A Critical Review on Enhancing Soil Properties Using Cement Kiln Dust and Polypropylene Fibre

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Abstract: Growing infrastructure leads to various kind and concentration of waste product at different stages. Most of these waste product is utilised nowadays in similar or different industry as a substitute for their raw material. The aim of the study was to review on soil stabilisation using various waste materials and analyse qualitatively to reach the optimum value (amount and percentages) of the waste materials along with using soil reinforcement techniques i.e. using various fibrous materials which enhance engineering properties of the soil providing required reinforcement with the soil. This study help in understanding the qualitative and quantitative effect of these waste materials as a stabiliser for the weak soil with improved strength parameters.

Index Terms - Soil stabilization, Cement Kiln Dust, Fly ash, Quarry dust,

Sisal fibre, CBR, OMC and MDD.

Introduction

Due to exponential growth in urbanization, industrialization and technological advancement makes the world a better place to live in while on the other hand poses various problems to human beings. Like due to population growth, the need for their shelters booms the civil engineering and different structures have been built for their needs, due to which land scarcity problem occurs. While dealing with soil and foundation engineering we encountered with expansive soil which has low strength and shows swelling and shrinkage behaviour when comes in contact with water. Having worked with such soil we left with two options i.e. either replace the soil with some good quality soil (which itself is tedious work) or enhance the in-situ soil properties. So there comes a need to use any of the industrial wastes along with the soil to enhance its engineering property which serves the two-way purpose of soil stabilization and optimum utilization of industrial wastes. Soil stabilization can be done by any of the following methods i.e. Physical, Mechanical and Chemical method. The physical method reduces the swell potential without effecting the soil chemistry while other methods chemically and structurally change in the soil geometry.

Soil stabilization: Stabilization is defined as the process of improving soil aggregate properties by blending in the materials that increase the load-carrying capacity, firmness and resistance to weathering or displacement. It can be defined as the process of altering soil properties by mechanical or chemical means thereby improving the desired engineering properties of such soils. It has been used for many years to improve the characteristics of the sub grade having problematic soil. Different types of soil treated with different techniques and the amount of stabilizing agents have been investigated by many researchers over the years.

Literature Review

Heeralal et al. [1] (2011) An experimental program was conducted to investigate the effects of discrete short polypropylene fibre (PP-fibre) on the strength and mechanical behaviour of soil and soil+ CKD mix. In the present investigation the soil samples were prepared at three different percentages of PP-fibre content (i.e. 0.25%,0.5%,1.0% by weight of the soil) and three different percentages of cement kiln dust content (i.e. 3%,5%,8% by weight of the soil) and unconfined compressive strength, direct shear test and C.B.R tests were carried out. U.C.S tests were carried out after a curing period of 28 days. The test results indicated that the inclusion of fibre reinforcement within soil and soil-CKD mix caused an increase in the unconfined compressive strength (UCS), shear strength, axial strain at failure, decreased the stiffness, and changed the soil's brittle behaviour to a more ductile one and C.B.R value increased even for unsoaked condition.

Pal1 et al. [2] (2015) On the basis of the analysis and interpretations of the results obtained from the experimental investigations carried out in the present research work, the following conclusions are drawn:

i. Compressibility of the Soil In case of the compressibility, it is concluded that there is a marginal decrease in the maximum dry density (ϒd(max)), with the addition of waste fibres of the polypropylene.
ii. The direct shear strength parameters of the soil reinforced with waste fibres of polypropylene used for the improvement of the engineering properties of the soil with 20 mm length and 0.35% weight of polypropylene by weight of dry soil sample, is found as 25.18% increase in the angle of internal friction (Φ) and 46.88% increase in cohesion (c).
iii. The unconfined compressive strength (UCS) of the soil reinforced with waste fibres of polypropylene used for the improvement of the engineering properties of the soil with 20mm length and 0.25% weight of polypropylene by weight of dry soil sample, is found as 52.80% increase in UCS.

Moses et al. [3] (2016) Laboratory test was conducted on black cotton soil treated with up to 16% Cement Kiln Dust (CKD) by dry weight of soil to assess its suitability for use as a road pavement material. Specimens were compacted using the energies of the British Standard Light (BSL) and West African Standard (WAS) or "intermediate". The expansive black cotton soil classified as A-7-6 (16) or CL using the America Association of Highway and Transportation Officials (AASHTO) and Unified Soil Classification System (USCS), respectively, Soils under these groups are of poor engineering benefit. The UCS values for the untreated soil are 178 and 381kN/m2 at energy levels of BSL and WAS respectively. CKD treated black cotton soil gave a peak 7 day UCS value of 394kN/m2 and 410kN/m2 at 12% and 8% CKD content at BSL and WAS energy level respectively. These values fall short of the 1710 kN/m2 specified for base materials stabilization using OPC. And this value also fails to meet the requirement of 687–1373 kN/m2 for sub-base material. The CBR recorded an improvement in the strength from 2% and 3% for the natural soil for BSL and WAS compaction effort to attain a peak C.B.R. of 12% at 12% CKD and 16% at 12% CKD treatment for BSL and WAS compactive effort respectively. However, soil –CKD mixtures failed to meet the minimum CBR value of 30% specified for use as sub-base course material when determined at MDD and OMC. The peak resistance to a loss in strength recorded for BSL and WAS were 13.2 and 16.1% (i.e. loss in strength) was attained at 16%

CKD content at both energy levels. The resistance to a loss in strength values also fell short of the acceptable conventional minimum of 80%.

Bushra et al. [4] (2012) To determine the geotechnical properties of Stabilized dune sand by Using Cement Kiln Dust (CKD) and to assess the suitability of resting shallow foundation on it, an extensive laboratory testing program was carried out. The results indicated that: Cement kiln dust (CKD) caused an irregular decrease in the liquid limit when it was mixed with sand. The mix of CKD allows compaction of the soil at the lower maximum dry unit weight and higher optimum water content. Cement dust caused an increase in φ and (c). The variation in shear strength parameters became almost constant after fourteen days of curing. Stabilization of collapsible soils with CKD can provide tremendous economic advantages. Adding CKD increases the ultimate bearing capacity to 250% for 8% CKD as an example.

Ayyappan et al. [5] (2010) In this study Polypropylene fibres with different fibre length (6mm, 12mm and 24 mm) were used as reinforcement. Soil - fly ash specimens were compacted at maximum dry density with a low percentage of reinforcement (0 to 1.50 % of weight). Third, an optimum dosage rate of fibres was identified as 1.00 % by dry weight of soil- fly ash, for all soil fly ash mixtures. Fourth, the maximum performance was achieved with a fibre length of 12mm as reinforcement of soil fly ash specimens. The relative benefit in CBR values due to fibres increases only up-to 1.00 % by dry weight and length up to 12mm for all soil-fly ash specimens. The results of a study of a randomly oriented fibre-reinforced soil- fly ash mixtures indicted that a maximum performance was achieved with 12 mm fibres in an optimum dosage of 1.00 % by dry weight of soil- fly ash mixtures.

Saravanan et al. [6] (2013) The expansive clay soil was collected from near Tiruchengode, Tamilnadu, India. The clay soil behaviour was studied in addition to a different percentage of fly ash. (0, 10%, 20%, 30% and 40%). The Specific gravity, Atterberg limit, Standard Proctor's compaction, Unconfined compressive tests were performed on expansive clay soil. The result shows that in addition to fly ash reduces the specific gravity and plastic index of expansive clay soil. The optimum moisture content (OMC) and maximum dry density (MDD) curves indicate that the addition of fly ash increases the OMC and maximum dry density of the expansive soil. The strength properties of the expansive clayey soil have increased by 21.1%. Based on the Standard Proctor's Compaction test, the Optimum Content of fly ash was found as (10 %).

i. The unconfined compression strength of the given soil sample has increased by 21% in addition to the fly ash content.
ii. The dry density of the clayey soil sample is increased by 15 % of the natural soil sample.
iii. The optimum moisture content of the clayey soil sample has decreased by 9% of the natural soil sample.
iv. The unconfined compression test has increased 21% from the natural soil sample.
v. The optimum content of the fly ash content has found that 10% in addition to the natural soil sample.

Sunny et al. [7] (2016) In this study the main objective to investigate the use of waste material such as banana fibre in geotechnical applications. Various tests such as unconfined compression (UCC), California Bearing Ratio (CBR), Atterberg limits, Compaction were carried out and the results are analysed. The percentage of banana fibre varies from 0%, 0.25%, 0.75%, 1%and 2%. The addition of banana fibre improved the properties of clay. The optimum value for marine clay stabilized with banana fibre was obtained at0.75%. It was seen that OMC value increased with the addition of banana fibre and dry density decreases. The shear strength increased from 8.5kN/m2 to 32.91kN/m2 with the addition of 0.75% of banana fibre and CBR value increased from 2.79 to 13.2 which makes it suitable for subgrade soil for road pavements.

Butt et al. [8] (2015) In this study, human hair fibres were used as an additive to the high compressibility clayey soil by weight (0.5,1.0, 1.5, 2.0 and 2.5 %) to evaluate the effect of human hair fibre on the mechanical behaviour of clayey soil. Human hair fibre is a natural non-degradable waste material, which creates health and environmental problem if not disposed-off in a scientific manner. This is available in abundance at a very low cost and can be easily used as a reinforcing material not only to improve poor/unsuitable construction sites for sustainable construction but also to avoid its disposal problems. The HHF randomly distributed in clayey soil samples were tested for its engineering properties by performing CBR and tri-axial test on a number of samples by using the different percentage of fibres and comparing the results with the non-reinforced soil. Fibres of the average length of 25 mm and an average diameter of 50mm were used.

Human hair fibre exhibits many advantages such as good strength properties, low cost and high toughness to biodegradability. However, by increasing the HHF content, it marginally affects the dry density-moisture content relationships of composite specimens. MDD initially reduces lightly due to the addition of lightweight hair fibre and then practically remains the same. OMC increases marginally due to moisture absorption of hair fibres. It has been seen that about 2 % of fibre content is the optimum quantity to enhance CBR and undrained shear strength of clayey soil.

Varghese et al. [9] (2016) The main aim of this study is to evaluate the effect of polypropylene fibres on shear strength parameters of the soil. The experimental study was carried out on compacted soil specimens with 0%, 0.05%, 0.15%, 0.25% and 0.35% polypropylene fibre additives, and the results of compaction, unconfined compression test were discussed. From the unconfined compressive test, it was observed that the unconfined compressive strength value of untreated soil was found to be 15.1 KN/m^2 and the strength value increased with increase in addition of polypropylene fibre up to 0.05% at the end then decreases. There is an increase in strength of about 54.37%. That may be due to increase in interfacial shear strength at 0.05 %. For higher amount of polypropylene fibre, it shows a reverse trend.

The strength is increased in the low percentage of PPF addition, it ensures more economical in construction. So finally it was concluded that the polypropylene fibre can potentially stabilize the clayey soil.

Mishra et al. [10] (2016) Polypropylene is mixed with soil- fly ash mixture is improving the soil properties like permeability, strength etc. The moisture - density relationship of soil-fly ash mixtures significantly affected due to the addition of fibres. The relative benefit in CBR values due to fibres increases only upto 1.00 % by dry weight and length up to 12mm for all soil-fly ash specimens. The results of a study of a randomly oriented fibre-reinforced soil- fly ash mixtures indicted that a maximum performance was achieved with 12 mm fibres in an optimum dosage of 1.00 % by dry weight of soil- fly ash mixtures. Polypropylene fibres reduce the water permeability, plastic, shrinkage and settlement and carbonation depth.

Ismail et al. [11] (2013) This work dealt with a chemical stabilization of an expansive high plastic soil of Pliocene deposits exposed at El-Kaw-the quarter using cement kiln dust (CKD) and cement kiln dust with lime (L) to reduce their swelling and improve their geotechnical properties. Several specimens of the studied expansive soil were collected from El-Kaw the quarter. Chemical analysis of the used cement kiln dust and the lime was conducted. Microstructural changes were examined using a scanning electron microscope (SEM) before and after chemical treatment of the studied soil. Geotechnical properties including plasticity, compaction parameters, unconfined compressive strength (qu), ultrasonic velocities and free swelling of the studied soil were measured before and after the treatment. The optimum content of the cement kiln dust was 16% (CKD). The optimum content of the cement kiln dust with the lime was 14% (CKD) with 3% (L) according to pH-test. The results showed that the addition of cement kiln dust and cement kiln dust with lime led to a decrease in maximum dry density and an increase in optimum water content. Unconfined compressive strength values were increased using cement kiln dust and cement kiln dust with lime at 7 days curing time. Ultrasonic longitudinal (Vp) and shear (Vs) velocities values were also increased by the addition of the cement kiln dust and the cement kiln dust with lime at 7 days curing time. Increment of the curing time from 7 to 28 days led to an increase in both unconfined compressive strength and ultrasonic velocities values. Free swelling per cent of the studied soil was reduced from 80.0% to 0.0% after the treatment.

T. Subramani et al. [12] (2016) This experimental study deals with the use of coconut Fibre for soil stability. Reinforcing the soil with coir Fibres/coir geo-textiles is a cost-effective solution to the ground/soil improvement problems. The study includes the properties of coir Fibre and clay and experimental workouts such as triaxial test, Stress state during a triaxial test, California bearing ratio, unconfined compression test, direct shear test have been conducted on soil and soil mixed with varying amount of coir Fibre (0.25, 0.50, 0.75, and 1.0%) and concluded results are followings:-

1. The strength of soil-coir mix increases with increasing the percentage of coir Fibre.

2. CBR and UCS values of soil-coir Fibre mix increases with an increasing percentage of Fibre.

3. Maximum improvement in U.C.S. and C.B.R. values are observed when 0.5% of coir is mixed with the soil.

4. It is concluded that the proportion of 0.5% coir fibre in the soil is an optimum percentage of materials having maximum soaked CBR value. Hence, this proportion may be economically used in stabilization of clay soil.

Gupta et al. [13] (2015) 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 a health hazard. Soil stabilization is the process of improving the engineering properties of soil. The purpose of a 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 the 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 the soil. The main aim of the present study is the evaluation of the behaviour of cadmium contaminated soil with the 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.

Solanki et al. [14] (2007) A laboratory study was undertaken to evaluate the effectiveness of different percentages of cement kiln dust (CKD) as a soil stabilizer, relative to the implementation of new Mechanistic-Empirical Pavement Design Guide (MEPDG). Cylindrical specimens were compacted and cured for 28 days in a moist room having a constant temperature and controlled humidity. After curing specimens were tested for resilient modulus (Mr), modulus of elasticity (ME) and unconfined compressive strength (UCS). The study revealed that the values of Mr, ME and UCS for the CKD stabilized specimen increased with CKD amount. Reaction products due to chemical reactions are clearly observed in the soil voids based on the micrographs obtained using a scanning electron microscope (SEM), and they are responsible for the increase in modulus and strength.

Baghdadi et al. [15] (2002) Cement kiln dust (CKD) is a waste by-product of Portland cement manufacture. This material poses a health hazard, storage problem, and a potential pollution source. Consuming such material in civil engineering works to upgrade marginal materials would help solve some of these problems. Dune sand, an abundant marginal soil, waste treated by varying amounts of CKD. In addition, 100% CKD was tested. Compacted specimens were tested for unconfined compression (UC) after seven, 28, and 90-day curing periods at different temperature levels. Further testing was conducted for specimens with CKD percentages that gave satisfactory results for road sub-bases. These tests included durability, the California bearing ratio (CBR), and split tension. The test results indicated that on the basis of utilization, CKD between 12 and 50% may be satisfactory. Specimens of 75% and 100% CKD gave relatively high strengths but failed the durability requirements.

Table 1: Summary of literature review

Author Name and Year	Material Used	Test/Technique or Method Used	Remarks
Heeralal et al. [1] (2011)	Polypropylene fibre and CKD	Proctor, UCS and CBR	The test results indicated that the inclusion of fibre reinforcement within soil and soil-CKD mix caused an increase in the unconfined compressive strength (UCS), shear strength, axial strain at failure, decreased the stiffness, and changed the soil's brittle behaviour to a more ductile one and C.B.R value increased even for unsoaked condition.
Pal1 et al. [2] (2015)	Polypropylene Fibre and Soil	Proctor, UCS and CBR	The unconfined compressive strength (UCS) of the soil reinforced with waste fibres of polypropylene used for the improvement of the engineering properties of the soil with 20mm length and 0.25% weight of polypropylene by weight of dry soil sample, is found as 52.80% increase in UCS.
Moses et al. [3] (2016)	CKD and Soil	Proctor, UCS and CBR	The CBR recorded an improvement in the strength from 2% and 3% for the natural soil for BSL and WAS compaction effort to attain a peak C.B.R. of 12% at 12% CKD and 16% at 12% CKD treatment for BSL and WAS compactive effort respectively.
Bushra et al. [4] (2012)	CKD and Soil	Proctor, UCS and CBR	The mix of CKD allowed compaction of the soil at lower maximum dry unit weight and higher optimum water content. Cement dust caused an increase in φ and (c). The variation in shear strength parameters became almost constant after fourteen days of curing. Stabilization of collapsible soils with CKD can provide tremendous economical advantages. Adding CKD increase the ultimate bearing capacity to 250% for 8% CKD as an example.

Ayyappan et al. [5] (2010)	Polypropylene Fibre and fly Ash	Proctor and CBR	The relative benefit in CBR values due to fibres increases only up-to 1.00 % by dry weight and length up to 12mm for all soil-fly ash specimens. The results of a study of a randomly oriented fibre-reinforced soil - fly ash mixtures indicted that a maximum performance was achieved with 12 mm fibres in an optimum dosage of 1.00 % by dry weight of soil- fly ash mixtures.
Saravanan et al. [6] (2013)	Fly Ash and Clayey Soil	Proctor and CBR	The optimum moisture content (OMC) and maximum dry density (MDD) curves indicate that the addition of fly ash increases the OMC and maximum dry density of the expansive soil. The strength properties of the expansive clayey soil have increased by 21.1%.
Sunny et al. [7] (2016)	Banana Fibre and Clayey Soil	Proctor, UCS and CBR	The optimum value for marine clay stabilized with banana fibre was obtained at 0.75%. It was seen that OMC value increased with the addition of banana fibre and dry density decreases. The shear strength increased from 8.5kN/m2 to 32.91kN/m2 with the addition of 0.75% of banana fibre and CBR value increased from 2.79 to13.2 which makes it suitable for subgrade soil for road pavements.
Butt et al. [8] (2015)	Human Hair and Clayey Soil	Proctor, UCS and CBR	Human hair fibre exhibits many advantages such as good strength properties, low cost and high toughness to biodegradability. However, by increasing the HHF content, it marginally affects the dry density-moisture content relationships of composite specimens. MDD initially reduces lightly due to the addition of light weight hair fibre and then practically remains the same. OMC increases marginally due to moisture absorption of hair fibres. It has been seen that about 2 % of fibre content is the

			optimum quantity to enhance CBR and undrained shear strength of clayey soil.
Varghese et al. [9] (2016)	Polypropylene Fibre and weak Soil	Proctor, UCS and CBR	From the unconfined compressive test, it was observed that the unconfined compressive strength value of untreated soil was found to be 15.1 KN/m^2 and the strength value increased with increase in addition of polypropylene fibre up to 0.05% at the end then decreases. There is an increase in strength of about 54.37%.That may be due to an increase in interfacial shear strength at 0.05 %. For higher amount of polypropylene fibre, it shows a reverse trend.
Mishra et al. [10] (2016)	Polypropylene and Fly Ash	Proctor, UCS and CBR	The results of a study of a randomly oriented fibre-reinforced soil- fly ash mixtures indicted that a maximum performance was achieved with 12 mm fibres in an optimum dosage of 1.00 % by dry weight of soil- fly ash mixtures. Polypropylene fibres reduce the water permeability, plastic, shrinkage and settlement and carbonation depth.
Ismail et al. [11] (2013)	CKD and Lime	Ultrasonic longitudinal and Shear Velocity (SEM)	The results showed that the addition of cement kiln dust and cement kiln dust with lime led to a decrease in maximum dry density and an increase in optimum water content. Unconfined compressive strength values were increased using cement kiln dust and cement kiln dust with lime at 7 days curing time. Ultrasonic longitudinal (Vp) and shear (Vs) velocities values were also increased by the addition of the cement kiln dust and the cement kiln dust with lime at 7 days curing time.
T.Subramani et al. [12] (2016)	Coconut Fibre and Expensive Soil	Proctor, UCS and CBR	It is concluded that the proportion of 0.5% coir fibre in soil is an optimum percentage of materials having maximum soaked CBR value. Hence, this proportion may be economically used in stabilization of clay soil.

Gupta et al. [13] (2015)	CKD and Chemically Contaminated Soil	Proctor, UCS and CBR	Interaction of CKD with a given soil depends on the chemical and physical properties of CKD as well as the nature of the soil. The main aim of the present study is the evaluation of the behaviour of cadmium contaminated soil with the 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.
Solanki et al. [14] (2007)	CKD and Expensive Soil	Scanning Electron microscope	The study revealed that the values of Mr, ME and UCS for the CKD stabilized specimen increased with CKD amount. Reaction products due to chemical reactions are clearly observed in the soil voids based on the micrographs obtained using a scanning electron microscope (SEM), and they are responsible for the increase in modulus and strength.
Baghdadi et al. [15] (2002)	CKD and Sand Dune	Proctor, UCS and CBR	The test result indicated that on the basis of utilisation, CKD between 12 and 50 % may be satisfactory. Specimens of 75% and 100% CKD gave relatively high strengths but failed the durability requirements.

Conclusion: - After going through the exclusive literature survey regarding the use of various waste materials for enhancing the engineering properties of soil following conclusions were made:-

1. Strength of weak soil can be improved by using waste materials like CKD, fly ash, etc.
2. Fibrous waste like polypropylene, sisal, coir, etc. Can be used as reinforcement in soil stabilisation.
3. Combination of CKD and polypropylene can improve strength and ductility respectively.
4. The utilisation of the waste product in soil stabilisation is a cost-effective fixation of waste product.

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