Stabilization of Silty Sand Soils with lime and Microsilica Admixture in presence of Sulfates

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ABSTRACT
In recent decades, using byproducts of industries to avoid accumulation and keep environment pure and safe is a necessity. Microsilica is one of such byproducts which are harmful for human health and environment. It contains approximately 95% silicon dioxide which can be used as a material in soil improvement in mixture with lime. Admixing Microsilica Fume and Lime into silty sand causes a reaction between silicon dioxide (SiO_2) of Microsilica and calcium hydroxide ($Ca(OH)_2$) of Lime and makes calcium silicate crystal which is a hard insoluble material. Such process increases strength parameters of soils. The main objective of this research is evaluation of effects of Microsilica and Lime admixtures on shear strength and swelling of Jandagh-Garmsar railway subgrade. The railway track of iran is located in the central desert of country.
Therefore to determine the best composition of Microsilica and Lime to improve mentioned soil, CBR tests have been performed. Results show that the addition of microsilica-lime to the silty sand soil increases the CBR strength and decreases swelling. So microsilica waste material can be successfully used to enhance silty sand soil resistance.

RÉSUMÉ-
Microsilice est l'un des sous-produits qui sont nocifs pour la santé humaine et l'environnement. Il contient environ 95% (SiO_2) qui peut être utilisé comme matériau dans l'amélioration du sol dans le mélange avec de la chaux. Mélangeant Microsilice fumées et de chaux dans le sable vaseux provoque une réaction entre (SiO_2) de microsilice et ($Ca(OH)_2$) de chaux et de cristaux de silicate de calcium fait qui est un matériau dur insolubles. Un tel processus augmente paramètres de résistance des sols L'objectif principal de cette recherche est l'évaluation des effets de microsilice et adjuvants chaux sur la résistance au cisaillement du sol et du sol enflure des Jandagh-Garmsar routier et ferroviaire sous-fondation.

1 INTRODUCTION

During the past decade, the road constructions of Iran have undergone a vast and rapid development.
Yet there is a major problem in providing an adequate road system, namely the scarcity of good road construction materials, which fit the adverse climate of different parts of the country and several other geological factors.

In facing with probable construction damage, civil engineers trials would aim in improving the engineering properties of the soil using different sorts of stabilization methods. For example, stabilization of subgrade railway soils which has traditionally relied on treatment with lime, cement, and special additives such as Pozzolanic materials. Pozzolanic materials, namely Fly Ash, Microsilica, and Rice Husk Ash, which are as waste material, may be used for soil improvement and would be described later on this research.

In the literature review different methods of sand stabilization are reported, including the main points of following papers, namely; use of cement (Bell, 1993; Aiban, 1994; Al-Aghbari et al., 2003); cement-by-pass dust (Baghdadi and Rahman,1990; Freer-Hewish et al., 1999; Al-Aghbari et al., 2003), bentonite (O'Sadnick et al., 1995), coal fly ash (Taha and Pradeep, 1997; Turner, 1997; Consoli et al., 2001) and asphalt (Wahab and Asi, 1997). Meanwhile re-enforcement of sand by fibers is being also reported (Al-Khanbashi et al., 2000; Kaniraj and Havanagi, 2001; Consoli et al., 2002).

indeed, a successful stabilization method depends on many factors such as: (1) soil type and properties; (2) stabilizing agent; (3) stabilizer content; (4) potential use of the stabilized soil; (5) field mixing method; and (6) economical considerations (Mohamedzein et al., 2006). Among all, the field mixing method could be considered as a powerful instrument for fulfilling the required stabilization goal.

Furthermore it is well-recognized that there is a difference between a well-controlled mixing environment in the laboratory and in the project field (O'Sadnick et al., 1995). Therefore, it is frequently important to construct small scale test sections in the field to validate the laboratory findings and to provide specifications for construction (Ali et al., 2000). The usage of incinerator ash in construction is widely reported in the project field for the latter aim (Ali et al., 2000).

Microsilica is a very fine pozzolanic material, composed of mostly amorphous silica produced by electric arc furnaces during the production of elemental silicon or ferro silicon alloys. In Europe until the late

1960's and in the United States till the mid 1970's, microsilica was being simply let to enter the atmosphere by industrial smoke. Nowadays, each year nearly 100,000 tons of microsilica is produced on purpose word wide. Iran also has a large amount of microsilica production.

Due to measuring by nitrogen absorption techniques, microsilica is shown to contain very fine vitreous particles with a surface area on the order of 20,000 (m^2/kg). (215,280 ft2/lb). These particles are approximately 100 times smaller than the average cement particle. Because of its extreme fineness and high silica content, microsilica is a highly effective pozzolanic material (Luther, 1990).

Due to the fact that Microsilica is sufficiently produced in IRAN and is widespread, this pozzolanic material could be potentially used in this country. When microsilica is led to burn under controlled temperature, higher pozzolanic properties would be observed. At first Silica which is the main mineral particle of microsilica once reacting with lime and would form a bonded gel [Ca (SiO_3)] (Abed El Aziz, 2003).

It should be noted that no experiment on the effects of microsilica on the geotechnical parameters of sandy soils has been described until now. In 1994, McKennon, et al. have found that the addition of microsilica fume plays a very important role on the improvement of chemical properties of lime treated clays. The addition of microsilica fume improves the reactivity of the mixtures of lime and soil. The concentration of aluminum in the aqueous phase is reduced when the microsilica fume is added to the mixture, and this reactions indicate that the addition of microsilica fume is an effective way to control the formation of deleterious products such as ettringite in sulphate bearing soils which stabilized with lime or other calcium based stabilizers such as Portland cement.

Ettringite formation is the cause of most of the expansion and disruption of lime or cement mixtures which involved in the sulphate attack (Collepardi, 2001). Furthermore another study by Kalkan, et al has established the positive effects of microsilica fume on the unconfined compressive strength, hydraulic conductivity, reducing the development of desiccation cracks and swelling pressure of clayey soils.

In this study we tried to improve California bearing ratio of silty sand soils by adding microsilica in construction of road and railways of Jandagh-Garmsar city.

2 Materials and methods

2.1 Silty Sand

The silty sand soil which used in these experimental researches was obtained locally and has been classified as SM according to the Unified Soil Classification System (USCS) with ASTM D2487 based on the gradation curve. (Figure.1).XRD pattern of this soil has shown in (Figure.2) and their chemichal property is summarized in (Tables 1).

2.2 Microsilica

Microsilica has been obtained from Ferroalloy Industrial Co (I.F.I) in Azna. The composition of microsilica mineral is shown in Table 2.

2.3 Lime

Quick lime which was used in this experiment was obtained by the industrial group Qom-Iran limestone and its chemical composition is shown in Table 3.

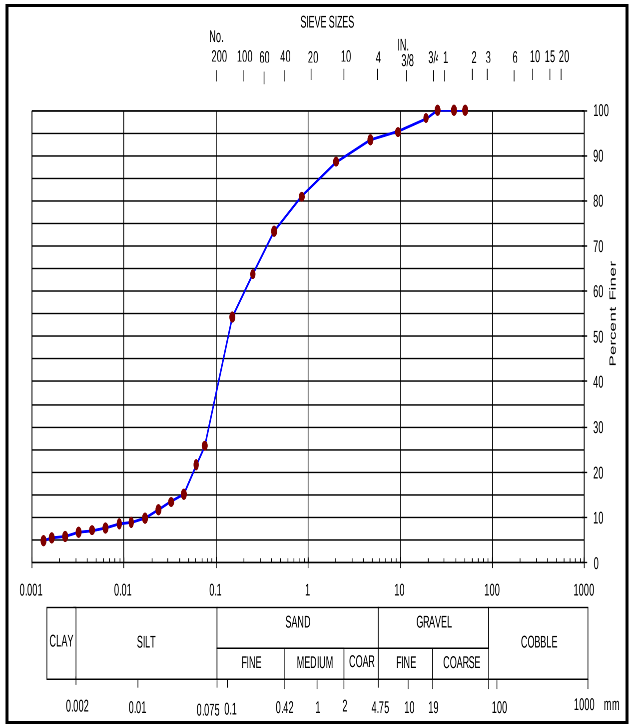

Figure. 1 Curve of Soil grading.

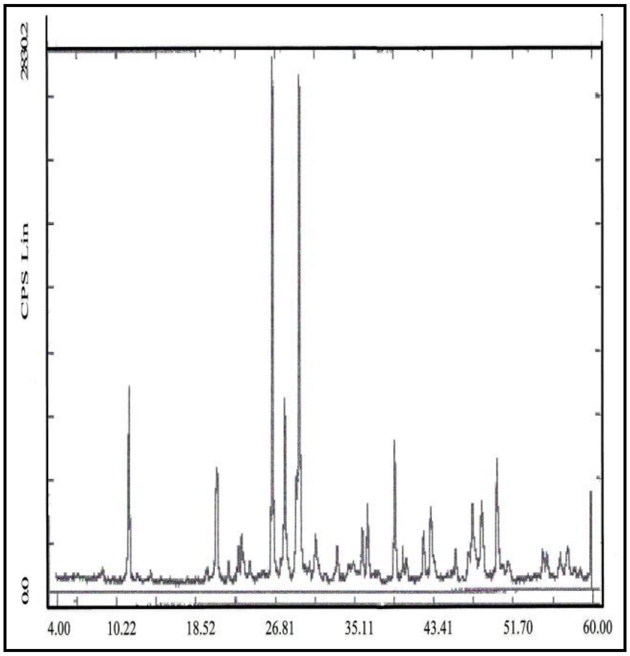

Figure. 2. XRD pattern of silty sand soil.

2.4 Specimen preparation

To prepare the mixtures of silty sand soil and Microsilica-lime, at first, the required amounts of silty sand soil and Microsilica-lime were measured by a total dry weight of sample and then they mixed together in the dry state. The dry silty sand soil and microsilica-lime were mixed with the required amount of water for optimum moisture content. Microsilica was added in percentages of 0, 1, 2, 5, 10 and 15% and lime was added in percentages of 0, 1, 3 and 5% by dry weight of the silty sand. The required amounts of microsilica and lime which were added to a dry silty sand sample were passing No. 4 sieve (4.75 mm). All mixes were mixed manually, and proper care was taken in order to prepare homogeneous mixtures at each stage of mixing.

Table 1. Chemical compositions of silty sand soil.

Chemical Names	Percentage
(MG, Fe)$_6$ (%)	2
$KAL_2SI_3ALO_{10}$ (OH)$_2$ (%)	4
$KALSI_3O_8$ (%)	5
$NaALSI_3O_8$ (%)	20
$CaSO_4$, 2H2O (%)	25
$CaCO_3$ (%)	20
SIO_2 (%)	23

Table 2. Chemical Properties of microsilica..

Chemical Names	Percentage
Mg O (%)	0.5~2
Ca O (%)	0.5~1.5
Fe_2 O_3 (%)	0.3~1.3
AL_2O_3 (%)	0.6~1.2
SIO_2 (%)	90~95
C	0.2~0.4
Na_2O_3	0.3~0.5
S	0.04~0.08
MnO	0.02~0.07
P_2O_5	0.04
LoI	0.4~3
PH	6.6~8.8
Moisture	0.01~0.4

Table 3. Chemical properties of lime.

Chemical Names	Percentage
K_2O (%)	4
SO_3 (%)	0.8
Mg O (%)	2.65
Ca O (%)	51.64
Fe_2 O_3 (%)	0.13
AL_2O_3 (%)	0.24
SIO_2 (%)	1.36

2.5 Compaction Tests

The modified proctor tests were conducted to find out the optimum water content and the maximum dry unit weight value of the microsilica stabilized materials in accordance to ASTM D 1557–1558.

2.6 CBR Tests

For CBR tests, the specimens were mixed at different percentages of microsilica and lime and then the optimum water content was addet to them. Then they were compacted in the molds. CBR tests in accordance to ASTM D 1883–1887. The compacted soil was cured in a sealed plastic bag at room temperature for 7 and 28 days and \soaking samples kept in water for 4 days under a overcharge weight of 5.5 kg. At the end of 4 day, the samples were taken out, drained and tested. The rate of penetration of the C.B.R plunger was kept at 1.27 mm per minute.

3 Results and Discussion

3.1 Compaction test

Modified proctor tests were done on both raw soil and microsilica and lime–soil mixed samples to determine their optimum water content and maximum dry unit weight. Due to the addition of microsilica and lime there was an increase in the optimum moisture content and a decrease in the maximum dry unit weight

The reason for increase in the optimum moisture content is due to the changes in surface area of composite samples. Microsilica changes the particle size distribution and surface area of the stabilized silty sand soils samples (Pera et al., 1997; Kalkan and Akbulut, 2004; Yarbasi et al., 2007). In the same way, the reason for decreasing in the maximum dry unit weight is the addition amounts of microsilica with low density, which fills the voids of the composite samples (Atom and Al-Sharif, 1998; Kalkan and Akbulut, 2004). According to the Proctor experiment results, the maximum dry unit weight of silty sand soil has reduced from 2 to1.66 kN/m³, whereas the optimum water content has increased from 9.6 to 13 %. The results are shown in (Figure. 3).

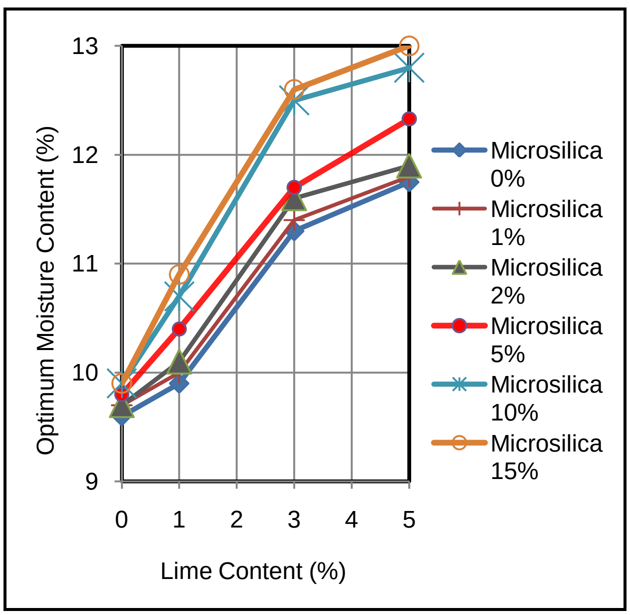

Figure.3. Influence of microsilica-lime on optimum moisture content of silty sand soil.

3.2 CBR tests

The samples were prepared with optimum water content and mixture of dry silty sand soil and microsilica and lime at percentages of 0, 1, 2, 5, 10 and 15% for microsilica and 0, 1, 3 and 5% for lime and then they were compacted. Compacted samples were cured in a sealed plastic bag at laboratory temperature for 7 and 28 days

The C.B.R results are as below. (Figure 4, Figure 5, Figure 6, Figure 7)

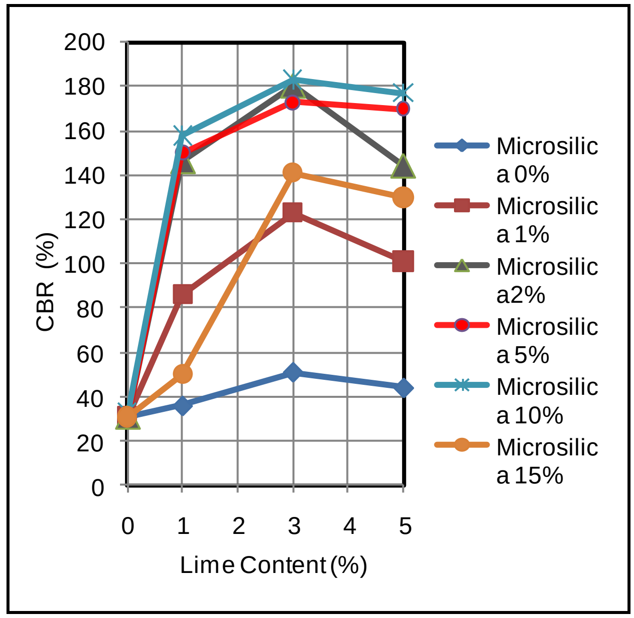

Figure. 4. CBR test results of the unsaturated silty sand soil stabilized by microsilica and lime (7 days cured).

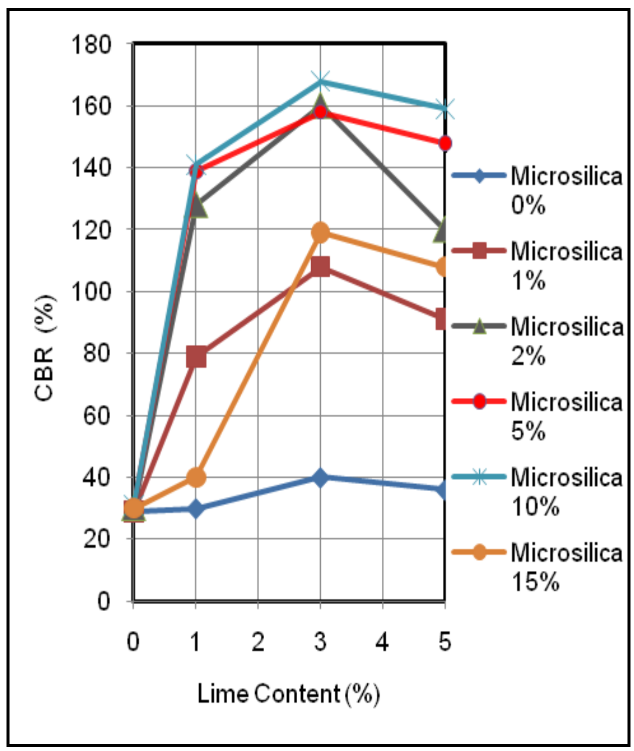

Figure. 5. CBR test results of the saturated silty sand soil stabilized by microsilica and lime (7 days cured).

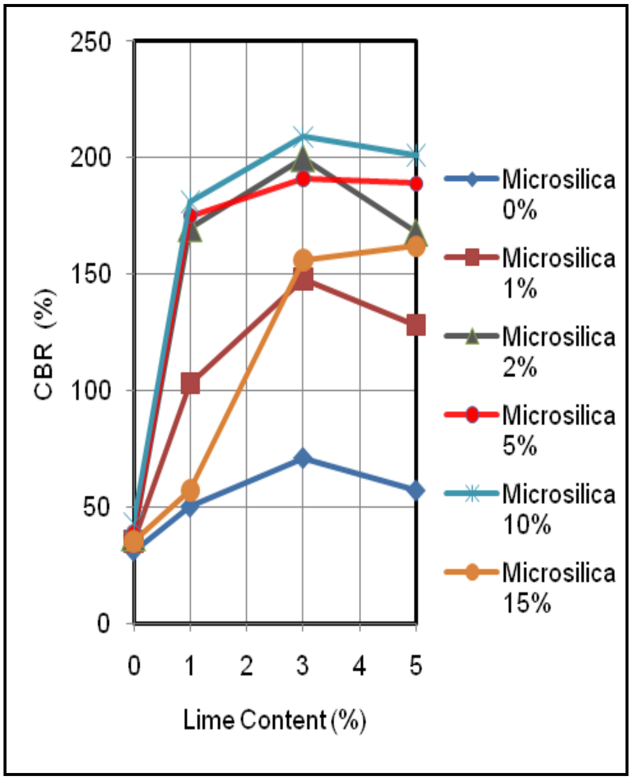

Figure. 6. CBR test results of the unsaturated silty sand soil stabilized by microsilica and lime (28 days cured).

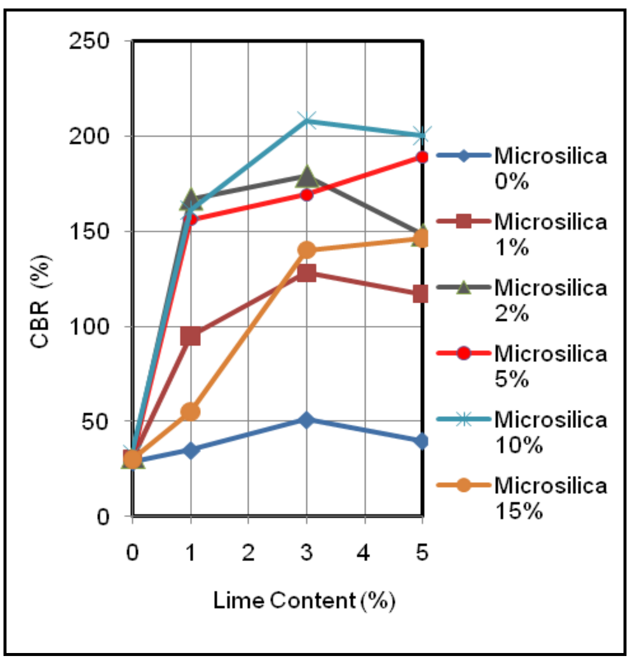

Figure. 7. CBR test results of the saturated silty sand soil stabilized by microsilica and lime (28 days cured).

Figure 4 and figure 5 describe the effects of microsilica-lime contents against the CBR for stabilized silty sand soil samples. CBR strength of stabilized samples significantly increases with microsilica content up to 10%.Moreover; the samples containing 15 %.of Microsilica would undergo a massive reduction of CBR resistance.

Due to the stabilized silty sand soil, maximum CBR strength of the samples which containin 10% microsilica and 3% lime increase from 31 to 209 %. Nevertheless, for the soaked samples we did not observed a significant CBR resistance reduction. The probable reason is the addition of higher amounts of microsilica with extra fine particles, which fills the voids of the composite samples and causes chemical reaction between microsilica and soil material, in contrast, the samples that were made only by lime show a lower resistance in saturated conditions.

As the figure 4 describes, when microsilica is only mixed with soil, it would not influence the resistance of soil, so significantly, if keep company with lime, it would results in a great soil resistance.

On this account, the stabilized silty sand soil samples have displayed high CBR strength. The increase in the CBR strength is attributed to the internal friction of microsilica particles and chemical reaction between microsilica-lime and silty sand soil. Increasing in microsilica content has made the stabilized silty sand soil samples more brittle than the natural silty sand soil samples, which is ductile as compared to all the stabilized samples. This phenomenon is as well reported by Kalkan (Kalkan, 2009)

3.3 Reaction Mechanism

Microsilica is a pozzolanic material and silica is a main mineral of it. When the active silica reacted with lime, it will form a bonded gel [Ca (SiO_3)]. Indeed silica reacts with calcium and hydroxide forming calcium silicate hydrate gels. This chemical modification is likely to cause stronger and more hardening forms of material composing microsilica-lime and soil mixture and decreases their volumetric shrinkage strain (Bell, 1993; Sherwood, 1993; Kalkan and Akbulut, 2004).

3.4 Swelling Tests

By using of microsilica swelling rate of mixtures have reduced considerably as far as there was only one specimen with 1 % microsilica and 1 % lime which had swelling.but mixtures which were made by lime and silty soil had swelling.(Table 4, Table 5).

Table 4. Swelling rate of soil-lime saturated samples

Soil-lime Swelling (mm)		
	7 days cured	28 days cured
Quicklime (1%)	10	7
Quicklime (3%)	0.93	0.5
Quicklime (5%)	1.09	0.91

Table 5. Swelling rate of soil-lime-microsilica saturated samples

Soil-1 %lime-1%microsilica Swelling (mm)		
	7 days cured	28 days cured
Quicklime (1%)	0.1	0.13

4 Conclusions

This paper examines the effect of adding microsilica and lime to the silty sand soils for improving CBR strength of road and railway subgrade of Jandagh city to Garmsar city in Iran.

The microsilica-lime mixture change compaction parameters. The addition of microsilica increases the optimum moisture content and decreases the maximum dry unit weight of specimens.

The addition of microsilica-lime to the silty sand soil increases the CBR strength. Yet it is concluded that up to 10 percent increase in microsilica helps the resistancy of soil but, if this percentage reach up to 15 percent we would observed a reduction in soil resistance.

Using only microsilica would not be useful for stabilization of silty sand soils and it would need to be performed along with an activator like lime.

The results of swelling showed that swelling rate has vice versa ratio with samples strength, and less strenght cuses more swelling

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