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RECYCLED GYPSUM AND RICE HUSK ASH AS ADDITIVES IN THE STABILIZATION OF EXPANSIVE SOIL

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ABSTRACT: Expansive soils pose great risk to the structural integrity of many overlying structures. Given the impracticality of mechanical means of ground improvement in smaller projects, chemical stabilization is preferred. An economic and sustainable way of improving weak soils can be achieved with waste utilization of discarded materials as enhancing additives. Clay loam from Kauswagan, Lanao del Norte were treated with varied proportions of recycled gypsum and rice husk ash. Evaluation of the effectiveness of the admixtures were done based from criteria and laboratory tests listed by NSCP 2010 Section 303.5 and ASTM D4609. Addition of gypsum as lone additive increases plasticity, while further addition of RHA finally diminishes plasticity. Compaction characteristics at 15% gypsum + 10% RHA had maximum dry density increased by 1.918 kN/m^3 and optimum water content decreased by 26%. While overall decrease in swelling was observed, only specimens with 15% gypsum + 10% RHA were considered non-expansive (EI < 20) by NSCP 2010. Mean compressive strengths of specimen were enhanced with a peak value of 1.128 MPa at 15% gypsum. Considering criteria from ASTM D4609 and NSCP Section 303.5, an admixture combination of gypsum and RHA can be considered effective in improving expansive soils.

Keywords: Expansive soils, Recycled gypsum, Rice husk ash, Soil stability, Expansion index

1. INTRODUCTION

Expansive soils are a type of soil that exhibit significant changes in volume. Comprised primarily from volcanic material, its composition enables this change as manifested through a cyclic shrink-swell behavior. Climatic conditions influence the soil condition due to its dependence on moisture [1]. Torrid weather facilitates shrinking in soil, while heavy rainfall triggers consequent ground swelling. The soil's characteristic is primarily determined by certain clayey minerals such as kaolinite and montmorillonite, components that allow greater water absorption [2]. Repeated shrink-swell cycles eventually result to differential ground movement, causing varying damage to overlying structures. Conventional solutions to poor soil conditions often implement soil replacement with better quality fill or compaction using heavy equipment. Despite their effectiveness, these practices raise concerns on their environmental footprint and economic viability. A more practical solution can be found through chemical soil stabilization. In this method, an additive is applied to the soil to improve engineering properties. Based from the National Structural Code of the Philippines (NSCP), improvement by chemical means is recommended when designing foundations [3] to prevent potential damages to houses and buildings. Additives in soil stabilization often contain cementitious or pozzolanic properties that are known catalysts in improving soil conditions. While materials such as lime and cement are established additives already, these promote excessive carbon dioxide emissions during production, leaving a great environmental impact in the process. Waste and other discarded materials can be considered cheaper and more sustainable options.

Gypsum is chemically known as calcium sulfate. As an industrial material, gypsum is commonly used in cement and drywall production. Discarded forms of gypsum can be sourced from waste plasterboards and manufacturing rejects. Originating in Japan, the practice of recycling gypsum was done in response to the growth of their construction industry beginning in 1970 [4]. It has been used in ground improvement for road embankments and highways. Its cementitious properties were found to induce strength development in past studies [5],[6].

Challenges may be encountered with gypsum as a lone stabilizer in wet environments. Previous studies raised the necessity for a solidification agent to improve its performance as a stabilizer [5]. A second additive should be paired with recycled gypsum to achieve better soil conditions.

Rice husk is the most abundant agricultural waste in the Philippines. While its original form provides little to no beneficial or nutritional use, its incinerated form exhibits good characteristics. RHA contains rich amounts of silica and aluminum that exhibit pozzolanic properties that can facilitate strength development [7]. It has been found as an effective stabilizing agent by reducing the swelling potential of expansive soil [8]. Moreover, RHA costs less and is produced in greater quantities compared to other chemical additives. Commonly, RHA is being used as fertilizer, fuel, or partial cement replacement.

The main objective of this study is to examine the effectiveness of a recycled gypsum-RHA mix in mitigating volume change and improving strength of expansive soils. Evaluation of results shall be measured using engineering properties such as Atterberg Limits, Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Expansion Index (EI) and Unconfined Compression Strength (UCS). The study also determines the physical and chemical composition of the tested expansive soil and each additive. Finally, the study aims to find the best gypsum-RHA mix proportion that yields the most desirable result in reducing swelling and enhancing compressive strength.

Repurposing waste gypsum for soil stabilization is necessary given that its disposal poses harmful impacts to the environment. Organic materials may react with sulfates in discarded gypsum to form hydrogen sulfide gas. Hence, recycling gypsum reduces its environmental impact. Moreover, the use of RHA is highly encouraged, given that the Philippine rice production marks at 2 million tons annually [9]. The measure presented by this study leans towards low-cost sustainable approaches to improve weak expansive soils and to provide alternate disposal options for discarded materials.

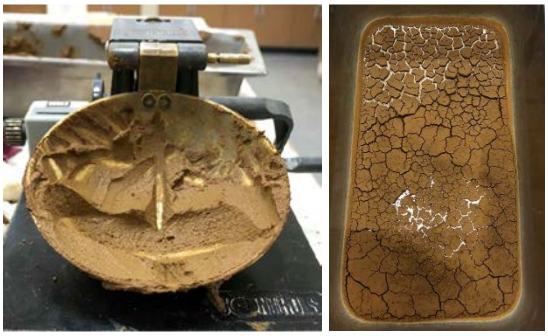
2. MATERIAL AND METHODS

2.1 Source of Expansive Soil

The soil to be investigated in this experiment was gathered from Kauswagan, a coastal municipality located in the province of Lanao del Norte in the Philippines. The specimen belongs under the Adtuyon soil series that was initially identified in barangay Adtuyon in the municipality of Pangantucan in Bukidnon. This soil series is characterized to have been developed from volcanic deposits that consist of basalt and andesite boulders. Surface soils were observed to be brown, friable, and granular like clay. Meanwhile, the subsoil is generally darker in color with hints of reddish tint in some cases. Possessing clayey properties, the subsoil is plastic in the presence of moisture, but hard and brittle in dry conditions [10]. Moist soil samples changed the color into a darkened pale brown mixture (Fig 1a). A sticky and viscous texture was also observed among all test specimens. This was indicative of the cohesive trait found in all clayey and expansive soils. Dry samples exhibit significant cracking and reduction in volume, indicating its shrink-swell tendencies (Fig 1b).

2.2 Source of Recycled Gypsum

Recycled gypsum was sourced from a small wet market stall that sells the powder as plaster for nearby construction projects. Recycled gypsum is typically prepared from three different sources. Waste are obtained from excess and rejected plasterboard from manufacturing, new construction, and demolition. Contaminants from nails, screws, paint, wall coverings etc. are removed prior to recycling process. The collected waste gypsum is pulverized into powder form and is typically heated at 130℃ to 160℃ depending on the preference of the recycling company.



a) moist soil b) dry soil

Fig. 1 Moist and dry soil samples from the study

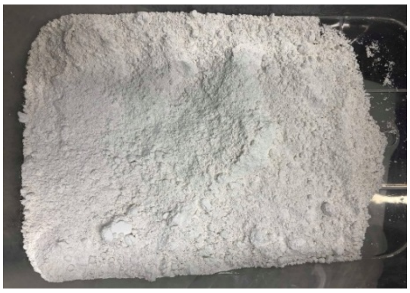


Fig. 2 Recycled gypsum samples used in the study

Fig. 3 Rice husk ash samples used in the study

2.3 Source of Rice Husk Ash

Rice husk ash was obtained from Restored Energy Biomass Power Plant in Muntinlupa City, Metro Manila. The rice husk sourced from the plains of Nueva Ecija were incinerated by the said company at a fixed high temperature to create power using biomass energy [11]. The byproduct of this process yields roughly textured ash. The material was sourced from a lone power plant to preserve the consistency of its properties. Moreover, the ash samples were stored away from environments, which may compromise its quality.

2.4 Experimental Procedure

Before proceeding with the primary laboratory tests required to determine additive effectiveness, test soil samples were subjected for verification on its expansivity in accordance with standards set by Section 303.5 of the NSCP 2010 [3].

Parameters given by the NSCP criteria were obtained using ASTM laboratory tests. Section 303.5 indicates that expansive soils can identified through its plasticity and particle size characteristics. Table 1 enumerates the required values that would classify a test soil sample as expansive.

Table 1 NSCP Criteria to Identify Expansive Soils

Parameter	Criteria
Liquid Limit, LL (%)	Greater than 50
Plasticity Index, PI (%)	Greater than 15
Percentage of soil particles passing the #200 sieve (%)	More than 10% of the particles pass the #200 sieve
Percentage of soil particles less than 5μm in size (%)	More than 10% of the particles are less than 5μm in size
Expansion Index, EI	Greater than 20

The laboratory tests performed on untreated and treated samples are enumerated in Table 2. These procedures were based from ASTM standards to establish a reference in evaluating the index properties and potential for shrink-swell behavior of tested samples.

The effectiveness of recycled gypsum and RHA as additives were tested as per provisions indicated by ASTM D4609. The criteria for assessing the test samples is summarized in Table 3.

Five experimental trials were performed for each soil-additive mixture. The test results from ASTM D4609 and ASTM D4829 were the basis for assessment on the effectiveness of the additives. The admixture is only considered effective when the sample meets the required value for expansion index and unconfined compressive strength.

Table 2 Laboratory procedures based from ASTM standards to determine index properties and potential for shrink-swell behavior

Laboratory Test	ASTM Standard
Specific Gravity Test	ASTM D854
Grain Size Analysis	ASTM D422
Liquid Limit Test	ASTM D4318
Plastic Limit Test	ASTM D4318
Expansion Index Test	ASTM D4829

Table 3 Laboratory procedures based from ASTM standards to evaluate the effectiveness of recycled gypsum and RHA as admixtures.

Parameter	Criteria
Liquid Limit, LL (%)	Significant reduction
Plasticity Index, PI (%)	Significant reduction
Maximum Dry Density, MDD (kN/m^3)	Increase by 80kg/m^3 (0.785 kN/m^3)
Optimum Moisture Content, OMC (%)	Decrease by 15%
Unconfined Compressive Strength, q_u (kPa)	Increase by 345 kPa

2.5 Mixture Preparation

The tests were divided into two sets: gypsum-only and gypsum-RHA mixtures. Both mixture sets were made by replacing varying percentages of the soil volume with the admixture. Calculations were based from the index properties of the soil and the additives. Both sets were mixed with gypsum at percentages of 5%, 10% and 15%. For the gypsum-RHA set, the rice husk ash was mixed at a constant percentage of 10%. Mixtures were cured for minimum period of 16 hours prior to performing laboratory tests.

3. TEST RESULTS

3.1 Soil Classification

Table 4 displays the resulting index properties of the test soil sample required for classifying the soil. The results indicated that the soil sample did not meet the criterion on particle size. However, the rest of the index properties classified the test soil as expansive as the value of the expansion index governs. The EI value of the test soil was found at 98. Based from values set by USCS Classification, Kauswagan soil is classified as MH (high plasticity silt).

Table 4 Summary of Soil Classification

Parameter	Criteria	Result	Remarks
Liquid Limit, LL (%)	> 50	64.78	Pass
Plasticity Index, PI (%)	> 15	18.64	Pass
Percentage passing #200 sieve (%)	> 10%	59.14	Pass
Percentage less than 5μm (%)	> 10%	0.00	Fail
Expansion Index, EI	> 20	98	Pass
USCS Classification	MH (high plasticity silt)		

3.2 Evaluation of Additives as Stabilizing Agents

3.2.1 Atterberg Limits

Atterberg limits are threshold markers that indicate the moisture content values which represent the transition of soil from one consistency to another. Table 5 provides the average values for the each Atterberg limit tested for the soil-additive mixtures. ASTM D4609 states that a soil additive is deemed effective when significant reduction in liquid limit and plasticity index.

Table 5 Atterberg Limits of Soil-Additive Mixtures

Mixture	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
Kauswagan Soil	64.776	46.847	17.929
5% Gypsum	79.060	42.937	36.122
10% Gypsum	75.326	39.851	35.747
15% Gypsum	71.815	37.486	34.329
5% Gypsum + 10% RHA	59.372	36.237	23.135
10% Gypsum + 10% RHA	56.184	36.828	19.356
15% Gypsum + 10% RHA	53.270	36.887	16.383

Test results show the trend in liquid limit values in the two set of additive proportions follow distinct behaviors. The inclusion of gypsum in the plain soil increased the liquid limit of the soil, yet a gradual increase in gypsum resulted into incremental decrease in liquid limit. A decrease is usually expected when introducing stabilizer agents, but several studies have reported the reverse occurrence [12],[13]. Gypsum used in construction manifests its ability to improve strength at high moisture content since its composition allows higher water absorption capacity. The eventual decrease in liquid limit with increase in gypsum was due to reduction of clay particles.

On the other hand, samples with a constant 10% RHA content saw a general decrease in liquid limit with the increase in gypsum content. RHA does not exhibit plasticity when exposed to moisture. Further soil particle replacement with the addition of non-plastic ash was a cause of the eventual decrease in plasticity.

3.2.2 Compaction Characteristics

Soil compaction demonstrates the relationship between densifying effect of repeated mechanical effort and the amount of moisture present in soils. Compaction parameters – maximum dry density and optimum moisture content – indicate the condition required to reach the most compact state of soil. Table 6 presents the values of these compaction parameters obtained using the proctor method.

Table 6 Compaction Values of Soil-Additive Mixes

Mixture	Maximum Dry Density (kN/m^3)	Optimum Moisture Content
Kauswagan Soil	11.916	42.415%
5% Gypsum	12.185	41.184%
10% Gypsum	12.405	39.940%
15% Gypsum	12.627	37.168%
5% Gypsum + 10% RHA	13.384	34.279%
10% Gypsum + 10% RHA	13.729	32.626%
15% Gypsum + 10% RHA	13.835	31.395%

ASTM 4609 requires a decrease of 15% for optimum moisture content and increase in 80kg/m^3 for maximum dry density. When converted into kN/m^3, the required increase in density is 0.785 kN/m^3. A maximum decrease of 12.37% in moisture content for gypsum-only specimen and 25.98% for gypsum-RHA specimen was observed. Moreover, increases of 0.711 kN/m^3 and 1.918 kN/m^3 were obtained for gypsum only and gypsum + 10% RHA samples respectively. The resulting values suggest that 15% gypsum was nearly statistically effective in stabilizing the tested soil, but a minimum content of 5% gypsum + 10% RHA was adequate to be considered effective. However, it should be noted that the conditions from ASTM D4609 were suggested values to ensure experimental error did not affect results. Individual trial results were found to be consistent in values, which allows the additives to be considered effective.

3.2.3 Unconfined Compressive Strength

The unconfined compression strength of a given soil specimen is the peak axial stress resisted by an unconfined cylindrical soil specimen. The absence of confining pressure in the specimen eases the determination of the undrained shear strength. Figure 4 displays the trend between the strength of each soil-additive mixture and the curing period. The weekly values indicate that longer curing improves strength.

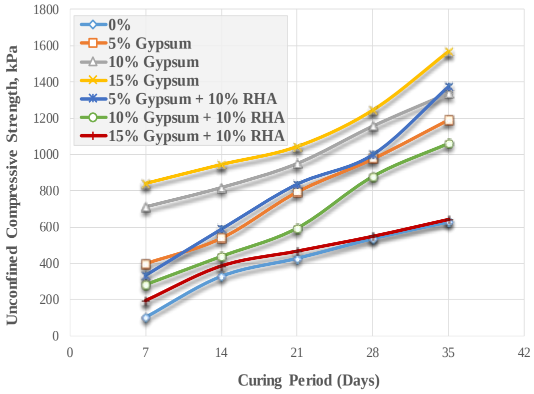


Fig. 4 Unconfined compressive strength of soil-additive mixtures vs. curing period

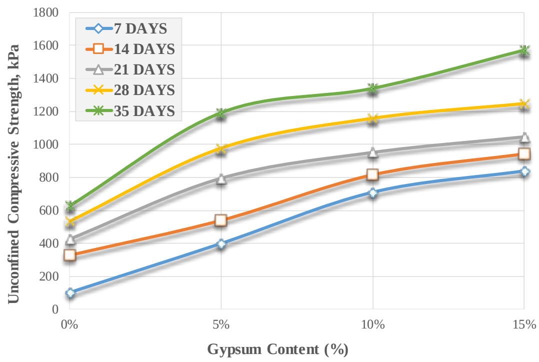


Fig. 5 UCS values of gypsum-only soil specimen vs. gypsum content

Reconstituted laboratory samples cannot recreate strength at in-situ conditions. However, particle rearrangement occurs when the remolded specimens were kept undisturbed during curing period. Constant moisture and composition when curing allows partial strength gains [14].

ASTM D4609 considers an additive effective when UCS increases by at least 345 kPa (50psi). The results shown by Figure 5 show that UCS of gypsum-only increase significantly with addition of gypsum for all curing period. Meanwhile, Figure 6 indicates that adding gypsum-RHA mix initially increases strength before decreasing eventually.

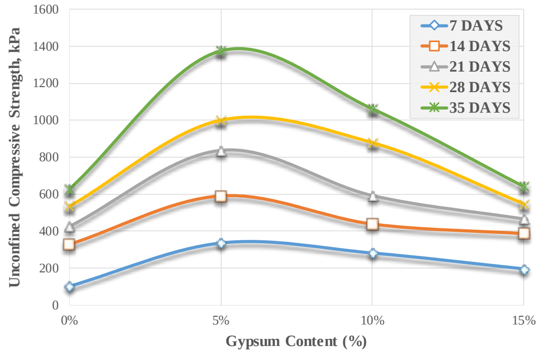


Fig. 6 UCS values of gypsum-only soil specimen vs. gypsum content

Gypsum has cementitious characteristics that enabled samples to gain strength over time. However, RHA is a non-cohesive material which deterred the strength development of the soil over time, resulting to the decrease for gypsum-RHA specimen.

3.3 Expansion Index

Expansion index measures the swelling potential of a given specimen. NSCP 2010 Section 303.5 defines EI as the determinant of the expansiveness of a given soil. The section states that a value exceeding 20 is considered expansive. Identifying the degree of expansiveness of a soil type is an important task in geotechnical engineering, considering the risks posed by weak soils to overlying structures. This parameter influences design considerations in foundations. Table 6 provides the mean expansion indices of each mixture.

The EI of the soil saw a diminishing trend with each addition of gypsum and rice husk ash into the specimen. Introducing 15% gypsum reduced EI from 98 to 33, while adding 10% RHA decreased EI further to 11. An expansion index of 11 is considered non-expansive by NSCP 2010. The significant dip in expansiveness of the specimen was a consequence of clay particles replaced by material with either cementitious or non-plastic properties. The soil contains large portions of clay particles, which can be linked to its high plasticity and expansion index. The calcium content of gypsum promoted particle hardening which limited the soil swelling. Moreover, RHA possessed good adsorption capacity which limited the attraction of water with clay particles when the specimen was fully inundated, eventually reducing EI into 11.

Table 6 Expansion Index of Soil-Additive Mixtures

Mixture	Expansion Index	Potential Expansion
Kauswagan Soil	98	High
5% Gypsum	72	Medium
10% Gypsum	54	Medium
15% Gypsum	33	Low
5% Gypsum + 10% RHA	52	Medium
10% Gypsum + 10% RHA	28	Low
15% Gypsum + 10% RHA	11	Very Low

4. CONCLUSION

The summation of findings from the conducted study, which introduced recycled gypsum and rice husk ash into expansive soil conclude the following:

Initial addition of gypsum increased liquid limit by 22%. However, a mixture of 15% gypsum and rice husk ash decreased liquid limit by 11.5%. This behavior cannot confirm the effectivity of the admixtures in diminishing plasticity of soil. Favorable results were found with compaction characteristics, with gypsum providing an increase in dry unit weight by 0.71 kN/m^3 and a decrease in OMC by 12.37%. Gypsum + RHA was more effective with improvements of 1.918 kN/m^3 and 26% respectively. Gypsum also greatly enhanced strength of 35-day samples with 15% gypsum providing 945 kPa mean increase compared to untreated samples. Slight increases in strength were observed with gypsum-RHA treated specimen, but improvement lessens with added gypsum content. Highest reduction in expansion index was achieved with 15% gypsum + RHA from 98 to 11. This is considered non-expansive based from NSCP Section 303.5.

Future work on this research are encouraged to focus on shear strength of soil based on short-term and long-term loading scenarios. Moreover, parameters such as CBR may also be tested. Other types of agricultural wastes may also be considered as complementary to recycled gypsum.

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REFERENCES

[1] Shi, B., Chen, S., Han, H., & Zheng, C., Expansive Soil Crack Depth under Cumulative Damage. The Scientific World Journal, 2014.

[2] Cokca, E., Use of Class C Fly Ashes for the Stabilization of an Expansive Soil. Journal of Geotechnical and Geoenvironmental Engineering, 2001.

[3] Association of Structural Engineers of the Philippines (ASEP), National Structural Code of the Philippines, Chapter 3: Earthworks and Foundations, 2010.

[4] Ahmed, A. & Issa, U., Stability of soft clay soil stabilised with recycled gypsum in a wet environment. Soils and Foundations, 54(3), 2014, pp. 405-416. http://dx.doi.org/10.1016/ j.sandf.2014. 04.09.

[5] Ahmed, A., Ugai, K., & Kamei, T., Investigation of recycled gypsum in conjunction with waste plastic trays for ground improvement. Construction and Building Materials, 25(1), 2011, pp. 208-217. http://dx.doi.org/10.1016/j.conbuildmat.2010.06.036

[6] Sivapullaiah, P. & Jha, A., Gypsum Induced Strength Behaviour of Fly Ash-Lime Stabilized Expansive Soil. Geotechnical and Geological Engineering, 32(5), 2014, pp. 1261-1273. http://dx.doi.org/10.1007/s10706-014-9799-7.

[7] Della, V., Kuhn, I., & Hotza, D., Rice husk ash as an alternate source for active silica production. Materials Letters, 2002, pp. 818-821.

[8] Adajar, M., Aquino, C., de la Cruz, J., Martin, C., & Urieta, D. (2019). Investigating the Effectiveness of Rice Husk Ash as Stabilizing Agent of Expansive Soil, Int. Journal og GEOMATE, Vol. 16, Issue 58, June 2019, pp. 33-40.

[9] Belonio, A., Utilization of Rice Husks in the Production of Renewable Energy. PHIL SCAT, 2014.

[10] Carating, R., Galanta, R., & Bacatio, C., The Soils of the Philippines. Quezon City: Springer, 2014

[11] Marsh, D., WRAP: Comprehensive life-cycle analysis of plasterboard. Global Gypsum Magazine, 2008, pp. 24-26.

[12] Degirmenci, N., The using of waste phosphogypsum and natural gypsum in adobe stabilization. Construction and Building Materials, 22(6), 2008, pp. 1220-1224. http://dx.doi.org/10.1016/j.conbuildmat.2007.01.027

[13] Kumar, S., Dutta, R., & Mohanty, B., Engineering Properties of Bentonite Stabilized with Lime and Phosphogypsum. Slovak Journal of Civil Engineering, 2014, pp. 35-44.

[14] Das, B., Principles of Geotechnical Engineering. Stamford, CT: Cengage Learning, 2010.