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Effect of Biochar for the Remediation of Heavy Metal Contaminated Industrial Site Soil

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Abstract. Biochar is a highly porous, organic material derived from wood, manure or plant based biomass through pyrolysis under limited oxygen environment. The purpose of this study is to evaluate the remediation potential of biochar on heavy metal contaminated soil. With the increase in industrial activities, soil pollution is becoming very serious and it is causing serious harm to the ecological environment. The soil used in this study was collected from the vicinity of Travancore Titanium Products Ltd., Trivandrum. Biochar, being a highly porous substance, has the ability to absorb and immobilize both organic and inorganic pollutants in contaminated soils. In this study; biochar was used as a remediating agent and the strength of the remediated soil was tested at different percentages of biochar. The remediation potential of biochar was assessed through column leachate tests and the shear strength of the remediated soil was analyzed using direct shear tests. The compaction properties of the biochar amended soil and the variation of the pH values with the addition of biochar were also studied. The results of this experimental study showed that the amendment of biochar in the heavy metal contaminated soil will help in the remediation of heavy metal contaminated soil.

Keywords: Contaminated Soil; Lead and Zinc; Direct Shear Test; Column Leachate Test

1 Introduction

Soil contamination can occur due to a number of reasons like bursting of underground pipes, leakage of tanks, use of fertilizers, percolation of landfill leachate to subsurface strata or direct disposal of industrial wastes to the soil. The heavy metals such as Lead, Cadmium, Zinc, Nickel, Chromium etc are highly toxic to human beings and animals. A large number of sites are getting polluted with a wide range of metals and metalloids due to different industrial activities. This may lead to the degradation of geotechnical as well as the mechanical properties of soil.

Beena and Jaya (2016) studied the physical as well as chemical characteristics of the soil collected from the industrial site of Kerala Minerals and Metals Ltd, Chavara, Kollam. The heavy metals present in the soil sample were above the permissible limits and were in the order Iron> Manganese > Chromium >Zinc> Lead>Cadmium. Susan and Febina (2017) studied the soil collected from the industrial site of Travancore Titanium Products Ltd, Kochuveli, Trivandrum. The remediation of the contaminated soil samples were done using chemical reagents like tartaric acid and EDTA solution.

Yang et al (2016) studied the potential uses of biochar as an engineered material for environmental remediation of soil. Biochar is a highly porous, organic material derived from wood, manure or plant based biomass through pyrolysis under limited oxygen environment. It was seen that biochar has the ability to absorb and immobilize both organic and inorganic pollutants in the contaminated soil. Reddy et al (2014) studied about the enhanced microbial methane oxidation in landfill cover soil amended with biochar.

Most recent research indicates that the use of biochar can be considered as an economically feasible approach for the remediation of heavy metal contaminated soil because of its porous structure and large surface area. The cost of remediation using biochar will be several times cheaper than the conventional methods such as physical treatment, electrokinetic remediation, biological remediation and phytoremediation.

A number of amendments can be used for the remediation of heavy metal contaminated soil. This study focuses on the remediation of the heavy metal contaminated soil using biochar which is a readily available and inexpensive additive. The objectives of this study are:

- Identification of the major heavy metals present in the industrial site soil near Travancore Titanium Products Ltd, Trivandrum.
- Effect of biochar on the shear parameters of the soil
- To find out the remediation potential of biochar using column leachate tests.
- To study the variation of pH on amending the soil with biochar.

2 Materials Used

2.1 Industrial Site Soil

The soil was collected from the industrial site of Travancore Titanium Products Ltd, Kochuveli, Trivandrum. The soil collected was found to be silty sand. The chemical characteristics of the soil was found out. The preliminary analysis of the contaminated soil was then performed. Various tests such as compaction tests, direct shear tests, pH tests and column leachate tests were done.

The geotechnical properties of the soil and the results of the chemical analysis of the soil are summarized in Table 1 and Table 2 respectively.

2.2 Biochar

The biochar used in this study was obtained from wood gasified at a temperature above 520° C. The resulting biochar were in the form of pellets. Biochar possesses high porosity, high water retention capacity and it is very alkaline in nature. This will help in moderating the soil acidity and it will aid in the growth of useful soil microbes. The biochar used in this study was collected from a local store in Thakaraparambu, Trivandrum.

3 Methodology

The chemical analysis of the industrial site soil was done and the major heavy metals present in the soil were found out. It was seen that the amount of the heavy metals present in the industrial site soil were within the permissible limits. Hence the industrial site soil was artificially contaminated with Lead Acetate and Zinc Sulphate. The soil was artificially contaminated by mixing 2500 mg/kg of both Lead Acetate and Zinc Sulphate. The soil was kept for curing for a period of 30 days.
The biochar was added to the contaminated soil at various percentages of 2%, 4%, 6%, 8% and 10%. The compaction properties of the biochar amended soil at various percentages were studied using Light compaction test as per IS: 2720, part 7, 1980. The variation of shear parameters with the increase in biochar content were studied using Direct Shear tests as per IS: 2720, part 13, 1986. The remediation potential of biochar were analyzed using Column Leachate tests according to US EPA 2013 Standards (Method 1314) and pH tests as per IS 2720, part 6, 1987. The specimens were prepared at optimum moisture content and maximum dry density and tests were conducted after a curing period of 7,14 and 28 days.

4 Results and Discussion

4.1 Light Compaction test

Light Compaction tests were done on both contaminated as well as biochar amended soil. The compaction curves are shown in Fig. 1. Fig. 2 and Fig. 3 shows the variation in Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) with the biochar content respectively.From the figures it is clear that upto 6 % biochar, OMC is increasing and MDD is decreasing and after 6% biochar, OMC is decreasing and MDD is increasing. Adding biochar to the soil will change the porosity and density of the soil. Biochar being a highly porous additive will increase the porosity of the soil hence there will be an increase in the OMC of the biochar amended soil. The decrease in MDD of the biochar amended soil is because of the addition of the biochar which has got very low density. The increase in OMC upto 6% due to change in surface area and the decrease in MDD upto 6% is due to the addition of less dense biochar and due to a change in soil structure.

Table 1. Geotechnical Properties of the Industrial Site Soil

Particulars	Value
Specific Gravity	2.56
Maximum Dry Density (g/cc)	2.05
Optimum Moisture Content (%)	11.11
Shear Parameters	
Cohesion (kN/m^2)	12
Angle of internal friction	27°
Particle Size Distribution	
Sand (%)	55
Silt (%)	27
Clay (%)	18
California Bearing Ratio	4.59

Table 2. Chemical Analysis of the Soil

Particulars	Value
pH	3.13
Electrical Conductivity (dS/m)	1.52
Fe	164.54 ppm
Mn	5.76 ppm
Zn	6.08 ppm
Cu	2.75 ppm
Pb	4.83 ppm
Cd	0.59 ppm
Cr	NIL

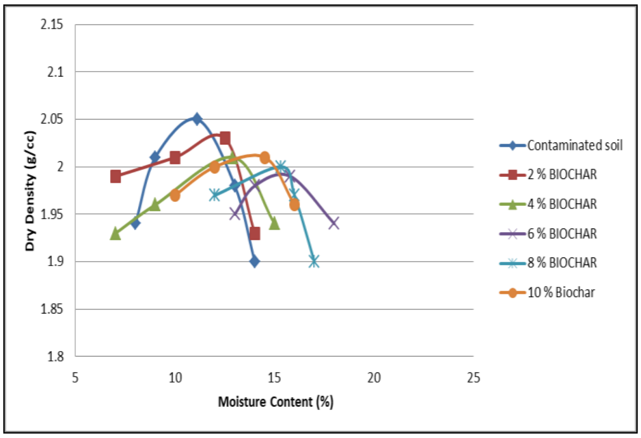

Fig. 1. Compaction curve

4.2 Direct Shear test

The contaminated soil was mixed with various percentages of biochar at 2%, 4%, 6%, 8% and 10% at OMC. The biochar amended soil was then kept for 7,14 and 28 days curing. Direct shear tests were done on contaminated as well as biochar amended soil. Direct shear test results are shown in Fig. 4, Fig. 5 and Fig.6. The variation of cohesion values with biochar content and the variation of angle of internal friction are shown in Fig. 7 and Fig. 8 respectively.
From the results, it is clear that the shear parameters such as cohesion and angle of internal friction increases with an increase in percentage of biochar upto 6%. The increase in cohesion could be because of the fact that the highly porous biochar underwent extensive particle re-arrangement under the applied vertical loads, which resulted in better interlocking and settlement of smaller particles within the void spaces, thereby resulting in better interparticle bonding.
Biochar is a material with very low density, hence it can be easily subjected to particle rearrangement which in turn results in the filling of the interparticle void spaces upon the application of vertical loads. This will result in a lesser probability of slippage.
The values of cohesion and angle of internal friction were found to be the highest at 6% biochar content, hence 6% can be taken as the optimum biochar content.

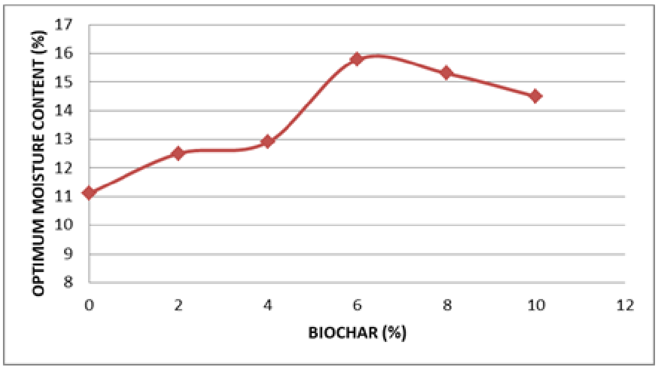

Fig. 2. Variation of OMC with biochar content

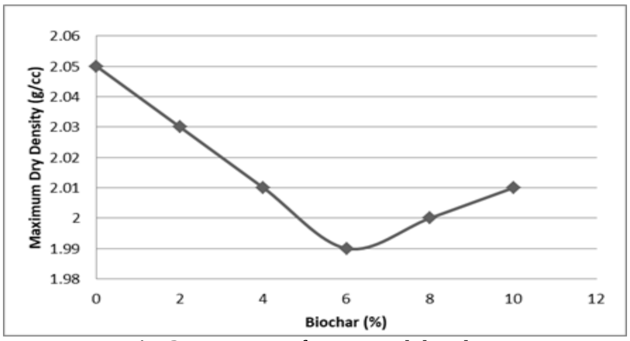

Fig. 3. Variation of MDD with biochar content

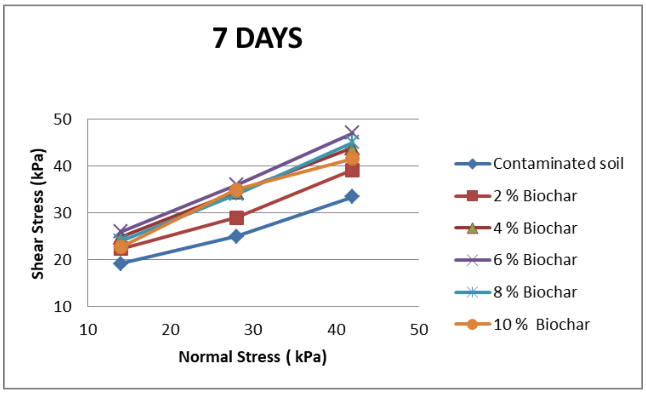

Fig.4. Direct shear result for 7 days curing

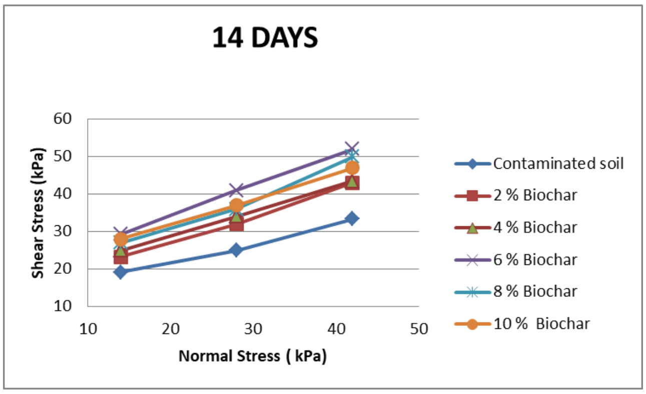

Fig.5. Direct shear result for 14 days curing

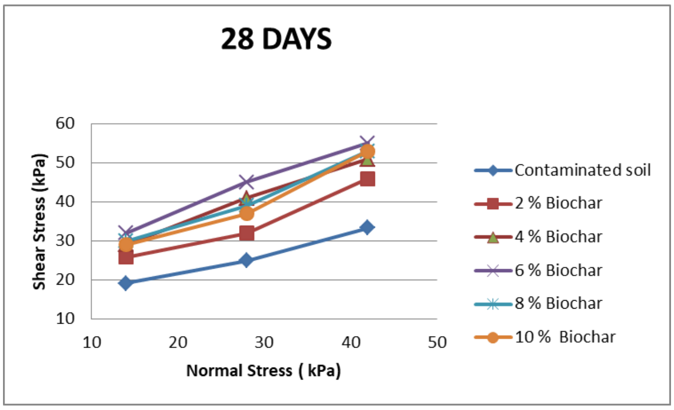

Fig.6. Direct shear result for 28 days curing

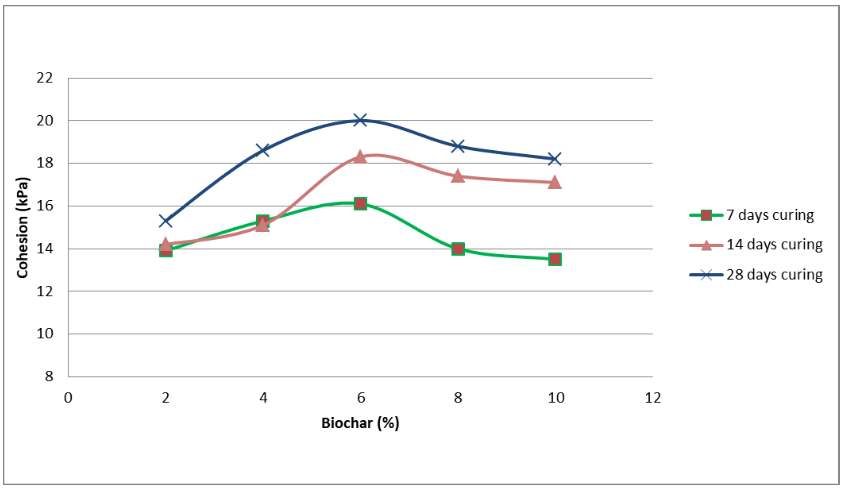

Fig. 7. Variation of Cohesion with biochar content

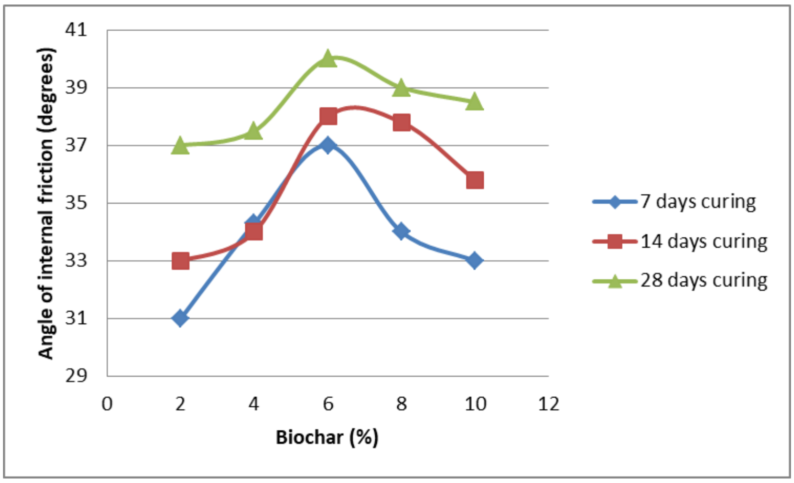

Fig. 8. Variation of Angle of internal friction with biochar content

From the graphs it is clear that cohesion (C) and angle of internal friction (ϕ) values increases upto 6% biochar and after that they are decreasing. So 6% biochar can be concluded as the optimum biochar percentage.

4.3 Column Leachate tests and pH tests

Column Leachate tests were conducted using columns of 11 cm diameter and 60 cm height. The columns were filled with contaminated soil and biochar amended soil at OMC and MDD obtained from the proctor test. The samples were filled to a height of 10 cm from the porous base which was located at 10 cm from the base of the column. A head of 15 cm of water was maintained throughout. A leachate collection mechanism was provided at the bottom of the column. The schematic diagram of the test setup is shown in Fig. 9. The leachate was collected after a period of 7,14 and 28 days. A quantitative determination of chemical elements using the adsorption of optical radiation by free atoms in the gaseous state known as the Atomic Adsorption Spectroscopy was performed on the leachate obtained.

From the results it can be interpreted that the concentration of lead and zinc in the leachate from contaminated soil were 15.61 mg/l and 17.52 mg/l respectively. As the biochar was added in different percentages, the lead concentration as well as the zinc concentration in leachate were reduced. For 6% biochar at 7 days, the lead concentration was reduced to 3.2 mg/l which is much below the permissible limit of lead as 5 mg/l and the zinc concentration reduced to 6.4 mg/l which is below the permissible limit of zinc which is equal to 13 mg/l. The lead concentration as well as zinc concentration in the biochar amended soil reduced by 80% and 64% respectively. The mechanisms for metal removal by biochar include adsorption, reduction, oxidation and most importantly, immobilization of heavy metals. The structure of biochar is very porous so it can also influence the behaviour of heavy metals present in the soil. The macro, micro and nano porous structures throughout biochar's matrix could create conditions that aid the reduction of metals into less mobile species.

From the results it can be interpreted that the concentration of Lead in the leachate from contaminated soil is 15.3 mg/l which is above the permissible limit of Lead and concentration of Zinc in the leachate from the contaminated soil is 16.9 mg/l at 28 days. As the biochar was added in different percentages, the lead concentration and the zinc concentration in the leachate were reduced. For 6% biochar, at 28 days, the concentration of lead and zinc were reduced to 1.5 mg/l and 3.7 mg/l respectively, which is much below the permissible limit of lead as 5mg/l and zinc as 13 mg/l (US EPA 1993). So at 6%, for a curing period of 28 days the lead concentration reduced to 90% and Zinc concentration reduced to 78%. Hence 6 % biochar can be used as an optimum percentage.

The pH of the soil was determined as per IS 2720, part 26, 1987. The results of the pH tests are shown in Table 6. It can be noted that there is an increase in the pH level of the biochar amended soil with the increase in biochar content. The pH of the contaminated soil increased by 70% with the addition of 6% biochar content. The pH is an important factor in the remediation process of the contaminated soil. The biochar is a highly alkaline substance, therefore it will be able to increase the pH of the biochar amended soil thus exerting a liming effect to the soil. The solubility and mobility of the heavy metals present in the soil can be reduced to a great extend with the increase in pH which will result in the increased sorption of positively charged metal cations. This will lead to the stabilization of the heavy metals.

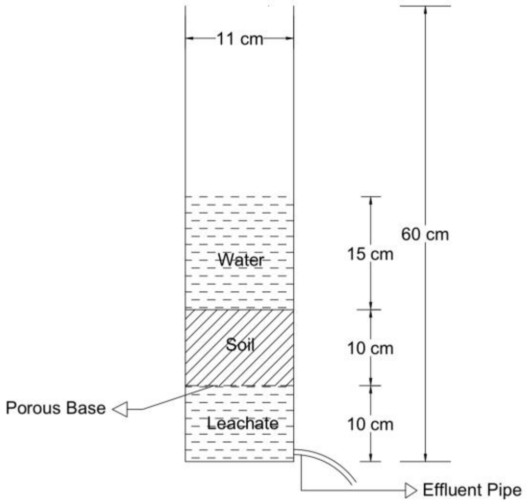

Fig. 9. Schematic diagram of Column Leachate Test Setup

Table 3. Concentration of Lead (Mg/L) And Zinc (Mg/L) in Leachate After 7 Days Curing.

Biochar content (%)	Lead (mg/l)	Zinc (mg/l)
0	15.6	17.5
4	5.5	9.4
6	3.2	6.3
8	3.1	5.2

Table 4. Concentration of Lead (Mg/L) And Zinc (Mg/L) in Leachate After 14 Days Curing

Biochar content (%)	Lead (mg/l)	Zinc (mg/l)
0	14.8	17.1
4	3.9	7.5
6	1.8	4.8
8	1.6	3.9

Table 5. Concentration of Lead (Mg/L) And Zinc (Mg/L) in Leachate After 28 Days Curing

Biochar content (%)	Lead (mg/l)	Zinc (mg/l)
0	15.3	16.9
4	3.6	5.2
6	1.5	3.7
8	1.2	2.6

Table 6. PH of Various Samples

Biochar content (%)	pH
0	4.83
2	5.52
4	6.82
6	8.21
8	12.56
10	13.40

5 Conclusions

In this study, biochar was used as an additive for the remediation of heavy metal contaminated industrial site soil. Tests were done on the biochar amended soil to evaluate the effects of biochar amendment on the strength properties of the contaminated soil. Compaction tests, Direct Shear tests, Column Leachate tests and pH tests were done on the contaminated as well as the biochar amended soil samples. Following are the conclusions based on the results:

1. The optimum percentage of biochar was found to be 6%. The OMC was found to increase upto 6% and the MDD kept on decreasing upto 6%. Addition of a less dense material such as biochar decreased the MDD of the soil and since the biochar is highly porous, OMC was found to increase. The decrease in MDD could be due to changes in soil structure and alteration of soil-aggregate sizes.
2. The shear parameters such as cohesion and angle of internal friction were found to increase with an increase in the biochar content upto 6% after a period of curing for 7 days. The cohesion values increased with the increase in biochar content maybe because of the particle rearrangement under the applied vertical loads. The angle of internal friction also increased with an increase in biochar content because of the better interlocking of the soil particles with the biochar.
3. From the column leachate test, it was found that the lead concentration as well as zinc concentration in the leachate has been reduced by 90% and 78% respectively which proves that biochar can be used as a suitable remediating agent in treating the heavy metal contaminated industrial site soil. The remediation potential of the biochar can be increased if a larger curing period is provided.
4. The pH of the contaminated soil increased by 70% with the addition of 6% biochar content. As the biochar content increases, pH also increases which exerts a liming effect in the soil. This will lead to the stabilization of heavy metals. It can be considered as an economically feasible approach for the remediation of heavy metal contaminated soil with its extraordinary remediation potential because of its porous structure and large surface area.

This study demonstrated that biochar amendment to soil can facilitate the remediation of the soil contaminated with Lead and Zinc. Additional research is warranted to investigate the impact of biochar on the remediation of other heavy metals. Moreover, future investigation should also assess the effect of biochar amendment on the remediation of contaminated soil over longer incubation periods.

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