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Evaluation of Cement Kiln Dust Stabilized Heavy Metals Contaminated Expansive Soil – A Laboratory Study

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ABSTRACT

The presence of man-made chemicals or other alteration in the natural soil environment may cause contamination of land. The most common chemicals involved are petroleum hydrocarbons, solvents, pesticides, lead and other heavy metals for e.g. Copper, Cadmium, Arsenic, lead, mercury etc. Contamination of soil not only changes the engineering properties of soil but also creates health hazard. Soil stabilization is the process of improving the engineering properties of soil. The purpose of modification is to increase the strength, reduce settlement, reduce permeability and inactivate contaminants present in the soil. Cement Kiln Dust (CKD) is a fine powdery material similar in appearance to Portland cement obtained as waste material during cement manufacturing process. Cement Kiln Dust added to soil in modest amount has a beneficial effect on the engineering behaviour of soil. Interaction of CKD with a given soil depends on the chemical and physical properties of CKD as well as the nature of soil. The main aim of the present study is the evaluation of behavior of cadmium contaminated soil with addition of CKD in varying percentage (1%, 2%, 4%, 6%, 8% and 10%). The effect of stabilization of contaminated expansive soil is reported in this paper.

Key words: CKD (Cement Kiln Dust), Stabilization, OMC-MDD, UCS

INTRODUCTION

There are lots of sources of contamination of soil but among the most commonly encountered soil contaminants are heavy metals, petroleum hydrocarbons and halogenated organics. The contamination may arise from the rupture of underground storage tanks, application of pesticides, and percolation of contaminated surface water to subsurface strata, oil and fuel dumping, leaching of wastes from landfills or direct discharge of industrial wastes to the soil. Many of these contaminants are highly toxic and potentially carcinogens. The heavy metals and other contaminants may also cause the adverse effect on human health. Some of these heavy metals have poisoning effect on human which may cause dysfunction of kidneys, brain, nervous system and liver [7]. The polluted lands which are used for a wide range of human activities and building constructions without remediation are potential source of hazard.

Soil stabilization is the process of improving the engineering properties of soil. It is required when the soil available for construction is not suitable for desired purpose. The purpose of modification is to increase the strength, reduce settlement, reduce permeability and if possible inactivate contaminants present in the soil. Different admixtures are: lime, lime-fly ash, cement & asphalt [10].

Cement Kiln Dust is byproduct of cement manufacturing process. The limestone, sand & iron ore are used in cement making process. The rock is quarried, crushed & blended to form the raw feed. The feed enters a sloping cement kiln, where it is heated to a temperature that exceeds 2500°F. The input material crystallizes by this heating process into an interim product known as clinker. Granular material that is captured in the main kiln bag house is known as Cement Kiln Dust. There are many beneficial uses for Cement Kiln Dust include: raw feed stock, base stabilizer for pavements, as solidifier and stabilizer for contaminated wastes, agricultural soil enhancement, low strength back fill material and municipal daily landfill cover[11]. Cement Kiln Dust is a valuable resource with many opportunities for reuse.

The present study is based on stabilization of heavy metal ‘Cadmium’ present (added to artificially contaminate the natural soil) in expansive soil and CKD has been used as an additive. The analysis of engineering behaviour of virgin soil, contaminated soil and stabilized soil has been carried out. The main aim of the present study is the evaluation of behaviour of cadmium contaminated soil with addition of CKD in varying percentage (1%, 2%, 4%, 6%, 8% and 10%). The effect of stabilization of contaminated expansive soil has been reported here in.

Soil stabilization is the process of improving the engineering properties of the soil. It is required when the soil available for construction is not suitable for the intended purpose. The concept of soil modification through stabilization with additive has been around of several thousand years old. The purpose of modification is to increases strength, reduce deformability, provide volume stability, lower permeability, minimize erodibility, enhance durability and control variability and inactivate contaminants present in the soil.

Traditional Methods of Soil Stabilization

Advantages of chemical stabilization are that they reduce the swell and shrink characteristics of expansive soils and also transform the soils less plastic. Lime stabilization is generally adopted for improving the swell and shrink characteristics of expansive soils among the chemical methods of stabilization. Different methods of stabilization are given below:

(i) Cement stabilization (ii) Lime stabilization (iii) Bituminous stabilization (iv) Chemical stabilization

(i) **Cement Stabilization-** Cement stabilization is done by mixing pulverized soil and cement with water and compacting the mix to attain a strong material. This soil-cement becomes a hard and durable structural material as cement hydrates and develops strength.

(ii) **Lime Stabilization-** Lime stabilization is done by adding lime to a soil. It is useful for stabilizing clayey soil. When lime reacts with soil there is exchange of cation in the adsorbed water layer and a decrease in plasticity of the soil occurs.

(iii) **Bituminous Stabilization-** Bituminous stabilization is generally done with asphalt as binder. Any inorganic soil which can be mixed with asphalt is suitable for bituminous stabilization. In cohesion less soils, asphalt binds the soil particles together and thus serves as a bonding or cementing agent. In cohesive soils, asphalt protects the soil by plugging its voids and water proofing it. It helps the cohesive soil to maintain low moisture content and to increase the bearing capacity.

(iv) **Chemical Stabilization-** In chemical stabilization soils are stabilized by adding different chemicals. The main advantage of chemical stabilization is that setting time and curing time can be controlled. Chemical stabilization is generally more expensive than other types of stabilization. The chemical used for soil stabilization are (i) Calcium Chloride (ii) Sodium Chloride (iii) Sodium Silicate

It was investigated that the chemical and physical characteristics of the CKDs plays major role for the interaction of CKDs with a given soil. Hence, the characterization of CKDs and their hydration products may lead to better suitability as soil stabilizers. A detailed chemical (X-ray diffraction), thermo gravimetric and morphological (scanning electron microscope) analyses of both the CKD powders and the hydrated CKD pastes show that high free lime content (~14–29%) CKDs, when reacted with water produced significant amounts of calcium hydroxide, ettringite and syngenite. These CKDs also developed higher unconfined compressive strength and higher temperature of hydration compared to CKDs with lower amounts of free-lime. Fig. 1 presents the Scanning electron micrographs for four samples of CKDs and close up of cluster containing both the agglomerated and spherical particles covered with very fine deposits [13].

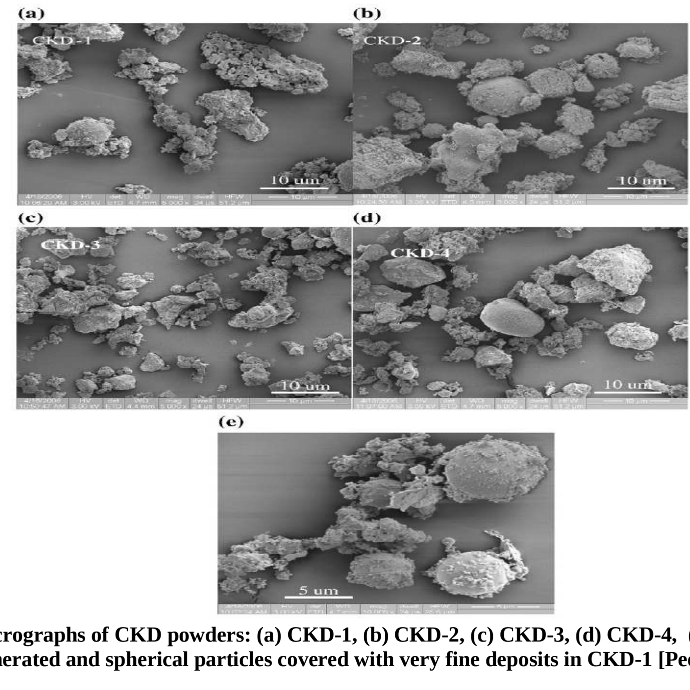

Fig.1 Scanning electron micrographs of CKD powders: (a) CKD-1, (b) CKD-2, (c) CKD-3, (d) CKD-4, (e) close up-of the cluster containing both the agglomerated and spherical particles covered with very fine deposits in CKD-1 [Peethamparan et al (2008)]

Tests on fresh and landfilled CKDs has been performed and their observations show that reactivity of both is limited. SEM analysis show fresh CKD particles are irregularly shaped and have a fairly smooth surface while landfilled CKD show reaction products in form of fibres. Fig. 2 presents the X-Ray differaction patterns for fresh and landfilles CKD[14]. Polat et al (2004), studies shows that CKD contains varies useful constituents Ca, Mg, Mn, Fe, Cu, Zn, B, S and P, along with appreciable amounts of toxic elements such as Cr, Pb, Hg, Ni, and V, As, Ba. Hence before use of CKD it is ensure that it has no harmful constituents.

The effect of soil contamination by diesel on the water infiltration characteristics of two soils has been investigated and it was observed that oil contamination of soil affects its capacity to retain and transmit water. There have been a few methods to improve the oil contaminated areas. Thus, in order to minimize potential environmental impact of this contamination, it must undergo an efficient chemical treatment, which may be followed by stabilisation/ solidification technologies to enhance non-leachability properties of the treated waste [9].

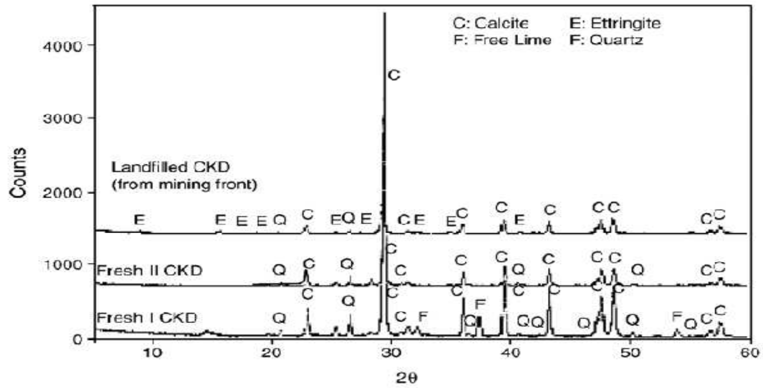

Fig.2 XRD patterns for fresh and landfilled CKD [Sreekrishnavilasam et al (2006)]

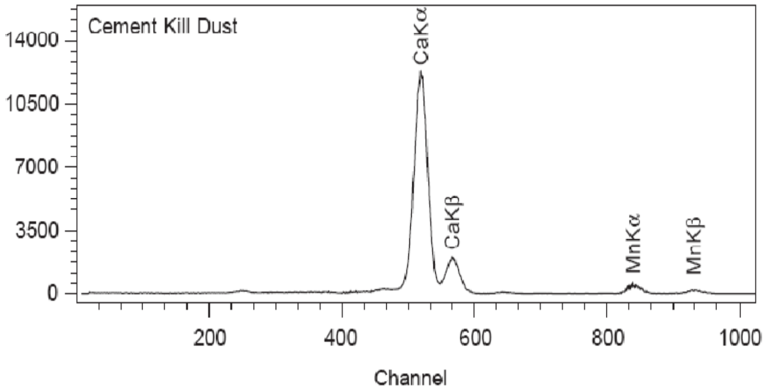

Fig.3 X-ray spectrum obtained for CKD specimen using ^{55}Fe excitation [Polat et al (2004)]

CKD addition to soils shows the improvement in engineering properties of soils like UCS and modulus etc [8]. Several factors influence the chemical and physical properties of CKD. Because plant operations differ considerably with respect to raw feed, type of operation, dust collection facility, and type of fuel used the use of the terms typical or average CKD when comparing different plants can be misleading. The dust from each plant can vary markedly in chemical, mineralogical and physical composition [6]. A great deal of work has been done on the use of CKD in blended cements. Bhatty has published a series of reports on the addition CKD Portland cement along with fly ash and blast furnace slag, with variable results [2-5]. The use of CKD by grinding and blending this dust with Portland cement has also been observed. Their data showed no evidence of adverse effects on blends' setting time, soundness, or shrinkage with up to 10 % CKD addition [1]. The chemical, mineralogical, and physical compositions of CKD varies from one plant to another. These depend on raw material, type of kiln operation, dust collection method, and type of fuel used in the plant [6]. When CKD mixed with sand, an irregular decrease in liquid limit has been observed. CKD permits the compaction of the soil at lower maximum dry unit weight & higher optimum moisture content. CKD has been caused an increase in angle of shearing resistance (Φ) & cohesion. There is no variation in shear strength after 14 days of curing [12].

MATERIALS AND METHODOLOGY

The soil collects from the local area Meja, Allahabad district for the present experimental work. The soil was characterised by grain size analysis and Atterberg limit tests and classified as clay with low compressibility (CL) and other geotechnical properties of soil are followed as per IS code. X-ray diffraction (XRD) and scanning electron microscopic (SEM) studies were conducted to estimate mineralogical constituents of the soil. The heavy metal

Cadmium used for the contamination, the soil is artificially contaminated in laboratory. The Cement Kiln Dust is used as the stabilizer material. The CKD collected from a cement industry in MP, India. The various operations involved in this study consist of evaluation of geotechnical properties of soil contaminated with Cadmium and its stabilisation with CKD. Initially soil is oven dried and passed through IS 425-micron sieve then after it is contaminated with different percentage of Cadmium and kept for one week period of time to ensure through absorption of contaminant in soil. After period of one week the geotechnical tests were carried out on contaminated soil as well as soils stabilised with CKD.

RESULTS AND DISCUSSION

Virgin Soil and Virgin Soil-CKD Mixes

Table- 1 presents the physical properties of CKD observed in the laboratory. Table- 2 presents the chemical composition of CKD and it was observed that calcium carbonate, silica and lime are the major component of CKD. Table 3 presents the properties of virgin soil and soil-CKD mixes. It was observed that the optimum moisture content and liquid limit are decreasing with increase in the percentage of CKD. Fig.4 is the graphical representation of OMC-MDD, and it was observed that the highest value of optimum moisture content is obtained by the virgin soil.

Table-1 Physical Properties of CKD

Property	Values
Gradation (75% passing)	0.030 mm (No. 450 sieve)
Maximum Particle size	0.300 mm (No. 50 sieve)
Specific Surface area (cm^2/g)	4600-14000
Specific Gravity	2.6-2.8

Table-3 Properties of Virgin Soil Mix with CKD

Soil	γ_d (gm/cc)	OMC	G	LL	PL	SL
Virgin	1.718	24	2.35	46.50	22.22	14.22
Virgin + 1% CKD	1.740	22	2.55	44.44	17.74	15.91
Virgin + 2% CKD	1.761	20	2.56	43.30	16.93	15.92
Virgin + 4% CKD	1.733	20	2.63	43.00	15.09	12.99
Virgin + 6% CKD	1.697	20	2.64	41.00	15.99	12.21
Virgin + 8% CKD	1.732	16	2.64	40.50	14.23	11.54
Virgin + 10% CKD	1.752	16	2.68	38.90	13.84	9.99

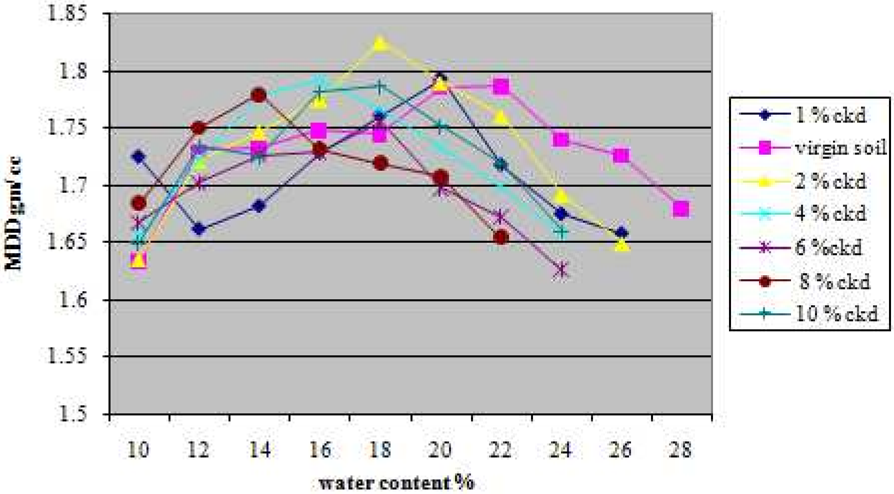

Fig. 4 OMC-MDD curve of virgin soil and virgin soil-CKD mixes

Table-2 Typical Composition of Cement Kiln Dust

Constituent	% by weight
$CaCO_3$	54.3
SiO_2	13.8
CaO	7.8
K_2SO_4	6.2
$CaSO_4$	5.5
Al_2O_3	4.3
Fe_2O_3	2.4
KCl	1.4
MgO	1.2
Na_2SO_4	1.5
KF	0.5
Others	0.8

UCS for Virgin Soil with CKD

Table 4 presents the UCS value of virgin soil and soil-CKD mixes. As the result of UCS analysis, it was found that the unconfined compressive strength is highly decreased when the small amount of CKD is mixed but as well as we increased the percentage of CKD in the soil, the UCS value is continuously increasing. If we compare the UCS value for virgin soil and virgin soil with 8% of CKD, we realized that the soil is highly stabilized. Fig.5 is the graphical representation of UCS value, it was found that the maximum value of UCS obtained for soil with 8% of CKD.

Table-4 UCS Value of Virgin Soil and Soil Added with CKD

Soil type: Virgin soil	UCS Value (KPa)
soil + 0 % CKD	229
soil + 1 % CKD	101
soil + 2 % CKD	199
soil + 4 % CKD	218
soil + 6 % CKD	257
soil + 8 % CKD	362

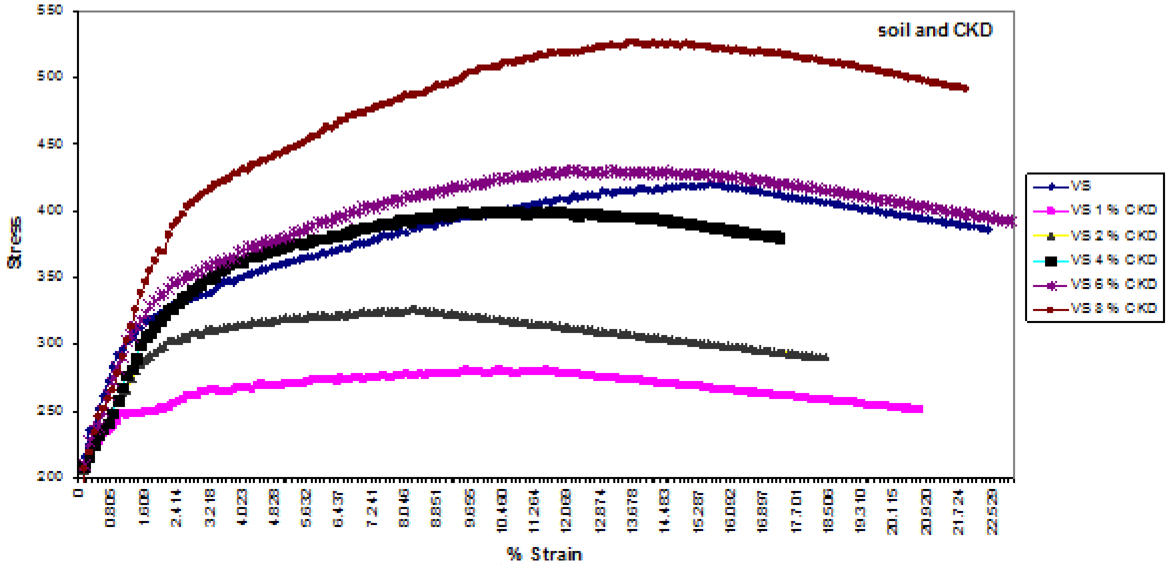

Fig.5 UCS value for virgin and virgin soil-CKD mixes

Soil contaminated with Cd and contaminated soil-CKD mixes

This study analysed the effect of CKD on Cd contaminated soil also. Table 5 presents the properties of Cd contaminated soil and contaminated soil-CKD mixes. It was observed that after contamination the optimum moisture content has decreased and after mixing of CKD the contaminated soil regain its property and the optimum moisture content was increased with increase the percentage of CKD. Fig. 6 is the graphical representation of Cd contaminated soil and contaminated soil-CKD mixes. Table 6 presents the UCS value of contaminated soil and contaminated soil-CKD mixes. It was observed that the UCS value was increased with the increase in the percentage of CKD and the maximum UCS value obtained with 8% CKD. Fig.7 is the graphical representation of UCS values of Cd contaminated soil and contaminated soil-CKD mixes.

Table-5 Properties of Contaminated soil with Cd nitrate mix with CKD

Soil	γ_b (gm/cc)	W	γ_d(gm/cc)	OMC	G	LL	PL	SL
Contaminated Soil	2.083	35.46	1.540	14	2.76	38.61	16.72	9.88
CS + 1% CKD	2.032	16.46	1.745	16	2.70	37.98	16.63	10.02
CS + 2% CKD	2.060	17.92	1.725	16	2.70	38.55	17.18	10.22
CS + 4% CKD	2.085	17.22	1.780	18	2.69	38.60	17.77	10.33
CS + 6% CKD	2.101	16.90	1.797	18	2.73	38.90	18.32	13.87
CS + 8% CKD	2.075	18.90	1.750	18	2.74	39.02	18.54	14.35
CS + 10% CKD	2.061	17.03	1.761	18	2.75	39.80	18.95	15.01

Table-6 UCS for Contaminated Soil with Cd nitrate mix with CKD

Soil type: Contaminated (Cd)	U.C.S. Value (KPa)
Contaminated (Cd) Soil + 0 % CKD	152
Contaminated (Cd) Soil + 1 % CKD	136
Contaminated (Cd)Soil + 2 % CKD	140
Contaminated (Cd) Soil + 4 % CKD	210
Contaminated (Cd) Soil + 6 % CKD	267
Contaminated (Cd) Soil + 8 % CKD	336

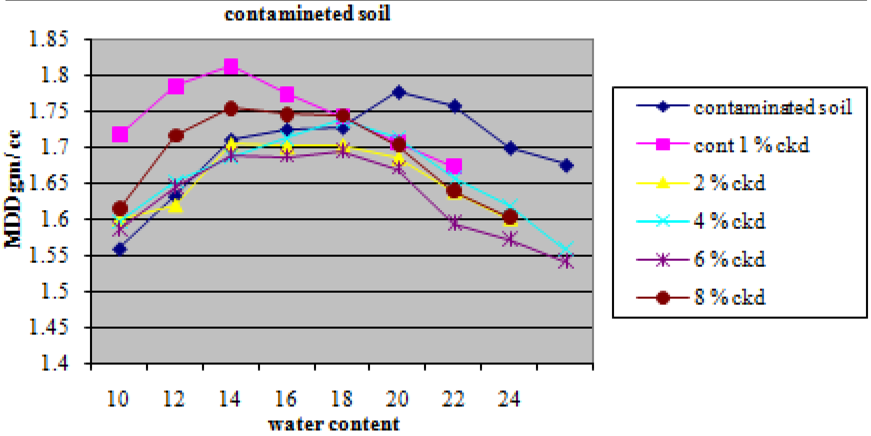

Fig. 6 OMC-MDD curve of Cd contaminated soil and contaminated soil-CKD mixes

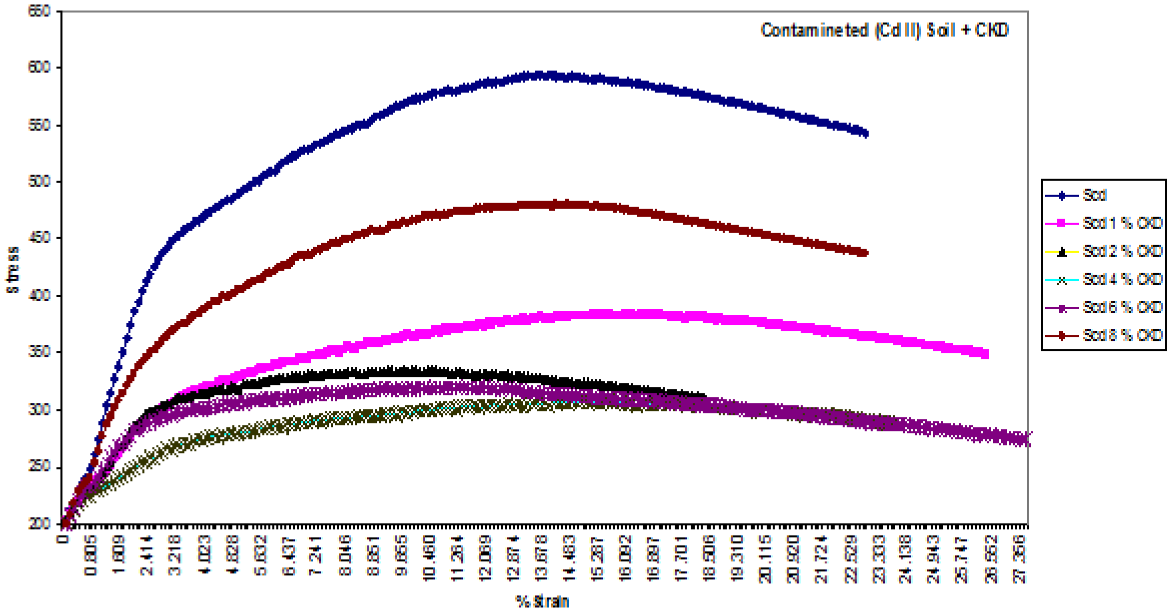

Fig.7 UCS values of Cd contaminated soil and contaminated soil-CKD mixes

CONCLUSION

The study concluded that the virgin soil is expansive in nature. It has been observed that there is an irregular decrease in Atterberg limits. The soil is turned to coarse grained after mixing of additives as comparable to virgin soil. The soil stabilized with the increasing percentage of CKD and the maximum stabilization obtained at 8% CKD mixed soil. After Cd contamination the soil properties were degraded but as well as the CKD mixes with contaminated soil, the soil regain its properties. Cadmium contaminated soil stabilization result shown the optimum amount of lime required is 4% and that of cement is 6% as well. From toxicity characteristic leaching procedure (TCLP) test indicate that 80.70% of Cadmium is inactivated/immobilized and only 19.30% can leach out.

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