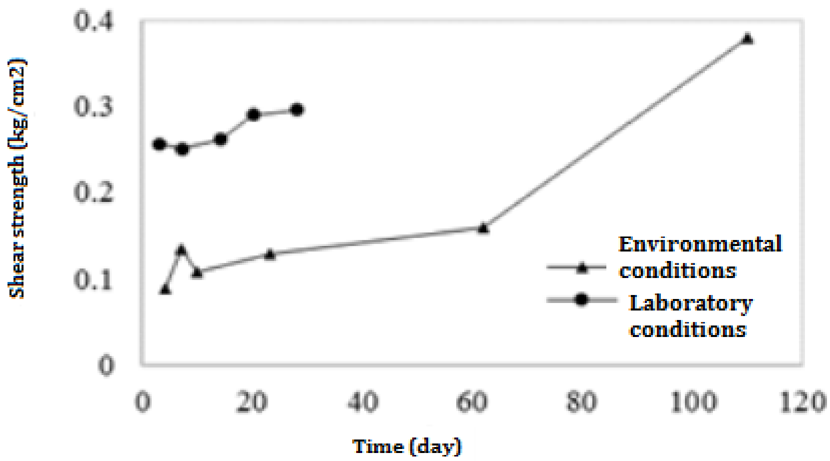



Figure 11. Comparison of shear strength of stabilized silica sand under laboratory conditions and environmental conditions.

## Investigation and comparison of existing methods in soil stabilization

Soil improvement methods vary depending on the type of project. Conventional methods used to stabilize the soil surface include the addition of gypsum, lime, cement, chemicals, Municipal waste, crop and food industry residues, water, salt, oil and coal mulches, various petroleum polymers and biodegradable environment, etc. Many researchers have discussed these methods. Risks of environmental pollution, high cost, short life and fire potential have challenged the use of these methods. There are more than 40,000 soil improvement projects in the world annually, all of which cost over $ 6 billion a year, and most of them use mechanical energy such as compaction, adding materials such as geosynthetics or cement to the soil. They come with a lot of costs.

Lime and cement are the most widely used materials in soil cementation and are found in abundance, and are relatively inexpensive. In cement remediation, high alkaline materials are added to the soil, which destroys the entire soil structure and reduces soil permeability to almost zero, thus changing the direction of groundwater movement in the soil depth. All chemical mortars used for cementation, except for sodium silicate, are toxic and have destructive effects on human health.

Therefore, with the expansion of cities to suburban areas and the reduction of suitable areas for the construction of buildings, there is a greater need for improvement. So far, no comprehensive study on soil cementation through large-scale microbial deposition of calcite has been conducted in Iran; Therefore, the question arises whether this issue is optimally and economically or not? Robin chemical mortars cost between $ 2 and $ 72, and biological mortars cost between $ 0.5 and $ 9 per cubic meter of soil (Tables 10 and 11).

Therefore, it is predicted that using this method to stabilize the soil surface will be much less expensive than stabilizing the soil depth. Of course, soil stabilization large-scale micro calcite deposition has been performed in several countries, and good results have been reported.

For example, the stabilization of the gas pipeline in the Netherlands in 2010, reduced polluted groundwater flow in the Dolostoni Formation with abundant joints in southern Ontario in Canada, assessed the capacity. Co-precipitation of heavy metals (strontium-90) with calcium carbonate and with the strategy of biostimulation of calcite microbial deposition in the Idaho National Laboratory in the USA, followed in Colorado, USA, and in the Netherlands and Austria to bio-block and reduce water seepage from water retaining structures. Microbial deposition of calcite was used.

The advantage of this method compared to other methods is that it is environmentally friendly and is done spontaneously in nature, but the speed of this process by adding a solution

Bacteria and cementation are added to the soil. Low viscosity quickly penetrates the soil pores, does not require injection pressure, improves soil resistance parameters without disturbing the soil, and costs less than other methods.

## Overall Conclusion

1. The use of biosynthesis causes a time-dependent increase in Shear strength in all three soil samples of silica sand t60 and carbonate sand compared to the sample was observed that the highest effect of bacterial solution concentration on shear strength at OD = 1.5 It was found that the best equilibrium state between The number of substances present and the number of bacteria in this study.

2. The type and solutes present in the soil and the distribution of granulation soil have a significant effect on the microbial deposition process of calcite, so that sand with carbonate origin has a more substantial increase in strength than the other two types of soil, which was siliceous. Showed shear and also in silica sand with a more proper grain size distribution, higher shear strength values were obtained which, slightly in the case of one injection, increased the shear strength in 28 days and optimal concentration, increase of about 38% in carbonate sand Compared to t90 silica sand and 54% increase compared to t60 silica sand.

3. In the case of double injection with an interval of 6 days, the resistance increased more than in the case of a single injection, so that in the optimal OD for 28 days, in t60 silica sand, The strength increased by 55% compared to the single injection mode, which was 30% in carbonate sand, with the final strength in carbonate sand being higher (0.9 kg / cm2) was obtained.

4. In the case of single injection and re-injection, in for more than 20 days, the rate of increase in resistance in all three soil types has decreased, which can be due to the lack of movement by microorganisms to do so form crystals. Calcite and unavailability of nutrients for activity; therefore, the optimal duration of 20 days is recommended.

5. With the addition of moisture, the values of shear strength increase due to the availability of nutrients by bacteria and do more activity; However, over more than 14 days, the addition of moisture reduces the cut-off resistance significantly, which can be due to leaching of salts, nutrients and bacteria to the lower depths of the soil.

6. The most comprehensive conclusion drawn from this study is that biological soil stabilization can be used as a suitable method to reduce wind erosion and control fine dust. According to the research done by the researchers mentioned in the text of the article, it is not limited in terms of implementation and economics. Of course, extensive and comprehensive studies on a larger scale to identify and review Challenges ahead in performance are recommended.

Table 9 Results of analysis of variance and comparison of the mean effect of time on shear strength of t60 silica sand in environmental conditions

| **Analysis of variance** | | | **compare of average** | |
|---|---|---|---|---|
| **Sources of changes** | Degrees of freedom | average of squares | time (day) | average |
| **Time** | 5 | 0.023 | 110 | 0.379 |
| **error** | 6 | 0.000 | 62 | 0.1592 |
| | | | 7 | 0.1354 |
| | | | 14 | 0.1284 |
| | | | 10 | 0.1083 |
| | | | 4 | 0.0880 |

Table 10 The cost of chemical mortars

| Chemicals | The value of additives ($/m 3 ) | The amount of additive required (kg/m3) | Price ($/kg) |
|---|---|---|---|
| **Lignosulphites - Lignosulphonates** | 0.1-0.3 | 20-60 | 2-18 |
| **Sodium silicate formulations** | 0.6-1.8 | 10-40 | 6-72 |
| **Phenoplasts** | 0.5-1.5 | 5-10 | 2.5-15 |
| **Acrylates** | 1.0-3.0 | 5-11 | 5-30 |
| **Acrylamides** | 1.0-3.0 | 5-12 | 5-30 |
| **Polyurethanes** | 5.0-10.0 | 1-5 | 5-50 |

Table 11 Cost of biological mortars

| Type of additive | The value of additives ($/m 3 ) | The amount of additive required (kg/m3) | Price ($/kg) |
|---|---|---|---|
| **Molasses+microorganisms** | 0.1-0.2 | 5-20 | 0.5-0.55 |
| **Homogenized food-processing wastes+ microorganisms** | 0.05-0.1 | 10-20 | 0.5-2.0 |
| **Iron one +organic wastes + microorganisms** | 0.1-0.2 | 10-20 | 1.0-4.0 |
| **Organic wastes (agricultural, horticultural, food -processing wastes)** | 0.05-0.1 | 10-20 | 0.5-2.0 |
| **Calcium chloride + urea + microorganisms** | 0.2-0.3 | 20-30 | 4.0-9.0 |

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