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A review of soil improvement in problematic black cotton soil by using dry kota stone slurry and fly ash

Akshaya Pratap[1], Rajendra Kumar[2], Monika Yadav[3]
[1,2,3]Rama University, *Mandhana – India*

ORCID: [1]*0009-0008-5691-7420*, [2]*0000-0001-8680-7187* [3]*0009-0001-5687-5565*

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Abstract**—** Black Cotton Soil (BCS) is particularly rapid-expanding and swelling when it meets water. This trait of soil results in extremely low soil strength and other attributes. Soil stabilization by various stabilizers is required to enhance its characteristics. Stabilization is a technique used to improve the soil's structural integrity. Soil stabilization raises the subgrade's load-bearing capacity, allowing it to better support the pavement and foundation. It is accomplished by increasing the soil's shear strength and regulating its shrink-swell qualities. Expansive soils could have their engineering qualities enhanced via several different means. The problematic soils are either excavated and replaced with excellent, higher-quality material or treated with an additive. This paper analyzes soil improvement in problematic BCS using dry Kota Stone Slurry (KSS) and Fly Ash (FA). In thermal power plants, FA is produced as a byproduct of burning coal. It's made up of dust and ash that are swept up in the exhaust when fuel is burned. The findings highlight its potential to address soil-related issues, enhance agricultural productivity, and contribute to sustainable land utilization practices.

Keywords: black cotton soil, fly ash, kota stone slurry, soil stabilization, optimum moisture content.

*Corresponding author.
Email: rajendrab25@gmail.com (Rajendra Kumar).
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I. INTRODUCTION

Black soil, which is ideal for producing cotton, may be found in the western half of Madhya Pradesh, as well as in some portions of Karnataka, Andhra Pradesh, the southern part of Rajasthan, and pretty much everywhere else on the Deccan plateau and Utter Pradesh. Twenty-five to twenty-five and a half percent of India's land area is black cotton and open soil. BCS is particularly troublesome because its volume fluctuates negatively in response to variations in moisture content; specifically, it expands when it comes into touch with moisture during the rainy season and contracts during the hot and dry seasons [1, 2]. BCS is very unstable for building on due to its tendency to expand and contract, yet it is highly fertile and hence beneficial for farmers. The swelling and the shrinking tendency of expansive soil cause serious damage to light-loaded civil engineering structures such as homes, pavements, and linings [3].

Kota stones are often utilized for various purposes, including cladding walls, embellishing floors, etc. It is not easily damaged by oil or water, is not slippery, and has great stone resolvability. It could be purchased in both tile and slab form. Deposits of Kota stone could be found in the Kota region and other parts of the Jhalawar District in Rajasthan. A fine slurry is created when Kota stones are cut, ground, and polished in the stone industry. About 3 to 3.25 million tons of stone slurry are generated annually and dumped in easily accessible locations. Every year, this affects between 5 and 10 hectares of productive land. This garbage has a wide-ranging negative impact on the environment, the economy, and human health. The loss of soil fertility from elevated alkalinity, the pollution of aquifers, the health risks posed by airborne slurry dust particles, the accumulation of stone slurry in piles, etc., are only a few of the issues identified. To keep the saws and polishers running smoothly, water is utilized to cool and lubricate them, and the resulting slurry is called KSS. Powdered KSS has several applications, including filler, stabilizer, and pozzolanic material.

a. Soil Stabilization

The term "soil stabilization" discusses enhancing a soil's strength or bearing capacity using appropriate admixtures or stabilizers, such as controlled compaction. Stabilization could increase the soil's shear strength and control the soil's shrink or swell conditions to better sustain pavements and foundations. Stabilization is used in many different contexts, including but not limited to roads, parking lots, site development projects, airports, and many more. Whether it's expanding clays or granular materials, Stabilization could be employed to remediate the subgrade. FA, Rice Husk, Lime, Portland Cement, etc., are some of the ingredients used in this method. The benefits of soil stabilization include Stabilization could be used for a variety of purposes, including but not limited to those listed below: cost reduction, increased soil strength, prevention of hidden settlement, enhanced soil workability, decreased dust levels in the workplace and enhancement of the engineering features of soil to render it acceptable for building. Building a Dam or Reservoir, Laying Pipelines, and Paving Roads [4]. In the United States, sand/clay combinations were used in the first soil stabilization tests, completed in about 1906. Road construction soil stabilization techniques were first used in Europe in the 1930s and 40s of the 20th centuries [5]. Soil quality could be enhanced by adding Portland cement, FA, bitumen, or a mixture of these materials before fully mixing and compacting into the pavement [6]. The soil's categorization and the intended level of improvement determine the kind of addiction and the quantity needed [7].

b. Black Cotton Soil (BCS) and its types

When wet, BCS is very unstable due to its expansive nature and high fluctuations in volume [8]. These soils have a high clay concentration, making them swell in wet conditions and contract in dry ones. It is necessary to enhance the qualities of this soil to compensate for this deficiency. This soil is prevalent in the northeastern region of Nigeria, but its widespread coverage makes it impractical to either avoid it or locate a suitable alternative. BCS has traditionally been stabilized with lime and cement to improve its geotechnical qualities. It was shown by [9] that lime and lime admixed with cement significantly enhanced the geotechnical qualities of BCSs. The deployment cost as a stabilizer is high, even though the material's qualities have been much enhanced. Research engineers' attention has been piqued by the financial implications of addressing soil deficiencies by using locally accessible materials that have the potential to be both cost-effective and readily available [10]. Figure 1 depicts the architecture of BCS.

Figure 1: Structure of Black Cotton Soil.
Sourse: Own elaboration.

The idea of stability has existed for at least the last five thousand years. Ancient cultures in Mesopotamia and Egypt employed treated earth roads, while cultures in Greece and Rome used the soil-lime combination [11]. There are three distinct types of black soil, distinguished by the thickness of their layering:

Shallow Black Soil

Black soil that is less than 30 centimeters in depth is considered shallow. The Satpura hills of Madhya Pradesh, the cities of Bhandara, Nagpur, and Satara in Maharashtra, and the regions of Bijapur and Gulbarga in Karnataka are all home to this species. These soil conditions are ideal for growing rice, jowar, gram, cotton, and wheat.

Medium Black Soil

The average depth of 30–100 centimeters in medium black soil. It extends wider, including Tamil Nadu, Andhra Pradesh, Madhya Pradesh, Maharashtra, and Gujarat.

Deep Black Soil

The thickness exceeds 1 meter. It occupies a sizable portion of the lowlands of the Indian peninsula. Between forty and sixty percent of the mass is composed of Clay and has an alkaline response. The soil is rich and ideal for growing various crops, including cotton, sugarcane, rice, citrus fruits, vegetables, and so on [12].

c. Problem with BCS

India is home to several California Bearing Ratio (CBR) method creators. With both in-lab and on-site CBR measurements with BCSs, this approach requires a 15-kg surcharge weight to account for the soil type's tendency to swell. The swelling pressure and edema caused by BCSs range from 20 to 80 tons per square meter. Therefore, CBR values are neither credible nor supported by science since they are calculated by arbitrary methods [13]. It is quite unlikely that paved roads could have a total thickness of 830 millimeters under CBR 2% and commercial vehicle traffic of 4500 per day. So that it could fit into the greater soil area [14]. The crust thickness of the stiff pavement is between 300 and 320 millimeters, which allows for some flexibility. The thickness must be just a third as much for flexible pavement [15]. BCS seems to be a good fit for cement concrete pavement. This kind of pavement can potentially lessen the need for emergency repairs on the project. The alternative is to make use of semi-rigid substructures. First, the correct method must be explained, and only then can the crust's thickness be calculated. It would reduce the quantity of crust required. Extreme traffic causes damage to both the compacted berm and the uncompacted berm (which received no treatment). Trapped front ends have been known to cause catastrophic incidents involving huge vehicles. Therefore, BMS must be established as an alternative benchmark [16]. Common issues with BCS include:

- High Compressibility: When wet, BCSs are very flexible and compressible. The footing, while resting on such soils, experiences significant consolidation settlements.
- Swelling: When the natural water content of the soil is low, as it is during the dry season, the structure moves at different rates during the wet season. It leads to the lifting and cracking of buildings resting on such swollen soil. Swelling pressures must have reached a certain level before the structure could be used.
- Shrinkage: A building would have settlement and shrinkage cracks if constructed near the conclusion of the rainy season when the natural water content is high [17].

d. Distinctive Features of Black Cotton Soil

Soils with high compressibility and a color range from dark reddish brown to black, known as "BCS", could be found at depths of 0.5 to 10 meters. The following Table 1 records the often-observed features of BCSs [18]:

Table 1: Characteristics of a sample of BCSs soil in its raw form.

Properties	Values
Specific Gravity	2.55
Grain Size Distribution	
Sand (%)	7.80
Slit and Clay (%)	92.20
Maximum Dry Density (MDD) (gm/cm3)	1.57
O.M.C (%)	18.20
Liquid limit (%)	71.20
Plastic limit (%)	30.50
Plasticity Index	40.70
CBR (%)	1.71 (Soaked)

Sourse: Own elaboration.

e. Properties of Black Cotton Soil

Twenty-five percent of India is covered with BCS, making it one of its most common soil types. The BCS has a very clayey texture and ranges in color from Gray to black1. The weathering of volcanic and basaltic rocks is the primary source of BCS. The presence of titanium oxide gives BCS its characteristic color. It has been discovered that BCS contains a clay mineral called montmorillonite, which has strong expanding properties. In this test, BCS was transported from the Porbandar neighborhood of the Saurashtra area. There are patches of BCS along the western coast of the Gujarat state. Table 2 lists some of the index features of BCS [19].

Table 2: Properties of the BCS.

S. No.	Geotechnical Properties	Values
1.	Optimum Moisture Content	24%
2.	Soil Classification	CH
3.	Particle Size:	
4.	Maximum Dry Density	13.24 KN/m^3
	Fine Sand	0%
	Medium Sand	1%
	Gravel Content	0%
	Silt and Clay	99%
	Coarse Sand	0%
5.	Atterberg's Limits:	
	Plastic Limit	40%
	Plasticity Limit	25%
	Liquid Limit	65%
6.	Specific Gravity	2.65
7.	Free Swell Index	65%

Sourse: Own elaboration.

II. METHODOLOGY

In its methodology for the study, this SR conducts its research in accordance with the recommendations made in the Preferred Reporting Items for SRs and Meta-Analyses (PRISMA) statement. PRISMA is a simplified set of standards for publishing SRs and meta-analyses. It's commonly used for reporting purposes, especially considering how people's involvement affected the outcome. It can also maintain tabs on SRs that don't consider interferences but analyze factors like prevalence, diagnosis, and prognosis.

a. Search Strategy

This Systematic Literature Review (SLR) focuses on BCS, specifically on soil improvement in problematic BCS utilizing dry KSS and FA principles, and the associated advantages regarding dependability, trustworthiness, structure, and openness. Science Direct, IEEE, Springer, and Scopus are the four major academic literature collections from which the data is collected. SLRs are undertaken when a researcher needs information on studies that have already been done on a particular topic or area.

The databases were searched multiple times with identical keywords to discover the appropriate academic literature; the most current search was done on January 25, 2023. The abstract, title, and topic were analyzed to determine which keywords to utilize in an in-depth examination of Scopus along with other databases. The permissible submission categories included articles, reviews, conference papers, proceedings articles, and bibliographical pieces. Table 3 lists keywords that have been looked for in both Scopus and Near. Searches were also conducted using various misspellings of the terms. This group of documents included eight separate files. Table 3 provides a collection of terms together with their intended contexts.

Table 3: Search strategy keywords.

	Keywords
1.	What are the Black Cotton Soil and its types?
2.	What is the influence of dry Kota Stone Slurry and FA on the shear strength parameters of BCS?
3.	What are the effects of dry KSS and FA on the geotechnical properties of BCS?
4.	What are the key characteristics and properties of problematic BCS?
5.	Can dry KSS and FA mitigate the swell-shrink behavior of problematic Black Cotton Soil?
6.	What is the long-term stability of problematic BCS treated with dry KSS and Fly Ash?

Sourse: Own elaboration.

b. The Selected Journal for Research

On January 1, 2023, I checked Elsevier's "Engineering Geology" magazine to determine which articles had been referenced most often in prior research. Took advantage of limitless keyword searching. There were two types of findings: (1) those meant to prove the study's credibility and (2) those meant to gather information for choosing the most suitable journal to publish the study in. Product-name-based keyword searches enabled our team to identify enterprises that created one of the top five best-selling items in 2021 or ten or more separate devices in the first wave of new releases expected for 2022. Publications were categorized according to their subject using keywords that were extracted from the abstracts, titles, and approaches of the studies. This was done so that (1) more trial aspects could be identified and (2) irrelevant literature could be weeded out of the study. They compiled a comprehensive inventory of everything that may be considered a match and then sent out follow-up inquiries. At the very end, eleven additional people were added to the mix. In the results section, the team provides a summary of the findings and details the search keywords used to identify each item.

- Scrutinizing of paper for study

Primary Studies (PS) participants are selected through four stages: i) discovery; ii) acceptance; iii) inclusion; and iv) screening. The first step is to locate all pertinent research; the initial search yielded 1284 items. Conference papers were searched for in digital archives and libraries including Science Direct, Springer, Scopus, Science Direct and IEEE Xplore. After removing duplicates and sorting the data, they were left with 217 investigations, of which 28% investigated the detection of emotional stress, 17% verified scientific feasibility and consistency, and 33% were exploratory studies of innovative scientific applications and breakthroughs. The next phase is a cursory assessment based on the article's heading, key words, and abstract. The study scope and optimization topic-related exclusion criteria accounted for the vast majority of the 928 entries that were discarded. The suspect and the compromised papers were passed on for further inspection.

It is necessary to manually search the bibliography for all relevant publications and reviews. Additional records were also examined. To determine which studies would be included in the present SR, the authors read the abstracts and extra materials for each study and compared them to the inclusion and exclusion criteria in Table 4.

Table 4: Inclusion & Exclusion Standards in SR.

Inclusion Criteria (IC)	Exclusion Criteria (EC)
IC1. There has must peer review of the study.	EC1: Studies that do not report stress-related outcomes or do not include suitable measurements of stress reduction.
IC2: The language of the paper must be English.	EC2: Grey literature
IC3: No restrictions on when it could be published	EC3: Duplicate research and publications
IC4: Researchers and writers should submit their works to journals that publish entire studies.	EC4: Ph.D. Theses, working papers, and project deliverables
IC5: There was no consideration given to the impact factor in the standard of paper.	EC5: Studies without a relevant control group or comparator condition.

Sourse: Own elaboration.

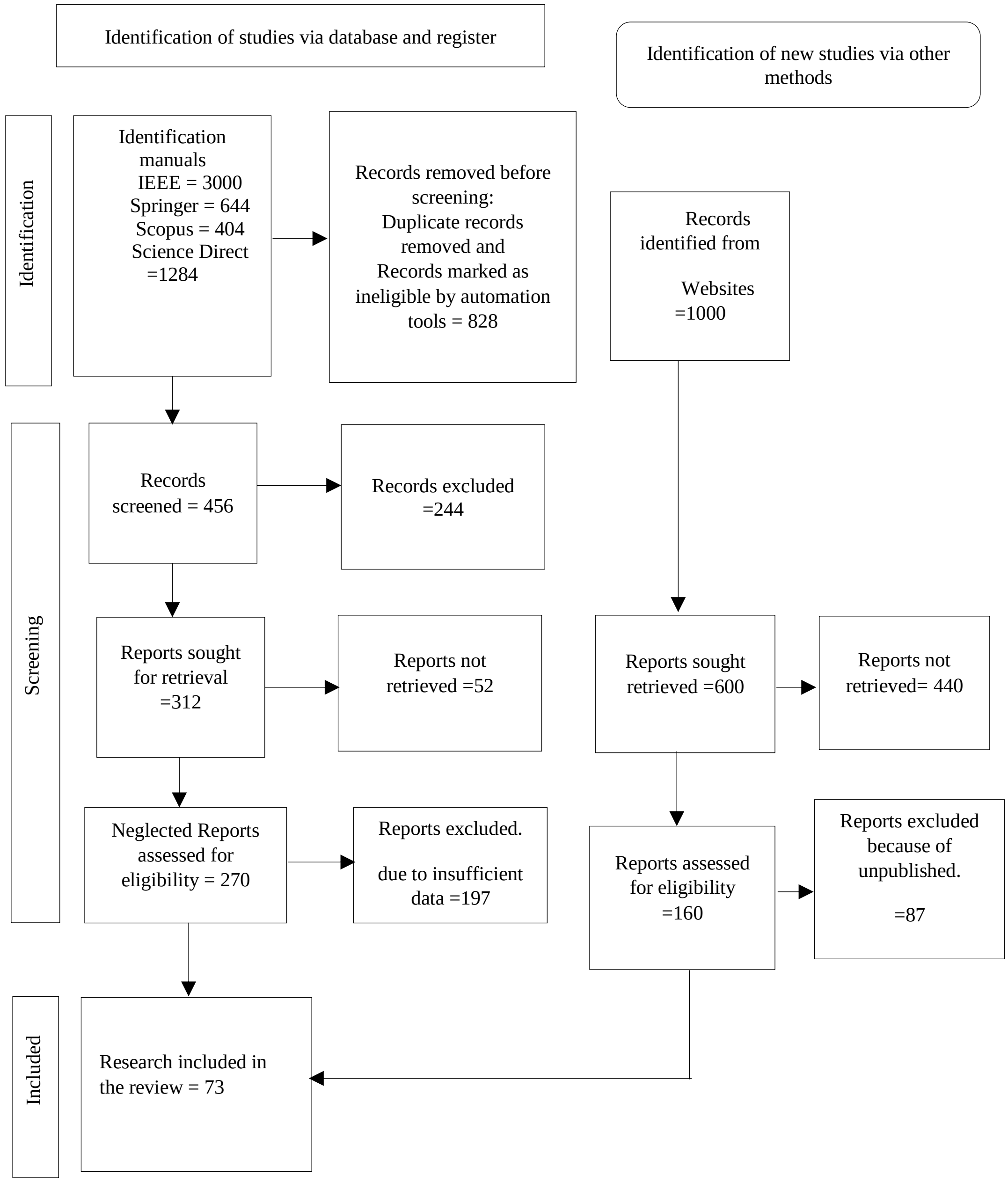

Figure 2: The procedure for doing a comprehensive literature search in a database.
Source: Own elaboration.

c. Objectives of the Current Study

The research objectives for analysis of soil improvement in problematic BCS using dry KSS and FA could include:

- Assessing the physical assets of problematic BCS: The research aims to examine the existing physical properties of BCS, such as moisture content, compaction characteristics, and swelling potential. This analysis will provide a baseline for evaluating the effectiveness of the proposed soil improvement techniques.
- Studying the impact of dry KSS on soil properties: The objective is to examine the additional properties of BCS. It may include evaluating changes in soil composition, particle size distribution, shear strength, and consolidation characteristics.
- Investigating the influence of FA on soil improvement: The research aims to reveal the impact of FA, a waste material from thermal power plants, on the engineering properties of problematic BCS. It could involve studying changes in soil strength, permeability, compressibility, and shrinkage characteristics after incorporating FA.
- Analyzing the combined effect of dry KSS and FA: The objective is to evaluate the synergistic effect of using both dry KSS and FA in improving the problematic BCS. The research could investigate the combined changes in soil properties, such as increased strength, reduced shrinkage, improved permeability, and enhanced compaction characteristics.
- Assessing the long-term performance and durability: The research aims to analyze the long-term behavior and durability of the improved soil using dry KSS and FA. It may involve studying the soil's resistance to weathering, erosion, and other environmental factors over an extended period.
- Developing guidelines and recommendations: Based on the research findings, the objective is to provide practical guidelines and recommendations for using dry KSS and FA as soil improvement techniques for problematic BCS. These guidelines could include optimum mix proportions, construction techniques, and maintenance practices for sustainable and cost-effective soil stabilization.

Overall, these research objectives seek to understand the effects of dry KSS and FA on the problematic BCS and provide insights into their potential as soil improvement materials.

The purpose of these SRs is to construct an open-source information platform to facilitate future research by aggregating and assessing key results from prior studies, characterizing and contrasting these findings, and calling attention to difficulties and caveats encountered during the research process. The existing state of knowledge was evaluated, and then research and analysis were carried out to enhance the soil in troublesome BCS employing dry KSS and FA. This section investigates and evaluates different sorts of researchers and their methodology considering the three primary research questions presented during the study's design phase.

RQ 1: How do adding dry KSS and FA affect BCS's compaction characteristics?
RQ 2: How does FA affect the engineering behaviors of problematic BCS?
RQ 3: What are the advantages of Black Cotton Soil?

To achieve these goals, we conducted an extensive literature review. Citation indexing databases and the Internet of Publications were scoured for works published over the preceding ten years that were relevant to the research subject using tools including Google Scholar, IEEE Xplore, Sage, MDPI, Science Direct, Emerald, and Springer Link. It was also researched online to find the best firms working on wrist-mounted gadgets. White papers, manufacturing manuals, and scholarly publications were used to weigh the findings.

III. LITERATURE OF REVIEW

This section draws on research from various published and theoretical sources and summarizes the comprehensive literature review.

Supraja et al., (2023) [20] suggested better use of expansive soil in construction by incorporating waste elements like FA and rice husk ash into BCS to make it more stable and resistant to shrinkage and swelling. Laboratory procedures such as the standard proctor test, liquid limit, plastic limit, CBR test, and others could be used to examine the material. The authors observe the influence of FA and rice husk ash on improving the performance of BCS. Therefore, a soil sample was mixed with FA at percentages of 5%, 10%, 15%, and 20%, and rice husk ash at percentages of 10%, 15%, 20%, and 25%.

Yin Z. et al., (2022) [21] analyzed technical properties of BCS stabilized with natural lime, Volcanic Ash (VA), and a mixture of the two. The results showed that the engineering properties of BCS were greatly improved by the addition of VA and lime. VA and lime were shown to be more effective in stabilizing BCS. After including 3% lime and 20% VA, the natural CBR values were multiplied by 10.76, the plasticity was lowered by 29%, and the swell percent was cut by 88%. The minimal swell, plasticity, and strength criteria are all met by stabilized BCS made with 3% lime + 20% VA. Therefore, it could be used in place of cutting and filling.

Paul A. et al., (2022) [22] examined the effects of mechanical and chemical Stabilization on BCS from the Eket senatorial district, which could expand and shrink. This analysis used a combined mechanical and chemical approach to Stabilization. The findings demonstrate that for all BCS from Etet, Ikot Abasi, and Eastern Obolo, the Optimum Moisture Content (OMC) of stabilized BCS rises in tandem with an increase in the partial percentage replacement of Bagasse Ash (BA) from 0% to 12%. The MDD increased simultaneously with increasing partial replacement of lime from 0% to 12% in stabilized BCS from the three sites in the Eket senatorial district, whereas the MDD decreased with increasing partial replacement of BA from 0% to 12% in stabilized BCS.

Tak D. et al., (2021) [23] suggested using the KSS powder as a stabilizing agent for BCS. The investigations concluded that incorporating a certain percentage of KSS powder into BCS improves its engineering qualities, such as its shrinkage limit, MDD, OMC, and Unconfined Compressive Strength (UCS). When the amount of KSS powder in expansive soil increases, its swelling properties, including a reduction in the swelling percentage and swelling pressure, are also enhanced. More than 20% slurry mixing reduces UCS value.

Chouhan H. et al., (2021) [24] examined the effects of varying the percentage of KSS to cement in mortar mixes (1:5) from zero to twenty percent in 2.5% increments. The energy needed to extract these resources and process and dispose of their waste was substantial. The fine fragments created during the polishing of stones pose a significant threat to human and environmental health. The nine mortar mixtures' density, compressive, flexural water absorption, tensile, and adhesive strengths were analyzed. The study found that the KSS could be used as a partial cement substitute (up to 10%).

Sharma R. et al., (2020) [25] demonstrated how Kota stone dust was successfully used to enhance the subgrade properties of BCS. MDD and OMC equal to 3% to 24% of KSS dust mixed with BCS in the variation of 3% were obtained using standard compaction tests performed in a laboratory. Laboratory CBR tests were performed using the above proportion of KSS dust after the determination of OMC and MDD of varying proportions, and the results showed that the soaked CBR value of BCS blended with 18% Kota stone dust augmented from 2.12 to 8.37, i.e., 295%.

Jangid A. et al., (2018) [26] focused on the behavior of BCS at varying concentrations. KSS concentrations ranging from 5% to 30% are incorporated into BCS for the proposed study. Tests are also used to establish engineering specifications. Atterberg's limits, a standard proctor test, a Differential Free Swelling (DFS) index, a swelling pressure test, and a wet sieve analysis are used to examine the behavior of BCS amended with varying concentrations of KSS.

Khatti J. et al., (2018) [27] addressed the issue of creating a flexible pavement utilizing BCS, Recron 3s fiber, and KSS in varying percentages (at least 15%). In this study, the Recron 3s fiber concentration ranges from 0.5 to 2.5 percent when combined with a KSS of 15 percent in BCS. The results of testing are also used to establish the engineering parameters. Atterberg's limitations, the standard proctor test, Sieve analysis, and the CBR are used to analyze the behavior of BCS mixed with various percentages of KSS for pavement.

Rathore A. et al., (2018) [28] calculated that using stone slurry waste makes the BCS more stable. The purpose of this study was to explore the influence of incorporating stone slurry waste into BCS in varied quantities on the material's strength, compaction, and compressive strength-to-loss ratio (CBR). Direct shear, compaction, and CBR were identified to be the fundamental features. The findings reveal that the BCS is significantly improved by adding stone slurry waste, demonstrating the efficiency of this commercial waste in this context.

Kulkarni A. et al., (2016) [29] presented an approach to stabilizing BCS utilizing a combination of BA and lime. Bagasse is the fibrous byproduct of burning sugarcane stalks left over after sugar is extracted. BA was shown to have pozzolanic qualities due to its high silica content and other pozzolanic elements, including potassium, iron, calcium, aluminum, and magnesium. This study compared the effects of lime, ash, and a mixture of the two on the characteristics of expanding clay soil. The objective is to affordably enhance the engineering qualities of the BCS so that structures erected on it can effectively resist applied loads.

Gohel D. et al., (2016) [30] purpose of this effort is to use FA and Lime to stabilize the soil. Testing has been performed with 5%, 10%, and 15% FA content, in addition to 4%, 8%, and 12% lime content. The soil tests used in this empirical research include the Unconfined Compression Test, Plastic Limit, Liquid Limit, Standard Proctor Test and CBR test, and their results vary according to the proportion of FA and lime in the soil. Hopefully, these efforts will lead to a boost in the BCS's engineering quality.

Rajput S. et al., (2015) [31] explain a test evaluating the effectiveness of increasing concentrations of FA in improving the qualities of expansive soil. Liquid limits, plasticity indices, and swelling indices have been shown to vary considerably. The percentage of voids filled by water (DFS) dropped from 52% to 14%, the liquid limit dropped from 55.2% to 36.3%, and the plasticity index dropped from 27.1% to 18.1% in expansive soil. After being compacted, the OMC was found to have increased from 19% to 23% and the MDD had decreased from 1.63g/cc to 1.52g/cc. The results of the tests suggest that the addition of FA might enhance the qualities of BCS.

Table 5 provides a summary of the related literature and the methodology the authors used in their study.

Table 5: Summary of Literature Review.

Authors	Techniques	Outcomes
Supraja et al., (2023) [20]	FA and Rice Husk Ash	Based on the findings, FA and rice husk ash could be utilized as soil stabilizers since they raise CBR after being soaked and before being employed by 5% and 10%, respectively.
Yin Z. et al., (2022) [21]	Stabilization	This study confirmed previous findings that lime, and VA substantially reduced BCS pliability.
Paul A. et al., (2022) [22]	Mechanical and Chemical Stabilization	When BA and lime admixtures were employed to stabilize BCS mechanically and chemically from the three sites, identical features in OMC and MDD were created.
Tak D. et al., (2021) [23]	Stabilization	The ultimate optimal blend of waste materials combined with BCS is an enhanced construction material that significantly saves costs in building flexible pavement design.
Chouhan H. et al., (2021) [24]	KSS	Based on the findings of this study, KSS might be utilized as a partial substitute for cement at a rate of up to 10%.
Sharma R. et al., (2020) [25]	KSS	UCS values are found to be at their highest on 15% mix specimens and to diminish following further KSS mixing.
Jangid A. et al., (2018) [26]	KSSP	The gravity of a mixture of KSS powder and BCS rises steadily with increasing percentages, while the impact is small.
Khatti J. et al., (2018) [27]	BCS with KSS	CBR values are as high as 10.15 percent and are achieved with a 2.0 percent fiber mix specimen combined with a 15 percent KSS in BCS.
Rathore A. et al., (2018) [28]	KSS	Therefore, it is established that the shear strength parameter of BCS could be increased by using a slurry composed of 15% Kota stone.
Kulkarni A. et al., (2016) [29]	BA and Lime	Based on the study's findings, it has been shown that a ratio of 2:3 BA to Lime is optimal for stabilizing BCS.
Gohel D. et al., (2016) [30]	FA and Lime	The highest value of UCS and CBR is achieved with an addition of 15% FA; as the percentage of FA in the mixture increases, this value decreases.
Rajput S. et al., (2015) [31]	FA	The findings show that the level of expansiveness has decreased to a modest level. According to the findings, FA can alter the properties of expansive Clay like BCS, making it ideal for various civil applications.

Source: Own elaboration.

IV. POLYPROPYLENE FIBRE (PPF)

A synthetic fiber made by polymerizing propylene, PPF is a linear polymer. It is advantageous in several ways, including its low weight, high strength, high toughness, and corrosion resistance. There are several applications for PPF, including the petrochemical sector, the energy sector, the apparel sector, environmental protection, and the building sector [32-34]. Concrete possesses various challenges in the construction industry due to its low tensile strength, poor fracture resistance and weak stress resistance. The permeability of the concrete is enhanced by the ease with which microcracks can be generated from the outside to the inside. The concrete's inside is highly permeable to water or other hazardous ions, which speeds up its breakdown [35]. The addition of PPF to concrete creates a 3-D random distribution network structure that inhibits the development of microcracks [36]. Therefore, the PPF could block the penetration of water and potentially damaging ions into the concrete. Adding PPF to concrete increases its durability [37, 38]. PPF's high-quality suits structural, pavement, and even hydraulic engineering [39]. Figure 3 also includes graphic representations of PPF [40].

Figure 3: Polypropylene Fibre [41].
Source: Own elaboration.

V. KOTA STONE SLURRY (KSS)

KSS is a byproduct generated during the cutting and polishing Kota stone, a popular natural stone used in construction and flooring applications. This slurry, which consists of fine particles and water, is usually considered waste, and disposed of without realizing its potential as a resource. However, recent research and practical applications have highlighted the value and benefits of utilizing KSS in various fields, including agriculture, soil improvement, and environmental conservation. Kota stone, known for its durability, attractive appearance, and resistance to wear and tear, is extensively quarried, and processed in regions where it is abundantly available. Large amounts of slurry are produced during the cutting and polishing processes, traditionally discarded as industrial waste, causing environmental concerns. However, recognizing the need for sustainable and eco-friendly practices, researchers and experts have started exploring the potential uses of KSS to minimize its environmental impact and maximize its value. The composition of KSS typically includes fine particles of stone, water, and trace amounts of chemicals used during the processing. These particles predominantly comprise calcium carbonate and other minerals in the stone. The slurry has a smooth, creamy consistency, making it suitable for various applications once its potential is harnessed. In recent years, studies and experiments have focused on utilizing KSS in soil improvement projects, particularly in addressing problematic soils like BCS. Figure 4 shows the Kota Stone Slurry.

Figure 4: Kota Stone Slurry.
Source: Own elaboration.

The unique properties of the slurry, such as its binding and stabilizing characteristics, make it an ideal candidate for enhancing soil stability, reducing erosion, and improving load-bearing capacity. Moreover, using KSS in agriculture has gained attention due to its potential as a soil amendment. The slurry's high calcium carbonate content can help neutralize acidic soils and improve pH levels, creating a favorable environment for plant growth. Additionally, trace minerals and micronutrients in the slurry can supplement the soil's nutrient content, promoting healthy plant development. Exploring KSS as a resource presents an opportunity to mitigate waste generation, reduce environmental pollution, and contribute to sustainable development practices. Recognizing the value of this byproduct and finding innovative applications can transform what was once considered waste into a valuable resource with wide-ranging benefits.

a. Human and Environmental Consequences of Kota Stone Slurry utilization

The mining sector has contributed to environmental issues due to poor waste management and inadequate planning [42]. The total dissolved solids and sulfates in the receiving water [43] rise when mining waste is placed in dry streams because the surface runoff [44] takes it downstream. Garbage harms the environment because it raises soil alkalinity, making it unsuitable for plant development [45, 46].

When garbage is dumped on the ground for long periods, it could influence the availability of groundwater because the microscopic slurry particles hinder the flow of the water as it percolates down the aquifers [47, 48]. The accumulation of stone slurry owing to poor disposal practices also detracts from the area's aesthetic attractiveness [49, 50]. Human health is negatively impacted when mining waste is dumped in excessive amounts. Incorporating this trash into the concrete production process can potentially reduce the high operational costs associated with waste management and treatment [51].

b. Physical and Chemical Properties of Kota Stone Powder

Kota stone is mostly sedimentary and may be found in a wide range of hues and textures. Due to the layered and distributed nature of stone deposits over well-formed weak planes, uniformly textured and smooth stone panels of varied thicknesses are possible. Kota stone has a softness rating of 3–4 on the Mohs scale of mineral hardness. It is ideal for use in the construction of concrete structures because of its low porosity and excellent water resistance. The KSS physical properties are shown in Table 6.

Table 6: Physical characteristics of KSS

Authors	Color	Specific Gravity	Water Absorption (%)
Jangid A. et al., (2018) [44]	Dirty Grey	2.35	15.6
Gautam et al., (2017) [52]	White	2.81	23
Chouhan et al., (2021) [24]	White	2.59	7.23

Source: Own elaboration.

The number of byproducts the flaggy limestone industry creates during stone processing approaches 10-12 million tons yearly. Water makes up most of the flaggy limestone, with just around 10% of flaggy limestone powder. Considering the magnitude of trash produced, there is an urgent need to reuse the rubble from stone construction projects to ensure the long-term viability and cost-effectiveness of the building industry. Table 7 presents t0068e Chemical Composition of KSS.

Table 7: Chemical composition of KSS.

Authors	Fe2O3 (%)	CaO (%)	SiO2 (%)	Al2O3 (%)
Lakhani & Tomar (2014) [53]	2.72	36.32	22.69	3.26
Hiren & Kumar Pitroda, (2017) [54]	-	38.86	26.67	2.20
Chouhan et al., (2021) [24]	1.94	37.85	23.5	3.10

Source: Own elaboration.

Burning pulverized coal in thermal power plants produces FA as a byproduct. It is a granular substance with particles ranging from submicron to 250 µm [55]. FA is interesting because its chemical composition, mineralogy, and reactivity vary greatly over particle sizes [56]. FA is favored over alternative materials in cement, concrete, and brick manufacture because of its pozzolanic property, tiny particle size, flow characteristic, and mix of crystalline and amorphous phases [57]. FA has various potential applications beyond simple filler material, including a reactive component. The production of geopolymers is one such application in which FA might be used as an active participant in a process [58].

VI. FLY ASH (FA)

Burning pulverized coal in thermal power plants produces FA as a byproduct. It is a granular substance with particles ranging from submicron to 250 µm [53]. FA is interesting because its chemical composition, mineralogy, and reactivity vary greatly over particle sizes [56]. FA is favored over alternative materials in cement, concrete, and brick manufacture because of its pozzolanic property, tiny particle size, flow characteristic, and mix of crystalline and amorphous phases [57]. FA has various potential applications beyond simple filler material, including a reactive component. The production of geopolymers is one such application in which FA might be used as an active participant in a process [58].

a. Physical and chemical properties of Fly ash

Fine powdery particles make up FA, generally spherical, solid, hollow, and amorphous. The typical gravity of coal ashes is roughly 2.0. However, this value fluctuates widely. Particle form, gradation, and chemical makeup are only a few of the components that contribute to this diversity [59]. FA could be categorized as sandy silt to silty sand depending on the distribution of their particle sizes. Most Indian coal ashes are silt-size, with a smaller percentage being clay-size [60]. FA's surface area and bulk density are high [61]. FA could range from orange to dark red, brown, or white to yellow, depending on the percentage of unburned carbon and iron [62, 63].

FA could be used in various ways, but its classification and selection are determined by its qualities. During the selection phase, it is crucial to keep a watch on the fineness and Loss of Ignition (LOI) of the FA [64]. In addition, distinct types of FA could be distinguished based on several additional physical and chemical characteristics. Several factors, including the kind of coal used, the chemistry and mineralogy of the mineral matter, the furnace's design and operation, and particle methods of control (such Sulphur Oxide (SOx) and Nitrogen Oxide (NOx) control technologies), all influence the final FA's physical properties [65]. Particle sizes for FA vary between 0.5 and 100 micrometers and are typically round. Researchers from various fields have examined the FA's physical characteristics in Table 8. These characteristics in the finished product affect properties, including workability, pumpability, water demand, and permeability.

Table 8: Physical properties of fly Ash [64].

Property	Huang et al (1995) [66]	Muhardi et al (2010) [67]	Maher & Balaguru (1993) [68]	Mitash N (2007) [69]
Specific Gravity	2.06	2.3	2.54	1.9-2.55
Moisture Content	0.53%	19.75%	13.60%	
Fineness	13.80% in No.325	0.6 - 0.001 mm		
Uniformity Coefficient			2.5	3.1-10.7
Permeability		4.87 x 10-7 cm/s	0.9 x 10-5 cm/s	10-5 - 10-3 cm/s
Maximum Dry Density		1.53g/cm^{3}cc	1.65 g/cm^3	0.9-1.6 g/ cm^3
Liquid Limit			16.8	
Coefficient of Consolidation		0.1 - 0.5 m^2/year		
Cohesion		3-34 kPa		Negligible
LOI	7.5			
The angle of Internal Friction		23°-41°		30°-40°

Source: Own elaboration.

The chemical components of FA are almost identical to those of Portland cement, as shown in Table 9. The primary on chemical basis, the four oxides (Silica Oxide, Al2O3, Fe2O3, and CaO) that make up both FA and cement (SiO2) are indistinguishable from one another. Natural pozzolan (class O) and FA (classes F and C) cement; Portland cement (class N) all include silica, although the relative amount of these compounds varies widely.

Table 9: Portland cement with fly ash chemical composition.

Chemical compound	**Pozzolan Type**			**Cement**
	Class N	**Class F**	**Class C**	
SiO	58.20	54.90	39.90	22.60
Al_2O_3	18.40	25.80	16.70	4.30
Fe_2O_3	9.30	6.90	5.80	2.40
Na_2O & K_2O	1.10	0.60	1.30	0.60
MgO	3.90	1.80	4.60	2.10
SO_3	1.10	0.60	3.30	2.30
CaO	3.30	8.70	24.30	64.40

Source: Own elaboration.

The proportion of lime (CaO) in Portland cement is much higher than in FA. The concentration of reactive silicates in FA was higher than that in Portland cement. Because of its pozzolanic activity, fly ash is recommended for use with Portland cement since it produces the same cementations compounds as Portland cement during hydration (see Figure 5) [70]. The Pozzolanic reaction inhibits efflorescence caused by free lime leaking out of treated concrete and gives strength at a similar time [71, 72].

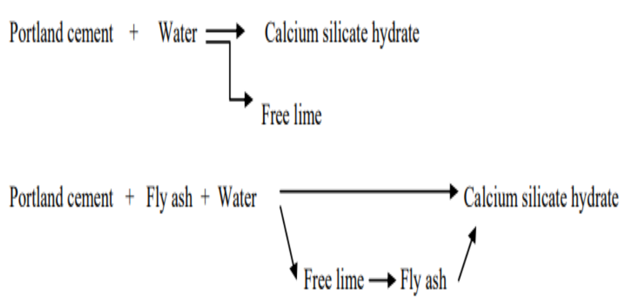

Figure 5 Reaction of fly ash in cement.
Source: Own elaboration.

b. Environmental Impact of Fly Ash

Using FA for soil improvement in problematic black cotton soil, combined with dry KSS, can have both positive and negative environmental impacts. It is important to consider these impacts to ensure sustainable and responsible practices. Here are some key points regarding the environmental impact of FA in this context:

I. Positive Environmental Impacts

Waste Utilization: FA is produced when coal is burned to generate electricity. Using FA for soil improvement reduces the waste material that would otherwise be sent to landfills, promoting its beneficial reuse.

Reduced Soil Excavation: Using FA in soil improvement reduces the need for traditional soil excavation and replacement methods. This helps preserve natural landscapes, minimize habitat disruption, and reduce the consumption of resources associated with soil extraction.

Reduced Carbon Footprint: FA has cementitious properties, which can reduce the need for energy-intensive materials like cement in soil stabilization. This substitution can reduce greenhouse gas emissions associated with cement production, thus lowering the carbon footprint of construction projects.

II. Negative Environmental Impacts

Heavy Metal Contamination: FA may contain trace amounts of heavy metals such as mercury, arsenic, and lead. If not properly managed and contained, these contaminants can leach into the soil and groundwater, posing a potential risk to ecosystems and human health. Following appropriate guidelines and regulations to safely handle and dispose of FA is crucial to prevent contamination.

Transportation Impact: FA is often sourced from power plants far from the construction site. Over long distances, transporting large quantities of FA can contribute to carbon emissions and air pollution. Minimizing transportation distances or considering alternative sources of FA can help mitigate this impact.

Environmental Monitoring: Regular monitoring and quality control measures should be in place to ensure that the utilization of FA in soil improvement does not result in unintended adverse effects on the environment. It includes monitoring potential contaminant leaching and assessing the treated soil's long-term stability.

To mitigate potential negative environmental impacts, adhering to relevant regulations and guidelines governing the use of FA and dry KSS is essential. Implementing proper handling, storage, and disposal practices, along with rigorous monitoring, can help minimize any detrimental effects and ensure the sustainability of the soil improvement process [73].

VII. CONCLUSION

Dry KSS, a byproduct of Kota stone manufacturing, could be used as a binding agent to efficiently stabilize BCS. It strengthens the soil's cohesiveness, lessens its flexibility, and diminishes its tendency to shrink or swell. FA, a byproduct of burning coal, has great pozzolanic qualities that improve the soil's strength, durability, and load-bearing capacity. The cementitious chemicals produced when FA interacts with calcium hydroxide in the presence of water improve the structural integrity of BCS. The combination of dry KSS and FA creates a synergistic effect, amplifying the benefits of each material. The mixture produces a stable and compacted soil mass that resists swelling and shrinkage, exhibits improved shear strength, and provides a solid foundation for construction projects. This review indicates that using dry KSS and FA for soil improvement in problematic BCS holds promise for enhancing its engineering properties and addressing its challenges. This approach offers a sustainable and cost-effective solution for soil stabilization, benefiting construction projects and the environment. Further study and field trials are recommended to validate and optimize the application of this technique in various scenarios.

VIII. CONFLICTS OF INTEREST

There is no conflict of interest.

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