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Effect of Gypsum in Proportion of Other Additives Used in Stabilizion of Deficient Soils: A Review

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Abstract: Soils viable for engineering works needs to attain certain strength properties in order to serve its intended purpose. Some available soil like Black Cotton Soil tends to show weakness in strength which necessitate it to be modified so that the desired strength can be achieved, this can be executed using materials that could improve the soil properties such as gypsum, lime, bagasse ash, cement, etc. This paper is a review of the viability of the use of gypsum in proportion to other stabilization material to improve the strength properties of soils. Research shows, gypsum in addition to other stabilization materials such as bagasse ash, rice husk, lime, NaCl, tin, fly ash, jute fibre etc. produce a better stabilized soil as compared to gypsum or any of this material as stand-alone stabilizer. Laboratory result after series of experiment to determine the Maximum Dry Density and Optimum Moisture Content, Unconfined compressive strength, California bearing ratio CBR and Atterberg limit values of the stabilized soil using gypsum with other additives, reveals that for effective soil stabilization with the use of gypsum and any other additives is a function of the type of soil being stabilized, nature of additives, percentage of applied additives, curing time, also the classification of the soil to stabilized. It is found that the use of these additives in proportion of each other, their percentage proportioned, curing time and the nature of soil, give different end point of stabilized soil.

Keywords: Gypsum, Plastic Soil, Black Cotton Soil, Stabilization, California Bearing Ratio, Unconfined Compressive Strength

1. Introduction

Soil stabilization is a mixture of soil with certain materials, in order to improve the engineering properties of soil [9]. The soil stabilization is by adding chemical materials to the soil. The most common additives are Portland cement, lime, bitumen and tar [10, 14].

In this research the stabilization of clay was done by adding gypsum and volcanic ash. Gypsum is mineral with calcium levels that dominate in the minerals. Gypsum as an additive material has better properties than organic additives because it does not cause air pollution, relatively cheap, fire resistant, and resistant to deterioration by biological factors and chemicals [5].

Soil stabilization is a process generally which improves the engineering properties of weak soil such as compaction characteristics, bearing capacity etc. and this can be achieved by controlled compaction or addition of suitable stabilizers like cement, lime fly ash etc. But the cost of these additives has also become expensive in recent years which opened the door widely for introducing the other kinds of soil admixtures like gypsum [1].

This review briefly describes the suitability of gypsum to be used in the stabilization of soil.

Gypsum is a soft white mineral consisting of hydrated calcium sulfate. The chemical formula is calcium sulfate dehydrate ($CaSO_4$. $2(H_2O)$). Gypsum has better properties than organic additives because it does not cause air pollution, relatively cheap, fire resistant, and resistant to deterioration by biological factors and chemicals.

Gypsum is a not unusual mineral, with thick and good sized evaporite beds in affiliation with sedimentary rocks. Deposits are recognized to occur in strata from as a long way lower back as the Archaean eon. It is deposited from lake and sea water, as well as in hot springs, from volcanic vapors, and sulfate answers in veins. Hydrothermal anhydrite in veins is commonly hydrated to gypsum by means of groundwater in near-floor exposures. It is regularly associated with the minerals halite and sulfur. It is the most not unusual sulfate mineral. Pure this rock is white, however other materials discovered as impurities might also deliver a huge range of colors to local deposits. Because it dissolves through the years in water, it is hardly ever discovered inside the form of sand.

Table 1. *Chemical, Physical and Optical Properties of Gypsum.*

Gypsum Chemical Properties	
Chemical Classification:	Sulfate minerals
Chemical Composition:	$CaSO_4{\cdot}2H_2O$
Gypsum Physical Properties	
Color:	Colorless to white; may be yellow, tan, blue, pink, brown, reddish brown or gray due to impurities Streak: White
Luster:	Vitreous to silky, pearly, or waxy
Diaphaneity:	Transparent to translucent
Mohs Hardness:	2
Specific Gravity:	2.31–2.33
Diagnostic Properties:	Transparent and bladed crystals Alabaster Fine-grained, slightly colored
Crystal System:	Monoclinic
Gypsum Optical Properties:	
Gypsum is under the microscope	
Crystal Habit Massive, flat. Elongated and generally prismatic crystals	
Cleavage	Perfect
Twinning	Very common on
Optic Sign	Biaxial (+)
Birefringence	0.010
Relief	Low

2. Literature Review

2.1. Soils Review of the Effect of Gypsum in Composition of Other Additive in Stabilizing Engineering

Syafwandi [23] Directed focus towards the effect of gypsum for stabilizing expansive soil. Using a various mix design at different percentage of gypsum (0, 4%, 8%, 10% and 15%) which was prepared and cured for 0, 7, 14 21 and 28 days. Then the unconfined compressive strength (UCS) was carried out on 38mm diameter x 76mm height specimens. The lowest unconfined compressive strength test results were found in the gypsum content of 0% and curing for 0 days of 3.8667 kg / cm^2. While, the largest found in the gypsum content of 8% with 28 days of 14.2 kg / cm^2.

The results of clay and clay soil testing with gypsum with a percentage of 0%, 4%, 8%, 10% and 15% with curing for 0 days, 7 days, 14 days, 21 days, and 28 days was evaluated as follows:

Based on the results, the liquid limit (LL) was 62.4% and the plastic limit (PL): 44.82. According to unified soil classification system, the soil was classified as clays with high development potential. Whereas, for the soil stabilization with gypsum addition of 0%, 4%, 8%, 10% and 15% with curing time of 0 days, 7 days, 14 days, 21 days, and 28 days, it shows that the LL values have decreased with increase in the percentage of gypsum. The liquid limit value shows a decrease.

Based on the results of the specific gravity test (Gs), there was an increase from Gypsum levels 0% with Gs 2.547 to 2.646 for Gypsum levels 15%.

The lowest unconfined compressive strength test results were found in the gypsum content of 0% and curing for 0 days of 3.8667 kg / cm^2. While, the largest found in the gypsum content of 8% with 28 days of 14.2 kg / cm^2.

Evaluation of the results shows that, Curing increases the strength of soil. The addition of the percentage of gypsum increases the soil strength, but there is a maximum point, if too many specimens dry out, the soil strength will decrease.

2.1.1. Experimental Study on Effect of Gypsum and NaCl in Improvement of Engineering Properties of Clayey Soil

Peddaiah [17] was able to investigate the effect of gypsum and NaCl on the engineering properties of clay soil with high compressibility (CH). Gypsum as source of calcium which has major mechanism that binds soil organic matter to clay in soil which gives stabilizes the weak soil.

In the investigation of the effect of gypsum and NaCl on clayey soil for which a series of Compaction tests and California Bearing Ratio (CBR) tests performed on both virgin soil and reinforced soil with varying percentages of gypsum and NaCl (3%, 8% and 13%). The results reflect that with increase in the percentages of both gypsum and NaCl, engineering properties of soil such as Maximum Dry Density (MDD) and CBR value are also increased significantly comparing with the properties of natural soil.

As per data and results obtained from the experimental work on stabilization of clayey soil with varying percentages of gypsum and NaCl (3%, 8% and 13, the following was drawn regarding the aspect of strength improvement of soil due application of Gypsum and NaCl as a mean of soil reinforcement.

Based on results from compaction test, it is observed that with increase in percentage of gypsum and NaCl, the compaction properties are also increased. The maximum dry densities were found to be 1.33g/cc for 3%, 1.49 g/cc for 8% and 1.72 g/cc for 13% of gypsum and NaCl and it shows an increasing trend in MDD value. it was also observed that there is decreasing trend in optimum moisture content with increase of gypsum and NaCl and this is due to the fact that, gypsum and NaCl absorbs more water during compaction process. It can be concluded that for effective soil stabilization, increase in gypsum and NaCl will give better results.

Based on CBR test results it is observed that addition of Sodium Chloride and Gypsum as stabilizing agent produces a marked increase in CBR value. It was seen that, with increase in gypsum and NaCl, the CBR values are also increased considerably as CBR is found to be 16.8% for 13% Gypsum and NaCl compared to natural soil.

From the discussions, it can be concluded that addition of gypsum and NaCl to the natural soil (clay) shows the considerable effect on the compaction properties and bearing capacity of soil. It is also concluded that, expensive methods like cement, lime etc. for soil stabilization can be replaced with gypsum and NaCl as an alternative to improve the weak soil properties.

Table 2. *Test Results Of Reinforced Soil With Gypsum And Nacl [17].*

S/N	Properties of Natural soil		Value
1	Specific Gravity (^{G}s)		2.78
2	Particle Size Distribution	Gravel (4.75mm-20mm)	0%
		Sand (4.75mm-0.075mm)	15%
		Silt (0.075mm-0.002mm)	25%
		Clay (<0.002mm)	60%
3	Atterberg Limits	LL	53%
		PL	27%
		PI	26%
4	Compaction Properties	MDD	1.25g/cc
		OMC	18.4%
5	Un-Soaked CBR Test	CBR	3.28%

Table 3. *Index and engineering properties of natural soil [17].*

S/N	Proportions of Reinforced Soil Sample			Compaction Properties		CBR Ratio
	Soil (%)	Gypsum (%)	NaCl (%)	OMC (%)	MDD (g/cc)	CBR (%)
1	100	0	0	18.4	1.25	3.28
2	94	3	3	16.2	1.33	10.4
	Percentage of Increment/Decrement* (%)			11.9#	6.4	217.1
3	84	8	8	13.2	1.49	14.6
	Percentage of Increment/Decrement* (%)			28.2	24	345.2
4	74	13	13	12.5	1.72	16.8
	Percentage of Increment/Decrement* (%)			32.1	47	412.1

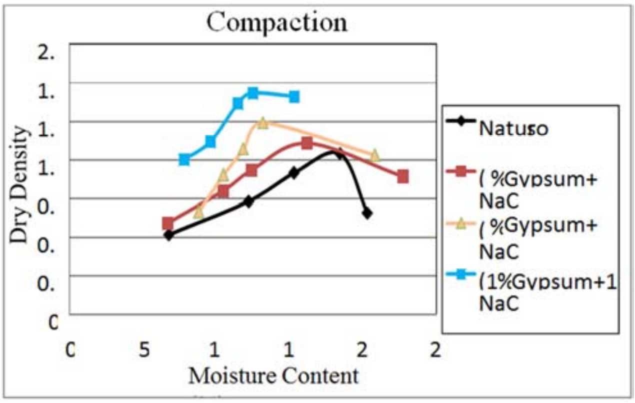

Figure 1. *Compaction Curve for Various Percentages Of Gypsum And Nacl [17].*

2.1.2. Stabilization of Soft Clay Soil Using a Gypsum Plafond Waste Based On CBR Testing

Herri [11] carried out research on soil improvement using a mixture of gypsum plafond waste (GPW) with a percentage of 5%, 10%, 15%, 20%, and 25% on a laboratory scale. The soft soil samples used for the research were taken in the Pakjo area of Palembang, South Sumatra Province.

The use of gypsum plafond waste as a mixture is expected to increase the bearing capacity of the red soil. The tests to be carried out are CBR (California Bearing Ratio) Soaked and Unsoaked. The results of this research: the highest of average CBR soaked value is in the gypsum plafond waste (15 GPW) mixture=11.44% with a soil bearing capacity) of 6.25. And the highest of average CBR unsoaked value is in the gypsum plafond waste (15 GPW) mixture=15.75% with a soil bearing capacity) of 6.85.

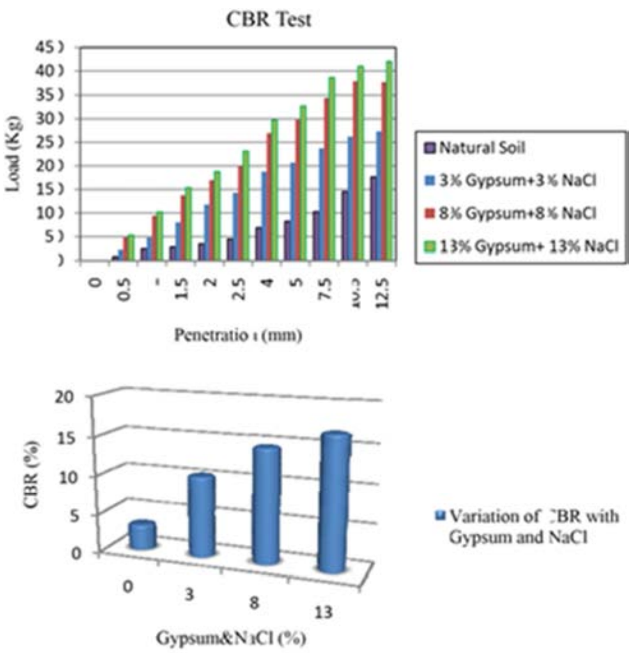

Figure 2. *Effect of Gypsum and Nacl On CBR Value [17].*

The followings were evaluated from the laboratory results obtained:

The soft clay soil in the Palembang Pakjo area based on the results of the index properties testing is included in the soil classification system or CH (USCS) and the A-7-6 (AASHTO) classification system.

The results of standard soil compaction testing were obtained: Optimum water content value of (OMC) as 22% and maximum dry content weight of (MDD) as 1.74 gr / cm^3.

The CBR soaked value of soft clay soil has increased in a mixture of 5%, 10%, and 15% gypsum plafond waste (GPW). The highest CBR soaked value is in the gypsum plafond waste (15 GPW) mixture of 11.44% with a soil bearing capacity) of 6.25.

The highest CBR unsoaked value is in the gypsum plafond waste (15 GPW) mixture of 15.75% with a soil bearing capacity (CBR) of 6.85.

2.1.3. Stabilization of Soil Using Lime, Gypsum and Jute Fibre

Suraj [22] focuses on increasing the workability, strength and durability of the soil naturally by bio-engineering work. 14 samples were prepared for investigating the properties of soil, out of which two specimens of each samples prepared with soil, soil-lime, soil-gypsum and soil-lime gypsum mix and some samples are prepared by adding random mix of 5% jute, 10% jute and 15% jute fibre of soil-lime-gypsum mix. Modified Proctor test and Unconfined compressive test are used to determine the optimum moisture content (OMC), maximum dry density (MDD) and compressive strength of the sample. From the results, it can be inferred that adding stabilizers increased the maximum dry density and the compressive strength of the soil.

The following was obtained based on the test results:

On addition of lime, gypsum and jute fibre, maximum dry density of soil increased marginally with the addition of 3% lime, 1% gypsum, 5% jute fibre however with *further increasing the content of lime,* gypsum and jute fibre the maximum dry density of soil starts decreasing.

The values of axial stress and axial strain of soil increased with addition of 5% jute fibre in soil lime-gypsum reference mix and values of axial stress and axial strain also increased with increase in the curing period.

However, the values of axial stress and axial strain of soil decreases with addition of 10% jute fibre in soil-lime-gypsum reference mix and values of axial stress and axial strain also increased with increase in the curing period.

5% jute fibre with reference mix samples shows multiple cracking with maximum compressive strength among all the sample.

It was concluded based on the results obtained that:

Adequate amount of gypsum helps in increasing the compressive strength and reducing the plasticity of soil.

The large cut length and higher content of jute fibre results in the balling formation, which further degrade the mechanical properties of soil. But the small cut length and adequate amount of jute fibre develops an intact structure and enhances the mechanical properties of jute.

2.1.4. Use of Gypsum and Bagasse Ash for Stabilization of Low Plastic and High Plastic Clay

Sadam [21] examined the effect of gypsum and bagasse ash on the properties of clays and evaluate their potential for the stabilization and improvement of engineering properties of these soils. Gypsum is naturally occurring mineral and bagasse ash is a waste product produced by sugar-mills. Two types of swelling clays i.e. Low plastic, and high plastic clay, were used in this research for stabilization.

Atterberg's limits, compaction characteristics, unconfined compressive strength, California Bearing Ratio and swell potential of these soils are determined in both untreated as well as in treated form with varying content of gypsum and bagasse ash. The improvement observed for the combination of gypsum and bagasse ash is more significant as compared to the individual effect of gypsum or bagasse ash. Results obtained indicate that gypsum and bagasse ash can provide an effective and economical method for the improvement of Low and high plastic clays.

The following evaluation was made on the basis of test results.

A decrease in liquid limit and plasticity index was observed when gypsum and bagasse ash were added to the Low plastic and highly plastic clay. This decrease was more significant when gypsum and bagasse ash were used as a combination as compared to the individual effect of gypsum. This change is associated with the flocculation and agglomeration of soil particles caused due to the addition of gypsum and bagasse ash.

This improvement changes the behavior of soil from clay to silt like. Maximum dry density is decreased by the addition and gypsum and bagasse ash while an increase in the optimum moisture content of soil is observed up to a certain percentage of admixture content.

Decrease in dry density is due to flocculation of soil particles. The soil becomes more friable and difficult to compact. While the increase in optimum moisture content is due to the increased surface area of soil particles due to the addition of gypsum and bagasse ash which are finer particles. The higher surface area, more water is required for wetting of soil particles. At admixture content larger than optimum values, maximum dry density starts to increase and optimum moisture content starts to decrease. This disparity in results is attributed to the fact the soil structure tends to become dispersed at higher admixture content resulting in increase in maximum dry density and decrease in optimum moisture content.

There is a significant improvement of unconfined compressive strength of soil with the addition of gypsum and bagasse ash for both Low plastic (natural soil) and high plastic (bentonite soil mix). Unconfined compressive strength increases up to an optimum percentage of admixture and then starts to decrease. This variation is attributed to the change of soil structure from flocculated to disperse beyond the optimum percentage of admixture. Moreover, the optimum moisture content is also increasing. Therefore, contributing to the decrease in unconfined compressive strength. The durability of the soil improved dramatically for treated soils. The loss in strength due to soaking for treated soil was significantly low as compared to untreated soil. This improvement in unconfined compressive strength is associated with the pozzolanic reaction between soil, gypsum and bagasse ash, which result in the formation of cementitious products.

The California bearing ratio of the soil was improved almost 3 times for treated soil as compared to untreated soil. Whereas one-dimensional swell potential was reduced to less than 1% for treated soil. So a sufficient improvement in California bearing ratio and one-dimensional swell potential was observed with the addition of gypsum and bagasse ash.

On the basis of the results obtained, it can be concluded that gypsum and bagasse ash can be efficiently used for the stabilization and improvement of Low plastic and high plastic clay soils. The improvement is more prominent when a combination of gypsum and bagasse ash is used as compared to the gypsum alone.

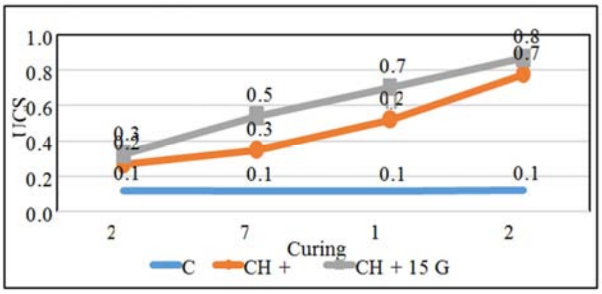

Figure 3. USC (Soaked/Unsoaked) Comparison at Various Curing Period for CH [22].

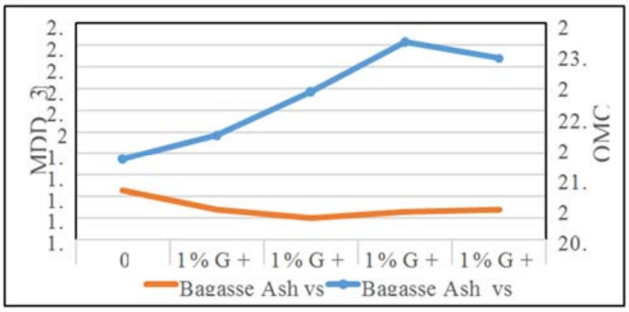

Figure 4. Variation of OMC and MDD Vs Optimum Gypsum and Various Bagasse Ash Content for CH [22].

2.1.5. A study on the Effectiveness of the Use of the Gypsum and Volcanic Ash Against the Stability of Clay Soil in Terms of UCT and CBR Values

Roesyant [19]. Postulated research goals as finding out the value of engineering properties of clay due to the addition of 2% gypsum and 2% - 15% paddy husk ash. Hence, the soil was classified as Clay –Low Plasticity (CL) based on USCS and was classified as A-7-6 (10) based on AASHTO classification system. The UCT value of original soil was 1.41 kg/cm^2. While the CBR soaked and unsoaked values of original soil were 4.41% and 6.23% respectively. The research results showed the addition of paddy husk ash decreased the value of unconfined compressive strength as well as CBR. The stabilized soil by 2% gypsum and 0% paddy husk ash gave maximum UCT value of 1.67 kg/cm2, while the maximum value of CBR were found 6.71% for CBR soaked and 8.00% for CBR unsoaked. The addition of paddy husk ash did not alter the soil classification according to AASHTO or USCS, even degrade the engineering properties of original soil.

From the research results, it could be said that:

Based on USCS classification, the soil samples are included in CL (Clay - Low Plasticity).

Based on the AASHTO (American Association of State Highway Transportation Official) classification, the original soil sample was A-7-6 (10).

From the Proctor standard test, the optimum moisture content of original soil was 20.50% and the maximum dry density was 1.31 gr/cm³. While the maximum dry density of all mixture was in the variation of 2% gypsum + 0% paddy husk ash which is 1.32 gr / cm³ and its optimum water content is 20.32%.

The specific gravity of original soil was 2.66. The specific gravity of the gypsum was 2.74 and the specific gravity of paddy husk ash was 2.55. The original soil had Liquid Limit (LL) of 45.76% and plasticity index of 28.05% and liquidity index (LI) of -0.18% (LI <0). The mixture of 2% G + 2% PHA had the lowest plasticity index of 22.46%. With a liquid limit value of 40.69%.

The CBR value of original soil was 4.41% for soaked CBR and 6.23% for unsoaked CBR respectively. The mixture of 2% G + 0% paddy husk ash produced highest value of CBR of 6.71% for soaked CBR and 8.00% for unsoaked CBR respectively.

The value of UCT original soil was 1.41 kg/cm^2. While the stabilized soil mixture with 2% G + 0% PHA had resulted the highest UCT value of 1.67 kg/cm^2.

Stabilized clay with 2% gypsum + 0% paddy husk ash, based on USCS classification was classified as CL (Clay - Plasticity) and based on AASHTO was classified as A-7-6 (9). While stabilized clay with 2% gypsum + 2% paddy husk ash was classified as A-7-6 (8). In addition, stabilized clay with 2% gypsum + 3% - 15% paddy husk ash were classified as A-7-6 (11).

The stabilized clay with a fixed percentage of gypsum and addition of paddy husk ash caused a decrease in shear strength of soil as shown in reduction of UCT and CBR value.

Table 4. Engineering Properties of Original Soil [19].

No.	TEST	RESULT
2	Specific Gravity	2.65
3	Liquid Limit	46.82%
4	Plastic Limit	17.42%
5	Plasticity Index	29.40%
6	Sieve Analysis	49.17%
7	Optimum Moisture Content	21.32%
8	Maximum Dry Density	1.31 gr/cm^3
9	CBR soaked	4.44%
10	CBR unsoaked	6.28%

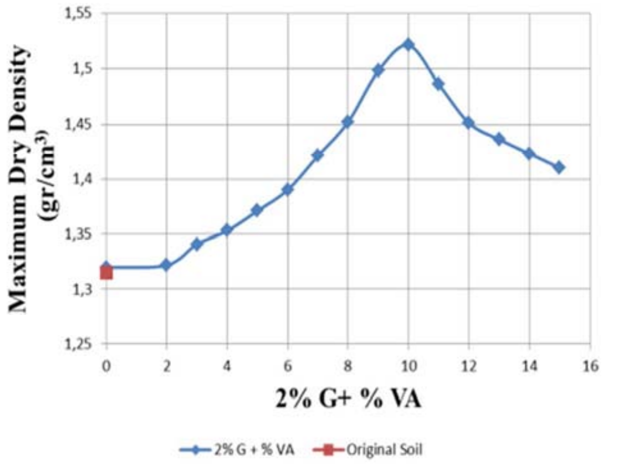

Figure 5. *Correlation of γdmax soil with the variation of 2% gypsum in the addition of 0% - 15% of volcanic ash [19].*

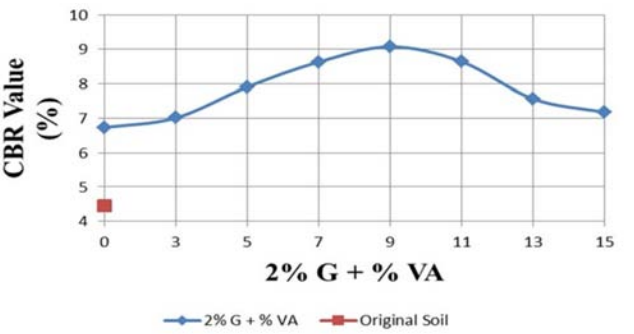

Figure 6. *Correlation of soaked CBR value with the variation of2% gypsum in the addition of 0% - 15% of volcanic ash [19].*

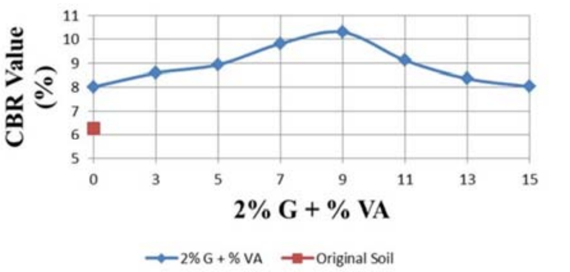

Figure 7. *Correlation of unsoaked CBR value with the variation of2% gypsum in the addition of 0% - 15% of volcanic ash. [19].*

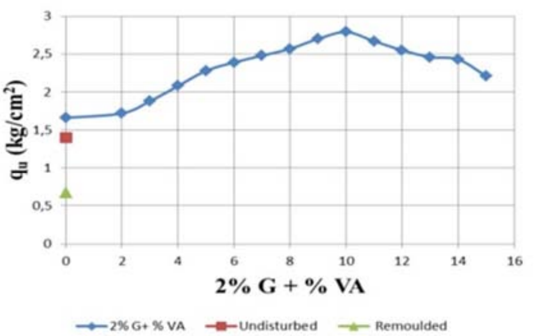

Figure 8. *Correlation of UCT value with the variation of2% gypsum in the addition of 0% - 15% of volcanic ash. [19].*

2.1.6. Stability of Soft Clay Soil Stabilized with Recycled Gypsum in a Wet Environment

Aly Ahmed [1]. This study investigates the effect of the soaking condition in a wet environment on the stability and durability of soft clay soil treated with recycled gypsum. Cement and lime are the two types of solidification agents used to improve the durability of the clay–gypsum mixture and to reduce the solubility of the gypsum in a wet environment because gypsum is soluble in water. The recycled gypsum was mixed with cement and lime in different ratios in the dry state, and different amounts of admixtures were mixed with the tested soil to explore the effect of the wet environment on the stability and durability of the stabilised gypsum–clay soil. Cylindrical stabilised soil specimens were cured for 3, 7, and 28 days and then soaked in water for different intervals up to 60 days. The soaked samples were evaluated based on the compressive strength, durability index, deformation changes, soil deterioration, and water absorption. The results show that increasing the content of both types of admixtures had a positive effect on the improvement of stability and durability for the tested soil in a wet environment, while the increase in the admixture ratio had a slightly negative effect on both the stability and the durability of the samples subjected to soaking. Short soaking times, up to 15 days, had a negative effect on the stability, durability, and changes in volume, and brought about a deterioration in the soluble soil and the water absorption compared with longer soaking times. The short curing times of 3 and 7 days exhibited a positive effect on the improvement of the stability, strength, and durability for the stabilised specimens subjected to soaking compared with the longer curing time of 28 days. Increasing the admixture content and soaking time had a significant effect on the water absorption and the soil deterioration of the tested soil. The effect of the soaking condition on the volume changes for the soil stabilized with the two admixtures was found to be insignificant, because the maximum volume change was found to be less than 0.15%.

The ratios and percentages of two admixtures investigated in this study demonstrated acceptable stability and reasonable durability in terms of strength, volume change, soil deterioration, solubility, and water absorption. The main purpose of this research was to confirm the potential use of recycled gypsum as a co-stabiliser material in ground improvement projects. It will help to cut down the cost of disposal, reduce the cost of ground improvement projects, and improve the sustainability of the environment [12]

Based on the results of tests on strength, durability, deformation changes, soil deterioration, and water absorption, the following conclusions was drawn:

The amount of admixture has a significant effect on the durability in samples treated with the B–C admixture in comparison with the B–L admixture. An increase in the B– C admixture content is associated with an increase in the durability, whereas no difference was observed for different amounts of admixture for B–L admixtures.

Stabilized soil specimens with a low content of the B–L admixture are more durable than the same samples stabilized with the B–C admixture. For B–C/L admixtures, the increase in the admixture ratio is associated with a decrease in the durability index, whereas an improvement in the durability was observed with an increasing admixture content.

The effect of the soaking time on the durability was much more pronounced during the early stage of soaking. After 15 days of soaking, the durability improved or stayed constant. The curing time has a positive effect on the durability of the stabilized soil, especially during the early stages of 3 and 7 days compared to the longer curing time of 28 days.

The effect of soaking on the volume changes of stabilized soil is not significant because the maximum change in deformation for all the samples was found to be less than 0.15%. This proves that the use of recycled gypsum, solidified with cement or lime in ground improvement projects within the investigated limits, is resistant to the effect of soaking actions in terms of deformational changes.

For both admixtures, an increase in the soaking time increased with the percentage of soluble soil deterioration up to 15 days. Subsequently, the percentage of deteriorated soil stayed constant and no more soil deteriorated from the specimens. The results demonstrate that no difference is observed with respect to the percentage of the deteriorated soil for different admixture ratios.

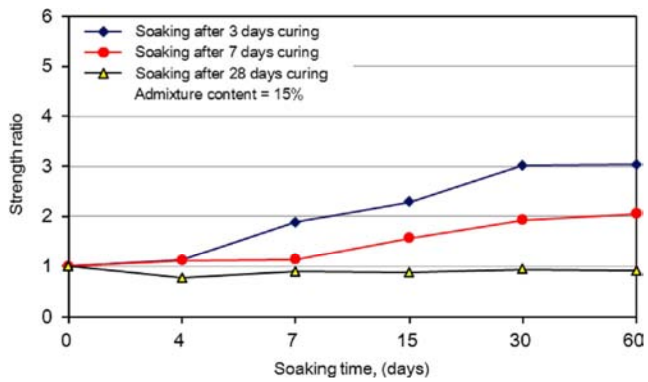

Figure 9. Effect of soaking time on strength ratio of soil stabilized with B–C admixture subjected to different curing times before soaking. [1]

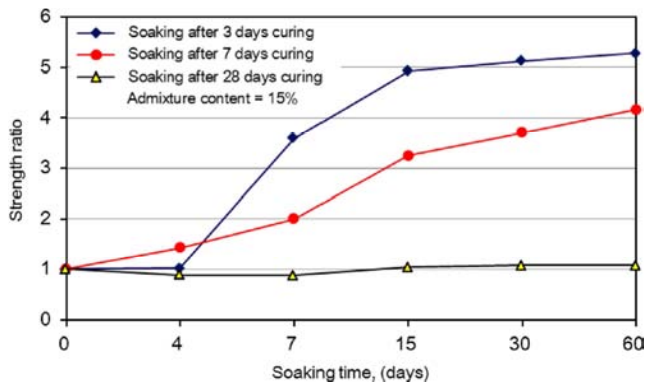

Figure 10. Effect of soaking time on strength ratio of soil stabilized with B–L admixture subjected to different curing times before soaking [1].

An increase in the admixture content and soaking time is associated with an increase in the water absorption for both admixtures. Both the content and the ratio of the B–L admixture had a more significant effect on the rate of water absorption than the content and the ratio of the B–C admixture. Based on the stability and durability results, the B–C admixture with a content of 22.5% and a ratio within 1:1 to 2:1 is recommended for preparing a stabilizer material that achieves sustainable durability. Generally, the use of furnace cement Type-B as a solidification agent is recommended because it leads to an improvement in the stability and durability of soft clay soil stabilized with recycled gypsum and can prevent solubility.

2.1.7. Chemical Stabilization of Sub-Grade Soil with Gypsum and Nacl

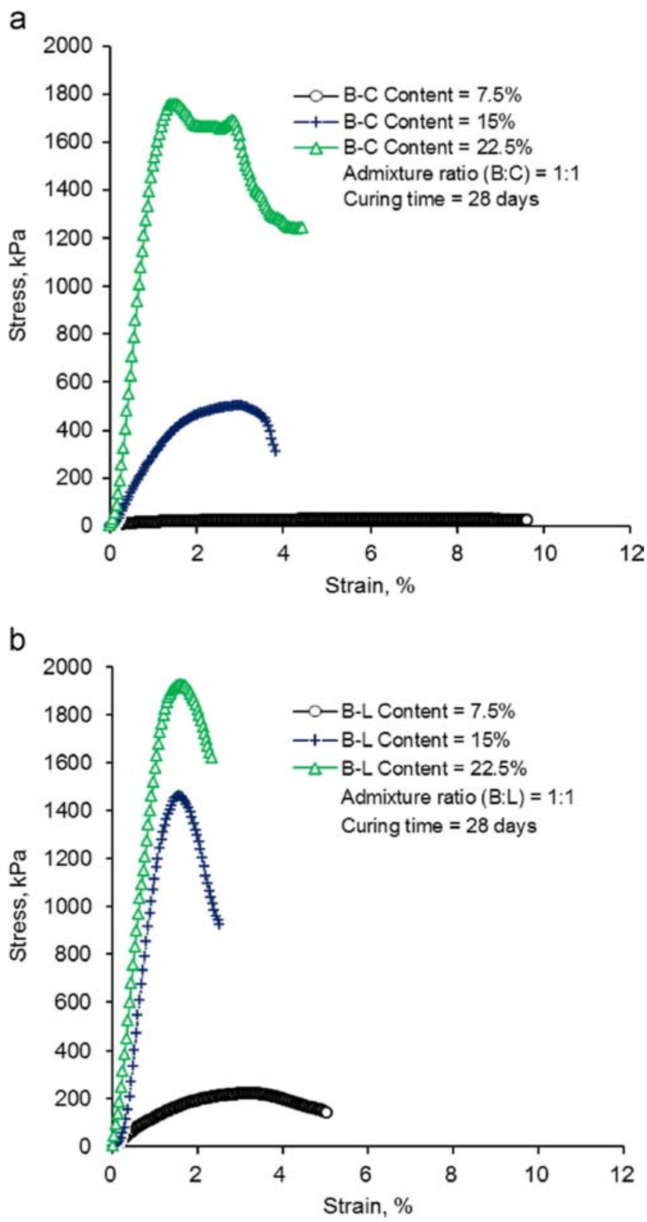

Figure 11. Effect of admixture content on stress–strain relationship for samples stabilized with b–c/l admixtures. (a) in case of b–c admixture. and (b) in case of b–l admixture [8].

Murthy [8]. Experiment the effect of adding different Compounds including (NaCl & Gypsum) on the engineering properties of silty clay soil. Gypsum is a source of calcium which is major mechanism that binds soil organic matter to clay in soil which gives stability to the soil aggregates. Gypsum complements or even magnifies the beneficial effects of water-soluble polymers used as amendments to improve soil structure. Significantly for alkaline soil gypsum is a suitable chemical for improvement of bearing capacity. In case of silty clay soils the engineering, properties are improved by adding chloride salts like Nacl, $Mgcl_2$ and $Cacl_2$. Chloride salts increase the maximum dry density (MDD) by decreasing the optimum moisture content (OMC). In this study an attempt is taken to analyze the properties of soil using gypsum and Nacl. Various amounts of salts (15%, 20%, and 25%) are added to the soil to study the effect of stabilizing agents on the compaction characteristics, consistency limits and compressive strength. The main findings of this study were that the increase in the percentage of each of the chemical compounds increased the maximum dry density and decrease the optimum moisture content. The liquid limit, plastic limit and plasticity index decreases with the increase in additives content. The unconfined compressive strength increases as the chemical content increases and also bearing capacity of soil increases.

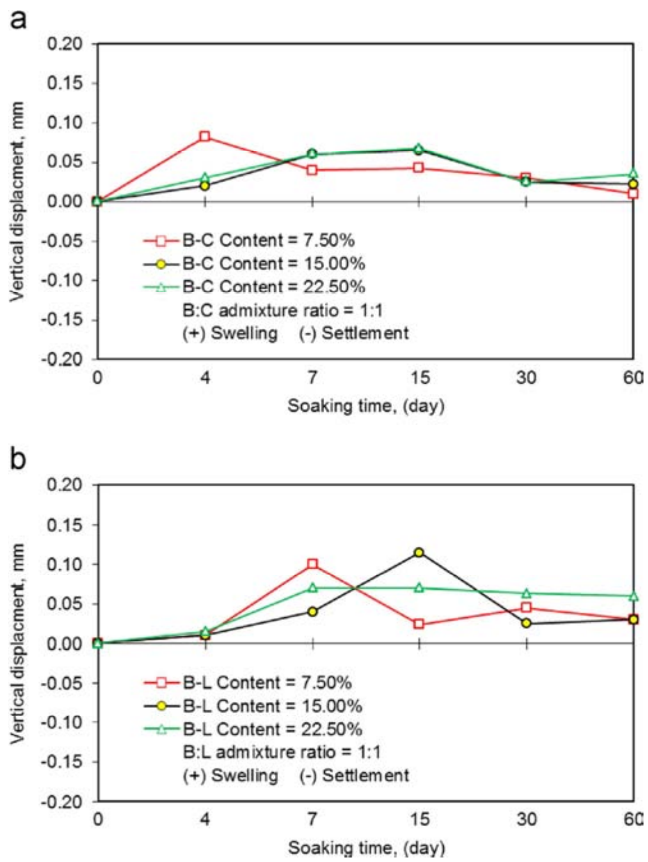

Figure 12. *Effect of admixture content on deformation changes for stabilized samples subjected to soaking. (a) In case of B–C admixture. and (b) In case of B–L admixture [8].*

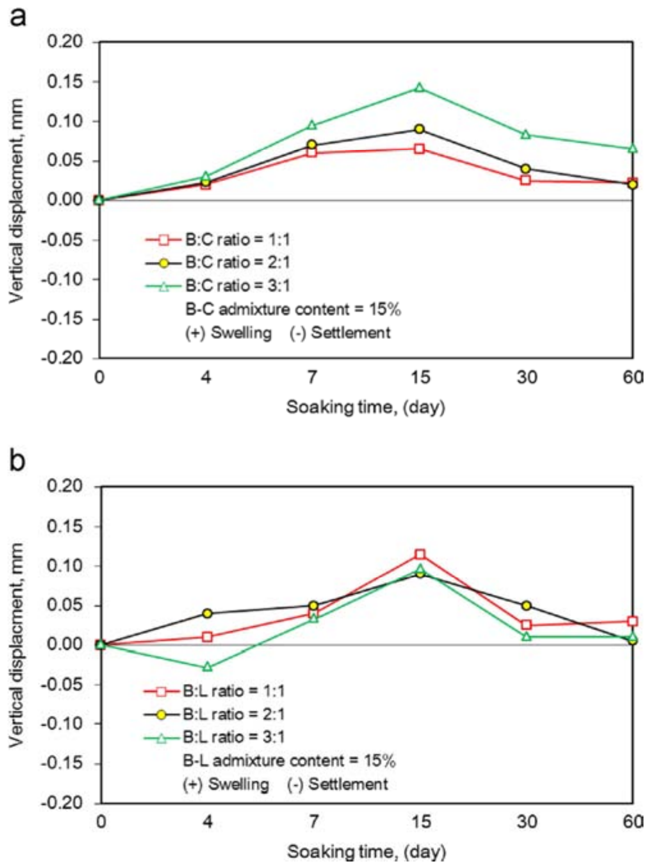

Figure 13. *Effect of admixture ratio on deformation changes for stabilized samples subjected to soaking. (a) In case of B–C admixture. and (b) In case of B–L admixture [8].*

Based on the laboratory tests result, the following conclusions was drawn:

The liquid limit, plastic limit and plasticity index decreased as the chemicals (NaCl &gypsum) Content increased.

The additions of chemicals (NaCl & Gypsum) to the soil increase the maximum dry density and reduce the optimum moisture content.

The addition of sodium chloride and gypsum as stabilizing agents produces a marked increase in CBR value.

The adding of stabilization agents increases the dry density and decrease of moisture content.

Finally concluded that the increase in the bearing capacity and decrease in the consistency limits.

Table 5. *Standard loads at specified penetrations [8, 12].*

Penetration depth (mm)	Unit Standard load (kg/ cm^2)	Total Standard load (Kg)
2.5	70	1370
5	105	2055
7.5	134	2630
10	162	3180
12.5	183	3600

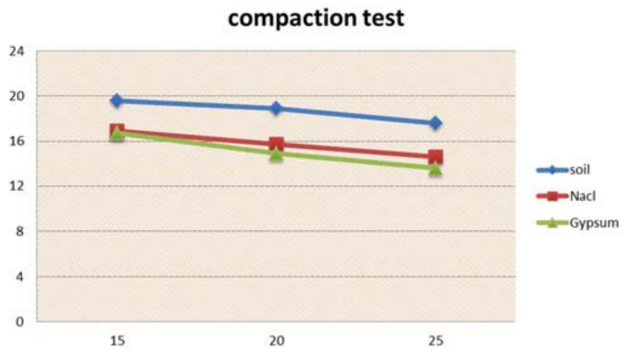

Figure 14. *Percentage of chemicals Vs. OMC Value [8, 12].*

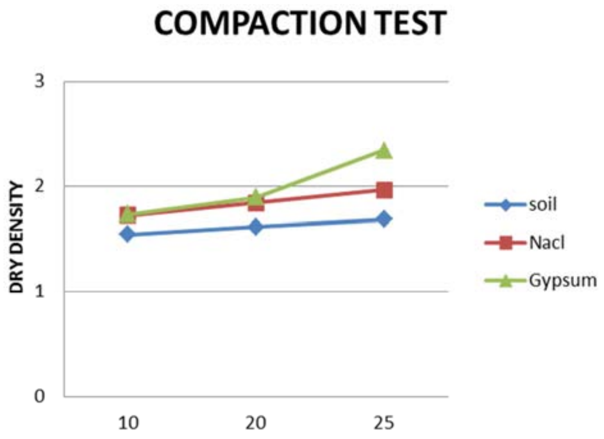

Figure 15. *Percentage of chemicals Vs. Dry density [8, 12]*

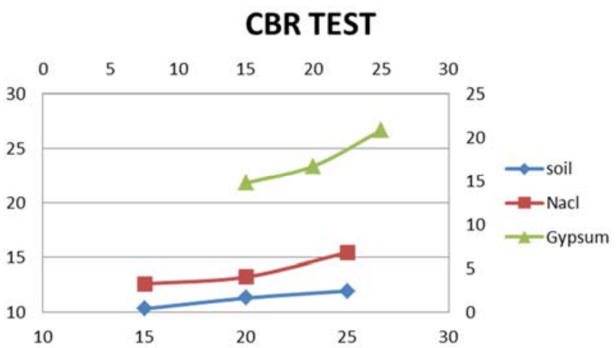

Figure 16. *Percentage of Chemical Vs CBR Value [8, 12].*

2.1.8. Soil Stabilization Using Waste Rice Husk Ash, Cement, Lime & Gypsum

Gupta [7]. This research takes critical review the available technology in the field of ground improvement by the use of waste rice husk ash for this purpose. India is one of the world's largest producers of rice. This paper therefore takes the review of the effect of rice husk ash on the properties of soil related to pavement such as Optimum Moisture Content (OMC), Maximum Dry Density (MDD) and California Bearing Ratio (CBR). The paper compares the use of rice husk ash with cement as an additive and lime and gypsum as an additive and critically reviews the effect on these mixtures on the aforesaid properties of soil.

The following conclusions are drawn out from the results obtained:

It was observed that in case of Marine clay, the MDD is improved by 17.00% on addition of 25% RHA and it has been further improved by 12.70% when 9% lime is added whereas the OMC decreases 18.52% on addition of 25% RHA and it has been further decreased by 42.63% when 9% lime is added

However, it was noticed in the other methods (A), (C) and (D) of regular expansive clay and lateritic soil that, the OMC is increased and MDD is decreased.

CBR value increases with increasing content of RHA. Further improvement is observed on addition of 3% gypsum in both soaked and un-soaked conditions.

Method (D) is found to be the most effective in cost as well as in gaining strength.

2.1.9. Stabilization of Clay Using Gypsum and Paddy Husk Ash with Reference to UTC and CBR Value

Roesyanto [20]. Experiment found out the value of engineering properties of clay due to the addition of 2% gypsum and 2% - 15% volcanic ash. The soil sample was classified as Clay – Low Plasticity (CL) based on USCS and was classified as A-7-6 (10) based on AASHTO classification system. The UCT values of original soil and original soil plus 2% gypsum were 1.40 kg/cm^2 and 1.66 kg/cm^2 respectively. The CBR soaked and unsoaked values of original soil were 4.44% and 6.28% correspondingly. Meanwhile, CBR soaked and CBR unsoaked values of original soil plus 2% gypsum were 6.74% and 8.02% respectively. The research results showed that the additives materials of gypsum and volcanic ash improved the engineering properties of clay. The UCT result from the stabilized soil by 2% gypsum and 10% volcanic ash gave value of 2.79 kg/cm^2 (increased 99.28% from original soil). For CBR test, the most effective mixture was in variation of 2% gypsum and 9% volcanic ash which gave value of 9.07% (104.27% increase from original soil) for CBR soaked and 10.29% (63.85% increase from original soil) for CBR unsoaked. The stabilized soil with 2% gypsum and 9% volcanic ash was classified as CL based on USCS and was classified as A-6 (4) based on AASHTO classification system.

From the research results, it could be concluded that: Based on the classification of USCS, the soil sample was classified in the Clay – Low Plasticity (CL).

Based on AASHTO classification, the sample of original soil was the A-7-6 (10) type. The specific gravity of original soil was 2.65. The specific gravity of the gypsum was 2.74 and the specific gravity of the volcanic ash was 2.62.

The original soil had Liquid Limit (LL) of 46.82% and plasticity index of 29.40%. The mixture of 2% G + 15% VA had the lowest plasticity index of 8.59% and liquid limit (LL) of 28.12% The optimum moisture content of original soil was 21.32% and the maximum dry density was 1.31gr/cm^3. While the stabilized soil mixture of 2% G + 10% VA had optimum moisture content of 19.06% and the maximum dry density of1.52 gr/cm^3.

The CBR value of original soil was 4.44% for soaked CBR and 6.28% for unsoaked CBR respectively. The mixture of 2% G + 9% VA produced highest value of CBR of 9.07% for soaked CBR and 10.29% for unsoaked CBR respectively.

The value of UCT original soil was 1.40 gr/cm^2. While the stabilized soil mixture with 2% G + 10% VA had resulted the highest UCT value of 2.79 gr/cm^2.

2.1.10. Stabilization of Bentonite and Kaolinite Clays Using Recycled Gypsum and Liquid Sodium Silicate

Mehmet [15]. Undertook series of laboratory tests to determine the strength development of bentonite and kaolinite clays blended with various quantities of: (1) 100% recycled gypsum, (2) 100% sodium silicate, in solution form, and (3) a 50%: 50% combination of recycled gypsum and sodium silicate. These stabilizers were explored as sustainable "low carbon" additives that can be used to ensure significant strength gain in poor quality stabilized clay soils via geo-polymer stabilization; it is envisioned that they can be used in place of traditional soil stabilizers such as lime and Portland cement. In this study, bentonite and kaolinite clays were stabilized with varying additive contents and cured in humidity controlled box and temperature-controlled room. Standard Proctor compaction tests were used to identify the ideal moisture content and density for treated specimen preparation. The enhancement of strength was analyzed utilizing UCS tests and supporting pH tests were utilized to look at the acidity/alkalinity during the stabilization reaction process. Additional microstructural test techniques including X-ray diffraction (XRD), FESEM/EDAX, FTIR, and N_2-BET surface area analysis were utilized to explore changes to soil microstructure that occurred during the post-stabilization curing process.

The admixture of recycled gypsum and sodium silicate solution has a different impact on the level of alkalinity of both soils. The pH of the kaolinite specimens is higher than the pH of bentonite specimens. Bentonite treated with the admixture increase the level of acidity until 7-days of curing; then it decreases importantly until 14 days of curing and reaches the lowest pH level, which could be related to slow dissolution rates of calcium and sodium ions in the binder. Beyond 14-days of curing, the initial level of pH gradually increases for the varying additive contents. This is due to dissolution of the recycled gypsum, and sodium silicate is releasing more calcium and sodium ions which react with silicate ions in the binder. However, the change of pH level is not significant with varying admixture contents in the soil.

The compaction behavior of treated bentonite and kaolinite clays at the different proportions of recycled gypsum and sodium silicate was assessed using a Standard Proctor compaction approach. The dry unit weight and optimum water content of stabilized bentonite and kaolinite act similarly in response to stabilization. The dry unit weight of the stabilized soils decreases slightly, and the optimum moisture content increases slightly with increasing amounts of recycled gypsum in the soil. This could be attributed to calcium ions from recycled gypsum altering granular particles in the soil.

Additionally, recycled gypsum has a lower specific gravity compared with the soil. Therefore, the weight of pure soils reduces with the increase in the proportion of recycled gypsum. The effect of the admixture of sodium silicate solution and recycled gypsum corresponding to strength development noticeably relies upon the type of the soils in this research. Kaolinite clay reveals more consistent results in comparison to stabilized bentonite specimens at the same additive content. Nevertheless, the maximum enhancement of the strength was obtained at a 6% additive ratio (50%: 50%) by mass for both soil types. Higher contents of admixture (more than 6%) tended to decrease the strength in any age of curing for the bentonite and kaolinite clays. This could be attributed to unreacted silica gel or an undesirable pH environment encouraging the dissolution of aluminate silicate source materials and fabrication of cementitious compounds in the binders since an excessive amount of sodium silicate gels prevents the other additives from effectively reacting and binding together. Both types of soils can be efficiently treated by adding up to 6% admixture for the long-term stabilization process.

2.2. Soils Review of the Effect of Gypsum in Composition of Other Chemicals and Organic Additives in Stabilizing Engineering Materials

2.2.1. Use of Gypsum Waste and Tin Tailings as Stabilization Materials for Clay to Improve the Quality of Subgrade

Apriyanti [4]. The laboratory experiment of soil characteristics carried out in this study were sieve analysis, soil specific gravity, compaction and direct shear test. In this study, the addition of gypsum waste and tin tailings in soft soil with 4 variations, namely clay with additional 8% gypsum waste and 20% tin tailings, clay with additional 8% gypsum waste and 30% tin tailings, and clay with addition 8% gypsum waste and 40% tin tailing, besides that, testing of the original soil was also carried out. The results of sieve analysis test showed that the addition of gypsum waste and tin tailings to clay soils could change the gradation of clay. Addition of gypsum waste and tin tailings on clay soil increases cohesion (c) and shear angel value so that increases soil shear strength. From the results of the study, the addition of gypsum waste and tin tailings can improve the stability of clay so Improve Quality of Subgrade.

Based on the results of sieve analysis and consistency limits test, classification of clay from the USCS method, including CL classification and based on the AASTHO method this soil includes classification A-7-6. Based on the results of specific gravity and compaction tests, specific gravity value of clay is 2,639, value of OMC (Optimum Moisture Content) is 19.31% and Maximum Dry Density (MDD) value is 1,739 gr/cm^3

In sieve analysis test, changes in the gradient of clay soil were obtained. In sieve analysis experiment, the original clay passed to the sieve no. 200 was 54.511%. After being mixed with 8% gypsum waste and tin tailing with variations of 20%, 30%, and 40%, the clay passed to the sieve no. 200 was decreased in a row to 50.23%, 47.31%, and 44.75%. So it showed that the addition of gypsum waste and tin tailings to clay can change the gradation of clay Based on the results of the direct shear strength test, cohesion (c) and shear angle (φ) have increased with the increase in the percentage of tin tailings.

Based on the value of cohesion (c) and the shear angle (φ), the shear strength can be determined. The increase in soil shear strength can be seen in Figure 4. In the direct shear test, the shear strength of the original clay was 21.77 KN / m^2. After adding 8% gypsum and tin tailing's variation of 20%, 30%, and 40%, the shear strength value has increased, the values respectively of 33.517 KN / m^2, 41.593 KN / m^2, and 49.447 KN / m^2, then the addition of gypsum 8% and 40% tin tailing produce the largest shear strength value. The shear strength is increase caused tin tailings to have coarse grain properties causing clay grains, which are fine-grained soils to change gradations into fine and coarse graded, as well as gypsum waste containing calcium which is useful as a binder for clay so that the soil becomes stiffer. These factors increase the cohesion value and soil shear angle so that the value of the soil shear strength increases.

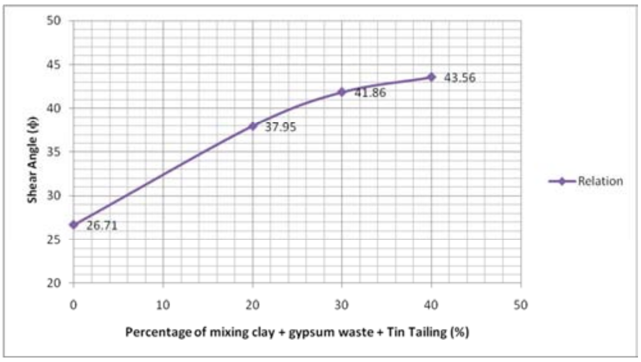

Figure 17. The effect of adding tailings and gypsum to the value of shear angle (φ) [4].

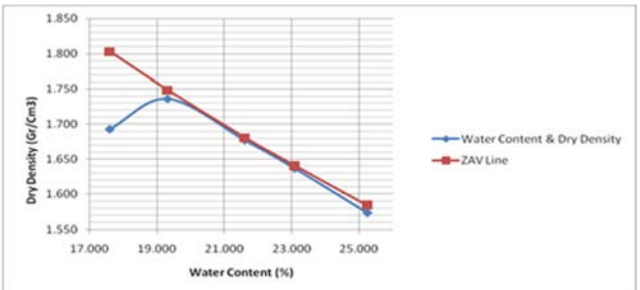

Figure 18. Compaction curve OMC Vs MDD [4].

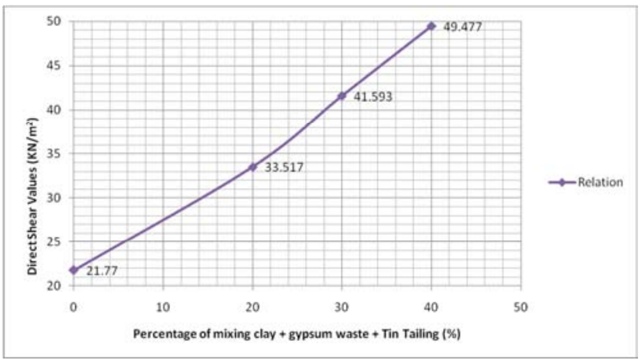

Figure 19. The effect of adding tailings and gypsum to the value of shear strength [4].

Addition of gypsum and tailings can increase the value of clay characteristics, namely the value of cohesion, shear angle, and shear strength. Furthermore, the addition of the material also changes the gradation of clay, from fine gradations to coarse gradations.

2.2.2. Effect of Lime and Gypsum on Stabilization of High Plasticity Clay

Özgür [16]. Investigated the effect of lime plus gypsum additives on the swelling percent, swelling pressure and unconfined compression strength of clay with high plasticity in order to determine the optimum mixture. The optimum water content and dry unit weight of natural clay were determined through standard compaction. Admixtures of 3, 6, 9, 12 and 15% lime, gypsum and lime plus gypsum (half/half) were prepared and tested at the end of 90 days. It is concluded that, swelling percent and swelling pressure reduce with increasing additive percent and time, while the unconfined compressive strength increases. The optimum mixture is adding 6% lime which corresponds to a 99.55% decrease for swelling percent, 98.98% decrease for swelling pressure and 191.87% increase for the unconfined strength along 90 days.

Results shows that:

Clay consists of 48.12% SiO_2, 12.76% Al_2O_3, 5.82% Fe_2O_3, 2.29% MgO, 1.72% K_2O, 0.82% CaO and 0.37% MgO according to order of abundance. According to XRD analysis, Na-smectite exists in the clay.

Na-smectite exists within the investigated clay which involves high swelling percent and swelling pressure potential. In case lime is added to clay, Na replaces with Ca, transforming Na-smectite into Ca-smectite which has low swelling percent and swelling pressure.

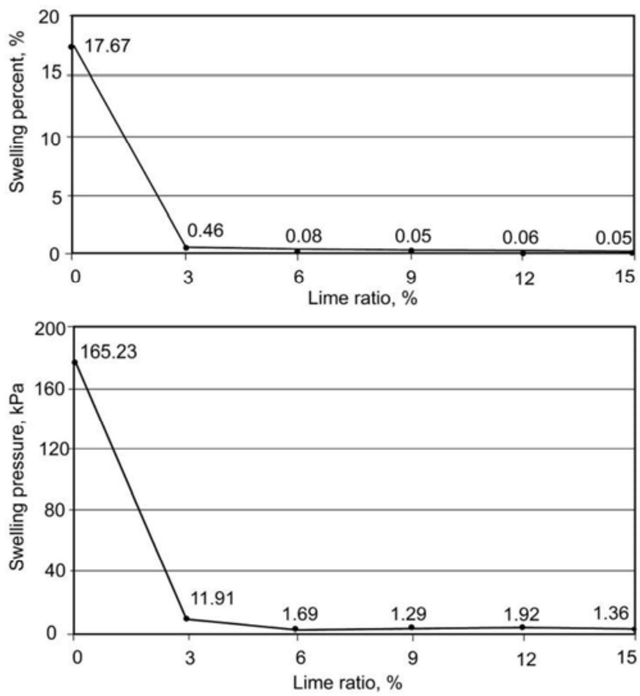

Figure 20. Lime ratio vs. swelling percent and swelling pressure at 90 days [16].

Since it seems hard to obtain a homogenous mixture of lime and gypsum and cost would be high, stabilization with lime might be more favorable. The highest improvement rate is for the 15% lime addition at the end of 90 days however, there is a negligible difference from the 6% ratio.

The time period is limited with 90 days in this study. It must be considered that; the swelling percent and swelling pressure will decrease while the unconfined compression strength will increase with progressing time.

It is concluded that, using 6% of lime would be enough to stabilize the high plasticity clays in order to deal with the swelling, settlement and bearing capacity problem for the constructions around Batikent area. It is appropriate to determine the thickness of the filling material and the loading vs. deformation relations of such layers might be tested by plate loading and California bearing ratio tests.

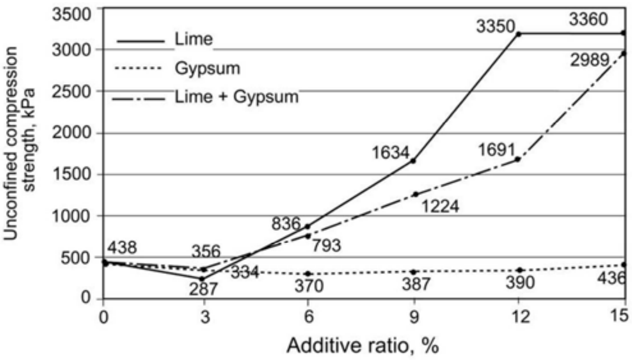

Figure 21. *Additives vs. unconfined compression strength [16].*

2.2.3. Soil Stabilization Using Gypsum and Powdered Glass

William [24]. This research reflects the stabilizing consequence of Gypsum and powdered glass on a clay soil. Broken waste glass and gypsum was collected in sufficient amount to carry out the work and it was converted to powder form which is suitable to add in the clay soil in variable quantities namely 2%, 4%, 6% and 8% by the heaviness of the soil selected to conduct test. Subsequently, the moisture content, specific gravity, particle size distribution and Plastic Limit, Liquid limit, Plasticity index, shrinkage, MOD and OMC tests were also conceded out to categorize the soil. California bearing ratio (CBR) and straight crop tests were also conceded out on the soil with and without the accumulation of gypsum and the powdered glass. The succeeding resources such as clay soil, gypsum and glass pieces were utilized for the preparation the test samples. The soft clay used for these tests has been brought from a saravanampatti near area site and the physical properties of the soil were determined as per IS specification.

Result obtained from test procedures shows:

In this experimental work the soil has been mixed with different percentages of gypsum such as 2%, 4%, 6%, and 8% and tests has been carried out for 10 days. The optimal moisture content (OMC) and maximum dry density (MDD) at 4% gypsum is 10.99% and 15.0KN/m3. The growth of soil reduced is from 47% to 3.10% and CBR Value increases from 2.54% to 8.54%.

2.2.4. Stabilization of Peat Soil Using Gypsum and Fly Ash

Kolay [13]. Stabilized local peat soil from Matang, Sarawak, using gypsum and fly ash. Peat soil has been identified as one of the major groups of soils found in Malaysia, which has high compressibility and low shear strength. Presence of soft or peaty soil is a major problem encountered by civil engineers in Sarawak.

The scope was based on the use of different percentages of gypsum (i.e., 2, 4, 6 and 8%) and fly ash (i.e., 5, 10, 15, 20 and 25%) added into peat soil at optimum moisture content (OMC) and its maximum dry density (MDD) determined by standard Proctor test. Unconfined compressive strength (UCS) test were conducted to determine the strength gain after 7, 14 and 28 days of curing periods.

Physical properties of the peat soil were also studied for identification and classification purposes. The unconfined compressive strength test results show that the peat soil gained strength due to the addition of different percentages of admixtures such as gypsum and fly ash and the strength also increases with the increase of curing periods

From the series of laboratory investigation carried out, the following evaluations was made:

The soil sample collected from Matang is categorized as peat soil. The unconfined compressive strength (UCS) values increase as the percentages of gypsum and fly ash added increase except for 8% of gypsum and 25% of fly ash.

Table 6. *Index properties of peat soil [13].*

Parameters	Results
Natural moisture content, MC (%)	678.47
Von Post humification for peat	H4
Fiber content (%)	70.83
Specific gravity, G_s	1.21
Loss on Ignition, LOI (%)	95.21
Organic content, OC (%)	94.47
Liquid Limit, LL	150
Maximum Dry Density, MDD, γ_d (gm/cc)	0.56
Optimum Moisture Content, OMC (%)	95.17

The unconfined compressive strength (UCS) values increase as the curing period increase for all percentages of stabilizer added.

The average value of unconfined compressive strength (UCS) from test results are 31.37, 32.92, 44.94 and 37.70 kPa for 2, 4, 6 and 8% gypsum added respectively for 28 days curing.

The average value of unconfined compressive strength (UCS) from test results are 54.01, 58.47, 78.17, 107.35 and 109.69 kPa for 5, 10, 15, 20 and 25% fly ash added, respectively for 28 days curing.

In this study, the test results indicate that peat soil treated with gypsum and fly ash result in improvement of strength of the soil as measured from unconfined compressive tests. In general, the compressive strength gain was observed primarily in the first 14 days of curing and then had a tendency to slow down the rate of strength gain afterwards. For 8% gypsum treated soil, drop in strength was observed when compared to 6% gypsum treated soil. Similar trend has been observed with 25% fly ash treated soil (compared to 20% fly ash) except for 28 days of curing, where slightly drop in strength was observed.

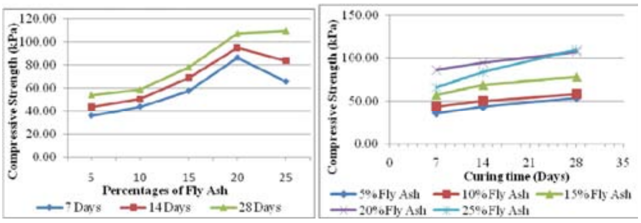

Figure 22. UCS test results for sample with respect of various (a) percentages of fly ash added (b) curing periods [20].

2.2.5. Stabilization of Peat Soil Using Gypsum and Fly as Ash Additives

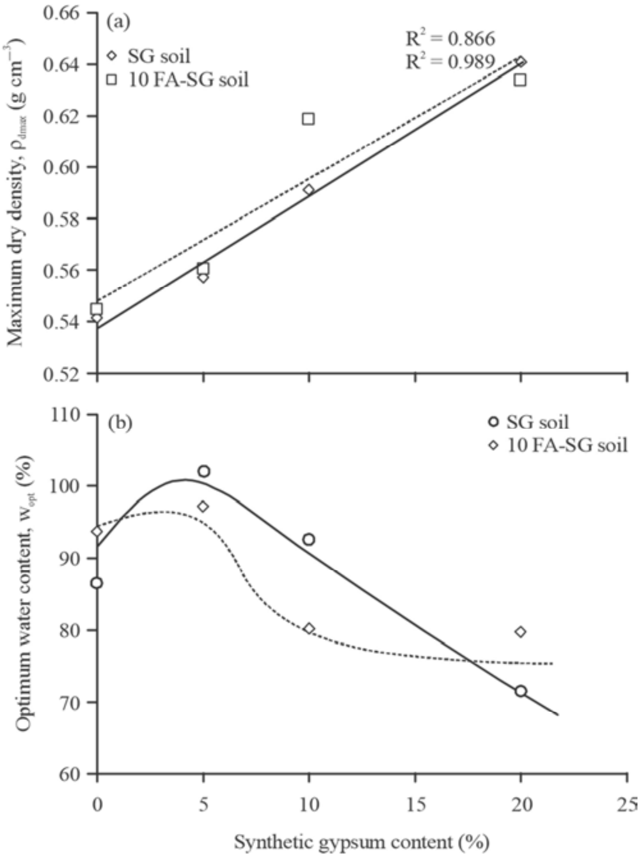

Figure 23. (a) Maximum dry density, ρ_{dmax} values and (b) Optimum water content, w_{opt} against synthetic gypsum contents for SG and 10 FA-SG soils [18].

Rahman [18]. Studied and investigate the effect of fly ash and gypsum on the mechanical properties of peat soil. Fly Ash (FA) is a by-product material that is generated from the burning of coal in thermal power plants. In this study, gypsum was prepared chemically in the laboratory to simulate residue from Neutralization Underflow Process (NUF). For the first batch of samples, the peat samples were initially treated with Synthetic Gypsum (SG) in the ranges between 0 and 20% of sample dried weight (SG treated soil). In a second batch, the peat samples were prepared with 10% FA and then mixed thoroughly with different amounts of SG contents (0, 5, 10 and 20%) (10FA-SG treated soil). The results showed that soil treated with mixture of 10% FA and SG indicated lower liquid limit values than the SG treated soil. In compaction tests, the maximum dry density of both increased in both SG treated soil and FA-SG treated soil. The permeability of SG treated soil increased with the increases in SG contents. Similarly, occurred to permeability of FA-SG treated soil however, its values are lower than the soil treated without FA. Shear strength of SG treated showed decreased with increasing amount of SG content. In contrast, the FA-SG treated soil exhibited higher strength if compared to that of SG treated soil. The result suggested that the application of FA and SG mixture is more effective in stabilization in mechanical strength and densification of peat soil than the use of SG only.

Table 7. Summary of basic characterization of peat and additive materials [18].

Material properties	Peat	Fly ash	Gypsum
Natural moisture content, w (%)	77-96	0.1	39.7
Organic content (%)	95.6	-	-
Humification class	H_4	-	-
pH	3.2	12.5	8.8
Specific gravity (G_s)	1.3	2.2	2.0
Liquid limit, w_L (%)	144-184	-	-
Permeability, k (×10G^5) (m secG^1)	4.9	-	-
Compaction test			
Maximum dry density, ρ_{dmax} (g cmG^3)	0.54	-	-
Optimum moisture content, w_{opt} (%)	86.5	-	-
Shear strength, C_u (kPa)	10-13	-	-

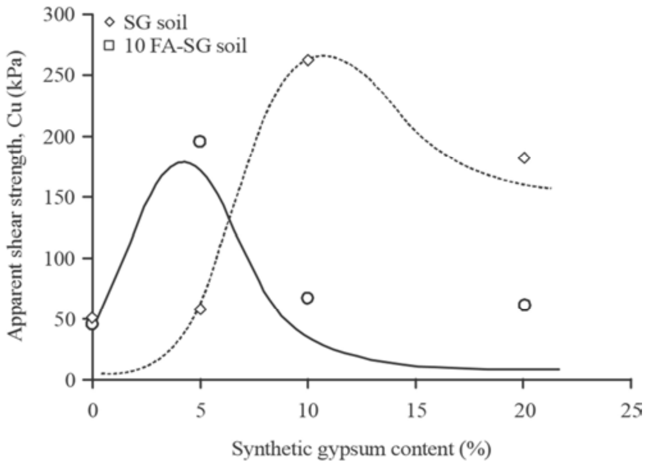

Figure 24. Shear strength against synthetic gypsum contents of SG and 10 FA-SG soils [18].

2.2.6. Use of Gypsum Mining and Lime on the Engineering Properties of Compressed Earth Blocks

Eliana [6]. Disadvantages of compressed earth blocks are their poor mechanical properties and low resistance to water damage. Therefore, their use is vulnerable to deterioration and require care and maintenance, which depends on the degree of stabilization and compaction of the clay soil. Gypsum mining wastes and lime used as stabilization materials to improve the properties of these construction materials. The compressive and flexural strength, softening in water, drying shrinkage and unit weight determined. Strength values increased with both mining waste additions. Highest resistance against softening in water obtained with a 25% of mining waste. Drying shrinkage reduced with increasing mining waste content. Dry unit weight was not in the recommended standards. Results showed that gypsum mining wastes can be used as alternative materials to stabilize compressed earth blocks. A laboratory test program conducted to evaluate the potential use of gypsum mining waste to produce CEBs. The hardened properties such as compressive strength, flexural strength, and water absorption was investigated. Subordinately, test results may provide a means to reduce a waste disposal problem while providing the construction industry with a new, useful, low cost raw material. Based on the experimental tests conducted on the CEBs, the following conclusions can be drawn:

The liquid and plastic limits of the clay-rich material are appropriated for the production of CEBs, although it is advisable to test a number of natural fibers to increase compressive and flexural strength and to avoid excessive cracking.

Clay-rich material corresponds to a granular soil, with > 50% of sand and gravel size, but the soil used is a sandy soil because > 50% of the coarse fraction is < 4.75 mm (No. 4 mesh ASTM). According to this and the behavior of the fine fraction of the soil, it classified as a clayed silty sand soil, settling near the boundary line suitable for the preparation of CEBs.

The chemical composition of the gypsum mining waste reveals that the elemental content would be suitable in principle for chemical stabilization, avoiding a waste with high levels of visible gypsum as this could create adverse conditions for the development of CEBs.

Non-stabilized CEBs showed values of compressive strength up to 0.251 MPa, which are below recommended limits. However, CEBs from the trial T3 (2.5% of gypsum mining waste and 3% of lime), the compressive strength was improved by up to 500% (5 times) reaching values of 1.574 MPa, that is within the minimum range required by Colombian construction standards.

Stabilized CEBs showed much better values of modulus of rupture compared with those obtained from non-stabilized CEBs. CEBs from the trial T5 (5% of gypsum mining waste and 3% of lime), showed the highest values of *MR*, achieving high levels of rigidity, although in the compressive strength test they are lower than those obtained for CEBs from the trial T3.

CEBs containing 10% gypsum mining waste showed compressive strength values lower than those obtained for CEBs containing 5 or 2.5% gypsum mining waste.

Non-stabilized CEBs from trials T2, T4 and T6, showed a slight improvement in the engineering properties with respect to Non-stabilized CEBs from trials T1, although not as pronounced as observed in lime stabilized CEBs.

A significant improvement was displayed by lime stabilized CEBs in extremely humid conditions, retaining their shape after being submerged in water 24 hours that confirms the activating ability of lime to generate reactions cementing between the clay-rich material and gypsum mining waste.

Non-stabilized CEBs, containing gypsum mining waste in several percentages, after water absorption, showed a completely unacceptable behavior; they completely disintegrated, making them unsuitable in extreme conditions.

The results of this study reveal that the engineering properties of the CEBs were not satisfactory in the criterion of authors, suggesting additional experimental work to improve the engineering properties of CEBs.

2.2.7. Stabilization of Bentonite Soil Using Lime-Gypsum

Ameta [3]. presents investigations on locally available lime and gypsum of commercial grade has been used for studying the effect of lime and gypsum mixture on the plasticity and swelling properties of bentonite soil. It is found that addition of 2% lime and 4% bentonite is more economical in reducing plasticity and swelling as compared to the other mixes under study.

In this investigation we have used lime and gypsum in combination and in different proportions to study its effect on swelling properties of bentonite soil of Rajasthan. There is considerable decrease in plasticity and swelling of bentonite soil by adding lime-gypsum mixture. We found that following mixtures of lime-gypsum have reduced plasticity and swelling of bentonite soil: (8% Lime + 2% Gypsum); (4% Lime + 3% Gypsum); (6% Lime + 3% Gypsum); (8% Lime + 3% Gypsum); (2% Lime + 4% Gypsum); (4% Lime + 4% Gypsum); (6% Lime + 4% Gypsum); (8% Lime + 4% Gypsum).

Also the cost analysis of different mixtures is studied and it is found that the mixture (2% Lime + 4% Gypsum) is quiet suitable for reduction in plasticity and swelling at possible lowest cost.

Table 8. *Comparison of optimum lime-gypsum mixtures w.r.t. pure lime and gypsum with bentonite soil [3].*

	Liquid Decrease Plasticity				Swelling	% Decrease in Swelling Pr.	Cost in Rs./Kg
S. No.	Mix	Decrease	Limit in Liquid	Index	Pr.		
1 6%Lime + 0 Gypsum	180.0	44.79	102.20	62.40	2.264	15.77	150.00
2 0% Lime + 3% Gypsum	149.0	54.29	79.90	70.60	1.627	39.47	21.00
3 8% Lime + 2% Gypsum	154.0	52.76	76.00	72.04	1.604	40.33	214.00
4 4% Lime + 3% Gypsum	148.5	54.45	72.20	73.44	1.839	31.58	121.00
5 6% Lime + 3% Gypsum	136.0	58.28	47.50	82.52	1.733	35.53	171.00
6 8% Lime + 3% Gypsum	126.0	61.35	38.10	85.98	1.568	41.67	221.00
7 2% Lime + 4% Gypsum	129.0	60.43	35.90	86.79	1.639	39.03	78.00
8 4% Lime + 4% Gypsum	134.5	58.74	43.10	84.14	1.651	38.58	128.00
9 6% Lime + 4% Gypsum	124.0	61.96	31.80	88.30	1.580	41.22	178.00
10 8% Lime + 4% Gypsum	144.0	55.83	53.00	80.50	1.721	35.97	228.00

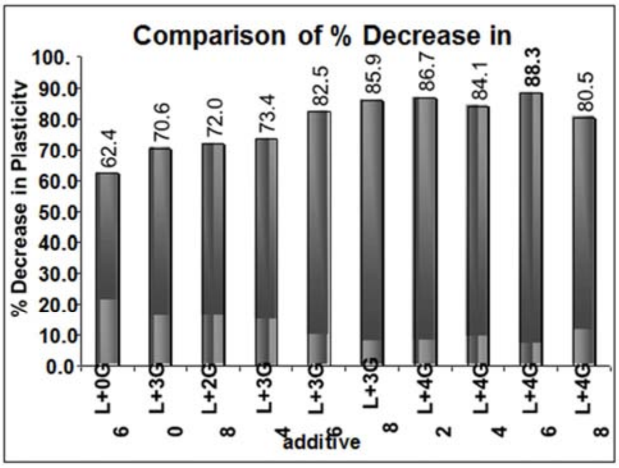

Figure 25. Comparison of% decrease in plasticity index of bentonite soil by addition of different lime-gypsum mixture [3].

2.2.8. Response of Soft Soil Mixing with Recycled Gypsum as Stabilized Agent for Soil

Al-Adili [2]. Evaluates the use of recycled gypsum, which is derived from gypsum waste plasterboard, as a stabilized agent for soft clay. Twenty-eight experimental tests have been conducted to improve a soil brought from a site in Basra (Garma Ali /south of Iraq) using four different recycled gypsum percentage varying from 0 to 15%. The properties which have been studied are grain size distribution, Atterberg limits, unconfined compressive strength, and compressibility. The results indicate that as the gypsum contents increase, the liquid limit decreases up to gypsum content of 3% and then increases. The plastic limit has been decrease up to 7% of the gypsum content and then increases. Furthermore, the maximum dry density decreases while the optimum moisture content is increased as the percentage of gypsum content has increased. The compression index (C_c) has increased as the gypsum content increases while the swelling index has increased up to 5% then it has decreased. The unconfined compressive strength has increased by adding recycled gypsum up to 5% while it is reduced as the percentages of gypsum has increased beyond 5%. Adding 5% of recycled gypsum raise the bearing capacity to approximately 167% compared with the bearing capacity of untreated one.

The main purpose of this work is to investigate and confirm the potential use of recycled gypsum as a stabilizer material for soft clay. Reducing the cost of soil improvement and in addition to improve the sustainability of the environment. Based on the results of the tests on strength, compressibility and durability, the following conclusions have been drowned:

The effect of adding recycled gypsum beyond 5% causes an increase in the optimum moisture content and reached a maximum value by adding 15% recycled gypsum while these is a sharp drop in dry unit weight is beyond 5% recycled gypsum additive.

By adding recycled gypsum up to 5%, there is a reduction in liquid limit while beyond this value; there is a great increase in liquid limit. The compression index (Cc) increase sharps up to 5% of recycled gypsum additive. This increment reduced beyond the 5% gypsum additive. The Percentage of increase in bearing capacity approaches 167% by using 5% Gypsum board as stabilized material compared with untreated one.

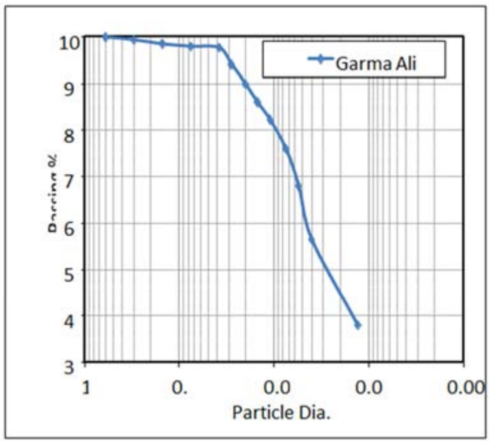

Figure 26. Grain size distribution curve for soil used [2].

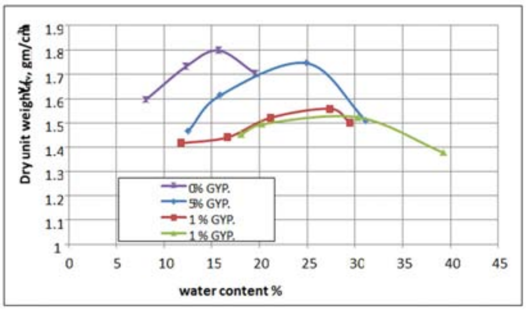

Figure 27. Optimum moisture content (OMC) obtained from the compaction test for untreated and treated soils [2].

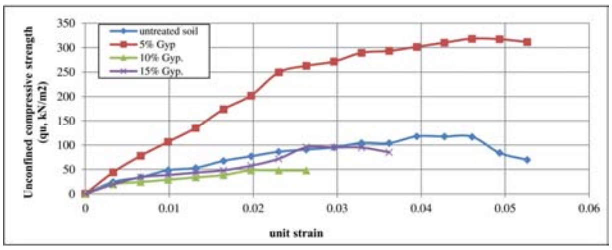

Figure 28. Effect of gypsum content on the unconfined compressive strength [2].

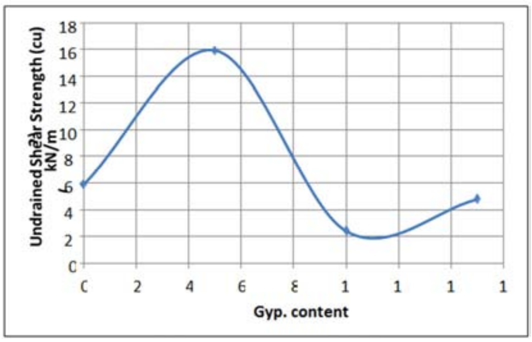

Figure 29. Effect of gypsum fibers content on undrained shear strength of soil. [2].

3. Conclusion

Review shows the viability of the use of gypsum and other additives (i.e lime, bagasse ash, HCl, fly ash, tin, glass etc.) used to improve engineering properties of soils was successful and prove to be an efficient means of stabilizing elastic soils depending on the original properties of the soil, composition of the additives, curing time etc.

Laboratory result reveals that for effective soil stabilization with the use of gypsum and any other additives is a function of the type of soil being stabilized, nature of additives, percentage of applied additives, curing time, also the classification of the soil to stabilized. It is found that the use of these additives in proportion of each other, their percentage proportioned, curing time and the nature of soil, give different end point of stabilized soil.

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