Strength Improvement of Clay Soil by Using Stone Powder

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ABSTRACT

Soil stabilization with stone powder is a good solution for the construction of subgrade for road way and railway lines, especially under the platforms and mostly in transition zones between embankments and rigid structures, where the mechanical properties of supporting soils are very influential. Stone powder often has a unique composition which justifies the need for research to study the feasibility of using this stone powder type for ground improvement applications. This paper presents results from a comprehensive laboratory study carried out to investigate the feasibility of using stone powder for improvement of engineering properties of clays.

The stone powder contains bassanite ($CaSO_4$. ½ H_2O), and Calcite ($CaCO_3$). Three percentages are used for stone powder (1%, 3% and 5%) by dry weight of clay. Several tests are made to investigate the soil behavior after adding the stone powder (Atterberg limits, Standard Proctor density, Grain size distribution, Specific gravity, Unconfined Compressive test, and California bearing ratio test). Unconfined Compressive tests conducted at different curing. The samples are tested under both soaked and unsoaked condition. Chemical tests and X-ray diffraction analyses are also carried out.

Stone powder reacts with clay producing decreasing in plasticity and The curves of grain size distribution are shifted to the coarse side as the stone powder percentage increase; the soil becomes more granular, and also with higher strength.

Keywords: strength improvement of clay, soil-stone powder mix, effect of stone powder.

تحسين قوة التربة الطينية باستعمال مسحوق الحجارة

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الخلاصة

تثبيت التربة بمسحوق الحجارة حل جيد لانشاء الطرق و خطوط السكة الحديد ، وخصوصا تحت الابراج في مناطق الانتقال بين السدة الترابية و الهياكل الصلبة. حيث ان الخواص الميكانيكية للترب الداعمة مؤثرة جدا. مسحوق الحجارة له في اغلب الاحيان تركيب فريد يبرر الحاجة لبحث دراسة عملية لاستعمال هذا النوع من مسحوق الحجارة لتطبيقات تحسين الارضية. يقدم هذا البحث نتائج لدراسة مختبرية شاملة نفذت لتحري عملية استعمال مسحوق الحجارة لتحسين الخواص الهندسية للطين.

مسحوق الحجارة يحتوي على كبريتات الكالسيوم ($CaSO_4$. ½ H_2O) و كاربونات الكالسيوم ($CaCO_3$) تم استخدام ثلاث نسب مئوية لمسحوق الحجارة (1% ، 3% و 5%) من الوزن الجاف للطين. تم اجراء العديد من الاختبارات لتحري سلوك التربة بعد اضافة مسحوق الحجارة (حدود اتربرك ، كثافة بروكتر القياسية ، التدرج الحبيبي للتربة ، الوزن النوعي ، اختبار الانضغاط الغير

محصور و اختبار نسبة تحمل كالفورنيا). اختبارات الانضغاط الغير محصور اجريت في معالجة مختلفة .تم اختبار النماذج في اطار كل من حالة المنقع و الغير منقع. الاختبارات الكيميائية و فحص XRD تم تنفيذهما ايضا.

مسحوق الحجارة يتفاعل مع الطين لينتج انخفاض في اللدونة وكذلك منحنيات التوزيع الحبيبي للتربة تحولت الى الجانب الخشن كما تم زيادة مسحوق الحجارة. لتصبح التربة اكثر حبيبية و ايضا زيادة في القوة بسبب التفاعلات الفيزيائية و الكيميائية بين التربة و مسحوق الحجارة و الماء.

الكلمات الرئيسية: تحسين قوة الطين ، خليط التربة – مسحوق الحجر ، تاثير مسحوق الحجارة.

1. INTRODUCTION

Pre-construction treatment of soft and weak deposits is necessary to ensure safety and stability of the building or infrastructure. The conventional method of soil stabilization is to remove the weak soil and replace with a stronger material, **Ingles, and Metcalf, 1972.** The high cost of this method lead to researchers to look for alternative methods, and one of these methods is the process of soil stabilization using stone powder.

Stone powder used may improve the engineering properties of clay to make them suitable for construction. The many advantages of stone powder, including low expansion, even after 48 hours and improved compressive strength. This paper presents a summary of a research project investigating one of the alternatives to improve soil. Specifically the paper presents results of a laboratory investigation of the stabilization properties of clay blended with stone powder.

2. REVIEW OF LITERATURE

Projects of Civil engineering located in soft clay have traditionally considered improving soil properties by using cement, lime and silica fume. Lately projects containing soil mixed with fly ash have been reported, **Reyes and Pando, 2007.** For the particular case the stone powder no literature was found reporting ground improvement applications, constitutes stone powder a cost effective and environmentally beneficial alternative with considerably less capital investment.

3. EXPERIMENTAL PROGRAM

The feasibility of using stone powder is investigated through a comprehensive laboratory experimental program. The program primarily involved assessing the stabilization characteristics of a clay soil when blended with stone powder. The stabilization characteristics are measured in terms of strength and stiffness gain, etc.

The following subsections describe the materials used (clay soil, stone powder), and experimental procedures (sample preparation, and test procedures).

3.1 Materials

Two materials are used for the laboratory experimental program carried out in this research: clay soil and stone powder.

3.1.1 Clay soil

The clayey soil used for this study is obtained from Baghdad city, located in center of Iraq. The geotechnical properties of the clay are determined by conducting grain size distribution, specific gravity, Atterberg limits, standard proctor density, unconfined compressive, and California bearing ratio (CBR). A summary of the main properties of the clay used for this research is presented in

Table 1. A grain size distribution analyses was carried out following ASTM Standard D 422 indicating the clay had 1% sands, 61% silt sizes, and 38% clay sizes. According to the Unified soil Classification system this soil classifies as a CL which corresponds to low plasticity clay.

3.1.2 Stone powder

Stone powder is defining a hard stones for dies characterized by enhanced hardness and low expansion. It can exhibit both pozzolanic and cementations properties. They must have high resistance to compression and abrasion. Stone powder is used in the teeth manufacture, chrome models. The product not classified as hazardous pursuant to directives 67/548/EEC and 1999/45/EC and subsequent amendments and upgrades and does not contain substances classified as being hazardous to human health or the environment pursuant to 67/548/EEC and subsequent amendments. The quantitative X-ray diffraction test is conducted on sample to determine the mineral contents of the stone powder. The State Company of Geological Survey and Mining, Ministry of Industry and Minerals, conducted this test.

Stone powder is contains some Calcite ($CaCO_3$), and calcium sulfate ($CaSO_4 . ½ H_2O$). A summary of the main properties of the stone powder used for this research is presented in Table 2.

3.2 Experimental Procedures

Prior to soil treatment, the clay soil from Baghdad city is air dried for two weeks and then processed using crushing equipment. The maximum particle size of the soil is restricted to 4.75 mm which corresponds to the opening of a standard Sieve No. 4.

The amount of stabilizer to be used is found from the following formula, **Geiman, 2005.**

$$\text{Amount of stabilizer} = \frac{p_s \times W_{tot}}{(1+w)} \tag{1}$$

where

p_s= Percent by dry weight of stabilizer to be used,

W_{tot} = Wet weight of batch prior to addition of stabilizer, and

w = Moisture content of soil prior to addition of stabilizer, expressed as a decimal.

Soil samples treated with stone powder are prepared with three amounts of stone powder (1, 3, and 5% of stone powder by weight).

The geotechnical properties of the clay stabilized with stone powder are determined by conducting the following laboratory tests.

1. Grain Size Distribution: Tests for sieve, and the hydrometer analysis, are performed after removing any unusually big chunks of clay. The test procedure provided in ASTM test designation D422.
2. Specific Gravity: Values for specific gravity of the soil solids are determined according to (B.S. 1377:1990, test No. 6 B) by placing a known weight of oven-dried soil in a flask, then filling the flask with water.
   The weight of displaced water is then calculated by comparing the weight of the soil and water in the flask with the weight of flask containing only water. The specific gravity is then calculated by dividing the weight of the dry soil by the weight of the displaced water.
3. Atterberg Limits: The liquid and plastic limits are determined in accordance with ASTM test designation D4318.

4. Standard Proctor Density: These tests are conducted on the clay samples treated with stone powder for determination of the moisture density relationship (ASTM D698).
5. Unconfined Compressive Tests: The specimens for unconfined compressive strength tests of clay soil blended with stone powder, are all prepared to the same target moisture content of 14.8% (i.e., the optimum moisture content of the untreated soil). The soil- stone powder samples are compacted inside standard proctor mold. The soil- stone powder blends are compacted by placing the mixtures in 3 equal layers and applying 25 blows to each layer using the standard proctor hammer. The sample for unconfined compressive strength tests is prepared 36.5 mm in diameter and 72.5 m in height. The samples are tested under both soaked and unsoaked. The unsoaked compacted samples are kept in box. The specimens are periodically sprayed with water for curing of 3, 7 and 28 days. At the end of the required curing period, the samples are withdrawn from the box, and kept in unconfined compression test machine. Another set of samples is also kept submerged in water for the periods mentioned as above before testing under soaked condition.

   Unconfined compressive tests are also carried out on uncured samples which are tested immediately after compaction, i.e., corresponding to an age of 0 day .A test procedure in general accordance with ASTM Standard D 2166.
6. CBR Tests: California Bearing Ratio tests are conducted using the procedure given in ASTM test designation D 1883-07. The samples are soaked for 4 days before performing the tests. A penetration rate of 1.25 mm per minute was used.

4. LABORATORY TEST RESULTS AND DISCUSSION

4.1 Grain Size Distribution

The grain size distribution curves for soil- stone powder mix, as obtained from sieve and hydrometer analyses are presented in **Fig. 1.** The curves are shifted significantly to the coarser side as the stone powder percentage increases; the soil becomes more granular. This may be caused by the immediately pozzolanic reaction which causes the flocculation of clay particles. The results of tests are listed in **Table 3.**

4.2 Specific Gravity

Fig. 2 shows the specific gravity values of the soil mixed with different percentages of stone powder. Also, it shows the decrease in specific gravity of soil with increasing of stone powder content due to the low values of the specific gravity of stone powder.

4.3 Atterberg Limits

In this section, the clay consistency is investigated during soil stabilization. The effect of adding stone powder to the clay soil on Atterberg limits is shown in **Fig.3.** One can notice a decrease in liquid limit because the calcium of the stone powder exchanges with the adsorbed cations of the clay mineral, resulting in reduction in size of the diffused water layer surrounding the clay particles.

This reduction in the diffused water layer allows the clay particles to come into closer contact with one another, causing flocculation/agglomeration of the clay particles. A reduction in plasticity happens when the clayey soil is mixed with stone powder due to converting the soil to the granular mass and at the same time the bonds between the soil particles become stronger due to cation exchange that takes place between negative ions on the surface clay particles and the calcium ions of the stone powder.

4.4 Compaction Tests

Figure 4 shows the relationship between dry unit weight and water content for different stone powder contents. While **Fig.5** presents the effect of stone powder on the optimum water content, and **Fig. 6** shows the effect of stone powder on the maximum dry unit weight.

It can be seen that there is a decrease in compactive effort due to reduction in the parallel orientation to the clay particles, **Fig.4** while **Fig.5** shows that the optimum water content increases from 14.8% to 17.21% at 5% stone powder. In **Fig.5,** the increase in the optimum moisture content is due, in spite of the reduced surface area caused by flocculation and agglomeration, to the additional fine contents to the samples which requires more water in addition to the stone powder that needs more water for the pozzolanic reactions to take place. The increase in optimum moisture content due to addition of stone powder may be caused by the absorption of water by stone powder.

The variations of maximum dry unit weight and stone powder content showed that stabilizer content decreases the maximum dry unit weight from 17.8 to 17.21 kN/m^3, **Fig.6.** The relatively low unit weight of stone powder treated samples of clay coupled with the observed increase in unconfined compressive (as discussed later in the paper) is an important consideration in determining suitability of stone powder treated clay for construction work.

4.5 Unconfined Compressive Tests

The relationship between unconfined compression and time are shown in **Figs.7** and **8** for stone powder in unsoaked and soaked condition respectively. Unconfined compressive tests on untreated soil are shown in **Fig.9.**

From the results for two conditions, it can be observed that the stone powder increases, this will lead to shear strength of the stabilized soil gradually increases with time mainly due to pozzolanic reactions. Interaction between water with stone powder lead to produces calcium hydroxyl. Calcium hydroxide in the soil water reacts with the silicates and aluminates (pozzolans) in the clay to form cementing materials or binders, consisting of calcium silicates and/or aluminate hydrates. For stone powder -soil mixture at the same stone content, the effect of increasing the curing is to increase strength. The curing and temperature has been found to affect the long term reactions between stone powder and clay. The increase factor of the unconfined compression strength in 28 days for the soaked and unsoaked condition is shown in **Table** 4 and **Table** 5 respectively. the five percent showing little strength gain in comparison with three percent .From unconfined compression test, it has been indicated that the optimum percent of stone powder of 3% from will increase the unconfined compression strength from 114 to 276 kN/m^2 in 28 days for the soaked condition and from 114 to 338 kN/m^2 in 28 days for the unsoaked condition.

4.6 CBR Tests

The results of CBR tests for various treated and untreated samples of clay are shown in Table 6. These values are based on 1.25 mm penetration. Comparison of CBR values for the different tests indicates that the significant improvement in CBR values can be achieved by treating samples of clay with stone powder admixtures.

5. CONCLUSIONS

This paper has discussed the results of a laboratory investigation involving use of elite stone powder for ground improvement of clays.

1. A decrease in liquid limit and plasticity index with the addition of stone powder. Pozzolanic reactions occur because of the siliceous and aluminous material which possesses little cementitious value and large particles which produces decrease in liquid limit.
2. A decrease in specific gravity of soil was obtained with increasing of stone powder content due to the low values of the specific gravity of stone powder (2.58).
3. The curves of grain size distribution are shifted significantly to the coarser side as the stone powder percentage increase; the soil becomes more granular. This may be caused by the immediately pozzolanic reaction which causes the flocculation of clay particles.
4. When are increased stone powders, the maximum dry unit weight decreases from 17.8 to 17.21 kN/m^3.
5. The optimum moisture content increases with increase of stone powder percents from 14.8% to 17.21%, due to due to the addition of stone powder contents to the samples which needed more water for the pozzolanic reactions to take place.
6. The shear strength of the stabilized soil gradually increases with time mainly due to pozzolanic reactions. Calcium hydroxide in the soil water reacts with the silicates and aluminates (pozzolans) in the clay to form cementing materials or binders.
7. the test results indicate that clay soils treated with stone powder result in adequate ground improvement as evidenced from higher strengths measured from unconfined compressive tests.
8. The five percent showing little strength gain in comparison with three percent.
9. The compressive strength gains were observed primarily in the initial 7 days of the curing period irrespective of stone powder contents used in the stabilized soil cushion and then had a tendency to stabilize showing little strength gain.
10. CBR values also improve with addition of stone powder mixtures to clay due to chemical interactions among soil, stone powder and water to form cementing materials or binders.

6. REFERENCES

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NOMENCLATURE

p_s = percent by dry weight of stabilizer to be used,
W_{tot} = wet weight of batch prior to addition of stabilizer, gram
w = moisture content of soil prior to addition of stabilizer, %

Table 1. Physical and chemical properties of soil.

Properties	Value
Liquid limit	38
Plastic limit	24
Plasticity index	14
Shrinkage limit	17
Specific gravity, Gs	2.72
Maximum dry density (Standard Proctor) (kN/m^3)	17.8
Optimum water content (Standard Proctor) (%)	14.8
Unconfined compressive (kN/m^2)	114
pH	8.45

So3 %	0.20
CL%	0.04
SiO2 %	35.82
Fe2O3 %	5.5
T.S.S	0.25

Table 2. Physical and chemical properties of stone powder.

Properties	Value
Water/powder ratio	25 ml / 100 g
Expansion after 2 h	0.08%
Expansion after 48 h	0.09%
Compressive strength after 1 h	42 MPa
Compressive strength after 48 h	60 MPa
Density	23 kN/m^3
Specific gravity	2.58

Table 3. Grain size distribution analysis results for soil- stone powder mix.

Stone powder %	**0%**	**1%**	**3%**	**5%**
Sand size %	1%	3%	3%	6%
Silt size %	61%	66%	67%	71%
Clay size %	38%	31%	30%	23%

Table 4. Increase factor of the unconfined compression strength in the soaked condition.

Soil treatment		**Normal soil**	**Increase factor %**
Stone powder additive %	**Unconfined compression in 28 day**	**Unconfined compression**	
1	206	114	44.6
3	276	114	58.6
5	319	114	64.2

Table 5. Increase factor of the unconfined compression strength in the unsoaked condition.

Treatment soil		**Normal soil**	**Increase factor %**
Stone powder additive %	**Unconfined compression in 28 day**	**Unconfined compression**	
1	253	114	54.9
3	338	114	66.2
5	378	114	69.8

Table 6. CBR results for soil- stone powder mix.

Stone powder additive %	CBR Results
0	4.5
1	5.2
3	6.0
5	7.1

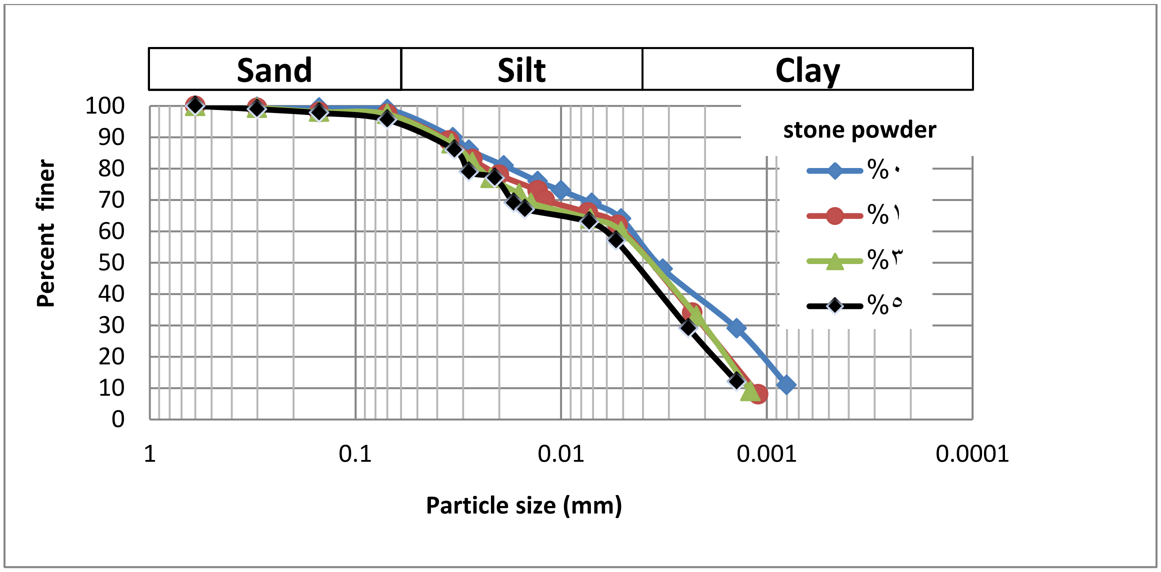

Figure 1. Grain size distribution of the soil stabilized with stone powder.

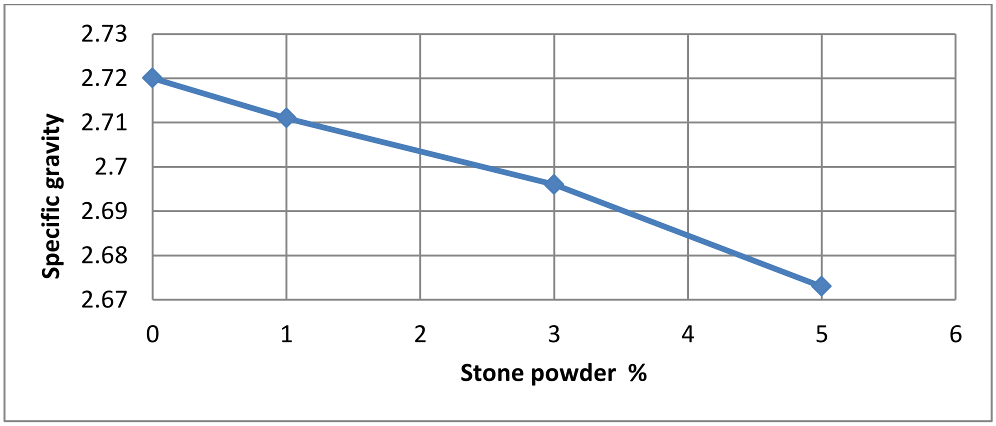

Figure 2. Effect of stone powder content on specific gravity.

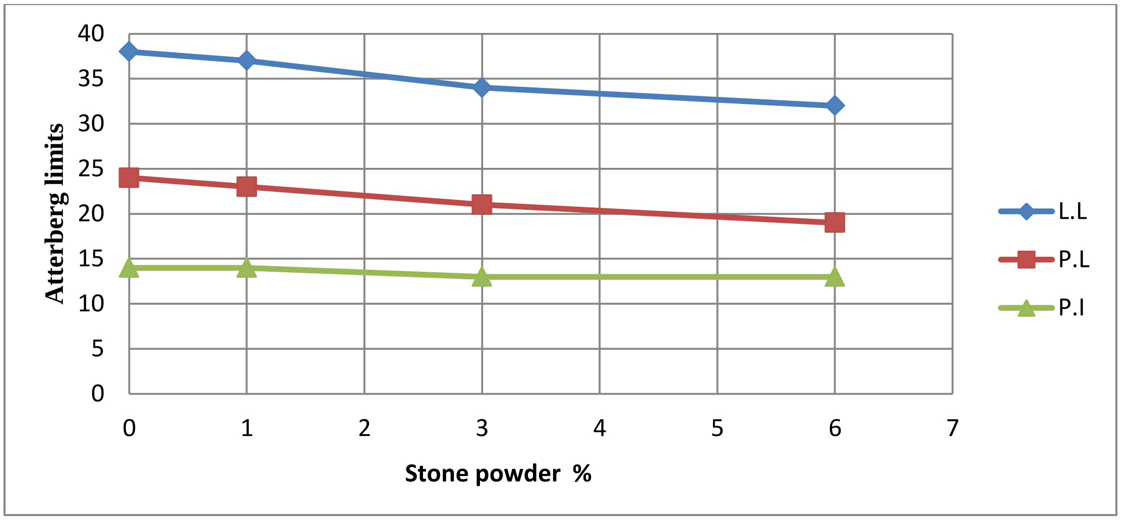

Figure 3. Effect of stone powder content on Atterberg limits.

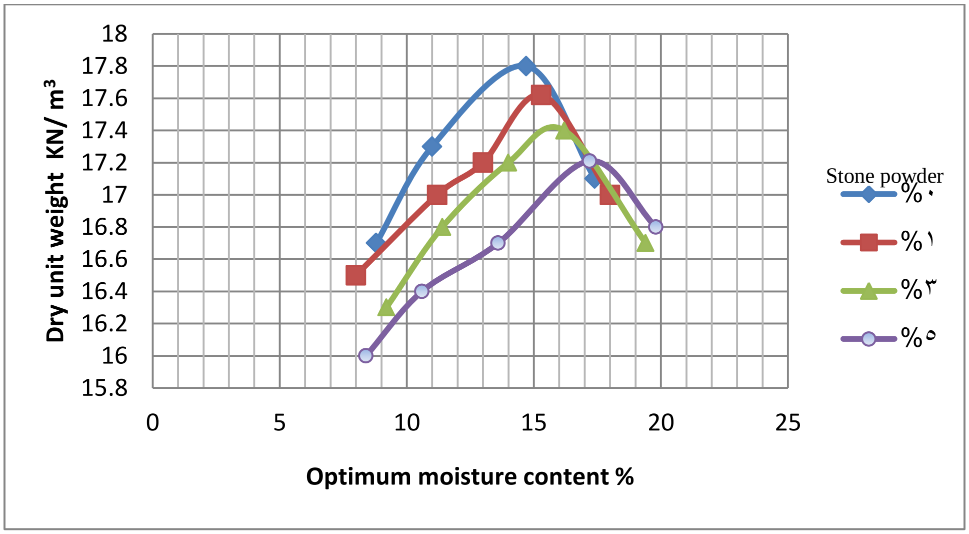

Figure 4. Effect of stone powder content on dry unit weight and optimum moisture content.

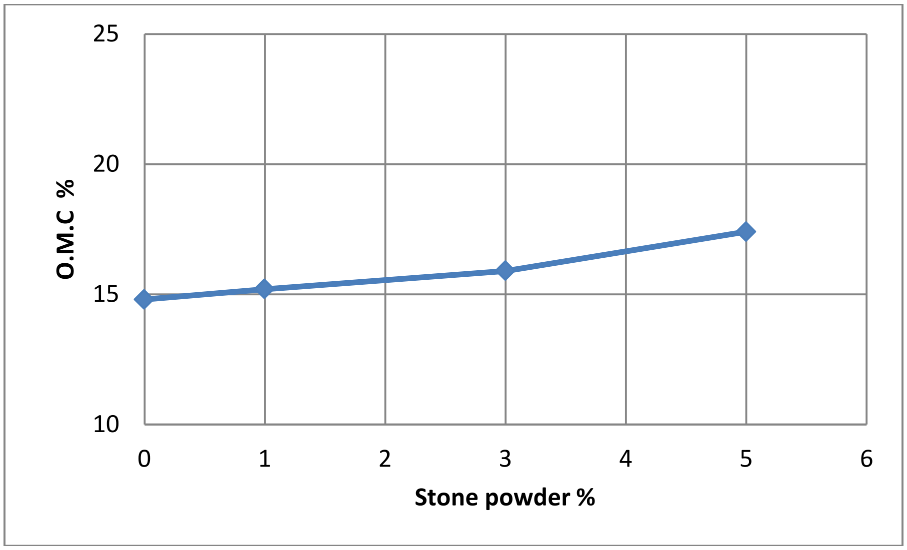

Figure 5. Variation of the optimum moisture content with stone powder percent.

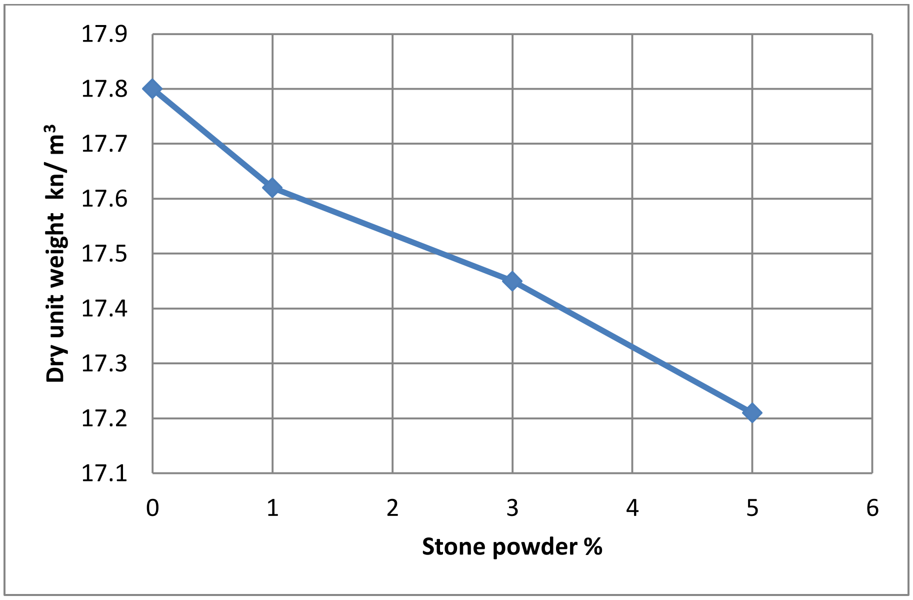

Figure 6. Variation of the maximum dry unit weight with stone powder percent.

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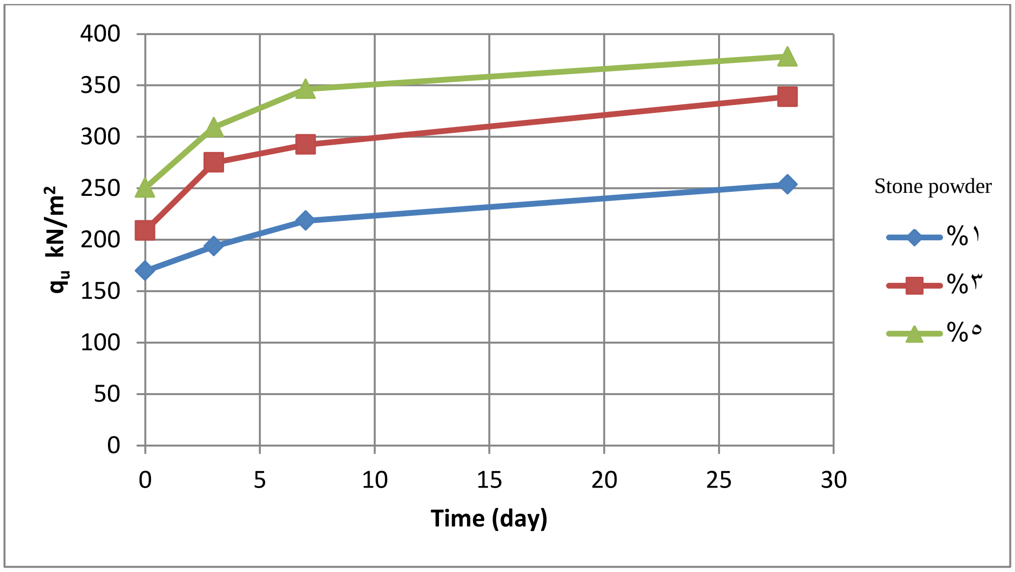

Figure 7. Effect of stone powder content on unconfined compression and time in unsoaked condition.

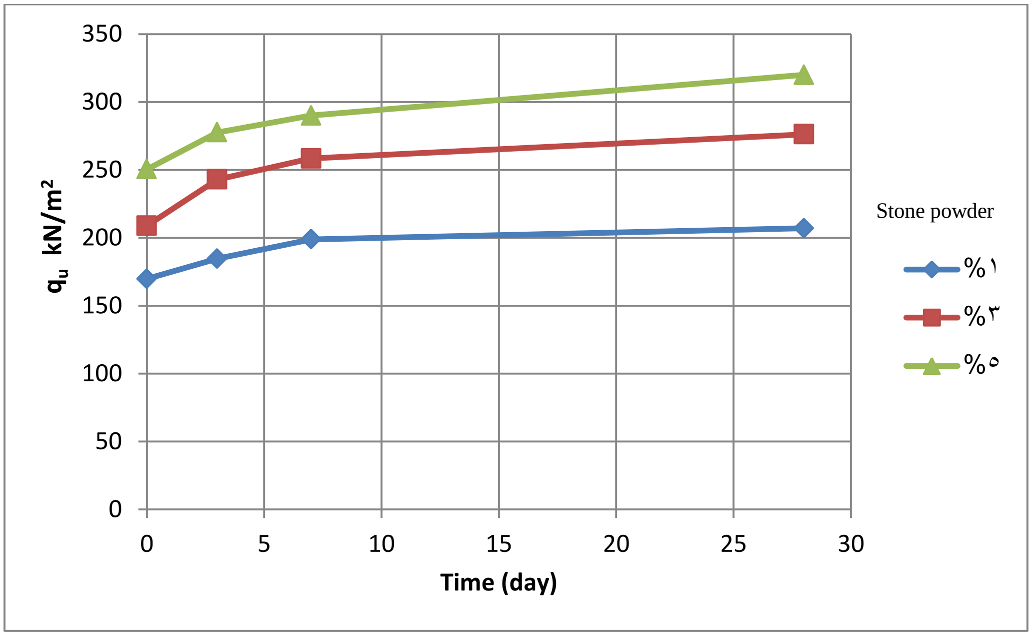

Figure 8. Effect of stone powder content on unconfined compression and time in soaked condition.

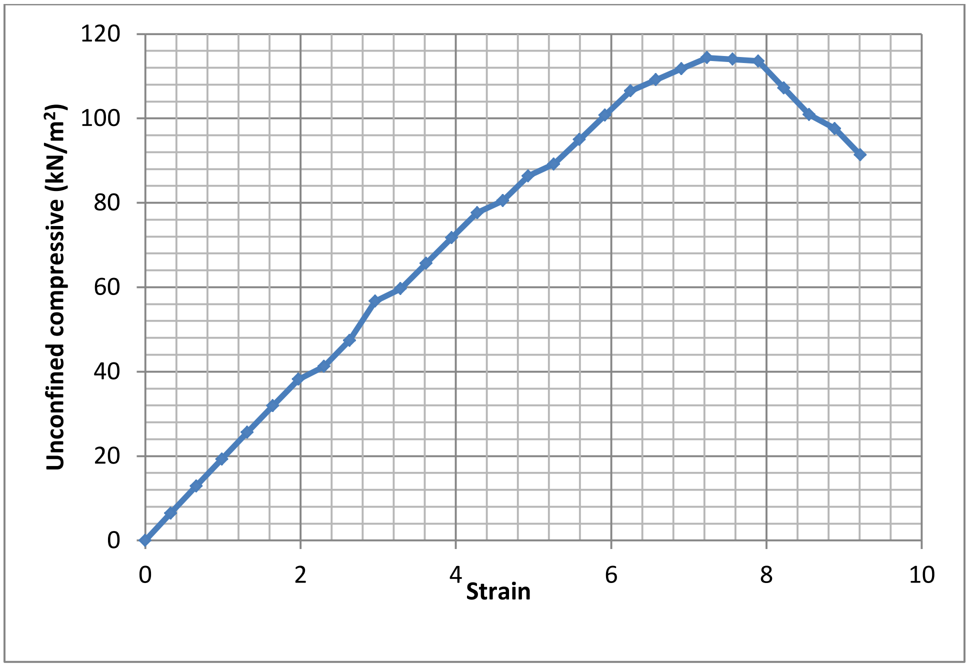

Figure 9. Unconfined compression on normal soil without stone powder corresponding to an age of 0 day.