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Experimental Analysis and Remediation Rate of Copper and Nickel Contaminated Industrial Site Soil Using Biochar

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Abstract:** The most crucial element for construction purposes is healthy and good soil. Through the incorrect disposal of carcinogenic compounds, which seeps into the earth and degrades soil quality, heavy metals and metalloids can contaminate soil. The goal of this project is to turn biomass into biochar and re-apply it to the soil in order to disrupt the source-receptor pathway, which will lead to heavy metal-free soil and an improvement in soil characteristics. Biochar is a material made of waste biomass that is highly porous, carbon-rich, and fine-grained. Pyrolysis is a process in which biomass is subjected to thermo-chemical conversion without oxygen. Rice husk biomass was pyrolyzed in a muffle furnace at temperatures between 500 and 700 °C to create the biochar that was employed in this experiment. Through physical adsorption or an ion exchange mechanism, biochar has the ability to remove heavy metal ions like copper and nickel. The soil used in this study was gathered from the Kurumbapalayam, Coimbatore, electroplating factory. AAS was used to evaluate soil samples in order to measure the amount of heavy metals present. A method that is useful for calculating the amounts of trace elements contained in the soil sample is the use of an atomic absorption spectrometer (AAS). In order to determine the presence of metal oxide X-Ray Diffraction was done and to know the connection between the biochar and the soil, scanning electron microscopy (SEM) was done. Using a direct shear test, the shear strength of soil treated with various amounts of biochar was evaluated. Additionally evaluated were the soil's compaction characteristics and pH fluctuation in response to the addition of various biochar percentages. The outcome shown that adding biochar to the soil neutralises heavy metals and enhances the characteristics of the soil.

Keywords: Contaminated soil, Copper, Nickel, Biochar, Compaction Test, Direct Shear Test, pH Test, AAS analysis and FTIR analysis, XRD, SEM.

I. INTRODUCTION

Numerous issues, including fertiliser use, tank leaks, underground pipe bursts, landfill leachate seeping into subsurface strata, and direct disposal of industrial waste into the soil, can contaminate soil. Lead, Cadmium, Copper, Nickel, Zinc, and Chromium are the most often found metals that are extremely harmful to both humans and animals. Sites that are becoming polluted as a result of industrial activity may cause the soil's geotechnical and mechanical qualities to deteriorate. The creation of biochar from agricultural waste (biomass) is a recent development that helps to improve soil qualities while reducing greenhouse gas emissions from burning agricultural waste in an open field.

As it causes harmful gases to enter the environment, direct burning of agricultural waste in the field is not an environmentally friendly practice.

Therefore, creating biochar from agricultural biomass using the pyrolysis process is preferable to adding biochar to contaminated soil to improve its properties. In addition to having a great capacity to absorb and immobilise contaminants from contaminated soil, biochar is also carbon-rich and very porous.

Using a muffle furnace, biomass is heated for a short period of time at temperatures between 300 and 700 °C without the presence of oxygen to produce biochar. Due to its porous nature and substantial surface area, biochar is an economically viable method for remediating heavy metals-contaminated soil.

When compared to other remediation techniques, using biochar is less expensive. This study focuses on the use of rice husk biochar, which is readily available, reasonably priced, and has strong properties, to reduce the concentration of Copper and Nickel in the polluted soil.

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II. MATERIALS AND METHODS

A. Biochar

Using a muffle furnace, biomass is heated for a short period of time at temperatures between 300 and 700 °C without the presence of oxygen to produce biochar. Due to its porous nature and substantial surface area, biochar is an economically viable method for remediating heavy metals-contaminated soil. When compared to other remediation techniques, using biochar is less expensive. This study focuses on the use of rice husk biochar, which is readily available, reasonably priced, and has strong properties, to reduce the concentration of Copper and Nickel in the polluted soil.

B. Soil Sample

The soil sample was obtained from the Kurambapalayam, Coimbatore, electroplating factory. Copper, Nickel, and Chromium will predominately contaminate the soil near the electroplating industry. The soil sample was taken between 0 and 15 centimeters deep. To determine the primary classification, the obtained soil sample is oven dried, ground, and then sieved through a 4.75mm size size. Atomic absorption spectrometers (AAS) are used to determine the original Copper and Nickel levels in polluted soil. The tables 1 and 2 demonstrate the chemical parameters and geotechnical characteristics of the soil from industrial sites.

Table 1 : Geotechnical Properties of the Contaminated Soil

<table>
<tr><th>SI.No</th><th>Property</th><th>Value</th><th>IS Method</th></tr>
<tr><td>1.</td><td>Specific Gravity</td><td>2.72</td><td>IS 2720 Part 3 1980</td></tr>
<tr><td>2.</td><td colspan="3">Particle Size Distribution</td></tr>
<tr><td></td><td>Gravel(%)</td><td>1</td><td rowspan="3">IS 2720 Part 3 1985</td></tr>
<tr><td></td><td>Sand (%)</td><td>57</td></tr>
<tr><td></td><td>Fines (%)</td><td>42</td></tr>
<tr><td>3.</td><td>Relative Density(%)</td><td>48</td><td>IS 2720 Part 14 1983</td></tr>
<tr><td>4.</td><td colspan="3">Shear Parameters</td></tr>
<tr><td></td><td>Cohesion (kN/m^2)</td><td>21</td><td rowspan="2">IS 2720 Part 13 1986</td></tr>
<tr><td></td><td>Angle of internal friction</td><td>13°</td></tr>
</table>

Table 2 : Chemical Characteristics of the Contaminated Soil

<table>
<tr><th>SI.No</th><th>Property</th><th>Value</th><th>IS Method</th></tr>
<tr><td>1.</td><td>pH</td><td>5.24</td><td>IS 2720 (Part 26) - 1987</td></tr>
<tr><td>2.</td><td>Electrical Conductivity(ds/m)</td><td>13.74</td><td>IS 14767 – 2000</td></tr>
<tr><td>3.</td><td>Copper (ppb)</td><td>14.16</td><td rowspan="2"></td></tr>
<tr><td>4.</td><td>Nickel (ppb)</td><td>11.76</td></tr>
</table>

C. Biochar as Soil Amendment

Several tests, including the pH test, compaction test, and direct shear test, were carried out at different concentrations of biochar (2%, 4%, 6%, 8%, and 10%) with soil in order to study the impact of biochar on the contaminated soil. Using AAS analysis, the effectiveness of heavy metal removal from contaminated soil was evaluated.

III. METHODOLOGY

The industrial site's soil was physically and chemically analysed, and an AAS analysis was used to determine the initial concentration of Copper and Nickel. The geotechnical characteristics and chemical analyses of the contaminated soil sample are shown in Tables 1 and 2. Even though it was discovered that the original level of Copper and Nickel was well below the allowable limit, only the impact of biochar on the heavy metals contamination of soil was focused on and analysed. The heavy metals-contaminated soil received additions of biochar at varying rates of 2%, 4%, 6%, 8%, and 10%. Using a compaction test in accordance with IS: 2720, part 7, 1980, the ideal moisture content and dry density at various percentages of biochar added soil are investigated.

Using a direct shear test in accordance with IS: 2720, part 13, 1986, the fluctuation in the shear characteristics with varying percentages of biochar enriched soil was also investigated. Biochar's ability to remediate was evaluated using a pH test in accordance with IS: 2720, part 6, 1987. For the direct shear test, the specimens were prepared with the ideal moisture content and maximum dry density.

IV. RESULTS AND DISCUSSIONS

A. Compaction Test

Both contaminated and soil modified with charcoal underwent a compaction test. The information on the compaction curve, the variation in the ideal moisture content, and the variation in the maximum dry density on adding various percentages of biochar to the contaminated soil is conveyed by the Figs 1, 2, and 3 shown below. The maximum dry density initially reduces and then increases up to 6% addition of biochar, as can be clearly seen from the following graphs. The ideal moisture content initially increases up to 6% addition of biochar to the contaminated soil. The porosity of the soil rises due to the porous nature of biochar and the change in surface area, which in turn increases the OMC of the biochar-amended soil [10]. The MDD of the soil supplemented with biochar initially falls up to 2% and later increases up to 6% [10] due to the less dense nature of biochar and the change in soil structure. The findings lead to the conclusion that 6% is the ideal figure.

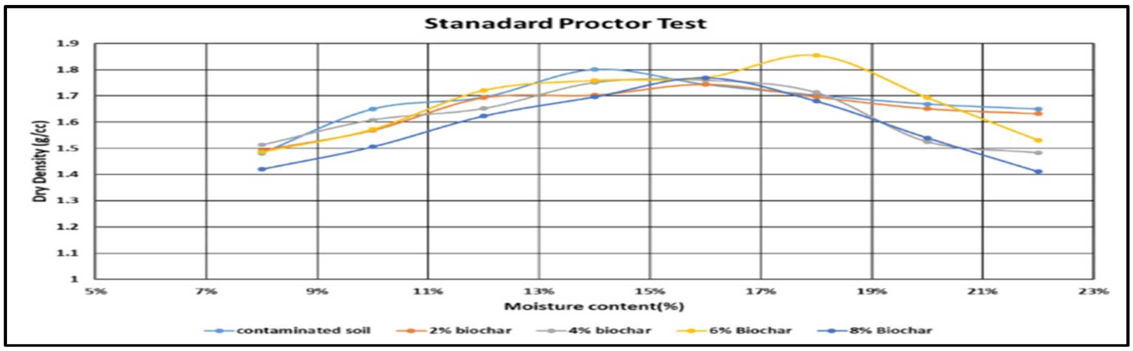

Fig 1 : Compaction Curve

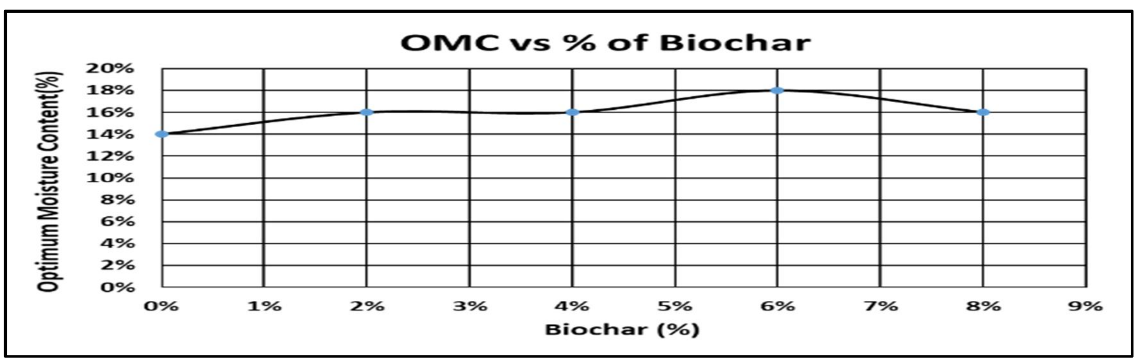

Fig 2 : Variation of OMC with Biochar Content

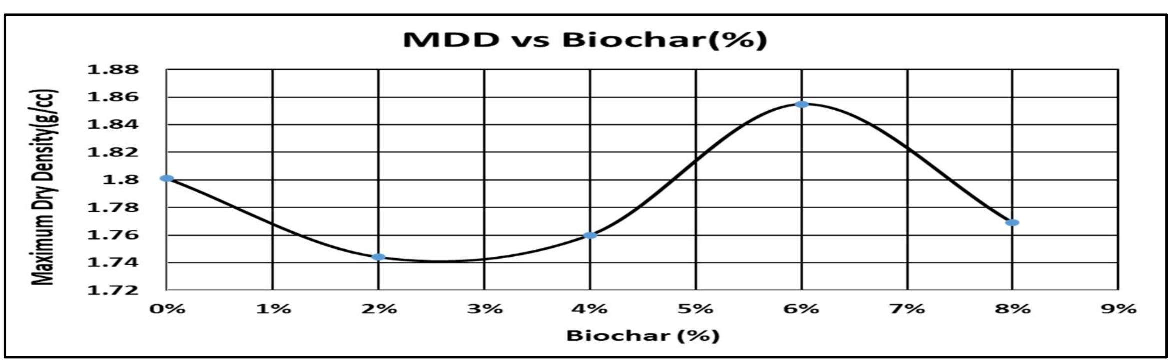

Fig 3 : Variation of MDD with Biochar Content

B. Direct Shear Test

At OMC, a direct shear test was performed on soil that had been treated with biochar (2%, 4%, 6%, 8%, and 10%). Figures 4, 5, and 6 show the direct shear results and changes in the shear parameter values after adding different amounts of biochar to the soil. The graph shows that as the amount of biochar increases up to 6%, the cohesiveness value and angle of internal friction value increase. Due to the low density of biochar, it is easily subject to particle adjustment because the void spaces between the particles are filled in when a vertical load is applied. The angle of internal friction is increased by this particle readjustment mechanism by up to 6%, and then it steadily decreases as all empty areas are filled. Because biochar has a high porosity, smaller particles settle and interlock better within the void spaces, increasing the cohesion value. Due to the interparticle bonding, the cohesion value keeps rising. Therefore, it is determined that 6% biochar is the ideal biochar percentage.

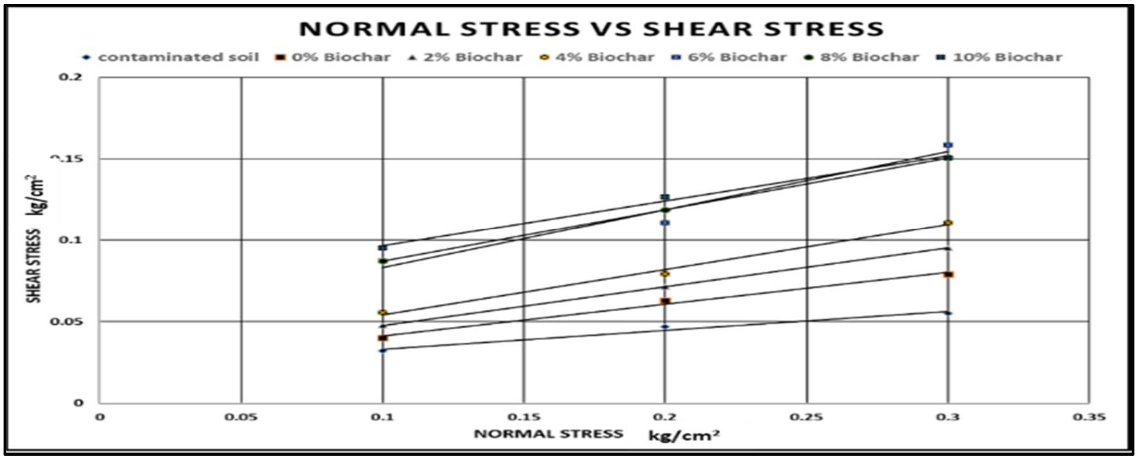

Fig 4 : Result of Direct Shear Test

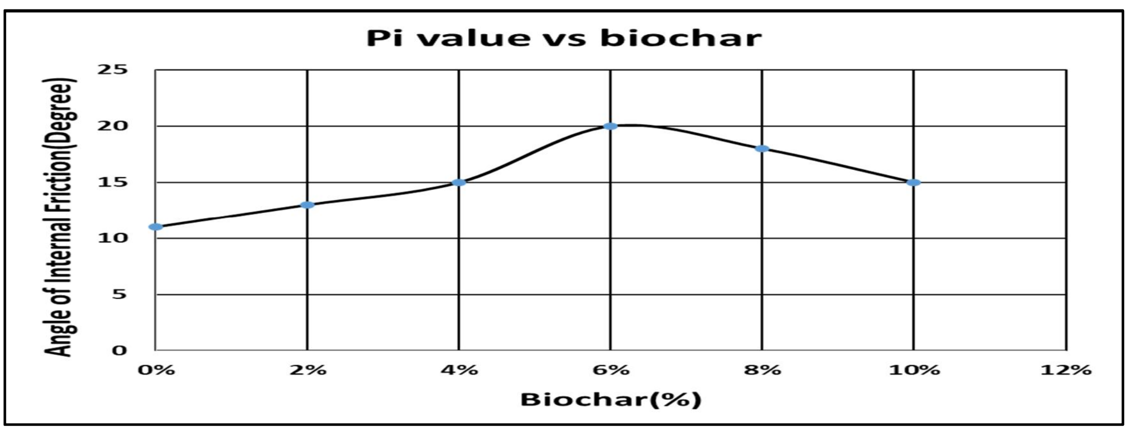

Fig 5 : Variation in Angle of Internal Friction Value at Various % of Biochar

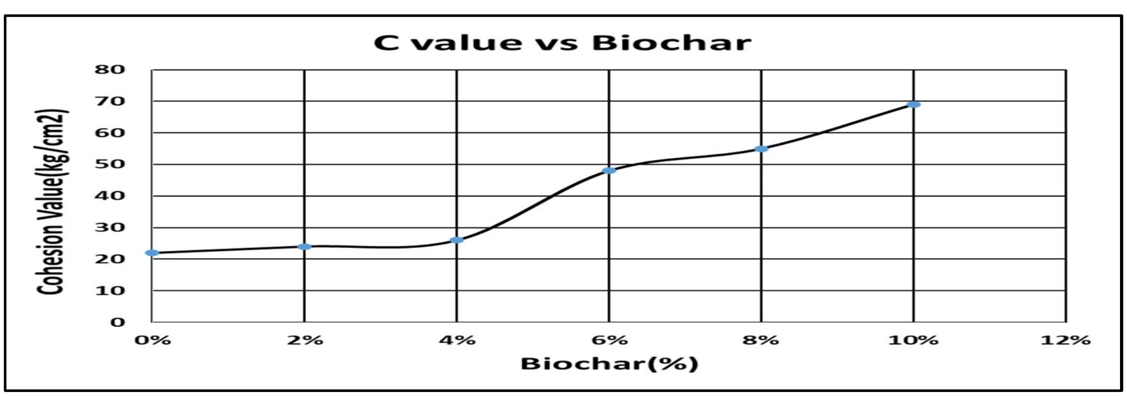

Fig 6 : Variation of Cohesion Value at Various % of Biochar

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C. pH Test

According to IS 2720, part 26, 1987, the pH of the contaminated soil and various percentages of biochar-amended soil were determined. The very alkaline nature of biochar causes the pH value of biochar-amended soil to rise as the proportion of biochar content increases. The neutralisation (or mobilisation) of heavy metals from the contaminated soil is concluded by an increase in pH level of the biochar-amended soil; this mechanism is referred to as sorption. The stabilisation of heavy metals will result from this increased sorption of positively charged metal cations. Table 3 displays the impact of soil treated with biochar on pH levels. From the table, it can be inferred that adding 6% of biochar raised the pH level of polluted soil by 60%.

Table 3 :Variation in pH Values

SI.No	Percentage of Biochar (%) + Contaminated Soil	pH Values
1	0%	4.9
2	2%	5.25
3	4%	6.54
4	6%	7.36
5	8%	8.11
6	10%	9.81

D. X-Ray Diffraction

The protective relationship between carbon and silicon controls carbon stability in biochars, including its bioavailability, sorption, dissolution, and ability to stabilise metals in soil, according to X-ray diffractometry (XRD) research.The primary mineral components of biochar—carbon, oxygen, and silicate—were thought to be crucial for its use as a soil supplement.Silicates are a major factor in the adsorption of metals.The main component of RHB (rice husk biochar), silica, produces a broad peak with a centre between 20° and 30° that was thought to be caused by the presence of disorded cristobalite. This broad peak also contains amorphous carbon. An intense peak at 21 degrees due to the presence of carbon can be seen on the analysis graph shown in fig 7 & fig 8, while two peaks at 11 and 29 degrees signify the presence of SiO_2.

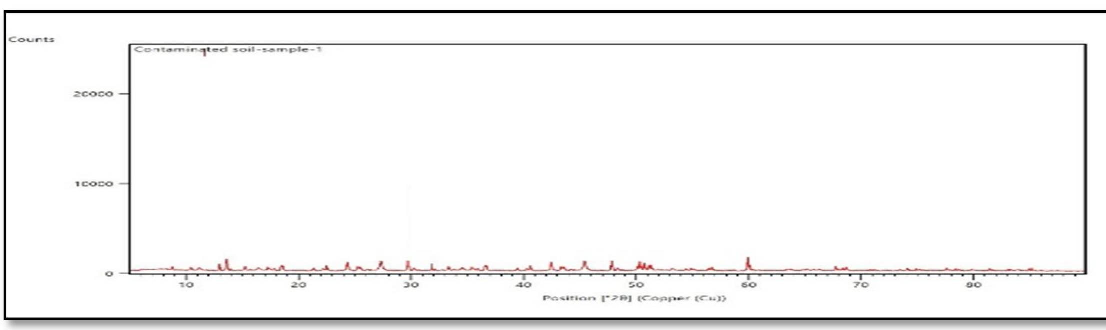

Fig 7 : XRD Analysis Graph of Contaminated Soil

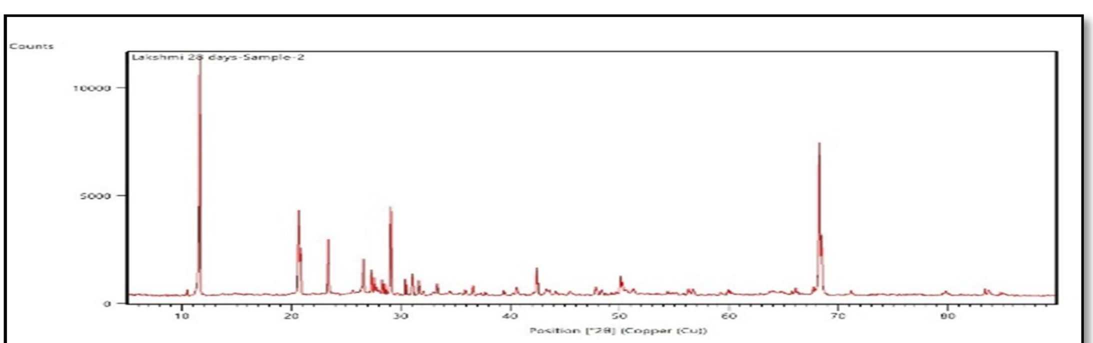

Fig 8 : XRD Analysis of RHB Amended Soil

E. Scanning Electron Microscopy

It was also determined to undertake SEM analysis in this study in order to comprehend the micro-mechanical interaction between the biochar and the soil particles as well as to comprehend the particle shape. As the pyrolysis temperature rises, the biochar's pores significantly develop, its highly ordered aromatic structure develops, and the mineral components' crystallinity increases. The biochar was shown to be taking up more and more of the soil's pore space in the figure shown in 9 & 10, which suggests that the biochar's qualities would have a bigger influence on soil characteristics.

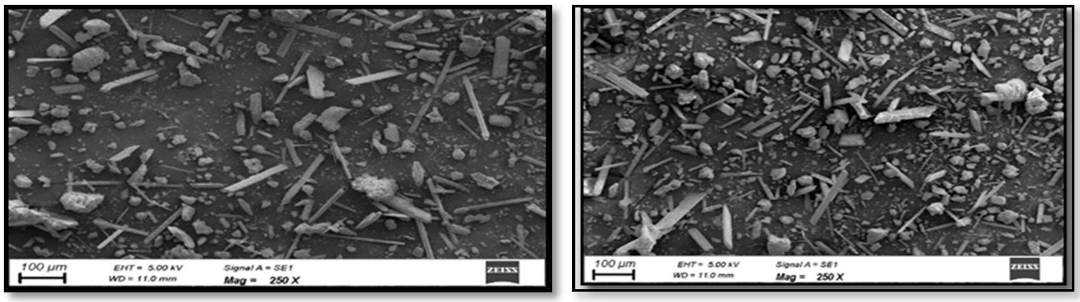

Fig 9 : SEM Images of Contaminated Soil

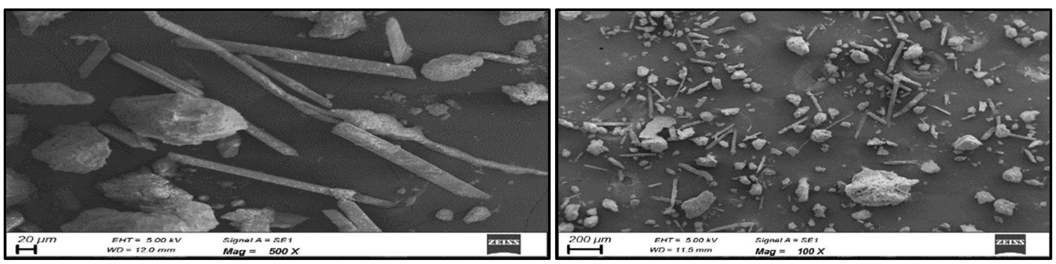

Fig 10 : SEM Images of RHB Amended Soil

V. CONCLUSIONS

The present study reveals the remediation of heavy metals contaminated industrial site soil on using the biochar as an additive. The conclusion of the result obtained from the compaction test, direct shear test, pH test, AAS analysis and FTIR analysis are as follows,

1) Due to biochar's high porosity and increased addition, the OMC of the soil increases by up to 6%. Due to changes in soil structure, the MDD of the soil first falls with increased biochar addition, then it eventually increases up to 6% of biochar concentration. Therefore, 6% was chosen as the ideal biochar content.
2) The soil's shear characteristics rise with the addition of more biochar, indicating that the concentration of heavy metals has an impact on how strong the soil is. Due to the soil's particle readjustment, the angle of internal friction value rises by up to 6%, and the cohesion value keeps rising.
3) Due to the alkaline nature of biochar, the pH of the soil rises as the amount of biochar added increases. The addition of 6% biochar raised the pH of the contaminated soil by 60%.
4) The presence of carbon and silicates that stabilize the heavy metals in soil by the adsorption mechanism is confirmed on X-Ray Diffraction analysis.
5) The pore development in RHB that stabilizes the heavy metals in the soil and intra soil pores which was occupied by the biochar and increases the soil’s strength was micro-mechanically studied clearly by Scanning Electron Microscopy.

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