SEBHA UNIVERSITY JOURNAL OF PURE & APPLIED SCIENCES VOL.23 NO. 1 2024
DOI: 10.51984/JOPAS.V23I1.2814

مجلة جامعة سبها للعلوم البحتة والتطبيقية
Sebha University Journal of Pure & Applied Sciences

Journal homepage: www.sebhau.edu.ly/journal /jopas

# Utilisation of Athel Leaves to Improve the Unconfined Compressive Strength of Soil

*Mohammed A. Ahweedi[a], Asma A. Muhmed[a], Omer R. Elzaroug [b]

[a] Civil Engineering Department, Faculty of Engineering, Tobruk University, Tobruk, Libya
[b] Civil Engineering Department, Faculty of Engineering, Omar Al-Mukhtar University, Al-Beida, Libya

**Keywords:**
Soil Improvement
Unconfined Compressive Strength
Sress-Strain
Failure pattern
Agricultural waste

## ABSTRACT

Athel Leaves (AL) are plentiful agricultural waste that might result in a detrimental effect on the environment owing to inadequate disposal. The purpose of this paper is to experimentally assess the impact of Athel leaves as a novel sustainable waste application on the unconfined compressive strength (UCS) of soil. For the purpose of fulfilling this main objective, five AL percentages (1%, 2%, 3%, 4% and 5% by dry weight of soil) and four curing periods (3, 7, 14 and 28 days) were selected. The failure pattern was also studied to better understand the ultimate behaviour of the improved soil. Assessment of the derived conclusions revealed that the inclusion of AL into soil enhanced the UCS. Careful inspection of the stress-strain relationships showed that inclusion of AL resulted in increased peak stress at large strains. Additionally, it was found that bulging and shear were the two patterns observed in this research. This study confirms the possibility of incorporating AL in geotechnical applications with significant environmental benefits.

# استعمال أوراق الأثل لتحسين مقاومة الضغط غير المحصورة للتربة

*محمد اهويدي[1] و أسماء محمد[1] و عمر الزروق[2]

[1]قسم الهندسة المدنية، كلية الهندسة، جامعة طبرق، طبرق، ليبيا
[2]قسم الهندسة المدنية، كلية الهندسة، جامعة عمر المختار، البيضاء، ليبيا

## الملخص

أوراق الأثل (AL) هي نفايات زراعية وفيرة قد تؤدي إلى تأثير ضار على البيئة بسبب عدم إيجاد الطريقة الملائمة للتخلص منها. الغرض من هذه الورقة هو التقييم التجريبي لتأثير أوراق الأثل (Athel Leaves)كتطبيق مستدام للنفايات على قوة الضغط غير المحصورة (UCS) للتربة. من أجل تحقيق هذا الهدف الرئيسي، تم اختيار خمس نسب من الأثل (1, 2, 3, 4 و5% من الوزن الجاف للتربة) وأربع فترات معالجة (3 , 7 , 14 و28 يوما) كما تمت دراسة نمط الفشل لفهم السلوك النهائي للتربة المحسنة بشكل أفضل. أشار تحليل النتائج إلى أن إضافة AL إلى التربة قد حسنت UCS. كما أظهر الفحص الدقيق للعلاقات بين الإجهاد والإنفعال أن إضافة AL أدى إلى زيادة إجهاد الذروة عند انفعالات كبيرة. بالإضافة إلى ذلك، قد وجد أن الانتفاخ والقص هما النمطان اللذان لوحظا في هذا البحث. تؤكد هذه الدراسة إمكانية دمج AL في التطبيقات الجيوتقنية مع فوائد بيئية كبيرة.

**الكلمات المفتاحية:**
الاجهاد والانفعال
تحسين التربة
سلوك الفشل
قوة الضغط غير المحصورة
النفايات الزراعية.

## 1. Introduction

Owing to the significant rise in the population of the world, a growing demand for adequate land for the building and enhancement of infrastructures and new cities is imminent. This might result in the necessity for building on weak soils. It is expected that variations in the weather would worsen the volumetric changes. This leads to a substantial distress to the elements of the structure due to possible unequal movement, which, if preventive actions are overlooked, can have a significant negative impact on the reliability of structures [1]. It is suggested that you undertake precautions, such as partial replacement of ground surface layer, chemical improvement with lime, cement, fly ash, and soil reinforcement to mitigate or prevent the negative consequences of a possible volume change [2]. In general, an agreement was achieved that treated materials by chemicals exposed improved properties compared with those noted on unimproved soil.

Even though soil improvement by chemicals is a proven method, however, the utilisation of these additives requires relatively large quantities and lengthy curing periods for substantial enhancement. In addition, production of the chemical additives is characterised by $CO_2$ emissions which affect climate change. moreover, large concentrations of these additives are considered to be unreasonable in terms of cost for

---

*Corresponding author.
E-mail addresses: Mohammed.Ahweedi@tu.edu.ly, (A. Muhmed) asma.abdelkhalig@tu.edu.ly, (O. Elzaroug) omer.elzaroug@omu.edu.ly

*Article History : Received 01 November 2023 - Received in revised form 21 February 2024 - Accepted 18 March 2024*

engineering projects [3]. consequently, utilising eco-friendly agricultural wastes can partially substitute the chemicals responsible for greenhouse gas emissions and decrease global warming.

One of the primary categories of wastes produced regularly and in substantial quantities is agricultural wastes. The disposal of these wastes has a potential negative environmental impact leading to air and water pollution and finally affecting the local ecosystems [4]. For the time being, great efforts are being put to reuse these wastes for various enhancement purposes. Disposal of agricultural waste can be decreased if the waste has desirable properties such that they could be utilised as additives in soil improvement. In soil system, additives such as salts, silica, rice husk, sugar cane straw, etc. act as catalysers to improve the physico-mechanical properties of treated soils. Based on the chemical analysis performed in previous studies [5-7], it was noticed that agricultural wastes are rich in $SiO_2$, $Al_2O_3$, $Fe_2O_3$ and salts that can be utilised to enhance the soils' engineering characteristics.

Soil improvement with agricultural waste materials is among the eco-friendliest and inexpensive methods. The reported findings of Akinwumi, Ojuri [8], Aziz, Saleem [9], Fauzi, Fauzi [10], Ekeocha and Agwuncha [11], and Pourakbar, Asadi [12] suggest that beneficial impacts of adding agricultural wastes to soil could be obtained. Moreover, Numerous researches were conducted to clarify the benefit of utilising agricultural wastes in enhancing the mechanical characteristics of soil. Rice husk is an agricultural waste obtained from milling of rice. approximately 108 tons of rice husks are produced globally every year. Meanwhile, the ash has been categorised under pozzolana, with about 67-70% silica and about 4.9 and 0.95% aluminum and iron oxides, respectively [13]. Alhassan [14] studied the impact of rice husk ash (RHA) on soil strength. The results of strength showed a rising pattern at 6% RHA and with cumulative curing time. This increase is probably owing to the reactions between the pozzolans presented in the RHS and the grains of soil. The quantity of clay and silt which existed in soil decreased because of the development of cementitious materials. Sarapu had made identical findings in this regard [15]. The influence of wheat husk and sugarcane straw ash on soil's strength behaviour was documented in studies carried out by Singh, Sharma [16], Naik, Patil [17] and Amu, Ogunniyi [18]. it was noticed that the treated soils' strength improved significantly.

Athel tree (Tamarix aphylla or salt cedar) is halophyte plant that has been found growing in sites of high levels of soluble salts. Sites with Athel have higher soil salinity and pH [19]. In Libya, at the oasis site of Awjlah, a twelfth-century mosque, which considered one of the oldest mosques in North Africa, consists of twelve bays covered with conical domes made of mudbricks [20]. These mudbricks formed from a mixture of water and desert clay mixed with Athel leaves to improve the strength and prevent mud bricks from cracking. Muhmed [21] conducted chemical element analysis of Athel leaves by using energy dispersive X-ray spectrometer. Data revealed that calcium carbonate ($CaCO_3$) and silicon dioxide ($SiO_2$) are the main compounds of AL at about (52.22% and 36.99% respectively). Many studies were undertaken to pinpoint scientific justification for the consequences of adding salts and silica (main compounds of AL) to soils. Geotechnically, the common salt compounds used in soil stabilisation are NaCl, $Na_2SO_4$, $MgSO_4$, $NaHCO_3$, $Na_2CO_3$, $CaSO_4$ and $CaCO_3$ [22].

Many categories of agricultural waste materials have not been studied scientifically as well as their effectiveness as additives of soil are whether still under discussion or unproven. To the authors' best knowledge, the utilisation of AL in soil stabilisation has not been investigated yet. Consequently, in this research, an experimental program was implemented to study the influence of AL on UCS of soil for quantifying its affect in enhancing the UCS characteristics.

## 2. Materials and Methods

### Materials:

Figure 1 shows the materials which utilised in this investigation, namely soil, Athel leaves and tap water. The properties of these materials are described below.

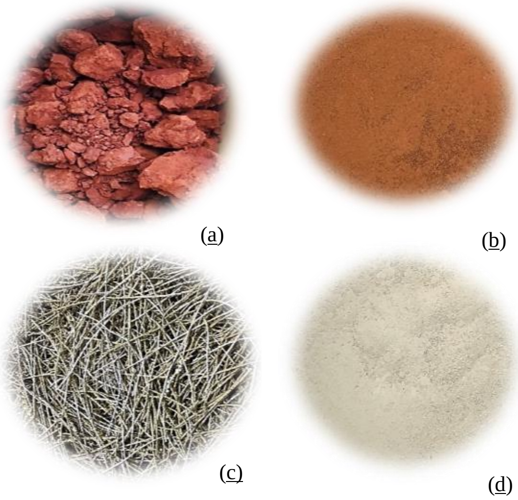

(a) (b) (c) (d)

**Fig. 1:** Materials used (a) soil as collected, (b) sieved soil, (c) Athel leaves as collected and (d) grained Athel leaves

### Soil:

The soil used in this study was sampled from Taknis, Al Marj, Libya where it is available and abundant with huge quantities in this region. It was extracted at a depth of about 1 m, crushed and sieved. Laboratory work was conducted to classify the soil. Based on the sieve analysis results, it was noticed that the soil percent passing through aperture size of 0.075 mm is about 98%. Soils passing the No. 200 sieve is silt-clay and are classified based on Atterberg limits. Plasticity chart for the sample (Figure 2) falls under MI group which indicates that the soil of intermediate plasticity. The basic physical properties of the soil used are tabulated in Table 1.

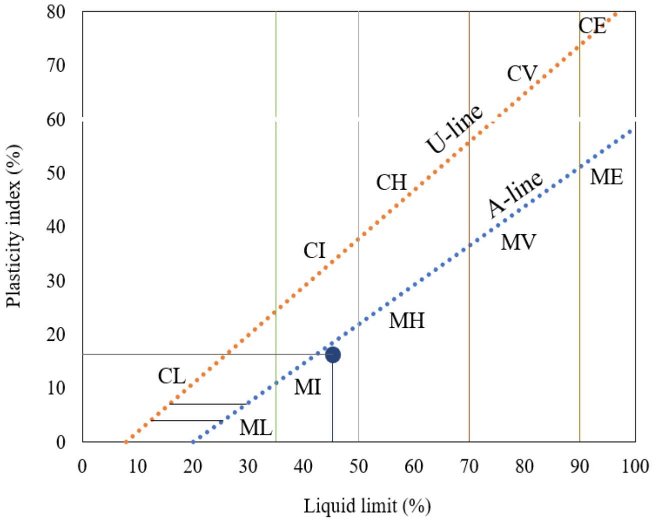


**Fig. 2:** Casagrande's plasticity chart

**TABLE 1: Basic properties of the studied soil**

| 1. Property | 2. Value |
|---|---|
| 3. Water content, % | 4. 6.5 |
| 5. Specific gravity | 6. 2.6 |
| 7. Liquid limit, % | 8. 45.3 |
| 9. Plastic limit, % | 10. 29.02 |
| 11. Plasticity index, % | 12. 16.3 |
| 13. Maximum dry unit weight, kN/m³ | 14. 15.53 |
| 15. OMC, % | 16. 23 |

### Athel Leaves:

Athel leaves were collected from Awjila oasis in Libya and used as agricultural waste. AL was formulated into particles of fine-grained, then added and mixed with soil in order assess its influence on the soil's UCS. The Sieve analysis of the AL is shown in Figure 3. It can be seen and noted that about 31% of the AL passed through aperture size of 75µm. The Athel leaves were analysed chemically by Muhmed [21]. The chemical elements of the utilised AL are tabulated in Table 2.

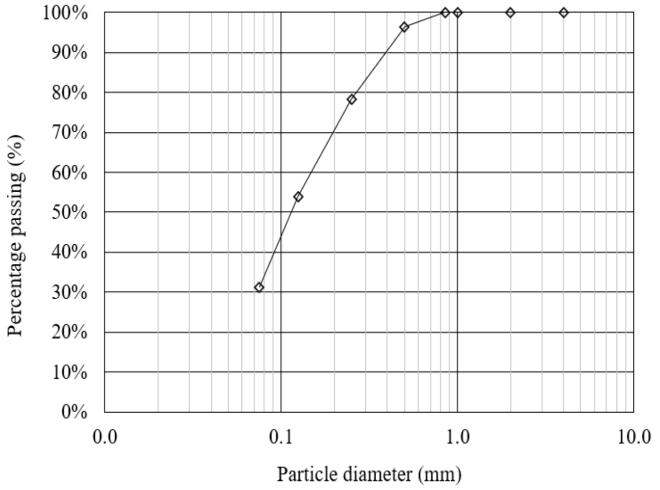


**Fig. 3:** Particle size distribution of AL

**TABLE 2:** The chemical elements identified in the Athel leaf [21]

| Composition | Wt. % |
|---|---|
| $CaCO_3$ | 52.22 |
| $SiO_2$ | 36.99 |
| Albite | 2.16 |
| MgO | 1.29 |
| $FeS_2$ | 2.00 |
| KCI | 3.18 |
| Feldspar | 0.58 |
| Wollastonite | 1.56 |

**Water:**

Tap water was used for mixing in this research.

**Methods:**

All planned tests were carefully and rigorously implemented and as specified in the British Standards. For studying the influence of the Athel leaves on the soil's strength, the experiments were conducted in two stages; firstly, the soil's index properties including particle gradation, specific gravity, water content, consistency limits (LL & PL), and compaction properties were considered. In the second stage, all specimens were prepared according to their respective maximum dry density and optimum moisture content, as determined by compaction tests in an unstablised state.

**Water Content:**

It is defined as the relation of the moisture weight in a given volume to the soil solid particles in that volume. The test was conducted according to BS1377-2 [23].

**Compaction Test:**

Basically, it is important to recognise the compaction properties of the soil which studied in this research. The test was performed for obtaining the soil's optimum moisture content and maximum dry unit weight. The specimen was compacted in 3 layers of which each layer received 27 blows by a 2.5 kg hammer falling from a height of 30 cm. The optimum moisture content and maximum dry unit weight found are tabulated in Table 1.

**Liquid Limit:**

It is the content of moisture at the point of transition from the plastic state to liquid state. Casagrande cup method which introduces dynamic effects was utilised for liquid limit (LL) determination. The test was conducted abiding to BS1377-2 [23].

**Plastic Limit:**

It is the content of water wherein soil begins to show cracks when it is rolled by the hand fingers on a plate of glass in a thread of three millimetres in diameter. The soil at this condition is stiff in its consistency. The test was carried out according to BS1377-2 [23].

**Plasticity Index:**

It is defined as the difference between liquid limit and plastic limit; based on the following equation:

$$PI = LL - PL \qquad (1)$$

**Specimens' Preparation:**

For preparing the specimens, predetermined quantities of dry soil were mixed with each AL content. The mixture was mixed until the additives were distributed evenly, as recognised by the appearance of the mixture's colour. Afterwards, water was added carefully to the specimens until they reached the desired water content. Therefore, using a specially designed mould with movable upper and lower plungers, specimens were compressed in 5 layers under static load to reach the required dry unit weight. After being removed from the compaction mould, the specimens were placed in double-sealed bags and covered with cling film to maintain their water's amount.

The weight, height and diameter of the cured specimens were measured, and the results were compared to those that were taken into account previously in the process of preparation, such as right after compaction. This comparison indicated that during the curing time, there was no alteration in the specimens' size or water content. The specimens at the OMC and MDUW for UCS test were prepared and conducted on the soil's specimens, with and without AL. The improved specimens were blended with increasing percentages (1, 2, 3, 4 and 5%) of Athel leaves. Moreover, the specimens were tested over a 3, 7, 14 and 28-days of curing period.

**Unconfined Compressive Strength:**

Due to its affordability and ease of use, UCS tests were implemented to study the assessment of soil compressive strength [24]. In addition, as recommended by Geiman [25], UCS test is the key test for the investigation of the needed amount of additive to be used in soil stabilisation. The UCS tests were undertaken abiding British standards BS1377-7 [26].

All the specimens were tested without considering any confining pressure throughout the test. The specimens were tested at a rate of an axial movement of 1mm per minute and the maximum load reached was recorded. This is abiding with the British Standard which specifies a strain rate in the range of 0.5% to 2.0% per minute. The highest UCS value from the UCS tests for each specimen was selected to analysis the strain-stress relationships. The UCS findings of 3 identical specimens, as advised by Consoli, da Silva Lopes Jr [27], should not deviate by more than 10 percent from the mean strength. The differ of UCS from the mean strength was found to not exceed ± 5% which reflects the effectiveness of specimen preparation technique.

## 3. Results and Discussion

**UCS Characteristics:**

For quantifying the impact of Athel leaves on the strength, series of UCS tests were executed. The unconfined compression strengths versus different periods of curing and AL contents are plotted in (Figure 4). The UCS number of the unimproved soil was determined to be 604.9 kPa. Because there are no chemical reactions between the soil and water, no changes during the curing time would be observed as confirmed by Zhang, Zhang [28].

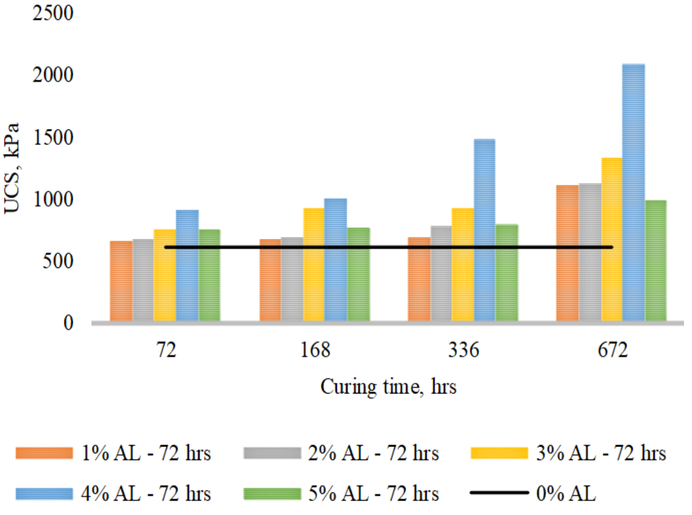


**Fig. 4:** Evaluation of UCS with AL content and curing time

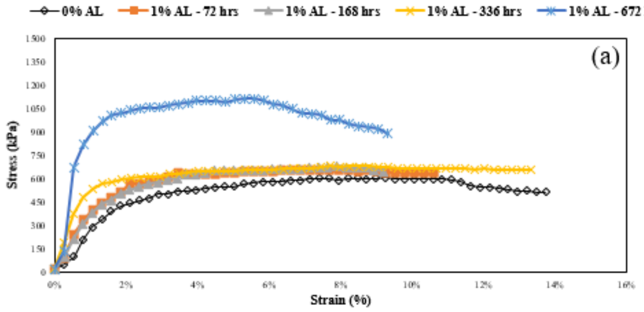
The data clearly illustrate a rise in strength as the specimens were tested after 72 hours of curing. Effect of adding various amounts of AL on the UCS of soil revealed that the UCS in improved specimens was increased from 604.9 kPa to 654.6, 670.8, 750.1, 905.7 and 755.0 kPa with adding of 1, 2, 3, 4 and 5% AL to soil respectively. The UCS of specimen improved remarkably with 4% AL (49 %). Although increasing AL percent more than 4% exhibited lower UCS, however, it is considered accepted when it is compared with the unimproved soil. As AL dissolves in the soil, calcium from $CaCO_3$ moves to the surface of soil particles and the carbonate ($CO_3$) in the AL reacts with the water ($H_2O$) to give free $OH^-$ ions, accordingly raising the pH where based on Ball [29], soil pH can be increased by liming the soil by lime or calcium carbonate. An increase in hydroxyl ions ($OH^-$) results in raising the alkalinity. In a high pH environment, the solubility of silica and alumina is greatly enhanced [30]. This process is termed as pozzolanic reaction which is time-dependent. However, large amount of salt can reduce the unconfined compressive strength of the soil [31] where higher pH (raised by 5% AL) can break down the flocculated structure resulting in forming a dispersed one [32].

The unconfined compressive strength of soil increased gradually as the number of curing hours increased. Curing the specimens up to 7 days resulted in a gain of strength of about 12, 13, 52, 66 and 27% for 1, 2, 3, 4 and 5% AL- soil specimens compared to the improved soil. Furthermore, A significant improvement in strength was achieved by extending the curing period to 28 days. The soil's UCS increased by 84, 86, 120, 244 and 63% compared to the UCS findings of the native soil. The observed increase in UCS might be explained by the composition of aluminate and silicate hydrate products owing to the existing of silica (available in Athel leaves and soil) for the pozzolanic reactions [33]. Moreover, it could be also interpreted as being a result of the excessive $Ca^{++}$ in the Athel leaves that promotes a greater production of pozzolanic materials [34]. This implies that during the allotted curing period in this investigation, there was enough reactive silica in the AL-clay combination to continuously react with the soil grains. In addition, calcium-sodium silicate could be formed where the Athel leaf contains Albite and Feldspar that have sodium. Davoudi [35] stated that calcium-sodium silicate gel improves the cementation faster than a calcium silicate gel.

**Stress-Strain Behaviour:**

The alterations in the stress–strain pattern of unimproved and improved soil tested after 72, 168, 336 and 672 of curing hours are shown in (Figure 5) to contrast the impact of the Athel leaves. The graphs below show that variation in strains did not exceed 10.5%. As noticed, the strain of all AL percentages reduced with curing period. An attribution can be said that the decline in axial strain might be caused by the development of cementing materials between the grains. It can be noted that the rise in the peak of stress was corresponded to the increase in curing time that found to play a major role in the underpinning stabilising. The cementing products development owing to the curing of the specimens results in an increased peak axial stress.

The addition of AL reduces the intra/inter-assemblage of pore spaces along with the creation of the CSH gel, which effectively bonds the grains of soil together. Different from unimproved specimens, inclusion of AL resulted in larger deformation at maximum compressive stress. The AL in specimens snapped and following the completion of the compression tests, the specimens had not fully disintegrated, and this could be attributed to the different particle sizes of AL that may held together some significant parts of the soil matrix, delaying failure. As the cracks were growing, AL hindered relative slippage of damaged sections and prevented soil block deformation, thus restraining crack development and improving the ultimate strain.



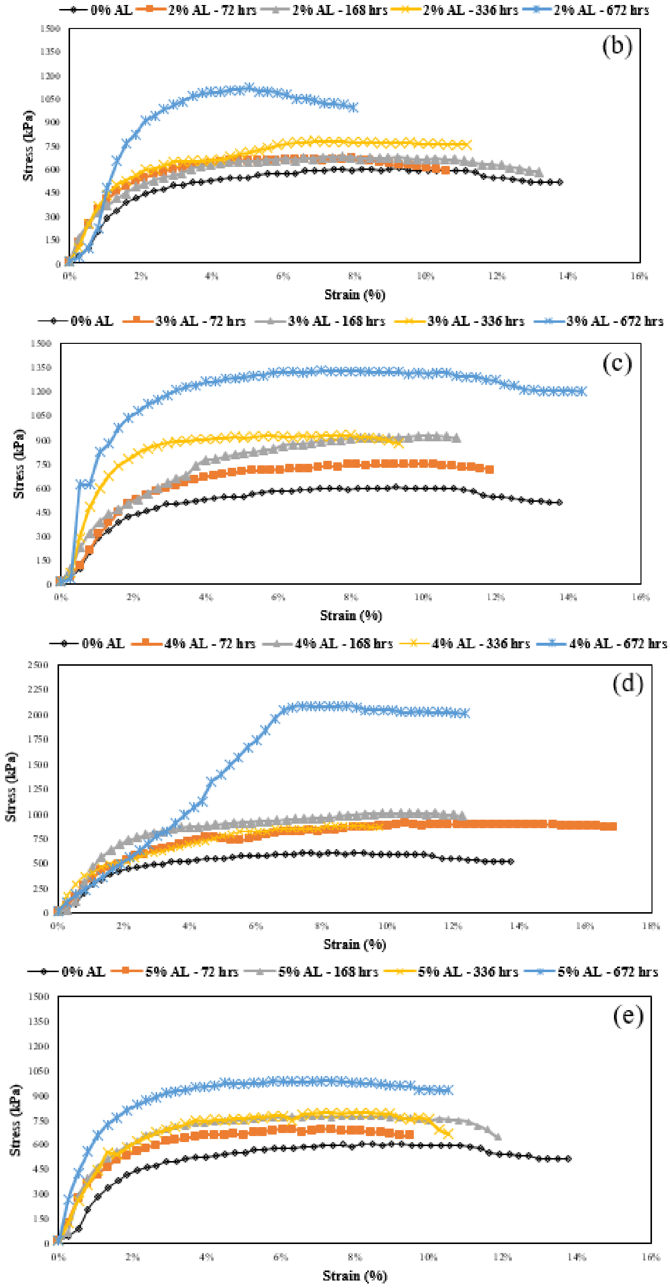


**Fig. 5:** Stress–strain curves of the improved specimens cured at different curing periods (a) with 1% AL, (b) with 2% AL, (c) with 3% AL, (d) with 4% AL and (e) with 5% AL

The curing-period increment and inclusion of AL resulted in increased the peak stress at large strains which indicate the improving of soil ductility and decreased brittleness. This improvement might be because of more bonds were created between the AL and grains of soil, and this helped to transfer the stress from soil to AL where according to Gerry [36], the Athel has a good shear strength. However, the higher strain found on the improved specimens (10.5%) suggests that the failure strain and the ductility of the specimen improved which is an indicator that the soil mixtures could take a large strain without failure.

**Failure Pattern:**

The patterns of failure of unimproved and AL-improved specimens are depicted in (Figure 6). The specimens were collected after completing of the UCS tests and compared. Figure 6a shows that there is no noticeable shear band is observed. This type of failure is referred to as plastic failure, and it is in line with the strain-stress behavior that was noticed (see Figure 6). It is evident that bulging and uneven lateral dilatation were the causes of the untreated specimen's failure. The collapse pattern is relevant to the specimen's strength at the time of testing, which is relevant to the treatment and curing conditions. With curing period (28 days), the factor of AL is significant in changing the failure mode. A greatly different failure mode from the plastic failure mode discussed above characterises the failures of AL treated soil, as indicated in (Figure 6). There was a translational failure noted for the specimens improved by 1, 2, 3, 4 and 5 % AL which were showed evidence of shear failure that started at the top end of the 2, 3 and 4% specimens, whereas started at the bottom end of the 1 and 5% specimens. According to Chakraborty, Bisai [37], shear failures occur when the adjacent cracks in close proximity coalesce together. This justifies that the AL within the soil increased the soil stiffness and limited the lateral deformation mentioned in bulging.

a. Untreated specimen b. 1% AL specimen c. 2% AL specimen

d. 3% AL specimen e. 4% AL specimen f. 5% AL specimen

**Fig. 6:** Photographs of failure patterns of untreated soil and soil mixed with different AL contents and cured for 28 days

## 4. Conclusion

Utilising agricultural waste is particularly advantageous because it is an economical and environmentally friendly method. The biggest benefit is that disposing of waste is no longer a major issue. The current research is a laboratory program to study the influence of Athel Leaves on the strength. for investigating this mechanism, the geotechnical properties as UCS were studied before and after improvement. Based on these investigations, the following findings can be drawn:

- The UCS of the soil enhanced with increasing AL percent up to 4 % and beyond that, a reduction in UCS occurred.
- According to stress-strain curves, all of the enhanced specimens demonstrated ductile behavior, which was defined by a gradual decrease in the post-peak stress as the axial strain increased.
- It was seen that bulging and shear are the two patterns noticed in this research.
- This study confirms the possibility of incorporating AL in geotechnical applications with significant environmental benefits.

## 5. References

[1]- Khademi, F. and J. Budiman, Expansive soil: causes and treatments. I-manager’s Journal on Civil Engineering, 2016. 6(3): p. 1-13.

[2]- Amhadi, T.S. and G.J. Assaf. Overview of Soil Stabilization Methods in Road Construction. in International Congress and Exhibition" Sustainable Civil Infrastructures: Innovative Infrastructure Geotechnology". 2018. Springer.

[3]- Yunus, N.Z.M., Effect of humic acid and chloride salts on the behaviour of lime-stabilised organic clay. 2012, University of Nottingham.

[4]- Onyelowe, K.C., et al., Critical state desiccation induced shrinkage of biomass treated compacted soil as pavement foundation. Építöanyag (Online), 2020(2): p. 40-47.

[5]- Kovács, H., Bánhidi, O., and Szemmelveisz, K., Distribution of chemical elements within ligneous parts of various trees. Material Sciences and Engineering, 2011. 36.

[6]- Raheem, A.A. and M.A. Kareem. Chemical composition and physical characteristics of rice husk ash blended cement. in International Journal of Engineering Research in Africa. 2017. Trans Tech Publ.

[7]- Salim, R.W., J.M. Ndambuki, and D.A. Adedokun, Improving the bearing strength of sandy loam soil compressed earth block bricks using sugercane bagasse ash. Sustainability, 2014. 6(6): p. 3686-3696.

[8]- Akinwumi, I.I., et al., Engineering properties of tropical clay and bentonite modified with sawdust. Acta Geotechnica Slovenica, 2017. 14(2): p. 47-56.

[9]- Aziz, M., M. Saleem, and M. Irfan, Engineering behaviour of expansive soils treated with rice husk ash [J]. Geomechanics and Engineering, 2015. 8(2): p. 173-186.

[10]- Fauzi, A., U.J. Fauzi, and W.M. Nazmi, Engineering quality improvement of kuantan clay subgrade using recycling and reused materials as stabilizer. Procedia Engineering, 2013. 54: p. 675-689.

[11]- Ekeocha, N. and F. Agwuncha, Evaluation of palm kernel shells for use as stabilizing agents of lateritic soils. Asian Transactions on Basic and Applied Sciences,(ATBAS ISSN: 2221–4291) vol, 2014. 4.

[12]- Pourakbar, S., et al., Stabilization of clayey soil using ultrafine palm oil fuel ash (POFA) and cement. Transportation Geotechnics, 2015. 3: p. 24-35.

[13]- Oyetola, E. and M. Abdullahi, The use of rice husk ash in low-cost sandcrete block production. Leonardo Electronic Journal of practices and technologies, 2006. 8(1): p. 58-70.

[14]- Alhassan, M., Permeability of lateritic soil treated with lime and rice husk ash. 2008.

[15]- Sarapu, D., Potentials of rice husk ash for soil stabilization. 2016.

[16]- Singh, M., R. Sharma, and A. Abhishek, Soil stabilization using industrial waste (wheat husk and sugarcane straw ash). International Research Journal of Engineering and Technology, 2017. 4(9): p. 589-596.

[17]- Naik, A., et al., Sub Grade Soil Stabilisation using Sugar Cane Straw Ash (SCSA). International Journal of Engineering Research & Technology, 2019. 8(9).

[18]- Amu, O., S. Ogunniyi, and O. Oladeji, Geotechnical properties of lateritic soil stabilized with sugarcane straw ash. American journal of Scientific and industrial Research, 2011. 2(2): p. 323-331.

[19]- Sher, A. and M.F. Quigley, Tamarix: a case study of ecological change in the American West. 2013: Oxford University Press.

[20]- Petersen, A., Dictionary of Islamic architecture. 1996: Psychology Press.

[21]- Muhmed, A., Impacts of dried athel leaves and silica fume as eco-friendly wastes on behaviour of lime-treated heavy clay, in Civil engineering. 2021, Bradford: United Kingdom.

[22]- Amu, O. and B. Salami, Effect of common salt on some engineering properties of eggshell stabilized lateritic soil. ARPN journal of Engineering and applied sciences, 2010. 5(9): p. 64-73.

[23]- BS1377-2, Methods of Test for Soils for Civil Engineering Purposes–Part 2 Classification tests. 1990, British Standard institute.: London.

[24]- Güneyli, H. and T. Rüşen, Effect of length-to-diameter ratio on the unconfined compressive strength of cohesive soil specimens. Bulletin of Engineering Geology and the Environment, 2016. 75(2): p. 793-806.

[25]- Geiman, C.M., Stabilization of soft clay subgrades in Virginia phase I laboratory study. 2005, Virginia Tech.

[26]- BS1377-7, Methods of test for Soils for civil engineering purposes - BS 1377-7: Shear strength tests (total stress), in BS 1377-7. 1990, BSI: London.

[27]- Consoli, N.C., L. da Silva Lopes Jr, and K.S. Heineck, Key parameters for the strength control of lime stabilized soils. Journal of materials in Civil Engineering, 2009. 21(5): p. 210-216.

[28]- Zhang, F., L. Zhang, and W. Hong, Stabilization of expansive soil with polyvinyl alcohol and potassium carbonate. Advances in Civil Engineering, 2019. 2019.

[29]- Ball, J., Understanding and correcting soil acidity. 1999: Samuel Roberts Noble Foundation.

[30]- Bhattacharja, S., J.I. Bhatty, and H.A. Todres, Stabilization of clay soils by Portland cement or lime–a critical review of literature. PCA R&D Serial, 2003. 60(1): p. 124-33.

[31]- Zhang, D., et al., Effect of salt concentrations on the electrical resistivity of cement-treated soils, in GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering. 2012. p. 1016-1025.

[32]- Chorom, M. and P. Rengasamy, Dispersion and zeta potential of pure clays as related to net particle charge under varying pH, electrolyte concentration and cation type. European Journal of Soil Science, 1995. 46(4): p. 657-665.

[33]- Ghorbani, A., et al., Effect of selected nanospheres on the mechanical strength of lime-stabilized high-plasticity clay soils. Advances in Civil Engineering, 2019. 2019.

[34]- Yunus, N.M., D. Wanatowski, and L. Stace, Effectiveness of chloride salts on the behaviour of lime-stabilised organic clay. International Journal of GEOMATE, 2012. 3(2): p. 401-412.

[35]- Davoudi, M.a.K., E, Interaction of lime and sodium chloride in a low plasticity fine grain soils. Journal of Applied sciences, 2011. 11(2): p. 330-335.

[36]- Gerry, E., Athel tamarisk: Tamarix aphylla (L.) Karst.(= T. articulata Vahl.), family Tamaricaceae. 1954.

[37]- Chakraborty, S., et al., Failure modes of rocks under uniaxial compression tests: an experimental approach. Journal of Advances in Geotechnical Engineering, 2019. 2(3): p. 1-8.