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Analysis of Nano Synthesis Based Enhancing Clayey Soil Behavior Using Biomass Char

Sri Balaji Palaniswamy[1], Banupriya Selvam[2], Ruthra Ramakrishnan[2*], Kalyana Chakravarthy Polichetty Raja[3], Pankaj Saini[4] and Gopal Kaliyaperumal[5*]

[1]*Consultant, NABCONS*

[2]*Department of Civil Engineering, St. Joseph's College of Engineering, Chennai, Tamil Nadu, India*

[3]*Department of Civil Engineering, Vels Institute of Science, Technology and Advanced Studies, Chennai, Tamil Nadu, India*

[4]*Department of Environmental Science, School of Basic Science and Technology, IIMT University, Meerut, Uttar Pradesh, India*

[5]*Department of Mechanical Engineering, New Horizon college of Engineering, Bengaluru, Karnataka, India*

***Correspondence to:**

Ruthra Ramakrishnan
Department of Civil Engineering,
St. Joseph's College of Engineering,
Chennai, Tamil Nadu, India.
E-mail: ruthraofficial@gmail.com

Gopal Kaliyaperumal
Department of Mechanical Engineering,
New Horizon college of Engineering,
Bengaluru, Karnataka, India.
E-mail: vkgopalme@gmail.com

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Abstract

Engineering structures built on weak or soft soil are considered dangerous. A variety of ground may be undertaken to improve techniques and improve the load bearing capacity of the soil. In the present investigation biomass char (BMC) is used as the stabilizing material which was randomly included into the soil at different percentages of biomass char content, i.e., 2.5%, 5%, 7.5%, and 10% by the weight of the soil. The investigation has been focused on the strength and CBR (California bearing ratio) behavior of soil with randomly included powdered biomass char. This BMC is analysed by proximate analysis and the parameters like fixed carbon, ash content, volatile matter, and moisture content is obtained. Comparison between soil and BMC added soil is presented. The test results are then compared with results from virgin samples, and conclusions about the suitability and efficacy of BMC are made. The addition of BMC powder was found to improve the soft clay soils with poor strength and high compressibility. We can draw the conclusion that BMC in powder form makes for an effective stabilizing agent. BMC is widely used in agriculture as a soil neutralizer, adsorbent, and soil additive.

Keywords

Stabilization, Biomass char, Proximate analysis, Unconfined compression test, California bearing ratio

Introduction

In foundation construction the role of soil is a crucial one, as it provides support for the foundation and the structure built on it. The properties of the soil, such as its composition, structure, and shear strength, have a direct impact on the stability and bearing capacity of the foundation. Soil has to be able to support the weight of the structure and any loads that will be placed on it, such as the weight of the building, wind loads, and seismic loads. The soil must also be able to resist deformation or failure and maintain its stability over time.

In order to design a foundation that will be stable and safe, it is important to have a good understanding of the soil conditions at the site. This can be done through soil investigations, which may include laboratory testing of soil samples and *in-situ* testing, such as cone penetration testing or standard penetration testing. The results of the soil investigations are used to determine the soil's properties, such as its composition, structure, and shear strength, and to identify any

potential soil-related problems, such as soil liquefaction or soil settlement. Based on the results of the soil investigations, the foundation design can be developed to take into account the specific soil conditions at the site. In some cases, soil improvement or stabilization techniques, such as the use of soil stabilizers or the placement of geotextile fabrics, may be necessary to improve the soil's ability to support the foundation and the structure built on it. The use of these techniques can improve the soil's shear strength, reduce soil settlement, and prevent soil erosion, among other benefits.

Soil stabilization refers to the process of improving the physical properties of soil to make it more suitable for construction or other engineering purposes. This can be done through a variety of methods, including adding chemicals, lime, or cement to the soil, or by mechanically altering the soil structure. Soil stabilization is often used to improve the load-bearing capacity of soil, to reduce settlement and erosion, and to increase the durability and lifespan of structures built on the soil. It can also be used to reduce the amount of settlement and settlement-induced damage that occurs during and after construction.

BMC is a type of solid material that is produced when organic matter, such as wood, agricultural waste, or other plant-based materials, is partially burned in a low-oxygen environment. The process of producing BMC is known as pyrolysis. Large quantities of volatiles are present in biomass, and pyrolyzed biomass produces a porous structure both inside and out [1]. The volatiles and levels of oxygen in biomass char are significantly lower than those of biomass, while the amount of fixed carbon is higher [2]. Silvani et al. [3] have examined pyrolysis emissions, the quality of biochar made from non-impregnated waste timber, as well as the potential application of such biochar for soil remediation.

In this, soil stabilization has been done with the help of powdered biomass char obtained from waste materials [4-6]. The focus has been placed on increasing the strength in shear and that various techniques have been used to compare and evaluate the resistance to shear forces. In the current examination BMC has been selected as the stabilizing material which was erratically included into the clayey soil at different percentages of BMC content, i.e., 2.5%, 5%, 7.5%, and 10% by the weight of the soil [7-9]. The examination has been engrossed on the compaction characteristics, shear strength, CBR and chemical behavior of soil with randomly included powdered biomass char. This BMC is analysed by proximate analysis and the parameters like fixed carbon, ash content, volatile matter, and moisture content is obtained.

Nanomaterials have emerged as powerful tools for enhancing the behavior of clayey soils in geotechnical engineering applications. One promising avenue for their utilization is in conjunction with BMC. These innovative combinations offer unique opportunities to improve soil properties and address environmental concerns simultaneously. In this context, nanomaterials like nano-silica and nano-clay have been found to enhance the mechanical properties of clayey soils, such as increased shear strength and reduced compressibility, when used in tandem with BMC.

One notable benefit of incorporating nanomaterials into clayey soil-BMC systems is their ability to mitigate the adverse effects of expansive clay soils. Expansive soils can cause significant damage to infrastructure through swelling and shrinking during wet and dry periods. Nanoparticles can modify the soil's microstructure, reducing its susceptibility to these volumetric changes and enhancing its overall stability. BMC, derived from organic waste materials, can further improve soil behavior by enhancing its organic matter content and promoting beneficial microbial activity.

Additionally, the use of nanomaterials in conjunction with BMC can contribute to sustainable soil improvement practices. By utilizing BMC, a waste product that would otherwise end up in landfills, we not only enhance soil properties but also reduce the environmental footprint associated with waste disposal. Moreover, the targeted use of nanomaterials allows for precise engineering of soil properties, minimizing resource consumption, and optimizing the effectiveness of soil improvement techniques.

In the integration of nanomaterials with BMC represents a promising approach to enhancing the behavior of clayey soils in geotechnical applications. These innovative combinations offer numerous advantages, including improved mechanical properties, reduced expansiveness, and environmentally friendly solutions. As researchers continue to explore and develop these technologies, they hold the potential to revolutionize soil stabilization practices, benefiting both construction and environmental sustainability efforts.

Materials and Method

Enhancing the behavior of clayey soils using nanoscale BMC is an innovative approach that combines nanotechnology and sustainable materials to improve the engineering properties of soils. Here's an overview of the concept and its potential benefits: Nanoscale BMC refers to fine-grained particles of charred organic materials derived from biomass sources such as agricultural residues, wood, or other organic waste. The char is processed and ground into nanoparticles or ultrafine particles with dimensions on the nanometer scale. This nanoscale material has a large surface area and unique properties that can influence soil behavior.

Nanotechnology has emerged as a groundbreaking field with vast applications, one of which is improving soil properties for construction and environmental purposes. This article delves into the analysis of how nanomaterials, specifically synthesized nanoparticles, can enhance the behavior of clayey soil when combined with BMC. Clayey soil is known for its poor engineering properties, including low strength and high compressibility. The integration of nanomaterials with BMC offers a sustainable and innovative approach to tackle these issues.

Nanomaterial synthesis

Nanoparticles, often derived from materials like silica, alumina, or iron oxides, are synthesized at the nanoscale to increase their reactivity and surface area. These nanoparticles are specifically engineered to address the unique challenges presented by clayey soils. For example, nanoparticles can be

functionalized to improve their affinity for clay particles and enhance their dispersibility within the soil matrix.

Synergistic effects

The combination of synthesized nanoparticles and BMC in clayey soil has shown promising results. Nanoparticles help bridge the gaps between clay particles, reducing their tendency to swell and improve soil cohesion. BMC contributes to improved porosity, drainage, and organic matter content. Together, they synergistically enhance soil behavior by increasing shear strength, reducing compressibility, and minimizing water retention.

Environmental sustainability

An additional benefit of this approach is its environmental sustainability. BMC is derived from renewable resources, and the use of synthesized nanoparticles in small quantities minimizes their environmental impact. This eco-friendly strategy aligns with the global push for sustainable construction practices and soil remediation methods.

Biomass char

BMC is a porous and highly carbonaceous material that has a number of beneficial properties, including high carbon content, high surface area, and low ash content. These properties make BMC an attractive material for a number of applications, including soil improvement, energy production, and carbon sequestration [10-12]. In soil improvement, BMC could be used as a soil amendment to increase soil structure and fertility, reduce soil erosion, and increase water-holding capacity. BMC can also help to reduce the amount of greenhouse gas emissions from soil, as it is a stable form of carbon that can persist in the soil for many years [13-15]. In order to find out the effect of BMC on clayey soil the different percentage of BMC content, i.e., 2.5%, 5%, 7.5%, and 10% by the weight of the soil were added.

Physical properties

Physical properties refer to characteristics of a substance that can be observed or measured without changing its chemical composition [16-18]. Physical properties include appearance, texture, color, odor, melting point, boiling point, density, solubility, and many others. Physical properties of BMC were tested and listed in table 1.

Chemical properties

A chemical property is any of a material's properties that becomes evident during, or after a chemical reaction. Chemical properties are the characteristics of a substance that describe its ability to participate in chemical reactions [19-21]. These properties cannot be determined by simply observing or measuring the substance, as they involve changes to the substance's internal structure and chemical composition. A chemical reaction results in a chemical change, where the substances are transformed into new compounds with different properties. The chemical properties of the BMC are listed in table 2.

Table 1: Physical properties of BMC.

Physical property	Value
Colour	Dark grey
Specific gravity	1.38
OMC (%)	10%
MDD (g/cc)	2.021
Volatile matter	13.6%
Ash content	56.5%
Fixed carbon	21.4%
Coefficient of curvature (Cc)	1.15
Coefficient of uniformity (Cu)	2.35

Table 2: Chemical properties of BMC

Chemical properties	Range of values (%)
Carbon (C)	34.08
Hydrogen (H)	4.33
Nitrogen (N)	5.34
Sulphur (S)	0.98
Oxygen (O)	19.69

Proximate analysis

The estimation of moisture, volatile matter, fixed carbon, and ash in coals, cokes, and chars has been done by proximate analysis [22-24]. In this investigation proximate analysis was conducted on BMC and results are shown in table 3.

Table 3: Proximate analysis of BMC.

Test parameters	Result (%)
Moisture content	8.51
Volatile matter	13.6
Ash content	56.5
Fixed carbon	21.4

Clayey soil

The clayed soil used in this investigation was taken at the Semmencherry (Chennai, Tamil Nadu, India). In the lab, experimental research was done to calculate the index and engineering parameters of the clayed soil. Laboratory tests were performed in accordance with Indian Standards IS: 2720-1987. Specific gravity, standard proctor compaction, and CBR are among the tests. Table 4 displays the clayey soil's characteristics.

Results and Discussion

Compaction characteristics

Figure 1 shows the differences in dry density for various BMC percentages at various water contents. The optimal

Table 4: Properties of virgin soil.

Type of soil	Clay of intermediate compressibility (CI)
Specific gravity	2.73
Liquid limits	40%
Plastic limits	10%
Plastic index	30%
OMC	12%
MDD	1.508 g/cc
UCS	1.215 Kg/cm2

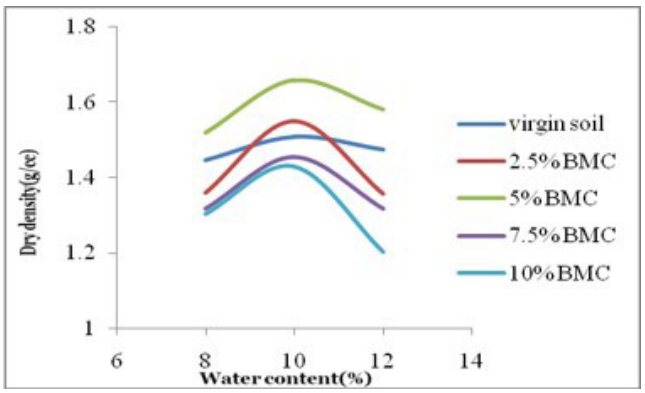


Figure 1: Effect of BMC on compaction characteristics of clayey soil.

moisture content (OMC) and maximum dry density (MDD) of the soil, as well as the soil with BMC combinations, were determined using the compaction tests. By weight of soil, different concentrations of powdered BMC in the range of 2.5%, 5%, 7.5%, and 10% were added, and traditional proctor tests were run on each of these combinations. With the help of test results which are shown in table 5 the compaction curves are plotted. In the compaction test it is very clear that as the percentage of powdered BMC increases the dry density. This is mainly because of the lightweight property of BMC. From the test result it is found that the max dry density of stabilized soil is 1.678g/cc and OMC is 10% is achieved at the soil with 5% BMC proportion.

Table 5: Compaction characteristics of virgin and stabilized soil.

Soil sample	Moisture content %	Dry density (g/cc)
Virgin soil	12	1.508
Soil + 2.5% BMC	10	1.550
Soil + 5% BMC	10	1.678
Soil + 7.5% BMC	10	1.455
Soil + 10% BMC	10	1.431

Strength characteristics

Unconfined compressive strength (UCS) tests were conducted as per IS: 2720 (Part-X) on both the soil samples S1 and S2 with various percentages of crumb BMC to determine the UCS value and to evaluate the suitability of soil stabilized with powdered BMC. The UCS tests were conducted on soil sample-powdered BMC mixture prepared at an OMC and MDD obtained corresponding to that particular soil-powder BMC mixture. The soil was mixed with crumb biomass of 2.5%, 5%, 7.5%, and 10% by weight of soil and UCS tests were conducted on these soil-powdered BMC mixtures. The stress–strain curve obtained from the UCS tests for different percentages of soil + powdered BMC mixture is plotted and shown in figure 2. The comparisons of UCS of virgin soil with stabilized soil having different percentages of BMC waste are explained in the table 6. Graph comparing the UCS of virgin soil and stabilized soil is done in figure 3. The UCS value increases with an increase in BMC content up to 5%. Thus, the UCS of the stabilized clay soil is 1.568 kg/cm^2. The consistency of clay is stiff as q_u lies between 100 to 200 kN/m^3.

California bearing ratio characteristics

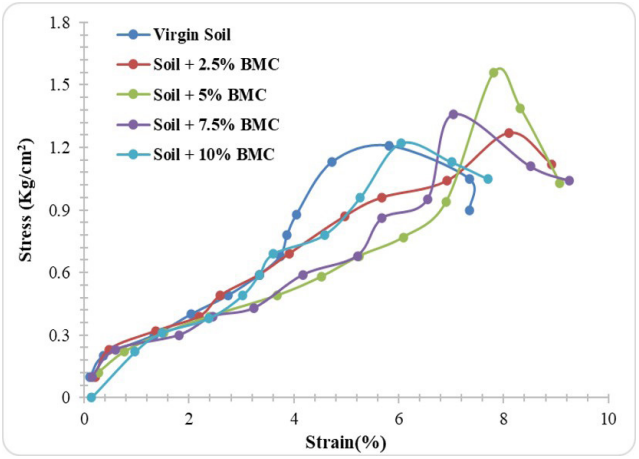


Figure 2: Stress vs strain for different percentage of BMC.

Table 6: UCS of virgin and stabilized soil.

Soil sample	Unconfined compressive strength (Kg/cm2)
Virgin soil	1.215
Soil + 2.5% BMC	1.270
Soil + 5% BMC	1.568
Soil + 7.5% BMC	1.368
Soil + 10% BMC	1.223

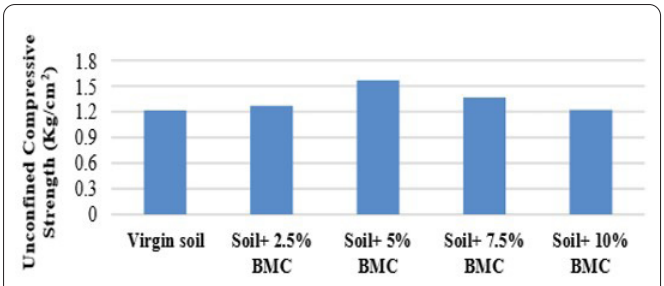


Figure 3: Comparison of strength characteristics of virgin with stabilized soil.

The IS 2720 Part XVI, 1987 is adhered to conduct the CBR test. The loading frame has a five-ton loading capacity and is equipped with a dial gauge with a 0.01 mm accuracy and a proving ring. On the base plate of the loading device's bottom plate, soil samples are inserted. To prevent soil upheaval, an annular surcharge with weight equal to that of the base material and the pavement is positioned. According to IS 2720 part XVI, 1987, the load is delivered at a strain rate of 1.25 mm/min. Strain gauges are used to measure penetration. At penetrations of 0.0, 0.5, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0, 7.5, 10.0, and 12.5 mm, loads are recorded. When standard loads are penetrated by 2.5 mm or 5.0 mm, the CBR value is represented as a percentage of the actual load. The CBR will be determined using the highest value for penetrations of 2.5 mm and 5.0 mm. The CBR is calculated as follows:

$$CBR = \frac{P_t}{P_s} \times 100$$

Where P_t is the customized test load for the selected penetration as determined by the load penetration curve and P_s stands for standard load at the same penetration depth.

Table 7: CBR value of virgin and stabilized soil.

Soil sample	CBR value
Virgin soil	1.9
Soil + 5% BMC	3.28
Soil + 10% BMC	2.18

The CBR values of stabilized soil with different proportions of biomass powder are explained in table 7. The variation of stress with penetration for different percentage of BMC is shown in figure 4 and table 8. Clayed soil being unfit for subgrade due to its low CBR values. CBR value also increases with an increase in BMC of 5%. Hence it will obviously reduce the thickness of the pavement. The CBR ratio for 5 mm exceeds the CBR of 2.5 mm and CBR is greater than 1. So, it

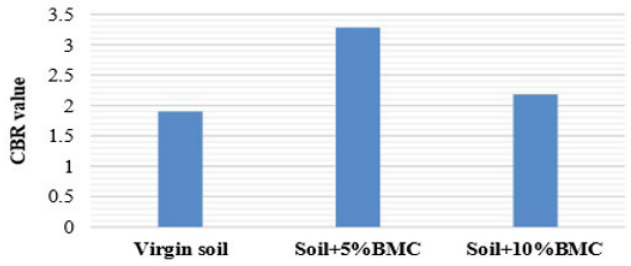


Figure 4: Comparison of CBR of virgin with stabilized soil.

fits for subgrade purposes. Figure 5 shows the variation of load with penetration for different percentage of BMC.

Conclusions

The adding of BMC increases the properties of clayey soil. The conclusions of the study are listed as follows:

- The clayey soil is classified as the intermediate plasticity (CI) with MDD and OMC of 1.508 g/cc and 12% respectively. The UCS and CBR of virgin soil is 1.215 kg/cm^2 and 1.9 respectively.
- BMC is chosen as stabilizer to enhance the shear strength property of virgin soil. The various proportions of BMC like 2.5%, 5%, 7.5%, and 10% by the weight of the soil were added. From the test result of standard proctor compaction, it is found that the MDD of stabilized soil is 1.678 g/cc and OMC is 10% is achieved at the soil with 5% BMC proportion.
- The value of shear stress increases by 20.57% at the optimal 5% of BMC in comparison to virgin soil. After that, the value of shear stress gradually drops as BMC is added. Thus, it is determined that 5% is the ideal amount of BMC to add to virgin soil.
- With BMC, there is an inherent difference in CBR. Strength gradually declines at the conclusion of 10% as BMC percentage rises after initial growth at 5%. With a 5% increase in BMC, CBR value likewise rises. The CBR is discovered to be 3.28% at 5% and 2.18% at 10%. This dirt may be utilized as a sub grade, according to Indian Road Congress IRC 37-2001. The addition of BMC changed the shear strength values c and. As a result, it is certain to thin down the pavement. The CBR ratio for 5 mm exceeds the CBR of 2.5 mm and CBR is greater than 1. Hence it fits for subgrade purposes.
- From the study it's found that, the usage of BMC in pavement helps to reduce the environmental impacts of disposing biomass as waste. Usage of BMC for soil stabilization greatly helps to reduce the use of other chemical agents like lime, cement and byproducts like fly ash and slag which has more problems like pavement failure and reduction in strength of building foundation.

Table 8: Load penetration value in CBR test.

Penetration (mm)	Load (Kgf)		
	Virgin soil	Soil + 5% BMC	Soil + 10% BMC
0	0	0	0
0.5	4.077	154.94	18.34
1	7.136	189.60	46.89
1.5	35.678	203.87	55.04
2	122.32	214.06	89.07
2.5	173.293	223.14	140.67
3	219.17	236.49	195.71
4	303.77	313.96	409.73
5	391.43	489.297	435.42

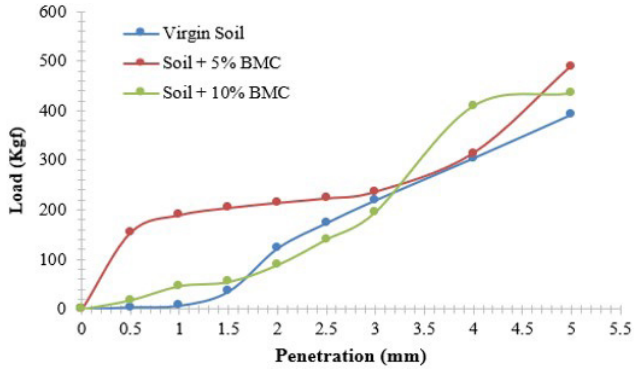


Figure 5: Variation of load with penetration for different percentage of BMC.

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Conflict of Interest

The authors have not faced any conflicts and declare that this study is relevant to the content of the article.

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