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A Review of the Status of Scientific Research and Practical Techniques Related to Using Cement Kiln Dust to Stabilize Weak Soils

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ABSTRACT

Urban expansion and industrial clusters have increased significantly, which requires unremitting efforts to dispose of solid waste for these activities, which create growing and dangerous environmental problems. Therefore, many companies and organizations have invented modern technology to deal with such problems. CKD is one of the widely used materials in soil stabilization, it also represents a significant cost-effective alternatives, where the conventional style of cementitious stabilizers (lime and cement) have adverse environmental effects throughout its production as well as high cost. This review summarized the new trends of both scientists and researchers about their attempt to find the ways to reuse and recycle these solid wastes in the industries again. From these solid waste, the CKD, which is producing as a by-products from the cement industry. In recent time, researchers began to investigate the using of such materials as chemical additives to pavement foundations for the purposes of subgrade construction failure prevention. These materials could be used as soil stabilizers. CKD has a good cementations property.

Key words*:* Weak Soil, Geotechnical Properties, Waste Dust, Soil Stabilization, Stabilization Mechanism.

Abbreviations: CKD, cement kiln dust. C–S–H, calcium-silicate-hydrate. C–A–H, calcium-aluminum-hydrate. $CaCO_3$, calcium carbonate. CaO, free lime. PR, Pozzolanic reaction. Ca $(OH)_2$, Calcium hydroxide. PI, Plasticity index. CBR, California bearing ratio. UCS, unconfined compressive strength.

1. INTRODUCTION

The construction process on the weak soil is a major risk. This is due to the poor shear resistance and high compressibility, low workability, high percent of water, which creates additional settlements. Therefore, the soil performance must be improved by using stabilization techniques to be able to resist the structural, environmental and subsequent geological conditions [1], [2]. It is necessary to know some of the important concepts in the process of soil stabilization as it is one of the important things facing engineers during the start of the first step in projects that are built on weak soil. In this part of the research, it includes a historical summary, the concept of soil stabilization, effective materials for stabilize the weak soils, stabilization mechanism, economic and environmental effects of CKD, and The Chemical Composition of CKD According to Completed Experimental Research.

2. BASIC NOTIONS RELATED TO SOIL STABILIZATION

2.1 Historical Summary of the Soil Stabilization:

Various methods of stabilizing weak soils and increasing their bearing capacity have been used for thousands of years [3]. Humans have used Cementous materials since the establishment of civilizations in many locations, and it is an ancient method of geotechnical engineering to strengthen weak soils by mixing them with these materials. The first use of soil stabilization dates back 5,000 years, where the idea of stabilizing the soil started by strengthening the road surface in ancient Mesopotamia and Egypt. Romans and Greeks added lime as a stabilizer to soil [4]. The ancient Babylonians used mud to construct a block for use in arches [5]. As the Sumerians used in bitumen as a material bonding to the walls because it gives a high permanence and strength. Ancient Egyptian civilization also developed ground technology to build earth dams that would protect them from flooding [6]. In ancient China, the sticky rice were used to make mortars that helped them build the Great Wall of China. In Europe, lime was used to make mortar. In 2459 BC, the Romans used volcanic ash and brick powder as an additive to lime mortar [7]. With the development and civil life, building materials have also evolved with them. Durability and strength have become as an essential goal. And with the discovery of Pozzolan materials, it also includes concrete (a mix of volcanic ash with a gypsum, added aggregates) known by the ancient Rome. With the start of the industrial revolution [8]. Portland cement was widely used in various construction projects, it was not limited to building only, but it went beyond it to stabilize the soil, hence the modern use of technologies in treating the soil with cement has start [6]. The first tests of soil stabilization was accomplished in the US in 1904, when Portland cement added were added to the weak soil of a road in Sarasota, Florida, in 1915, while lime was added for the first time in the expansion of road, to coincide with the increase in traffic in 1924[4]. Today, the use of lime and Portland cement is one of the most popular means of improving poor soil specifications [9]. The stabilization soil by means of nanotechnology is considered one of the modern methods that have been used in recent years, Among the nanocomposites used for soil stabilization, for example only, are nano-SiO_2, Nano Al_2O_3,carbon nanotube, nano-calcium carbonate, Nano MgO and nano-ZnO [10], [11].

2.2 The Concept of Soil Stabilization:

Soil in its general sense is the most abundant material on the Earth's surface [12]. Fast growing in modern infrastructure requires more land with good bearing specifications to withstand the stresses of higher buildings safely [13], [14]. The soil properties depend on the mineral content, soil water actions, water ground level, etc. These properties vary from place to place [15]. One of the important challenges that geotechnical engineer faces is to improve the weak-situ soil specifications so that it can withstand the loads satisfactorily. One of the general approaches used to improve soil specifications is stabilization soil [16], [17]. In this regard, a brief explanation can be given of the reason for the weak soil, clay is a mixture of a group of fine particles bound together under the influence of their weight to form networks. Each clay unite generates its individual contact forces (IPF) by the adjacent particle. IPF hold all the single units at their positions. Sudden entry of water to create pressure in the soil leads to loss of particle cohesion. In this case of loss of adhesion, the soil becomes weak and disjointed, and loses its dense feature. As a result the additional settlement, soil flow as a liquid and landslides of soil have occurred [18]. As for coarse soils permanently governed by mineralogical structure while a fine soils mostly effected by minerals characteristics in a big extent [19]. The concept of soil stabilization can be defined as the process in which the properties of weak soil are enhanced in order to accomplish its tasks as bases for the structural structure based on it [20], [21], [22].

The process of improving soil performance includes the geotechnical properties of weak site soils such as shear strength, load bearing capacity, soil permeability and durability, as a result, stabilized weak soils can be used in the construction of dams, roads, railways, embankments and high-rise projects [23]. Weak soil must be defined in this context. Expansive, Soft, Weak, or Poor soil are a common term with soil swelling-shrinkage problems occurs when water enters the soil particles, and when the water evaporates, or it comes out of the voids, the soil becomes dry, cracked. Because of this plasticity behavior of weak soil, damage take place to different elements of civil structures based on them. [24]. Weak soils are undesirable because of their low-shear strength of soil and high value of soil compressibility [25]. Another definition of soil stabilization is to increase the soil's bearing capacity to the limits permitted for construction [26], [20]. One of the definitions of soil stabilization is the modification of one or more properties of soil by mixing them with chemical additives, to produce a developed the soil behavior to the desired properties. Thus, the strengthening of the soil and its remaining in place for the process of building on it later is what is known as soil stabilization [27], [28]. Generally, Stabilized soils are complex soils, whose properties are improved by additives [29], [26]. Finally, the soil stabilization is an increase in its engineering characteristics (resistance, durability, bearing capacity, and hydraulic conductivity) when it exposed to wetting-drying cycle, in addition to environmental revitalization [6], [21]. It is a practical treatment for a weak soil to withstand or the proficiency of its durability or raise its efficiency as a good building material [30]. On the other hand, soil stabilization process can be faced some of limitations. Especially if soils contain chemicals that change and affect the cement and lime [31].

2.3 The Effective Materials for Stabilize the Weak Soils

There are two common and widespread methods of soil stabilization which are mechanical and chemical [32]. The mechanical improvement of the soil is the enhancement of the soil strength by physical means such as compact the soil to an acceptable degree, piles, consolidation, good water drainage, stone columns, and the application of an external weight [6] [33]. The chemical treatment is carried out by the chemical reaction between the added element and the original soil [34]. Among these added chemical compounds are cement, lime, lignin, asphalt, fly ash-C class, resin, asphalt, and polyvinyl acetate (PVA). calcium chloride, blast kiln slag, gypsum, and enzymatic stabilizer, rice husk residue as well as C-S-H which produces an industrial material through the interaction of hydration in weak soils, [35], [6], [24], [26], [29], [36].

These additives increase cohesion, shear resistance, permeability, compressive strength, durability, frictional angle, elasticity modulus, and the CBR [33]. The CBR test is achieved to estimation the bearing value of soil and it’s the mechanical strength [37].The two most common additions to soil stabilization are cement and lime, which are referred to as the old-style stabilizers [35], [38]. Studies show that the rate of effective addition of cement as a stabilizer ranges at 12% [23]. In any case, the stabilizer must fulfill the required specifications for good soil [39]. The global large increase in waste materials has required the usage of certain waste materials as unconventional stabilizers to increase the strength of weak soils. These waste materials can be industrialized waste, agricultural, and municipal solid waste, waste materials are used as standalone stabilizers in addition to cement or lime additives to enhance the performance of conventional additives [35], [40]. Soil stabilization with cement is a quick process, it is used for a wide type of soils. But, the best used of cement stabilizer have been detected on silt soil in addition to coarse aggregates, where adding cement to soil leads to increasing the compressive strength. [2], [41]. As for lime, it is the preferred technique to stabilize the plastic clays. Lime is not used in clay soil containing a high percentage of sulfites [42], [43]. Lime is an inorganic mineral that mainly contains calcium, where carbonates, hydroxides, oxides predominated [44] .As an alternative to cement and lime, biological methods are examined in the field of soil stabilization. This technique is based on microbial addition and by-product precipitation. Especially, microbial made polymers have been presented as a new category of construction stabilizer (binder), particularly for soil stabilization [6].

One of the industrial waste materials that is frequently used in soil stabilization is CKD, it is collected from the waste of cement factories as a by-product. It is accumulated into Electrostatic filters (an air well controlled system to capture small CKD particles) that are placed at the outlet of the cement kiln gases. Cement plants is produced an enormous collection of CKD [26]. CKD is a very smooth and divided material very similar in appearance and behavior to Portland cement. CKD is a cement material that has an effective adhesion to other materials and is used to treat specific types of soils, just like cement, which is used as an effective addition to increase shear resistance, change plasticity, and decrease swelling pressure of poor soils [24].

Generally, CKD is characterized by its heterogeneous nature in terms of the size of the particles and its chemical composition, due to several reasons, including origin raw materials, whole equipment arrangement, fuels, kiln heat treatment nature, and the type and specifications of cement to be manufactured. In modern cement plants, CKD is recycled back to the clinker making machines. However, there are strict restrictions on reuse due to the resulting alkaline nature. International standards limit the alkali ratio in Portland cement to maximum value of 0.6% by cement weight to avoid a total alkaline reaction [45].

As for the contact of CKD with a given soil depends on the physical and chemical properties of CKD [46]. Finally, the following is a simplified explanation of how CKD is produced as a by-product of the cement manufacturing process. Materials containing specific proportions of aluminum, lime, iron and silica are inserted into the upper kiln nozzle, after which the process of mixing different materials begins in the kiln that rotates at a constant speed, then the fuel burning process starts at the lower end of the kiln at 1400 ^{o}C, after which the mixed raw materials turn to a cement clinker. Through this process a percentage of the CKD is produced. The properties of CKD differ from factory to factory [47]. But most of CKD comprise silica, $CaCO3$, and CaO, it can also contain chlorides, alkali sulfates and additional secondary components [46] .On the other hand, the choice of the material to be added to the soil depends in particular on the surrounding field conditions and the type of soil in general [48]. It is necessary for the soil to be able to interact with additives to be able to stabilize the soil [49], [49].

2.4 Stabilization Mechanism

In this paragraph, the mechanism for soil stabilization will be explained in cement, lime or fly ash. The first stage is the connection of water with cement, then the first hydration process begins, and cementing mixes of C–S–H and C–A–H generates in the soil, and extra $Ca(OH)_2$ is released[50], [43]. Some of the calcium ions that were released early during mixing with water helped early in stabilize the clays. The previous mechanism are called cation exchange, this process is usually relatively quick, occur in a few hours, can be illustrated in Figure 1 [51]

The entire quantity of $Ca\ (OH)_2$ created from Portland cement is about 31% by total weight. Hydrate compounds assist to stabilize flocculated fine clay units through cementation process. The interactions of hydration and strength rises, completely occur from one to 28 days. In any case, the cement remains in a state of hydration, but at a declining rate, as long as there is moisture. [26].The calcium quantity reduced after 12 hours from adding the cement in the soil. Subsequently, water and calcium were finally reduced and Ca (OH)2 and C-S- H were produced [50]. The calcium helps the clay units to flocculate into a sand-like arrangement that decrease the soil plasticity, which is known as soil modification, reduces the shrinkage and swelling features of the soil [49], [52].

Flocculation process of clay is the transfer its arrangement from a flat and parallel unites to a more random positioning (edge-to-face), then agglomeration process follows as the flocculated units of clay, at this moment a weak connection starts forming at the external edge of clay particles due to the gathering of cementitious substantial at the interfaces of clay unit. The flocculation and agglomeration procedure is illustrated in Figure 2. Agglomeration procedure starts the creation of bigger unites from finely units of clay and further develops the clay texture. [51]. C-S-H and C-A-H (cementitious material) produce a complex system (network) and its function as a gummy that give strength and strength in a clay mixes modified with cement, cementitious hydration shown in Figure 3 [51]. The second stage of stabilization mechanism is PR, it assumes the binding of calcium ions with alumina and silica melted from the clay matrix to produce additional C-S-H and C-A-H [53]. Some studies have shown that PR may be occurred from relations between clay and Ca $(OH)_2$ because of a high degree of pH environment. [26], [51]. PR can be demonstrated as Figure 4.

2.5 Environmental Benefits of Using CKD

Urban expansion and industrial clusters have increased significantly, which requires unremitting efforts to dispose of solid waste for these activities, which create growing and dangerous environmental problems. Therefore, many companies and organizations have invented modern technology to deal with such problems [54]. Portland cement is one of the most widely used materials in civil engineering projects. Currently, using lime and cement is soil stabilization is not preferred because of an environmental issues [55]. Several studies interested in estimating the quantities of cement and global demand indicated that by 2050 the demand will reach 5 billion tons annually, which will constitute a real environmental threat to the natural resources and needed for the burning of raw materials [56]. In addition, the production of such industrial materials generates large amounts of carbon dioxide emissions (CO2), during the various stages of the process of burning materials and manufactured [9].

The cement manufacturing process consumes approximately 5,000 MJ per ton, which produces a CO2 emission of approximately 700–1100 Kg per ton of cement. [1]As indicated in the previous section previously. Cement production generates huge amounts of CKD, a big quantity of which are thrown in landfills [47]. The production of one ton of cement generates from 600 to 700 kg of CKD. Statistics show that the quantities of CKD are estimated at about 2.6 billion tons annually [56]. As for the amount of CKD generated in the United States annually, it is estimated at 14.2 million tons, a large portion of them, approximately 64%, is reused as a raw material for the clinker kiln. The rest, which constitutes 36%, is considered solid waste, and only a small percentage 6% of them are used in different applications. The bulk of industrial solid waste of CKD is disposed of with non-environmental manner into landfill and is estimated at 4.3 million tons annually [46], [57], [58]. As a result of these significantly increased amounts of cement and the environmental problems that are being created.

Therefore, the search for sustainable environmental solutions became necessary and urgent, alternatives such as CKD are being investigated. What encourages the use of CKD in a wide range of engineering projects instead of cement in soil stabilization is the alike chemical reaction between them as well as the products of the hydration process [56]. One of the advantages of CKD is that it produces a relatively high percentage of alkalinity (PH) when mixed. The softness and small size of its particles and the adhesive nature of it, it makes CKD highly practical for several uses: waste solidification, soil stabilization, replacement of cement binder in concrete mixtures (block industrial), building of hydraulic obstacles in a landfill liner, fast flowing filling, agricultural soil modifications, and mineral fillers in flexible pavement [46]. The improvement of replacements for adding to poor soil by industrial waste such as CKD is an ecofriendly alternative [59].

2.6 Economic Benefits of Using CKD

High-quality materials are characterized by their high cost, which is why engineers are motivated to search for low-cost alternatives while maintaining appropriate performance [58], [2], [60]. Here, it becomes possible to take advantage of local soil by treating and stabilizing it, at a low cost. By-products are usually less expensive than conventional materials, it creates an attractive substitute if acceptable properties can be obtained [29]. Generally, the removal of industrial waste in addition to being a worldwide problem is costly to the economy of the countries [58]. It is for this reason that researchers have completed several studies on the possibility of using this material in soil treatment [26], [61], [36]. In recent decades, the noticeable increase in built-up areas in weak soils has been closely associated with increased demand to stabilize soils in these areas. It is recommended that soil enhancement will be important in geotechnical techniques to implement economical solutions, and to accomplish decreases in amounts of natural material [62]. Sustainability can be defined as the process of providing environmental engineering alternatives using materials that reduce the cost and depletion of raw materials while maintaining performance [63]. In any case, there is an urgent need to search for alternatives that are more economical than cement and lime, to ensure similar or better performance. One important thing to mention is the continuous increase in the price of asphalt, lime, and cement led to a significant increase in road maintenance, rehabilitation and construction of highways [64]. Finally, CKD represents a significant cost-effective and environmental alternatives, where the conventional style of cementitious stabilizers (lime and cement) have adverse environmental effects throughout its production as well as high cost [65], [66], [66].

2.7 Soil stabilization for pavement layers

The soil properties play a most important effect on the pavements design of road. Therefore, adding waste materials can be developed the engineering properties of poor soil, it is necessary for facilities subject to vibrations [67]. The long-term construction service of the road is greatly affected by the stability and toughness of the subgrade [12].

In road paving facilities, the subgrade represents the lower course of the road cross section, so that both the surface layer and the base layer and/or subbase layer is above it, this means that all of the layers that are located above it are affected by the properties of subgrade. However, it plays the essential role in the strength and stability of the entire paving. Establishment of pavements courses on subgrade with good soil properties decreases the designed thickness of the courses and therefore decreases the maintenance budget of roads and vice versa. Therefore, pavement will be increased [66], [68].

In the event that the subgrade soil is weak, it cannot support the traffic and thus represents a major cause of pavement failure during the road service period. [25], [69], [70], [71], [72]. Soft soils undergo volumetric changes during the wetting process, and this soil is described as expensive. This soil suffers from the continuous swelling and contraction, and for this period, the engineering structures built upon it are damaged, as are road structures. [73], [74]. CKD can be added into weak soils to develop their inherent engineering properties, where CKD increase the subgrade soil texture, the shear strength and decrease the swell features [49]. It can be added to base, subbase course and subgrade as a good replacement material in this domain [66]. In the subgrade soil preparation for highway construction, adding wide-ranging additives of conventional agents are inevitable because of financial and environmental considerations [67]. Some types of expansive soils may be swelled about 1000% or more. Light infrastructures such as highway pavements that rest on expansive soils weakened overtime due to subsequent cracks according to the resulting seasonal volumetric changes (soil swelling and shrinkage)[75], [76].

2.8 The Chemical Composition of CKD

In this aspect of the research, the chemical composition of the CKD will be highlighted, according to various studies that a group of researchers has been able to implement and present in their research. Table 1 illustrates this chemical composition.

3. LITERATURE REVIEW

In 2017, Anil Kumar, and A.K. Singh, used the cement solid waste (dust) up to 30% dry weight of the tested samples to improve and stabilization of the soil for enhancing of compaction characteristics, Atterberg's limits, compressive strength, CBR and permeability and then they found that the soil strength and bearing capacity were improved and gave good results. The physical properties of the soil could be improved by adding different additives. CKD and powder of lime, silica and fibers named (RBI Grade 81) are utilize to improve the soil characteristic including the plasticity, compaction and CBR and other properties. The results said that the dry density of the soil is increased and the moisture content is decreases while the CBR values of the soil were became higher from about 1.6 up to 21 % when CKD and (CKD plus RBI Grade 81)[36] were added to the tested samples [24]. In their research, Zahraa Jwaida. et. al. 2017 they mixed the clayey soil with CKD and other materials to show the effects of these materials on the soft soil properties on different samples with different compositions. These properties including the moisture content, dry density, compaction and CBR. The most impotent results belongs to our research indicated that the binder with 100% addition with CKD sustained a value of CBR of about 19 % [25]. While, J.F. Rivera and others in 2020 tested the effects on mechanical properties of the addition of fly ash lime, alkali-activated cementitious additives to clayey soil. The results shown that there were no significant changes in compaction and extraction volume percentage in the treated samples with comparison with the reference samples. In addition, the weight losses are also behave the same and there were no changes happened [9]. In other research, the waste sludge (the sludge from alum dosages for settling tanks) which is produced from wastewater treatment plant was used as soil stabilizer. The results indicated that the CBR was become higher and increased from 6.5 % to 17 % and at same alum dose of 8% the PI was became 35 and Optimum Moisture Content (OMC) reached 21 while the maximum dry density (MDD) reached a value of 116.4 [23]. Two solid wastes were tested in a research was done to investigate the effects of using CKD and the rice husk ash (RHA) to the soil to improve the physical properties of the soil used as subgrade in roads pavements. The results indicated that the best results are achieved at optimum value of stabilizer ratio of CKD: RHA of 10: 8 % and the corresponding results are tabulated as shown in Table (2) below, [35]. E A Adeyanju and C A Okeke in 2019, tested the use of CKD as soil stabilizer for the a clayey soil taken from damaged roads and used in powder form with tested soil in different compositions of 7.5, 10, 12.5 and 15%. The results for the soil properties are found that unsoaked CBR of the soil increased from 1.49 to 28.6%, and the best results was found at 10% CKD added at 7 days curing interval. The plasticity index (percent) is decreasing from 81.54 to 28.6%, while the dry density is also reduced from 1.63 to 1.49 g/cm3. These changes indicated that the workability of the soil is improved and this approved that the soil properties are improved. The researchers continued their investigations by using different waste additives were added to the subgrade soils to improve the soils properties. A CKD was used as soil stabilizer to improve the performance of the soil itself with different admixtures. All results gave the same trends with corresponding to the mechanical properties. One of these mixtures are named (Red's mixture) where the 7% CKD was added to the soil sample. The results of this sample indicated that the plasticity index was reduced from 45 to 13, the CBR (US strength at optimum ratio) was increased from 6400 to 17500 psf and the maximum unit weight was decreased from 94 to 85 Ib /ft3 [56]. In 2017 Ahmed Mosa and others investigated the subgrade soil to reduce the pavement thickness layer by adding CKD to soil sample to improve the mechanical properties and reducing the pavement cost. They concluded that the tested soil sample achieved the target by increasing the CBR from 3.4 to 48 % and reduced the cost by about $26 / m2 of pavement layer [66]. With different compositions of a hydrated CKD samples, Peethamparan and other researchers in 2008 investigated the improvement of mechanical properties of tested soil samples (Powder and hydrated Samples). Results indicated that the CBR is increased from 0 to about 9000 kPa with increasing of temperature up to 100 oC where a changes in chemical composition identified. CKD was used in a varying compositions of 1, 7, 8 and 9% with soil used as stabilizer for subgrade foundation soil. The results show that the CBR is increased from 10.91 to 17.48 N/mm2 @ 28 days while the placidity index is decreased from 22.99 to 11.15 @ 7% CKD Additive [27]. Al abo Hussien and Asi, 2019, studied the possibility of developing weak soil properties by adding CKD caught by special filters through manufacturing process of cement in Hama cement plant, Syria. They added three proportions (5, 10, and 15%) of CKD by total dry soil weight. The Laboratory tests were achieved to define the weak soil characteristics of subgrade for control (without additives) and modified (with CKD) samples, and then compare the results have achieved. The research stated that adding the CKD to weak Sub-grade enhanced its performance, where PI decreased by 14%. Additionally, load capacity of weak soil, where CBR increased at good value depending on CKD percentages. CBR values noted in two phases. The first stage without immersion in water, and the second stage is immersion in water for 7 days, the value of CBR improved up to 55%. Consequently, the increased CBR means economic savings and a reduction in future maintenance and also a suitable environmental alternative. The study also showed that the percentage of 15% of CKD is the best ratio for addition to the subgrade soil [77]. Improving poor local soil specifications carried out by Al-Homidy and others in 2017, they studied the possibility of adding CKD for stabilizing the properties of weak local soil (sabkha earth). This soil represents salt flat. Test specimens prepared with replacement ratio of 10, 20 or 30% CKD as well 2% cement by total dry weight, and then tested to define their UCS, soaked CBR and soil durability. Stabilization Mechanism is investigated applying innovative techniques, such as the energy dispersive X-ray examination. The results stated that the modified soil with 30% CKD and 2% cement could be added as soil stabilizers for a subbase course in concrete pavements. Adding of CKD leads to practical and cost-effective benefits [78]. Another research to improve soil performance was carried out at the beginning of the year 2000 by Miller and Azad,a laboratory tests were carried out to evaluate the adding of CKD into weak soil as a soil additive. PH, maximum density, value of UCS and PI were tested testing. The research shown that rises in the value of UCS for weak soil which is modified with CKD. But, this Increases in strength were proportional inversely to the PI of the natural soil. There is a significant decrease in the value of PI for soil treated with CKD, especially for soils having a high PI. Investigations show that the alteration in pH of untreated soil (without stabilizer) as a function of CKD ratio is correlated to the PI for these soil, and worthy correlation was observed between the pH response and performance of the soil treated with CKD. 15% CKD is a practical higher value for cost-effective solution [47]. Another result presented by Parsons in 2000, he proves to the proportion of CKD is 6% is preferred to add to the weak soil, where he studied both the limits of Aterberg and durability of weak soil., he added CKD with different ratio 1.5, 3, 5, 6, and 7% of total weight. The study of durability was to subject the samples to 12 cycles of drying and moisture [26].

4. CONCLUSION

Industries usually produce large quantities of solid waste which create universal environmental problems. These waste are affecting and damaging the environmental systems. Scientists and researchers attempt to find the ways to reuse and recycle these solid wastes in the industries again. From these solid waste, the CKD, which is producing as a by-products from the cement industry. In recent time, researchers began to investigate the using of such materials as chemical additives to pavement foundations for the purposes of subgrade construction failure prevention. These materials could be used as soil stabilizers. CKD has a good cementations property. Therefore it could be used as an effective binder for specific soils. Clayey soils usually are not safe for using in road pavement because of their lower shear strength and high compressibility. Failure of pavement subgrade, could be avoid by using some chemical additives to the site's soil. As a results, CKD is considered as soil stabilizer which is used to enhance the soil plasticity, shear strength and lower swelling pressure of certain expansive soils. In addition, these materials are considered as good sustainable sources of low cost additives material in soil modification processes. Using these materials in such industry will prevent environment from the harmful effects. So the use of different waste as soil modifiers can be considered as a low-cost soil stabilizer and overcome the environmental problems with enormous ways and methods. Utilizing these materials could be improve the mechanical properties of soil in a process called stabilization. This process is effective to enhance and improve the soil characteristics such as CBR, plasticity index and dry density. To achieve a good and valuable results many solid wastes were used as stabilizers.

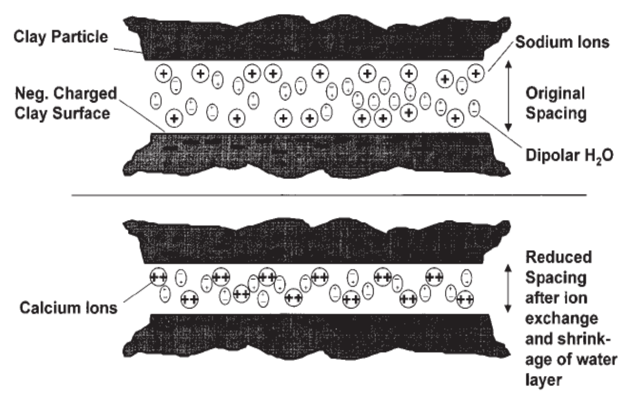

Figure 1: Cation exchange as by [(Prusinski, J. R., & Bhattacharja, 1999)]

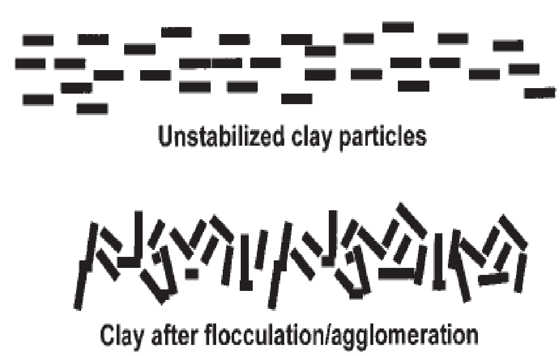

Figure 2: Flocculation and Agglomerations as illustrated by [(Prusinski, J. R., & Bhattacharja, 1999)]

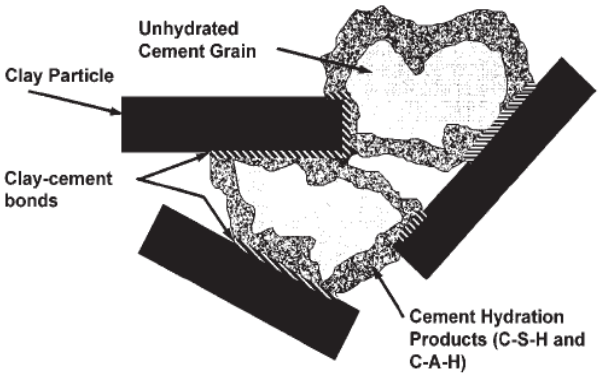

Figure 3: Cementitious Hydration as illustrated by [(Prusinski, J. R., & Bhattacharja, 1999)]

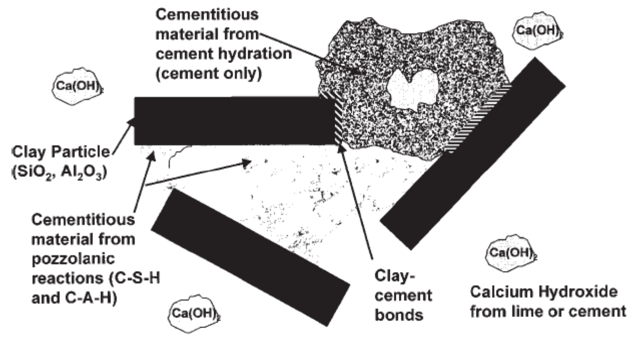

Figure 4: Pozzolanic reaction. as illustrated by [(Prusinski, J. R., & Bhattacharja, 1999)]

Table 1: Shows the difference between CKD ratios depending on the country in which the study was conducted

Reference	CaO	Al_2O_3	SiO_2	Fe_2O_3	Mn_2O_3	Na_2O	MgO	K_2O	Loss of Ignition
(Kumar and Singh 2017)	50.81	4.71	17.18	1.92	0.002	0.001	-	1.35	24.03
(Sudheer Kumar and Janewoo 2016)	55.06	9.9	11.9	3.4	-	0.5	1.7	0.1	4.7
(Jwaida et al. 2017)	12.5	3.5	-	2.5	-	-	0.5	5.5	-
(Aamir et al. 2019)	1.2	37.85	28.91	14.97	-	0.86	0.6	1.73	10.77
(Adeyanju et al. 2020)	0.69	21.56	49.35	14.46	-	0	1.53	0,69	-
(Adeyanju and Okeke 2019)	62.8	4.27	16.93	2.57	-	0	2.03		7.05
(Parsons et al. 2004)	62.09	4.9	17.62	2.58	-	0.56	1.93	3.7	4.94
(Mosa, Taher, and Al-Jaberi 2017)	13	1.86	12.58	1.44	-	1.5	-	1.5	15.82
(Olek, and Lovell 2008)	46.24	4.24	12.18	1.71	0.05	0.51	1.24	4.89	14.22
(Oza and Gundaliya 2013)	14.02	13.05	18.5	0.62	-	-	0.84	-	-
(Miller and Azad 2000)	43.5	3.43	15.9	1.9	-	0.3	1.64	2.94	-
(Ahmmad al abo Hussien 2019)	48.3	2.65	7.47	1.42	-	-	1.48	-	-

Table 2: Comparison of different researches results for the properties of plasticity index, CBR and Dry Density

#	Reference No.	Plasticity Index %		CBR		Dry Density	
		Before Stabilization	Recent Values	Before Stabilization	Recent Values	Before Stabilization	Recent Values
1	Anil kumar, and A.K. Singh (2017)	19.03	7.50	2.64	6.74	14.10	16.30
2	(J. Sudheer Kumar. Upma Janewoo 2016)	32.3	6.77	88.3 kN/m2	976 kN/m2	1.68	1.67
3	(Zahraa Jwaida. et. al. 2017)	19.94	48	4.3	18.9 @9% Binder,100% CKD	1.62 Mg/m3	1.628 Mg/m3
4	(J.F. Rivera et. al., 2020)	-	-	-	UCS28D values of 6.55	1.56 g/cm3	1.59 g/cm3
5	Muhammad Aamir et. al., 2019	0	35	6.53	16.86	111.7	116.4
6	Emmanuel Adeyanju et. al., 2020	0	35.29	0.5	16	-	1.725 g/ cm3
7	E A Adeyanju and C A Okeke 2019	81.54	28.6	1.49	28.6	1.63	1.49 g/ cm3
8	Robert L. Parsons and Justin P. Milburn, 2004	45	13	6400 psf	17500 psf	94 lb/ft3	85 (pcf)
9	Ahmed Mancy Mosa, et. al., 2017	16%	-	3.4 %	48 % at 30%CKD	1887 kg/m3	-
11	Sulapha Peethamparan a,b, Jan Olek b,□, Janet Lovell c, 2008	-	-	0	9000 kPa	-	-
12	J.B.Ozaa, and P.J. Gundaliyab , 2012	22.99	11.15 @ 7% CKD Additives	10.91 N/mm2	17.48 N/mm2@ 28 days.	-	-
13	(Ahmmad al abo Hussien 2019)	18	15.8	8.3	10.8	1.8 gr/cm^3	1.92

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REFERENCES

1. P. Ghadir and N. Ranjbar, 2018. **Clayey soil stabilization using geopolymer and Portland cement**. *Constr. Build. Mater, 2018.*
2. F. Sariosseiri and B. Muhuntha, 2009. **Effect of cement treatment on geotechnical properties of some Washington State soils**. *Eng. Geol*., 2009.
3. S. A. N. M. Yusoff, M. Azmi, H. Ramli, I. Bakar, D. C. Wijeyesekera, and A. Zainorabidin, 2017. **Laboratory investigation of TerraZyme as a soil**. **stabilizer** .*Conf. Proc., vol. 1892, no. October, 2017.*
4. A. A. Firoozi, C. Guney Olgun, A. A. Firoozi, and M. S. Baghini. **Fundamentals of soil stabilization**. *Int. J. Geo-Engineering*, 2017.
5. M. D. V Zutting, 2020. **Soil Stabilization by using Scrap Tire Rubber**. *vol. 9, no. 06, pp. 1382–1388, 2020.*
6. I. Chang, J. Im, and G. Cho, 2029. **Introduction of Microbial Biopolymers in Soil Treatment for Future Environmentally-Friendly and Sustainable Geotechnical Engineering**, 2016.
7. Y. FUWEI, 2010. **Study of Sticky Rice - Lime Mortar Technology**. *Accounts Chem. Res. /American Chem. Soc*., *vol. 43, no. 6, pp. 936–944, 2010.*
8. N. J. Delatte, 2001. **Lessons from Roman cement and concrete**, *J. Prof. Issues Eng. Educ. Pract*., *vol. 127, no. 3, pp. 109–115, 2001.*
9. J. F. Rivera, A. Orobio, R. Mejía De Gutiérrez, and N. Cristelo, 2020. **Clayey soil stabilization using alkali-activated cementitious materials**. *Mater. Constr*., *vol. 70, no. 337, pp. 1–12, 2020.*
10. D. M. Nakum, S. H. Rathod, K. H. Agher, and S. M. Kacha, 2020. **Literature Survey of Soil Stabilization Containing Diverse Nanomaterial Literature Survey of Soil Stabilization Containing Diverse Nanomaterial**. *no. July, 2020.*
11. M. R. Taha and J. M. A. Alsharef, 2018. **Performance of soil stabilized with carbon nanomaterials**. *Chem. Eng. Trans., vol. 63, no. November, pp. 757–762, 2018.*
12. Khalid Akbar Shah, 2020. **A Study on Alluvial Soil Stabilization using Bitumen Emulsion**. *Int. J. Eng. Res*., vol. V9, no. 06, pp. 229–239, 2020.
13. T. N. Dave, D. Patel, G. Saiyad, and N. Patolia**.,** 2020**. Use of Polypropylene Fibres for Cohesive Soil Stabilization**. *Lect. Notes Civ. Eng., vol. 56, no. August, pp. 409–417, 2020.*
14. M. V. Kuznetsov, E. V. Marinchenko, and A. V, 2020. **Chmshkyan. The study of materials for soil stabilization and their practical application**. *IOP Conf. Ser. Mater. Sci. Eng., vol. 698, no. 2, 2019.*
15. M. K. Soni and S. Singh, 2019. **Statistical interpretation of marble dust and alccofine for soil stabilization.** *Int. J. Innov. Technol. Explor. Eng., vol. 8, no. 7, pp. 1609–1613, 2019.*
16. A. L. Ayodele, S. Pamukcu, R. A. Shrestha, and O. A. Agbede, 2018 **Electrochemical Soil Stabilization and Verification**. *Geotech. Geol. Eng., vol. 36, no. 2, pp. 1283–1293, 2018*.
17. M. H. Fasihnikoutalab, 2105. **Olivine for Soil Stabilization**. *Pertanika J. Sch. Res. Rev., vol. 1, no. 1, pp. 18–26, 2015.*
18. S. Saride, B. Umashankar, and D. Avirneni, 2019. **Lecture Notes in Civil Engineering Advances in Geotechnical and Transportation Engineering**. *2019*.
19. S. Bhuvaneshwari, 2119. **Soil Stabilization on Problematic Soil with Traditional Stabilizer**. *Int. J. Recent Technol. Eng., vol. 8, no. 4, pp. 11361–11364, 2019.*
20. K. Subba Rao. **Soil stabililzation.** *Def. Sci. Organ. Minist. Defence, New Delhi. Def. Sci. J., vol. 2, no. 4, pp. 208–217, 1952.*
21. I. Zorluer and S. Gucek, 2020. **The usability of industrial wastes on soil stabilization.** *Rev. la construcción, pp. 80–89, 2020.*
22. S. S. Mohapatra and P. K, 2021. Pradhan. **Review on Study of Soil Stabilization by Application of Microorganisms. Springer Singapore**, *2021*.
23. M. Aamir et al**. Performance evaluation of sustainable soil stabilization process using waste materials.** *Processes, vol. 7, no. 6, 2019*.
24. J. Sudheer Kumar and U. Janewoo, 2016. **Stabilization of Expansive Soil with Cement Kiln Dust and RBI Grade 81 at Subgrade Level**. *Geotech. Geol. Eng., vol. 34, no. 4, pp. 1037–1046, 2016.*
25. Z. Jwaida, A. Dulaimi, H. M. Jafer, and W. Atherton2017. **Soft Subgrade Stabilisation Using Cement Kiln Dust and Ground Granulated Blast Slag**. *No. June, 2017.*
26. R. L. Parsons and J. P. Milburn, **Engineering Behavior of Stabilized Soils**. *In Transportation Research Record*, *2003*.
27. J. B. Oza and P. J. Gundaliya, **Study of black cotton soil characteristics with cement waste dust and lime**. *In Procedia Engineering, 2013.*
28. M. V. Parikshith and D. C. Sekhar. **Feasibility of flyash based geopolymer for soil stabilization.** *Int. J. Innov. Technol. Explor. Eng., vol. 9, no. 1, pp. 4348–4351, 2019.*
29. E. A. Basha, R. Hashim, H. B. Mahmud, and A. S. Muntohar. **Stabilization of residual soil with rice husk ash and cement.** *Constr. Build. Mater., 2005.*
30. J. M. lal J. and Saranya. **Soil Stabilization an Optimum Method with Porous Phenomena.** *No. December, 2019.*
31. O. Cuisinier, T. Le, D. Deneele, and F. Masrouri. **Quanti fi cation of the effects of nitrates, phosphates and chlorides on soil stabilization**

with lime and cement. *Eng. Geol., vol. 117, no. 3–4, pp. 229–235, 2011.*

32. P. Ghasemi, A. Zamani, and B. M. Montoya, **Tri-Axial Behaviour of Steel Fiber-Reinforced Sand**. *Geo-Congress 2019, no. Hagen 1999, pp. 143–151, 2019.*
33. M. A. Rahgozar, M. Saberian, and J. Li. **Soil stabilization with non-conventional eco-friendly agricultural waste materials: An experimental study**. *Transp. Geotech., 2017.*
34. A. B. Landage. **Soil stabilization using soil isomorphism**. *No. August, 2014.*
35. E. Adeyanju, C. A. Okeke, I. Akinwumi, and A. Busari, **Subgrade Stabilization using Rice Husk Ash-based Geopolymer (GRHA) and Cement Kiln Dust (CKD)**. *Case Stud. Constr. Mater., vol. 13, p. e00388, 2020.*
36. A. Kumar and A. Singh. **Stabilization of expansive soil using cement kiln dust**. *Imp. J. Interdiscip. Res., vol. 6, no. 6, pp. 1089–1095, 2017.*
37. I. González Farias, W. Araujo, and G. Ruiz. **Prediction of California Bearing Ratio from Index Properties of Soils Using Parametric and Non-parametric Models.** *Geotech. Geol. Eng., vol. 36, no. 6, pp. 3485–3498, 2018.*
38. J. D. J. Arrieta Baldovino, R. L. Dos Santos Izzo, É. R. Da Silva, and J. Lundgren Rose. **Sustainable Use of Recycled-Glass Powder in Soil Stabilization.** *J. Mater. Civ. Eng., vol. 32, no. 5, pp. 1–15, 2020.*
39. A. A. Al-Homidy, M. H. Dahim, and A. K. Abd El Aal, 2017. **Improvement of geotechnical properties of sabkha soil utilizing cement kiln dust.** *J. Rock Mech. Geotech. Eng., vol. 9, no. 4, pp. 749–760, 2017.*
40. K. K. Shirke, P. S. Mathe, V. Rane, S. Patil, and S. Hirkane, 2019. **Soil Stabilization using Waste Materials**. *no. April, 2019.*
41. **J. R. Prusinski and S. Land. Effectiveness of Portland cement and Lime in Stabilizing Clay Soil.** *pp. 215–227.*
42. J. James and P. K. Pandian**,** 2016**. Industrial Wastes as Auxiliary Additives to Cement/Lime Stabilization of Soils**. *Advances in Civil Engineering. 2016.*
43. G. A. Archibong, E. U. Sunday, J. C. Akudike, O. C. Okeke, and C. Amadi, 2020. **A review of the principles and methods of soil stabilization.**pdf. *Int. J. Adv. Acad. Res., vol. 6, no. 3, 2020.*
44. S. Balaji, M. D. Wadhave, A. P. Waghe, D. C. Rathod, and S. S. Razvi, 2018. **Soil Stabilization by using Lime.** *Int. J. Eng. Manag. Res., vol. 8, no. 02, pp. 79–86, 2018.*
45. M. Maslehuddin, 2008. **Usage of cement kiln dust in cement products – Research review and preliminary investigations**. *vol. 22, pp. 2369–2375, 2008.*
46. S. Peethamparan, J. Olek, and J. Lovell. **Influence of chemical and physical characteristics of cement kiln dusts (CKDs) on their hydration behavior and potential suitability for soil stabilization.** *Cem. Concr. Res., vol. 38, no. 6, pp. 803–815, 2008.*
47. G. A. Miller and S. Azad. Influence of soil type on stabilization with cement kiln dust. *Constr. Build. Mater. 2000.*
48. M. R. Asgari, A. Baghebanzadeh Dezfuli, and M. Bayat, **Experimental study on stabilization of a low plasticity clayey soil with cement/lime**. *Arab. J. Geosci., 2015.*
49. R. L. Parsons, D. Ph, E. Kneebone, and J. P. Milburn, Final report: use of cement kiln dust for the stabilization of soil. *KANSAS Dep. Transp. Div. Oper. Bur. Mater. Res., no. October, 2004.*
50. L. Chen and D. F. Lin. **Stabilization treatment of soft subgrade soil by sewage sludge ash and cement**. J. *Hazard. Mater. 2009.*
51. S. Prusinski, J. R., & Bhattacharja. **Effectiveness of Portland cement and Lime in Stabilizing Clay Soils.** *Transp. Res. Rec., vol. 1652, no. 1, pp. 215–227, 1999*.
52. Geo-Synthetics. **Soil Stabilization Geogrids**. *pp. 1–11, 2019.*
53. W. Al-jabban, J. Laue, and S. Knutsson. **Applied sciences A Comparative Evaluation of Cement and By-Product Petrit T in Soil Stabilization**. *No. December, 2019.*
54. S. Khatri and S. Suman, 2019. **Use of Brick Dust and Fly Ash as a Soil Stabilizer Use of Brick Dust and Fly Ash as a Soil Stabilizer**. *No. November, 2019.*
55. A. Gaur, N. Mathur, and P. Somani, 2020. **Experimental investigation of bottom ash as a capable Soil & Stabilizer**. *IOP Conf. Ser. Mater. Sci. Eng., vol. 872, p. 012138, 2020.*
56. E. A. Adeyanju and C. A. Okeke, 2019. **Clay soil stabilization using cement kiln dust**. *IOP Conf. Ser. Mater. Sci. Eng., vol. 640, no. 1, 2019.*
57. Feras Al Adday, 2020. **Investigational assessment of modified performance of used tire concrete mixtures**. *Int. J. Emerg. Trends Eng. Res., vol. 8, no. 5, pp. 1804–1808, 2020***.** ***doi.org/10.30534/ijeter/2020/52852020.***
58. Feras Al adday and Fatima Alsaleh**,** 2020**. Manufacture of Lightweight Thermal Insulation Concrete Using Recycled Aggregates and Syrian Pozzolan** *Int. J. Adv. Trends Comput. Sci. Eng., vol. 8, no. 3, pp. 959–962, 2019*. *doi.org/10.30534/ijatcse/2020/178932020*
59. N. C. Consoli, E. J. B. Marin, R. A. Q. Samaniego, K. S. Heineck, and A. D. R. Johann**,** 2019**. Use of sustainable binders in soil stabilization.** *J. Mater. Civ. Eng., vol. 31, no. 2, 2019.*
60. Feras. Al Adday, 2020. **Selecting the Best Method for Adding Recycled Aggregate.** *International Journal of Emerging Trends in Engineering Research vol. 8, no. 6, pp. 2253–2258, 2020. doi.org/10.30534/ijeter/2020/08862020*
61. Feras. Al Adday, 2018. **Eco-Friendly Hot Mix Asphalt by Using Recycled Concrete Aggregate and Waste Plastic**. *International Journal of Civil*

Engineering and Technology, 9(7), 2018, pp. 226–236. http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=7

62. S. H. Bahmani, B. B. K. Huat, A. Asadi, and N. Farzadnia, **Stabilization of residual soil using SiO2 nanoparticles and cement**. *Constr. Build. Mater., 2014.*
63. N. E. Feras Al adday, Hadeel Mahasneh, Aymen Awad, Fatima Alsaleh, 2020. **Sustainable pavement performance during freezing and variable immersion periods in water**. *Int. J. Adv. Trends Comput. Sci. Eng., vol. 8, no. 3, pp. 959–962, 2019. doi.org/10.30534/ijatcse/2020/142932020*.
64. Olaolu G. Fadugba Samuel a. ola, f.i. harris, 2020. **Verification of the effect of lateralite on soil stabilization for construction annals of Faculty Engineering Hunedoara**. *Ann. Fac. Eng. Hunedoara – Int. J. Eng., no. May, 2020.*
65. S. Pourakbar, A. Asadi, B. B. K. Huat, and M. H. Fasihnikoutalab, 2015. **Stabilization of clayey soil using ultrafine palm oil fuel ash (POFA) and cement**. *Transp. Geotech., 2015.*
66. A. M. Mosa, A. H. Taher, and L. A. Al-Jaberi, 2107. **Improvement of poor subgrade soils using cement kiln dust**. *Case Stud. Constr. Mater., vol. 7, no. June, pp. 138–143, 2017.*
67. A. E. Eltwati, Tarhuni, 2020. **Engineering properties of clayey soil stabilized with waste granite dust**. *J. Crit. Rev., vol. 7, no. 20, pp. 794–802, 2020.*
68. I. Juliana, A. R. Fatin, R. Rozaini, M. N. Masyitah, A. H. Khairul, and A. Nur Shafieza, 2020. **Effectiveness of crumb rubber for subgrade soil stabilization**. *IOP Conf. Ser. Mater. Sci. Eng., vol. 849, no. 1, 2020.*
69. Y. H. Huang, 2004. **Pavement Analysis and Design.** *Second Edition," Up. Saddle River, NJ07458 Prentice Hall., 2004.*
70. Feras Al Adday, Aymen Awad, Mohd R. Suliman Al-Kharabsheh and Amjad Zeno, 2018. **Early-High-Strength concrete pavement with recycled aggregates and silica**, *International Journal of Civil Engineering and Technology, 9(2), 2018, pp. 990–1004. http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=9&IType=2*
71. A. T. Yadav Santosh, Saxena Anil Kumar**,** 2013**. Performance Evaluation of Waste Plastic and Bitumen Concrete mix in Flexible Pavements.** *Int. J. Sci. Eng. Res., vol. 4, no. 10, pp. 473–478, 2013.*
72. N. R. C. Yoon-Ho Cho, Taeyoung Yun, In Tai Kim. **The application of recycled concrete aggregate (RCA) for hot mix asphalt (hma) base layer aggregate.** *KSCE J. Civ. Eng., vol. 15, no. 3, pp. 473–478, 2011.*
73. G. Kollaros and A. Athanasopoulou, 2011. **Sand as a Soil Stabilize**r. *Bull. Geol. Soc. Greece, vol. 50, no. 2, p. 770, 2017.*
74. R. B. Kassa, T. Workie, A. Abdela, M. Fekade, M. Saleh, and Y. Dejene, 2020. **Soil Stabilization Using Waste Plastic Materials**. *Open J. Civ. Eng., vol. 10, no. 01, pp. 55–68, 2020.*
75. S. Gautam, S. He, and X. Y, 2109. **Stabilization of expansive soil using injection of liquid ionic soil stabilizer: A case study between field and laboratory treatmen.** *Geotech. Spec. Publ., vol. 2019-March, no. GSP 309, pp. 335–343, 2019.*
76. Feras Al Adday, Aymen Awad, 2019. **Pre-Wetting of Recycled Concrete as Alternative of Chemical, Natural and Industrial Waste Additives**. *International Journal of Innovative Technology and Exploring Engineering (IJITEE). DOI: 10.35940/ijitee.L3166.1081219.*
77. M. A. Ahmmad al abo Hussien, 2019. **Improving the Performance of Sub-grade of Asphalt Pavements Using Raw Materials Mill Dust of Cement Factories.** *J. Hama Univ., 2019.*
78. A. A. Al-Homidy, M. H. Dahim, and A. K. Abd El Aal, 2107. **Improvement of geotechnical properties of sabkha soil utilizing cement kiln dus**t. *J. Rock Mech. Geotech. Eng., 2017.*