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DISPOSAL PRACTICE OF BRICK KLIN WASTE THROUGH STABILIZATION OF FINE-GRAINED SOILS- A REVIEW

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ABSTRACT

Brick klin waste (BKW) is a byproduct generated during the manufacture of bricks in traditional brick klins. Its improper disposal results in environmen- tal deterioration and health hazards. In recent times, engineers and researchers have explored soil stabilization as a sustainable and eco-friendly avenue to man- age and utilize BKW. This approach has a two-fold advantage: one to get rid of the tremendous environmental issues associated with indiscriminate dumping of BKW occupying valuable land, and a second to minimize the stabilization cost of soft or marginal soils. This review assesses the effectiveness, environmen- tal impact, and potential applications of brick klin waste in soil stabilization of clayey geomaterials. The outcomes depict that most of the physical, chemical, mineralogical, toxicity, microstructural, and geotechnical characteristics of BKW are in the range of other geomaterials. It is established that incorporating BKW in soft soils in certain percentages improves their strength and stability char- acteristics significantly. According to many researchers, the blended mixture of BKW and fine grained soils attain better gradation features, more volume stabil- ity, enhanced bearing capacity, and a higher California bearing ratio (CBR). As such, BKW alone or replacing a certain percentage in soft soils finds its scope in the different applications of geotechnical engineering. Additionally, it can result in its mass consumption and an improvement in the soil properties in a much more sustainable and economical manner.

Keywords: Brick Klin Waste (BKW), Fine Grained Soils, Soil Stabilization, Solid Waste Management, Sustainability, Geo-Mechanical Properties

1. INTRODUCTION

Clayey geomaterials refer to the soils or sediments that are predominantly composed of clay-sized particles in addition to the presence of clay minerals. Low bearing capacity, excessive deformations, reduced permeability, and volume instability are the characteristics of such soils. Civil engineering constructions are always at a greater risk when founded on such soils. Furthermore, the foundation cost of any structure has a direct bearing on the soil conditions over which it is built. Damages to buildings constructed on soft soils amount to billions of dollars in many nations [1–6]. As such, there is a need to address the various issues associated with fine-grained soils to ensure sustainable and economical construction.

In general, the term "soil stabilization" refers to the processes involved in improving the geotechnical properties of soils in order to make them more suitable and efficient for foundation medium or as a construction material [7, 8]. There are numerous materials and stabilization techniques available; however, the material selection and the method to be employed is project-specific [9]. Thorough geotechnical analysis must be conducted to ascertain the most relevant stabilization process for the project in hand. Out of the various stabilization techniques available, chemical stabilization has been promptly employed for improving the physical and mechanical properties of clayey soils. Among which, cement and lime are very popular traditional materials employed in different percentages to improve the mechanical behavior of clayey geomaterials [10, 11, 11].

Although cement, lime, and other chemically treated clayey soils exhibit an improvement in geo-mechanical properties and overall better performance, yet the utilization of such materials to stabilize soils is presently discouraged on many fronts. Firstly, the production of these materials is a costly affair on account of being energy intensive; secondly, it involves the consumption of natural resources; and at last but not least, a contributor to the carbon footprint and greenhouse gas emissions [12–15]. As an illustration, the production of 1 ton of cement in factories releases approximately 1 ton of carbon dioxide.

Globally, there is a drastic shift in how societies can attain economic and infrastructural development while ensuring the preservation of natural resources, with a motive to achieve a more sustainable and safe environment for the future. In such a scenario, alternate ways and means to achieve the target of soil stabilization are the need of the hour. Out of the different options available, the application of industrial wastes for the purpose of soil stabilization appears to be more suitable and genuine [16, 17]. Utilization of industrial waste in soil stabilization results in twin advantages of disposal issues associated with the waste and achievement of better soil characteristics in a more economical way.

Industrialization has brought a lot of benefits to societies in terms of economic and infrastructural development, urbanization, technological advancements, etc. However, industrial processes produce a significant amount of wastes and byproducts that need to be managed properly. Globally, solid waste management is a significant and evolving issue [18]. Brick kiln waste (BKW) is one among the industrial wastes that gets generated in substantial amounts during the different processes of producing bricks in traditional brick kilns. Brick masonry is popular to raise infrastructure in nations like India [19, 20]. India's population, economy, and urbanization have all increased the demand for physical infrastructure, including public, commercial, industrial, and resi- dential structures. Estimates put the growth of building construction in India between 2005 and 2030 at 6.6% annually. Brick masonry has proven to be one of the most reliable and durable building construction techniques to date. The brick is the fun- damental building block in such a construction. In order to fulfill the requirement of a huge population, there is pressure to produce ever-increasing quantities of bricks. India is the world's second-largest brick manufacturer after China. Its annual brick production rate is rising by 5–10% and can reach up to 250 billion bricks per year. This leads to the production of massive amounts of brick kiln waste (BKW), which results in environmental degradation as well as disposal issues. The current practice of handling BKW is to dispose of it in the landfill sites, which turns out to be uneconom- ical on account of transporting it from brick kilns to the landfill site and occupying a large space in the landfills.

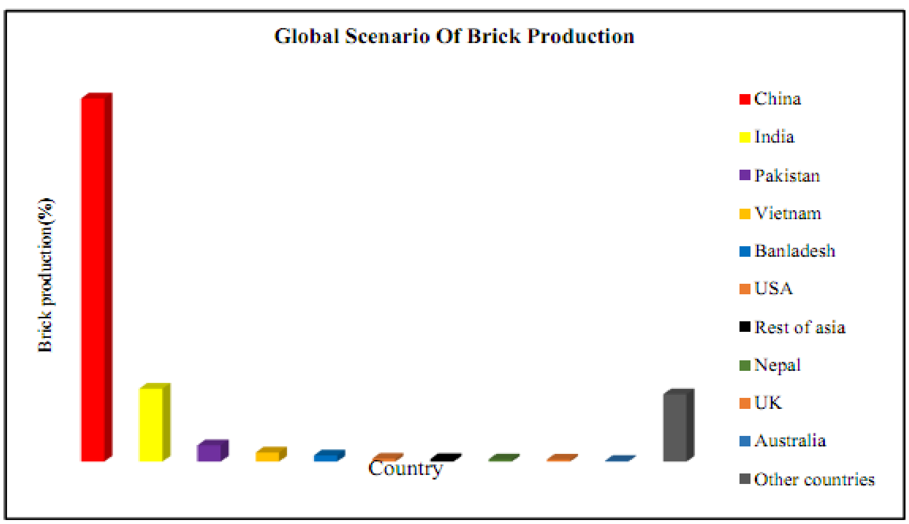

Fig. 1 Global scenario of brick production

Brick kiln waste is a waste product that is produced in large amounts after the burning of bricks in kilns. Clay, sand, burnt wood and coal residue, and other small and big broken brick pieces, along with some unburned carbon, are common constituents of brick kiln waste. If improperly handled, it might have negative consequences on the environment and human health [21, 22]. This necessitates the creation of design strate- gies and their implementation in the construction sector for sustainable management of BKW. The utilization of BKW in the construction industry offers multiple benefits summarized below:

1. Disposal of BKW in geotechnical applications can prevent its air, water, and geo- environmental hazards, thereby favoring environmental safety.
2. The disposal space required either around the brick kilns or in landfills and the disposal cost for BKW can be minimized after its utility in the construction sector.
3. Utilization of BKW in soil stabilization can lead to the conservation of natural resources which are otherwise the raw materials required for the manufacture of other stabilizing agents like cement, lime, bitumen, etc.
4. Usage of BKW as a stabilizing agent in replacement of other expensive industrial manufactured stabilizers is an economical option.
5. The usage of BKW in place of chemicals like cement and lime for the purpose of soil stabilization can reduce carbon dioxide and other greenhouse gas emissions.
6. BKW-treated clayey soils find much wider applications in the construction sector, ranging from subgrade material for road and railway embankments, foundation medium for buildings and other structures, backfill for retaining walls, etc., due to its better geotechnical performance.

In light of the above, there is a need to gather evidence on the suitability of BKW- stabilized fine-grained soils for safeguarding its field applications. The prime motive of this study is to review the various aspects of BKW-stabilized clayey geomaterials . The article covers three sections: Section 1 is reserved to review the physical, chemical, mineralogical, toxicity, microstructural, and geotechnical characteristics of BKW. Section 2 covers the various geo-mechanical characteristics of BKW-treated clayey soils includ- ing plasticity characteristics, compaction characteristics, shear strength parameters, and California bearing ratio. Section 3 is devoted to practical use of BKW-stabilized clayey soils with recommendations.

2. PROPERTIES OF BRICK KLIN WASTE

The properties of brick klin waste vary depending on the type of raw materials, firing temperature in klins, fuel type for burning, type of additive used for bricks, etc. Some of the properties of BKW are described below.

2.1 COLOUR AND TEXTURE

The colour and texture of BKW varies from one location to another and even from one brick klin to another. In general, BKW is brownish-red in colour. Most of its particles are coarser than 75m and are rough textured.

2.2 CHEMICAL COMPOSITION

Most of the researchers have carried out the chemical analysis of BKW using XRF technique. The major constituents found in BKW include silica (as SiO2), alumina (as Al2O3), iron oxide (as Fe2O3), and calcium oxide (as CaO) as shown in Table1. The (SiO2 + Al2O3 + CaO + Fe2O3) fraction of BKW in each study is more than 70% of its total content and can be classified as silica-aluminous material. Therefore, the chemical composition of BKW renders its use as a pozzolanic material. The chemical composition of BKW resembles other geomaterials. Therefore, BKW alone or mixed with some additive finds its applications in various fields of civil engineering.

2.3 MINERALOGICAL AND TOXICITY ANALYSIS

XRD analysis has been carried out by few researchers to get an insight about the mineralogy of BKW. The kind of minerals and their concentration in the raw materials have a critical role in controlling the mineralogy of the products produced after their combustion.

Table 1 Oxide composition of (BKW)

Composition (by wt. %)				
SiO_2	50.60	60.42	56.20	68.10
Al_2O_3	19.40	24.71	17.40	16.35
Fe_2O_3	11.40	5.01	12.54	6.04

CaO	5.93	1.57	3.37	2.05
MgO	1.72	1.89	2.65	1.43
K_2O	2.23	—-	2.88	2.38
Na_2O	1.60	1.79	0.95	1.20
TiO_2	0.93	0.85	0.96	0.85
P_2O_5	2.94	—	—	0.26
Others	3.25	3.76	3.05	1.34

Quartz has been reported as the prominent mineral in each study of brick kiln waste because it has a comparatively high melting point of 1400°C. Further, clay utilized for brick making is rich in iron, so the mineral hematite is found to be present in BKW. To completely comprehend the behavior and properties of the soil, gradation anal- ysis of soil is frequently carried out in combination with other geotechnical tests. Different researchers employed dry sieve analysis for the fraction retained on 75 m sieve size and hydrometer analysis for the passing part in the gradation study of BKW. It has been revealed that the majority of particles in BKW are coarser than 75 m and has appreciable silt content. As such, BKW has been categorized as sand with substantial amounts of silt (SM) [23]. The abundance of sand (Tab2) in BKW makes it attractive for its use in many geotechnical applications like backfill for retaining walls,
as a subgrade material in the construction of embankments, etc.

Table 2 Particle sizes/Soil grading

Particle sizes/Soil grading			
Gravel (%)(4.75-80mm)	0.0	0.0	0.0
Sand (%)(4.75–0.075mm)	72.3	86.0	84.0
Silt size (%)(0.075–0.002mm)	27.7	14.0	26.0
Clay size (%)(¡0.002mm)	0.0	0.0	0.0

2.4 SPECIFIC GRAVITY

Specific gravity of soil solids is the fundamental property that plays a key role in its various applications of geotechnical engineering. The specific gravity of BKW particles has been determined by the different researchers adhering with the codal guidelines. They acknowledge that the specific gravity of BKW particles typically falls below 2.5, which is relatively low when compared to the specific gravities of other geomaterials. This feature of BKW particles has been explained for the presence of cenospheres or hollow spaces within them. Lower specific gravity value results in lighter geomaterial and is beneficial in reducing lateral earth pressure on retaining structures.

2.5 PLASTICITY CHARACTERISTICS

Plasticity characteristics are crucial for geotechnical characterization of soils, as it influences the phenomenona like compaction, settlement, and shear strength. Most of the researchers have not been able to find the liquid limit of BKW employing Casagrande's method. The author is of the opinion that the liquid limit of BKW can be determined using cone penetration method. Due to the non-plastic nature of BKW, its plastic limit has not been reported in literature [24].

2.6 COMPACTION CHARACTERISTICS

Compaction of soils plays a key role in the construction of several civil engineering projects, including the construction of canal embankments, earthen dams, embank- ments for roadways and railways, etc. Both Standard and Modified Proctor tests have been employed for BKW by several researchers to obtain its compaction characteris- tics as per standard practices. The maximum dry density (MDD) values from both Standard and Modified compaction tests have been reported to be relatively low when compared to other geomaterials. Further, the optimum moisture content (OMC) for BKW is found to be on the higher side as compared to other materials. The low specific gravity of BKW particles and the existence of cavities in the BKW particles are the main explanations offered by most studies for the lower values of maximum dry density. Researchers have justified the higher values of OMC as a result of the existence of cenospheres or voids and due to unburnt carbon in BKW. Higher values of OMC allow the soil to be workable over a wider range of water content without being sticky.

Kinuthia et al. 2011 [24] have performed the British standard (BS) Proctor compaction test on BKW supplied by Brick Fabrication Ltd., Gemini Works, Pontypool, South Wales, UK. The values of MDD and OMC for the BKW under study have been reported to be 15.5 kN/m3 and 17% respectively.

As per the guidelines of the Ministry of Road Transport and Highways (MORTH), Government of India, for the construction of roads in India, the subgrade material should possess a minimum density of 17.5 kN/m3 under modified compactive effort, which is not satisfied with the BKW alone. Therefore, BKW alone cannot find its application for subgrade for highways.

2.7 SHEAR STRENGTH PARAMETERS

Shear strength is the fundamental property of soils that plays a crucial role in the analysis and design of foundations, stability of slopes and retaining walls etc. Cohesion and angle of internal friction are the primary factors in imparting the shear strength to the soil. Researchers have evaluated the shear strength of BKW using shear boxes. It has been affirmed by the researchers that the shear strength of BKW is relatively much better as compared to other geomaterials especially clayey soils. In a direct shear test, BKW exhibits cohesion with an appreciable angle of internal friction. The presence of angular and rough-textured BKW sand particles in bulk is responsible for the high angle of internal friction for BKW. The same has been confirmed by conducting FSEM micrographs on BKW by various researchers.

2.8 CALIFORNIA BEARING RATIO ANALYSIS

The mechanical strength of the soil subgrade and other materials used in the pavement, as well as the design of pavements, is widely carried out using the California bearing ratio test. The greater the CBR value, the more competent the soil is to withstand the stresses brought on by environmental factors and the traffic. The CBR for any material is computed as the ratio of the load at 2.5mm penetration or 5mm penetration to the load required for a standard material under similar conditions and expressed in percentage. Among the different properties, CBR has been one the target properties of the researchers. Both soaked and unsoaked CBR tests have been carried out by different researchers on BKW following the relevant codal guidelines. It has been reported that BKW has much better CBR value compared to other clayey geomaterials in both conditions. Rich in angular and rough textured sand and nonplastic nature of BKW have been put forward the reasons for the higher CBR value of BKW.

2.9 PERMEABILITY CHARACTERISTICS

The permeability of soil plays a key role in the design of foundations, retaining struc- tures, landfills, dams, and other underground structures. Researchers have determined the permeability of BKW to evaluate its potential in various applications of civil engi- neering. It has been reported the permeability of BKW equal to 7.29 10−5 cm/s. As such, BKW is a good draining material. This may be attributed to the occurrence of a bulk proportion of sand in it, and this property of BKW makes it suitable for use as backfill material in retaining structures, road embankments, etc.

3. INFLUENCE OF BKW ON THE PROPERTIES OF FINE GRAINED SOILS

3.1 EFFECT OF BKW ON THE PLASTICITY CHARACTERISTICS

Plasticity of soil is a key factor in deciding its behavior in various geotechnical applications [25]. The liquid limit (L.L), plastic limit (P.L) and the plasticity index (P.I) are the relevant parameters to define the plasticity of soil. Notably, plasticity of soil is a better parameter to judge the volume stability of soils. Different researchers have added BKW to the clay geomaterial in different dosages varying from 10 to 50% to study its impact on their plasticity characteristics. When compared to fine-grained soil, the blended mix of fine-grained soil and BKW has less plasticity [24]

There is a general consensus among the different researchers for the improvement in the plasticity characteristics of clayey geo-matrix as a consequence of replacement of clay and silt particles by nonplastic particles of BKW.

3.2 EFFECT OF BKW ON THE COMPACTION CHARACTERISTICS

Building foundations, roads, embankments, dams, and airport runways are just a few of the construction projects that require compacted soil. Soil that has been properly compacted offers a stable and reliable foundation for buildings, reducing the risk of excessive settlements. Compaction parameters are the key indicators to judge the soil behavior during the compaction process. Addition of BKW to the fine-grained soil in different dosages ranging from 10 to 50% has proved to influence the compaction parameters of the soil. It has been reported that the addition of BKW to the clayey geomaterial slightly reduces its maximum dry unit weight and increases its optimum moisture content.

All the researchers have pointed out the decrease in the dry density as a consequence of the lesser specific gravity of BKW particles compared to the geomaterial and the presence of hollow space in the BKW particles. An increase in the optimum moisture content has been referred to the high water absorption due to the porous nature and presence of unburnt carbon in BKW. Lower unit weight geomaterials find their application as backfill for the retaining structures. On the other hand, a higher value of optimum moisture content allows the material to be workable over a much wider range of moisture content without being sticky.

3.3 EFFECT OF BKW ON THE SHEAR PARAMETERS

Geotechnical engineers need to know the shear strength of soil in order to construct foundations, analyse slope stability and to evaluate the stability of earthen structures. The shear strength of soil is primarily derived from cohesion and the friction among its particles. Researchers have employed direct shear test to evaluate the shear strength parameters of BKW stabilized fine grained soils.

Adding BKW to the fine grained soil has increased the frictional component and decreased the cohesion. Increase in the frictional resistance has been accounted due to the replacement of smooth textured fine grained particles with the angular and rough textured BKW particles. Cohesion and the angle of internal friction play a vital role in determining the bearing capacity of soils. A comparison of the ultimate bearing capacity of a shallow isolated footing on the clayey geomaterial with the same foundation type resting on the blended mix of clayey geomaterial and BKW was made. It was calculated that the ultimate bearing capacity of the blended mix of clayey soil and BKW in the ratio of 60:40 increased by 21%

3.4 EFFECT OF BKW ON THE CBR VALUE

CBR value is frequently used in the field of transportation engineering to develop affordable pavement constructions and assess the performance of subgrade soils. It is a valuable tool in the design of flexible pavements. CBR value has remained the target parameter in most of the studies involving the stabilization of clayey soils with BKW. CBR tests have been performed on BKW alone and BKW stabilized clayey soils both in soaked and unsoaked conditions as per the relevant codal procedures. In general, CBR value has been found to improve significantly up to a certain percentage of BKW replacement beyond which a drop in the CBR value has been observed.

Better gradation characteristics, reduced plasticity and sand rich mix has been the justifications put forward by different researchers for the increase in the CBR value. The reduction in CBR upon soaking has been found to fall in the range of 50% to 60% in all the cases.

4. SUMMARY AND CONCLUSIONS

Following a meticulous analysis of the literature on BKW, its potential to stabilize soft soils, and its applications in the field of geotechnical engineering, the broad findings of this study are summarized as below:

Based on the geotechnical characterization, BKW resembles other geomaterials and has been classified as silt with appreciable sand (SM). Further, the chemical analysis carried out by many researchers has revealed the percentage of (SiO_2 + Al_2O_3 + CaO + Fe_2O_3) is greater than 70%, hence BKW can be grouped in the category of pozzolanic materials. However, the percentage of CaO in BKW is not sufficient for its self-cementing property.

- Quartz is the most prominent mineral of BKW in every study due to its high melting point.
- The specific gravity of BKW particles is typically low (less than 2.5) as compared to other geomaterials, therefore rendering its use as a lighter construction material.
- Due to the high sand content in BKW geomaterial, researchers have reported BKW as a non-plastic material (NP).
- The maximum dry density of BKW achieved in Proctor tests is low compared to other geomaterials due to its low specific gravity. Moreover, the optimum moisture content is high because BKW particles are porous and contain unburnt carbon.
- When mixed in certain proportions with the clayey geomaterial, there is a slight decrease in the maximum dry density with an increase in the optimum moisture content. Lesser unit weight geomaterials find their scope in geotechnical applications like backfill for retaining walls, material for construction of embankments, etc. Fur- thermore, a higher value of optimum moisture content allows the soil to be workable in a much wider range of moisture content without being sticky.
- BKW treated clayey geomaterials acquire low plasticity characteristics, thereby reducing the threat of volumetric changes in such soils and adding to the volume stability of such soils.

- BKW is a frictional material and can be blended with fine-grained soils to improve its shear strength.
- BKW can be added to the subgrade soils to improve their CBR value significantly.
- The reuse of BKW in the construction sector is a cost-effective and environmentally friendly option for its proper disposal.

5. RECOMMENDATIONS

- BKW is a pozzolanic waste material with similar geophysical features as other geo- materials. It can be used in certain percentages with clayey geomaterials for various geotechnical applications including subgrade for road and railway embankments, airfields, backfill material for retaining structures, and as a foundation medium for various civil engineering constructions.
- The optimum replacement percentage of various clayey geomaterials by BKW has been reported in the range of 20-40%.
- Triaxial testing should be carried out on BKW and BKW treated clayey geo- materials to assess the accurate determination of its shear strength parameters after simulating the in-situ state of stress, stress-strain behavior, and pore pressure response under undrained loading for a wide range of engineering applications.
- Limited research is available on the hydraulic conductivity of BKW and BKW treated clayey geomaterials. A study in this area could broaden its applications.
- There is hardly any work carried out on the consolidation characteristics of BKW and on BKW treated clayey soils. A study in this area can further extend its scope for applications in the field of geotechnical engineering.
- To protect the geo-environment, a comprehensive toxicity investigation may be performed on each kind of BKW before using it for any of its geotechnical uses.

CONFLICT OF INTERESTS

None

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None

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