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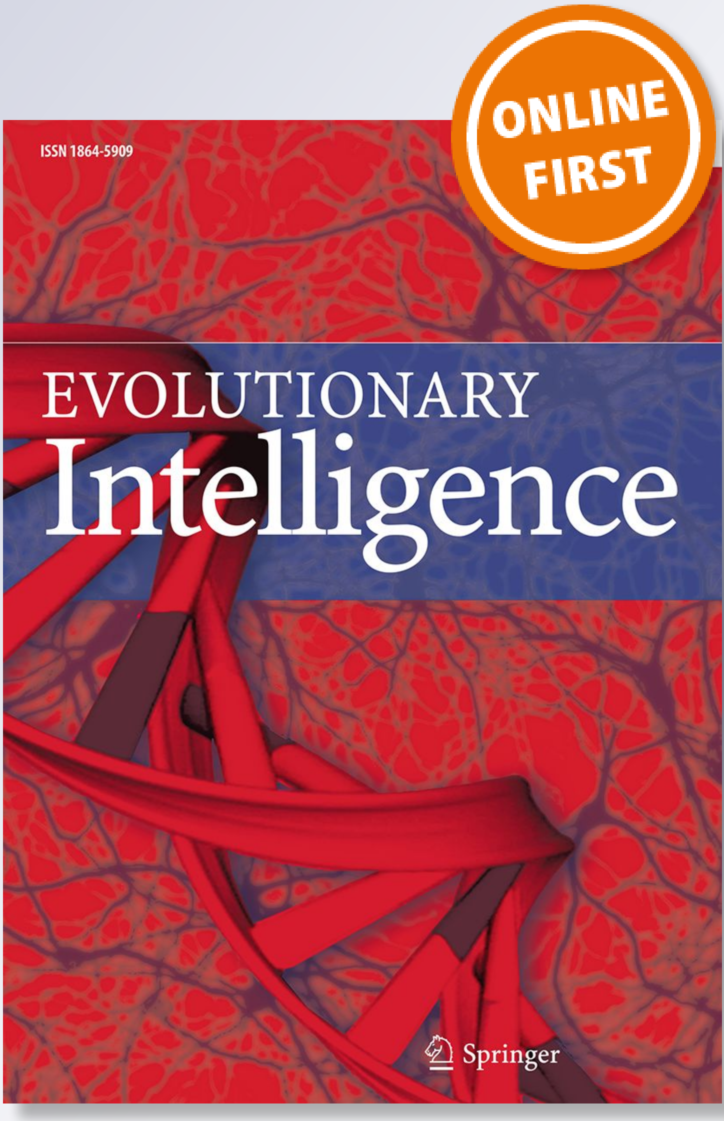

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SPECIAL ISSUE

Enhancing load bearing capacity of alkaline soil with agricultural and industrial waste by the stabilization process

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Abstract
In highway construction, the most important procedure is the sub-grade soil stabilization. The main motive of this research paper is to evaluate the value of industrial and agricultural waste as the soil admixture, and aimed to enhance the soil properties. Especially, for improving the alkaline soil's load-bearing capacity, the current study explains the behavioral phase of alkaline soils blended along waste materials of industries like FA, TD, and agricultural waste material RHA, PM. The analysis is made to find the effect of both agricultural and industrial wastes on specific mix proportions on distinct soil properties like OMC, MDD, UCS, and CBR, and the comparison is also made. The results conclude all stabilizers such as FA, TD, RHA, and PM accomplish its optimal strength after the curing period of 7 days.

Keywords Alkaline soil · Stabilization · Industrial and agricultural waste · OMC · MDD · UCS · CBR

Abbreviations

FA Fly ash
TD Tiles dust
OMC Optimum moisture content
PM Press mud
GA Genetic algorithm
MDD Maximum dry density
RHA Rice husk ash
TW Tile waste
XRD X-ray diffraction
PI Plasticity index
UCS Unconfined compressive strength
LL Liquid limit
CBR California bearing ratio

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1 Introduction

The building of roadways and landing strip on soft soils is a standout amongst the well-known structural building issues in various world parts as soft soils usually prove minimal strength as well as maximum compressibility [1]. Enhancement of some coveted properties of soil such as shear strength, bearing limit as well as penetrability attributes could be embraced by an assortment of ground enhancement procedures, for example, densification, and reinforcement along with stabilization strategies [2]. Developing trends under the utilization of waste particles in the stabilization of soil or strengthening of soil is being worked everywhere throughout the world nowadays [3].

Indian country delivers a huge measure of various kinds of waste supplies as results from various areas such as agricultural, industrial, and so forth [4]. Further, if the waste materials are not secure, it may leads to be risky. As the population increases, the generation quantity of both industrial, as well as agricultural waste is also getting increased [5]. The respective waste particles might remains in this earth even for long duration of time as it is unutilized; this leads to nondecaying waste materials [6]. One of the alternate solutions to this issue is: reusing the waste material into valuable items. In our country, recent research is to study the prospective for the utilization of locally accessible wastes in soil stabilization [7]. The fundamental purpose of this pattern is the unnecessary generation of waste like FA, TD, RHA, and PM, which doesn't just risk yet, in addition, making deposition issues [8]. By using these

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waste materials in stabilization practice will decrease the issue to an incredible degree. On account of FA, Indian coals, however has less sulfur, includes a higher measure of ash (around 35–45%), results in the large amounts of fly ash in India [9]. The yearly fly ash generation has expanded; likewise, it can give a satisfactory cluster of divalent and trivalent cations in ionized circumstances that could advance flocculation of scattered mud materials [10]. In this manner, extensive soils could be possibly settled by cation trade utilizing fly ash.

Furthermore, rice husks and RHA are the generated shells among the paddy's de-husking process, and that varies from 20 to 23% by paddy weight [11]. The rice husk is concerned as the waste particles, which is in effect commonly discarded by copying or dumping in the boiler to do the paddy processing [12]. The process of burning of rice husk creates 20% of its weight like ash. The RHA is characterized as a material of pozzolanic because of its greatest nebulous silica material. In India, the yearly paddy generation is around 100 million tons, in this way producing in excess of 4 million tons of RHA [13]. Also, 65% of foundry sand along with 55% of tile waste stays unutilized in India [14]. In recent times, the geotechnical scientists have utilized tile waste materials in the stabilization of soil. Finally PM, Indian sugar factories are as of now independent in energy, as of now using PM to define the prerequisites of steam as well as power [15, 22, 23]. As just 20–30% of entire PM is utilized for the respective reasons; this recommends the rest of the 2/3 of PM is as of now a paper industry. With the use of these waste materials, the bearing capacity and strength of the alkaline soil are enhanced by the experimentation procedure.

The main motive of this research paper is to examine the wastes value to enhance the soil properties. Especially, for improving the alkaline soil's load-bearing capacity, the current study explains the behavioral phase of alkaline soils blended along waste materials of industries like FA, TD, and agricultural waste material RHA, PM. Finally, the analysis is done to find the effect of admixtures on specific mix proportions on distinct soil properties like OMC, MDD, UCS, and CBR, and the comparison is also made. The paper is organized as follows: Sect. 2 discusses the existing papers related to stabilization of soil with the admixture of FA, RHA, TD, etc., Sect. 3 portrays the influence of waste material in soil, Sect. 4 describes the experimental process involved in the sample preparation and curing, Sect. 5 depicts the properties evaluation of alkaline soil admixture with waste materials. At last, the conclusion part is described in Sect. 6.

2 Literature review

Anupam et al. [16] presents the lab study on FA and RHA as the stabilizers of soil. Utilizing the respective stabilizers, the disfigurement subgrade soil-blends behaviors under rehashed triaxial stacking has also directed. Admixing of FA and RHA lessens the MDD, however, increment the demands of water. The varieties of versatile disfigurement and strong modulus were fundamentally impacted by FA and RHA contents. The outcomes acquired from the lab affirm the possible subgrade soil admixed utilization with FA as well as RHA regarding the changeless deformation.

Kumar et al. [17] investigated the outcomes of the investigational program takes place in the research center for assessing the adequacy of utilizing FA and foundry sand with TW for stabilization of soil by evaluating the strength and compaction attributes for utilizing as sub-review particle. The impact of blending various foundry sand proportions, FA and TW with the consideration of California bearing ratio and clayey soil on compaction.

Choobbasti et al. [18] examined the impact of supplementing the RHA on the reaction among soil as well as lime and have decides soil physical and mechanical qualities. In this way, adequate research facility soil tests, for example, compaction, Atterberg limits, direct shear test and CBR were done and they have also examined the outcomes. The outcomes, for the most part, show that including lime and RHA makes lessening in dry density and the greatest expansion in optimum water content [19]. An effort has been made to open up the road of soil stabilization, for the use of sugarcane PM as an added substance to lime; this type of soil stabilization was investigated by James, and Pandian in 2016. UCS tests were set up with lime as the stabilizer with and without PM and restored for various periods. The samples utilized for UCS tests were then pounded and pummeled for performing Atterberg and pH tests. The outcomes demonstrated that the inclusion of PM to lime expanded the strength of lime- stabilized soil and lessened its plasticity property.

Trivedi et al. [20] planned a model dependent on GA that could be utilized to foresee variety in the estimations of CBR of the Sub-review Soil with the expansion of an explicit level of Fly Ash. For the investigation purpose, the input values were those specifically influence the CBR esteems i.e., straightforwardly corresponding to CBR. Further, this incorporates LL, PI, OMC along with Fraction of FA included (F.A in %). For examination of soil stabilization utilizing FA, Evolver 5.7, it include programming of exceeding expectations is utilized.

3 The influence of waste material in soil

Generally, soil swells fundamentally when interacted with moisture and therapist when the moisture crushes out, and this sort of soil will have a low bearing capacity. Consequently, it is important to stabilize powerless soil by mixing some waste material with it, thus enhancing the load-bearing capacity of a subgrade. Increased number of industries has developed the transfer of effluent to open land or to common water resources. Waste materials from various industries may change in proportions relying on the production source [21]. Agricultural and industrial waste may contain essential nutrients as well as some poisonous substances; it helps to stabilize the soil. The available macronutrients and micronutrients of effluents can improve the soil richness.

4 Methodology

The proposed methodology analyzes the direction of improving engineering properties of locally available alkali soil by adding admixtures such as FA, TD, RHA, and PM waste materials in suitable proportion. In the investigational study, the soil's properties, like physical and chemical properties, are also determined. At the examination time, the preparation of stabilized soil samples is done at various admixture proportions and tested after 1, 7, and 4 days of curing. The engineering properties such as MDD, OMC, UCS, and CBR are investigated for different mixing proportions. The CBR is analyzed with different compositions of waste materials under the soaked and unsoaked conditions.

4.1 Materials

4.1.1 Soil collection

4.1.1.1 Alkaline soil Alkaline soil used in this experiment was collected from pehowa Kurukshetra, Haryana. For this study, the (A-7-6) soil (Soil of medium compressibility) is utilized. Further, the soil's index properties like plasticity index, liquid limit, plastic limit, and some other vital properties according to United States soil classification systems as well as AASHTO (Fig. 1).

Fig. 1 Alkaline soil

4.1.2 Waste materials used in the proposed study

In the proposed study, the waste materials used for making stabilized alkaline soil are named as:

- Industrial waste materials viz. FA and TD.
- Agricultural waste material viz. RHA and PM.

4.1.2.1 Fly ash (FA) In this study, FA is used, and was from Deenbandhu Chhotu Ram Thermal Power Station located at Yamuna Nagar. This was offered free of cost. The classification of FA was made as silts of low compressibility (ML). The ash rely properties under physical, chemical, as well as engineering upon source of coal and type has also used. Further, the degree of preparation of coal, cleaning process and pulverization, and the respective methods has also used. Different kind of power generation and the respective processing in terms of ash collection, ash handling as well as the models for storage purpose was also used. Thus the FA properties might be varied from plant to plant along within the similar plant.

4.1.2.2 Tile dust (TD) Tile waste that was utilized in the study was gathered from the campus on NIT Kurukshetra construction site. Tile waste is crushed in the Geotechnical laboratory in fine grain powder. The TD's engineering and chemical properties are purely dependent to the type of tile.

4.1.2.3 Rice husk ash (RHA) In general, RHA is mainly the siliceous material that was attained by firing the rice husk either in open fire or boiler. Further, several test has been made, and particularly the lime reactivity tests were conducted, and that specifies the completely burned RHA reveal superior reactivity. The waste particles including pozzolonic properties are also used in the process of stabilization to construct road. In this study, RHA was attained from paddy mill, Kurukshetra. In nature light, this was identified to be the fine-grained siliceous and gray in color (Fig. 2).

4.1.2.4 Press mud (PM) For this study, press mud, was obtained from Sugar cane industry, Kurukshetra. The benefits of utilizing sugar cane presumed for application of soil are its least cost, gradual nutrients release, the trace element existance, holding ability (high water) as well as mulching properties. Further, both the chemical and physical properties of FA, TD, RHA and PM are evaluated in the lab, and are summarized in Table 1.

4.2 Mix design of waste materials in alkaline soil

In the sample design process, manual mixing strategy was utilized deliberately to make effective field working circumstances. Initially, sub grade soil was subjected to dry, which is subsequently pulverized legitimately along the assistance of little crowbar and spatula for making lump-free soil. Several tests have been made to assure the manipulation of FA, TD, RHA, and PM on the geotechnical characteristics under certain soil types. Particularly, tests like UCS, Standard Proctor and CBR test were conducted. Several combinations were used to do the tests and some of the combinations were soil-TD, soil-FA, soil-RHA and soil-PM mixtures, which were summarized in Table 2.

4.3 Laboratory investigation

Different samples with various mix proportions are prepared by the mixture of alkaline soil and waste materials like FA, TD, RHA and PM. For example, the samples (with the use of

Fig. 2 Waste materials. **a** Fly ash, **b** tile dust, **c** rice husk ash and **d** press mud

Table 1 Physical and Chemical Properties

S. no.	Property	Soil	FA	DT	RHA	PM
1	Specific gravity	2.63	2.19	2.55	1.95	1.75
2	MDD (g/cc)	1.96	1.36	–	0.96	0.73
3	OMC (%)	12.5	28	–	85	93
4	Liquid limit (%)	37	–	–	–	–
5	Plastic limit (%)	23	NP	NP	NP	NP
6	Is classification	CL	ML	SM	ML	ML
S. no.	Constituent (%)	Soil	FA	TD	RHA	PM
1	Loss on ignition LOI	5.20	1.80	0.43	5.96	30.79
2	Silica SiO_2	69.16	60.89	64.01	88.69	51.40
3	Iron Fe_2O_3	4.13	10.87	2.09	0.16	2.17
4	Aluminium Al_2O_3	15.62	24.51	18.34	0.31	5.20
5	Calcium CaO	2.23	0.35	8.82	1.16	5.83
6	Magnesium MgO	1.04	0.80	4.43	0.42	1.20
7	Sodium Na_2O	0.21	0.20	0.21	0.16	0.80
8	Potassium K_2O	1.05	0.35	0.89	2.89	2.05
9	Sulfur trioxide SO_3	0.20	–	0.15	–	–

Table 2 Combinations of soil with waste materials

Combinations	Soil (% by total dry weight)	TD (% of total dry weight)	PM (% of total dry weight)	FA (% by total dry weight)	RHA (% of total dry weight)
1	100	0	0	0	0
2	92,88,84,80,76	0	0	8,12,16,20,24	0
3	96,94,92,90,88	4,6,8,10,12	0	0	0
4	96,92,88,84,80	0	0	0	4,8,12,16,20
5	95,90,85,80,75	0	5,10,15,20,25	0	0

industrial waste material) are: parent soil, admixed soil with FA, admixed soil with TD and admixed soil with FA + TD for different proportion. Another set of samples (with the use of agricultural waste material) are: parent soil, admixed soil with RHA, admixed soil with a PM and admixed soil with RHA + PM for different proportion. The prepared soil samples were brought to the laboratory test as per the standard IS 1727, 1760 under the testing period of 1, 7 and 4 days. The laboratory investigation and the sample preparation appears in Fig. 3.

4.3.1 Soil compaction

Generally, the compaction is the procedure of soil densification by doing air voids minimization in soil. The most important objective is to set up the OMC and MDD of soil. Generally, particles having more MDD at generally little moisture content and demonstrate the better material to be used for sub base, subgrade, or base courses. Here, Standard Proctor (SP) compactive exertion was utilized to set up the relationship of moisture-density. In fact, the general Proctor compaction was proficient in using the 2.5-kg rammer falling via 30 cm onto 3-layers in compaction mold having a stature of 116.43 mm and 101.6-mm width, everything getting 25 consistently dispersed blows.

Fig. 3 Sample preparation

4.4 Characterization of X-ray diffraction

Here, the XRD was utilized for characterizing the reaction products and alkaline soil along 4% of calcium sulfate. Then, the attainment of XRD patterns was done by utilizing Siemens D5000 powder X-ray diffraction machine. From the air-dried soils, the preparation of XRD Specimens was done that was either with or without contamination. The sample of soil (1 and 2 g) was located in sample holder that was in 3 mm deep. Parallel beam optics was used to analyze the samples including CuKa radiation at 30 m and A40 kV. The entire samples were subjected for scanning for reflections (2 h) that is ranged from 0_ to 70_ at a step size of 0.02_ and a 2 s count time per step (Table 3).

5 Result and discussion

In this work, the soils' behavioral aspect that are combined with manufacturing waste particles like FA & TD and agricultural waste material RHA & PM are described for improving the load-bearing ability of the alkaline soil. Using the tested samples, the impact of both agricultural and industrial wastes on specific mix proportions under soil properties like MDD, OMC, UCS, and CBR has been studied.

5.1 Analysis of optimum moisture content and maximum dry density

The characteristics of MDD and OMC are analyzed for parent soil, soil with FA, soil with TD, soil with PM and soil with RHA and its values are plotted in the graph. As shown in Figs. 4, 5, 6 and 7, the soil's OMC maximizes with raising percentage content of TD, PM, FA, and RHA. When compared to other stabilizer types, the maximization are highly prominent for PM admixed soil-mixtures. PM is highly enriched with Fiber and crud wax than that of FA, TD and RHA. All the RHA, TD and FA is influenced with hydration impact and the affinity for moisture while doing the process of chemical reaction. The soil's density under dry mode

Table 3 X-ray diffraction characteristics of materials

Materials	Ref. code	Score	Compound name	Displacement (°2Th.)	Scale factor	Chemical formula	Semi-Quant (%)
Soil	01-070-3755	77	Quartz	0.127	0.975	Si O2	86
	01-070-3752	32	Albite	0.062	0.037	(Na0.98 Ca0.02) (Al1.02 Si2.98 O8)	14
FA	01-089-1961	80	Quartz low, syn	0.094	1.016	Si O2	70
	01-074-8556	52	Aluminum silicon oxide	0.014	0.091	Al2 (Al2.544 Si1.456) O9.728	30
TD	01-083-1766	83	magnesium calcium bis(carbonate)	0.127	0.813	Mg Ca (C O3)2	99
	03-065-0466	34	Quartz low, syn	0.070	0.006	O2 Si	1

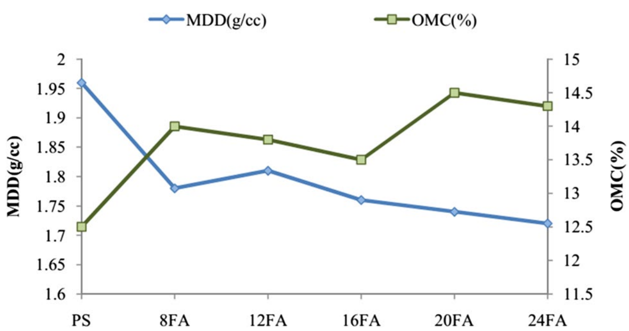

Fig. 4 MDD and OMC of soil with fly ash

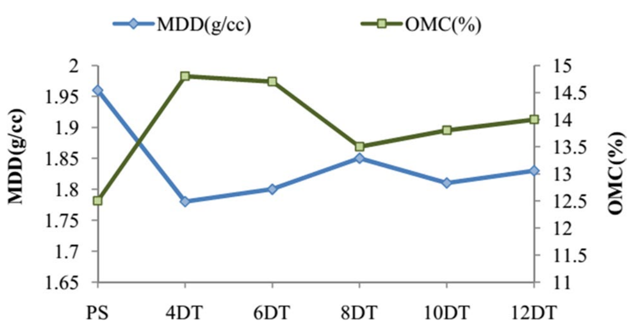

Fig. 5 MDD and OMC of soil with tile dust

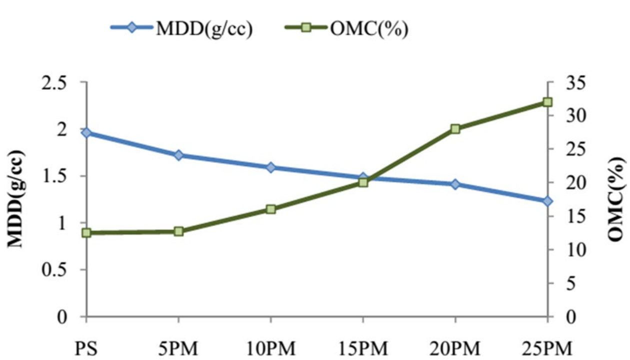

Fig. 6 MDD and OMC of soil with press mud

minimizes with the increased percentage of TD, FA, RHA and PM (Figs. 4, 5, 6, 7). The density minimization was straightly subjected to aggregation/flocculation and forms the cementitious products. The respective minimization was really prominent for RHA than some other stabilizers.

5.2 Analysis of CBR

In this work, the CBR test was carried out for assessing the road sub grades' strength, and the test is actually the fundamental penetration test. The resistance of sub grade is determined for deforming under the load from vehicle wheels. In simple, it is stated that, ''How stronger the ground where

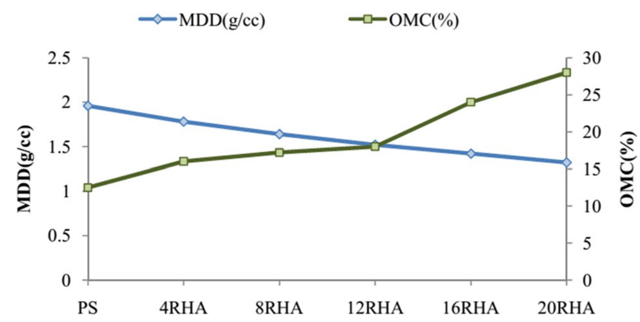

Fig. 7 MDD and OMC of soil with rice husk ash

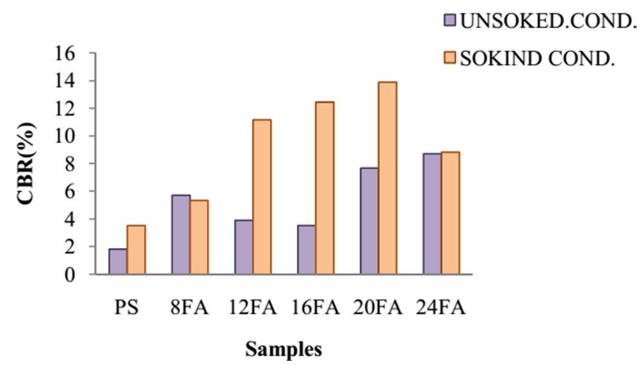

Fig. 8 CBR for admixed soil with fly ash

we goanna construct the road''. Increasing the CBR reading indicates how strong the subgrade is and minimal thick that need for designing and constructing the road pavement, which grants the substantial cost saving. Contrast to this, reduced CBR reading specifies that the sub grade was weak and we should develop a appropriate thicker road pavement for spreading the wheel load on more area of weaker sub grade thereby the weak sub grade particle might not deformed, which makes the road pavement fail. The CBR value is subjected under the analysis purpose for various admixture soil, and more importantly, the analysis is done under various waste material proportion.

Figures 8 and 9 show the CBR value for admixed soil with FA and TD respectively, under un-soaked and soaked conditions. The soil samples are admixed along FA, deviating from 8 to 24%, soil with tile dust 4–12% for 1 day curing. The respective examinations are done on the mentioned samples once the soil is soaked in water almost for 4 days according to IS 2720. While comparing the two conditions, the sample of soil (soaked) achieves greater CBR value, which makes the sub grade material stronger. The CBR value of soaked soil raises by adding FA from 12 to 20% of FA. Afterwards, the values get minimizing as per Fig. 8. This respective trend (maximizing CBR values with the FA percentage content) is around linear up to 20% of admixing. The unexpected maximization of CBR values is

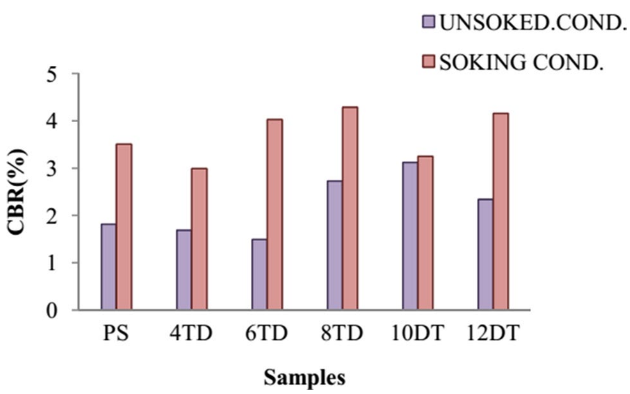

Fig. 9 CBR for admixed soil with tile dust

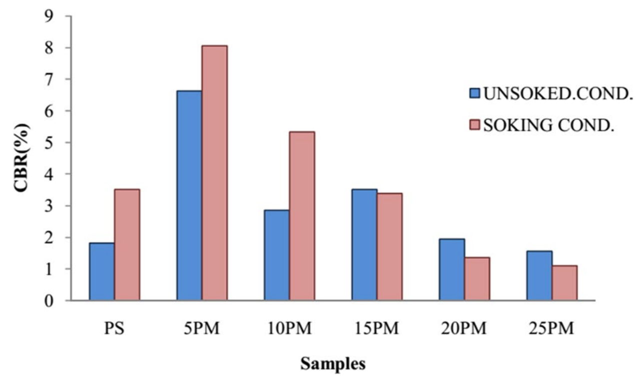

Fig. 11 CBR for admixed soil with press mud

observed among 12% and 20% FA of admixing. Further, it is also identified that the CBR is maximized from 11.17 to 13.9% in curing period from 1 day of FA admixed along soil. Under the case of TD, CBR has improved increasingly up to 12% having further TD addition. The respective behavior is prominent for FA-soil compared to TD-soil.

Figures 10 and 11 illustrates the value of CBR for admixed soil having FA as well as TD respectively in two conditions (soaked and un-soaked). The soil samples admixed along the rice husk ash, and the CBR is deviates from 4 to 20% and soil along the 5–25% press mud were cured for a single day. The respective investigations were performed with the samples after doing the soaking process for 4 days according to IS 2720. Figures 10 and 11 shows the resultant value of average CBR values for soil-PM and soil-RHA. At the same time, RHA admixing has improved the value of CBR in the un-soaking constraint considerably from 8 to 12% of replacement level (Fig. 10). The CBR values of soaked soil is attained during admixing of TD and that has maximized from 4 to 12%. Under the soaking condition, the value of PM in 5% is increased after the press mud value is minimizing. Altogether, the enhancement observed under soaked CBR on stabilizers admixing was because of

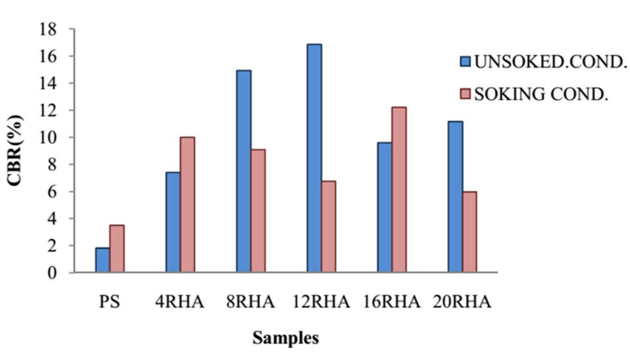

Fig. 10 CBR for admixed soil with rice husk ash

frictional resistance that has been worked from the FA, TD, RHA and PM.

5.3 Analysis of unconfined compressive strength (UCS)

Further, the test like UCS is also conducted for quick obtainment of compressive strength measure for soils, which has shown the enough cohesion for permitting examination in unconfined state. In normal, the test specimens are of height-to-diameter ratio 2:1 and they have compacted the oven-dried mixture via split-cylindrical mold that is of size 38 mm (internal diameter) by 76 mm (height of the mold) in corresponding OMC. Then, the trimming process was carried out for the compacted mixed samples and that is to the height of 76 mm along the knife edge once the elimination of mold collar. Then the trimmed compacted samples were eliminated from split UCS mold and have sealed in double wrapping in polyethylene bags. Some of the bags were placed in humidity room for allowing the uniform moisture distribution and have cured at the steady temperature of 25_2 °C for 1 day, others were placed under uniform moisture distribution for more than 7 days, and the final sets were processed under the UCS test right away after the extruding for assessing its strength under various curing constraints. The deviations of UCS of 100% Parent soil, and the different proportions of FA, TD, RHA and PM-stabilized along parent soil is illustrated in Figs. 12, 13, 14 and 15.

Figures 12 and 13 describes the values of UCS for different admixed soil proportion along FA and TD. The developed samples were cured for 1 day, 7 days as well as 4 days. The UCS values under 1st day and 4th day for 100% parent soil were 2.76 and 2.83 kg/mm^2, respectively. The Parent soil's UCS values with fly ash mixes maximum weight from 3.15 kg/mm^2 (first day) and 3.29 kg/mm^2 (7 days) and 3.57 kg/mm^2 (4 days). Similarly, values of UCS of Parent soil along 12% FA, 16% FA, 20% FA and 24% FA are also examined. Likewise, in TD the strength maximizes in 1 day,

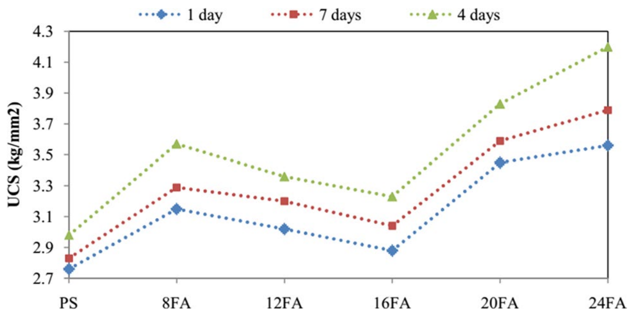

Fig. 12 UCS for admixed soil with FA

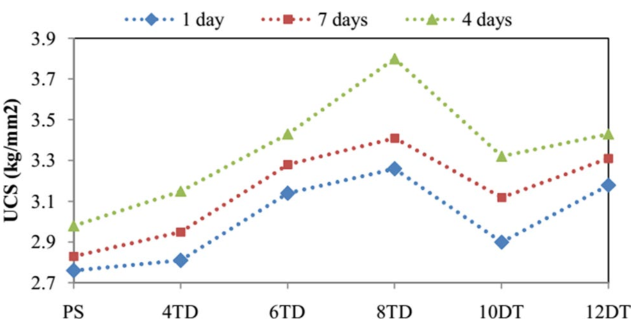

Fig. 13 UCS for admixed soil with TD

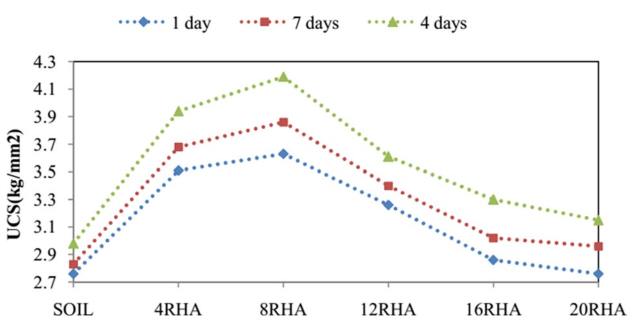

Fig. 14 UCS for admixed soil with RHA

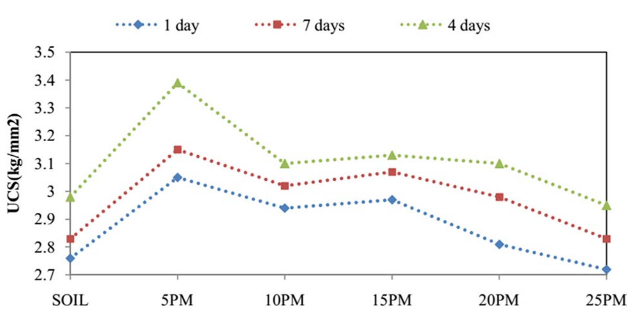

Fig. 15 UCS for admixed of soil with press mud

7 days and 4 days. At 8% TD attains a high value and then minimized with rising in the percentage of TD.

Figures 14 and 15 illustrates the value of UCS for different admixed soil proportion with RHA and PM respectively. The prepared samples are cured for the period of 1 day, 7 days and 4 days. The optimum UCS for admixed soil with RHA (Fig. 14) is achieved in the mix proportion of 8% richest husk ash, the values are 3.63 kg/mm^2 (first day) and 3.83 kg/mm^2 (7 days) and 4.19 kg/mm^2 (4 days). Then the strength of soil decreases with increased proportions of RHA with alkaline soil. In press mud at 5% with soil unconfined compressive strength gain maximum strength. After that, increasing the proportion of PM decreases the strength of alkaline soil. The UCS values of the Parent soil with press mud mixes increased weight from 3.05 kg/mm^2 (first day) and 3.15 kg/mm^2 (7 days) and 3.39 kg/mm^2 (4 days).

6 Conclusion

In this work, the performances of different agricultural as well as industrial waste materials in soil stabilization were examined via laboratory investigation. Further, the soil admixed with FA, TD, RHA and PM samples were cured up for 7 days before testing. Different tests like liquid limit, Plastic limit, Compaction test, CBR and UCS test were conducted. Admixing of FA, TD, RHA, and PM made to have higher optimum moisture content as the dosages of stabilizers increased and the better CBR result is observed for the mixing of rice husk ash in unsoaked condition. But dry densities were decreasing with increase in the percentage of FA, TD, RHA, and PM. This decrement was more pronounced for Press Mud to that of other stabilizers. The unconfined compressive strengths of fly ash-stabilized soils increase up to 4.2 (kg/mm^2) and rice husk ash- stabilized soil (4.19 kg/mm^2). The results conclude that 7 Days sample lose the strength and 4 days sample give the maximum strength. Based on the present study, all stabilizers viz. FA, TD, RHA, and PM attain its optimal strength after 7 days curing period. It is suggested that these can be utilized as an effective soil stabilizer if available in abundant quantity. The results are based only on laboratory investigations and hence it is further recommended that the viability and long-term performance in the field, of this material, should be determined in actual soil stabilization projects.

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