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# The Preliminary Application of Biochar in Geotechnical Engineering

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**Abstract**—Biochar is a carbonaceous material produced by the pyrolysis of biomass, which has a porous structure and a high specific surface area. In recent years, with a focus on environmental protection and sustainable development, biochar, a new type of environmentally friendly material, has received extensive attention and research. In geotechnical engineering, biochar can be used in soil improvement, contaminated soil treatment, and other fields but also in slope protection, landfill engineering, and other aspects. This review aims to look back at the current research status of biochar application in geotechnical engineering and look forward to future development.

## 1. Introduction

Biochar, a charcoal produced through biomass pyrolysis, has been recognized as a potential tool to address environmental challenges related to soil fertility, carbon sequestration, and waste management [2] [3] [4] [13]. In recent years, the application of biochar in geotechnical engineering has gained increasing attention due to its unique properties for enhancing soil quality and stability.

Biochar is a well-known substance that is valued for its high surface area. This kind of characteristic is due to its porous structure and adsorption properties. Depending on the feedstock and pyrolysis conditions, the surface area of biochar can range from 50 to 500 $m^2/g$. Because of its high surface area, biochar can effectively adsorb and retain nutrients, water, and pollutants in the soil. This results in enhanced soil fertility and the prevention of groundwater contamination. Numerous studies have shown that biochar can be used as a soil conditioner to improve the fertility of acidic soils. This method is primarily based on biochar, which has a porous structure and acts as a carrier [10]. Heavy metals in the soil can be solidified through the addition of microorganisms, as shown in Figure 1, which presents biochar application. Biochar can fix heavy metals in the pores by directly or indirectly changing the soil properties to prevent them from spreading to other areas through groundwater [11] [12].

Furthermore, biochar can alter the physical and chemical properties of soil, such as pH, cation exchange capacity (CEC), and water holding capacity (WHC) [3].

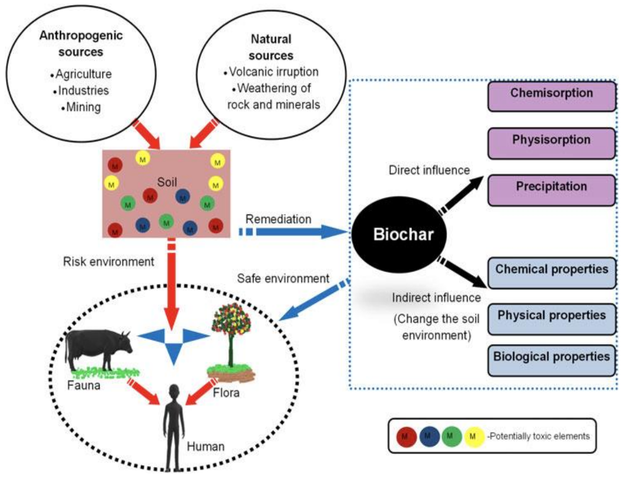


**Figure 1.** The Biochar immobilization process of potentially toxic substances (PTEs) in the environment.

Due to the presence of mineral components, biochar typically has an alkaline pH, which can neutralize acidic soils and increase the nutrient supply for plant growth [5]. Biochar also has a high CEC, which can promote the retention and release of nutrients in the soil [6]. Additionally, biochar can improve the WHC of soil, reducing the risks of soil erosion and drought stress [4].

In geotechnical engineering, biochar has been applied in various soil improvements projects, such as landfill cover systems, slope stabilization, and road construction [7] [8] [9]. Adding biochar to landfill covers can enhance gas diffusion, reduce leachate production, and improve the overall stability and safety of the landfill [7]. Using biochar in slope stabilization can increase soil shear strength, reduce soil erosion, and prevent landslides and soil settlement [9]. In road construction, biochar can be added as a stabilizer to the soil to improve the strength and

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stability of the subgrade and reduce pavement deformation and wear [8].

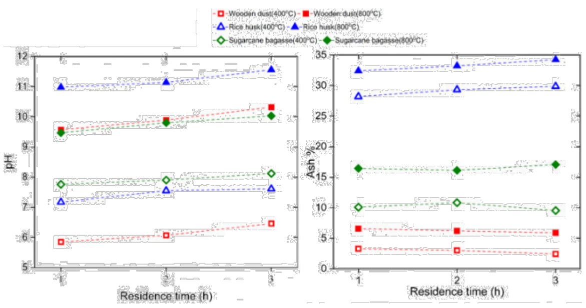
This branch of civil engineering deals with engineering problems involving geology, soil, rock, etc. It is an essential part of civil engineering. In order to ensure the stability and safety of engineering structures, this project studies the physical and mechanical properties of soil and rock and their impact on engineering buildings. A series of excellent biochar properties can improve soil quality and enhance stability. In view of the fact that such reviews are relatively rare, this study only reviews research on the influences of biochar production and its applications in soil improvement and geotechnical engineering to suggest problems and helpful suggestions.

## 2. Soil Improvement with Biochar

In the realm of geotechnical engineering, implementing the use of biochar in soil can bring about a multitude of benefits. These advantages include amplified compressive strength in the soil, diminished expansion and shrinkage, heightened stability, and reduced deformation and settlement. Geotechnical engineering benefits from it.

Notability, biochar increases soil's porosity and permeability and improves the facilitating drainage and anti-seepage. Those benefits mentioned above all lead to enhance soil quality. When biochar is used as a soil amendment, it can improve the soil's physical structure, which makes the soil looser and more conducive to plant growth.

Biochar shows the potential of improving soil fertility, which in turn allows plants to be planted on slopes, increasing the impact of slope anti-scalability. Temperatures of pyrolysis and raw material sources affect the functional performance of biochar. The following figure (Figure 2) illustrates the effects of different pyrolysis temperatures on the final biochar product's pH value. The pH value of the final product is alkaline except for the wood ash that is thermally cracked at a low temperature (400 °C).




(a)

**Figure 2.** The pH value, surface area of different raw material biochars after pyrolysis at different temperatures. [1]

As part of their research, Gupta et al. performed mechanical tests on biochar samples formed under various curing conditions with or without biochar samples and water-available porosity to compare the strength of single compression, flexural strength, splitting tensile strength, water permeability, and absorption [26]. This study used wood saw powder to pyrolyze under different temperature conditions (300 °C and 500 °C) to produce two different biochars ( Figure 3).


**Figure 3.** (a) Wood saw powder used in the preparation of biochar; (b) Preparation results of biochar. [26]

Figure 4 shows the results of the compression test. Figure 4a gives a sense of the sample's compressive strength under wet curing, and Figure 4b displays the sample's compressive strength under dry curing. It can be found that the strength of the sample after wet curing is higher when compared with the two figures.

There was a significant difference in compressive strength between samples that were added to biochar that had been pyrolyzed at different temperatures and samples that had not been added. Saturated biochar increases the strength of the modified sample compared to unsaturated biochar and lower temperatures. This phenomenon is because the pores of the pre-impregnated biochar are filled with more water, which can make the hydration reaction of the concrete curing process longer and improve the development of its strength.

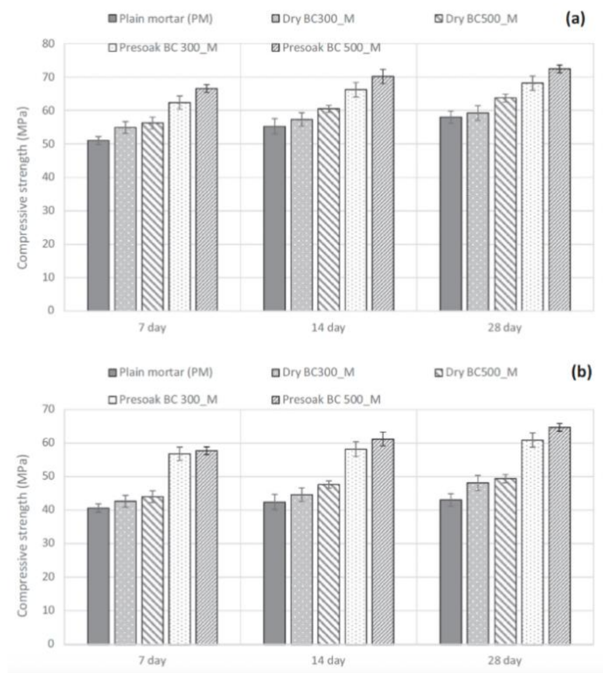



**Figure 4.** Results of compressive strength of different modified specimens. [26]

In a six-year field study of hillside farmland in the Sichuan Basin, Tuyishimire et al. (2022) investigated the effects of honeysuckle planting and biochar application on soil structure and hydraulic properties [14].

A variety of parameters were used to determine soil structure (soil organic matter ,so called the SOM; aggregate soil's stability, bulk density) and permeability. It was demonstrated that planting honeysuckle alone increased the SOM content, and planting honeysuckle with biochar improved the SOM content to a greater extent, as well as a significant increase in SOM content in deep soil (20 cm - 30 cm and 30 cm - 40 cm). Biochar increased the SOM concentration in the top 20 cm of soil. Combining honeysuckle planting and biochar amendment can improve the stability of soil aggregates. Additionally, the biochar modifier increased K-s directly or indirectly by increasing the SOM. Furthermore, honeysuckle planting and biochar amendments increased saturated soil water content more than saturated soil hydraulic conductivity.

It should be noted, however, that the value of the SOM in bare land was significantly lower, suggesting that both honeysuckle planting and biochar may improve the soil quality by increasing the amount of the SOM in it.

## 3. Biochar Used in Landfill Projects

Wani et al. discuss using biochar as a soil amendment in geoengineering. Biochar has many advantages and is widely used in agronomy, environmental management and geoengineering [15]. A total of 180 studies were randomly selected from 1996 to 2020 to assess biochar's role in geoengineering. Research papers and parameters were collected using the snowball approach. The main objective was to analyze critical gaps in the research on biochar for soil stabilization in geoengineering applications. Despite this, the production and application of biochar are still confined to the laboratory and require larger-scale research. Several studies have demonstrated conflicting results regarding the effect of biochar application; for instance, some studies suggest that biochar increases soil water retention capacity, while others suggest the opposite.

Further considerations must be given to the properties and cost-effectiveness of biochar, such as its negative impacts, its in-situ application in compacted engineered soils, and its cost-effectiveness in preparation and application. It will be necessary to develop preliminary guidelines on appropriate and optimal biochar percentages for use in green engineering infrastructure in the future. In addition, the study needed more information regarding the availability and properties of biochar feedstock, its cost-effectiveness compared to other soil stabilization options, and its useful life.

Sun W. and Li M. presented the use of biochar to improve the traditional clay cover of landfills to reduce methane emissions into the atmosphere. They also discussed the effects of particle size and biochar content on the air permeability characteristics of the improved soil [27]. It is an ideal material for soil improvement as it has a porous structure, high specific surface area, and strong adsorption properties (Figure 5). Adding biochar can change the pore structure of the soil, thereby improving the mobility of gas in the soil. Although the mechanism affecting landfill overburden's gas flow characteristics remains unclear, environmental factors still play a role in that field.

**Figure 5.** Morphological characteristics of biochar and clay. (From the Internet)

A flexible wall gas phase permeation test device was used to evaluate the air permeability characteristics of biochar-clay mixed soil in this study (Figure 6). By combining nuclear magnetic resonance technology, the gas permeability coefficients of mixed soils and the change laws of soil pore size distributions were analyzed.

Results of the study indicate that for a biochar-clay mixed soil whose dry density has not fallen below 90% of clay's maximum dry density, it contains the optimal amount of biochar, and its gas permeability coefficient reaches the lowest level. The gas permeability coefficient decreases with the increase of biochar when the amount of biochar is less than the optimal value; the increase in biochar causes the gas permeability coefficient to decrease gradually with the increase in biochar.

By comparing the gas permeability coefficients of biochar and clay mixed soil in non-intersecting particle size groups. It is easily to observe a gradual decrease as the biochar particle size is reduced. This study provides guidelines for selecting biochar content and particle size for the design and construction of biochar-modified clay final covers in landfills.


①—Air source; ②—Aqueous gas storage tank; ③—Digital fine-tuning regulator; ④—U-shaped tube (accuracy: 10 Pa); ⑤—water pressure controller;⑥—pressure chamber;⑦ sample

**Figure 6.** Flexible wall gas phase permeation test setup

Matovic compared Canada's carbon emissions from 1990 to 2008 and biomass energy production in a year(see figure 7), which was strongly suggested by the researcher that Canada could generate electricity by burning biomass to reduce carbon emissions [17]. For emissions, this study only briefly describes the issues related to whether biochar can be used for carbon storage in Canada. It does not mention detailed storage technologies or related methods.

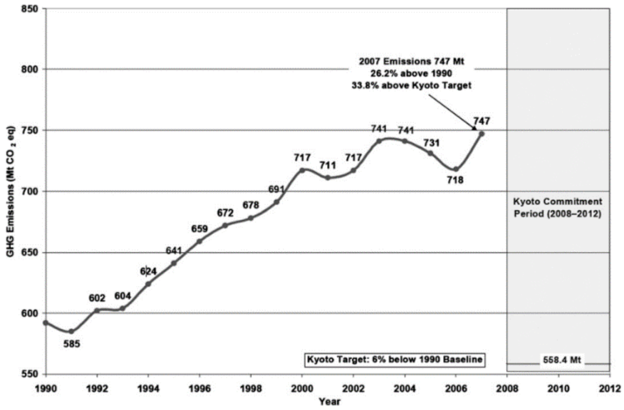



**Figure 7.** Statistics of Canada's carbon emissions over the years. [17]

Woolf et al. believed biochar could mitigate greenhouse gases in the future [18]. This is mainly through the thermal cracking of biological waste generated to produce biochar and its by-products such as bio-oil, natural gas, and process. The heat generated can be applied as an energy source that humans can use again. Biochar can be utilized as a soil improver to improve land with poor fertility due to its characteristics.

Composing it into the world's carbon cycle through nature is complex, so that it can be applied to carbon sequestration (Figure 8). This study uses three different models to simulate carbon emissions estimation under different scenarios. It compares carbon emissions reduced by biochar for analysis.

This study used sensitivity analysis and the Monte Carlo method to analyze biochar production. The variables analyzed included raw materials from different biomass sources, as shown in Figure 9.The left side of Figure 9 displays the amount of carbon that can be avoided and the amount of carbon emitted by eight raw materials used as biochar. The avoided emissions are positive, and the generated emissions are harmful. The right side of Figure 9 shows the combined results of biochar and biomass combustion. The results show that turning existing biomass into biochar can reduce greenhouse gas production and emissions.

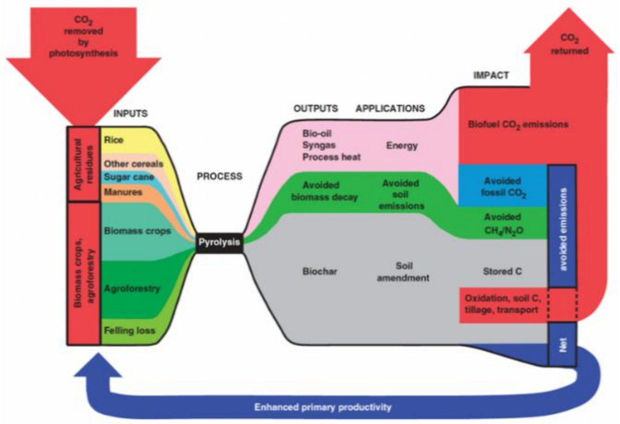



**Figure 8.** Conceptual flow chart of carbon sequestration via biochar. [18]

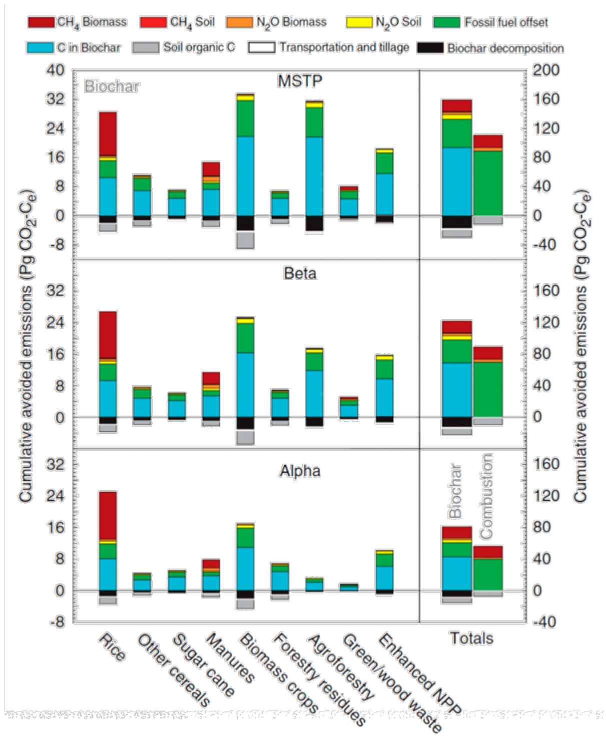



**Figure 9.** The results of predicting the greenhouse gas emissions [19]

Fuss et al. and others sorted out seven technologies currently related to harmful emissions, including carbon capture, bioenergy, afforestation and reforestation, direct air capture and storage, enhanced weathering, ocean fertilization, biochar, and soil carbon sequestration [19].

Other seven technologies are reviewed. Figure 10 calculates the amount of carbon emission reduction to quantify the potential index of this technology and its cost. This is the basis for this review. Although biochar is quite effective in reducing emissions, it is too expensive for its high price and cannot be used. Large-scale biochar production and sequestration require long-term underground storage, and the impact on local microbial systems cannot be estimated. Therefore, more research is still needed on this technology.

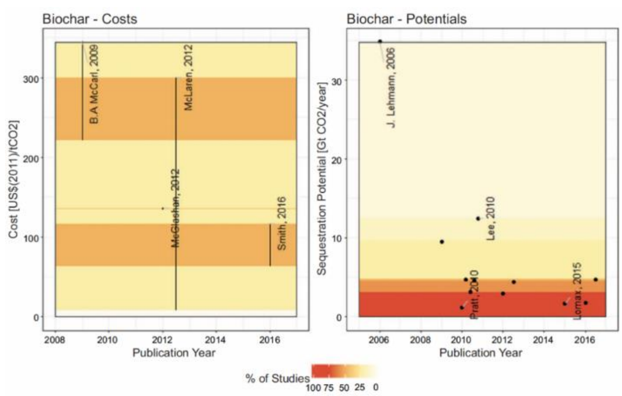



**Figure 10.** Assessment of negative emission potential of biochar. (Fuss et al., 2018)

## 4. Conclusions

This review aims to provide an overview of how biochar technology, which has emerged in recent years, can contribute to geotechnical engineering. Additionally, it reduces carbon emissions. Biochar improves the physical and mechanical properties of the soil as well as permeability and benefits plant growth and slope protection [10] [11] [21] [22] [23] [24] [25]. Biochar can also be used as a soil improvement for landfill projects and as a concrete amendment. Biochar improvement can strengthen soil structure and increase soil water retention, which can be utilized as a basis for future green development.

As an environmentally friendly material, biochar has broad application prospects and is of tremendous research importance in geotechnical engineering. It is imperative to study biochar's physical and chemical properties and application effects in the future. Exploring more innovative application methods should also be pursued, as well as promoting their development and application in geotechnical engineering.

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