Advance Geotechnical Possessions of Soils Using Industrial Wastes: A Review

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Abstract:- The engineering problems of problematic soils are mainly related to their mechanical, physical, and mineralogical properties. Extensive efforts have been directed to mitigate damages that may happen for structures constructed on, or in these soils' types. Both conventional materials (e.g. cement, lime, etc.), chemical and produced materials were blended, mixed, or added to soils to improve their geotechnical properties. In the last years, different additives from the wastes of industrial processes have been adopted in engineering researches to improve soils. This paper reviews different industrial wastes materials (e.g., fly ash, blast slag, rice husk ash) as soil stabilizers, where the use of them has economic and engineering benefits. The effect of these materials on physical properties, compaction characteristics, compressive strength, and bearing ratio of soils have been presented, studied, and discussed. The contents of these materials are widely varied from reference to reference and reach a maximum value of 50%. These materials cause reduction in Atterberg limits and swelling potential to different degrees. For some soils, MDD and OMC increase with the addition of these materials, and verse versa. Almost, these materials cause an improvement in soils' strength and CBR. However, some wastes reveal more efficiently to improve the soil.

Keywords: Problematic soils, Soil stabilization, compressive strength, CBR, compaction, industrial wastes materials

1. INTRODUCTION

There are many engineering problems associated with soils like high settlement, low bearing capacity, high erodibility, ground heave or collapse, liquefaction potential, soil deformations (curling, desiccation cracks, shrinkage, and creep), migration fine particles due to movement water table etc. [1-6].

The stabilization and improvement of geotechnical properties of soils aim to increase the shear strength, decrease properties like deformability and permeability, enhance the durability of soil, and provide soil volume stability [7-9]. The engineering techniques of soil stabilization either by mechanical stabilization, or using of cementitious material like hydraulic lime, Portland cement, or mixing soils with the correct content of cohesionless soils [10-15].

The production of cement has severe environmental impacts, using large amounts of fossil fuels lead to speared and emission of more than 5% of carbon dioxide worldwide [16]. Hence, the use of the alternative cementitious materials in soil stabilization application has been studied and recorded a noticeable performance. These materials are industrial cementitious materials that are waste or by- products and possess hydraulic and pozzolanic characteristics Rios et al [17]. The advantage of these materials stabilized the soil and them more economic in the filed construction and significant reduction of environmental pollution.

A review regarding improving different soils using industrial waste materials such as fly ash, cement kiln dust, ground granulated, blastslag, rice husk ash, etc. was presented in the current paper.

2. USING INDUSTRIAL WASTES IN SOIL IMPROVEMENT

2.1 Cement kiln dust

Cement kiln dust (CKD) is a waste by-product of Portland cement manufacture. This material considered a storage problem, health hazard, economical solution. Baghdadi et al. (1995) [18] utilized CKD in order to treat dune-sand (SP). For light applications, it was expected that (12 to 30)% should be tolerance to upgrade dune sand, while for heavily loaded applications, it was required to increase the CKD amount up to 50%. However, the content between 12% and 50% may be adequate, but if the content increased it to (75 and 100) %, that led to failure in durability. CKD (up to 50%) filling the void of soil and cementing its particles, thus causes a maximum dry density (MDD) and California bearing ratio(CBR) increased, after 50% CKD, the properties continue to reduce while optimum moisture content (OMC) decreased at adding CKD around 0%-40% then increased. Three types of soils (low and high plasticity) have been investigated by Miller and Azad (2000) [19]. Six dosages of CKD were used (5%- 30%, increment 5%). It was found that the optimum content of CKD was 25%. The result of these authors showed an increase in soil strength (unconfined compressive, UCS), and optimum moisture content (OMC), while a significant decrease in soils' plasticity index (PI) and maximum dry density (MDD) were recorded.

An evaluation of the effectiveness of three different CKD from different Portland cement conducted by Miller and Zaman (2000) [20]. The CKD was compared with lime to improve the soil. The results indicated different advantages due to using CKD than lime. CKD both modified and stabilized the soil properties. Regarding the strength improvement, the strength development in soil modified with CKD found more quickly. Delay time in mixing and compaction processes of soil and CKD mixture was eliminated in comparison to that required for soil and quicklime mixtures. They found that CKD is effective at improving both cohesionless and cohesive soils.

The effectiveness of CKD in stabilization different soils (ranged from cohesive high plastic to low plastic, and non-cohesive soil) was studied by Parsons et al. (2004) [21]. According to the soil's type, these authors recorded different ratios of improvement at optimum added contents of CKD. The responses of the investigated soils are shown in the following figures. Figures 1, 2, 3. 4 and 5 show the responses of different soils to CKD as a stabilizer. It can be noted that the plasticity of soil is highly affected by CKD content. The response of the liquid limit (LL) is varied widely as the soil type change. The low plasticity clay (CL) soils exhibited a slight increase in LL due to CKD addition while CH soils show a reversed response; they showed a decrease in LL values. It can see the MDD decrease as CKD increase, while, in general, the OMC increase with increasing the CKD. Finally, high improvement can be seen for soil strength with the content of the stabilizer (Fig. 4).

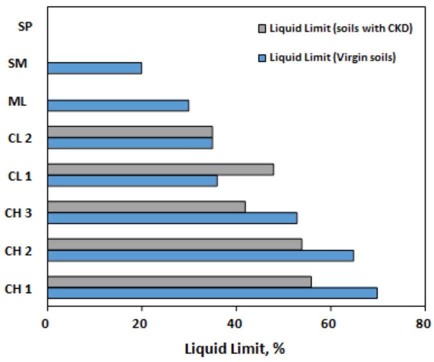

Figure 1. Effect of CKD on liquid limit.

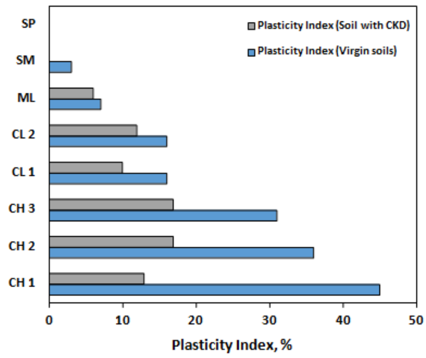

Figure 2. Effect of CKD on plasticity index.

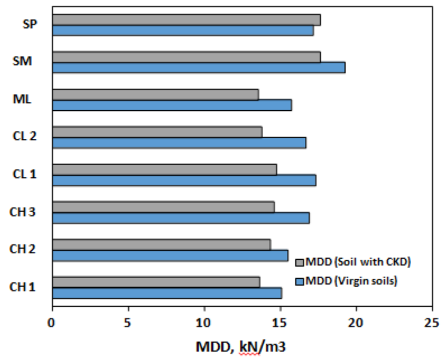

Figure 3. Effect of CKD on maximum dry density

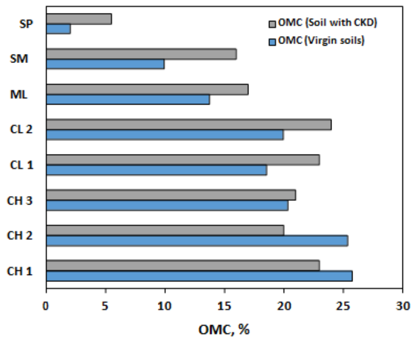

Figure 4. Effect of CKD on optimum moisture content (OMC)

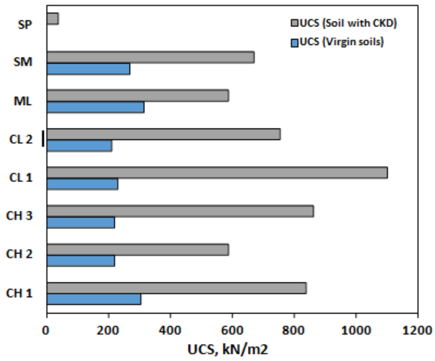

Figure 5. Effect of CKD on unconfined compressive strength

Amadi (2010) [22], Jimoh et al. (2011) [23] investigated the use of CKD to enhance the durability of quarry fines (QF) modified subgrade black cotton soil (BC). BC soil specimens were prepared by mixing the soil with constant QF content (10% QF) and five CKD proportions (0%, 4%, 8%, 12%, and 16% by dry weight of soil). Test results revealed that each Atterberg limits decrease with CKD added. Mixtures of low CKD contents (from 0% to 4%) caused fail the CBR and swell limits. also led to the loss of the strength criterion. The mixtures that have higher CKD contents (from 8 to16%) were satisfied the results of the CBR and swell as well as strength immersion criterion. The maximum dry unit weight was improved on the addition of quarry fines. Dry unit weights were thereafter generally lowered when CKD was introduced. The optimum moisture content, on the other hand, increased for the BC soil when QF was added. Gathering of QF and CKD led to a noticeable performance of the BC soil due to improving the structural properties of it. The increase in unconfined compressive strength, UCS, was noted to be, almost, linearly with an increase in the CKD content.

Al-Homidy et al. (2017) [24] investigated the feasibility of utilizing CKD for improving the properties of weak soil (SM or SC soils, sandy soil or muddy soil, sandy carbonate, mud soil). Soil samples were prepared with 2% cement and (10%, 20%, or 30%) CKD. It is observed that the soil-2% cement samples mixed with 30% CKD showed high improvement and can be used in rigid pavements as a sub-base material. However, the use of the mentioned content of CKD led to environmental and economic benefits. The results of Al-Homidy's study proved that the optimum moisture content, California bearing ratio, and unconfined compressive strength increase while the maximum dry density decreases.

The ability to use the CKD as an alternative material for cement was studied by Mahdi et al. (2018) [25]. They concluded that using 20% of CKD increased CBR value, optimum moisture content, density, and shear strength of type (B) subbase soil.

Different studies have been carried out to investigate the effect of various combinations of CKD and different materials such as rice husk ash, tire rubber powder, etc. [26-27]. It was found that the plasticity of soil was reduced with the addition of tire rubber powder and CKD. The addition of rice husk ash gave higher elastic modulus, water resistance, and lower water absorption.

Al-Baidhani and Al-Taie [28] presented a review that included many materials used as a stabilizer for expansive soil such as CKD. They noted that the plasticity index of the montmorillonite clay reduced, improvement in shear strength, reduced maximum density of the soil, while the values of optimum moisture content and California bearing ratio were increased.

The findings of Hussein et al (2020) [29] indicated that the critical behavior of plastic soil can be mitigated by mixing with 15% or 20% of CKD.

From overall group researchers can make a chart as shown in Fig. 6. The adding of CKD to all engineering types soils has been demonstrated that CBR values were more efficient in non-plastic soils. CBR values recorded slightly dropped at CH and CL soils, this reason belonged to the usage of incorporation of CKD with other materials such as quarry fines (QF), rice husk ash (RHA). A noticeable performance in swelling pressure can be observed, this reason deported to a lack in the ratio of fine aggregates. However, the usage of 30% CKD with 2% cement at silty sand (SM) or clayey sand (SC) soils considered a significant reduction in cement consumption.

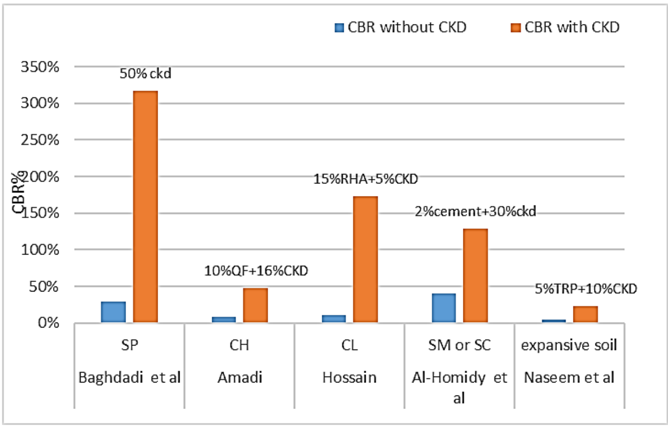

Figure 6. CBR values respected to different researchers with and without CKD

Figure 7 illustrated the behavior of sandy soils-CKD and clayey soils-CKD mixtures under compaction. It can be seen that the compaction characteristics in sandy soils-CKD mixtures are differ from clayey soils-CKD mixtures. In sandy soil, the first MDD increased with higher CKD due to the voids between sand particles filled with CKD particles. After that, MDD decreased because CKD continued to react with water due to calcium oxide in CKD loved water. The Interpretation in clayey soil, MDD decreased with CKD adding ,due to pozzolanic stabilizer can be bind soil particles together and reduce water absorption by clay particles.

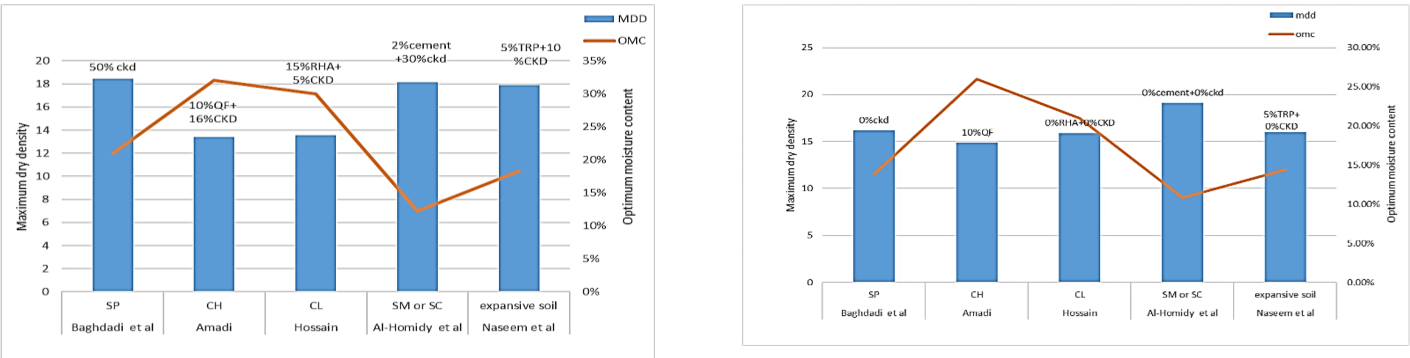

Figure 7. MDD and OMC respected to different researchers without CKD

2.2 Red mud

Red mud, or RD, is another byproduct waste material of the bauxite industry. The effects of this waste material on the geotechnical soil properties have been investigated by a number of researchers [30-32].

Expansive soils have been stabilized using RD. Kalkan (2006) [30] found that the stabilization of expansive soils with RD improve the shear strength, the RD decreased the swelling percentage and in hydraulic conductivity.

The addition of red mud to clay soil was studied by Kocserha et al. (2018) [31]. These authors examined the effects of RD on compaction properties of soil with earth alkali carbonate content, in one hand, and soil without earth alkali carbonate content, on the other hand. The findings of this study showed that the maximum dry density of the soil increase as red mud increase up to an optimum value (40%).

The effect of various combinations of red mud and other materials like lime and fly ash has been examined by Sridevi et al. (2019) [32]. The result of this combination used to stabilize the expansive clay. Red mud, as well as fly ash, stabilized with 4% lime, and this mixture is added to the expansive soil in various contents serious (from 10% to 50%, in 10% increments). As a result, the geotechnical properties of the soil improved

2.3 Ground granulated blast furnace slag

Different types of industry by-product Ground Granulated slags include Furnace Slag and carbide slags have been used in soil stabilization technology. In their study, Yi et al. (2014) [33] used an industry by-product, carbide slag (CS), to activate another industry by- product, ground granulated blast furnace slag (GGBS) to enhance soft clay in comparison to Portland cement (PC). The optimum CS content for the CS–GGBS stabilized clay was 4%–6%, varying slightly with curing age and GGBS content. The mixtures of clay- CS-GGBS exhibited higher UCS values when compared to the mixtures of clay-PC (more than twice). The following hydration products were detected for clay- CS-GGBS mixtures: "Calcium Aluminate Hydrates", (CAH); "Alumino Ferrite Monosulfate", (AFM); and "Calcium Silicate Hydrates", (CSH).

Al- Khafaji et al. (2017) [34] investigated the effect of GGBS on the physical and engineering properties of the soft soil (type CI). GGBS was added in various percentages (3, 6, 9 and 12%). The results indicated an increase in the MDD maximum dry density increased and decrease in the OMC optimum moisture content with increase GGBS content up to around 9%, after that, at 12% the MDD and OMC gave reversed trend. In terms of Atterberg limits, the liquid limit decreased, the plastic limit increased and the plasticity index decreased with increase GGBS content. Based on the UCS tests, the strength indicator increased up to 80% at the optimum amount of GGBS (6%).

Padmaraj and Chandrakaran (2017) [35] tested the effect of Ground Granulated Blast Furnace Slag (GGBS) -lime mixtures in the stabilization of soft soil (CI) to use as subgrade soil. The percentages added were (5-10-15-20%) of weight soils. A significant increase in UCS and CBR value and reduction in the plasticity characteristics were observed when GGBS content reached 10 percent. The strength enhancement is further improved when 5 percent of lime is added as an activator.

Gonawala et al. (2018) [36] used the Electric Arc Furnaces (EAF) slag and Ground Granulated Blast Furnace Slag (GGBFS) in base/sub-base layer of Flexible Pavement. This material has an advantage in waste utilization by contributing to sustainability. The GGBFS proportions were taken 5%, 10%, 15% and 20% of the total dry weight. EAF slag + 15% GGBFS satisfied the strength criteria for Rural Road. The OMC and MDD increase in the proportion of GGBFS. The UCS value of EAF Slag + 15% GGBFS indicated satisfy for the optimum mix as Rural Road.

2.4 Bio-fuel co-product

Ceylan et al. (2010) [37] investigated the use of lignin-containing biofuel coproduct in pavement soil stabilization. Biofuel coproducts improve the strength of the Iowa Class 10 soil classified to CL or A- 6(8). The result of this study showed that the UCS of coproduct-treated soil samples increased with the increase in the content of co-products, Atterberg limits and optimum moisture content increased while maximum density decreased.

Ceylan et al. (2011) [38] utilized the sustainable material known (Bio- fuel Co-Product A and B) Containing Lignin in geotechnical engineering practices to improve roadbed strength and engineering properties. The optimum is proportional to Biofuel Co-Product A (25% lignin and up to 25% water with a pH value of 2.2) and Biofuel Co- Product B (5% lignin, 50% hemicellulose, 20% cellulose, and other components). BCP demonstrated a significant amendment results to stabilize clayey soils as improving the durability, efficiency, economy, environmental impact, UCS increased with 12% of co-products. The co-product B increased the plasticity of soils as a result of arising in the liquid limit and plastic limit values.

For reduction of soil stabilization costs, utilization of lignin-based BCPs (biofuel co-products) as an alternative to stabilize pavement subgrade soil has been investigating by Uzer (2015) [39]. The optimum dosage was 12% (BCP). Four types of soils have been collected from Iowa, USA (SC, CL-ML with fines 62.5%, CL-ML with fines 53.1%, ML).The results of this study showed that the shear strength values increased up to two times for all soil types.

2.5 Fly ash

Kolias et al.(2005) [40] investigated the effectiveness of using high calcium fly ash and cement in stabilizing two fine-grained soils, high plasticity (CH), and low plasticity (CL) clays. The percentages of fly ash (FA) and cement content used were (5%, 10%, and 20%) and (2%, and 4%) by weight of soil respectively. The results indicated that the soil became non-plastic after mixing with fly ash. The MDD and OMC increased as fly ash added. At 10% fly ash with 4% cement, the UCS value revealed the highest levels.

Zhang and Solis (2008) [41] had used fly ash as a suitable stabilizer of local gypsiferous soil. Soil samples were treated with varying the percentages of (10%, 15%,20%,25%) of fly ash with gypsiferous soil. Based on the results obtained from the laboratory testing on gypsiferous soils before and after the addition of fly ash, the strength is increased when the curing period is increased.

Han-bing et al. (2009) [42] investigated the effect of additive fly ash on silty clay soil in order to enhance this soil. The proportions of fly ash to soil 1:4, 1:2 and 1:1. The result of the strength index at 1:2 was tolerable and better than another ratio. The frost heave decreases with raised of fly ash.

Senol et al. (2012) [43] improved the engineering properties of the low plasticity clay subgrade by blending the soil with Class C fly ash and Virgin Homopolymer Polypropylene (VHP). The best results were achieved when soil mixed with 10% of fly ash and 0.25% of VHP. The unconfined compressive strength (qu) of the low plasticity clay increases and reaches a peak value of approximately 200% when the fly ash content 10% and 0.25% of VHP. On the other side, at 15% fly ash content, the increase in qu was dramatic decrease which could be even neglected. The OMC decreased, at fly ash content increased.

Sabat and Moharana (2015) [44] investigated the effects of compaction energy on engineering properties of an expansive soil by using the fly ash-granite dust as a stabilizer on it. The maximum dry density increased and optimum moisture content decreased with compaction energy increased, so the soaked CBR increased and UCS increased at 42% FA-GD, however, UCS goes on decreasing when FA-GD overflow 42%.

Turan et al.(2019) [45] studied the effects of consistency, swelling and strength characteristics of class C fly ash with one day curing period as a stabilizer for clayey soil. This type of stabilizer considers as eco- friendly. The results prove that the addition of fly ash leads to mitigate of the plasticity index, the swelling, and the compressibility index, on the other side compressive strength increased. The maximum dry density decreased while optimum moisture content increased at 5 % fly ash by dry weight of the Soil. At fly ash content increased up to30%, both of MDD and OMC have been taken reverse trends. UCS increased gradually with increasing fly ash content up to 30%.

2.6 Dust wastes

Bhavsar and Patel (2014) [46] resolved the problem of swelling and shrinkage for swelling soil (black-cotton soil) by replacing the soil by stabilizing agents such as brick dust. The proportion of blending was 50% of soil and 50% brick dust. The addition of 50% this dust increased the maximum dry density by more than 13% and reduced the optimum moisture content by more than 6% compare to black- cotton soil. Generally, the addition of 50% brick dust mitigated the swelling and shrinkage behavior of black-cotton soil.

Incorporated of brick dust (10%,20%,30% and 40%) with fly ash (10%,20%,30% and 40%) have been investigated by Wanare (2018) [47]. The author noted that the fly ash effectiveness is higher than brick- dust with soil, specifically Atterberg limits. On the other side, the MDD is, almost, constant for both waste materials, while OMC was differed in the mixture of soil-brick-dust and flyash.

Al-Baidhani and Al-Taie (2019) [48] presented a review around brick-wastes in the improvement of expansive soils. The optimum content of waste used was ranged from (40 to 50)%. These wastes considered as successful materials in reducing the problems of expansive soils.

Al-Baidhani and Al-Taie (2020a) [49] studied the effects of three different content of brick dust (10%, 20%, and 30%) on shrinkage and strength characteristics of cohesive soil. The results prove that the addition of brick dust leads to mitigate of the critical behavior of soil. At brick dust content increased up to (20 to 30)% the shear strength increased gradually.

Incorporated of ceramic dust (10%,20%,30%, 40% and 50%) with expansive soil has been investigated by Al-Baidhani and Al-Taie (2020b) [50]. These authors showed that the ceramic dust is effective in improving expansive soil, specifically Atterberg limits, compaction properties. On the other hand, they were found that significant improvement in strength values are obtained in the mixture of soil and ceramic dust.

3. CONCLUSIONS

Industrial waste materials are widely used as a stabilizer to mitigate the adverse effects for engineering's soils through the reactions with soil particles which lead to improving the soils' engineering properties. A review of these waste materials was shown and presented in this paper. The industrial waste materials discussed in this paper included cement dust, red mud, ground granulated blast, furnace slag, bio-fuel co-product, fly ash, and dust wastes. The contents of these materials are widely varied from reference to reference and reach a maximum value of 50%. In general, these materials cause reduction in Atterberg limits of soils. The swelling potential of soils mitigates to different degrees, depending on the type of material used. The response of soil's compaction properties are varied depending on the waste materials type, for some soils, the maximum dry density (MDD) and optimum moisture content (OMC) increase with the addition of industrial waste materials, and verse versa. Almost, the industrial waste materials cause an improvement in shear strength and the bearing ratio of all soils. It has been demonstrated that CBR values were more efficient in non-plastic soils. The incorporation of some waste material with other wastes can improve the efficiency of these materials as a soil stabilizer. However, industrial wastes such as cement dust, red mud, ground granulated blast, furnace slag reveal more efficiently to improve the soil when compared with other materials. Finally, the utilization of industrial waste materials can reduce soil stabilization costs.

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