Influence of in-house produced biochar on geotechnical properties of expansive clay

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Abstract: The current study aims to explore geotechnical properties of expansive soil amended with in-house produced biochar. Biochar was produced in-house using slow pyrolysis (at constant temperature of 500 °C) of commonly available Prosospis Juliflora (invasive weed) in a muffle furnace. This study also motivates alternative use of Prosospis Juliflora, whose reduction can help to minimize transmission of malaria and also threat to biodiversity. The biochar was uniformly mixed with expansive black cotton soil at 5% and 10% content. Both basic and geotechnical properties (CBR and unconfined compressive strength) was determined for modified and unmodified soil samples. Based on results, it can be concluded that the plasticity index of an expansive soil is reduced significantly with an increase in biochar content. On the other hand, change in shrinkage limit was negligible. There is an increase in unconfined compressive strength and also reduction in free swell index of expansive soil amended with biochar. This is despite the significantly lower specific gravity and higher porous structure of biochar particles. The result is contrary to application of biochar in sandy soils in literature. The possible mechanism could be due to formation of bonds between negatively charged surface functional groups of biochar and positively charged ions of an expansive soil.

1. Introduction

Prosopis juliflora is considered as an invasive weed in many Asian and African countries, thereby creating a negative biodiversity [1, 2, 3]. The weed can easily survive in draught and saline environment and hence their growth is rapid in adverse conditions as well. In addition to the threat to biodiversity, Prosospis juliflora also enhances the transmission capacity of malaria [4]. It is therefore necessary to control the growth of Prosopis juliflora in order to preserve bio-diversity and also spread of malaria. One of the approaches could be to produce a value added product (i.e., biochar (BC)).

The BC obtained from this weed are generally utilized for enhancing agricultural productivity [5]. Recent studies [6, 7] indicate that the BC produced from Prosospis juliflora can enhance plant productivity and also adsorbs contaminant (Chorimum).

However, its conversion to BC for utility in geotechnical engineering infrastructures such as landfill cover, soil slopes [] is relatively less explored. Addition of biochar (5%, 10% and 15% by weight) to landfill cover soil enhanced the hydraulic conductivity and shear strength of the soil, while it decreases compressibility. These effects are further enhanced with a reduction in particle size of biochar [8].
Biochar has higher porous structure, which can enhance water holding capacity of sandy soil and also reduces its density and specific gravity [9]. Biochars from different production process contains varying carbon, volatile matters and ash content [10], that may further influence soil properties differently. Addition of biochar in soils can lower the pore-water pressure and can also provide resistance to liquefaction [11] and soil erodibility [12]. Addition of biochar can also reduce gas permeability by retaining more water in sandy soils [13].

As far as authors are aware, very few studies analysed engineering properties of expansive soil amended with biochar from Prosopis Juliflora [14]. Previous studies were conducted mainly on agricultural soil, which are generally less dense (65% degree of compaction) as compared to engineered green infrastructure (95% degree of compaction). Packing of soil particles could affect the interaction of BC particles and hence, any engineering properties of soil. Any alternative use of Prosopis Juliflora can also provide means of mitigating bio-diversity threat, thus lead to sustainable infrastructure development and long term carbon sequestration [15]. The gas properties of soil modified with biochar at different soil densities was studied using KNN modeling by Garg et al. [16]. The influence of in-house produced biochars on cracks and retained water during drying and wetting cycles are compared between conventional plant, animal and nano biochars [17].

The aim of this study is to explore the engineering properties (Unconfined compressive strength, Free swell index including basic properties) of an expansive soil amended with Prosopis Juliflora BC at two different amendment (5% and 10%). The results are interpreted with that of mineralogical characteristics.

2. Materials
In this study, expansive black cotton soil (BCS) was adopted. The soil consists of 72% fines (silt and clay) and around 27% sand. According to guidelines prescribed by Unified Soil Classification System, the soil was classified as highly compressible clay (CH). pH of soil was found to be 8.35. The soil mainly constitutes of positively charged ions including silica (42%), calcium (4.8%), sodium (0.78%), potassium (2.8%), magnesium (0.64%) and aluminum (13.8%). Liquid limit of soil was relatively high at around 62%. Plastic limit was found to be 20%.

In this study, biochar was produced in-house from Prosopis juliflora, which was produced by slow pyrolysis carried out in a muffle furnace [14, 18, 19]. The pyrolysis temperature was maintained at 500 °C. The biochar contains 55% particles of size less than 4.75 mm, 40% less than 2 mm and 5% less than 0.075 mm. Results of elemental analysis [20] reveals that carbon and nitrogen make up around 7% and 0.25%, respectively in biochar. The C/N ratio and cation exchange capacity of biochar was found to be 395 and 21 cmol/kg respectively.

3. Results and Discussions
This section describes the index and geotechnical properties of BCS with and without amendment. The black cotton soil consists of 68% of fine particles less than 0.075mm. Addition of biochar increases the percentage of fines in BCS. The specific gravity of pure biochar is 0.85, which is at least more than 3 times lower than that of soil. This indicates that biochar is a much lighter material than soil. The specific gravity is found to reduce with an increase in biochar content (i.e., 2.50 and 2.45 for 5% and 10%, respectively). The reason for decrease in specific gravity may be due to the fact that the organic biochar particles having lower dry density replace the expansive soil particles having a comparatively higher dry density.

Standard Proctor compaction tests (for density-moisture relationship) were also conducted on both modified and unmodified soils. Maximum dry density and corresponding optimum moisture content for BCS are 16.5 kN/m³ and 17.6% respectively. With an addition of biochar, a sharp reduction in MDD and OMC was observed. This may be because of presence of light biochar particles (i.e., lower specific gravity) [21] and also smaller tendency to compress at a given compaction energy [22]. The higher OMC is likely due to porous structure and hence, larger surface area of biochar.
Atterberg limits (Liquid limit, Plastic limit and Plasticity index) are determined for pulverised BCS and biochar amended BCS according to ASTM D 4318 (ASTM 2000a). The variation of shrinkage limit and plasticity index with biochar amendment rate is shown in figure 1. Biochar is found to be non-plastic in nature. The reduction in plasticity index implies that more cohesionless material is replacing the clay particles in the soil matrix. These results are different from that of biochar amended silty soil, wherein presence of biochar generally results in an increase in liquid limit and plastic limit [12]. Biochar amendment rate seems to have insignificant impact on shrinkage limit. This conclusion is similar to the findings from that of literature [12].

Free swell index of biochar amended BCS was determined so as to explore the swelling potential of soil. Free swell index was determined using guidelines prescribed in ASTM D2166-06. The test was conducted on 10 gram of BC blended soil passing through IS 4.75mm sieve in two graduated cylinders containing equal volumes of distilled water and kerosene. The free swell is reported as the percentage increase in volume of soil in water compared to kerosene after 24 hours of soaking.

Unconfined compressive strength (UCS) experiments were conducted on BCS and biochar amended BCS (Fig. 2) at a constant strain rate of 1.2 mm/min. Both modified and unmodified soil samples (at optimum moisture content and maximum dry density) were prepared in 38 mm diameter and 76 mm height cylindrical molds. Soaked CBR tests is were conducted for both modified and unmodified soil according to guidelines prescribed in ASTM D1883 – 16. Before conducting tests, soil samples were soaked in water for 4 days. A static load was applied at a constant rate of 1.25 mm/min on the specimen through a loading frame (50 mm diameter plunger). It is observed that soaked CBR values were enhanced almost 2 times with a gradual addition of biochar. The possible mechanism could be formation of bonds between positively charged clay particles [14] with the negative surface functional groups of biochar. This mechanism was supported by the absorbance through wavelength (1000-2000) due to an addition of biochar.

![Graph: Variation of PI and SL of BCS with % of biochar](image)

**Fig 1:** Variation of PI and SL of BCS with % of biochar
Fig 2: Variation of CBR (soaked) and compressive strength of soil with biochar amendment rate

4. Conclusions
Expansive soil exhibits significantly low volumetric stability in presence of moisture, rendering it unsuitable for foundations. The present emphasizes on stabilization of expansive black cotton soil by using biochar obtained from Prosopis Julifora. The use of Prosopis Juliflora contributes to a sustainable environment, by reducing the threat to bio-diversity as well the transmission of malaria.

Addition of biochar to BCS leads to reduction of plasticity index of soil by a considerable amount. The free swell of the soil also gets reduced due to chemical reaction of biochar with BCS, thereby rendering the soil to be stable against shrink/swell in presence of water. However, addition of biochar does not significantly alter the shrinkage limit of BCS. Addition of biochar has a significant effect on MDD and OMC of BCS. MDD decreases due to addition of biochar because of decrease of compressibility at a given compaction energy. High porous structure and enhanced surface area of biochar particles may be the cause of higher values of optimum moisture content in BCS. The CBR and the unconfined compressive strength values increased almost two fold in biochar amended BCS. This increase in strength may be due to the hydrophilic surface functional groups developed due to addition of biochar to BCS.

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