People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University of Kasdi Merbah Ouargla

Faculty of Applied Sciences

Department of Civil and Hydraulic Engineering

Graduation Thesis for the Master's Degree

Field: Public Works

Specialty: Roads and Technical Structures

Prepared by:

BENCHEIKH Ibrahim

BENALI Khireddine

Soil stabilization using date palm ash

Publicly supported before a jury composed of:

KEBAILI Mustapha	MCA	UKM Ouargla	President
ZENKHRI Abderrezak	MAA	UKM Ouargla	Examiner
ABDELDJOUAD Lokmane	MCA	UKM Ouargla	Supervisor

ACADEMIC YEAR: 2024/2025

Acknowledgement

After giving thanks and praise to Allah Almighty for his blessings, grace, and continued health and well-being, and sending prayers upon the Messenger of Allah, peace be upon him.

We begin by expressing gratitude to Allah, who guided us to successfully complete this research.

We would like to extend our sincere thanks and appreciation to everyone who supported and guided us throughout this period.

I would like to express my deep gratitude to the management of the institution LEC (Laboratory of Studies and Control) for providing this valuable opportunity, and to all the staff who generously shared their advice and expertise, which greatly contributed to broadening our knowledge and refining our practical skills.

We also extend our sincere thanks to the academic supervisor, Lokmane Abdeldjouad, for his valuable guidance and constructive feedback, which played a significant role in completing this research. In addition, we thank the discussion committee for accepting to review our dissertation.

We would also like to thank all the professors of the Civil and Hydraulic Engineering Department at Kasdi Merbah University, Ouargla.

Lastly, we do not forget our colleagues who were excellent companions throughout this journey. Thank you for your cooperation and constant support.

We ask Allah to grant us all success and guide us towards what is good and successful, hoping that this research will be a positive step toward achieving our professional aspirations.

Dedication

In the Name of Allah, the Most Gracious, the Most Merciful

Peace and blessings be upon the most noble of messengers

I dedicate this humble effort:

To my beloved parents

Who sacrificed everything precious for my sake,

Being a light that illuminated my path and an unwavering support.

To my teachers and supervisors

Who showered me with their knowledge and patience,

Whose guidance served as a map that led me to safe shores.

To my siblings and friends

Who stood by me in moments of despair,

And strengthened my resolve with their faith in me.

To the spirit of my grandfather/grandmother/those who have left us

Who instilled in me values,

And here I am, reaping the fruits of what they planted.

And finally... To my beloved homeland

For you, I strive and give,

For you is the land to which we belong,

And you are the dream we work to fulfill

IBRAHIM BENCHEIKH

Dedication

I dedicate this work with heartfelt gratitude:

To my dear parents, for their endless love, support, and sacrifices that have shaped who I am today.

To my beloved siblings, for their encouragement and constant presence throughout my academic journey.

To my supervisor, Lokmane Abdeldjouad, for their invaluable guidance, patience, and insightful advice.

To all my professors, whose knowledge and dedication have inspired me along the way.

And to my fellow students and friends, with whom I shared unforgettable moments and mutual support.

Thank you all for being part of this journey

BENALI KHIREDDINE

Table of Contents

List of Tables

List of Figures and Images

Introduction

Soil stabilization is one of the effective and beneficial methods of treating the engineering characteristics of soils with different additives wich change the soil properties in order to improve its strength, durability, or other qualities. This method gives economic interests, particularly when unsuitable soils are available on-site, since it won't be an expense for supplying and transporting suitable soil, and no need to use landfill for the unsuitable in situ soil.

Calcium-based binders (i.e. lime and cement) combination by this method gained some popularity because of their robustness, easy adaptability, and cost-effectiveness. Despite that these traditional materials (i.e., lime and cement) can enhance many engineering properties of treated soil columns, they still have several downsides, the largest of them being the shortcomings when viewed from an environmental perspective. The need for full or partial replacement of Calcium-based binders with cleaner and more sustainable materials was highlighted in recent soil stabilization methods.

In this regard, many types of stabilizing materials, like alkali-activated materials, pozzolanic materials, and reinforcement materials, can be used to improve soils. In such a case, these stabilizer materials must have strength and durability characteristics that can be similar to or superior to those of lime and cement within an identical curing period.

Pozzolanic resources, which are plentiful in silica and alumina with some or no cementitious value, cannot react totally by themselves through stabilization. Nevertheless, when some pozzolanic resources having silica and alumina are added through the hydration of cement and lime binders, the reaction provides extra amounts of calcium silicate hydrate (C-S-H) and calcium aluminum hydrate (C-A-H), which are regarded as the main reinforcing components.

Although all, we still have some issues, as the curing condition and the role of parent soil (i.e., presence of clay in soil and pH) in alkaline activation, which are not well recognized. But ignoring that, if you want to get the ideal economic profits of this new technique for the aim of soil treatment, you have to have a high necessity to discover the resources that affect the volume of waste, especially the locally existing resources. Throughout the possibilities of using different raw materials and by-products, the use of date palm ash (DPA) is worth special consideration.

To provide the breakthrough needed to make the soil stabilization more environmentally friendly and sustainable, utilize the by-product. Theoretically, the reactive silica and alumina present in DPA, a vitreous component, are quickly dissolved. Hence, the reaction between Al and Si to form a well-structured aluminosilicate polymerized framework takes place. Adding DPA enhances this potential to improve the engineering properties of soils.

It's well-known that each ton of cement generates a ton of CO_2 gas, which is the major reason for global warming. Other than CO_2, they produce nitrogen oxides too. However, most of these NOx are generated in cement kilns, which can affect the acid rain and greenhouse gas consequences. Despite it all, the usage of cementitious binders shows poor tensile and flexural strength and brittle behavior. For example, when the cemented soil is exposed to seismic loads, lateral earth pressures, or horizontal displacements, the stabilized soil fails under tension mostly, due to its brittleness. The main objective of this study is to develop waste-based binders for soft soil stabilization.

In addition to the introduction, this thesis is composed of three chapters. In Chapter 1, in the first stage, different soil stabilization materials, including lime and cement (traditional cementitious materials) and supplementary traditional binders (pozzolanic resources). Chapter 2 presents the characteristics of materials used with methods. Chapter 3 investigates the role of date palm ash as a pozzolanic material. At the end, the conclusions and recommendations of this research are presented.

Chapter One: Literature Review

1. Introduction

Soil stabilization is a process aimed at improving the engineering and physical properties of a given soil mass, particularly when the available soil is unsuitable for construction purposes. This process involves various techniques such as compaction, pre-consolidation, drainage, and others that enhance soil stability and performance while reducing the likelihood of undesirable geotechnical behavior [1].

The integration of additives in soil stabilization has become increasingly popular due to their effectiveness and adaptability. However, conventional stabilizing agents such as cement, lime, and pozzolanic materials have notable environmental drawbacks, primarily due to the high energy consumption and emissions associated with their manufacturing processes, in addition to elevated production costs [2].

Globally, the demand for cement continues to rise due to the construction boom. Given the energy-intensive nature of cement production and its associated high carbon dioxide (CO_2) emissions, this industry is considered environmentally unsustainable. Data indicate that global cement production increased from 500 million tonnes in 1990 to 900 million tonnes in 2015, according to the Cement Sustainability Initiative [3]. Reports further suggest that the cement industry consumes approximately 2% of global energy and 5% of industrial energy, contributing around 5% of total global CO_2 emissions [4]. If current trends persist, this could significantly intensify global warming, potentially surpassing the critical 2°C temperature increase threshold, unless CO_2 emissions are reduced to less than 50 grams per kilogram of cement produced [5].

To mitigate CO_2 emissions, several strategies can be adopted, including:

1. Partial replacement of conventional cement with supplementary cementitious materials (SCMs) derived from natural, agricultural, and industrial waste sources such as fly ash, ground granulated blast furnace slag (GGBFS), natural pozzolan, rice husk ash, and palm oil fuel ash.
2. Development of geopolymer concrete as a low-emission alternative.
3. Carbon capture and storage (CCS) during production processes.
4. Fuel substitution and process optimization in clinker production.

Among these, the partial replacement of cement with SCMs is considered the most practical and cost-effective approach. It can be readily implemented in cement manufacturing and ready-mix concrete plants, according to the Portland Cement Association [6].

2. Traditional Cementitious Materials

Cement is widely used as a primary binding material in civil engineering applications due to its durability and ease of use. However, its production has significant environmental drawbacks, and its cost remains a subject of ongoing debate. [7].

On the other hand, lime offers a cost-effective alternative for soil stabilization and demonstrates efficiency in enhancing soil properties through various physical and chemical mechanisms. The improvement in mechanical strength of lime-treated soils is often attributed more to the increase in cation exchange capacity than to cohesion resulting from pozzolanic reactions. When lime is mixed with clay-rich soils, such as those containing montmorillonite, interlocking crystalline structures resembling needles are formed, resulting in soils that are more stable and less susceptible to moisture fluctuations. The term "lime stabilization" typically refers to pozzolanic reactions, in which the silica and alumina present in the soil react with lime in the presence of water to form calcium silicate and aluminate compounds. These products significantly enhance the long-term structural integrity and stability of the treated soils[8].

3.Pozzolanic Materials

Agricultural waste is frequently burned on open fields to swiftly and easily maximise crop rotation, which makes recycling it crucial. Burning waste releases dangerous chemicals and substances into the atmosphere, such as carbon monoxide and soot, which spread throughout the atmosphere and cause a number of illnesses in people This statement is considered scientifically unfounded. [9].

Previous successful construction products based on tree wastes, specifically from bamboo, coconut, corn, date palm, elephant grass, olive, oil palm, rice husk, sugarcane bagasse, and wheat straw, were developed in response to the aforementioned issues [10]. Date palm is one of these agricultural wastes that is frequently disregarded in the literature despite having the potential to be included as SCM.

For engineering purposes, "soil stabilization" means any physical or chemical improvement of typical soil characteristics. However, in many cases, it makes sense to use different binders to improve or change the in-situ soils before placing various structures on top. The chemical and physical characteristics of soils can be improved or treated with additional additives, such as traditional stabilizers based on calcium. The use of different additives has become more and more common because of their adaptability and endurance. Conventional cementitious stabilizers, such as cement, have detrimental effects on the environment during manufacture in addition to their high manufacturing costs. Lime and cement are made from fossil fuels, which are the primary cause of carbon dioxide (CO_2) emissions. However, because it utilizes a lot of fossil fuels and generates emissions that contribute to more than 5% of global carbon dioxide emissions, the production of cement and lime has a substantial negative environmental impact [11].

Numerous studies have shown that using ash-based cementitious materials is environmentally friendly.

Moreover, these materials exhibit mechanical properties that are comparable to, or even better than, those of conventional Portland cement concrete.

For instance, researchers have investigated the effect of substituting oil palm shell (OPS) and palm oil fuel ash (POFA) at levels ranging from 0% to 25% on the fresh and mechanical properties of lightweight concrete.

Due to the packing effect and pozzolanic reactivity, they reported that concretes made with 10% POFA(palm oil feul ash) had the highest workability and compressive strength. On the other hand, because of the weak interfacial zone between the POFA particles, there was a decrease in the pulse velocity, split tensile strength, flexural strength, and modulus of elasticity [12] The attached table1 is provided below .

Table .1. Summary of scientists' studies on pozzolanic resources for soil development

Type of by-product	Source of waste	Type of soil	References
silica fume	Silicon and ferrosilicon alloy production	Clayey soil	Kalkan E,et , Akbulut 2004 [13]
Fly ash	Coal-powered power stations	Ordinary Soil	Mateos, M [14]..1964
metakaolin	Calcination of kaolinite clay	Clay Soil	Ahmed D and Hamza 2015 [15]

[10] assessed the chloride ion penetration at a replacement level of 0–40% in grout made from ground POFA derived from fruit bunches and kernels in terms of durability. They discovered that the filler effect reduced the charges passed in these grouts by roughly 30% and 60%, respectively.

4. Date Palm Ash

The date palm tree is registered as one of the oldest and top numerous trees worldwide. It is reported that about 105 million date palm trees are currently existing [16]. The productivity rate of these trees is continuously increasing and recorded to increase from 6.54 million tons to 7.42 million tons during the period from 2004 to 2009, respectively [16]. According to a report of the United Nations' (UN) Food Authorization Organization (FAO), the global highest productivity of dates was recorded around 7.2 million tons in 2010. A mature age date palm tree has around 125 greenish palms, from which every year up to 25 new leaves are formed and up to 25 leaves are required to be plucked during the seasonal fruit collection [17,18]. Date palm is the most popular crop cultivated in many parts of the world, especially in the Arab world. Saudi Arabia is known as the mother land for, and the origin of date palm trees, where these trees originated 10,000 years ago [19]. It is estimated that more than 300 types of date fruits are available in the Arabian Peninsula.

In construction engineering applications, the incorporation of date palm waste is uncommon as a cementitious material. For instance, as a cementitious material, Khellou et al. [20] started the incorporation of 4–12% of date palm ash with crusting tuff blends and investigated the mechanical properties of the Algerian pavement construction. The authors found a potential possibility in the extension of their research from their results that 8% ash dosage yields an optimum mix, which can significantly improve the compression strength and bearing index. Likewise, Al-Kutti et al. [21,22] replaced up to 30% traditional cement with date palm ash (DPA) in concrete and mortar mixes. They observed that 10% DPA content dramatically improves the mechanical and durability characteristics. Recently, the suitability of date palm seed ash (DPSA) by partial replacement of Type I cement, at an interval of 2%, from 0%–10%, was investigated by Gunarani and Chakkravarthy [23]. They investigated strength, rate of water absorption, and durability of mortar in an alkaline environment. Their results revealed that 4% DPSA was the optimum replacement dosage to Type I cement, whereas 2% and 8% replacement dosages may also be effectively utilized in structures exposed to acid attack and higher bond strength requirements, respectively.

The goal of this research was to determine how improving the geotechnical characteristics, developing the mechanical details, and enhancing the unconfined compressive strength of the soil will be affected by introducing glass fiber as a reinforcing member and candidate in the alkali activation process. In this case, soft soil and glass fibers were combined while being subjected to an alkaline activator in order to evaluate the potential use of a novel mixture as a construction material. Compressive stress tests were performed after the samples had been cured for 7 and 28 days. The conclusions reached indicated a stronger inclination toward ductility. The current study will look at how changes in soft soil develop compressive strength in response to prolonged curing time. The curing period was suggested to be 180 days to allow for the effect of geopolymerization and glass fiber induction on ductility and strength evolution The attached table2 is provided below .

Table .2. Summary of scientists' studies on date palm ash for soil development

Type of by-product	Source of waste	Type of soil	References
Palm ash (5%.10%.15%)	Palm	Sundy Soil	Karkouba.y And Bahloul.s 2024[24]
Palm ash (0%.20%.25%.30%)	Palm	Clay Soil	Otonyo.A.W et Chukuigwe 2018 [25]
Palm ash (3%.6%.9%.12%)	palm	lateritic soil.	Apata, A. C et al.2022[26].

In light of the above literature, it can be seen that most of the research in the past has been carried out from the waste products of palm trees using POFA or OPS replacement, mostly in

Malaysia and Nigeria. Because Malaysia is the largest palm oil producing country generates millions of tons of solid wastes known as palm oil fuel ash (POFA), which is disposed of annually by palm oil mills all over the country. It is a by-product obtained from burning the remains of extracted palm oil fibres and shells in the palm oil mill. This ash, which does not have sufficient nutrients to be used as fertilizer, is dumped in open fields in the vicinity of the palm oil mills and thus becomes one of the pollutants to the environment. This has prompted Malaysian researchers to conduct studies on exploring the possibility of using this ash to produce a new construction material. Similarly, the Kingdom of Saudi Arabia also has one of the largest cultivations of more than 300 types of Date Palm trees [20], while no research has been carried out by the local or international researchers in the area of construction and building infrastructure, particularly with the use of PA. Therefore, there was a need to explore the optimum dosage of local material and investigate the properties of mortar and concrete specimens prepared with date palm ash.

The review of literature indicates that knowledge gaps exist to explore date palm ash as a cementitious material, evaluate its long-term strength and durability performance, as well as to understand its microstructural characteristics. Therefore, the primary objective of this research is to develop a local Arabian Gulf date palm ash-based construction product by replacing traditional cement.

5. Summary

Soil improvement is a significant challenge for engineers, especially in areas with poor or low-quality soils, when constructing roads, dams, foundations, and other engineering structures. The soil can be improved through certain geotechnical methods.

Previous studies have conducted limited experiments on the effect of palm ash alone in stabilizing soil and improving its physical and chemical properties. Palm ash is a pozzolanic material, and this technique offers several advantages, such as high strength, durability, cost-effectiveness, and environmental friendliness compared to cement and lime. These characteristics make it a promising strategy for soil stabilization.

Chapter Two:

Experimental Methods and Materials Used

1.Introduction

Soil testing provides critical data used to assess the bearing capacity of the ground for structures and to determine whether soil improvement is necessary to support future loads. These tests also help identify the groundwater level. Among the key tests conducted are grain size distribution, compaction tests, and unconfined compressive strength tests.

Geotechnical laboratories play a vital role in measuring and analyzing soil properties. These analyses are essential for ensuring environmental protection and promoting the sustainability of natural conditions. This includes soil reinforcement and the utilization of natural residues, such as palm waste, within a scientifically grounded framework.

2. Sieve Analysis Test:

NF P 94-056 [27]: A French standard that includes quality tests, mechanical and chemical tests. It covers investigation, testing, and particle size analysis, as well as the “washed sieve” method.

Particle size analysis allows for the classification of soil types and particles by passing the soil sample through a series of sieves with progressively smaller mesh openings (5 – 4 – 2.5 – 1.25 – 0.63 – 0.315 – 0.16 – 0.08 mm), and measuring the weight retained on each sieve.

This analysis is used for:

Geotechnical classification of soils determines the suitability of the soil for use in roads, dams, airports, and other infrastructure.

Understanding water movement within the soil, as the particle size distribution significantly influences compressibility.

The compressibility decreases with increasing grain diameters and increases with the heterogeneity of the particle size distribution.

Materials and Equipment:

1 kg of sand

A set of standard sieves

An electronic balance

Figure -1- A set of standard sieves

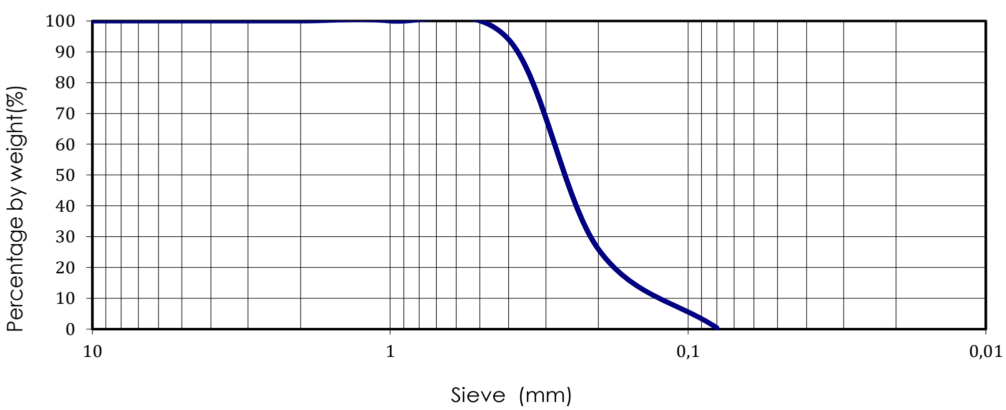

Figure-2- Grain Size Distribution Curve

Soil Fineness Modulus 1.76

Coefficient of Curvature:0.81

Coefficient of Uniformity : 4.29

We conclude that the soil is coarse

3. **Determination of Maximum Dry Density as a Function of Moisture Content (Soil Compaction – Proctor Test)NF P 94-093**[28] The objective of the compaction test is to determine the optimum moisture content of a given fill soil under constant compaction conditions, resulting in the best possible compaction or maximum load-bearing capacity.

The test consists of compacting the soil sample under study in a standard mold using a 3 kg hammer. Various amounts of water are added to the soil, and the moisture content and specific weight are measured after compaction and drying.

The test is repeated several consecutive times on samples prepared with different moisture contents. This allows for plotting several points on a curve, where the peak represents the optimum moisture content and the corresponding maximum dry density.

Materials and Equipment Used

3 kilograms of dry sand.

Water (with varying proportions each time: 10%, 14%, 16%, and 22%).

A compaction mold.

A Proctor compaction device.

An electronic balance.

A soil mixing container.

Preparation Method:

Approximately 3 kilograms of soil passing through a No. 2 sieve are prepared, with its natural moisture content previously determined. Water is then added to achieve a moisture content of approximately 10%, followed by thorough mixing of the soil.

The weight of the cylindrical mold along with its base is then measured.

Compact the soil in three layers, compacting each layer 25 Hammering before adding the next one, using a hammer or a standard roller, and following the standard method for height.

Separate the mold from the ring, and using a straightedge, trim off any excess soil to level it with the surface of the mold. If any voids are present, add fine or coarse material to fill the gaps.

Weigh the cylindrical mold together with the base and the compacted soil.

Detach the base, then carefully extract the soil sample.

Take a representative sample of the compacted soil from the bottom, middle, and top of the mold (approximately 100 to 300 grams) to determine the water content. Repeat the steps several times, gradually increasing the water content, until you observe that the weight of the mold with the base and soil starts to decrease despite adding more water.

Record the dry density of the soil (γd) with the corresponding water content. Plot these values to create a curve from which the maximum dry density (γd max) can be determined; this is the highest point on the curve. The water content corresponding to this point represents the optimum moisture content.

Standard Proctor Test for Soil-Ash Mixtures

The compaction test (sand + ash) aims to determine the optimal moisture content. The test involves compacting a mixture of sand and a constant 15% proportion of ash in a standard mold using a 3 kg hammer. The water content is varied at 10%, 14%, 16%, and 22%. Multiple points are then obtained from the compaction curve to determine the optimal moisture content.

Materials and Equipment Used:

3 kg of sand sieved using a 2 mm sieve.

Ash (15% and 30%) — sieved using a 0.4 mm sieve.

Water content ratios: 10%, 14%, 16%, and 22%.24%

Compression testing machine (Proctor).

Electronic balance.

Figure -3- Ash

Preparation of Ash:

Palm leaves are collected and placed in a large metal container, then ignited for combustion.

The leaves should be evenly distributed to ensure uniform and complete burning.

Once the combustion process is complete, the ash is allowed to cool before being filtered to remove any impurities.

Results :

By mixing soil with 15% ash and testing with different water contents, it was determined that the optimal moisture content is 16%.

By mixing soil with 30% ash and testing with different water contents, it was determined that the optimal moisture content is 15%.

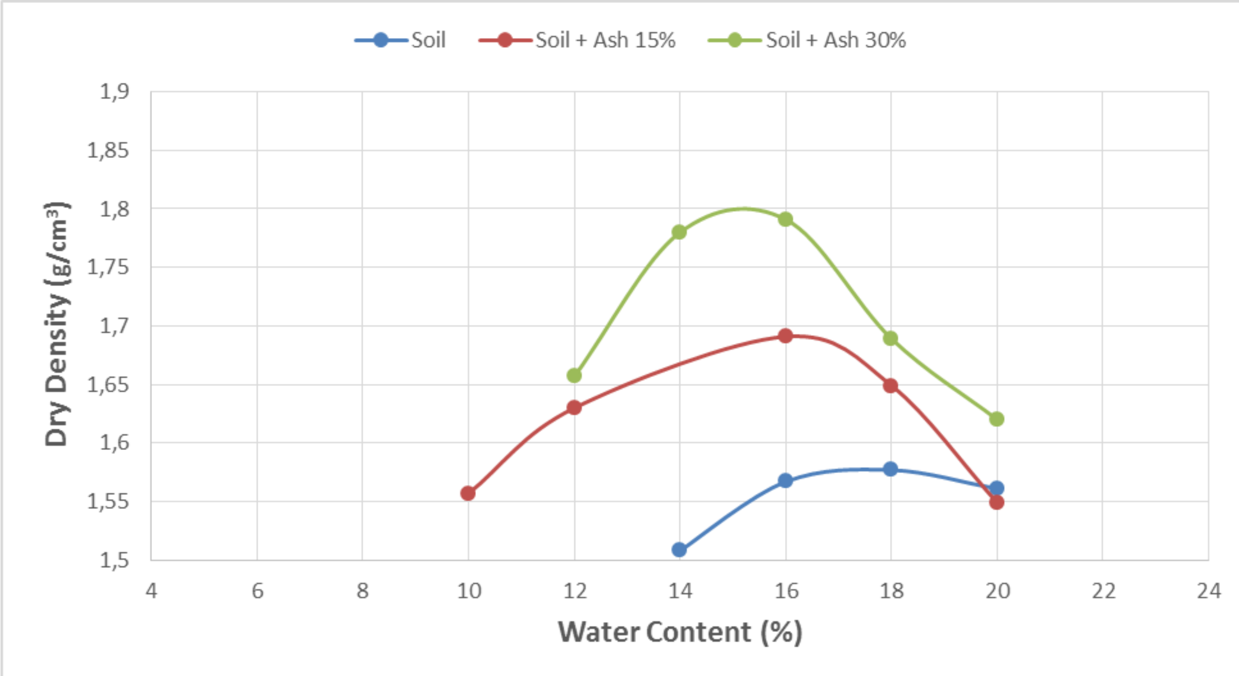

Figure-4 - Compaction curve of soil and soil-ash mixture

4. Sample Preparation

Samples with dimensions of (5×10 cm) are prepared using a total mix of 379 grams, composed of sand, ash, and water. The ash content is varied in each mix at 15%, 20%, 25%, and 30%, while the water content is fixed at 16%, as determined from the compaction test. For each ash percentage, 12 samples are produced. The samples are then wrapped in plastic film and allowed to cure for different periods: 3 days, 7 days, 14 days, and 28 days. At the end of each curing period, simple compression and tensile strength tests are conducted. For tensile testing, the samples are tested only after 28 days.

Figure -5- Sample

5. Unconfined Compression Test NF P 94-077[29]

It is one of the methods used in soil treatment in construction to examine its density and strength. This process involves several steps: preparation, then applying compression. A compression device is placed, and the deformation is measured to determine the amount of stress the soil can withstand.

The samples were prepared and tested at different time intervals. These samples were subjected to the unconfined compression test, as illustrated in the following image:

Figure-6- Unconfined compression machine after applying load to the sample

6.Tensile Test

It is one of the methods used in soil treatment in construction to determine its strength. This process involves several steps, including sample preparation (for 28 days only). Then, the sample is placed horizontally between two wooden columns. The device is then operated, and the readings displayed on the device are recorded. .

Figure-7-The specimen during the test

8. Summary:

The results obtained from the experiments showed the following:

- The fineness modulus of the sand is 1.76.
- The optimal water content for soil compaction is 18%.
- The optimal water content for soil and ash compaction is 16%.
- Through the compression test conducted on cylindrical concrete specimens, it was found that the maximum compressive strength of the sample reached 500 kPa. The failure was observed to be shear along the surface of the specimen.

Chapter Three:
Results and Discussion

1. Introduction

Soil stabilization is a fundamental step in construction, as it plays a crucial role in ensuring the stability and durability of structures built upon it. This study aims to evaluate the effect of using palm ash as a soil stabilizer by examining its mechanical properties under unconfined compressive strength and tensile strength tests.

In the compressive strength test, the sample was placed in the designated device, and the settings were adjusted according to the sample's height. After starting the device, the vertical movement was controlled using the designated button, and the maximum value was recorded from the device's display. All samples underwent the same procedure to ensure consistent testing conditions.

For the tensile strength test, the sample was positioned horizontally, and the results were measured and recorded as shown in table3:

Table.3: Results of Specimens Subjected to Unconfined Compression and Tension

28 DAYS		14 DAYS	7 DAYS	3DAYS	DAYS / Ash%
Tension	Compression				
68 kPa	164 kPa	110kPa	68kPa	19kPa	15
135 kPa	228 kPa	178kPa	132kPa	50 kPa	20
203 kPa	382 kPa	260kPa	178kPa	96kPa	25
303 kPa	485 kPa	335kPa	238kPa	168kPa	30

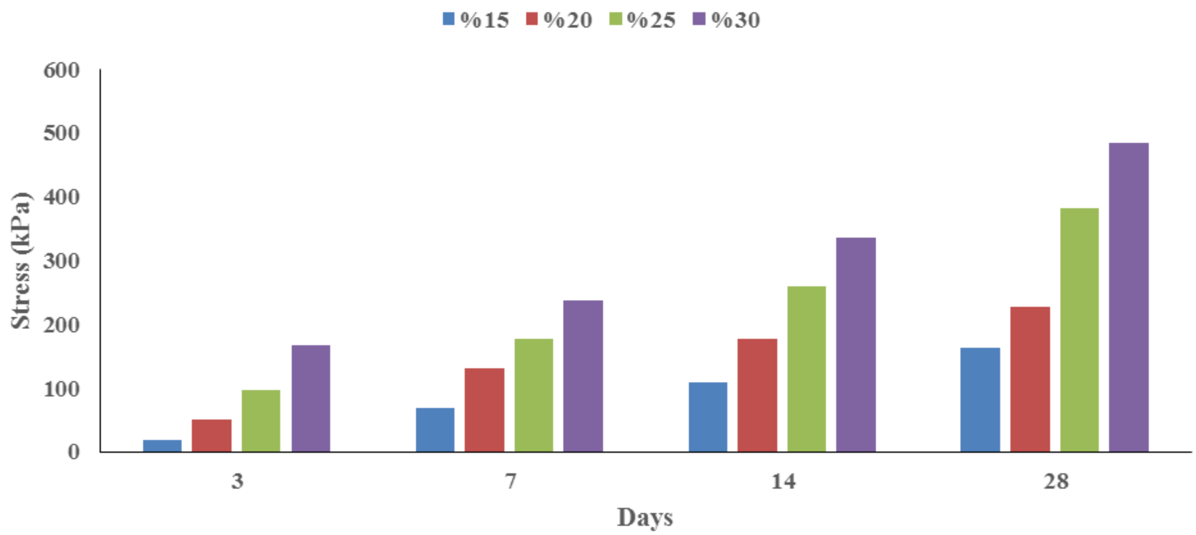

Figure-8- Stress Response Curve of Tested Samples

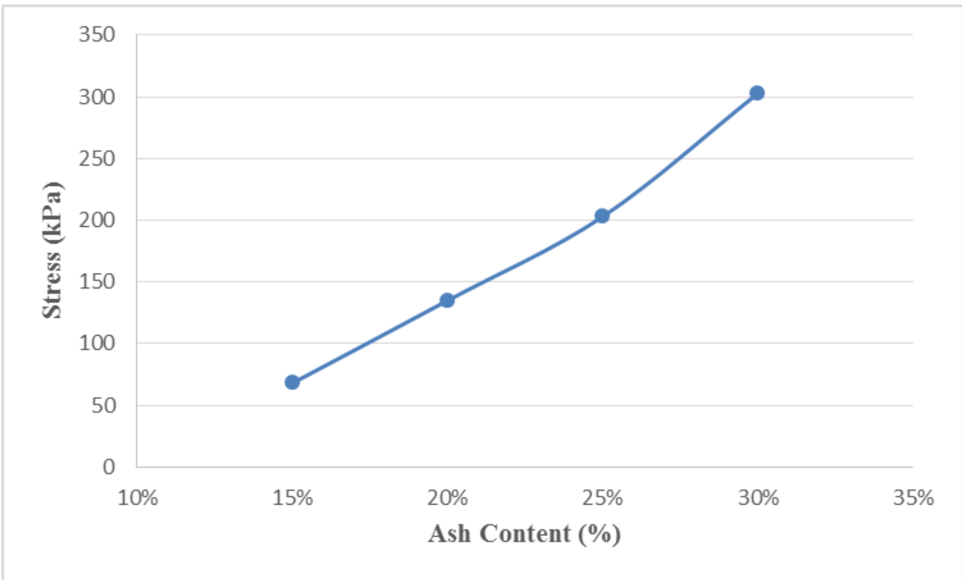

Figure -9- Stress-strain curve of tensile-tested specimens

3. Discussion:

For the mixture (Soil + 15% ash), a slight increase in compressive strength was observed after 3, 7, 14, and 28 days. However, the soil's load-bearing capacity remained weak overall.

For the mixture (Soil + 20% ash), a noticeable increase in strength was recorded at 3 days compared to the 15% ash mix. Furthermore, strength continued to improve at 7, 14, and 28 days, with significant enhancement especially evident after at 14 and 28 days of curing.

For the mixture (Soil + 25% ash), a clear improvement in compressive strength was observed, particularly after 14 and 28 days of curing.

For the mixture (Soil + 30% ash), a substantial improvement in compressive strength was recorded, reaching its maximum value at 28 days.

Tensile Strength:

At 28 days, the tensile strength continued to increase with higher ash content, reaching a maximum value of 303 kPa at 30% ash content.

From the results obtained through the unconfined compression test, the addition of ash to the soil at ratios of 15%, 20%, 25%, and 30% over curing periods of 3, 7, 14, and 28 days showed a significant improvement in the soil's strength. This improvement was particularly notable after 14 and 28 days, indicating that extended curing periods contribute to a considerable increase in compressive strength.

Based on previous studies and experimental findings, it was demonstrated that ash is an effective and promising stabilizing material due to its high calcium oxide content. As the ash percentage increases, more calcium silicate compounds are formed. In this study, the 30% ash content at 28 days achieved approximately 500 kPa of compressive strength, making it the most effective ratio. Therefore, palm ash can be considered a viable and promising soil stabilizer when used at a 30% content.

4. **Summary:**

The results showed that the mixture containing 30% date palm ash exhibited higher compressive strength compared to the mixtures with 15%, 20%, and 25% ash content at early ages. However, after longer curing periods (14 and 28 days), the mixtures containing 25% and 30% date palm ash demonstrated significant strength development, reaching higher compressive strength level.

Conclusion:

The use of pozzolanic materials for soil stabilization is not a recent concept, as various natural substances have been employed for this purpose since ancient times. However, in recent decades, this technique has undergone significant development and has attracted growing interest in the field of construction. As a result, many new types of pozzolanic materials have been introduced and proven, through various studies, to enhance soil strength and cohesion.

In this study, a series of laboratory experiments were conducted to evaluate the quality and geotechnical properties of the soil and its suitability for construction. The soil used was red soil from the ELhadjira, while palm waste ash was incorporated as a pozzolanic additive in varying proportions. Water content, being a critical component of the mix, was carefully controlled, as both excess and deficiency can negatively affect the workability and performance of the mixture.

The mechanical tests carried out—specifically unconfined compressive strength and indirect tensile strength—indicated that the inclusion of palm waste ash in certain proportions20% 25% 30% 15% had a positive effect on the soil's mechanical behavior. The results revealed that the optimal ash content for improving both compressive and tensile strength is 30%, as this ratio yielded the highest performance.

REFERENCES :

[1] Archibong, G. A., et al. "A review of the principles and methods of soil stabilization." International Journal of Advanced Academic Research Sciences 6.3 (2020): 2488-9849.

[2] Khechiba Seif dinne et Derouiche Med Tidjani Mémoire du diplôme de Master Evaluation de la résistance du sol traité par activation alcaline et son comportement face à la salinité page 6

[3] CSI Council. Global Cement Database-Cement Sustainability Initiative. 2015. Available online: http //www.wbcsdcement.org/ (accessed on 1 February 2018).

[4] Worrell, E.; Price. L.; Martin, N.; Hendriks, C.; Meida, L.O. Carbon dioxide emissions from the global cement industry. Annu. Rev. Energy Environ, 2001, 26, 303-329. [CrossRef]

[5] Meinshausen, M.; Meinshausen, N.; Hare, W.; Raper, S.C.; Frieler, K., Knutti, R.; Frame, DJ: Allen, M.R. Greenhouse gas emission targets for limiting global warming to 2 C. Nature 2009, 458, 1158-1162. [CrossRef]

[6] Portland Cement Association. Flash Report-The Monitor, Portland Cement Association Skokie, IL, USA, 2004

[7] Abdeldjouad, Lokmane, Wisam Dheyab, Yaser Gamil, Afshin Asadi, and Sanjay Kumar Shukla. "Thermal curing effects on alkali-activated treated soils with palm oil fuel ash." Case Studies in Construction Materials 19 (2023): e02455. https://doi.org/10.1016/j.cscm.2023.e02455

[8] Makusa, Gregory Paul. "Soil stabilization methods and materials in engineering practice: State of the art review." (2013).

[9] Estrellan, CR; lino, F. Toxic emissions from open burning Chemosphere 2010, 80, 193-207. [Crossite

[10] Aprianti, E; Shafigh, P., Bahri, S; Farahani, JN. Supplementary cementitious materials origin in agricultural wastes-A review. Constr. Build. Mater. 2015, 74, 176-187. [Cross Ret]

[11] Abdeldjouad, Lokmane, Afshin Asadi, Haslinda Nahazanan, Bujang BK Huat, Wisam Dheyab, and Ahmed G. Elkhebu. "Effect of clay content on soil stabilization with alkaline

activation." International Journal of Geosynthetics and Ground Engineering 5 (2019): 1-8. https://doi.org/10.1007/s40891-019-0157-y

[12] Al-Kutti, W., Islam, A. S., & Nasir, M. (2019). Potential use of date palm ash in cement-based materials. Journal of King Saud University-Engineering Sciences, 31(1), 26-31.

[13] Kalkan, E., & Akbulut, S. (2004). The positive effects of silica fume on the permeability. swelling pressure and compressive strength of natural clay liners. Engineering geology, 73(1-2), 145-156.

[14] Mateos, M. (1964). Stabilization of soils with fly ash alone. Highway Research Record, (52), 59-65.

[15] Ahmed, M. D., & Hamza, N. A. (2015). Effect of metakaolin on the geotechnical properties of expansive Soil. Journal of Engineering, 21(12), 29-45.

[16] Agoudjil, B.; Benchabane, A., Boudenne, A., Ibos, L., Fois, M. Renewable materials to reduce building heat loss: Characterization of date palm wood. Energy Build 2011, 43, 491-497. CrossRef]

[17]. Haimour, N.M.; Emeish, S. Utilization of date stones for production of activated carbon using phosphoric acid. Waste Manag, 2006, 26, 651-660. [Cross Ref] [PubMed]

[18] Abdelouahhab, Z., Arias-Jimenez, E.J. Date Palm Cultization; Food and Agriculture Organization (FAO): Rome, Italy, 1999, No. 156.

[19] Assirey, E.A.R. Nutritional composition of fruit of 10 date palm (Phoenix dactylifera L.) cultivars grown in Saudi Arabia. J. Taibah Unit. Sci. 2015, 9, 75-79. [CssRef]

[20] Khellou, A., Kriker, A.; Hafssi, A.; Belbarka, K.; Baali, K. Effect of the addition of by-product ash of date palms on the mechanical characteristics of gypsum-calcareous materials used in road construction. AIP Conf. Proc 2016, 1758, 030005

[21] Al-Kutti, W.; Islam, A.B.M.S.; Nasir, M. Potential use of date palm ash in cement-based materials. J. King Saud Unre. Sci. 2017. [Cross Ref]

[22] Al-Kutti, W., Nasir, M., Johari, M.A.M.; Islam, A.B.M.S; Manda, A.A.; Blaisi, N.I. An overview and experimental study on hybrid binders containing date palm ash, fly ash, OPC and activator composites. Constr. Build. Mater. 2018, 159, 567-577. [Cross Ref]

[23] Gunarani, G.L; Chakkravarthy, SP. Experimental studies on effect of Date Seed Ash (DSA) on strength properties of cement sand mortar. IOP Conf. Ser. Earth Environ. Sci. 2017, 80, 012015. [Cross Ref]

[24] Karkouba.y And Bahloul.s 2024 مذكرة تخرج ماستر دراسة تثبيت التربة بواسطة رماد بقايا النخيل

[25] Otunyo, A. W., & Chukuigwe, C. C. (2018). Investigation of the impact of palm bunch ash on the stabilization of poor lateritic soil. Nigerian Journal of Technology, 37(3), 600-604.

[26] Apata, A. C., Etuke, J. O., Imoh, U. U., & Busari, U. B. (2022). A comparative study of the stabilization of two lateritic soils from South-western Nigeria for highway pavement using Palm Bunch Ash (PBA). Indian Journal of Engineering, 19(52), 354-363.

[27] sol reconnaissance et essais analyse granulumetrique methode par tamisage a sec apres lavage mars 1996

[28] NF P 94-093 essai de proctor normale october1999

[29] La norme NF P 94-077 essai de compresion simple Décembre 1997.

ملخص:

يُعد تثبيت التربة من التقنيات الشائعة لمعالجة مشاكل التربة، ويتميز بمزايا عديدة مقارنة بعملية استبدال التربة، منها انخفاض التكلفة وسرعة التنفيذ. من بين تقنيات التثبيت المقترحة، يُعد استخدام المواد البوزولانية أحد الحلول الواعدة. وعلى الرغم من التشابه في آلية التحسين والخصائص النهائية من حيث الصلابة والهشاشة بين التربة المعالجة بالمواد البوزولانية وتلك المعالجة بالإسمنت، فإن هذا البحث يهدف إلى تقييم مدى جدوى استخدام رماد النخيل كمصدر للتفاعلات البوزولانية في تحسين خصائص التربة وجعلها أكثر ملاءمة للتطبيقات الإنشائية. تم إجراء سلسلة من التجارب باستخدام أربع نسب مختلفة من رماد مخلفات النخيل كمادة مضافة إلى التربة، وتم تقييم الأداء من خلال اختبارات الضغط والشد الغير المحصور. أظهرت النتائج أن الخليط المحتوي على 30% من رماد النخيل قدّم أعلى مقاومة ضغط وشد عند المقارنة مع الخلطات ذات النسب الأقل (25%، 20%). ومع ذلك، بعد فترات معالجة أطول (14 و28 يومًا)، أظهرت الخلطات التي تحتوي على 25% و30% من رماد النخيل تطورًا ملحوظًا في المقاومة، في حين بقيت الخلطة ذات النسبة 15% دون المستوى المطلوب، بسبب عدم كفاية كمية الرماد اللازمة لتكوين المادة الهلامية الإسمنتية (CSH) . تقدم هذه الدراسة رؤى جديدة حول إمكانية استخدام المواد البوزولانية، مثل رماد النخيل، في تثبيت التربة، مؤكدةً أهمية التركيب المعدني للتربة المستضيفة، والذي يلعب دورًا مؤثرًا في فعالية التثبيت وسلوك المادة الرابطة الناتجة.

الكلمات المفتاحية: رماد النخيل، تثبيت التربة، التفاعلات البوزولانية.

Abstract:

Soil stabilization is a well-known technique for addressing soil-related issues, offering advantages such as lower cost and faster implementation compared to soil replacement. Among the proposed stabilization methods, the use of pozzolanic materials has gained attention. Although the strengthening mechanism and the final characteristics—such as hardness and brittleness—are similar to those observed in cement-stabilized soils, this study aims to investigate the feasibility of utilizing palm ash as a precursor for pozzolanic reactions in order to enhance soil properties for various engineering applications. Four different percentages of palm ash were used to stabilize the soil, and the resulting mixtures were evaluated using unconfined compressive strength (UCS) tests. The results revealed that the mixture containing 30% palm ash exhibited the highest compressive strength compared to those with 25% and 20%. However, after extended curing periods of 14 and 28 days, the mixtures with 25% and 30% palm ash achieved significantly higher strength levels than the one with 15%, as the lower ash content was insufficient to produce the required cementitious gel (calcium silicate hydrate, CSH). This study provides new insights into soil stabilization using pozzolanic materials, offering a relatively

novel and efficient approach. The mineral composition of the host soil plays a critical role in the stabilization process, as it affects the behavior of the binding material formed through pozzolanic reactions.
Keywords: Palm ash, soil stabilization, pozzolanic reactions.
Résumé :

La stabilisation des sols est une technique bien connue pour traiter les problèmes liés aux sols, offrant des avantages tels qu'un coût réduit et une mise en œuvre rapide par rapport au remplacement du sol. Parmi les méthodes proposées, l'utilisation de matériaux pouzzolaniques suscite un intérêt croissant. Bien que le mécanisme de renforcement et les caractéristiques finales — telles que la dureté et la fragilité — soient similaires à celles observées dans les sols stabilisés au ciment, cette étude vise à évaluer la faisabilité de l'utilisation de la cendre de palmier comme précurseur des réactions pouzzolaniques afin d'améliorer les propriétés du sol pour diverses applications en génie civil. Quatre pourcentages différents de cendre de palmier ont été utilisés pour stabiliser le sol, et les mélanges obtenus ont été évalués à l'aide d'essais de compression non confinée. Les résultats ont montré que le mélange contenant 30 % de cendre de palmier présentait la résistance à la compression la plus élevée par rapport à ceux contenant 25 % et 20 %. Toutefois, après des périodes de cure prolongées de 14 et 28 jours, les mélanges avec 25 % et 30 % de cendre de palmier ont atteint des niveaux de résistance nettement supérieurs à celui contenant 15 %, en raison d'une quantité insuffisante de cendre pour produire le gel cimentaire (silicate de calcium hydraté – CSH). Cette étude offre de nouvelles perspectives sur la stabilisation des sols à l'aide de matériaux pouzzolaniques, en proposant une approche relativement nouvelle et efficace. La composition minéralogique du sol hôte joue un rôle essentiel dans le processus de stabilisation, influençant le comportement du liant formé par les réactions pouzzolaniques.
Mots-clés : Cendre de palmier, stabilisation des sols, réactions pouzzolaniques.