IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Mathematical Modelling of Engineering Problems
Vol. 10, No. 3, June, 2023, pp. 1047-1052
Journal homepage: http://iieta.org/journals/mmep

Evaluating the Efficacy of Calcined Waste Products as Soil Stabilizers

Yahya K. Atemimi[1], Maki J. M. Al-Waily[2*], Alyaa. A. K. Ameri[1]

[1] Department of Civil Engineering, College of Engineering, University of Babylon, Babylon 51001, Iraq
[2] Technical College of Al-Musaib, Al-Furat Al-Awsat Technical University, Babylon 51001, Iraq

Corresponding Author Email: maki_jafar@atu.edu.iq

https://doi.org/10.18280/mmep.100340

Received: 28 September 2022
Accepted: 19 December 2022

Keywords:
fly ash, pozzolanic, west materials, recycled materials

ABSTRACT

With many prime construction sites already developed, less desirable locations with poor soil conditions are increasingly being considered for future projects. Soil enhancement techniques enable construction in areas previously deemed unsuitable and allow for the modification of existing soils to achieve desired engineering properties. Moreover, the reuse of waste materials and industrial byproducts can help conserve valuable natural resources. This study investigates the potential of calcined agricultural and industrial waste products, namely cardboard, dry-date kernels, and rice husks, as soil stabilizers. The waste materials were calcined at three different temperatures (500, 700, and 900°C) and for three distinct durations (1, 2, and 4 hours). The ASTM C618 standard recommends conducting XRD and XRF chemical tests to determine the oxide content of the resulting fly ashes. Notable oxides included SiO_2, Al_2O_3, and FeO_2, with rice husks serving as a control byproduct material. The combustion of cardboard and dry-date kernels yielded over 60% of the measured oxides. Optimal combustion efficiency was achieved for cardboard and dry-date kernels at 500°C for four hours, while rice husks exhibited optimal combustion at 900°C for two hours. The oxide percentages resulting from the combustion of cardboard and dry-date kernels were close to 60%, aligning with the ASTM C618 and AASHTO M295 classifications for class C fly ash. In contrast, rice husks demonstrated high oxide concentrations, accounting for more than 95% of the total raw material.

1. INTRODUCTION

Clayey soils exhibit problematic behavior when water content increases above the optimum level, leading to low shear strength, low bearing capacity, high permeability, and significant volume change and surface area. These characteristics result in high liquid limit and plasticity index, rendering such soils unsuitable for construction sites [1]. One solution to utilize weak soils for construction purposes is their improvement to enhance strength, permeability, and durability [2]. Lime has traditionally been used for this purpose, but its availability is limited in some regions. Consequently, researchers have begun investigating alternative products, such as ashes [3].

ASTM C618 and AASHTO M295 classify fly ash based on the sum of SiO_2, Al_2O_3, and Fe_2O_3 percentages in the ash mixture into two classes: F and C. Benefits of fly ash addition include improved workability, resistance to alkali-aggregate reaction, reduced heat of hydration, permeability, drying shrinkage, and creep. Fly ash also provides resistance to sulfate attack and offers effective carbonation and corrosion protection with appropriate curing [4].

The production of modern agriculture, industrial, and construction wastes has increased, resulting in costly treatment demands and varying pozzolanic and calcium contents. Some researchers have explored the potential of class F fly ash to stabilize clayey soils without sulfates [5]. Studies have demonstrated the value of agricultural waste products as an alternative to conventional soil improvement materials, reducing waste and environmental pollution [6-8]. Examples of such materials include rice husk ash, locust bean waste ash, palm oil fuel ash, banana leaf, bagasse, coconut shell, bamboo leaves, corn cobs, cassava peels, and palm kernel shells, which can improve the engineering properties of soil particles [9].

Rice husk ash (RHA) has been shown to significantly increase the unconfined compressive strength (UCS) of clayey soils when burned at controlled temperatures [10]. The addition of cement, lime, and rice husk ash (CLR) has been observed to reduce soil plasticity and enhance compaction [11]. Furthermore, incorporating 10% date nuclei powder (DNP) into clayey soil can improve its shear strength [12]. The growing volume of solid waste in urban areas necessitates the development of integrated municipal solid waste management (IMCD) systems [13]. The use of agricultural and industrial waste as supplemental cementitious material (SCM) presents a practical alternative to Portland cement, an energy-intensive product with a substantial carbon footprint [14]. Metakaolin (MK) is another effective pozzolan that can be used as partial cement replacement material in the construction industry [15]. The optimal temperature for producing MK with a high pozzolanic index varies between 600 and 850°C for 1-12 hours [16]. Burned date palm seeds powder as ash (DSPB) has been found to be more effective than date palm seeds powder (DSP) in improving kaolinite clay soils, with curing time playing a critical role [17]. The bearing capacity ratio can be significantly increased by installing a reclaimed asphalt pavement (RAP) material trench below the surface [18].

Researchers have studied various materials to improve soil properties while reducing overall project costs. Approaches to improve clayey soils include increasing particle size through agglomeration and flocculation, reducing the liquid limit by decreasing surface area, and reducing compressibility and increasing permeability to shorten consolidation time [19]. The addition of biomedical waste incinerator ash (BWIA) has been shown to significantly increase the UCS and CBR of soil while reducing the free-swell index due to the formation of flocculated structures [20].

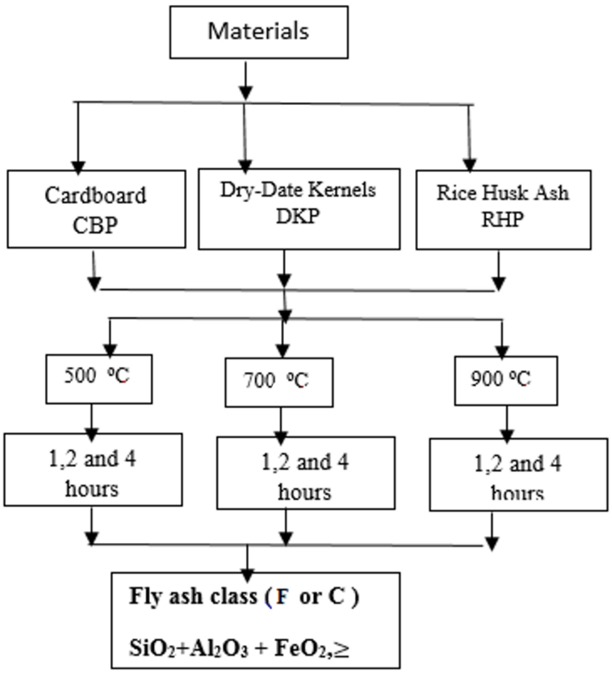

Figure 1. Flow chart of the experimental program

The present study investigates the potential use of three locally sourced industrial waste materials—dry date cores, rice husks, and cardboard fragments—as additives to improve the properties of problematic soils. These materials are subjected to various burning temperatures and durations to obtain oxides that can be used as additives for soil improvement. Through this approach, the study aims to reduce environmental pollution caused by waste materials, decrease soil treatment costs, and enhance the properties of problematic soils. Figure 1 illustrates the experimental program employed in this investigation.

2. METHODOLOGY

The present work used three raw materials burned at different temperatures (500°C, 700°C, and 900°C) with three other burning times (1, 2, and 4 hours) as shown in Figure 1 and plate 1. The literature and the trial and error approach [10, 18] were employed to establish the suitable temperature and time duration.

2.1 Pozzolanic materials

In this part, RHA was employed as reference material because of its extensive history of use in geotechnical applications [9]. Carton (cardboard) waste from the industrial sector and a dry- date cores from an agricultural product were used in this experiment. Both used resources were highly valued in the local market, and the free (and extremely cheap) commodities required mobilization expenses.

(a) Cardboard pieces (CBP)

(b) Dry- date cores pieces (DKP)

(c) Rice husks Ash (RHA)

Plate 1. Images describing burning of the three-raw materials

2.2 Preparation of pozzolanic materials

The following steps represent a summary of the practical part of the current study to obtain pozzolanic material from particular wastes that can be used later as an improved material for soft soils after incineration operations are carried out on them in different periods. Three specific raw materials were brought as industrial wastes, one of which was cardboard which is used in furniture packaging because it is a significant volume. Two agricultural residues, one of which is dry date cores and the other were rice husks from private factories in Hilla's industrial area (the center of the government of Babylon and located to the south of Baghdad, a distance of 100 km).

Samples preparation was conducted as follows:

(1) The large pieces of cardboard were obtained from furniture stores and cut into small chunks before being burned at various temperatures (500℃, 700℃, and 900℃) and for multiple periods, 1, 2, and 4 hours. This model was given symbols beginning with (CBP- cardboard pieces) in an incinerator to create a pozzolanic material that can be utilized to improve and stabilize soft clay soils.

(2) The dry- date cores were collected as industrial waste from molasses manufacturers in Hilla's south. It was cleaned carefully to remove impurities and dry for two hours with hot air before being crushed into tiny bits by crushed stone. The little bits were then pulverized into powder using a special grinder. The burning took place at the same temperatures and for the same time periods as in the cardboard. The models were encoded with symbols beginning with (DKP- dry date cores pieces) for all models, considering the temperature and period.

(3) The rice husks were gathered from rice mills in Hilla's industrial region. The husks were recognized as byproducts of rice manufacturing that are discarded as undesired waste and produce environmental problems that require enormous sums of money to dispose of. It was also utilized as a standard material with cardboard and dry- date cores, as it had been previously and widely used in enhancing soil qualities. This material was burned using the same manner as the previous two materials, at the same temperatures and for the same time periods. The models were given symbols (RHP).

After all of the models mentioned earlier have been incinerated, they were left to cool, and markers were placed on them to indicate burning temperature, and a period for burning, after which the models were transferred to the laboratory to undergo chemical tests to determine the proportions of chemical compounds in the mixture, and then classify the models based on the results, as shown in the results section.

3. RESULTS AND DISCUSSION

In the German laboratory, 34 tests were performed to examine oxides for expert XRF spectrometers for elemental composition analysis in the Department of Earth Sciences at the College of Science at the University of Baghdad.

According to the results that are presented in Figure 2, each amount of oxides produced by burning cardboard pieces used in furniture packaging (CBP) at temperatures between 500 and 900℃, and it was around 40%. Compared to the percentage of oxides produced by burning the raw materials at the two preceding temperatures, the amount paid by burning this material at 700℃ was roughly 25% lower and equal to 29%. On the other hand it was found that the proportion of oxides increased somewhat when the raw material was burned at temperatures of 700℃ and 900℃ for two or four hours. Even when burning was conducted at 500℃ for four hours, oxides increased by 50% from the first hour of burning.

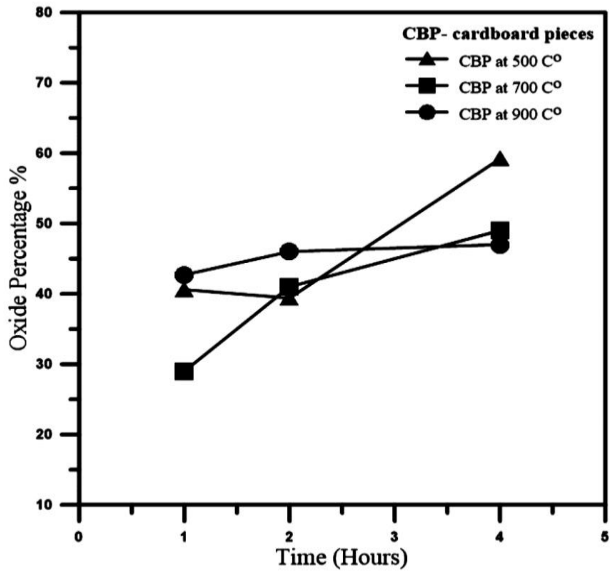

Figure 2. Oxides percentages versus time of the burning of CBP

As illustrated in Figure 3, the burning temperature and oxide content of cardboard cut material (CBP) are inversely related at four hours burning while in two hours exhibited increase amount of oxide, on the other hand at one hour the relationship not clear due to few oxides were generated and formation not completed yet. According to the graph, the highest concentration of oxides was created after four hours of burning at 500℃, followed by the other temperatures. When CBP was burned at 700 and 900℃ for the same four-hour period as mentioned previously, the percentage of oxides produced was dramatically reduced. There was a significant increase in the rate of oxides formation with increase in burning temperature for 1 and 2 hours. Nonetheless, this proportion increased marginally when burning time was raised to four hours, and all burning degrees were used. Except for a few slight variations, plate 1 illustrates comparable burning picture. The results refer to the product obtained was fly ash class C. This type of fly ash (class C) can be used as a cementation materials to improve the strength characteristics of clays, especially the soft and expansive. Soils after improved can be used in different projects as embankments, highways, control shrink-swell properties of expansive soil and reduction the moisture content in compaction application at soil depth reach to 30cm [21].

From the results of oxide percentage versus time of the burning of (DKP) that are presented in Figure 4, it can be seen that, formation of most oxides was increased over time while burning the dry-date corns pieces (DKP) material. For all searing temperatures, the 500℃ degree is better than the other burning degrees due to it gives the percentage of oxides (46, 51.5, and 61) for 1, 2, and 4 hours, respectively. On the other hand, the four-hour interval produced 40% more oxides at the same burning temperature of 500℃ than the first hour. When burning at 500 and 900ºC temperatures, a quarter of an hour produced the maximum percentage of oxides. It was found that the growth in oxides at 500℃ was 200% greater than that at 900℃ when comparing the two different burning temperatures just by comparing their percentages. It is not suggested to use 700℃ when the burning period increases because of the decrease in the percentage of oxides noticed.

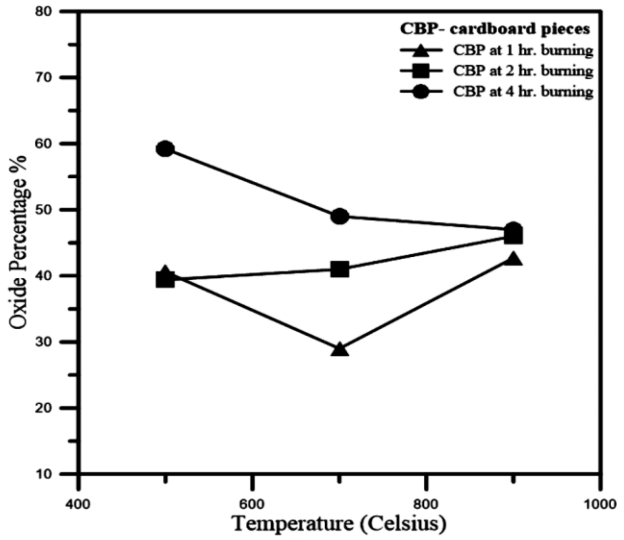

Figure 3. Oxides percentages versus temperature of the burning of CBP

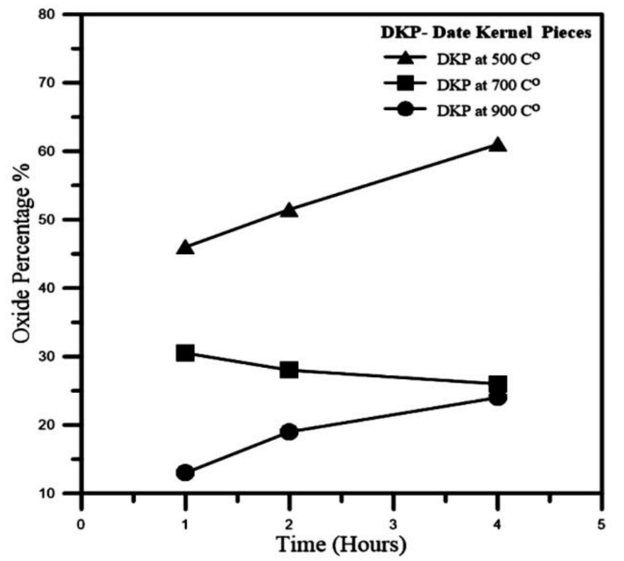

Figure 4. Oxides percentages versus time of the burning of DKP

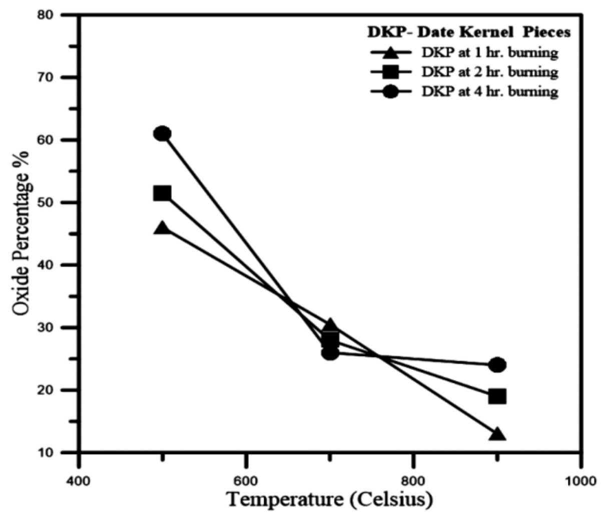

Figure 5. Oxides percentages versus temperature of the burning of DKP

When the dry-date cores pieces (DKP) were burned for four hours, the most significant percentage of oxides was observed at a burning temperature of 500°C, and these oxides were at their highest after four hours of burning. At 500°C, 700°C, and 900°C, the percentage of oxides for (DKP) reached (51.5, 28, and 26) after two hours of burning. When the burn period is prolonged to four hours, these percentages become (61, 26, and 24), (Figure 5). The results showed the product was fly ash class C due to oxide percentages more than 50% from raw materials used [4]. Due to these results obtained from previous section can be refer to the fly ash class C which used as a stabilizer and water adsorption to reduce the surface area of clay by agglomeration of clay particles and decrease the ability of expansion with increase permeability [21, 22].

From the results that are shown in Figures 6 and 7, it is clear that, the highest percentage of oxides occurred during combustion (RHP-rice husk ash pieces). The same temperatures as the preceding ones (500°C, 700°C, and 900°C) when compared to the oxides formed during the combustion of cardboard and dry-date cores. After four hours and at all burning temperatures, these oxides achieved their maximum concentrations. Additionally, as illustrated in Figure 4, burning at 900°C resulted in the greatest results for all burning hours. After two hours, the highest percentage of oxides was observed. Extending the burn time beyond two hours at 900°C resulted in a minor rise that could be termed uneconomic. According to prior findings, the optimal temperature for producing a high proportion of oxides from RHP is 900°C, with a two-hour burn time. Additionally, burning at temperatures of 700°C and 900°C produced comparable results when the duration of the burn was one hour or four hours. Whereas the percentage of oxides was (77.8% and 77.3%) after one hour of burning at these temperatures, it climbed to (95% and 98%) after four hours of burning. From these results fly ash class F obtained which can be recommended used the RHP in all clay types as soft and expansive due to increase shear strength, bearing capacity, permeability which reduce consolidation time and reduce liquid limit because surface area decrease and particle size increase [10, 23]. Nalbantoğlu [24] studied the relation between temperature degrees and calcination to product the pozzolanic materials. They concluded the weight of mixture reduced after 500°C and the activity of pozzolanic depend on type of ash. On the other hand, these researchers studied the duration of burning and found two hours is better [24, 25].

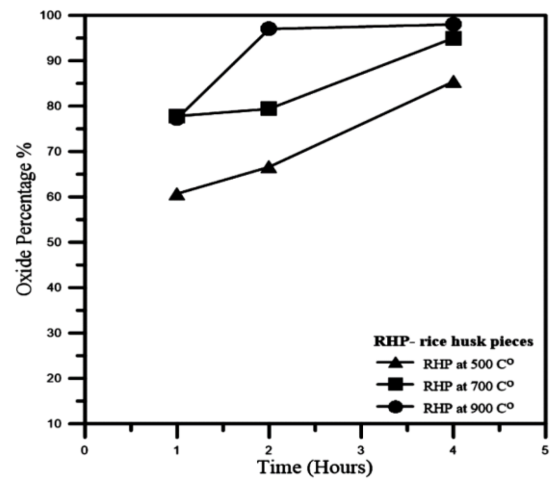

Figure 6. Oxides percentages versus time of the burning of RHP

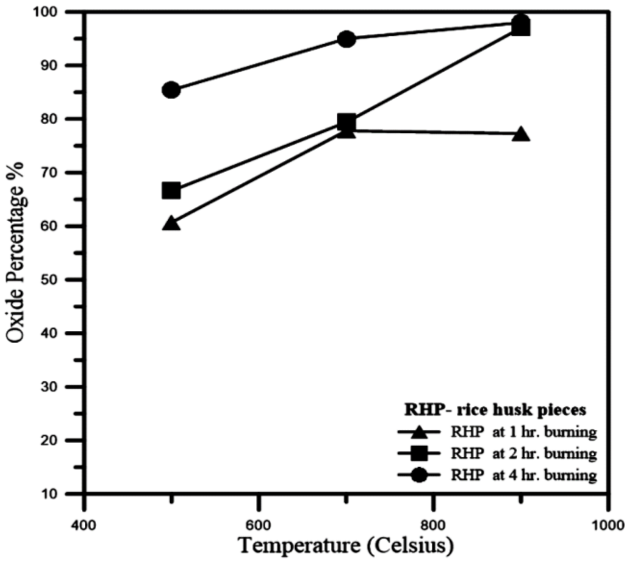

Figure 7. Oxides percentages versus temperature of the burning of RHP

4. CONCLUSIONS

From the obtained results in this study, it can be concluded that, Using the burning method for three local raw materials considered industrial or agricultural waste, namely cardboard and dry-date cores for four hours, it has been recommended to use 500°C for the burning degree required, which saves much money due to the low burning degree required. The rice husks were burned at 900°C for two hours only, which is both economical and efficient because it reduces the amount of time spent burning. Also, the percentage of oxides produced by the combustion of cardboard and dry-date cores were close to 60% and is categorized as fly ash class C by ASTM C618 and AASHTO M295 standards. Oxides were present in high concentrations in rice husks, with more than 95% of the total. This material is Fly Ash class F. The preceding two varieties (class C and F) can be employed in soil stabilization and improvement while meeting the requirements for usage.

REFERENCES

[1] Kang, X., Kang, G.C., Chang, K.T., Ge, L. (2015). Chemically stabilized soft clays for road-base construction. Journal of Materials in Civil Engineering, 27(7): 04014199. http://dx.doi.org/10.1061/(ASCE)MT.1943-5533.0001156

[2] Garzón, E., Cano, M., O'Kelly, B.C., Sánchez-Soto, P.J. (2015). Phyllite clay–cement composites having improved engineering properties and material applications. Applied Clay Science, 114: 229-233. http://dx.doi.org/10.1016/j.clay.2015.06.006

[3] Patel, M.A., Patel, H.S. (2012). A review on effects of stabilizing agents for stabilization of weak soil. Civil and Environmental Research, 2(6): 1-7.

[4] ASTM. (2014). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete designation: C618 − 12a" ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States, pp. 1-5. http://dx.doi.org/10.1520/C0618-22

[5] Adhikary, S., Jana, K. (2016). Potentials of rice husk ash as a soil stabilizer. International Journal of Latest Research in Engineering and Technology, 2(2): 40-42.

[6] Kosmatka, S.H., Panarese, W.C., Kerkhoff, B. (2002). Design and Control of Concrete Mixtures, vol. 5420, pp. 60077-1083. Skokie, IL: Portland Cement Association.

[7] Adisa, O.K. (2013). Economy of RHA (Rice husk ash) in concrete for low-cost housing delivery in Nigeria. Journal of Civil Engineering and Architecture, 7(11): 1464. http://dx.doi.org/10.17265/1934-7359/2013.11.013

[8] Ako, T., Yusuf, I. (2016). Effect of palm kernel shell ash on compaction characteristics of a lateritic soil webs. Journal of Science and Engineering Application, 5(1): 449-45.

[9] Motorola Semiconductor Data Manual. (1989). Motorola Semiconductor Products Inc., Phoenix, USA. https://www.researchgate.net/publication/318209325.

[10] Abdulsattar, Z.M. (2015). Soil stabilization with rice husk ash and cement. Infrastructure University Kuala Lumpur, 65. http://dx.doi.org/10.13140/RG.2.1.4334.4243

[11] Ishola, K., Olawuyi, O.A., Bello, A.A., Etim, R.K., Yohanna, P., Sani, J.E. (2019). Review of agricultural waste utilization as improvement additives for residual tropical soils. Arid Zone Journal of Engineering, Technology and Environment, 15(3): 733-749. https://azojete.com.ng/index.php/azojete/article/view/56.

[12] Adhikary, S., Jana, K. (2016). Potentials of rice husk ash as a soil stabilizer. International Journal of Latest Research in Engineering and Technology, 2(2): 40-42.

[13] Bagheri, Y., Atemimi, Y.K., Ahmad, F., Ismail, M.A. (2013). Soil Strength improvement by using a new compound stabilizer. Caspian Journal of Applied Sciences Research, 2: 84-90.

[14] Atemimi, Y.K., Fahad, A.T. (2017). Effect of dates nucleus powder on some engineering properties of clayey soil in comparison to lime. Al-Qadisiyah Journal for Engineering Sciences, 10(4): 516-524. http://dx.doi.org/10.30772/qjes.v10i4.501

[15] Mustafa, A.S., Mohsin, A.A., Ali, L.N. (2018). Management of municipal solid waste in Baghdad, Iraq. International Journal of Environmental and Ecological Engineering, 11(7): 700-704. http://dx.doi.org/10.5281/zenodo.1316235

[16] Aprianti, E. (2017). Many artificial waste materials can be supplementary cementitious material (SCM) for concrete production–A review part II. Journal of Cleaner Production, 142: 4178-4194. https://doi.org/10.1016/j.jclepro.2015.12.115

[17] Sabir, B.B., Wild, S., Bai, J. (2001). Metakaolin and calcined clays as pozzolans for concrete: A review. Cement and Concrete Composites, 23(6): 441-454. https://doi.org/10.1016/S0958-9465(00)00092-5

[18] Rashad, A.M. (2013). Metakaolin as cementitious material: History, scours, production and composition–A comprehensive overview. Construction and Building Materials, 41: 303-318. https://doi.org/10.1016/j.conbuildmat.2012.12.001

[19] Atemimi, Y.K., Saeed, K.A. (2016). Study the effect of date seed powder on the strength of kaolinite clay soil. Muthanna Journal of Engineering and Technology (MJET), 4(2).

[20] Al-Waily, M.J.M., Al-Qaisi, M.S. (2022). Evaluation of RAP engineering characteristics in layered soil. Journal of Rehabilitation in Civil Engineering, 10(1): 21-32. https://doi.org/10.22075/jrce.2021.24176.1536
[21] Al-Waily, M.J. (2019). Effect of mixing granular materials on soft soil properties. In 2019 4th Scientific International Conference Najaf (SICN), pp. 172-177. https://doi.org/10.1109/SICN47020.2019.9019337
[22] Tseganeh, A.B., Geberegziabher, H.F., Chala, A.T. (2021). Stabilization of expansive soil using biomedical waste incinerator ash. Journal of Management Science & Engineering Research, 4(2): 49-58. https://doi.org/https://doi.org/10.30564/jmser.v4i2.3707
[23] Senapati, M.R. (2015). Fly ash from thermal power plants – Waste management and overview. International Journal for Scientific Research & Development, 100(12): 1791-1794. https://www.jstor.org/stable/24077549.
[24] Nalbantoğlu, Z. (2004). Effectiveness of class C fly ash as an expansive soil stabilizer. Construction and Building Materials, 18(6), 377-381. https://doi.org/10.1016/j.conbuildmat.2004.03.011
[25] Breesem, K.M., Faris, F.G., Abidin, R.Z., Yusof, N., Abidin, M.R.Z., Dom, N.M., Jassam S.H., Abdel-Magid, I.M. (2015). Influence of calcination temperatures on microstructures of alum sludge and its pozzolanic properties. Australian Journal of Basic and Applied Sciences, 9(28): 181-188.

NOMENCLATURE

CBP	Card board pieces
DKP	Dry date cores pieces
RHP	Rice husks pieces