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STABILIZATION OF SOILS USING CEMENT KILN DUST (CKD) AND SUGARCANE BAGASSE ASH (SBA)

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INTRODUCTION

Now-a-days in India, growth of the population increasing like a boom has become a major problem. Correspondingly, the basic necessity of life (such as food and shelter) is required by the vast multitude of the people. This leads to the rapid industrialization and urbanization which has been the two worldwide phenomenon in the present century. It cannot be disavowed that these are the necessity of the people of the society but their negative impacts which has become a threat to our environment and social life can also not be denied.

The major impact of these processes leads to the increasing demand of construction materials. As cement is one of the most broadly used building material therefore, a large number of industries (like cement industries, fertilizer industry, food processing industry, mills, *etc*) have been set up in the rural areas near the crop fields or forests. After further increment or development of industries and the processes adopted by these factories leads to emit a tremendous amount of wastes like cement kiln dust (CKD), rice husk ash (RHA), sugarcane bagasse ash (SBA), waste paper sludge (WPS), silica fumes (SF), cement fly ash (CFA), lime fly ash (LFA), *etc*. By these global processes the major ill effects comes into the light is the production of enormous quantities of industrial as well as agricultural wastes, the problems which has become threat to our environment, several health associated hazards and their safe disposal and management.

One of the most important issues of these industrial and the agro-industrial wastes in view of the availability of land for their purposes which is squandering with the passing each and every year is their safe disposal. Even the disposal and storage of these industrial and agro-industrial wastes resulting the devastation of land and their near-by areas where it leads to dump. This also causes a biggest threat to the environment causing flinty ecological problems and several health hazards.

The furthermost challenge before the processing and manufacturing industries is their safe disposal and management of their industrial and agro-industrial wastes. Waste products that are dumped in the ground have inimical environmental consequences. Thus disposal of this agricultural waste is the major issue for the present generation. So, there is an immense need of that processes which warrants an effective, economic and the environment friendly method to tackle with the disposal of residual agro-industrial waste products. One of the most common and the feasible tradition to utilize this type of waste products is to explore their use in construction of roads, highways, embankments and a fill material.

To convene the requisite of appropriate amount of soil that is essential in the construction of roads and highways, a huge amount of the trees are being cut down which in cause deforestation, soil erosion and the loss of fertility of soil which also hampers the productivity of the agricultural land. An effective use of these agricultural wastes, as an alternate for natural soil, in the construction will not only ease out the problems of disposal and environmental pollution but will also help to preserve the natural soil. This will provide number of significant benefits to these construction industries as well as to the country as a body by conservation of the natural resources, by reduction in the volume of waste to the landfills, by using the construction materials of cheaper cost and by lowering waste disposal costs. Usage of these industrial wastes in the manufacture of the materials has been become one of the most effectual avenues in the field of Civil Engineering. In the same line, utilization of industrial wastes in soil engineering is being researched heavily in recent times, especially in soil stabilization. So one of the best process in regarding the valuable use of these industrial and agro-industrial wastes lowering the cost of construction materials is stabilization of soil.

SOIL STABILIZATION

Generally, 5000 years ago the approach to stabilization was antiquated or dated. McDowell (1959) stated that in ancient Mesopotamia and the Egypt the roads were used which had gone through the process of stabilization, and after that the Greek and the Romans used the stabilized road with mixtures of soil and lime.

Kezdi (1979) reported that around 1906 in USA the very first experiments on the stabilization of soils were achieved with the mixture of sand and clay. And around 20th century, especially in the thirties, the process of stabilization of soils appropriate to the road construction and other uses was implemented in Europe.

Attoh-Okine (1995) stated that the term soil stabilization can be defined as the process of modifying the soil"s geotechnical properties to gratify the engineering requirements for the constructions and Winterkorn and Sibel (1991) stated that generally Stabilization of soil is a process by the physical, chemical, bio-logical, or combined method of changing any virgin soil"s geotechnical properties to serve the engineering purpose for the constructions. Improvements include the increment in the unit weight bearing capability and performance of *in-situ* sub-soils, sands, and other waste materials in an order to strengthen road surface.

Soil stabilization results the increment in the noted bearing capacity found in the foundation of the structure and the other properties like strength, water tightness, resistance to washout, *etc* are improved. Mostly the process of soil stabilization is used in the constructions on the site where the soil of industrial and civil buildings is sagging; for intensifying the banks adjoining highways in a hollow walls of any ditch, where the ground is impregnated with water; for preventing landslides; in sinking shafts and in creating filtration-proof barriers in foundations of hydraulic structures; for protecting concrete structures (foundations) from aggressive industrial effluents; and for improving the piles and large diameter support‟s bearing capacity *(Adamovich and Koltunov, 1949).*

William Powrie (1997) conclude that there are various methods which are used for problematic soils like expansive soils and the fine-grained soil with softness in nature to enhance their geotechnical properties. This issue of these problematic soils can be determined by treating it using mechanical/chemical stabilization or by removing and replacing the soil with a material of better quality. There are different methods which can be bring in process for enhancing and treating the problematic soil‟s geotechnical properties (such as the stiffness and the strength). There are also various methods that can be preferred which compromises densifying treatments (such as preloading or compaction), the bonding of soil particles (with the process of grouting and chemical stabilization, ground freezing), reduction techniques of pore water pressure (like as electro-osmosis or dewatering) and treating with reinforcing elements (like geo-textiles and stone columns).

Geo-technically soil improvement could either be done by modification or stabilization or both. The term soil modification is the process of adding of any modifier to soil to change/improve its engineering properties, while the term soil stabilization represents the process in which the required soils is treated so that the strength and the durability of the soils can be improved such that the soils become perfectly suitable for the construction beyond soil‟s original classification.

The five leading functions of ground improvement in the soil are:

- To get the increment in the bearing capacity of the weak soil.
- To accelerate consolidations and to control deformations.
- To provide it lateral stability.
- To form cut-off to the seepage and environment control.
- To get increment in the resistance against liquefaction.

These functions of the soil can be accomplished by modifying the ground‟s character with or without addition of any foreign materials. Improving the ground at the surface is usually easy to accomplish and relatively inexpensive. When at depth, however, the task becomes more difficult, usually requiring more rigorous analysis and the use of specialized equipments and construction procedures.

Basic Principle of Soil Stabilization

- To calculate the given soil's geotechnical properties.
- To choose effective end economical method of soil stabilization and the soil's lacking properties are to be decided.
- Designing the mix of stabilized soil for better durability values and for intended stability.

Cement Kiln Dust (CKD): An Overview

With the hasty increasing rate of building forests, leads to the rapid growth in the demand of cement in all over the world which results the production of the cement kiln dust (CKD) in massive quantities. Sustainability is the foundation stone of the cement industry, just not only in the products that use cement, but also in its manufacturing process. Cement kiln dust (CKD) is a noteworthy by-product waste material which is formed during the manufacturing process of clickers in the cement industries, which poses a threat to our environment. According to the U.S. Geological Survey, India is the second largest producer of cement after China and its production is 285.83 million tons per year.

Approximately 30 million tons of the cement kiln dust (CKD) generation is estimated at worldwide per year, and at more than 4 million tons per year in the US. Production amount of the cement kiln dust (CKD) can be roughly estimated by considering the produced clinker amount. In fact, the cement kiln dust (CKD) generation can be assumed to be 7% of total clinker generation by weight (Naik *et al.*, 2003).

Sugarcane Bagasse Ash (SBA): An Overview

Annually, 4.4 billion tonnes of the solid waste material is being generated by the Asia alone (*Yoshizawa and Tanaka,*2004). Our India is again on the second rank after Brazil in the world in the production of sugarcane (*i.e.* second largest producer in the world). In the world over 110 countries‟s major growing crop is sugarcane and it is estimated that the total production of sugarcane is crossing the figure of 1500 million tonnes. In India alone, sugarcane production is over 350 million tonnes per year. As a result, it would not be wrong to say that the sugarcane bagasse is a foremost extent of waste generated from agricultural sources.

India alone produces just about 90 million tonnes of the bagasse as a solid waste material in sugarcane industry. Sugarcane bagasse is a type of fibrous material that is obtained after extracting the sugarcane juice from the sugarcane plant. In the sugar industry or in any sugar mill, the amount of bagasse generates is about 30% of every lot of sugarcane crushed. And this bagasse is then further utilized for the power plants and industrial boilers as a better bio-fuel and in the manufacturing of paper. In this processing of utilizing bagasse results the formation of ash which is known as "Sugarcane Bagasse Ash (SBA)". It is estimated that in this whole process sugar mills generates near about 10 million tonnes of the sugarcane bagasse ash (SBA) as a waste material. One tonne of the sugarcane can be able to generate just about 26% of the bagasse which gives near about 0.62% of the residual ash. These burnt residues of the sugarcane bagasse as an ash is called as sugarcane bagasse ash (SBA) and considered as a waste. This is due to the fact that these ashes are the last waste consequential from the related agro-industrial processes without any possibility to diminish it further (*Lima et al.* 2012).

RESEARCH METHODOLOGY

In order to achieve the above objectives of the study the following methodologies were adopted:

i. Literature survey: Different types of literatures; such as text books, academic journals, seminars and research papers pertaining to clayey soil, and different soil stabilization techniques with different stabilizers were reviewed.
ii. Sampling and testing: Material sampling and testing methods that are going to be employed are critical, since they are required to characterize material and physical properties of the soil that can potentially affect the performance of the road or sub-grade.
iii. Sample preparation of the experimental work involved air drying, pulverization and sieving of the natural soil sample to the required particle sizes. Classification of soil was made by running grain size distribution and Atterberg limit tests. Then Atterberg limit, compaction, California bearing ratio and uniaxial compressive strength tests are carried out on natural soil as well as on soil-sugarcane bagasse ash and soil- sugarcane bagasse ash-cement kiln dust mix to study the effect of the stabilizers.
iv. Analysis and discussion of test results: Based on the theories and laboratory tests performed, the results obtained have been analyzed and discussed thoroughly.
v. Formulation of conclusions and recommendations based on the results obtained.
vi. Finally compiling and writing of the thesis work.

REVIEW OF LITERATURE

It is very important and worthwhile to have a state-of-art review of literature before undertaking any project. Accordingly, in view of the objectives of the present study, the literature available on geotechnical properties and parameters of soils, cement kiln dust, sugarcane bagasse ash and their mixes with different percentages of cementitious and agro-industrial materials were thoroughly reviewed. Some of them found important and relevant to the study are being briefly reproduced in the following sections.

Previous Studies on Cement Kiln Dust and Sugarcane Bagasse Ash

Various studies have been done on different type of cementations and agro- industrial wastes mixed with soil to check the suitability of such materials in civil engineering constructions.

McCoy and Kriner (1971) examined the utilization of the cement kiln dusts (CKDs) in the process of stabilization of soil by mixing it with clayey type soils. He performed a series of experiments on the soil and cement kiln dust (CKD) mixes at various percentages as 3, 8, and 10% of the cement kiln dust (CKD) for testing various geotechnical properties, such as consistency limits, moisture-density relationship, the uniaxial compressive strength. From the study, it was concluded that the use of cement kiln dust (CKD) was potentially promising in the stabilization of soils for the application of sub-base and other engineering constructions.

Miller *et al.* (1980) had also demonstrated the utilization of cement kiln dust (CKD) and the fly ash as the cementitious materials in building pozzolanic bases. They reported properties of the bases stabilized with CKD and fly ash are analogous to those stabilized with other cementitious materials. However, they also pointed out that the use of any particular cement kiln dust (CKD) and the fly ash combination to underlay

optimum properties for the appropriate mix design would necessitate an assessment of the chemical and the strength test data.

Nicholson (1977, 1982) had presented various numbers of the patents for bringing forth the sub-base materials with different types of aggregates for a string of inquisitions on cement kiln dust (CKD) and the fly ash mixtures. He used upto 16% cement kiln dust (CKD) by the total weight of the used mixture by which he procured a stable mass by get reacting with water at ambient temperatures.

Collins and Emery (1983) determined the effectiveness of adopting cement kiln dust (CKD) in the place of lime in a series of lime-fly ash-sandy combined compositions for the engineering construction of the sub-base. The observed results shows that the greater part of the cement kiln dust (CKD) treated with fly ash and the aggregate mixtures that is used in materials were as good as in the strength, dimensional stability, durability, and the other desirable engineering properties as compared to those of the typical lime with fly ash and the aggregate mixtures.

Napeierala (1983) investigated the prospecting use of cement kiln dust (CKD) in stabilization of sandy soils for the pavement sub-grade applications. He concluded that an addition of 15% of cement kiln dust (CKD) having 5.9% of free CaO and MgO, and 0.97% of the total alkalies (K_2O + Na_2O) assured a compressive strength of 360 psi (2.5 MPa), which we get by treating with Portland cement in 14 days standard observation for the sub-grade.

Table 2.1: Summary of Soils and CKDs Investigated by Other Researchers

Investigator	Properties of CKD		Percentage of CKD used (by dry weight of soil)	Type of soil used
	Free lime (%)	LOI (%)		
Napierala (1983) (From Bhatty *et al.*, 1996)	5.90	- - -	15.0	Sandy soils
Baghdadi and Rahman (1990)	- - -	- - -	30-70	Siliceous dune sand
Baghdadi *et al.* (1995)	- - -	33.0	15-50	Dune Sand (SP) $\rho_{d\ max}$ =1.52 g/cc and OMC=22.5%
Baghdadi (1990)	5.33	26.0	- - -	Processed and pure kaolinite (G_s =2.62, LL=40%, PI=9%). Commercially available bentonite (LL=513%)
Zaman and Sayah (1992)	- - -	28.0	5-40	Expansive clay (LL=99%, PI= 64%, OMC=32.7% , ρ_{dmax}=1.37 g/cc)
Miller and Azad (2000)	- - -	22.1-29.1	15-40 (Depends on the type of soil)	Natural soils from Oklahom: CH (LL=55%, PI=40%, OMC 23.3%, ρ_{dmax} =1.59 g/cc); CL (LL=48%, PI=33%, OMC=16%, ρ_{dmax} =1.75g/cc) and ML (LL= 23%, PI=6%, OMC=14%, ρ_d= 1.86 g/cc)
Miller *et al.* (2003)	- - -	22.1-29.1	- - -	Soil 1: CL (LL=48%, PI=30, OMC=18.9%, ρ_{dmax} =1.7g/cc, Soil 2: CL (LL=45%, PI=24% OMC=16.0%, ρ_d =1.71g/cc, Soil-3: sand: SP-SM (OMC= 16.5% and ρ_{dmax} = 1.72 g/cc).

ignition as 14.22% and 29.63% respectively. They varied the percentages used to mix the cement kiln dust in the kaolinite clay from 8 to 25% of the dry weight of the total clay. They concluded that the strength of kaolinite clay treated with cement kiln dust is directly proportional to the content of the cement kiln dust used and to the content of free lime that is present in it. For an example, the significant improvement in the strength of the kaolinite clay is observed for a cement kiln dust with 13.85% of free lime and loss on ignition (LOI) with 14.22%, (the UCS increased by 6 times for 15% CKD samples of 7- days). The cement kiln dust which has higher content of free lime (13.85%), the increment in the compressive strength at 7 days become twice than that of cement kiln dust with lower content of free lime (5.32%).

Particularly, the available free lime, soluble alkalies, and fineness of cement kiln dust effects the stabilization of soil, whether the underlying the process of stabilization may be ion-exchange or primarily pozzolanic or an incorporate combination of both.

Osinubi and Thomas (2007) explained the influence of compactive efforts on the black cotton soils treated with sugarcane bagasse ash. The investigational study involved the tests like Atterberg limit test, the moisture-density relation, CBR and UCS. The obtained results and conclusions of the study can be summarized as follows:

- ✓ The UCS value increased with the increasing content of sugarcane bagasse ash.
- ✓ The CBR value was increased with the increasing percentages of sugarcane bagasse ash content. But, the values obtained were hardly satisfies the minimum specification given by the Nigerian general specification of 1997 of 15% CBR for a sub-grade material.

The research accomplished concludes that the soil stabilized with the sugarcane bagasse ash cannot be used as a pavement material. But it can be further profitably used as an admixture with a conventional stabilizer such as cement or lime.

Osinubi *et al.* (2009) investigated the utilization of sugarcane bagasse ash in the stabilization of the lateritic soil. The investigational study was compiled with the tests like moisture-density relation, CBR and UCS. The observed results and conclusions of the study can be summarized as follows:

- ✓ The OMC and MDD of the sugarcane bagasse ash treated soil generally showed the increasing and decreasing trends, respectively with the increasing percentages of sugarcane bagasse ash content.

- ✓ The values of CBR and UCS generally showed the increasing trends with the increment in the content of sugarcane bagasse ash.

Generally, the research accomplished that sugarcane bagasse cannot be used as standalone but can be utilized with some admixture in the stabilization.

Chittaranjan *et al.* (2011) studied the „Agricultural wastes as the soil stabilizers". In his study the agricultural wastes like sugarcane bagasse ash (SBA), rice husk ash (RHA) and groundnut shell ash (GSA) was being used to stabilize the weak sub-grade soil. This weak sub-grade soil is then treated with these above three wastes separately at 0, 3, 6, 9,12and 15% and the CBR test is carried out for each percent. The observed results of these tests showed improvement in CBR value with the increase in percentage of waste.

Table 2.2: CBR with Increase in Percentage of Waste as Stabilizers

Agriculture Waste (%)	CBR Value for RHA	CBR Value for SBA	CBR Value for GSA
0	7.66	7.66	7.66
3	10.63	11.63	9.35
6	14.33	17.54	12.69
9	19.62	21.26	18.36
12	23.96	25.54	20.87
15	24.23	26.68	21.23

MATERIALS AND METHODS

This chapter includes detailed description of the materials used for pursuing the present study. Various tests carried out on soil and soil mixed with different waste materials as stabilizers are described in the following sections:

Materials Used

The study is conducted on materials such as a soil, cement kiln dust (CKD) and sugarcane bagasse ash (SBA) collected/procured from different places.

The sample of soil was collected from Sitarganj (Khatima), district U.S. Nagar (Uttarakhand). It was mixed with sugarcane bagasse ash (SBA) and cement kiln dust (CKD) in different proportions for conducting various laboratory tests. The representative soil sample was oven dried, cooled in the desiccators and was gently pulverized before conducting tests on it and preparing different mixes with adding SBA and CKD.

Fig. 3.1: Oven Dried Soil Sample

Fig. 3.2: Weighing of the Soil Sample

(Madhya Pradesh). Jaypee Rewa Plant is the largest capacity plant of Jaypee Group with 3 million tons of cement production per annum. Cement kiln dust (CKD) is a fine powder material like ordinary Portland cement and is grey in colour (Fig. 3.3). The physical and/or geotechnical properties of the CKD were provided by its manufacturer M/S Jaypee Rewa Plant, Rewa.

Fig. 3.3: Oven Dried Cement Kiln Dust (CKD) Sample

Sugarcane Bagasse Ash (SBA)

The sample of SBA was arranged from Kesar Sugar Factory situated at Baheri Bypass Road, Baheri–243 201, district Bareilly (Uttar Pradesh). It is black/dark grey in colour (Fig. 3.4) but sometimes it is greyish black. The SBA sample was dried in sun before using it in the study.

Fig. 3.4: Oven Dried Sugarcane Bagasse Ash (SBA) Sample

Testing Methodology

The experimental programme is carried out by conducting following tests as per IS standard procedures. The brief description of the tests conducted in the study follows as under:

Grain Size Distribution

The percentage of various sizes of particles in a given dry sample of soil and SBA is found by particle size analysis or mechanical analysis.

By mechanical analysis is meant the separation of the particles into its different size fractions by conducting

1. Sieve analysis
2. Sedimentation analysis

Grain size analysis was carried out for the materials used in this study as per IS: 2720 (Part 4)-1985. The grain size distribution of coarse grained soil is determined through the sieve analysis using the set of sieves consisting of 4.75mm, 2mm,

RESULTS AND DISCUSSION

This chapter presents the results of different laboratory tests and a discussion pertinent to the results so obtained. The experimental results obtained on the soil samples, soil samples mixed with SBA and the soil samples mixed with SBA and CKD were evaluated and compared in order to bring out changes in properties of the soil on addition of SBA and CKD. The tests include Atterberg limits, moisture density relationship (compaction) and California bearing ratio (CBR). Atterberg limits, moisture density relationship (compaction) and CBR are conducted. Further, these results have been discussed for drawing conclusions so as to explore the structural constructive use of waste materials contributing environment pollution such as SBA and CKD.

Geotechnical Parameters of the Materials

After the soil was dried, following basic tests were performed on it:

- Grain size analysis (IS: 2720 Part IV-1985)
- Atterberg‟s limit analysis (IS: 2720 Part V-1985)
- Pycnometer Analysis (IS: 2720 Part III-Section I/II-1980)
- Standard proctor Analysis (IS: 2720 Part VII-1980)
- California bearing ratio Analysis (IS: 2720 Part XVI-1987)
- Uniaxial compressive strength Analysis (IS: 2720 Part X-1991)

The results of the tests conducted for identification/determination of properties of the natural soil before applying sugarcane bagasse ash and cement kiln dust are calculated and presented below:

Specific Gravity

Specific gravity is one of the important properties needed for geotechnical and other applications. The specific gravity of soil and bagasse ash was determined according to IS: 2720 (Part III/Sec 2)-1980. The specific gravity of the soil is obtained as 2.53 and that of sugarcane bagasse ash as 1.85 and that of cement kiln dust is 2.80.

Grain Size Distribution

The grain size analysis is performed according to IS: 2720 (Part IV)-1985. Figs.4.1, 4.2 and 4.3 represents the typical plot of grain size analysis for soil, sugarcane bagasse ash and cement kiln dust respectively.

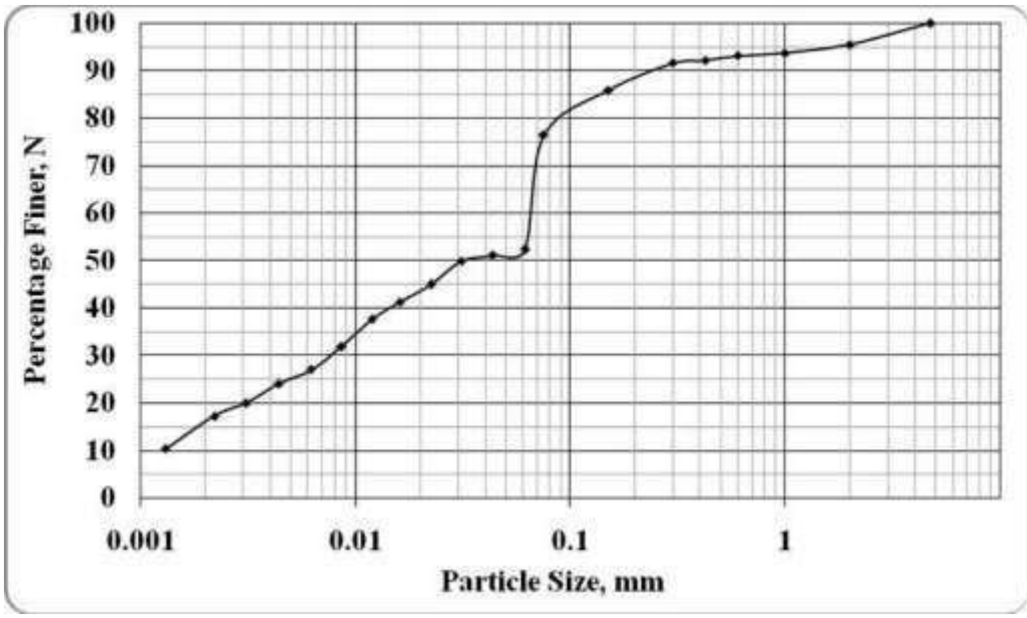


Fig. 4.1: Grain Size Distribution of Soil

From Fig. 4.1, percentage particle sizes of Soil are as under:

- Clay - 15.00%
- Silt - 61.40%
- Sand - 23.60%

According to „Indian Standard Soil Classification System", soil was classified as „ML-CL" type.

From Fig. 4.2 , percentage particle sizes of sugarcane bagasse ash are as under:

- Silt - 74.00%
- Sand - 26.00%
- According to „Indian Standard Soil Classification System", soil was classified as „ML" type.

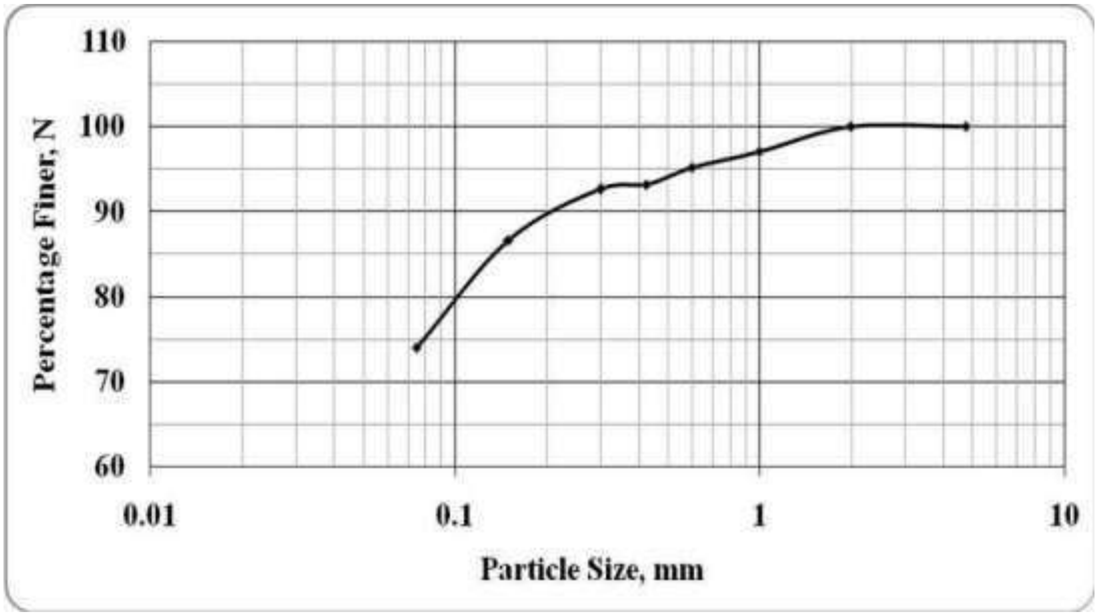


Fig. 4.2: Grain Size Distribution of Sugarcane Bagasse Ash

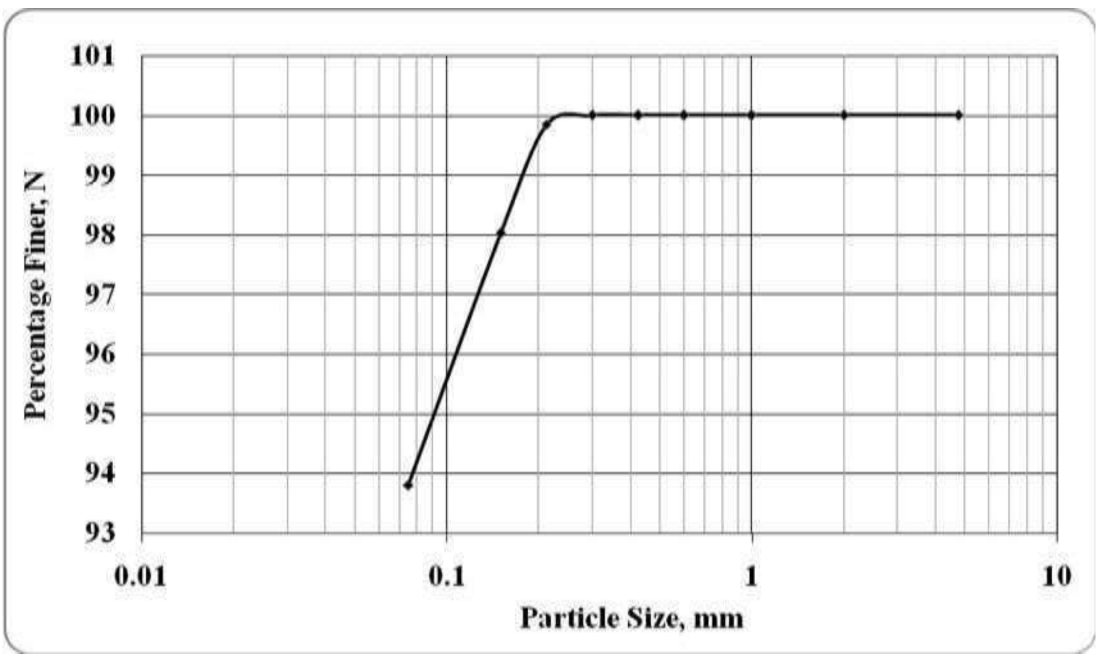


Fig. 4.3: Grain Size Distribution of Cement Kiln Dust

From Fig. 4.3, percentage particle sizes of cement kiln dust are as under:

- Silt - 93.80%

Consistency Limits

The test for consistency limits were conducted as per IS: 2720 (Part V)-1985. The liquid limit for soil is 28.20 whereas of cement kiln dust and sugarcane bagasse ash is nil. The plastic limit test could not be conducted because the cement kiln dust and sugarcane bagasse ash exhibits non- plastic behavior. Therefore, the plasticity index of the cement kiln dust and sugarcane bagasse ash is reported as non- plastic (NP).

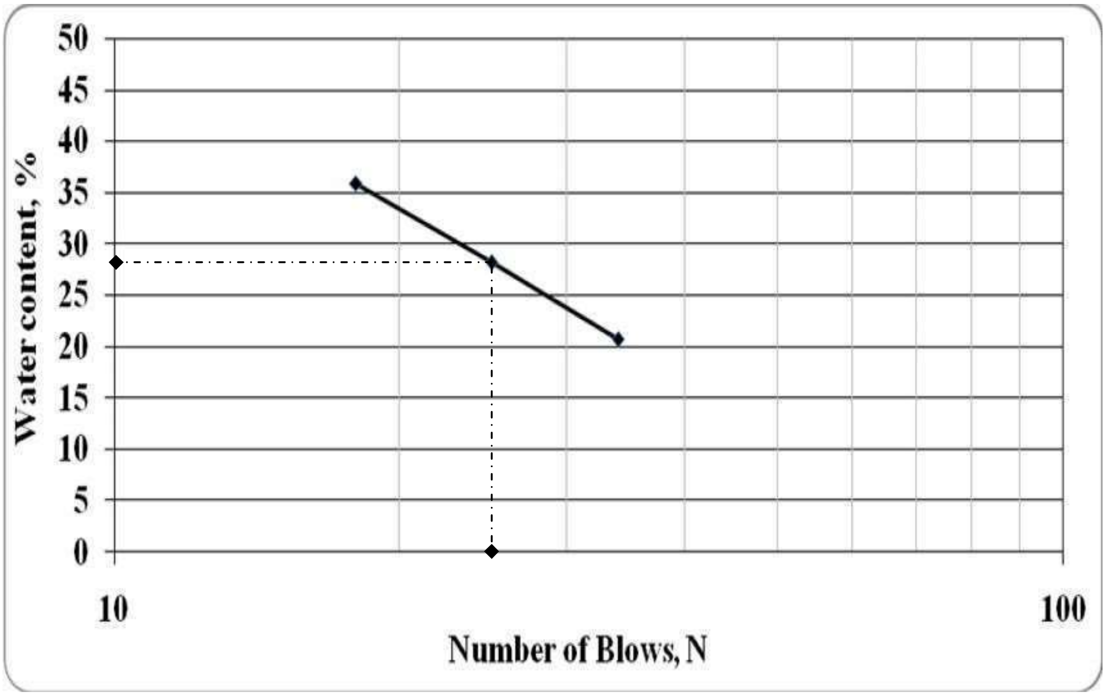


Fig. 4.4: Flow Curve of Soil

The above figure shows the typical plot of liquid limit analysis for soil. From this plot, it is concluded that the liquid limit of soil was observed as 28.20%. Plastic limit of the soil sample was 16.67%. So, plasticity index (PI) of soil was 11.53%. Shrinkage limit of soil was observed as 15.28%.

Table 4.1: Engineering Properties of Soil

Parameters	**Results**
Grain size distribution:	
Clay size fraction (%)	15.00
Silt size fraction (%)	61.40
Sand size fraction (%)	23.60
Soil type as per IS: 1498-1970	ML-CL
Liquid limit (%)	28.20
Plastic limit (%)	16.67
Shrinkage limit (%)	15.28
Plasticity index (%)	11.53
Maximum dry density, MDD (kN/m^3)	17.10
Optimum moisture content, OMC (%)	16.00
California bearing ratio value (CBR): Unsoaked (%)	3.63
Soaked (%)	1.21
Uniaxial compressive strength (kN/m^2)	250.00

Table 4.2: Engineering and Chemical Properties of Materials

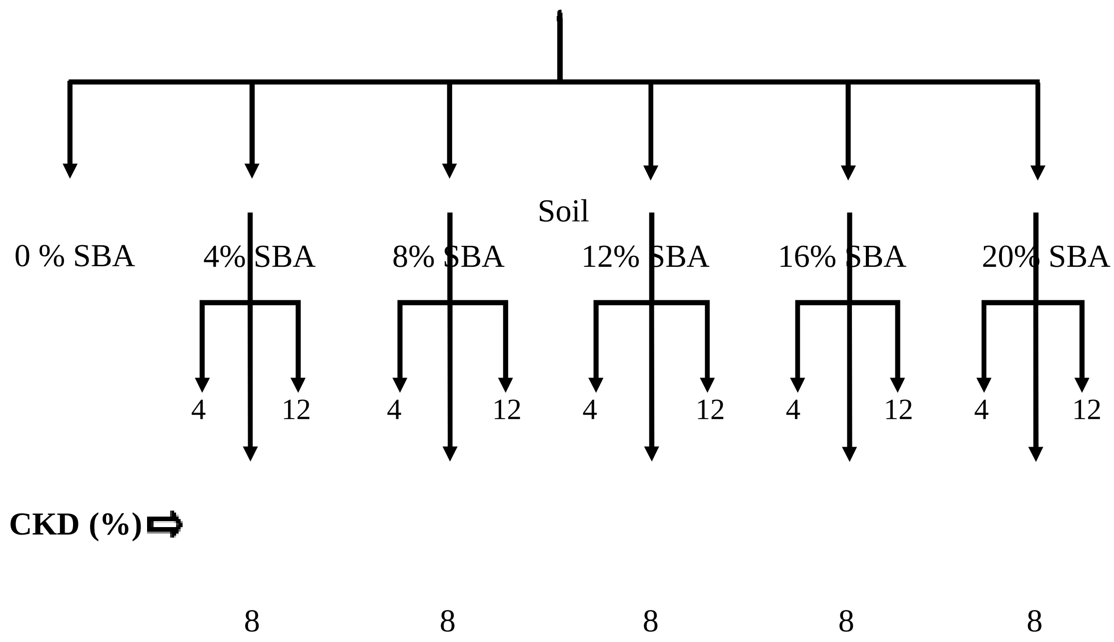
Parameters	**Value**	
	SBA	**CKD**
Grain size distribution:		
Clay size fraction (%)	-	-
Silt size fraction (%)	74	93.80
Sand size fraction (%)	26	6.20
Soil type as per IS: 1498-1970	ML	ML
Plastic Index (%)	Nil	Nil
Specific gravity	1.85*	2.80*
Compound	**Percentage**	

Description	**Abbreviation**	**SBA***	**CKD** **
Calcium oxide	CaO	8.4	63.9
Silica	SiO_2	64.15	11.9
Alumina	Al_2O_3	9.05	9.9
Iron oxide	Fe_2O_3	5.52	3.4
Magnesia	MgO	2.85	1.7
Sodium oxide	Na_2O	0.92	0.5
Potassium oxide	K_2O	1.35	0.1
Loss on ignition	-	4.90	4.7

After: *Ganesan *et al.* (2007) and **Khandaker and Hossain (2011).

Geotechnical Behaviour of Soil Mixes

Standard proctor tests were conducted to determine the relationship between moisture content and dry density of the samples for a specified compactive effort. These tests were performed using various combinations of soil, sugarcane bagasse ash (SBA) and cement kiln dust (CKD) samples. The results obtained have been used to draw inferences under each category of mixes. The whole working plan for the study is shown below:



The standard proctor tests were carried out in two phases. In the first, the study is carried out by treating soil with varying percentages of sugarcane bagasse ash (SBA) as 0, 4, 8, 12, 16 and 20%. And in the second phase, the sugarcane bagasse ash (SBA) was treated with varying percentages of cement kiln dust (CKD) as 4, 8 and 12%. The results are reported as an average value of three tests conducted on same mix.

The optimum moisture content (OMC) and maximum dry density (MDD) of the soil *i.e.* 0% SBA had been already calculated and presented in Table 4.2 and Fig. 4.5**.** The relationship between dry density and moisture content of soil + SBA mixes are presented in Figs. 4.9 to 4.13.

Table 4.3: OMC and MDD of Soil + SBA Mixes

Sl. No.	Mixture	OMC (%)	MDD (kN/m^3)
1.	Soil + 0 % SBA	16.00 %	17.10
2.	Soil + 4 % SBA	17.30 %	16.74
3.	Soil + 8 % SBA	18.20 %	16.23
4.	Soil + 12 % SBA	19.40 %	15.92
5.	Soil + 16 % SBA	20.70 %	15.46
6.	Soil + 20 % SBA	21.60 %	15.03

Table 4.4: OMC and MDD of Soil + SBA + 4% CKD Mixes

Sl. No.	Mixture	OMC (%)	MDD (kN/m^3)
1.	Soil + 4 % SBA + 4% CKD	17.20	16.32
2.	Soil + 8 % SBA + 4 % CKD	21.40	16.10
3.	Soil + 12 % SBA + 4 % CKD	24.20	15.42
4.	Soil + 16 % SBA + 4 % CKD	27.40	14.80
5.	Soil + 20 % SBA + 4 % CKD	29.20	13.40

SUMMARY AND CONCLUSIONS

The ever increasing population demanding rapid industrialization and urbanization has resulted in the increasing demand for more agriculture produce and construction materials. Consequently more than 4.4 billion tonnes of the solid waste material is being generated in the Asia alone. One of the most important issues arising out in such a scenario is the safe disposal and management of the huge quantity of industrial and agro-industrial wastes. It is not only causing the devastation of precious land and the near-by areas but is also posing a serious threat to the environment. In a country like India, sugarcane bagasse ash (SBA) and cement kiln dust (CKD) are two of such bye-products. The present study is an attempt to explore structural use of SBA and CKD in the construction industry. An extensive experimental programme, as presented in the earlier chapters, is carried out in order to have an insight for searching the optimum dose of SBA and CKD which can be utilized in the stabilization of soils. Tables 5.1 and 5.2 summarize the main results of the study. On the basis of the general trends appeared in test results and their subsequent analysis, the conclusions of the present study are summarized in the following sections.

CONCLUSIONS

The experimental study permits following conclusions:

- The optimum moisture content increases from 16.0% to 21.6% with the increase in SBA percentage from 0% to 20%.

- The maximum dry density decreases from 17.12 kN/m^3 to 15.03 kN/m^3 on increasing SBA content from 0% to 20%.

- The study shows that the SBA has a good potential to be used as a modifier, particularly in clayey soils because of its low specific gravity, freely draining nature, ease of compaction, insensitiveness to changes in moisture content, good frictional properties. Apart from constructive use of SBA in bulk, such an enhancement in geotechnical properties of expansive soils makes it suitable to be used in construction

SCOPE OF FUTURE STUDY

- ✓ More investigations are suggested in order to promote the utilization of waste materials such as SBA, fly-ash, stone-dust, rise husk ash, waste marble dust, etc, particularly in prospective areas which could the utilize them in bulk, e.g. in soil stabilization, ground improvement, earth structures and engineering constructions.
- ✓ It is also suggested to explore the secondary reaction of CKD and SBA using advanced methods like X-ray diffraction (XRD) analysis, thermal analysis (TGA) and scanning electron microscopy (SEM), *etc.*
- ✓ The literature review available on the study of various parameters such as energy and type of compaction, curing and hydraulic conductivity appears to be scanty. Therefore more studies are suggested in this area.
- ✓ It is wished that the industries which are producing wastes polluting the land and the environment work in collaboration with the R & D organizations and the universities in the country and establish research teams to further study the use of wastes like sugarcane bagasse ash (SBA) and cement kiln dust (CKD) as a soil stabilizing material on different types of soils.

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