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A Review On Stabilization Of Black Cotton Soil Using Industrial Waste (Copper Slag)

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Abstract

Soil stabilisation is necessary when the available soil for construction projects, such as black cotton soil, is not adequate for the intended application. In order to improve the strength and stability of a certain soil mass as well as other engineering and physical features, a process known as soil stabilisation is performed. For the purpose of a foundation, the soil must be solid and sturdy. However, the expansive nature of some soils, particularly black cotton soil, causes issues. cotton in black Montmorillonite is present in large concentrations in black cotton soil. Which is the cause of the expansiveness. These properties result in sudden soil cracks. When atmospheric conditions change, using this kind of land could seriously injure the building. The soil can be stabilized by applying an admixture that lowers its swelling potential in order to get rid of it. This article discusses a variety of soil stabilizing techniques. Some techniques, such as chemical stabilization and lime stabilization, have a negative impact on the soil's chemical composition. One of the most efficient methods for stabilization is to employ industrial waste. It has been shown that using waste materials for this purpose improves the geophysical characteristics of expansive soils. Industrial wastes such as cement kiln dust, saw dust, electrolyte lignin, fly ash, micro fine slag, copper slag, red mud, brick dust, polyvinyl waste, ceramic dust and other wastes utilized for soil stabilization are discussed here. Finally, we'll talk about the future aspects of usage of Copper slag, which is commonly utilized in civil engineering, may also be used to stabilize soil.

Keywords: Black cotton (BC) soil, Industrial Waste, Copper slag (CS)

1. Introduction

Most of the world's black cotton soil is located in Africa, Asia, Australia, and the South American subcontinent. It covers over 3% of the planet's land area. The Indian subcontinent, China, and Russia make up the majority of its part in Asia. Black cotton soil is primarily found in the southern region of India, which is a portion of the Deccan lava plateau and the Malwa Plateau. It takes up about 20 percent of the country's land area. [1]

The smectite group, which is quite expansive in character, makes up black cotton soil. Depending on the amount of moisture in it, its volume changes. In monsoon conditions, it expands as more water is added, while in dry summer weather, it contracts and develops wide surface cracks. This is why using it in constructions causes the biggest problems. The minerals in the soil, such montmorillonite, cause the BC soil to inflate and compress. A twice-tetrahedral layer sits between an octahedral core in the three-layer element known as montmorillonite. A weak bond between components, which can be damaged by water absorption, is one cause of swelling. [2]

The problem of a lack of earth material is currently affecting a significant number of construction businesses, including canal building, earth dam construction, road construction, railway ballast, etc. It became frightful when the existing soil was problematic, like black cotton soil. Transporting rich soil from a different location at that time would incur an additional cost. Stabilizing the current soil and enhancing its physical properties is a key remedy for this. One of the main solutions is to use cement or lime to stabilise the soil, however this has the drawback of being expensive and environmentally damaging. . Additionally, it has been proposed that soils with an excessive amount of lime or cement may develop carbonation shrinkage cracks. As a result, sulphate reactions occur quickly, making it challenging to reach the necessary strength without the addition of chemicals.[3]

CS is created when copper is extracted from copper ore. During this process, unwanted components are chemically or physically discarded, and the copper amount is steadily increased. After the waste products have been physically restrained from the mineral, the leftover copper extract must go through a series of chemical treatments to separate the iron and Sulphur. Smelting is the term for this procedure. Copper slag is a byproduct of the smelting process that is a waste product. As per [4] Nearly 2.2 times the amount of CS is received for every unit of copper metal created, and world copper production generates roughly 24.6 million tonnes of CS each year. Table 1 shows the primary CS producing locations and their amounts. [5]

Table 1. Production of copper slag

Territory	Copper slag (in million tonnes/annum)
Africa	1.23
South America	4.18
North America	5.90
Oceania	0.45
Europe	5.56
Asia	7.26

CS can be used as a binding material when mixed with soil to ameliorate poor soils. Like BC for use in highway embankments, subgrades, and sub-bases. The angularity of CS is considerable, and aggregates with a high friction angle (close to 52 degrees) help with strength and capacity to resist load.

2. Material

2.1 Black cotton soil

In BC soil moisture content changes result in volume changes. There is generally a volume gain while getting moisture, and a volume decrease when losing moisture. Swelling characteristics are usually strong in BC soils that is due to the clay mineral montmorillonite (a smectite). Silica (SiO_2) tetrahedral sheets and Aluminum (Al) or Magnesium (Mg) Oxide octahedral sheets are the major assets from which the clay is formed. Figures 1 depicted them.

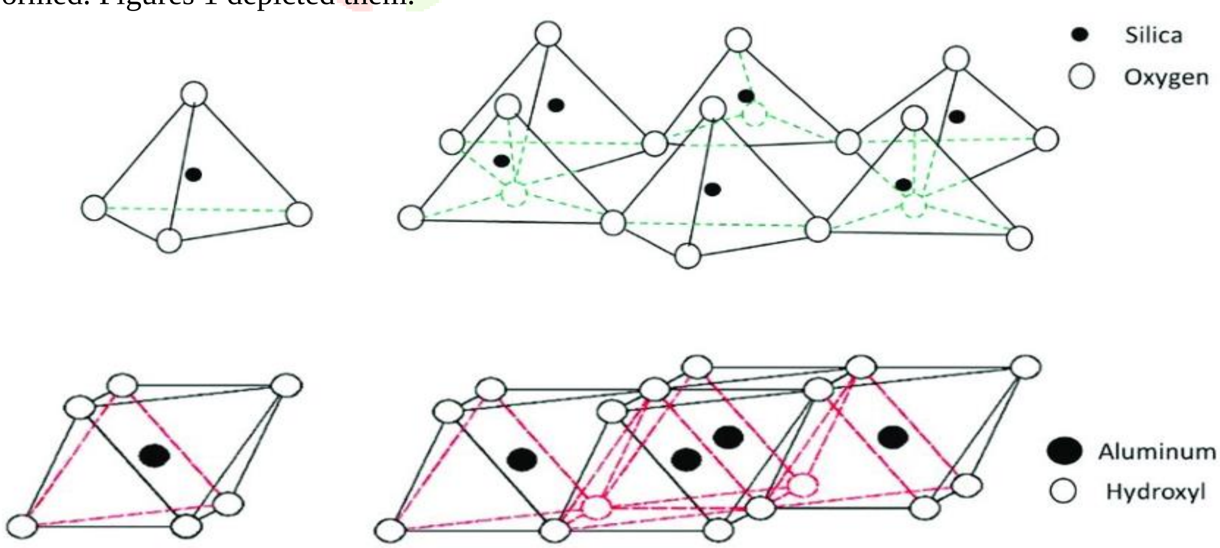

Fig1. Silica (SiO_2) tetrahedral sheets and Aluminum (Al) or Magnesium (Mg) Oxide octahedral sheets.

Montmorillonite is a three-layer element with a core octahedral sheet sandwiched with twofold tetrahedral sheets. The weak connection between the components, which can be broken owing to water absorption, is one cause of swelling. [6]

2.2 copper slag

CS is a granulated slag from metal smelting operations that is an abrasive blasting grit (also called iron silicate). Copper refining and smelting produce CS as a by-product. Refineries create a lot of non-metallic dust, soot, and rock when they extract metal from copper ore. Collectively, these materials make up slag, every day, Copper-manufacturing facilities in India waste a significant quantity of CS. A large quantity of collected slag is thrown and remained on expensive property, causing the loss of precious farmland. The United States Environmental Protection Agency, which regulates solid waste characteristics, classifies CS as a non-hazardous compound. It may be utilized for a surprising number of applications in the building and industries. CS's physical and chemical characteristics are shown in Tables 2 and 3. [7]

Fig 2. Copper slag

Table 2. Physical properties of copper slag

SR. NO	PROPERTIES	ANALYSIS
1.	Specific gravity	2.50
2.	Crushing value in %	20
3.	Impact value in %	22
4.	Abrasion value in %	19
5.	Bulk Density in kg/m3 Loose state Dense state	 1069 1188
6.	Water absorption in %	0.18

Table 3. CHEMICAL PROPERTIES OF COPPPER SLAG

SR.NO.	COMPOUND	ANALYSIS RANGE IN %
1	Cu	0.6-0.70
2	FeO	42-48
3	SiO_2	26-30
4	Al_2O_3	1-3
5	S	0.2-0.3
6	CaO	1-2
7	MgO	0.8-1.5
8	Fe_3O_4	1-2

3. Methods of soil stabilization

Soil stabilization is the act of altering the physical qualities of a soil so that it has the ability to reach the necessary strength. Because of the stability of the soil, a thinner foundation and pavement layer is required, resulting in cost savings. It also decreases the shrink/swell potential of the soil and the detrimental impacts of freeze/thaw cycles. Also Soil stabilization can reduce the need for costly remove-and-replace procedures, which can save money in the long run. [8]

There are 3 main methods for soil stabilization:

3.1. Mechanical stabilization

This category comprised physical activities like compacting or tamping using various equipment's such as rollers like sheep foot roller and pneumatic tyre roller and rammers. Another technique is to produce soil stability by mixing (adding or removing) various soil particles in order to establish efficient particle dispersion.

Fig No. 3 soil stabilization using sheep foot roller and rammer

3.2. Polymer Stabilization

The use of polymers to improve the physical and engineering characteristics of soils is known as polymer soil stabilization. The interaction of polymers with clayey particles in the soil increases the soil's strength, as well as its water retention capacity and shear strength. Biopolymers and Synthetic Polymers are the two primary kinds of polymers utilized for soil stabilization. Biopolymers are more environmentally benign than conventional chemical soil stabilizers. Geotextiles, Geogrids, steel fibers, and other soil stabilizing materials are examples.

Fig No. 4 Geogrid and Geotextile

3.3. Chemical Stabilization

Chemical stabilization refers to the employment of different chemicals such as cement, Cement Kiln Dust, lime, Bitumen, or other industrial products and waste to improve the stability and engineering qualities of soil. Soil stabilization is formed by a reaction between the chemical and the soil mineral particles structure. Cement, bitumen, lime, red mud, CS, polymer waste, fly ash, and other industrial waste are among them. Some of them are described in the following paragraphs.

3.3.1 Cement and cement kiln dust.

Cement is a composite material formed from limestone, sand, and clay that contains calcium, silica, alumina, and iron. All of them are processed, kiln-fired, and crushed into a fine powder. When cement reacts with water, it produces a hydrogel that surrounds soil particles in an interconnecting matrix, resulting in faster hardening and higher initial strength. Cement is an excellent alternative when there are sandy, coarse-grained soils, but there is a risk of undesired shrinkage cracking, which allows water to infiltrate and cause more damage. Some experts, such as [9], conducted tests on BC soil and discovered that using cement dust as a stabilizing agent for BC soil gives significant and long-term advantages. In comparison to lime and a mixture of lime and cement dust, the plasticity index of BC soil utilized with cement dust changes more significantly. However, a research was done by [10]. A FORTRAN-based first-order dependability evaluation was used to analyses the safety index of load carrying capacity of cemented BC soils treated with iron ore. Although the use of a cement–iron ore tailings combination to increase the bearing capacity of BC soil is not advised, but the observed trends have a significant impact on the plasticity index, shear strength, and bulk density. [11] In their study The efficacy of Cement Kiln Dust as a key stabilizing factor in combination with Quarry Fines for BC soil was examined. Plasticity, unit weight, and CBR were assessed in compositions comprising a constant dosage of 10% Quarry fines and varying amounts of Cement kiln dust (0 to 16 percent with a 4% increase). According to the findings, mixtures made with the suggested ratios are efficient in lowering plasticity features and raising CBR to levels acceptable with engineering performance goals, demonstrating the efficacy of this treatment approach.

3.3.2 Lime.

Quicklime (CaO), often known as lime, is the most effective soil-drying agent and improves soil engineering characteristics through modification. Lime's long-term strength benefits can persist up to a year since the first application. This type of stabilization provides the calcareous ingredient as well as the necessary different initial conditions for a wet soil to be permanently stabilized Lime is an alkaline that raises overall pH of the soil to the point where naturally occurring alumina and silica become dissolved. Once dissolved, they are ready to interact with the calcium in the lime and create pozzolonic linkages. As a consequence, we get calcium-silicate-hydrates (C-S-H) and calcium-aluminate-hydrates (C-A-H), which are more durable and improve the subgrade's resiliency. As per [4] There are volume variations in expansive soils with seasonal water changes. The authors' research revealed they used cement-stabilized and lime-stabilized CS as a cushioning layer over expansive soil beds to minimize heave in clay soil beds there is a greater reduction with a growth in the proportion of lime or cement in the cushion, or with a larger cushion thickness. Lime is more effective than cement in reducing heave when mixed with CS and used as a cushioning element above the expansive soil substrate.

3.3.3 Bitumen

Bitumen is produced by distilling petroleum or reforming petroleum products. It's a thick, gooey substance. Bitumen, unlike lime and cement, does not react with soil when added with it instead, it physically improves the soil by plugging in the gaps. The main drawback of bitumen is that it is a pricey substance, thus quantity is an important consideration. In comparison to sandy, coarse-grained soils, finely grained soils require greater bitumen dose rates to stabilize the soil. Bitumen soil stabilization creates a flexible, waterproof layer with increased load bearing capability. Other important parameters are viscosity and temperature. The best results are generally achieved once the bitumen seems to be the most viscous, allowing it to blend readily with the soil.

3.3.4 Industrial wastes

Industrial wastes such as saw dust, electrolyte lignin, fly ash, micro fine slag, CS, red mud, brick dust, polyvinyl waste, ceramic dust, and others have been studied as soil stabilizers. The main benefit of employing industrial waste in soil stabilization is that it is cost effective, and because we utilize it in civil engineering, it helps to safeguard the environment because if it was placed anywhere, it would result in the waste of valuable land. As per [12] research Using saw dust ash and lime, BC soil may be enhanced stabilized with as little as 4% lime, as opposed to simply lime stabilization, which requires a greater amount of lime to provide appropriate strength. [13] study reveal that, When Electrolyte Lignin, Fly Ash, or a blend of these compounds are applied to stabilize BC soil geotechnical characteristics including Atterberg limits, compaction characteristics, and permeability, these parameters improved. UCS has substantially improved the natural BC soil and by lowering the free swell index from 50% to 2%, the crucial bulging issue of BC soil has been solved. As per study [6] results The BC soil can also be stabilized with micro fine slag Micro-fine slag greatly enhanced the maximum dry density, plastic limit, unconfined compressive strength, and unsoaked CBR of the soil when combined up to 6–7% of the soil weight. [14] research discuss Industrial waste is being used to stabilize expansive (BC) soil. CBR value and other soil characteristics are improved by waste such as polyvinyl waste, CKD, red mud, CS, brick dust, fly ash and ceramic dust.

3.3.5 Copper slag

As previously stated, CS is a granulated slag from metal smelting operations that is used as an abrasive blasting grit. CS includes silica and alumina, and it may have pozzolonic characteristics that help to improve soil conditions. CS and CS admixture with other compounds have been studied by certain researchers. [15] were observed When soil was treated with CS and lime, the expansive soil's liquid limit and plasticity index were reduced by 40% and 55%, respectively, while the MDD was enhanced by 20%. The California Bearing Ratio amount was found to have risen by 502 percent. The addition of 19 % CS and 8% lime increased the modified soil structure subgrade flexible pavement's load bearing capacity by 392 percent. [16] has observation for the stability of BC soil admixture with a 5 to 30% increase in CS, Dry Density rises from 1.46 to 2.06. The increase in dry density is a whopping 48 percent. The unsoaked CBR value rises from 1.86 to 16.66, showing a 495 percent increase in CBR value. The soaked CBR value rises from 1.80 to 6.32, showing a 67 % growth in California Bearing Ratio value, with Augmentation of 30% CS with a rise in in % of Fly-Ash from 2% to 10% Unsoaked CBR value grows from 6.66 to 46.24, showing a 395 percent increase in CBR value. Unsoaked CBR value increases from 6.32 to 45.56, indicating a 247 percent increase in CBR value. As per [17] study, the conclusions are In a Tri-axial test, the absolute MDD increased and reached to optimum value, and the angle of shearing resistance was 48° for the blend of 50% Clay and 50% CS. The most satisfying combination for effective soil stabilization was 70 percent clay with 30 percent CS versus 30 percent clay with 70 percent CS. In [18] paper The impact of CS on the strength characteristics of cement-treated Singapore marine clay is studied by varying the quantity of CS up to 100% moisture content and continuous workability of the cement-clay combination. The UCS at 28 days curing time is found to be consistent when the workability of cement-treated clay with and without CS is maintained fixed. As a result, it appears that CS may be utilized to cure soft marine clay while using fewer cement and zero loss of strength is achieved. [19] explained that from an engineering standpoint, expansive soil is the most problematic. As a result, when these soils are utilized for building, they must be stabilized. As a stabilizing agent, CS and fly-ash were used. Dry density rises from 1.46 to 2.06 and CBR value rises to 495 percent when CS content rises from 5% to 30%. With the blending of 30% CS and an increase in Fly-Ash from 2% to 10%, the CBR value rises to 395 percent, indicating effective soil stability. [20] in his research found that the CBR value of a 30:70 combination of CS and BC soil is 9.1%. For subgrade, a minimal CBR value of 2% is necessary. (IRC: 37-2001). As a result this blend may be used as a subgrade material since it has a minimal free swell index of 38 percent. The permeability coefficient of the CS and soil mix (30:70) was determined to be 5.7 x 10^9 m/s. Permeability refers to a material that is virtually impermeable and may be utilized as a road pavement subgrade. Based on the outcomes of this study, CS might well be suggested as a suitable stabilizing material for enhancing soils for highway embankments. In places close to slag supply areas, using CS as a stabilizing agent may be cost-effective. Using CS in this way offers the added benefit of repurposing an industrial waste by-product while minimizing environmental impact and possible land use.

4. Research gap

According to a study of research, the majority of effort done on stabilizing BC soil is for road embankment purposes. We can work on CS stabilized soil for building and other applications in the future. Because of its usage in road embankment construction, the most common tests performed are CBR and UCS tests. In our practice, we will also do a swelling pressure test. The variance of adding CS is 10% in most studies, but we're looking for a 2.5 percent variation for a more accurate optimal number.

5. Conclusion

We may conclude from the foregoing overview of studies that black cotton soil, if adequately stabilized, can be used for civil engineering and geotechnical purposes. Copper slag is an excellent soil stabilizer, and utilizing it for geotechnical reasons can help alleviate the problem of industrial waste disposal.

The test findings show that as the percentage of copper slag addition grows, soil properties including Maximum Dry Density and Optimal Moisture Content, as well as the Unconfined Compressive Strength and California Bearing Ratio value, improve. The soil then becomes porous as a result of the extra coarser particles after adding more than 30%. As a result, we can remark that 30 percent copper slag addition is the best value for black cotton soil stability.

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