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Influence of Stone Powder on the Mechanical Properties of Clayey Soil

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ABSTRACT

In this experimental study, the use of stone powder as a stabilizer to the clayey soil studied. Tests of Atterberg limits, compaction, fall cone (FCT), Laboratory vane shear (LVT), and expansion index (EI) were carried out on soil-stone powder mixtures with fixed ratios of stone powder (0%, 5%, 10%, 15%, and 20%) by the dry weight. Results indicated that the undrained shear strength obtained from FCT and LVT increased at all the admixture ratios, and the expansion index reduced with the increase of the stone powder.

Keywords: recycling, clayey soil, stone powder, undrained shear strength, unconfined compressive strength.

دراسة تأثير أضافة مسحوق الحجر الجيري على الخواص الميكانيكية للتربة الطينية

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الخلاصة

تهدف هذة الدراسة الى اظهار مدى تأثير اضافة مسحوق الحجر الجيري كعامل مثبت للتربة الطينية لاحتوائة على نسب عالية من السيليكا , وبالنظر لكونة مادة تنتجها الطبيعة تم استخدامة سابقاً في الكثير من مجالات البناء لقيمته الاقتصادية الواطئة.

تمت الدراسة بأضافة مسحوق الحجر الجيري بنسب ثابتة (0 – 5 – 10-15 -20)% من الوزن الجاف للتربة واجريت الفحوصات المختبرية التالية اختبار السقوط المخروطي – اختبار القص الدوراني – اختبار حد السيولة واللدونة – اختبار الرص و فحص الانتفاخ

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اظهرت النتائج المختبرية ان قوة القص الناتجة من اختبار القص الدوراني واختبار القص المخروطي قد ازدادت بشكل ملحوظ لجميع نسب الخلط فيما اظهرت تناقص في قوة القص بزيادة نسب الحجر الجيري لفحص الانتفاخ.

الكلمات الرئيسية: اعادة تدوير، تربة طينية، حجر الكلس الجيري، اختبار القص الدوراني، قوة القص.

1. INTRODUCTION

Soil stabilization and strengthening using waste materials have become an essential topic in recent times. Many wastes material such as nano-silica, white cement, fly ash classes family, lim, copper slag, red mud, blast furnace slag, and so on are available for stabilizing clay soil. They are eco-friend, economical, and easy to find in site and market **(Safi, and Singh, 2022).**

Many researchers investigated the use of different waste materials in enhancing different types of soil. **(Ahmed, and Adkel, 2017)** investigated the use of tyre ash material in four percentages (2, 4, 6, and 8) in soft clay soil by examining the physical and chemical properties, consolidation, compaction, shear, and CBR tests. The results showed that adding 8% tyre ash gave the best results in undrained shear strength, compaction, and CBR. The influence of another type of the soil's properties of waste materials like Cement Kiln Dust (CKD) and waste plastic bottles (WPB) on the geotechnical properties of expansive soils was investigated by **(Rashed et al., 2022)**, with stabilizer ratios from 0% to 20%. The results indicated that the 12% CKD and WPB mixture is the best utilization percentage after 28 days of curing age. **(Kumar, 2021)** studied the stone dust's effect on black cotton BC soil's architecture and quality properties. Tests such as compaction consistency, triaxial compressive quality, and proportion of California bearing were evaluated, and their varieties with stone dust zone unit substance were assessed. The results showed that black cotton soil had improved sub-review efficiency attributes.

Attempts were carried out to turn these wastes into valuable construction materials. **(Al-Joulani, 2012)** obtained results investigating the effects of using the stone powder and lime on some geotechnical affections of fine-grained soil. The disposal of stone powder has been developing positively through many applications. They used 0-30% of stone powder and lime by weight and then evaluated the strength, direct shear, and CBR properties. They found that adding 30% stone powder has enlarged the friction angle (φ) by almost 50% and reduced the cohesion by about 64%. Also, at the same amount of stone powder addition, the CBR values gained from 5.2 to 16.

(Demirel, 2010) studied the effects of the marble stone dust on the compressive strength of concrete by adding the dust at particular proportions; the strength displayed an enhancing effect with the additive of marble stone dust. Also, the sewage sludge entered in manufacturing of the artificial aggregate. Also, **(Mahzuz et al., 2011)** studied stone powder as an alternative to sand in concrete mix and mortar. In that study, the stone powder concrete gained a compressive strength of 15% higher than concrete with normal sand. The highest strength of mortar with stone powder reached 33.02 MPa. **(Campos et al., 2020)** studied the use of stone powder to produce low cement high compressive strength concrete to reduce the risk of cumulative amount of stone powder on the environment and reduce the emission of CO_2 during the manufacturing of cement. It was found that the use of 20% stone powder is the most efficient amount to give a compressive strength of 104 MPa with the use of only 288 kg/m^{3}, which resulted in a 44% reduction in CO_2 emission. Likewise, **(Yang et al., 2020)** replaced the quarry stone powder with 22.2%-44.4% of cement to produce environmentally-friendly ultra-high strength concrete and minimize the risk of the huge amount of the solid waste material. The effects of the stone powder on both fresh and hardened properties of concrete were investigated. As a result, the stone powder improves the flowability of fresh concrete. Also, the compressive strength of 56 days of curing was comparable with the reference mixture.

In the study of **(Nakayenga et al., 2021),** the effects of waste granite powder were investigated in cement-treated clay mixed composites. Tests of liquid limit, unconfined compressive strength (UCS), and microstructural characteristics were investigated. Results indicated a reduction in the UCS of cement-treated clay–stone powder composites occurred compared to the control sample with a 30% stone powder addition, and equal or improved strength was observed with 50% and 70% additions. Furthermore, **(Bayesteh et al., 2020)** used stone powder selected as a cost-effective additive at the addition ratios of 0%, 20%, 30%, and 40% in soil-cement (soilcrete) columns created by jet grouting for the improvement of marine sediment. The results showed that adding 20% stone powder eliminated the water's negative effects and increased the sand-cement samples' strength but had little effect on the clay-cement strength. The highest strength obtained in clay-cement samples was 5.2 MPa at a stone powder ratio = 0.7%. The highest strength obtained in sand-cement samples was 7 MPa at 20% stone powder. Thus, this mixing method is recommended for sand-cement-based columns.

(Abdulrasool, 2015) investigated the use of three percentages for stone powder (1%, 3%, and 5%) by dry weight of clay. Tests of (Atterberg limits, Standard Proctor density, Grain size distribution, Specific gravity, Unconfined Compressive test, and California bearing ratio test). Unconfined Compressive tests were conducted at different curing. Results showed that Stone powder reacts with clay, decreasing plasticity. The grain size distribution curves are shifted to the coarse side as the stone powder percentage increases; the soil becomes more granular and with higher strength.

(Ahmed et al., 2011) tested the 28-days compressive strength of concrete cubes whose cement was partially replaced with marble dust and sand with stone dust. The 10% and 20% of marble stone and stone dust cubic samples recorded aba out 15.23% increment in compressive strength.

(Corinaldesi et al., 2010) investigated the 28-days compressive strength of the concrete that substituted sand with waste marble stone. The concrete provided compressive strength higher than the control concrete mixture. **(Sakalkale and Dhawale, 2014)** studied the effect of marble dust stone by replacing it with sand for about 50% of the dry weight on the compressive strength of concrete. The result shows an approximately 10.72% increase in compressive strength.

In this study, laboratory tests carried out to establish whether the stone powder could be effectively used as a stabilizer for the clayey soil. This study can be useful to provide further valid uses for stone powder.

2. TEST METHOD

The soil collected from the Gaziantep university campus has been grinded into fine particles to pass through a #200 sieve. Then the fine soil and the stone powder were dried in an electric oven for 24 hours before being used as an additive to the clayey soil. Hence the admixtures were manufactured with stone powder at five ratios (0%, 5%, 10%, 15%, and 20%) by weight.

Tests like Atterberg limits, compaction, unconfined compressive strength, fall cone, laboratory vane shear, and swelling were accomplished to examine the performance of the additives on the geotechnical properties of the soil. Furthermore, tests of Energy Dispersive spectrometer EDS analysis and Scanning Electron Microscope SEM pictures were performed on stone powder samples to examine the chemical composition and the internal structure of the material.

Atterberg limits tests were applied according to **(ASTM D4318, 2000)** standard to obtain liquid limit (LL), plastic limit (PL), and plasticity index (PI). Differences in soil PI were examined for the soil with and without stone powder. Compaction tests can obtain the maximum dry unit weight (γ_{dmax}) and optimum moisture content (OMC) of the soil and the mixtures of soil with stone powder specimens at different water contents. Furthermore, the obtained OMC from compaction tests was used to control the water amounts for the approved samples for unconfined compressive strength and potential swelling tests, which were performed to find the stress; immediately without curing time volumetric swell of soil specimens, respectively. The fall cone test was performed to evaluate the liquid limit (LL) and the undrained shear stress for the soil and the soil with the admixtures. Also, the laboratory vane shear test was accomplished to obtain the undrained shear strength.

3. RESULTS AND DISCUSSION

3.1 Characteristics of materials

3.1.1 Untreated soil

Table 1 shows the properties of the untreated soil. The soil in this study was categorized as SC soil according to USCS classifications. By AASHTO, the soil is grouped into the category of A-1-a.

Table 1. Properties of untreated soil.

Liquid limit (LL)	34.5
Classification (USCS)	ML
Classification (AASHTO)	A-1-a
Maximum unit weight (KN/m3)	1.65

Optimum moisture content (%)	17.58
Unconfined compressive strength (KPa)	400
Plasticity index (PI)	6.55

3.1.2 Stone powder

The same procedures were carried out to test the chemical components of the stone powder. In the EDS/SEM results shown in **Table 2**, it's seen that the stone powder lacks the oxides that control or accelerate the pozzolanic reaction. Furthermore, it is rich in calcium, which improves the ability of the stone powder to enhance the mechanical properties of soil. Also, it has the shape of a regular and semi-spherical grain, as it's seen in **Fig. 1**.

Table 2. EDS analysis results for the stone powder (in wt%)

Elements	Al	Fe	Si	Mg	Ca	O	C	Na	K
Stone powder	0.513	0.172	0.634	0.243	29.34	54.648	13.403	0.15	0.02

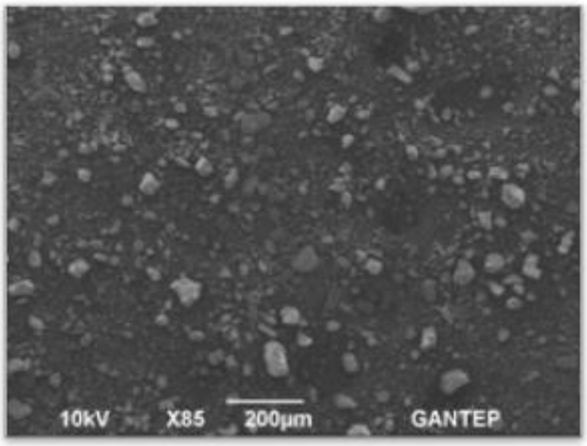

Figure 1. SEM picture of stone powder used during the study work.

3.1 Atterberg limits

To investigate the effect of stone powder on the physical properties of clayey soil, tests of plastic limit and liquid limit were accomplished according to ASTM D4318 standards.
In general, the smaller PI means the better workability of the soil. The results show that the liquid limits of the stone powder mixtures increased slightly with increasing the additive dosage. The maximum rate of increase is about 9%, recorded at a 20% stone powder mixture, as shown in **Fig**. **2.** With the addition of stone powder, the workability of the soil increased as the plasticity index reduced, as shown in **Fig. 3**; it can be found the higher workable mixture is the 15% stone powder mixture as it recorded the lowest plasticity index equal to 21.

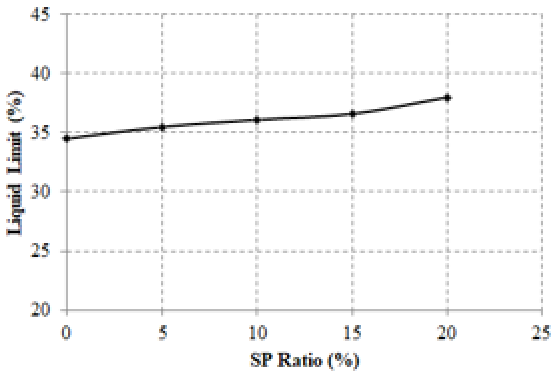

Figure 2. Variation of the liquid limit with the addition of stone powder.

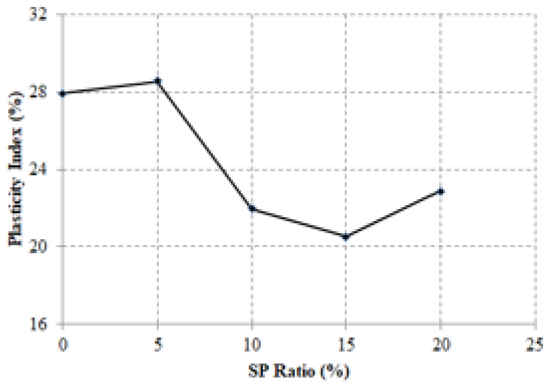

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Figure 3. Effect of addition of stone powder on the plasticity index.

4.1 Compaction Test

The compaction is carried out to re-build the soil particles by mixing the soil with water and applying external energy to the soil. Hence, the soil can grasp its densest condition with watering and re-building particles by compaction energy. According to **(ASTM D 1557-98, 2000). Fig.4** shows the effects of the additives on the compaction properties of the soil. The results indicated that each stabilizer showed its compaction behavior with optimum moisture content and maximum dry density (γ_{dmax}). However, it can be seen that the addition of the stone powder had a minimal impact on the compaction behavior. The addition of the stone powder resulted in noticeable changes in the untreated soil properties. The stone powder admixture improves the interlocking force between the soil particles as the optimum moisture content is lowered with the amount of stone powder. The whole stresses are moderated among the soil particles. The soil stress rises with the reduction of water-generated stress.

The addition of stone powder does not affect the optimum moisture content and the dry density. The results were very close to that of the untreated soil.

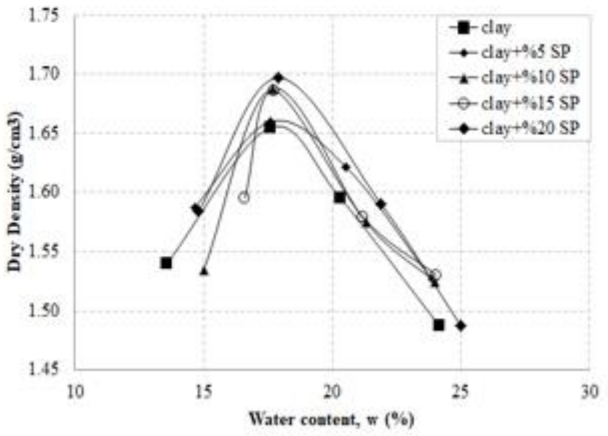

Figure 4. Effect of addition of stone powder on the density-moisture content relationship.

4.2 Unconfined Compressive Strength

Fig. 5 shows the unconfined compressive strength at different amounts of stone powder added to the soil and according to **(ASTM D 2166-98, 2000)**. All the specimens were tested immediately after mixing.

When the treatment started with a stone powder admixture, the UCS decreased at all stages; the mixture content of 5% and 20% stone powder recorded a reduction of 27% and 17%, respectively. However, it is noticeable that the soil tended to behave more ductile. **Fig 5** shows that the area under the curve is equal to the absorbed energy by the soil mixture. The highest ductility was recorded in the mixture containing 5% stone powder, as shown in **Fig. 6**. Ductility is the capability of the materials to deform under tensile stress or the capability of the material to resist plastic deformation without rupture. It can be evaluated by the engineering strain at which the material fractures during the uniaxial tensile test. The lack of ductility is termed brittleness. In general, the differences in ductility and brittleness do not affect the strength of the material, but the material with high ductility is often more desirable. The more ductility improved at the 10% stone powder mixture, and the more strength was at 20% stone powder.

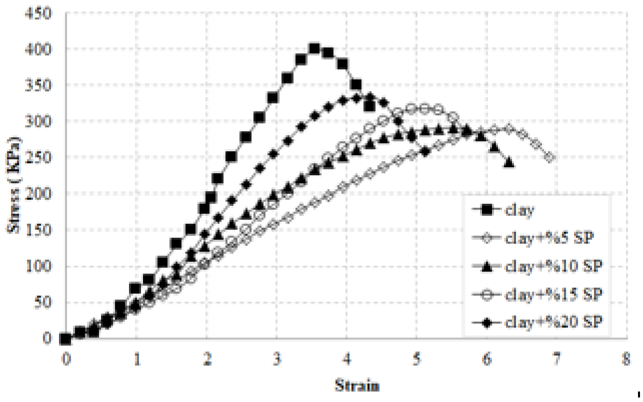

Figure 5. Effect of stone powder on the unconfined compressive strength.

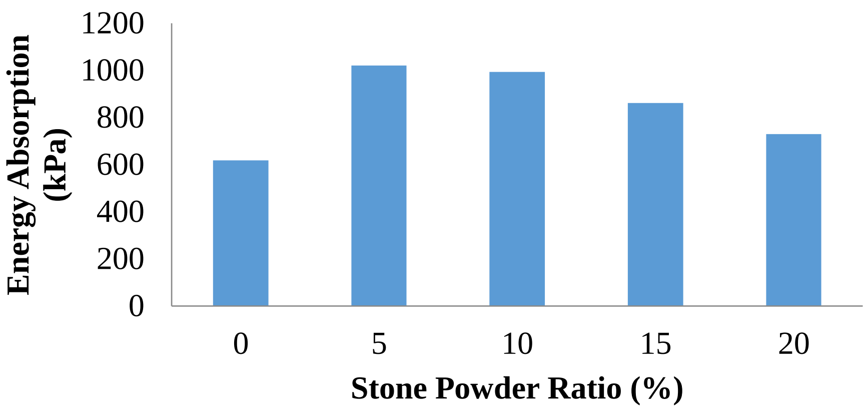

Figure 6. Effects of stone powder on energy absorption.

4.3 Fall Cone Test

The FCT was conducted following the **(BS 1733,1990)** standards, using the British fall cone apparatus with a 30º cone and 80 gm. weight. After adding stone powder, the FCT was carried out to evaluate the undrained shear strength and find the liquid limits for the raw soil. The soil samples were placed in a stainless-steel cup of 55 mm in diameter and 40 mm in height, so the cone tip touched the sample surface. The cone was then released into the sample for five seconds. Then, the penetration depth was recorded by a dial gauge, and the following equation calculated the Su:

$$s_u = k\frac{mg}{d^2} \tag{1}$$

Where;

Su is the undrained shear strength (KPa), k is the cone factor depending on the cone angle. K = 0.0255 **(Wood, 1985)** according to the cone angle, which is 30º in this study,

m is the cone mass = 80 (gm),

g is the earth acceleration,

and d is the cone penetration depth.

The results indicated a near-linear relationship between cone penetration and the water content for all the clay-stone powder mixtures. According to (BS 1377 1975), the liquid limit is the water content at the cone penetration of 20 mm. From **Fig. 7** it can be observed that the cone penetration increases with increasing water content for all mixtures. The variation of cone penetration for the stone powder mixtures was found to be nearly parallel to the best fit line of the pure clay as the amount of stone powder increased. The best fit line for the mixture with lower stone powder content have relatively steeper slopes. For example, the fit-line of the 5% stone powder mixture has a slope of 1:9, whereas the slope of the 20% stone powder mixture is 1:12.

It can be held from **Fig. 8** that the undrained shear strength showed less values for the stone powder mixtures than for the pure sample. At the same time, the strength decreased as the water content increased. For example, the 20% stone powder mixture resulted in 7.30 KPa, whereas the pure soil resulted in 9.25 KPa. The main influential factors affecting the undrained shear strength are the soil particles' cohesion and internal friction angle directly related to the soil water content. This test clearly shows that the stone powder particles reduced the clay portions because of the flocculation and agglomeration effect. The stone powder particles caused a formation by increasing the friction strength of the soil particles.

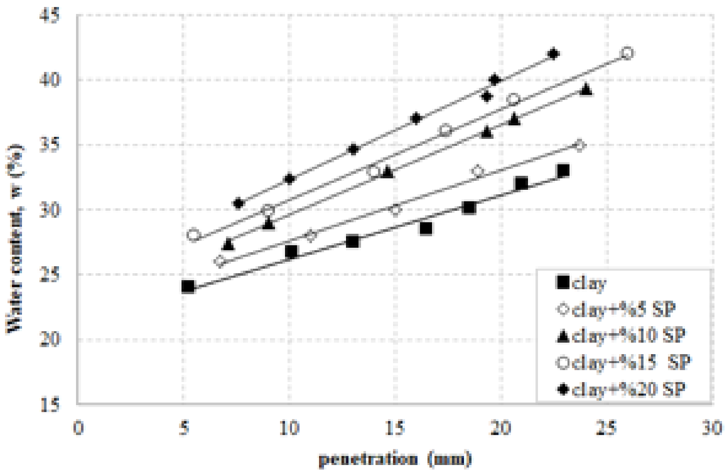

Figure 7. Relationship between cone penetration depth and water content at different ratios of stone powder.

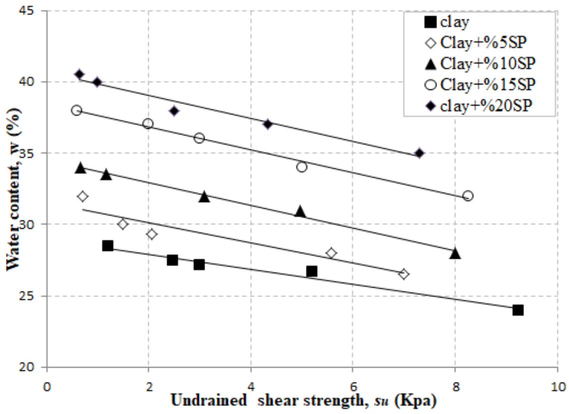

Figure 8. Variation of undrained shear strength from FCT with the addition of stone powder.

4.4 Laboratory vane shear test

The laboratory vane shear test was performed on the coequal samples tested in the fall cone test and according to **(ASTM D 4648-49, 2000)** standards. The device comprehends four blades connected at right angles to each other; according to the standards, the height of the vane should be twice the diameter of each blade. The test procedures are to insert the vane into the sample in a metal cup and rotate it constantly until it fails. At the failing moment, the torque is then recorded by the dial gauge to be used; with the analysis of the vane size and geometry, the undrained shear strength calculation. The following equations are used in the shear strength calculations,

$$s_u = \frac{T}{K} \qquad (2)$$

Where:

T =the max torque to shear the samples, which is the angle of rotation and the spring stable,

K = constant lean on the dimension and the shape of the vane; it's measured by the Eq (3)

$$K = \frac{\pi D^2}{2} * \left(1 + \frac{D}{3H}\right) \qquad (3)$$

Where,

H is the height of the vane.

D is the diameter of the vane, and

The undrained shear strength influences principally by the internal friction angle and cohesion, which are already affected by sample water content. The relationship between the vane shear strength and the water content for the untreated and treated soil for all the additive ratios is shown in **Fig. 9**. The results showed the undrained shear strength determined by the vane test decreases with the increase in water content for all the proportions of stone powder by about 15%; the water content primarily controls the undrained shear strength. These results showed that the addition of stone powder accelerates the reduction or loss of clay fractions due to the flocculation and agglomeration effect, considering the particle size distribution.

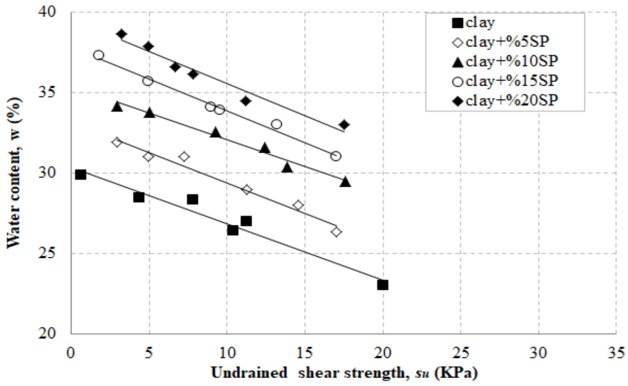

Figure 9. Variation of undrained shear strength from LVT with the addition of stone powder.

4.5 Expansion Index (Primary swell) test

This test has been carried out to determine the expansion potential of soil following **(ASTM D 4829-95, 2000)** test specification. The expansion potential has classified the soil, according to **Table 3** (Day, Robert W., soil testing manual), as it has very low, low, medium, high, or very high expansion potential.

Test procedures were first to prepare the soil specimens of untreated and the treated sample with the fixed ratios of additives. Each sample was mixed at its maximum dry density and optimum moisture content conditions. The soil sample was compacted in a ring of 50 mm in diameter and 10 mm in height. The ring mold included the soil sample, then placed in a surrounding container with dry and clean porous plates above and under the ring sample. Then placed, this container with the sample was in the center of the consolido-meter device; the recorded Initial dial reading was within the first 10 minutes of applying the pressure. The container was then filled with water and allowed to swell for 24 h. The primary swell is considered 10% of the expansion index, which is calculated by Eq. 4:

$$EI = \frac{1000(h_f - h_i)}{h_i} = 10(\%\, primary\ swell) \quad (4)$$

Where;

EI = the expansion index;

h_f = final reading (height) of the specimen at the end of 24 h of swelling; and

h_i = initial reading (height) of the specimen.

Table 3: Typical soil properties based on expansion potential.

Expansion potential	Very high	high	medium	low	Very low
Expansion index (%)	>130	91_130	51_90	21_50	0-20

The results showed that the stone powder affects the soil by increasing the swelling index up to 50% for the mixture containing 20% stone powder, and the soil is to be considered a very high expansion index, as shown in Table 3. In general, the finer particles of soil, the more expansive soil. The soil used in the study is classified as fine soil size that is passed sieve #200. This is the cause of the high expansion potential property, as well as it’s proved why the stone powder has not significantly affected the expansion potential because it is finer than the clay particles of the soil used.

5. CONCLUSIONS

This study is dedicated to reducing the damage of sewage sludge ash and stone powder in the form in which they are converted into effective materials. Results from the experimental work can be concluded as follow:

1. The Atterberg Limits test results indicate that the liquid limits of the stone powder have increased as the stone powder amount increased, and the liquid limit increased by 9% higher than the pure soil. Furthermore, the plasticity index shows a reduction while increasing the stone powder amount, which improves the workability of the soil.

2. The unconfined compressive strength of stone powder soil samples decreases with admixture amount but at the same time improve the ductility of the soil. The best mixture after the pure soil is the 20% stone powder mixture, the unconfined compressive strength for this mixture found to be 17% less than the pure soil.
3. Fall cone test results indicate that there is a linear relationship between cone penetration and water content for all stone powder mixtures.
4. The undrained shear strength obtained by the fall cone test or the vane shear test, the undrained shear strength obtained from both fall cone and vane shear tests recorded a decrease with the

increasing amount of stone powder by about 15%. The best-undrained shear found in the 15% stone powder mixture is found to be 8.27 KPa, while the pure soil is 9.25 KPa.

5. The swelling potential is clearly increased for stone powder admixtures by about 50%, which converts the soil properties from high to a very high expansion index.

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