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Optimizing Soil Performance: Using Cement Kiln Dust along with Polymer Integration for Soil Stabilization

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Abstract

The present study explores contaminated soil collected from solid dump yard and its treatment with cement kiln dust in combination with epoxy liquid polymer. The study explores the improvement in mechanical and geotechnical characteristics of stabilized soil's properties by adding Cement kiln dust and a liquid polymer in different proportions. The comparison for Maximum Dry Density, Unconfined Compressive Strength and California bearing ratio test for untreated and stabilized soil was done. The optimal mixtures of the 10% Cement kiln dust dosage indicate that with usage of cement kiln dust, decreases maximum dry density and optimum moisture content increases. However, Cement kiln dust and epoxy liquid polymer resulted in Unconfined compression test increase from 402.11 kN/m² to 1288 kN/m²and 1005.27 kN/m2 to 3221.825 kN/m^2 for a curing time of 14 days and 28days. Moreover, the California bearing ration values also improved 38% with the addition of Cement kiln dust. Over curing periods of 7 and 14 days, Unconfined compression test and California bearing ratio test outcomes show increases due to the of cementitious materials. Additionally, the treated soil exhibits a notable reduction in harmful compounds like Chromium and Lead. The cohesion and frictional properties of stabilized soil showed significant improvement too.

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Contaminated; Dump; Epoxy; Soil; Strength; Waste.

Introduction

Municipal Solid Waste (MSW) is a challenge in growing urban areas, especially in developing countries like India, due to rapid urbanization and population growth. MSW comprises residential, industrial, construction, municipal and commercial waste. The volume of garbage poses significant challenges for waste management in developing regions like Punjab, India with cities such as Jalandhar facing severe issues. MSW landfills exacerbate problems like landfill gas emissions, odors and leachate leakage which harms soil and groundwater. The pioneer research on oil contaminated soils were carried on the effects of stabilizers on diesel-contaminated soil, assessing changes in permeability, hydrocarbon and heavy metal levels, compaction

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properties, and compressive strength using materials like cement kiln dust and Ordinary Portland.[1-4] The solidification of heavy metals with OPC and fly ash on the contaminated soil was also explored.[5-7] The dump sites generate wastewater that further contaminates soil and groundwater emphasizing the need to understand these interactions for environmental and public health reasons. Leachate, a liquid byproduct of MSW contains high concentr-ations of toxic substances due to the organic and inorganic chemicals released from waste. The study investigated leachate toxic materials that contain arsenic thereby contaminating soil and groundwater by percolate through soil layers.[8,9] Heavy metals having lead contaminated soil studied by few researcher.[10-12] The oil contaminated soil and its solidification has been also studied for environmental effects.[13,14]

The polymer has controlling effect on liquefaction phenomenon and used synthetic polymers on soil stabilization.[15,16] The reviewed studies collectively address various aspects of soil contamination and stabilization techniques, highlighting their environmental and engineering implications. Their findings stress the need for comprehensive studies to understand soil contamination's impacts on ecosystems and human health, advocating for proactive waste management in urban areas.

The present study explores an innovative approach to soil stabilization by mitigating contamination with use of Cement Kiln Dust (CKD) and epoxy liquid polymer. The addition of CKD at varying proportions (5%, 10%, and 15%) with and without epoxy for liquid limit, plastic limit, and plasticity index and Compressive strength gain, thereby improving soil workability and stability.

Materials and Methodology

Contaminated soil was collected from the dump of Wariana, Jalandhar, Punjab, India. After removing the organic layer on top, we placed the soil on a floor and used a hand roller to break down any lumps. Next, we sifted soil using No. 4 sieve to eliminate unwanted vegetative materials and pebbles. The soil was the air dried and stored in plastic bags. In a lab, the physical characteristics of polluted soil were assessed. Cement kiln Dust(CKD) was acquired from an Indian cement mill in Himachal Pradesh. The Characteristics of contaminated soil and CKD are mentioned in Table1 and 2. The Fig 01 shows Particle size distribution curve.

Epoxy Liquid Polymer

Epoxy polymer was collected from the main market of the city Jalandhar, Punjab, India. Epoxy Resins are formed by the reaction between nepichlorohydrin with bisphenol Epoxy Resins have ingredients i.e. plasticizer, hardener, an accelerator and the monomeric resin. Epoxy resin are chemical organic compounds. It consists of atoms such as sulfur hydrogen, carbon, nitrogen an a little of oxygen.

Table 1: Physical Parameters of Contaminated soil

Physical Characters	Values
Specific Gravity	2.42
OMC (%)	14
MDD (g/cc)	1.6
UCS (kN/m2)	84.60
LL	28
PL	16
PI	12
pH	5.2
Cohesion	13.92676
Angle of Friction(ϕ)	6.675522

Table 2: Chemical Parameters of Cement kiln dust

Chemical Composition	Cement kiln dust
Cao	55.06
SiO2	11.9
Al2O3	9.9
Fe2O3	3.4
SO3	1.48
MgO	1.7
Na2O	0.5
K2O	0.1
Loss of ignition	4.7

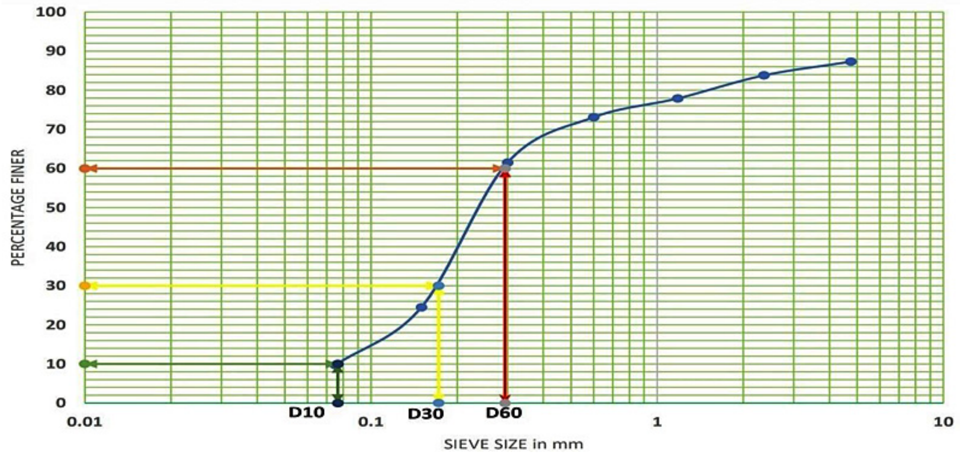

Fig. 1: Particle size distribution curve

Specimen Preparation

Contaminated soil was mixed manually in its dry state with CKD and liquid polymer. The necessary water content was then mixed, ensuring thorough mixing for minimum 6 minutes and squeezing to eliminate any air. The standard Proctor test was utilized to analyze the Optimum Moisture Content (OMC) content and Maximum Dry Density (MDD) for each mixture. Unconfined Compressive Strength (UCS) and California bearing ratio (CBR) specimens were prepared in cylindrical shapes moulds. The weight and density were done as per IS static compaction test. These samples were then stored in desiccators until they were examined at 7- and 14-days post-curing.

For CBR Test,[17] the sample was prepared using a mold that conforms to the compaction test. The test was conducted using a plunger with a diameter of 5 cm, and the reading was taken at a penetration of 5.0 mm.

Experimental Program for Testing

The contaminated soil was dried in the oven for 24 hours. The Table 3 shows the test details for various combinations of C.S and CKD with CKD and liquid polymer for testing. The experiments involve compaction test, Atterberg limits.[18,19]

Table 3: Testing Methodology for The Study

Material Type	Cement Kiln Dust (%)	Polymer (%)	Tests
C.S	-	-	Sieve analysis, Standard Proctor Test, UCS, CBR, Direct Shear Test, LL, PL
C.S	5%,10%,15%	-	Sieve analysis, Standard Proctor Test, UCS, CBR, LL, PL
C.S (89%)	Optimum value10%	1%	Sieve analysis, SPT, UCS, CBR, Direct Shear Test, LL, PL
C.S (88%)	Optimum value10%	2%	Sieve analysis, SPT, UCS, CBR, Direct Shear Test, LL, PL
C.S (87%)	Optimum value10%	3%	Sieve analysis, SPT, UCS, CBR, Direct Shear Test, LL, PL

Chemical Analysis of X-Ray fluorescence Contaminated Soil

Table 5 reveals results of X-Rf test conducted on soil. The lead (Pb) predominates in soil sample that comprising 73.57%. In contrast, cadmium (Cd) constitutes a lesser proportion at 52.33% compared to lead. Manganese, copper, zinc, and aluminum are detected in minimal quantities which shows that the soil is contaminated significantly.

Results and Discussions

Effect on Index Properties

The contaminated soil can also be classified based on its plasticity through conducting liquid and plastic limit tests. The contaminated soil was non plastic while adding CKD in different proportions the soil exhibits binding properties which is critical for strength gain. The readings are mentioned below in Table 4 and Fig.2.

Table 4: Index Properties soil mix with different proportion of Cement kiln dust

Material	LL	PL	PI
C.S	23	0	0
C.S+5%CKD	28	15	13
C.S+10%CKD	25	18	7

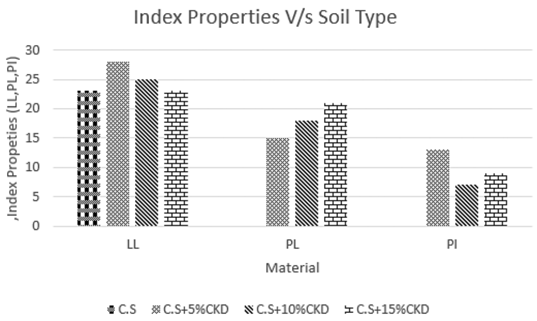

Fig 2: LL, PL, PI of Contaminated soil with CKD

Table 5: Heavy metal index of leachate of Wariana Dump

Traced Elements	HPI Value
Chromium (Cr)	13.5
Manganese (Mn)	0.116
Iron (Fe)	1.80
Nickel (Ni)	23.66
Copper (Cu)	0.072
Zinc (Zn)	0.00073
Arsenic (As)	2.55
Cadmium (Cd)	52.33
Lead (Pb)	73.57
Aluminum (Al)	0.754

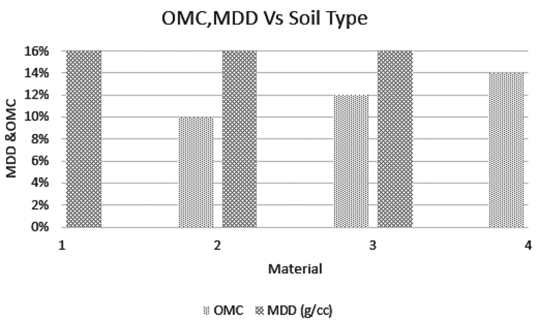

Fig 3: MDD and OMC for C.S and CS with CKD

Compaction Test

The Compaction tests were done in order to have OMC and MDD of contaminated soil, mix of contaminated soil with 5%,10% and 15% of CKD. Optimum moisture content of contaminated soil is 14% and when mixed with 5% ,10% and 15%.

Table 6: Results of Standard Proctor Test

Material	OMC	MDD (g/cc)
C.S	14%	1.57
C.S +5%CKD	10%	2.010
C.S +10%CKD	12%	1.97
C.S +15%CKD	14%	1.81

An increase in the CKD content has been noted to correlate with a reduce of the higher dry density (MDD) and an elevation in the optimal moisture content (OMC) as shown in Fig.3. The cohesion among soil particles, influencing soil firmness, may contribute to this effect by potentially reducing MDD and increasing OMC. During compaction, these cohesive particles may separate, potentially leading to an increase in MDD and a decrease in moisture content.

X-RAY Fluorescence

The comparison between X-Ray Florescence of Contaminated soil, Contaminated soil with 10% CKD, Contaminated soil with 10% CKD and Epoxy liquid polymer showed in Table 7.[14]

That the heavy metals like Cr, Mn, Fe, Ni Cu, Zn, As, Cd, Pb, Al, V, Se, Ba, Sr decreases with the mixing of Cement Kiln powder and Polymer. On comparing Contaminated soil+ 10% Cement Kiln Dust with Contaminated Soil+ 10% Cement kiln dust + 3% Polymer, the heavy metals i.e. Cr, Mn Cu, Zn, As, Cd, Pb, Al decreases whereas Fe, Ni, V, Ba, increases. CaO of contaminated soil increases with cement kiln dust and liquid polymer.

Table 7: Results of X-Ray Fluorescence of Contaminated soil with Cement kiln dust and Polymer Stabilized soil

S.NO	Elements	Contaminated Soi	Elements of Contaminate soil+ 10% CKD	Elements of Contaminate soil+ 10% CKD+ 3% POLYMER
1	Cr	0.0245	0.0238	0.0148
2	Mn	0.0379	0.0341	0.0277
3	Fe	1.50	1.26	1.33
4	Ni	0.0059	0.0056	0.446
5	Cu	0.0232	0.0253	0.0201
6	Zn	0.0671	0.0421	0.0392
7	As	0.0002	0.0001	<0.001
8	Cd	0	0.0001	0.00
9	Pb	0.0089	0.0069	0.0067
10	Al	3.17	2.76	2.76
11	V	0.0119	0.0061	0.0071
12	Se	0.00	0.00	0.00
13	Ba	0.0211	0.00	0.0137
14	Sr	0.0136	0.0088	0.0089
15	CaO	14.6	20.8	20

Effects on Unconfined Compressive Strength

The compressive results of treated soils with both cement kiln dust (CKD) and a blend of CKD with epoxy resin polymer are reported in Fig.4. The of addition CKD with polymer in different dosages the works as stabilizers and with curing durations. This phenomenon could be attributed to the secondary process over time, leading to the formation of pozzolanic compounds. The initial strength of contaminated soil for 28 days was 211.5 kN/m^2. When 5% of Cement kiln dust (CKD) was added to soil, its strength rises to 639.72 kN/m2 whereas on addition of 10% and 15% of CKD to the contaminated soil the strength after 28 days of curing rises to 1005.27 kN/m^2 and 954.26 kN/m^2 respectively. Optimum value of Unconfined strength was observed at 10% of Cement Kiln Dust. Similarly, when the contaminated soil with 10% of CKD was mixed with 1%,2% and 3% polymer the observed strength was 577.55, 1219.885 and 3221.825 kN/m^2 respectively. The optimum value was at contaminated soil with 10% CKD and 3% polymer.[10]

Table 8: compressive strength values of Contaminated soil with Cement kiln dust and Polymer

Material	7days kN/m^2	14days kN/m^2	28 days kN/m^2
C.S	34.52	84.60	211.5
C.S+5%CKD	50.802	255.89	639.725
C.S+10%CKD	213.366	402.11	1005.27
C.S+15%CKD	132.810	380.904	954.26
C.S+10%CKD+1% Polymer	177.017	225.023	577.55
C.S+10%CKD+2% Polymer	258.970	487.954	1219.885
C.S+10%CKD+3% Polymer	362.523	1288.73	3221.825

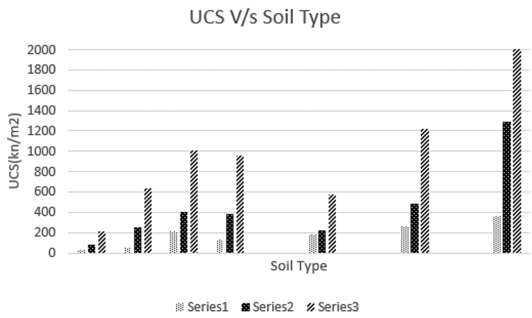

Fig 4: UCS test of C.S with CKD, Polymer

Effect on Shear Strength

Undrained shear strength done as per standards,[20] demonstrate fluctuations in cohesion (Cu) concerning the proportions of (Fig. 5) cement kiln dust (CKD) and polymer in the treated soil. The Cu value shows an uptrend after the mixing of both cements kill dust and polymer. This enhancement in strength might be ascribed to the cohesive properties, gel creation, and the presence of fibers within the stabilizing agents.

Table 9: Results of Shear Strength

Materials	Shear Strength (7Days kN/m²)	Shear Strength (14 Days kN/m²)
C.S	17.26	42.3
C.S+5%CKD	25.401	127.945
C.S+10%CKD	106.83	201.055
C.S+15%CKD	66.405	190.452
C.S+10%CKD+1%Polymer	88.508	112.511
C.S+10%CKD+2%Polymer	129.485	243.977
C.S+10%CKD+3%Polymer	181.261	644.365

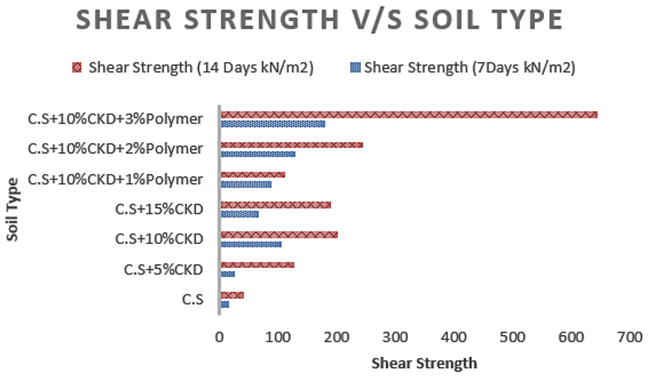

Fig 5: Shear Strength of C.S with CKD and Polymer

Effects on California Bearing Ratio

The California Bearing Ratio (CBR) test is a laboratory technique which determines the load-bearing capacity of a compacted soil sample under specific moisture and density conditions. The CBR value of contaminated soil was 4.102% initially which rises when 5%, 10% and 15% of CKD was mixed. At 5% of CKD mix with soil the CBR value rises to 22.95%, at 10% CKD the CBR values was 42.59% and at 15% of CKD mix it was 8.173%. The optimum value was observed at Contaminated soil with 10% of Cement Kiln Dust. When the contaminated soil was mixed with 10% CKD and 1%,2%,3% liquid polymer, the CBR was 14.53%, 21.15% and 13.26% as shown in table 10 and 11 and Fig. 6 are in confirmation with past studies.

Table 10: California bearing ratio test value of Contaminated soil +(5/10/15) % Cement kiln dust

Materials	Unsoaked CBR values %
Contaminated Soil	4.102
Contaminated Soil+5% CKD	22.95
Contaminated Soil+10% CKD	42.59
Contaminated Soil+15% CKD	8.173

Table 11: California bearing ratio value of Contaminated soil +(5/10/15) % Cement kiln dust with Polymer Percentages

Materials	Unsoaked CBR values %
Contaminated Soil+10% CKD+1%Polymer	14.53
Contaminated Soil+10% CKD+2%Polymer	21.15
Contaminated Soil+10% CKD+3%Polymer	13.26

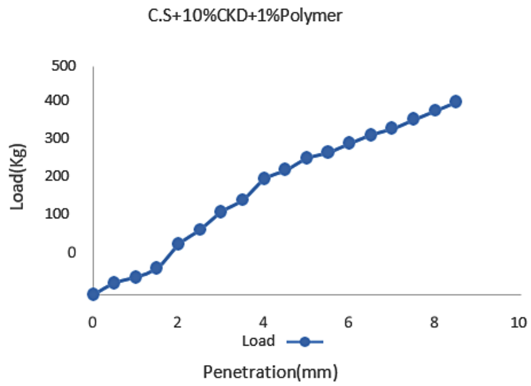

Fig 6: CS+10%CKD+1% Polymer

Conclusion

The main conclusion of the study is explained in this section. The addition of CKD proportions at 5%,10% and 15% contributes to the density increase from 1.57g/cc to 2.010g/cc, 1.97g/cc and 1.81g/cc respectively. The compressive strength of the stabilized soil mixture rises with higher percentages of CKD and epoxy liquid polymer.

The liquid limit, plastic limit, and plasticity index reduces for optimum dose of CKD i.e., upto10%. While, in combination with polymer and CKD, sub-grade strength in pavement improves with durability with passage of time. On other hand addition of cement in contaminated soil the optimal water content increases and maximum dry density fall. Overall, the Unconfined Compressive Strength rises when addition of cement with CKD. This is mainly due to increased cohesion of treated soil.

X-ray fluorescence data, it can be concluded that the contaminated soil treated with 10% CKD and 3% polymer, the concentrations of heavy toxic metals such as chromium (Cr), lead (Pb), and aluminum (Al) decrease in the presence of both CKD and polymer. The changes may be attributed to the interaction between CKD and polymer, which changes the chemical environment of heavy metals in the composite soil matrix. Additionally, the calcium oxide (CaO) content of the contaminated soil increases significantly with the incorporation of CKD and polymer which is good sign of removal of contaminants from soil.

The combined use of CKD and polymer may obe a promising approach for mitigating the environmental risks associated with heavy metal contamination in soils.

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Data Availability Statement

This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions

- **Dr. Rajiv Chauhan:** Conceptualization, Supervision, Data representation, Manuscript review Drafting.
- **Amit Suman:** Conceptualization, Data Collection, Methodology, Writing – Original Draft.
- **Akashdeep Singh:** Writing, Editing.

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