Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 1 Volume 28 January 2022

Civil and Architectural Engineering

A Review on Expansive Soils Stabilized with Different Pozzolanic Materials

Ahmed M. Al-Kalili *
MSc. Student
College of Engineering
Al-Nahrain University
Baghdad-Iraq
ahmadm1995414@gmail.com

Ahmed S. Ali
Professor
College of Engineering
Al-Nahrain University
Baghdad-Iraq
ahmed_sltn2007@yahoo.com

Abbas J. Al-Taie
Professor
College of Engineering
Al-Nahrain University
Baghdad-Iraq
al.taiegeo@gmail.com

ABSTRACT

Soils that cause effective damages to engineer structures (such as pavement and foundation) are called problematic or difficult soils (include collapsible soil, expansive soil, etc.). These damages occur due to poor or unfavorited engineering properties, such as low shear strength, high compressibility, high volume changes, etc. In the case of expansive soil, the problem of the shrink-swell phenomenon, when the soil reacts with water, is more pronounced. To overcome such problems, soils can be treated or stabilized with many stabilization ways (mechanical, chemical, etc.). Such ways can amend the unfavorited soil properties. In this review, the pozzolanic materials have been selected to be presented and discussed as chemical stabilizers. The selected pozzolanic materials are traditional, industrial, or byproducts, ashes of agricultural wastes, and calcined-clay types. They are lime, cement, blast furnace slag, fly ash, silica fume, rice husk ash, sugarcane straw ash, egg ash, coconut husk ash, and metakaolin. In general, the stabilization of expansive soils with pozzolanic materials has an essential impact on swelling and Atterberg-limits and positively affects compaction and strength parameters. However, there is a wide range for the percentages of pozzolanic materials used as stabilizers. The content (15% to 20%) is the most ratios of the stabilizers used as an optimal percentage, and beyond this ratio, the addition of the pozzolanic materials produces an undesirable effect.

Keywords: Problematic soils, expansive soil, engineering properties, shrink-swell, pozzolanic materials, calcined clay.

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2022.01.01

Article received: 25/2/2021
Article accepted: 10/4/2021
Article published:1/1/2022

مراجعة للتربة الانتفاخية المثبتة بمواد بوزولانية مختلفة

احمد معد الخليلي*
طالب ماجستير
كلية الهندسة, جامعة النهرين

احمد سلطان علي
استاذ
كلية الهندسة, جامعة النهرين

عباس جواد الطائي
استاذ مساعد
كلية الهندسة, جامعة النهرين

الخلاصة

ان التربة التي تسبب أضرارًا فعالة للهياكل الهندسية (مثل الطرق والأساسات) تسمى بالتربة ذات المشاكل أو الصعبة (بما في ذلك التربة القابلة للانهيار والتربة الانتفاخية وما إلى ذلك). تحدث هذه الأضرار بسبب الخصائص الهندسية الضعيفة أو غير المفضلة (قوة القص المنخفضة ، الانضغاطية العالية ، التغيرات الحجمية الكبيرة ، إلخ). في حالة التربة الانتفاخية ، تكون مشكلة الانكماش والانتفاخ ، عندما تتفاعل التربة مع الماء ، أكثر وضوحًا. للتغلب على مثل هذه المشاكل ، يمكن معالجة التربة أو تثبيتها بالعديد من طرق التثبيت (الميكانيكية ، الكيميائية ، إلخ). مثل هذه الطرق يمكن أن تعدل خصائص التربة غير المرغوب بها . في هذه المراجعة ، تم اختيار المواد البوزولانية لعرضها ومناقشتها كمثبتات كيميائية. المواد البوزولانية المختارة هي مواد تقليدية أو صناعية أو نواتج عرضية للصناعة , ورماد من النفايات الزراعية ، وأنواع من الطين المكلس. هذه المواد تتضمن النورة والأسمنت وخبث الفرن العالي والرماد المتطاير ودخان السيليكا ورماد قشر الأرز ورماد قش قصب السكر ورماد البيض ورماد قشر جوز الهند والميتاكولين. بشكل عام ، يكون لتثبيت التربة الانتفاخية بالمواد البوزولانية تأثيرًا مهمًا على قابلية الانتفاخ وحدود وأتربيرك وله تأثير إيجابي على معاملات الرص ومقاومة القص. وعلى اية حال, هناك نطاق واسع للنسب المئوية للمواد البوزولانية التي تستخدم كمثبتات للتربة. المحتوى (15 ٪ إلى 20٪) هو النسبة المثالية والاكثر استخداما لتثبيت التربة باستدام المواد البوزولانية ، وما وراء هذه النسبة ، تصبح إضافة المواد البوزولانية الى التربة ذات تأثيرً غير مرغوب فيه.

الكلمات الرئيسية: التربة ذات المشاكل, التربة الانتفاخية, الخصائص الهندسية, الانكماش والانتفاخ, المواد البوزولانية, الطين المكلس.

1. INTRODUCTION

Expansive clay soils are a term applied to soils that have a significant change in volume due to the shrinkage and swelling during changes in the climate condition and other factors such as water content and loading condition (**Nelson and Miller, 1992**). The upper layer in the active zone of this soil is the most affected by climate conditions (**Nelson, et al., 2015**). The depth of this zone depended on the geo-climatic parameters of this zone (**Jones and Jefferson, 2012**). The changes in the volume of these soils cause significant damage to the engineering structures (**Fredlund, 2006; Karunarathne, et al., 2012; Ozer and Nihat, 2012; Salahudeen, et al., 2014; Al-Baidhani and Al-Taie, 2019; 2020**). Such damages in engineering structures (due to soil shrink and swell) cost billions of dollars worldwide. In The united states of America, yearly, the cost of damages due to swelling problems is exceeded 100 billion dollars, while in the United Kingdom, the cost exceeded 150 million pounds (**Gourley, et al., 1993; Khademi and Budiman, 2016)**. Sometimes the replacement of expansive soil at shallow depth can overcome its problem; also, the controlling of soil moisture content to a constant value can help overcome the damages of expansive soils (**Al-Taie, 2002; Al-Taie and Al-Shakarchi, 2016)**. Generally, the most usual practice for swelling problems is the stabilization of the expansive soils using different materials and additives (**Hussein, et al., 2019; Al-Naje, et al., 2020**). In the last decades, the utilization of different pozzolanic materials for enhancing soils was increased (**Al-Naje, et al., 2020**). Such materials are popular due to their cost-effectiveness. Good geotechnical properties of soils can be achieved using different pozzolanic materials **(Hussein, et al., 2021**). Such materials are either natural or artificial, e.g., lime-cement, silica fume, blast furnace slag, fly ash, rice husk ash, sugarcane straw ash, egg ash, coconut husk ash, metakaolin, etc. **(Khatib, et al., 2018; Yusuf and Zava, 2019; McCarthy and Dyer, 2019)**. The application of pozzolanic materials in problematic soils stabilization can solve the problems of these soils, on the one hand. It can solve some of the issues of the environment, on the other. The application of these materials was shown as stabilization agents for expansive soils. It was reviewed and discussed in this paper.

2. STABILIZATION OF EXPANSIVE SOILS WITH THE INDUSTRIAL POZZOLANIC MATERIALS

The problems of expansive soils can be reduced using traditional additives such as cement or lime. Also, the application of "silica-alumina" or "silica" based materials in wide soil stabilization represents an economical substitution to traditional materials of cement and lime. These materials show pozzolanic reactions that produce gel materials that enhance the strength of soils. The pozzolanic materials can be industrial or byproduct materials such as blast furnace slag, fly ash, silica fume, etc. (**Baalbaki and Blondin, 1994; Khatib, et al., 2018; Hussein, et al., 2019)**. In this paper, the mentioned pozzolanic materials have been reviewed and summarized in **Table 1**.
As presented in this Table, different contents of pozzolanic materials (traditional additives and industrial or byproducts) have been used to stabilize expansive soils. In the presented studies, the pozzolanic materials are either one material used alone or mixing of more than one material such as lime with cement, cement with fly ash, fly ash with lime, fly ash with gypsum, slag with cement. It can be seen that there are optimum dosages of the pozzolanic materials where the maximum improvement in the properties of the soils can be reached. The optimum contents have been recorded as follows: (2% and 4%) for lime, (8%) for cement, (15% and 20%) for fly ash, and 30% for slag. Furthermore, the use of industrial or byproduct pozzolanic materials reduces the consumption of traditional additives (i.e., cement and lime), where the last materials are of most importance in construction materials. In general, the stabilization of expansive soils with traditional additives and industrial or byproduct pozzolanic materials produces improvements, to different degrees, in the soils' geotechnical properties (it has an essential impact on swelling and Atterberg-limits and has a positive effect on compaction-parameters).

Table 1. Application of industrial pozzolanic materials in soil stabilization.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
Lime and Cement			
Ismaiel, 2004	Expansive soil	10% of lime. 10% of cement.	The shear strength parameters are directly proportional to the stabilizer content.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
		2.5% to 7.5% of lime and cement	
Ampera and Aydogmust, 2005	Expansive soil	(2%, 4%, 6%) of lime. (3%, 6%,9%) of cement	The shear strength of cement-treated samples is larger than that of lime-treated samples. Lime stabilization is more appropriate than cement stabilization for construction delay.
Rao, et al., 2018	Expansive soil	(1%, 2%, 4%, 6%) of lime.	Lime has an important impact on swelling and Atterberg-limits. It has a positive effect on compaction parameters.
Al-Rawas, et al., 2005	Expansive soil	Different percentages and combinations of lime and cement	Lime shows better suitability to decrease the swelling potential of the soil.
Saride, et al.,2013	Organic Expansive soil (OES).	(3% - 6.5%) for lime and cement.	Reducing the dry density of treated OES due to the soil's weight decrease. Plasticity decreased in the samples with lime stabilization larger than in the samples treated with cement.
Khemissa and Mahamedi, 2014	Over-consolidated expansive soil	Different cement-lime mixing ratios.	California bearing ratio (CBR) values increased for the treated samples. Optimum values for soaked and unsoaked CBR were obtained when used lime (2% and 4%) and (8%) for cement. Also, the best improvement in bearing capacity was reached at (8%) of cement and (4%) lime.
Barasa, et al. 2015	Expansive soil	4%,5%,6% of lime	The increase in lime decreased the plasticity index of the soil and its swelling and shrinkage when adding lime. CBR increasing with the increased amount of lime significantly.
Silica Fume			
Kalkan and Akbulut 2004	Expansive soil	Different silica fume mixing ratios	The addition of silica fume reduced plasticity index, permeability and increased the UCS of the soil.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
Negi, et al., 2013	Expansive soil	Different silica fume mixing ratios	Adding silica fume improves the index parameters of the soil.
Fly Ash			
Al-Dulaimy, 2003	Expansive soil	different percentages of fly ash	15% of fly ash produced the minimum swelling. 5% of fly ash produced the highest value of UCS.
Pandian, et al., 2001	Black cotton soil.	0%-100% (class-f) fly ash with an 10% increment.	CBR value increased to 20% at 10% of fly ash. CBR value reduced beyond 10% of fly ash.
Bose, 2012	Expansive soil	Different ratios of fly ash	Adding fly ash reduced the plasticity, linear shrinkage, moisture content free swell -index, and swelling pressure while shrinkage limit increased. 20% of fly ash achieved the maximum value of maximum dry density and UCS. Beyond 20% of fly ash, the strength decreases.
Hasan, 2012	Expansive soil	Different ratios of fly ash.	20% of fly ash decreased all the following properties of the soil: Liquid limits (74% to 56), Plastic limits from (31% to 25%), Plasticity index (44%-31%), Maximum dry density (1.697 to 1.275) g/cm3. 20% of fly ash increased the optimum moisture content from (19.2 to 29.3)%.
Gopala Krishna, et al., 2013	Black cotton soil	Different ratios of (class-f) fly ash and zycosil	3% fly ash and 2% of zycosil achieved the highest value of unsoaked CBR. 4% fly ash and 2% zycosil achieved the highest value of the soaked CBR.
Ramkrishna and Pradeepkumar, 2006	Expansive soil	Different combined ratios of (class-F) fly ash- Aluminum chloride and fly ash- Magnesium chloride.	The swelling properties reduced at a certain amount of the stabilizer, but the properties remained stable beyond this percentage.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
Amu, et al., 2005 A	Expansive soil	Different ratios of cement and (Class- F) fly ash.	3% fly ash 9% cement stabilization was better than 12% of cement stabilization.
Ray, et al., 2020	Expansive soil	fly ash with lime and gypsum on different percentage.	Using fly ash with lime gave higher CBR values compared to gypsum.
Cokca, 2001	Expansive soil	0%-25% (class-C) fly ash	Properties of cured soil samples such as activity, plasticity index, and swelling potential decreased with adding fly ash. There is an optimum value of fly ash, which is 20%.
Blast Furnace Slag			
Ortega-López, et al., 2014	Clayey soil	Five different types of slag at 5% increment	Higher volumetric stability, CBR values, and strength were achieved. A reduction in the swelling behavior was noted.
Yadu and Tripathi, 2013	Soft soil	Different ratios of slag.	At 9% of slag, the UCS was increased up to 28%.
Mujtaba, et al., 2019	Lean clay Fat clay	Different ratios from (0% to 55%) of slag.	At 50% of slag, the maximum dry density was increased by 10%. At 50% of slag, the CBR value increased from (3.2% to 11.5%) for fat clay, and for lean clay the result was from (2.4% to 10.7%). At 20% of slag, the swelling potential reduced from (5% to 2%) for lean clay. At 30% of slag, the swelling potential reduced from (8% to 2%) for fat clay. At 30% of slag, the shear strength increased up to 35% with 28 days of curing.
Cokca, et al., 2009	Expansive soil	Different ratios of slag and cement-slag with a proportion of 5%	Total amount of swelling was decreased.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
		to 25% at 5% increments	
Osinubi, et al., 2009	Black cotton soil.	Different ratios of slag and cement.	The compaction delay decreased the treated soil's strength

3. STABILIZATION OF EXPANSIVE SOILS WITH THE AGRICULTURAL WASTES POZZOLANIC MATERIALS

The identification of agricultural wastes as pozzolanic materials has been recorded in many researches. The ashes produced from the burning of the agricultural wastes' materials are of good pozzolanas properties (**Tsado, et al., 2014**). Among these agricultural wastes, rice husk ash, sugarcane straw ash, egg ash, coconut husk ash, etc. Different researchers investigated the suitability of the ashes of the agricultural wastes as soil additives to replace the classic expensive additives like cement. The utilization of these ashes in the field of soil improvement can assist in solving the environmental problems of these waste materials. It can save the cost of soil stabilization using traditional materials.

The review of different researches regarding the application of agricultural wastes as pozzolanic materials in soil stabilization has been conducted and summarized in **Table 2**. As shown, different dosages of ashes have been used to stabilize soils. In the reviewed researches, the ashes materials are either used alone or mixed with other materials such as lime, cement, gypsum, polypropylene fibers, calcium chloride, quarry dust, and granite powder. It can be noted that there are optimum contents of the ashes' materials at which the best improvement in the properties of the soils can be achieved. The recorded optimum content for rice husk ash, sugarcane straw ash, egg ash, and coconut husk ash is (10% to 15%), (4% to 10%), (3% to 20%), and (4% to 8%), respectively. Also, one can be noticed that the ashes' materials are highly affected by curing. The development of soil strength was increased when the treated samples were cured for a suitable period of time, fourteen to twenty-eight days. In general, the treatment of soils with agricultural wastes (as pozzolanic materials) causes improvements, to different degrees, in the soils' engineering properties like bearing ratio values, soils' plasticity, shear strength parameters, swelling properties. The efficiency of these materials increases when they are mixed with other materials (such as lime, cement, gypsum, polypropylene fibers, calcium chloride, quarry dust, and granite powder).

Table 2. Application of agricultural wastes as pozzolanic materials in soil stabilization.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
Rice Husk Ash, RHA			
Basha, et al., 2003	Expansive soil (bentonite).	Different ratios of RHA and cement.	The optimum amount for stabilization was (10%-15%) for RHA and (6%-8%) for cement.
Muntohar and Hantoro, 2000	Expansive soil	Different ratios of RHA and lime.	Improvements in CBR, plasticity index, strength parameters, swelling index, etc. was noted
Rao, et al., 2011	Expansive soil	Different ratios of RHA, lime, and gypsum	At 3% of gypsum, 5% of lime, and 20% of RHA, CBR value increased 13 times with 14days curing period and the UCS five times for 28 days curing period.
Ramkrishna, and Pradeepkumar, 2006	Black cotton soil	Different ratios of RHA and cement	The best strength parameters were obtained with (10% and 8%) RHA and cement, respectively
Alhassan, 2008	Expansive soil	Different ratios of RHA	Increasing in RHA amount decreased the maximum dry density and increased the optimum moister content with a slight improvement in CBR and UCS values
Sabat, 2013	Expansive soil	Different ratios of RHA and lime sludge	At 10% of RHA and 15% of the lime sludge, the compaction water content, shear strength parameters, and bearing ratio were increased. This increase continued with the curing period. Maximum compaction density, swelling pressure, and coefficient of compaction were reduced with the increasing of the stabilizer, and this reduction increased with the curing
Sugar Cane Straw Ash, SCSA			
Reddy and Prasad, 2017	Clayey soil	10%, 15%, 20% and 25% of sugarcane and (o.5%,1% and 1.5%) of Polypropylene	At 20% of sugarcane only, the MDD values increased from (1419 kg/m3) to 1690 kg/m3), UCS from (35 kPa to 44 kPa, and Soaked CBR values also increased from (1.39% to 2.15%). Beyond this percentage of the stabilizer, all the results above were reduced.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
		fiber mixed with 20% of sugarcane	The optimum moister content was reduced from (28.1% to 15.6%) at 20% of sugarcane and then start to increase again beyond this percentage. 1% of the fiber mixed with 205 of sugarcane, the Soaked CBR was increased from (1.39 to 3.94) and then decreased. UCS was increased from (35 kPa to 134 kPa) at 1.5% of fiber and 20% of sugarcane.
Singh and Sharma, 2017	Black cotton soil	Different of mixed sugarcane and wheat husk ash ratios as (3%+3%, 5%+5%, 7%+7%, 9% +9%, and 11%+11%)	At (7%+7%) of the two stabilizers, many engineering properties were increased as shown: Soaked CBR value up to(29.33). UCS value to (35.7 MPa). MDD (1480 kg/m3). Liquid Limit (39%). Plastic limit (23%). Plasticity Index (16%). But these values were decreased beyond these percentages of the stabilizers. Optimum moister content was reduced at (7%+7%) of the two stabilizers, but it increased again beyond these percentages
Chakraborty, et al., 2016	Expansive soil	(5%, 10% and 15%) of SCSA	CBR and UCS values were increased at 10% of SCSA with the increasing of curing days
Osinubi, et al., 2009	Black cotton soil	Different ratios of SCSA and lime	A combination of 8% of lime and 4% of SCSA produced the highest CBR value
Kharade, et al., 2014	Black cotton soil	Different ratios of SCSA	The bearing capacity and shear strength were strengthened at 6% of SCSA
Egg Ash			
Kumar and Tanilaransan, 2014	Expansive soil	0.5% to 5.5% ratios of egg ash at 0.5% intervals	3% was the optimum amount of egg ash, but undesirable results occurred beyond this percent.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
Amu et al., 2005 B	Expansive soil	Different combination ratios egg ash and lime	3% lime + 4% ESP was the optimal percentage which served as control. 7% of lime was better than 3% lime + 4% ESP for tests like UCR, CBR, undrained triaxial test, and maximum dry density
Barazesh, et al.,2012	Expansive soil	Different ratios of egg ash	The addition of the egg ash produced a positive effect on the engineering properties of the soil
Paul, et al., 2014	Clayey Soil	Different ratios of egg ash and Quarry Dust (QD).	Atterberg's Limits and shear strength increased with the egg ash increasing to 20%, and they were reduced. Maximum dry density, angle of friction, and cohesion were decreased with the increase of the egg ash, but the OMC was increasing. Maximum dry density, angle of internal friction, and shear strength were increased with the addition of QD at 20% of egg ash. Atterberg's limits, optimum moisture content, and cohesion decreased with the addition of QD at 20% of egg ash. 30% of the QD was the optimal percentage
Coconut Husk Ash, CHA			
Oluremi, et al., 2012	Poor lateritic Soils	(2%, 4%, 6%, 8% and 10%) of coconut ash	The addition of the CHA increased the CBR values and plastic limit but reduced the plasticity index.
Vysakh and Bindu, 2012	Lateritic Soils	Different ratios of coconut shell, leaf and husk ash	The addition of CHA improved the strength properties. The optimum CHA content was 7%.
Ikeagwuani, e al., 2015	Lateritic Soils	Different combination ratios of CHA and lime	A combination of 5% CHA and 4% lime improved soil's compressibility properties.
Ikeagwuani, et al., 2017	Lateritic Soils	4% lime+(4% to 20%) of CHA at 4% intervals	The combination of 8% of CHA and 4% and lime increased the cohesion from 38 kPa to 52 kPa.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
			The angle of internal friction was slightly affected. 16% CHA and 4% lime increased the MDD from 1510 kg/m^3 to 1650 kg/m^3.

4. STABILIZATION OF EXPANSIVE SOILS WITH THE CALCINED-CLAY POZZOLANIC MATERIALS

The calcined-clay pozzolanic material is a type of pozzolanic material. This type of pozzolanic material is not industrial or waste; its production requires high energy. The metakaolin is an example of calcined clay produced by calcinating the kaolin clay (**Khatib, et al., 2018**). The use of metakaolin as a pozzolanic material increased the recent decades [64]. Metakaolin can be considered as an alternative pozzolanic material used to improve the geotechnical properties of soils. The use of metakaolin reduces the negative effect of problematic soils. This review shows the importance of using metakaolin in the field of geotechnical soil stabilization. **Table. 3** summarizes the reviewed papers that show the effects of adding metakaolin on the geotechnical properties of clay soils. Different contents of metakaolin have been used in literature (from 0% to 20%). According to the literature available in Table 3, it is clear that the metakaolin reduces some soil properties such as specific gravity, the compaction moisture content, the free swell, plastic limits, and linear shrinkage. At the same time, other properties show an increase in their values, such as maximum dry density, unconfined strength, CBR value, and ultimate bearing capacity.

Table 3. Application of metakaolin as pozzolanic materials in soil stabilization.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
Ahmed and Hamza, 2015	Expansive soil	Different ratios of metakaolin.	The addition of metakaolin reduced the specific gravity from (2.78 to 2.72). The maximum dry density was increased with the addition of a stabilizer, and the optimum moisture content and free swell were decreased. The addition of 10% metakaolin increased UCS, but UCS was decreased beyond this content.
Abba and Abubakar, 2019	Black cotton soil	(0%_15%) of metakaolin at 3% increments.	At 15% of metakaolin, the free swell was decreased from (59% to 29%) and the plastic limit was reduced to 33.33%.

References	Type of the treated soil	The percentage used of the stabilizer by the soil weight	Main Conclusions
			Linear shrinkage was reduced to about 2.54% at 15% of metakaolin. At 12% of MK, the durability was improved to 36.1%.
Prakash, et al., 2018	Expansive soil	(10%, 20% and 30%) of metakaolin and granite powder.	With 30% additive, the liquid limit and plastic limit was decreased from (80% to 19%) and (25.51% to 9%), respectively. OMC was decreased from (12 to 7)%, while the CBR value was increased from (9.2 to 12)% with 30% of the stabilizer.
Venkateswarlu, et al., 2021	Soft clay	Different ratios and combinations of MK and calcium chloride	The optimum amount of the stabilizers were 15% of MK and (9% + 1%) of MK + calcium chloride. At 15% of MK, the soaked CBR was increased to about 78% and to 80% when treated with (9%+1%) of MK and calcium chloride. The ultimate bearing capacity was increased to 44% at OMC when treated with MK and increased to 53% at OMC when treated with MK + calcium chloride.

5. CONCLUSIONS

The application of pozzolanic materials in problematic soils stabilization can solve the problems of these soils, on the one hand, and can solve some of the problems of the environment, on the other. The application of these materials was shown as stabilization agents for expansive soils. The pozzolanic materials shown in this paper are traditional (lime and cement), industrial or byproduct (blast furnace slag, fly ash, silica fume), ashes of agricultural wastes (rice husk ash, sugarcane straw ash, egg ash, coconut husk ash), and calcined-clay (metakaolin). These materials have been reviewed and discussed and concluding the following points:

- Using the pozzolanic materials to stabilize the expansive soil is very important for improving the soil properties and, are cost-effective than other stabilization methods.
- The use of industrial or byproduct pozzolanic materials reduces the consumption of traditional additives (i.e., cement and lime), where the last materials are of most importance in the field of construction materials
- There is a wide range for the percentages of pozzolanic materials used as stabilizers were (ranged from 1% to 100%), but the most effective contents occur in the range from 1.5% to 30%. Also, the content of 15% is the most ratio of the stabilizers used as

an optimal percentage, and beyond this ratio, the addition of the pozzolanic materials produces an undesirable effect. However-type of the stabilizer used also depends on the area of the work and the availability of the stabilizer.

- In general, the stabilization of expansive soils with pozzolanic materials produces improvements, to different degrees, in the soils' geotechnical properties (it has an important impact on swelling and Atterberg-limits and has a positive effect on compaction and strength parameters.

NOMENCLATURE

MDD= maximum dry density.
CBR= California bearing ratio
OES = organic expansive soil
RHA = rice husk ash
SCSA= sugar cane straw ash.
UCT = unconfined compression test.

REFERENCES

- Abba, H.A., and Abubakar, M.H., 2019. Evaluating the strength characteristics of metakaolin modified black cotton soil from demsa Kaduna Polytechnic, NIGERIA, Modibbo Adama University of Technology, Yola. *NIGERIA Journal of Applied Geoscience and Built Environment, 1(2),* pp., 1-5.

- Ahmed, M.D. and Hamza, N.A., 2015. Effect of metakaolin on the geotechnical properties of expansive soil. *Journal of Engineering, 21 (12).*

- Al-Baidhani, A.F., and Al-Taie, A.J., 2019. Review of brick waste in expansive soil stabilization and other civil engineering applications. *Journal of Geotechnical Studies, 4(3),* pp., 14-23.

- Al-Baidhani, A.F., and Al-Taie, A.J., 2020. Recycled crushed ceramic rubble for improving high expansive soil. *Transportation Infrastructure Geotechnology*, 7, pp., 426–44. https://doi.org/10.1007/s40515-020-00120-z

- Al-Dulaimy, A.A., 2003. Treatment of expansive clayey soil with fly- ash. M.Sc. Thesis, Civil Engineering department, Baghdad University, Iraq.

- Alhassan, M., 2008. Potentials of rice husk ash for soil stabilization. *AUJ.T., 11(4).* pp., 246-50.

- Al-Naje, F.Q., Abed, A.H. and Al-Taie, A.J., 2020. A review of sustainable materials to improve geotechnical properties of soils. *Al-Nahrain Journal for Engineering Sciences, 23(3)*, pp., 289-305. https://doi.org/10.29194/NJES.23030289.

- Al-Naje, F.Q., Abed, A.H. and Al-Taie, A.J., 2020. Improve geotechnical properties of soils using industrial wastes: A review. *Civil Engineering Beyond Limits, 4*, pp., 28-34.

- Al-Naje, F.Q., Abed, A.H. and Al-Taie, A.J., 2021. Compaction characteristics of natural cohesive subgrade soil stabilized with local sustainable materials. *IOP Conference Series Materials Science and Engineering, 1105*.

- Al-Rawas, A.A., Hago, A.W., and AlSarmi, H., 2005. Effect of lime, cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman. *Building and Environment, 40(5),* pp., 681-87. http://dx.doi.org/10.1016/j.buildenv.2004.08.028

- Al-Taie, A.J., 2002. Properties and behavior of dune sands as a construction material. M.Sc. Thesis, University of Baghdad, Iraq.

- Al-Taie, A,J., and Al-Shakarchi, Y.J., 2016. *Dune Soils Of Mesopotamian Plain As Geotechnical Construction Material*. LAP LAMBERT Academic Publishing.

- Ampera, B. and Aydogmust, T., 2005. Recent experiences with cement and limestabilization of local typical poor cohesive soil. *Geotechnik-kolloquium Freiberg, 2,* pp., 121-44.

- Amu, O.O., Fajobi, A.B. and Afekhuai, S.O., 2005A. Stabilizing potential of cement and fly ash mixture on expansive clay soil. *Journal of Applied Sciences, 5(9),* pp.,1669-1673.

- Amu, O.O., Fajobi, A.B., and Oke, B.O., 2005 B. Effect of eggshell powder on the stabilizing potential of lime on an expansive clay soil. *Journal of Applied Sciences, 5,* pp., 1474-78.

- Baalbaki, O., and Blondin, J., 1994. International patent, method of slaking quick lime contained in ashes. *European Publication Nos: EP0511286 A1*.

- Barasa, P.K., Too, D., and Mulei, S.M., 2015. Stabilization of expansive clay using lime and sugarcane bagasse ash. *International Journal of Science and Research, 4(4),* pp., 1912-1915.

- Barazesh, A., Saba, H., Gharib, M., and Rad, M.Y., 2012, Laboratory investigation of the effect of eggshell powder on plasticity index in clay and expansive soils. *European Journal of Experimental Biology, 2(6),* pp., 2378-84.

- Basha, E.A., Hashim, R. and Muntohar, A.S., 2003. Effect of the cement- rice husk ash on the plasticity and compaction of soil. *Electronic Journal of Geotechnical Engineering, 8 (A).*

- Bose, B., 2012. Geo engineering properties of expansive soil stabilized with fly ash. *Electronic Journal of Geotechnical Engineering, 17.1,* pp., 1339-1353.

- Chakraborty, A, Borah, A., and Sharmah, D., 2016. Stabilization of expansive soil using sugarcane straw. *Journal of Engineering Technology*, 4 (1).

- Cokca, E., 2001. Use of class C Fly ashes for the stabilisation of an expansive soil. *Journal of Geotechnical and Geoenvironmental Engineering, 127(7),* pp., 568-73.

- Cokca, E., Yazici, V. and Ozaydin, V., 2009. Stabilisation of expansive clays using granulated blast furnace slag (GBFS) and GBFS-cement. *Geotechnical and Geological Engineering, 27(4),* pp., 489-499.

- Fredlund, D., 2006. Unsaturated soil mechanics in engineering practice. *Journal of Geotechnical and Geoenvironmental Engineering, 132(3),* pp., 286-321.

- Gopalakrishna, Y.S.S., Padmavathi, M. and Prashanth Kumar, K.S., 2013. Stabilizati- on of black cotton soil treated with fly ash and zycosoil, *International Journal of Civil Engineering and Building Materials, 3(3),* pp., 133-44.

- Gourley, C.S., Newill, D., and Shreiner, H.D., 1993. Expansive soils: TRL's research strategy. *Proceedings of 1st International Symposium on Engineering Characteristics of Arid Soils*.

- Hasan, H.A., 2012. Effect of fly ash on geotechnical properties of expansive soil. *Journal of Engineering and Sustainable Development, 16(2),* pp., 306-316.

- Hussein, A, Ali, A., and Al-Taie, A.J., 2019. A review on stabilization of expansive soil using different methods. *Journal of Geotechnical Engineering, 6(3),* pp., 32-40.

- Hussein, A, Ali, A. and Al-Taie, A.J., 2021. Some geotechnical properties of plastic soil enhanced with cement dust, *Journal of Engineering, 27(10),* https://doi.org/10.31026/j.eng.2021.10.02
- .

- Ikeagwuani, C.C., Nwoji, C.U. and Okonkwo, C., 2015. Compressibility characteristics of lateritic soil admixed with coconut husk ash and lime. *International Journal of Engineering Research and Technology, 4 (2),* pp., 31-39.

- Ikeagwuani, C.C., Nwonu, D.C., Eze, C., and Onuoha, I., 2017. Investigation of shear strength parameters and effect of different compactive effort on lateritic soil stabilized with coconut husk ash and lime. *Nigerian Journal of Technology, 36(4).*

- Ismaiel, H.A.H., 2004. Treatment and improvement of the geotechnical properties of soft fine grained soils using chemical stabilization. Ph.D. thesis, Mathematisch-Naturwissenschaftlich-Technischen Fakultät der Martin-Luther-Universität Halle-Wittenberg, Germany. Shaker verlag.

- Jones, L.D., and Jefferson, I., 2012. *Expansive Soils.* In ICE Manual of Geotechnical Engineering., edited by J. Burland, 413-441. London, UK: ICE Publishing

- Kalkan, E., and Akbulut, S., 2004. Positive effects of silica fume on the permeability, swelling pressure and compressive strength of natural clay liners. *Engineering Geology, 73,* pp., 145-56.

- Karunarathne, A.M.A.N., Gad, E.F., and Sivanerupan, S., 2012. Review of residential footing design on expansive soil. *2nd Australasian Conference on the Mechanics of Structures and Materials (ACMSM22).*

- Khademi, F., and Budiman, J., 2016. Expansive soil: causes and treatments J-manager's. *Journal on Civil Engineering. 6(3),* pp., 1−13.

- Kharade, A.S., Suryavanshi, V.V., Guja,r B.S. and Deshmukh, R.R., 2014. Waste product bagasse ash' from sugar industry can be used as stabilizing material for expansive soils. *International Journal of Research in Engineering and Technology, 3(3),* pp., 506-512.

- Khatib, J.M., Baalbaki, O., and. El-Kordi, A.A., 2018. *Metakaolin*. Waste Suppl. Cem. Mater. Concr. Characterisation, Prop. Appl. 51–77. https://doi.org/10.1016/B978-0-08- 102156-9.00002-X

- Khemissa, M., and Mahamedi, A., 2014. Cement and lime mixture stabilization of an expansive overconsolidated clay. *Applied Clay Science, 95*, pp., 104-10. http://dx.doi.org/10.1016/j.clay.2014.03.017

- Kumar, M.M., and Tanilaransan, V.S., 2014. Effect of eggshell powder in the index and engineering properties of soil. *IJETT, 11(7)*, pp., 319-321. https://doi.org/10.14445/22315381/ijett-v11p261.

- McCarthy, M.J., and Dyer, T.D., 2019. *Pozzolanas And Pozzolanic Materials, In Lea's Chemistry Of Cement And Concrete*. (Fifth Edition), 363-467. https://doi.org/10.1016/B978-0-08-100773-0.00009-5

- Mujtaba, H., Aziz, A., Farooq, K., Sivakugan, N., and Das, B., 2019. Improvement in engineering properties of expansive soils using ground granulated blast furnace slag. *Journal of the Geological Society of India, 92(3)*, pp., 357–362.

- Muntohar, A.S., and Hantoro, G., 2000. Influence of rice husk ash and lime on engineering properties of a clayey subgrade. *Electronic Journal of Geotechnical engineering, 5.*

- Negi, C., Yadav, R.K., and Singhai, A.K., 2013. Effect of silica fume on index properties of black cotton soil. *International Journal of Scientific and Engineering Research, 4(8)*, pp., 828-832.

- Nelson, J.D., and Miller, D.J., 1992. *Expansive Soils Problems And Practice In Foundation And Pavement Engineering*, John Wiley and Sons, Inc.

- Nelson, J.D., Chao, K.C., Overton, D.D., and Nelson, E.J., 2015. *Foundation Engineering For Expansive Soils*: Wiley.

- Oluremi, J.R., Adedokun, S.I., and Osuolale, O.M., 2012. Stabilization of poor lateritic soils with coconut husk ash. *International Journal of Engineering Research and Technology, 1(8*).

- Ortega-López, V., Manso, J.M., Cuesta, I.I., and González, J.J., 2014. The longterm accelerated expansion of various ladle-furnace basic slags and their soil-stabilization applications. *Construction and Building Materials, 68*, pp., 455464.

- Osinubi, K.J., Ijimdiya, T.S., and Nmadu , I., 2009. Lime Stabilization of black cotton soil using bagasse ash as admixture. *Advanced Materials Research, 62-6*4, pp., 3-10.

- Ozer, M.R.U., and Nihat, S.I., 2012. Evaluation of damage to light structures erected on a fill material rich in expansive soil. *Bulletin of Engineering Geology and the Environment, 71(1*), pp., 21-36.

- Pandian, N.S., Krishna, K.C., and Sridharan, A., 2001. California bearing ratio behavior of soil/fly ash mixtures. *Journal of Testing and Evaluation, 29(2*), pp., 220–26.

- Paul, A., Anumol, V.S., Moideen, F., Jiksymol, K. J., and Abraham, A., 2014. Studies on improvement of clayey soil using egg shell powder and quarry dust. *Int. Journal of Engineering Research and Applications 4(4).*

- Prakash, N., Gokulnath, S., Ramkumar, M., Vasudevan, R., and Sakthiganesh, M ., 2018. Stabilization of expansive soil using metakaolin and granite powder. *International Journal of Civil and Structural Engineering Research, 6(1),* pp., 13-17.

- Ramkrishna, A.N., and Pradeepkuma, A.V., 2006. Stabilization of black cotton soil using rice husk ash and cement. *Proceedings of National conference, Civil Engineering meeting the challenges of Tomorrow 215-20.*

- Rao, B.V., Kumari, K.P., and Kumar, N.D., 2018. Geotechnical characteristics of expansive soil blended with lime, calcium chloride and fly ash: an experimental comparative evaluation. *International Journal of Civil Engineering and Technology, 9(10)*, pp., 517–23.

- Rao, D.K., Pranav, P.R.T., and Anusha, M., 2011. Stabilisation of expansive soil using rice husk ash, lime and gypsum- an experimental study. *International Journal of Engineering Science and Techology, 3(11),* pp., 8076-85.

- Ray, P., Paul, A., and Ghosh, S., 2020. An experimental study on fly ash with lime and gypsum for quality improvement in pavement subgrade materials. *SN Appl. Sci., 2*, pp., 1991- 2005. https://doi.org/10.1007/s42452-020-03852-2

- Reddy, T.S., and Prasad, D.S.V., 2017. Stabilization of soil using sugarcane straw ash and polypropylene fibers. *International Journal of Engineering and Applied Sciences, 4(6).*

- Sabat, A.K., 2013. Engineering properties of an expansive soil stabilized with rice husk ash and lime sludge International. *Journal of Engineering and Technology, 5(6),* pp., 4826-4833.

- Salahudeen, A.B., Eberemu, A.O., and Osinubi, K.J., 2014. Assessment of cement kiln dust treated expansive soil for the construction of flexible pavement. *Geotechnical and Geological Engineering, 32(4),* pp., 923-31.

- Saride, S., Puppala, A.J., and Chikyala, S.R., 2013. Swell-shrink and strength behaviors of lime and cement stabilized expansive organic clays. *Applied Clay Science, 85*, pp., 39-45. http://dx.doi.org/10.1016/j.clay.2013.09.008.

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

- Tsado, T.Y., Yewa, M., Yaman, S., and Yewa, F., 2014. Comparative analysis of properties of some artificial pozzolana in concrete production. *International Journal of Engineering and Technology, 4(5).*

- Venkateswarlu D., Anjan Kumar M., Prasada Raju G.V.R., and Dayakar Babu R., 2021. Load–Settlement Behavior of Soft Marine Clay Treated with Metakaolin and Calcium Chloride. In: Latha Gali M., Raghuveer Rao P. (eds) Problematic Soils and Geoenvironmental Concerns. *Lecture Notes in Civil Engineering, 88*. https://doi.org/10.1007/978-981-15-6237-2_32

- Vysakh, P., and Bindu, J., 2012. Stabilisation of lateritic soil using coconut shell, leaf and husk ash. *International Conference on Green Technologies (ICGT*), Trivandrum, India. https://doi.org/10.1109/ICGT.2012.6477985

- Yadu, L., and Tripathi, R.K., 2013. Effects of granulated blast furnace slag in the engineering behaviour of stabilized soft soil. *Procedia Engineering*, *51*, pp., 125-31. http://dx.doi.org/10.1016/j.proeng.2013.01.019.

- Yusuf, I.T., and Zava, A.E., 2019. Investigating the suitability of coconut husk ash as a road soil stabilizer. *International Journal of Technology, 10(1),* pp., 27-35.