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Sustainable soil stabilization using combination of geotextile, fly-ash and saw dust for pavement subgrade

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ABSTRACT

Purpose: This paper investigates the combined effect of fly ash, sawdust and geotextile in stabilizing the soil.

Design/methodology/approach: A thorough geotechnical testing was carried out in order to study the potent characteristics of soil and soil mixes. The present investigation was set up in two stages. In the first stage, effects of fly ash (5, 10, 15 and 20%), sawdust (2.5, 5 and 7.5%) and layers of geotextile placed at different depths were studied separately to determine their effect on soil stabilization. In the second stage, fly ash, sawdust and geotextile were mixed with soil sample in order to obtain the optimum dosage which can be used for stabilization of soil i.e. their combined effect as stabilizer on soil stabilization.

Findings: It was observed that by introducing fly ash, sawdust and geotextile to the soil, the CBR values increase and thickness of pavement layer decreases. It also decreases the amount of stress on subgrade leading to enhancement of pavement stability with cost effectiveness.

Research limitations/implications: Economical use of industrial waste has been proposed in the present research which otherwise prove to be a malady to climatic change and human health. From the study, an optimum dosage of fly ash (2.5%) and saw dust (5%) and depth for geotextile (6 cm) has been proposed.

Originality/value: The article explores the possibility of a ternary blend, i.e., geotextile, fly-ash and saw dust on effectively stabilizing pavement subgrade. Limited literature was available to address the issue of utilizing the industrial wastes that otherwise pose disposal issues.

Keywords: Soil stabilization, Sawdust, Fly-ash, Geotextile, Unconfined compressive strength

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PROPERTIES

1. Introduction

Stabilization of weak soil is the easiest way of altering its overall properties. Stabilizing a soil will not only improve the engineering properties but also improves the overall bearing strength. There are many stabilizing processes adopted world-wide but some common are stabilizing with cement, lime, bitumen etc. Many studies have been conducted on stabilization of soil using cement, lime, rice husk ash, saw dust and fly ash because of its availability and low cost. Pandey and Rabbani (2017); Ibtehaj Taha Jawad et al. (2014); Boobathiraja et al. (2014) [1-3] observed the feasibility of lime and cement, rice husk ash and pozzolanic material in soil stabilization process and found significant improvement in terms of properties and strength. Improvement in these properties will not only improve the overall engineering properties but it will also increase the overall bearing strength which ensures high life and durability. Yadav et al. 2019 [4], assessed the load deformation behavior of rubber fiber-reinforced cemented clayey soil and observed that rubber fiber can be utilized up-to 7%. Moreover, with addition of stabilizing material like rubber fiber, the initial stiffness of soil decreased with increase in overall ductility of the soil. Assessment of strength behavior of clay soil using pozzolanic material like pond ash and cement with randomly distributed fibers was observed by Yadav et al. 2018 [5], where author observed that addition of fiber and in partial replacement of pond ash, resulted in increase in strength of soil with decrease in stiffness. Nath et al. (2017) [6] studied the strength behavior of organic soil with fly ash and found that the plastic index of soil got reduced. Moreover, adding fly ash as stabilizer in the soil increased the dry density and bearing strength while the optimum water content reduced. This increase in bearing strength of soil is because of the properties of the fly ash it possesses such as low compressibility, insensitive to moisture variation, low unit weight, high shear strength and pozzolanic content which react with soil forming a stiffer base [7]. Tastan et al. (2011) [8] determined the unconfined compressive strength using fly ash as stabilizer and found that strength and resilient modulus increased when percentage of fly ash increased. Similar to fly ash, saw dust is also a stabilizer that can be used in a ground improvement process. It is generally a waste result formed during carpentry works. Adding saw dust in soil as a stabilizer, increases optimum moisture content (OMC) and California bearing ratio (CBR) resulting in increased bearing capacity but it decreases maximum dry unit weight and plasticity index property of a soil [9]. This decrease in maximum dry unit weight and plasticity index is due to the presence of porous grains that allows water to absorb. However, Jasim and Çetin, (2016) [10] observed that 3% of saw dust addition in soil gives optimum results in terms of bearing strength, plastic limit and liquid limit. Etim et al, 2017 [11] observed the influence of saw dust (burnt and unburnt) in uncontaminated soil and observed that unburnt possesses lower values as compared burnt saw dust in terms of its optimum moisture content, CBR value and bearing capacity. Geotextile is another similar stabilizer used in today's day-to-day construction process. Geotextiles are generally a fabricated synthetic material which has higher tensile strength which allows soil to gain its strength under heavy loadings. Many researches have been carried out to check its feasibility as a stabilizer in soil stabilization process. Jadvani and Gandhi, (2013) [12] found that the use of geotextile in soil gives effective alternative to issues of drainage, stability and durability in land slide control, stabilization of pavement subgrade in roads and erosion control. Meshram et al. (2013) [13] determined the application use of geotextile coir for road construction and found that adding coir in subgrade and base course increased the bearing capacity. This increase in strength is due to the interlocking of soil because of addition of geotextiles. Many investigations have been conducted on stabilization of soil using stabilizer in combined form in appropriate proportions or adding them separately. However, studies on addition of fly ash, saw dust and geotextiles together in soil as a stabilizer is done in rare quantity, which is attempted in this paper. The experimental investigation is done in two stages. In first stage fly ash (5, 10, 15 and 20%), sawdust (2.5, 5 and 7.5%) and layers of geotextile in different depths was placed and positioned to determine Atterberg's Limit Test (ALT), Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR) and Standard Proctor Test (SPT) to check its effects on stabilization of soil. In second stage fly ash, sawdust and geotextile was mixed with soil sample in order to obtain the optimum dosage which can be used for stabilization of soil.

2. Material and methods

Soil sample at 1.5 m depth was obtained from Gulbela village, Metherlam, Laghman, Afghanistan. The sample was of A-4 class (AASHTO-M415) having maximum dry unit weight 1.942 g/cm^3 and optimum moisture content (OMC) 11.3% used throughout the work. Table 1 represent the other evaluated properties of soil according to ASTM and AASHTO standards. Figure 1 represents the particle size distribution graph of soil sample. Fly ash of F-class was taken from Goindwal Sahib power plant, Tam Taran district, Punjab, India. Table 2 presents the chemical composition of fly ash. Figure 2 represent the particle size distribution of fly ash.

Table 1.
Evaluated properties of soil

S. No	Tests conducted	Results
1	Classification	A-4 class
2	CBR	4.8
3	Liquid Limit	21.80%
4	Plastic Limit	18.49%
5	Plasticity Index	3.31%

Saw dust was obtained from carpenter shop at Mehterlam, Laghman, Afghanistan. Geosynthetic having thickness of 1.2 mm, tensile strength 7.5 KN/m and mass per unit area 150 g/m^2 was obtained from Bengaluru, Karnataka, India. Table 3 represent the various other properties of geo-textiles.

Table 2.
Chemical composition of fly ash

S. No	Compound	Percentage range
1	LOI (%)	2.3
2	CaO (%)	3.5
3	Al_2O_3 (%)	26.5
4	SiO_2 (%)	55
5	Fe_2O_3 (%)	4.8
6	MgO (%)	2.5

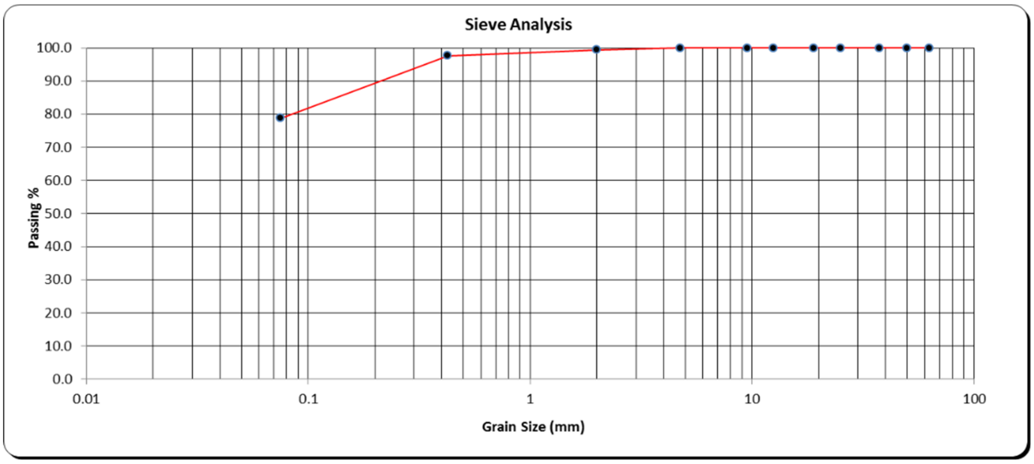

Fig. 1. Particle size distribution of soil sample

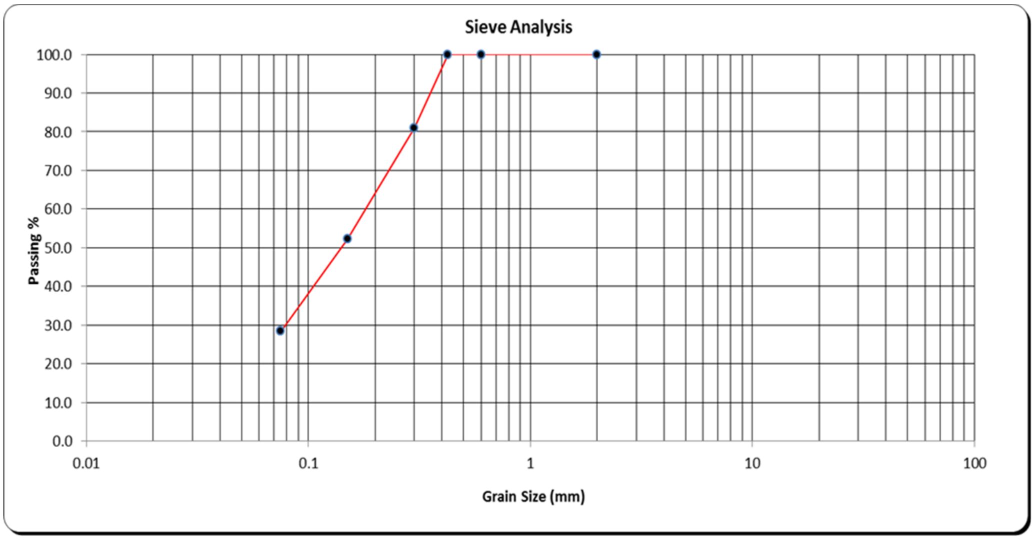

Fig. 2. Particle size distribution of fly ash

Table 3.
Properties of geo-textiles

Property	Test Methods	Value
CBR Puncture Strength	CBR Puncture Strength	CBR Puncture Strength
Trapezoidal Tear Strength	ASTM D 4533 [14]	0.21 kN
Permittivity	ASTM D 4491 [15]	NA
Apparent Opening Size	ASTM D 4751 [16]	0.15 mm
Elongation	ASTM D 4595 [17]	50%

3. Experimental program

The collected soil sample was kept in large polythene bags and dried for 7 days. The experimental program was carried out in 4 stages. In first stage fly ash (5, 10, 15 and 20%) was mixed with soil sample and Atterberg Limit Test (ALT), Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR) and Standard Proctor Test (SPT) were performed to obtain optimum dosage. Table 4 represent the mix proportioning of fly ash and soil sample. Sawdust (2.5, 5 and 7.5%) was mixed with soil sample. Table 5 represent the mix proportioning of saw dust and soil sample. The UCS of specimen was made using a metal mould with detachable collar, the dimension of mould were 38 mm diameter and 76 mm height. Reinforcements were cut in circular shape with diameter of 37 mm and were placed at depth of 19 mm in 4 intervals throughout the specimen length.

Table 4.
Mix proportion of fly ash and soil sample

Samples	Soil	Fly Ash
1	100%	0%
2	95%	5%
3	90%	10%
4	85%	15%
5	80%	20%

Table 5.
Mix proportion of saw dust and soil sample

Samples	Soil	Sawdust
1	100%	0%
2	97.5%	2.5%
3	95%	5%
4	92.5	7.5%

The layers of geotextile were placed at the depth of H/4, where H (76 mm) is the height of specimen. Geotextiles were placed and positioned at top, between top and middle, between middle and bottom and bottom. Various trails were performed to obtain the optimum layer, the test procedure was followed as similar to Bera et al. 2009 [18]. Table 6 represent the mix proportioning of geo-textile and soil sample. In second stage fly ash, sawdust and geotextile was mixed with soil sample to evaluate the combined effect of the materials and abovementioned test were performed to obtain optimum doses. Table 7 represent the mix proportioning of combined fly ash, saw dust, geo-textile and soil sample. ALT was performed as per BS 1377-part-2, 1990 [19], UCS was performed as per ASTM-D2166 [20] , CBR was performed as per ASTM-D1883 [21] and SPT was performed as per ASTM-D1557 [22].

Table 6.
Mix proportioning of geo-textile and soil sample

S. No.	Position of geotextile in soil
1	Top (3 cm depth of mould)
2	Middle (6 cm depth of mould)
3	Bottom (9 cm depth of mould)
4	Two layers (top + middle) (3 cm+6 cm depth of mould)
5	Two layers (middle + bottom)(6 cm+9 cm depth of mould)

Table 7.
Mix proportioning of combined fly ash, saw dust, geo-textile and soil sample

Samples	Soil	Fly ash	Sawdust	Geotextile
1	92.5%	5%	2.5%	6 cm
2	85%	10%	5%	6 cm

4. Result and discussion

4.1. Effect of fly ash

Index properties

Atterberg Limit is a very important property for the characterization of soil within a broad category. Figure 3 shows the variations of liquid limit, plastic limit and plasticity index with varying percentages of fly ash. The liquid limit of the virgin soil sample was found to be 21.8%. Upon addition of fly ash at the dosages of 5, 10, 15 and 20%, the liquid limit was found to be 23.20, 23.60, 23.70 and 25.70%, respectively. The plastic limit of the virgin soil sample was found to be 40%. The plastic limit of the soil with addition of fly ash was found to be 40.6, 41.3, 43 and 45% respectively for 5, 10, 15, and 20%. For 5, 10, 15 and 20% of fly ash addition the plasticity index of the soil was found to be 43, 44.8, 45.3 and 49.2%, respectively. Hence, on addition of 0-20% fly ash the liquid limit ranges from 21.80 to 25.70% and the plastic limit ranged from 17.67 to 19.85% as compared to liquid and plastic limit of soil sample. Fly ash increase the liquid limit up to 15.2%, plastic limit up to 8.92% and plasticity index up to 14.63%. Tastan et al. (2011) [8] showed similar results and explained beneficial changes in engineering properties. These changes in liquid and plastic limit are mainly attributed to cationic exchange, flocculation of the clay, agglomeration, and pozzolanic reactions. The increase in index property of soil upon addition of fly ash is mainly due to the pozzolanic reactivity between soil and fly ash. The pozzolanic reactivity of fly ash with soil influence the soil properties due to the formation of gelatinous pozzolanic reaction compounds. The similar trend was observed by Sivapullaiah et al. 1996, where author added fly ash in 1-3% of total weight of soil.

Compaction characteristics

Figure 4 demonstrates the plot between maximum dry unit weight and Optimum Moisture Content with varying percentages of fly ash. The maximum dry unit weight and OMC of soil sample was found to be 1.942 g/cm^3 and 11.3% respectively The maximum dry unit weight of the soil with addition of 5, 10, 15 and 20% fly ash by weight of soil was found to be 1.850, 1.820, 1.776 and 1.698 g/cm^3 respectively and the corresponding OMC found to be 12, 12.3, 12.5 and 12.7% respectively. Fly ash decrease maximum dry unit weight up to 14.4% but increase OMC up to 11%. Kaniraj and Havanagi, (2011) [23] made similar observations regarding the trend in plot. The maximum dry unit weight had decreased due to the agglomeration and flocculation of clay particles because of the cation exchange reaction. This had led to reduction in weight-volume ratio. The cause of decrement can also be due to the replacement of soil sample by fly ash which has relatively low specific gravity compared to that of soil sample. Further, the optimum moisture content of soil sample increases with increase in the fly ash content. This increase in the OMC is due to the extra water required for hydration.

California Bearing Ratio

Figure 5 shows the variation of CBR value with varying fly ash content. The CBR value of soil sample was found to be 4.8%. Due to the addition of fly ash at the dosages of 5, 10, 15 and 20%, the CBR values recorded were 7, 11.3, 12.3 and 18%, respectively. Fly ash increase CBR value up to 73.3%. The increase in CBR is mainly due to the cation exchange in soil-fly ash mix in which sodium ions of soil are replaced by calcium ions present in fly ash, thereby reducing settlement and increasing CBR. The similar trend was observed by Pal and Rajak (2015) and Satyanarayana et al. (2013) [24,25], where author had added fly ash in varying percentage. Thus, with increasing percentage of fly ash the CBR values increase significantly, which is highly desirable.

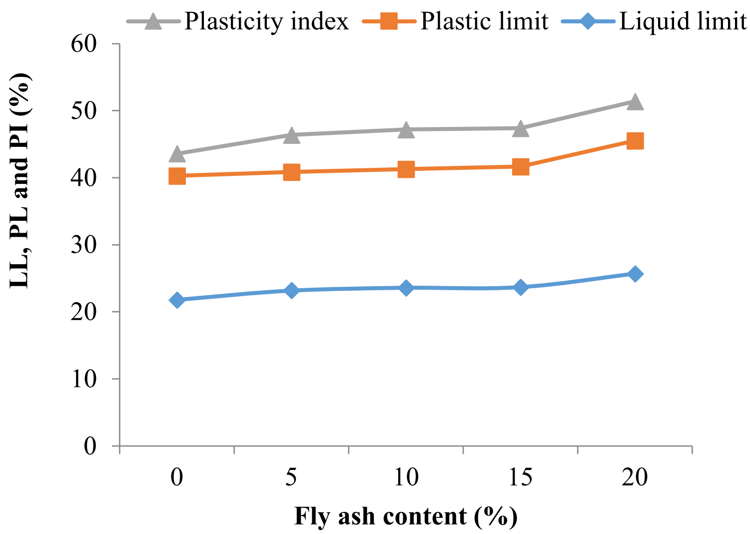

Fig. 3. Variation of index properties with varying fly ash content

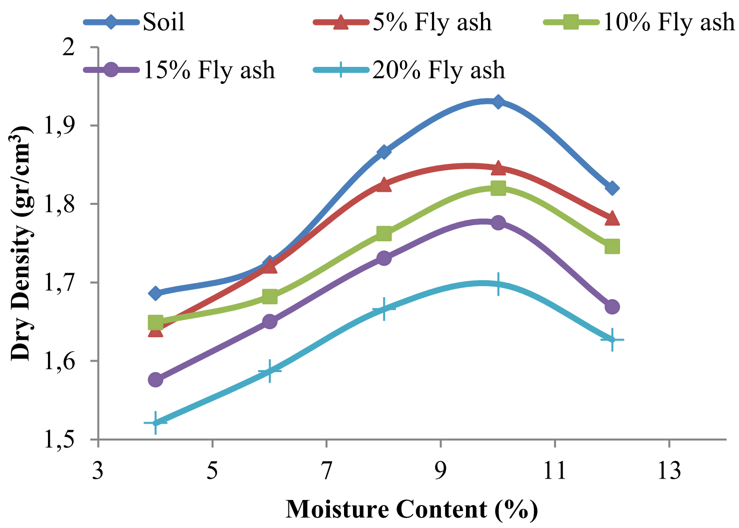

Fig. 4. Variation of OMC and maximum dry unit weight with varying fly ash content

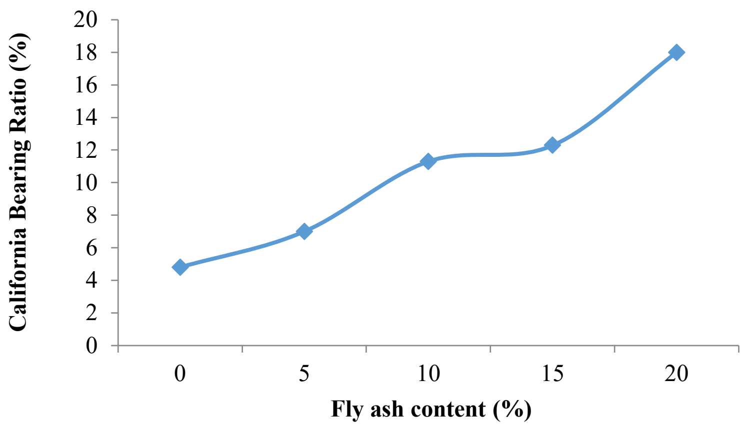

Fig. 5. Variation of CBR value with varying fly ash content

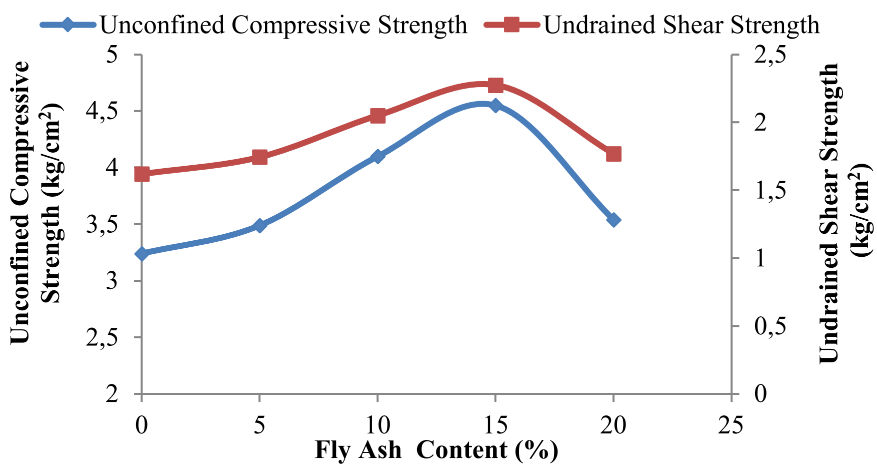

Fig. 6. Variation of UCS and un-drained shear strength with varying fly ash content

Unconfined Compressive Strength

Addition of fly ash to the soils resulted in a significant increase in q_u relative to that of the un-stabilized soil. Figure 6 shows that there is a rapid increase of UCS and un-drained shear strength with the addition of fly ash content up to15%. For 15% fly ash the UCS and undrained shear strength increases up to 28.8% and if we add 20% fly ash the UCS and undrained shear strength decreases up to 8.5%. Further, the UCS and un-drained shear strength of the soil sample was found to be 3.24 kg/cm^2 and 1.62 kg/cm^2 respectively. The UCS of the soil with addition of 5, 10, 15 and 20% fly ash by weight of soil was found to be 3.49, 4.1, 4.55 and 3.54 kg/cm^2 respectively and the corresponding un-drained shear strength found to be 1.745, 2.05, 2.275 and 1.77 kg/cm^2 respectively. The reason for the increment in UCS and un-drained shear strength is due to the formation of cementing gels (hydrate) due to reaction between CaO of fly ash with Al_2O_3 and SiO_2 of soil sample.

4.2. Effect of saw dust

Index properties

Figure 7 shows the variations of liquid limit, plastic limit and plasticity index with varying percentages of saw dust. With the addition of saw dust in dosages of 2.5, 5 and 7.5%, the liquid limit was measured to be 24.7, 28.90 and 30%, respectively. The plastic limit of the soil with addition of 2.5, 5 and 7.5% sawdust by weight of soil was found to be 19, 23.03 and 26.07% respectively. Similarly, the plasticity index was measured to be 5.7, 5.87, and 3.93% for dosages of 2.5, 5 and 7.5%, respectively. Sawdust increase the liquid limit up to 27.3%, plastic limit up to 29.1% and plasticity index up to 15.8%. Thus, on addition of 2.5-7.5% sawdust the liquid limit ranges from 21.80-33%, and plastic limit ranges from 18.49-26.07%. It is observed that both the liquid limit and the plastic limit increases with the increase of sawdust content.

Compaction characteristics

Figure 8 shows the effect of sawdust on the OMC and maximum dry unit weight of soil. It was observed that the maximum dry unit weight decreases with the increasing amount of sawdust while the OMC increases gradually. The maximum dry unit weight of the soil was found to be 1.784, 1.654 and 1.587 g/cm^3 for 2.5, 5 and 7.5% addition of saw dust and the corresponding OMC was found to be 12.7, 14.5 and 16.5%, respectively. Sawdust decreased maximum dry unit weight up to 22.4% but increased OMC up to 31.5%.

California Bearing Ratio

Figure 9 shows the CBR value of varying saw dust content. For 2.5, 5 and 7.5% addition of saw dust, the CBR value of the soil was measured to be 2.5, 5 and 7.5%, respectively. Addition of 2.5% sawdust increases the CBR value up to 48.4% and if we use more sawdust (5%, 7.5%) the CBR value will decrease up to 12.7%. This increase in CBR value is observed because saw dust is coarser than soil sample.

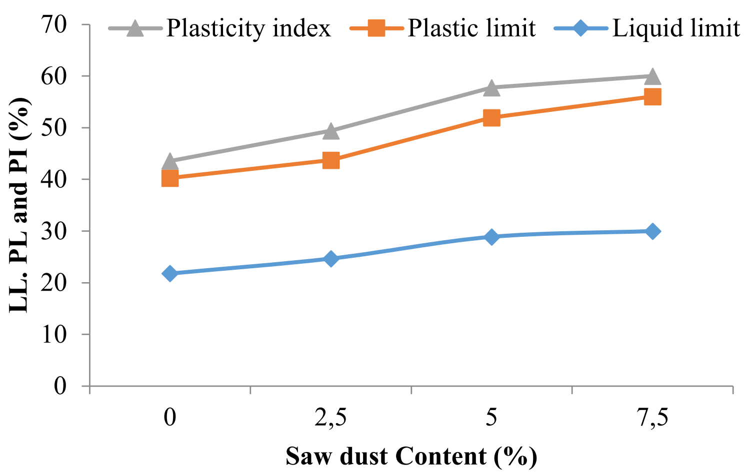

Fig. 7. Variation of index properties with varying saw dust content

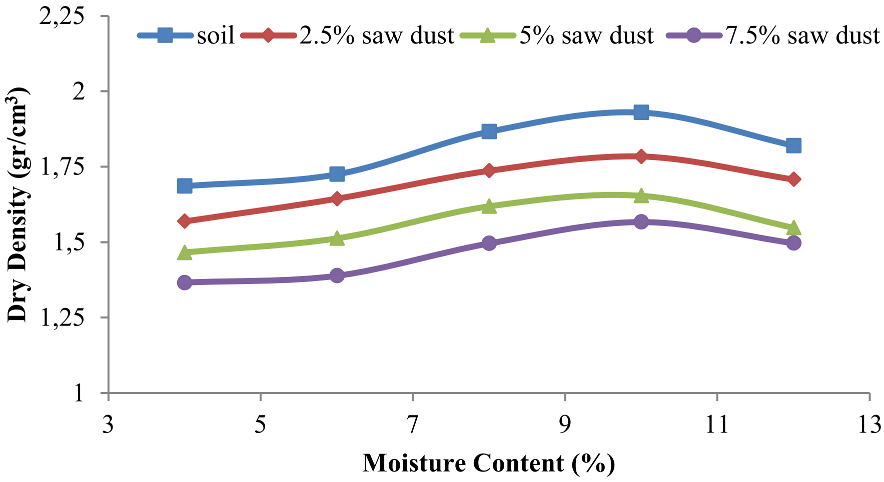

Fig. 8. Variation of OMC and maximum dry unit weight with varying saw dust content

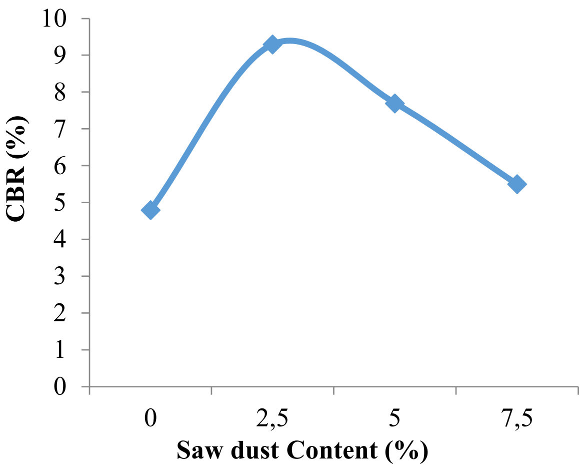

Fig. 9. Variation of CBR value with varying saw dust content

Unconfined Compressive Strength (UCS)

Figure 10 shows the variation of UCS and un-drained shear strength with varying saw dust content. The UCS of the soil with addition of 2.5, 5 and 7.5% sawdust by weight of soil was found to be 3.35, 3.77 and 2.86 kg/cm^2 respectively and the corresponding un-drained shear strength was found to be 1.675, 1.885 and 1.43 kg/cm^2 respectively. For 5 % fly ash the UCS and undrained shear strength increases up to 14.1% and if we add 7.5% fly ash the UCS and undrained shear strength decreases up to 13.3%.Addition of saw dust above 5% resulted in decrement of UCS value. Table 15 shows the results and percentage variation of sawdust on UCS and undrained shear strength.

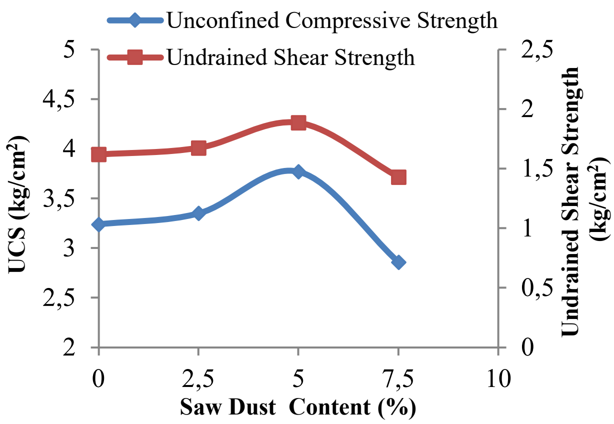

Fig. 10. Variation of UCS value with varying saw dust content

4.3. Effect of geo-textile

California Bearing Ratio

Figure 11 shows the CBR value of varying geo-textile content. The CBR value of the soil by placing of geotextile in varying depth of 3, 6, 9, (3+6) and (6+9) cm was found to be 4.9, 10.3, 9.8, 7.3 and 8.7% respectively. Placing of geotextile in middle position 6cm depth the CBR value will increase up to 52.2% and if we place geotextile in 3, 6, 9, (3+6) and (6+9 cm) the CBR value will decrease up to 43.7%. Thus, it has been observed that the geotextile used in middle (6 cm depth) of the sample is beneficial and increases the CBR value more as compared to other position.

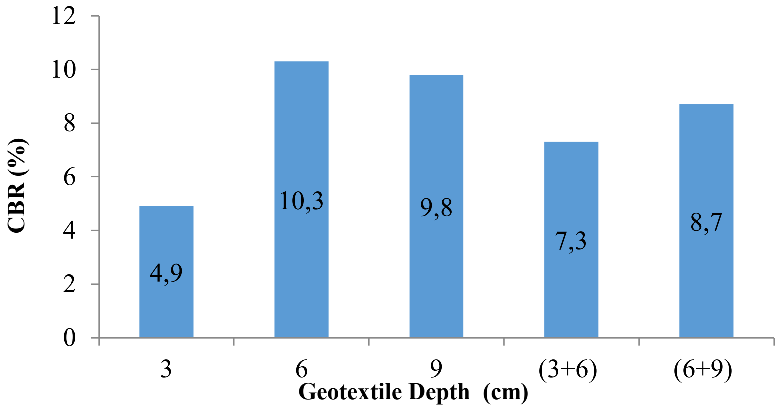

Fig. 11. Variation of CBR value with varying geo-textile content

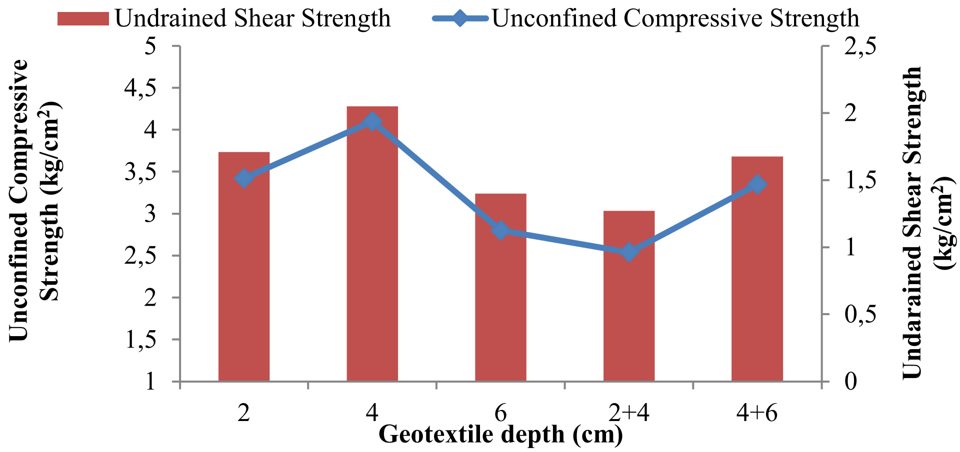

Fig. 12. Variation of UCS and un-drained shear strength with varying geo-textile content. Optimum dose of combined fly ash saw dust and geo-textile

Unconfined Compressive Strength

Figure 12 shows the variation of UCS and un-drained shear strength with varying geo-textile content. The UCS value of the soil by placing of geotextile in varying depth of 2, 4, 6, (2+4) and (4+6) cm was found to be 3.42, 4.1, 2.8, 2.54 and 3.35 kg/cm^2 respectively and the corresponding un-drained shear strength is found to be 1.71, 2.05, 1.4, 1.27 and 1.675 kg/cm^2 respectively. Placing of geotextile in middle position 4cm depth the CBR value will increase up to 16.6% and if we place geotextile in 2, 4, 6, (2+4) and (4+6 cm) the CBR value will decrease up to 2.1%. Thus, addition of geotextile in middle layer of the sample gave good results as compared to the top and bottom layers.

Compaction characteristics

Figure 13 shows the combined effect of fly ash, sawdust and geotextile on maximum dry unit weight and OMC of soil. The maximum dry unit weight and OMC of soil sample + 2.5% sawdust + 5% fly ash and geotextile used in middle (6 cm depth) was found to be 1.723 g/cm^3 and 13.6%. The maximum dry unit weight and OMC of soil sample + 5% sawdust + 10% fly ash and geotextile used in middle (6 cm depth) was found to be 1.612 g/cm^3 and 16.8%.

California Bearing Ratio

The CBR value of the soil sample mixed with combination of sawdust, fly ash and geo-textile shows higher result as compared to fly ash, saw dust and geo-textile separately as shown in Figure 11. CBR value of sample containing 2.5% sawdust is 9.3, 5% fly ash is 7 and for geotextile layer introduce at 6cm depth is 10.3 whereas for sample having combined 2.5% sawdust, 5% fly ash and geotextile layer at 6cm depth was found to be 11.1. This indicates that mixing of soil with combined saw dust, fly ash and geotextile improve the CBR values and is effective in partially replacing the sawdust and fly ash.

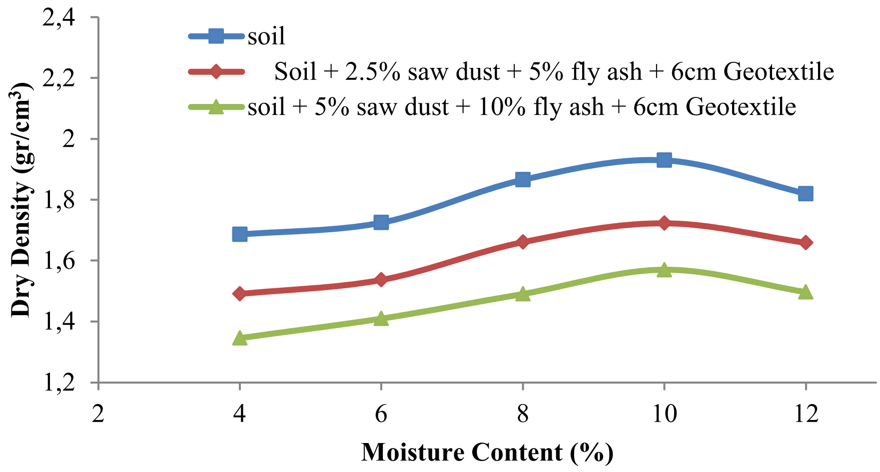

Fig. 13. Variation of OMC and maximum dry unit weight with varying % of fly ash, saw dust and geo-textile

Table 18.
Combined effect of fly ash, saw dust and geotextile

S/No	Sample	Max. dry unit weight, g/cm^3	Δ	OMC, %	Δ	CBR, %	Δ	UCS, kg/cm^2	Δ
1	Soil+2.5%sawdust+5%fly ash+geotextile @ 6 cm	1.723	0	13.6	0	11.1	0	5.55	0
2	Soil+5%sawdust+10%fly ash+geotextile @ 6 cm	1.612	-6.9	16.8	19.0	9.9	-12.1	4.87	-14.0

Unconfined compressive strength

UCS and un-drained shear strength value of the soil sample mixed with combination of sawdust, fly ash and geotextile shows higher result as compared to fly ash, saw dust and geo-textile separately as shown in Figure 12. UCS and un-drained shear strength values of sample containing 2.5% sawdust is 3.35 and 1.675, 5% fly ash is 3.49 and 1.745 and for geotextile layer introduce at middle position is 4.1 and 2.05 whereas for sample having combined 2.5% sawdust, 5% fly ash and geotextile layer at middle position was found to be 5.55 and 2.775. Table 18 shows the results and percentage variation of combined fly ash saw dust and geo-textile on index properties, CBR, maximum dry unit weight, UCS and undrained shear strength.

5. Conclusions

The present study describes the possible way to use fly ash, saw dust and geo-textile for stabilization of soil. Some studies experimentally investigated from the present study are as follows:

- With addition of fly ash the Index properties viz. liquid and plastic limit, plasticity index increases significantly as compared to index properties of soil sample but shows slight decrement in the maximum dry unit weight value. Further, OMC, CBR value, UCS and un-drained shear strength increases significantly with addition of fly ash.
- With addition of saw dust Index properties viz. liquid and plastic limit, plasticity index increases significantly as compared to index properties of soil sample but shows slight decrement in the maximum dry unit weight value. Further, OMC and CBR value increases significantly with addition of fly ash. The UCS and un-drained shear strength show increment up-to 5% of saw dust addition above it slight decrement in the strength was observed.
- With addition of geo-textile it has been observed that the geotextile used in middle (6 cm depth) of the sample is beneficial and increases the CBR value more as compared to other position. UCS and un-drained shear strength shows slight increment with addition of geotextile in middle layer of the sample.
- Addition of fly ash (5 and 10%), saw dust (2.5 and 5%) and geo-textile (6 cm depth) shows slight decrement in the maximum dry unit weight value and slight increment in the OMC value. CBR value, UCS and un-drained shear strength also increases with addition of combined fly ash, saw dust and geo-textile.

- From the present study it has been investigated that combination of 2.5% fly ash, 5% saw dust and geo-textile at 6 cm depth can be beneficial for stabilization of soil.

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