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Effects of Domestic Sewage Sludge on Gypseous Soil's Geotechnical Properties

Ahmed Abdulkadhim Mohsin[1*], Sepanta Naimi[1], Ayad Sleibi Mustafa[2]

[1] Department of Civil Engineering, Engineering and Architectural Faculty, Altınbaş Üniversitesi, İstanbul 34672, Turkey
[2] Department of Civil Engineering, Faculty of Engineering, University of Anbar, Ramadi 31001, Anbar Province, Iraq

Corresponding Author Email: ahah081@gmail.com

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ABSTRACT

Sewage sludge is a product of wastewater treatment plants. This study aims to evaluate adding different percentages of sewage sludge as a weight ratio to gypsum soil to develop some physical and mechanical soil properties. Samples of soil were obtained from the city of Ramadi, and the sewage sludge was accumulated directly at the Al-Rustamiyah wastewater treatment plant located north of Baghdad, Iraq. The laboratory experiment was undertaken on the original gypsum soil samples and the soil treated with sewage sludge ash. This study also involves testing XRF and energy-dispersive X-ray spectroscopy (ESD) of the sewage sludge material. There was a rise in the liquid limit and plasticity index for Atterberg limits. The compaction results indicated increased maximum dry density and optimal moisture content. The optimum unconfined compressive strength (UCS) value is obtained by adding 20% of sewage sludge. The best maximum dry density was achieved with 20% sewage sludge ash. After adding sewage sludge ash, the dry density of gypsum soil increased significantly to 1.65 g/cm^3. Also, the optimum water content is gradually increasing. The bearing capacity ratio for the untreated soil was 5%, and the California Bearing Ratio (CBR) values were recorded as 22.3% for the gypsum soil treated with SSA at 20% with a curing time of 14 days. There is a significant increase in cohesion values with between 10 and 20 percent of the sewage sludge added to the soil. This increase has a significant effect on engineering soil behaviour. The elements are found in sewage sludge ash, based on XRF, EDS, and SEM tests: Si (10.5%), Al (3.6%), Ca (15%), and Fe (6.2%). Sewage sludge can be used successfully as an additive to improve the properties of gypseous soils by a weight ratio of 20%.

1. INTRODUCTION

The management of sewage sludge or biosolids through their usage in civil engineering projects has gained attention in recent years as a novel strategy. So, an essential part of using biosolids in civil engineering is understanding how they compact and their geotechnical properties.

Biosolids refer to dried, stabilized sewage sludge with solid properties that typically contain more than 50% dry solids by weight [1]. Wastewater sludge comprises a broad range of organic and inorganic chemicals and traces of metals [2]. Sewage sludge's capacity to modify the soil's engineering properties should be taken into account because of its usefulness in geotechnical applications. Generally, sewage sludge is difficult geomaterials due to its extremely low permeability coefficient [3]. Thirty percent of Iraq is covered with gypseous soil, which contains varying amounts of gypsum and is troublesome [4]. About 0.6% of the Earth's landmass consists of gypseous soils, mainly in Australia, Europe, and Argentina. Additionally, they may be found in other Arab nations, including Tunisia, Algeria, Libya, and Syria [5].

Significant deformations of buildings are inevitable when constructed over gypsum soil because of its collapsibility.

Cracks, tilting, and even overturning of structures that rely on gypseous soils for support have been documented; these issues can be extremely hazardous if left unaddressed.

Several studies have been looking for the best ways to stabilize gypsum soil for some time now, and many different approaches have been tried to boost the soil's geotechnical properties [6-14]. Based on a review of the literature, many studies have been carried out to improve soil characteristics with SSA for engineering applications [15-23].

This study is a new approach to developing geotechnical science using by-products of wastewater treatment plants as sludge material for improving the geotechnical characteristics of gypseous soils. Due to the limited literature review in Iraq about using sewage sludge in gypseous soils, the present study attempts to understand the behaviors of adding sewage sludge (SS) to gypseous soil. However, mixed sludge waste material with the soil has been used, and different percentages of sludge waste, i.e., 10, 15, and 20%, by the weight of gypseous soil.

2. MATERIALS AND METHODS

2.1 Preparing materials

The research reported here is mostly an in-lab effort into the potential benefits of gypsum soil treated with sewage sludge. The phases of the experiments may be summed up as follows:

1-Collecting and preparing sewage sludge and gypsum soil, Plates (1) and (2).

2-Performing the procedure of adding various types of sewage sludge to the prepared gypsum soil Plate (3).

Gypseous soil samples were brought from the Al-Anbar University site in Ramadi (100 km west of Baghdad), Iraq. Soil samples are taken from 1.5 m underground and then packed in thick nylon bags. The soil specimens are tested at the Soil Laboratory, College of Engineering, AL-Mustansiriya University. In Table 1, we see the physical features of gypseous soil in detail. To see how the sizes of soil particles how distributed, go to Figure 1.

Plate 1. Location of Gypsum soil collection

Plate 2. Location of sewage sludge collection

Plate 3. Samples of the soil and sewage sludge

Table 1. Gypseous soil physical characteristics

Soil properties	Value	Standard
Water Content %	5.2	[24]
Field Density mg/m^3	1.26	[25]
Classification, USCS	SP	[26]
Liquid Limit (LL)	30.23	[27]
Plastic Limit (PL)	N. A	
Plasticity Index (PI)	N. A	
Maximum Dry Density (MDD) mg/m^3	1.48	[28]
Optimum Moisture Content (OMC) %	15	
CBR Without Submerged (%)	6	[29]
CBR with Submerged (%)	4	
Specific Gravity (Gs) with Water	2.13	[30]
Specific Gravity (Gs) with Kerosene	2.47	
Gypsum Content (%)	36	[31]
Bulk Density, gm/cm^3	1.2	[25]
C (Kpa)	0.5	
Φ (°)	30	
Organic Content %	1.143	

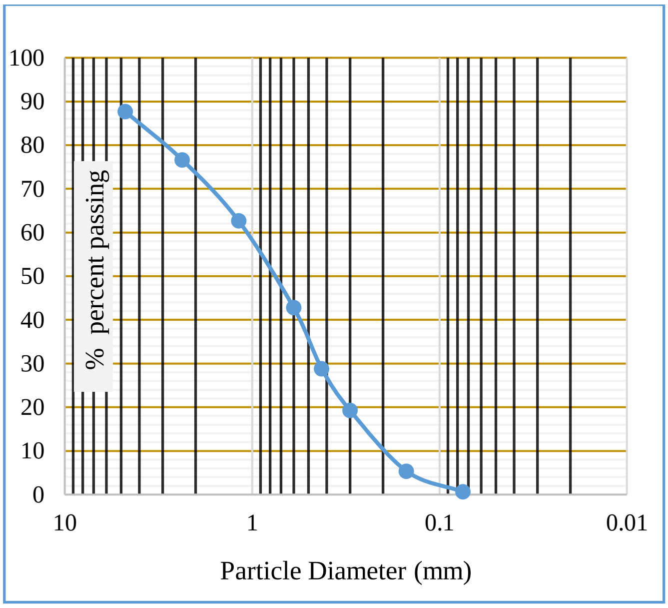

Figure 1. Sieve analysis for gypseous soil

2.2 Chemical properties of sludge materials

The sewage sludge was also collected from the Al-Rustamiyah WWTP located north of Baghdad-Iraq. Raw sewage sludge (RSS) was incinerated at 950°C for two hours in the furnace to produce sewage sludge ash (SSA) [32].

Table 2. Elements of raw sewage sludge for EDS test

Element	Weight %	Weight % Error
C	21.5	1.7
O	52.6	3.6
Al	2.3	0.3
Si	9.1	0.4
S	3.6	0.5
Ca	8.7	0.4
Fe	2.1	0.4
Zn	0.1	0.1
SUM	100	

The results obtained from (EDS) are presented in Tables 2 and 3 and Figures 2 and 3 for RSS and SSA materials, respectively. The primary elements in the sewage sludge materials are Silica, Calcium, Ferric, Aluminum, and Oxygen in sewage sludge ash. Carbon ions are unavailable. EDS analysis showed that they were bound to SiO_2, Al_2O_3, and Fe_2O_3, the main oxides employed in the pozzolanic reaction. [33]. This suggests that SSA can long-term react with pozzolan with aluminosilicates in cohesive soil fine particles. In general, the quicker the pozzolanic reaction occurs, the higher the CaO content of the stabilizers utilized [34].

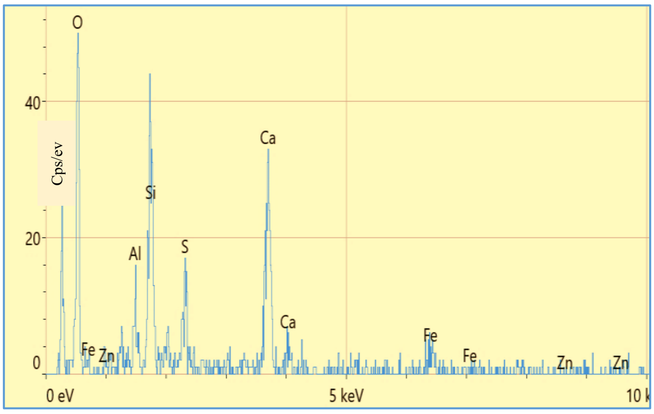

Figure 2. EDS results for raw sewage sludge

Table 3. Elements of sewage sludge ash for EDS Test

Element	Weight %	Weight % Error
O	47.6	6.3
Al	3.6	0.7
Si	15.6	1.0
S	6.9	0.8
Ca	17.3	1.2
Fe	8.0	1.4
Zn	1.0	1.0
SUM	100	

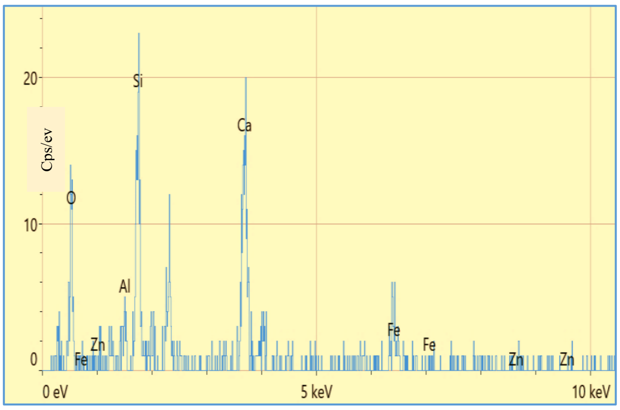

Figure 3. EDS results for sewage sludge ash

2.3 Soil samples tests

Four equal portions of soil were taken. Each piece was completely mixed with SSA at (10, 15, and 20)% of dry soil weight. As a next step, we used the "standard Proctor test (ASTM D698) to condense the samples. They were packed down to their highest possible dry density and optimal moisture content (OMC) (MDD). Atterberg limits, particle sieve analysis, CBR, and unconfined compression tests, to name a few, were among the standard laboratory procedures performed on the samples. UCS was performed on both treated and untreated samples using [35] as the standard. The pieces were cured for three, fourteen, and twenty-eight days [36]. The samples were kept dry by being sealed in nylon bags for the specified times. The unrestricted compression machine had a maximum load of 2 kN and a 1 mm/min compression rate. The CBR test measures the soil's strength after it has been compacted. The state transportation agency of California is responsible for creating the exam. The procedure is outlined in AASHTO T193. CBR, one of the essential strength characteristics, reaches its maximum value after alum sludge is added at a concentration of 8% and then begins to decrease at 10% [37].

3. RESULTS AND DISCUSSIONS

3.1 Influence of SSA on soil properties

3.1.1 Sieve analysis of the gypseous soils

The Sieve analysis applied on the original soil and the soil treated with the variation of percent SSA by weight are displayed in Figure 4. The figure shows that particle size distribution shifts as a function of SSA concentration. Since the gradation curves are so closely spaced, it may be concluded that the SSA's gradation is quite similar to the original soils.

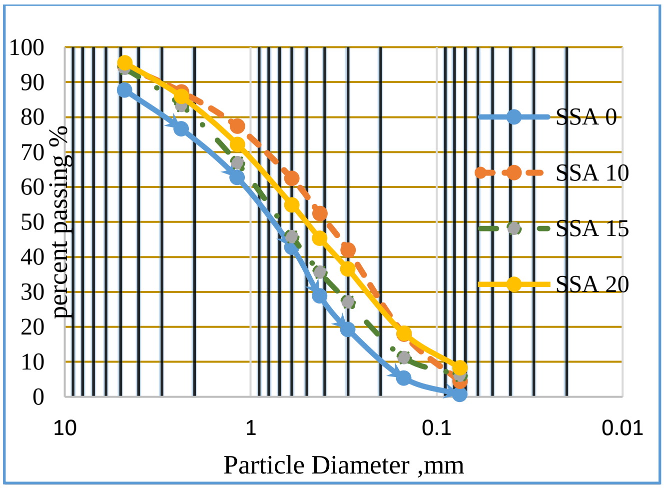

Figure 4. Sieve analysis for different percentages of SSA

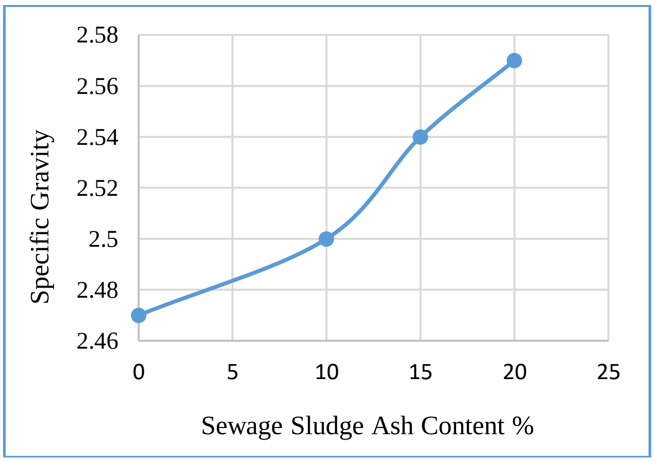

Figure 5. Ratio of ash content to specific gravity of sewage sludge

3.1.2 The specific gravity

Soil-specific gravity values for a range of SSA concentrations are depicted in Figure 5. An increase in SSA content leads to a rise in soil-specific gravity because more lightweight elements of a similar volume are present because of the density being minimum in sludge ash. When combined with kerosene, the specific gravity of SSA is around 2.6.

3.1.3 Atterberg limits

Plastic and liquid limitations and the plasticity index define the Atterberg limits, sometimes called consistency limits. Figure 6 displays the varying consistency thresholds as a function of SSA content. L.L, P.L, and P.L were all shown to rise linearly with sewage sludge concentration. The remarkable ability of sewage sludge to absorb water is credited with these findings. After 14 days of curing, it becomes evident that the liquid limit and the plastic limit increased with increasing SSA concentration; this is likely due to the SSA reaction during hydration, which results in pozzolanic activity. From this, we may deduce that the liquid limit of the starting soil was around 30% and that after curing for 14 days, it increased to 33.4%. In comparative research [17]. Found that adding 10% SSA to soil improved the plasticity index (PI) to 23%, while adding 20% SSA increased the PI to 26.1%.

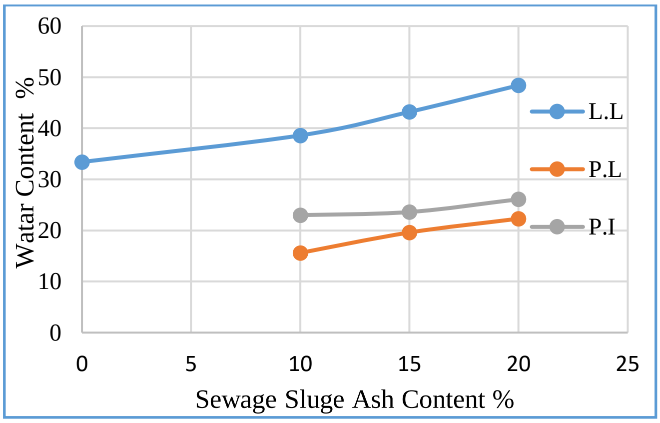

Figure 6. Water content versus SSA

3.1.4 Compaction characteristics

Table 1 displays the results of field soil tests showing a density of 1.26 mg/m^3. Figures 7-9 illustrate the effect of SSA concentration on the optimum moisture content and maximum dry density (γdmax). Increases in SSA concentration result in a larger (γdmax). However, as the concentration of SSA increases, so does the optimal moisture level. Because SSA has a higher specific gravity because more water is needed for hydration, its usage may raise the dry density and the optimum moisture content. Samples treated with 0 percent, 10 percent, 15 percent, and 20 percent SSA are denoted by the notations 0% SSA, 10% SSA, 15% SSA, and 20% SSA, respectively. The soil's optimal moisture content was 15% with SSA 0, and its maximum dry density was 1.48 mg/m^3, but with the addition of 20% SSA, those values climbed to 16% and 1.65 mg/m^3, respectively.

Specific gravity rose along with SSA concentration because pure SSA has a lower density than gypsum soil particles. Over a 10% SSA content, the lack of plastic behavior indicated that the mixture became progressively friable and lacked plastic behavior. High SSA concentration mixes maintained granular formation and did not form clods even when more water was added. There was a great deal of (Si) in the mixes, and its behavior is understood to be unrelated to the amount of water used; as shown by Hunt [38], even a negligible amount of Si may significantly alter the plastic limit.

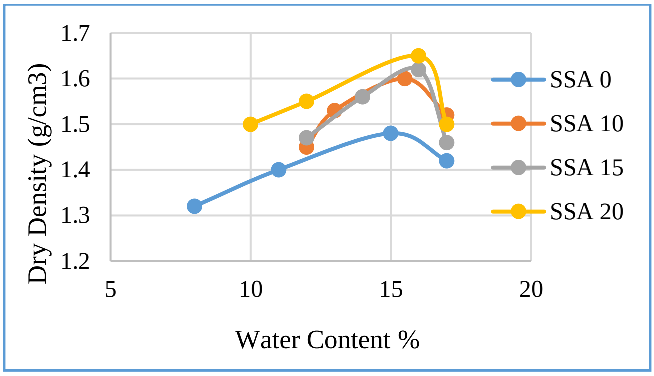

Figure 7. Water content versus dry density

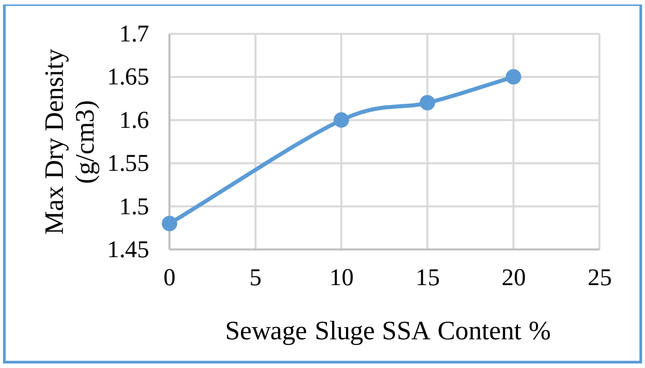

Figure 8. Maximum dry density versus SSA content

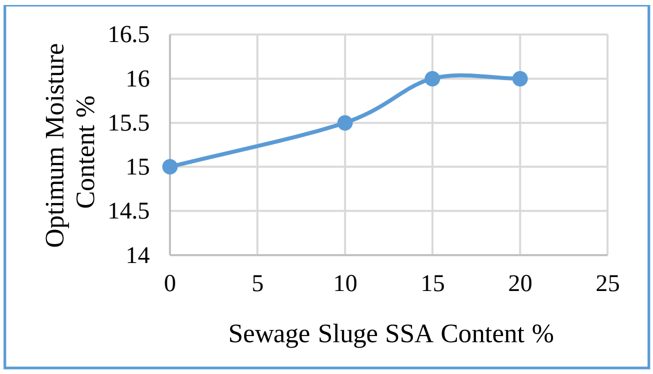

Figure 9. Optimum moisture content versus SSA content

3.1.5 Unconfined compression test

Figures 10 and 11 show the stress-strain relation for untreated soil and gypsum soil after adding sludge ash at periods of 3 and 14 days. Figure 12 compares SSA concentration and unconfined compressive strength after 3 and 14 days of curing. After 3 days of curing, UCS is 19.4 kPa for the original soil, 31 kPa, 44.8 kPa, and 68.3 kPa for SSA added to soil with 10%, 15%, and 20%, respectively. After 14 days, the UCS of soil without SSA is 28.2 kPa, but it's 36.4 kPa at 10%, 47.7 kPa at 15%, and 80.3 kPa at 20%. Increased strength may be due to pozzolanic interactions between SSA's pozzolana and soil calcium hydroxide. CaO may have been in SSA, allowing Ca and Si molecules to react with moist soil components. Numbers show that when sludge ash was added to soil samples, their strength increased significantly compared to untreated soil.

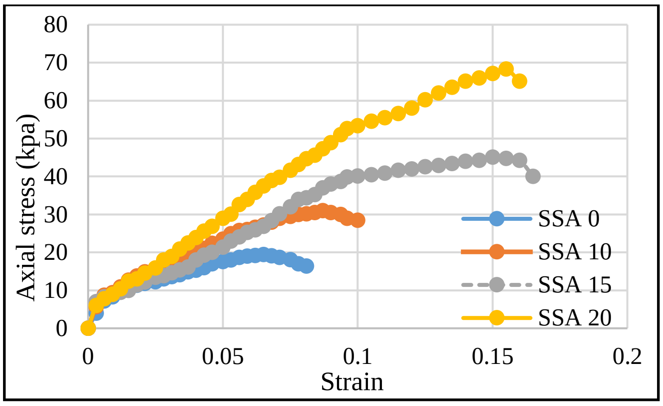

Figure 10. Strain versus axial stress after 3 days

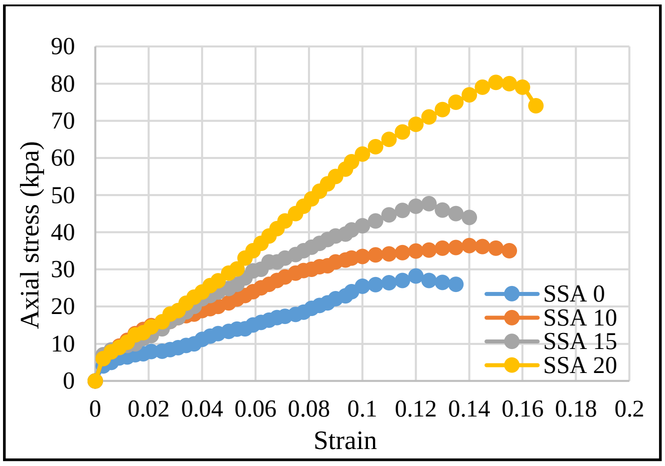

Figure 11. Strain versus axial stress after 14 days

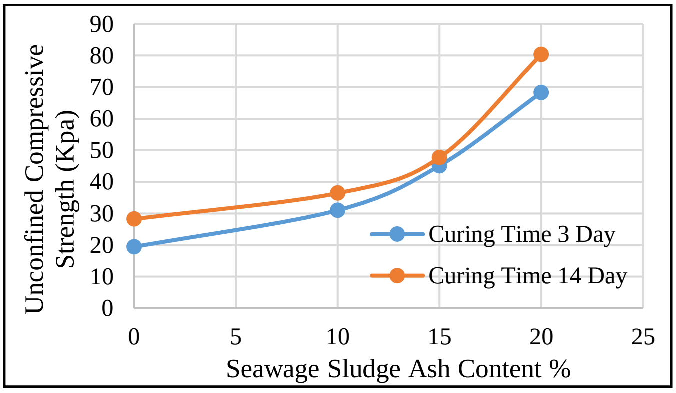

Figure 12. Unconfined compression versus sewage sludge ash content for periods 3 and 14 days

However, during both 14-day curing intervals, the rise in strength was constrained by the growing quantity of sludge ash. With a 20% ash concentration from sewage sludge, the ash was more porous, allowing it to absorb more water and blend more easily with the soil to create clods. As a result, the mixture dried out somewhat over the course of 14 days and gained density while losing water. The samples' water absorption decreases with increasing curing time and improves with increasing SSA. This is indicative of the fact that unconfined compressive strength improves as curing time lengthens. Unconfined compressive strength with SSA increases after 3 days of curing and again with 20% SSA. However, this deviates from the typical trend of increasing strength with extended curing time. Plate 4 shows the form of the sample after 3 days of curing time, and Plate 4 shows the shape of the sample after 14 days of curing time in an unconfined compression test. The failure planes in plate 1's untreated soil sample are visible as vertical fissures. Plates B, C, and D indicate that as SSA percentage and curing time rise, fewer fractures emerge in samples before failure.

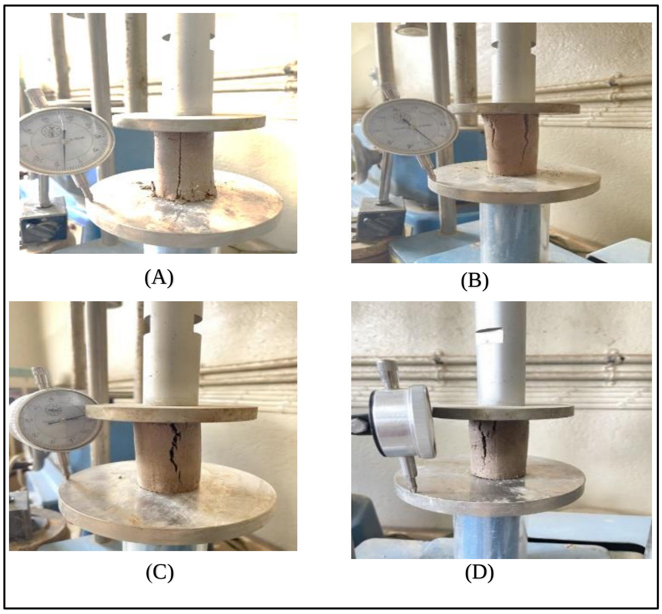

Plate 4. (A, B, C, D) showing how the failure behavior of soil specimens in an unconfined compression test changed after being exposed to SSA concentrations of 0%, 10%, 15%, and 20% for 14 days

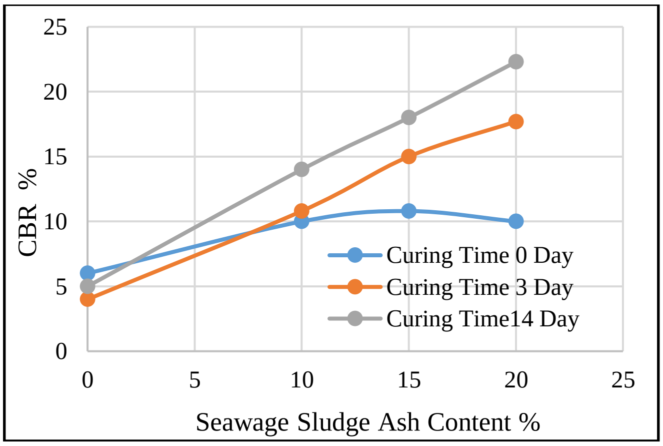

Figure 13. CBR with sewage sludge ash content

3.1.6 California Bearing Ratio (CBR)

Figure 13 shows that when the amount of ash from sewage sludge increased in the soil samples, the CBR values also rose. When 10%, 15%, and 20% were added to sewage sludge ash, the CBR values increased to 14%, 18%, and 22.3%, respectively, when the treatment duration was 14 days. Figure 13 shows that the CBR value of gypsum soil without any sludge ash content was equal to 6%. Based on the results obtained, it was found that SSA additives can efficiently improve soil properties with an increasing amount of SSA added, which is in agreement with the research [39]. According to the research [40], the optimum moisture content had an inverse relationship with CBR, while CBR was correlated with maximum dry density. The increase in CBR values may be attributed to SSA's pozzolanic or hydration response, which strengthened the soil.

The gypsum soil was treated with sludge ash for 0, 3, and 14 days. Table 4 displays the characteristics of gypsum soil after it has been modified with sewage sludge ash (SSA). Table 5 shows how different processing times affect the properties of SSA-treated soil. In another way, the increased optimal moisture content was a direct consequence of the sludge ash increasing the soil's specific surface area, making it better equipped to absorb water.

Table 4. Characteristics of SSA-treated gypsum soil

Soil properties	**Sewage Sludge Ash (%)**			
	0%	**10%**	**15%**	**20%**
Specific GRAVITY	2.47	2.5	2.54	2.57
Classification, USCS	SP	SP-SM	SP-SM	SP-SM
Max. Dry Density(g/cm3)	1.48	1.6	1.62	1.65
Optimum Moisture Content (%)	15	15.5	16	16

Table 5. Characteristics of SSA-treated gypsum soil with different curing times

Soil properties	**Curing time (days)**	**0%**	**10%**	**15%**	**20%**
Liquid Limit (L.L) %	0	30.23	36.4	41.8	45.9
	14	33.4	38.6	43.2	48.4
Plastic Limit (P.L) %	0	Na	13.8	18.5	20.8
	14	Na	15.6	19.6	22.3
Plasticity Index (P.I) %	0	---	22.6	23.3	25.7
	14	---	23	23.6	26.1
Unconfined Compression (kPa)	3	19.2	31	45.1	68.3
	14	28.2	36.4	47.7	80.3
California Bearing Ratio CBR (%)	0	6	9.5	10.8	10
	3	4	10	15	17.7
	14	5	14	18	22.3

4. CONCLUSIONS

This study shows the following conclusions:

1- AL-Ramadi soil is classified as poorly graded sands (SP) of gypsum content of about 36%. After addition, the proportion of SSA in the soil treated is classified as SP-SM.

2- When SSA was added to the gypsum soil, the plasticity index increased as the SSA increased to 20% of the gypsum soil dry weight. The finding has been linked to the response of SSA during hydration, which facilitated bonding and solidification.

3- There is a positive relationship between the proportion of sewage sludge and unconfined compression strength. When 10% and 20% of the sewage sludge are applied, the unconfined compression strength and cohesiveness parameters improve dramatically. With the addition at 20% SSA, this optimal percentage during the initial curing period, the unconfined compressive strength rises (3 days).

4- The compressive strength, confined and unconfined, of all SSA components increases with curing time. When utilizing 20% sewage sludge ash and modifying the treatment time to 14 days. The treated samples yielded much more significant values for unconfined compressive strength.

5- The best maximum dry density was achieved with 20% sludge ash. After adding sludge ash, this dry density as for gypsum soil is significantly increasing to 1.65 g/cm^3. Also the optimum water content is gradually increasing.

6- The bearing capacity ratio for the untreated soil was 5%, and the CBR values were recorded as 22.3% for the gypsum soil treated with SSA at 20% with a curing time of 14 days.

7- Sewage sludge could be used successfully as an additive to modify the characteristics of gypseous soils by a percentage of 20%.

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NOMENCLATURE

CBR	California rearing ratio, %
USC	Unconfined compression strength, KPa
L.L	Liquid Limit, %
P.L	Plastic Limit, %
P.I	Plasticity Index, %
OMC	Optimum Moisture Content, %
ASTM	American Society for Testing and Materials
Gs	Specific gravity
C	Cohesion, Kpa
WWTP	Wastewater treatment plant
SP	poorly graded sand
SP-SM	poorly graded sand - silty sand
SS	Sewage sludge
RSS	Raw sewage sludge
SSA	Sewage sludge ash

Greek symbols

γdmax	Maximum dry density, mg/m^3
ϕ	Angle of internal friction, (Deg.°)
ρd	Dry Density, mg/m^3