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Stabilization of Expansive Soils Using Industrial Wastes

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Abstract: India is a vast country with several types of soil among which expansive soils constitutes over an area of 5,46,000 km^2. Expansive Soils consists of various clay minerals which enhances swelling and shrinkage characteristics that needs to be treated with stabilizers to prepare it for constructional activities without causing any distress to structures founded on them in reality. Generation of industrial wastes produced by industries nowadays is increasing enormously and causing potential threat to the environment. In the present experimental study, natural expansive soils were procured from different locations in Karnataka having liquid limit range from 45% to 75%. A detailed study of Index properties and compaction characteristics for IS light and heavy compaction of Plain soils and soils replaced by design mix proportion of Steel dust and Sugarcane bagasse ash have been carried out. Correlations were established between the compaction, swelling and shear strength characteristics with index properties using MLRA (Multiple Linear Regression Analysis). The MDD and UCS of blended soils was found to be higher than the plain soils, thereby achieving the design economics.

Keywords: Industrial wastes, Steel dust, Sugarcane bagasse ash, Compaction characteristics, Swelling and shear strength characteristics.

1. Introduction

The foundation of a building is a crucial component for the efficient transmission of loads to the subsoil that lies underneath it. When expansive soils come in contact with water it results in volume change and it needs stabilization of soil to adequate sufficient strength. Soils with and without cohesion can be stabilized by various methods. Expansive soils expand during the wet season which exerts an upward pressure on structure and they contract during the summer which creates a downward draw. So, there is a need to stabilize soils effectively, efficiently and in an eco-friendly manner.

Engineers of today are facing difficulty when it comes to disposing of quantities of industrial wastes that are being produced. This results in serious issues which will significantly disrupt the ecosystem. The present experimental study examines how to stabilize expansive soils using industrial wastes. There have been several attempts documented in the literature that, regarding the use of various chemical admixtures to increase the strength and engineering properties of soil, it should be environmentally safe, locally accessible, and economical. Treating the soil with stabilizers is one of the most practical and economical solution. In the current experimental study, bagasse ash and steel dust were replaced in different mix proportion to stabilize soil.

2. Literature Review

Bagasse ash significantly improves shear strength and decreases swelling potential when it is dried from wet state (Gandhi K S, 2012). In addition, the bagasse ash act as a stabilizer (Suhas K. Salunkhe et al., 2014). It is also observed that the plasticity characteristics of blended soils improves significantly (Athira T and Sini T, 2019). Bagasse ash with varying percentage when blended with expansive soils, improves density, CBR & Unconfined compressive strength (Kiran R G and Kiran L, 2013). Further, steel slag can be blended with expansive soils to improve the plasticity characteristics, increased strength and drainage properties of expansive soils (malasavage et.al, 2012) and Unconfined compressive strength & CBR values (Jun Wu et al., 2019) (Amit S. Kharade et al., 2014). Increase in percentage of steel slag with fly ash mixtures in expansive soils, results in decrease in the values of cohesion and angle of internal friction (Kayal Rajakumaran, 2015). Marl, sand stabilized with cement (2%) and Electric arc furnace dust i.e, EAFD percentages from 5 to 30% can be used in the sub-base for rigid and flexible highway embankments and it is found to be durable (Omar S. Baghabra Al-Amoudi et al., 2016). Increase in OMC and decrease in MDD of soft soils were observed when blended with GGBS and fly ash (Laximikantyadu et al., 2018). The studies related to stabilization of expansive soils having different liquid limits with industrial wastes (Bagasse ash and steel dust) is very scanty.

Based on the detailed literature review, the following objectives were arrived to bridge the research gaps envisaged.

- To use steel dust and bagasse ash from industrial wastes as a stabilizing substance and to address the issue of waste disposal.
- To evaluate the strength characteristics of expansive soils replaced with constant percentage of steel dust i.e., 8% and different percentage of sugarcane bagasse ash varying from 12 to 20%.
- To provide an effective and economical solution to enhance the engineering properties of soil with the help of these industrial wastes.

3. Materials and Methods

3.1 Materials

3.11 Soil

Nearly ten field soils were collected from various places around Mysuru and Chamarajanagar districts, Karnataka State, India. Out of these, finally three soils were selected based on their liquid limit and free swell ratio (Prakash et.al 2004).

1. Field Soil-1 from Kollegal, Chamarajanagar district, soil having montmorillonite (M) clay mineral dominance.

2. Field Soil-2 from Yalandur, Chamarajanagar district, soil having kaolinite (K) clay mineral dominance
3. Field Soil-3 from Dattagalli, Mysuru district, soil having montmorillonite (M) clay mineral dominance.

3.12 Bagasse ash

Bagasse is the fibrous material left behind after sugarcane is crushed to extract the juice, and bagasse ash is created when bagasse is burned. These substances can pollute air and water if they are disposed improperly. Additionally, they could accumulate in the solid waste deposited near sugar factories. Bagasse ash with high silica content is thought to be a suitable pozzolanic material with non-relative behaviour that might be employed in soil stabilisation for building projects and pavement subgrade stabilisation. It was collected from the Jaggery plant in Muthahalli, Mandya district, Karnataka state, India. From the laboratory test results on bagasse ash, the specific gravity was observed to be 1.31 and the chemical properties of bagasse ash are shown in Table 2.

3.13 Steel dust

Steel dust was procured from Shimoga Steels Ltd., Hebbal Industrial Area, Mysuru district, Karnataka state. The chemical properties of steel dust are shown in Table 3.

Table 1: Laboratory Evaluated Properties of Pure Expansive Soils

Property	Soil 1	Soil 2	Soil 3
Free swell ratio	1.5	1.4	2.3
Specific gravity	2.68	2.69	2.87
Liquid limit (W_L) %	53	64	74
Plastic limit (W_p) %	19.50	21	26
Plasticity index (I_p) %	33.50	42.60	48
Grain size distribution (%)			
Clay size	22.5	11	26
Silt size	34.2	77	52
Sand size	43.3	12	22
IS Light compaction:			
Maximum dry density(kN/m^3)	16.45	15.72	14.8
OMC (%)	16.7	22.14	25
IS Heavy compaction:			
Maximum dry density(kN/m^3)	18.25	17.34	16.90
OMC (%)	9.4	18.3	19.5
Dominant Clay Mineral	M	K	M
IS Classification of soil	CH	CH	CH

Table 2: Composition of Bagasse Ash

Sl. No	Compounds	Percentage (%)
1	Silica	73
2	Alumina	6.7
3	Iron oxide	6.3
4	Phosphorous pentoxide	4
5	Magnesium oxide	3.2
6	Calcium oxide	2.8
7	Potassium oxide	2.4
8	Sodium oxide	1.1

Table 3: Composition of Steel Dust

Sl. No	Element	Percentage (%)
1	Iron	67.83
2	Oxygen	22.72
3	Carbon	8.66
4	Silicon	0.79

3.2 Methods

3.21 Preparation of mix proportion

The selected field soils were blended with varying percentages of Bagasse ash (12 to 20%), by keeping steel dust at constant percentage (8%). Sufficient care was taken to blend the admixtures with soils. These soils with and without reinforcement tested for physical, index, compaction properties and unconfined compression strength according to the Bureau of Indian standards (BIS).

3.22 Compaction Test

IS Light and Heavy compaction tests were conducted on the natural and reinforced soils (Standard or Light Compaction) [IS: 2720-Part 7 (1980)], and (Modified or Heavy Compaction) [IS: 2720-Part 8 (1983)]. For these compaction tests, each sample of mass 3 kg were mixed with different percentages of moisture contents for saturation. After keeping the soil samples for a saturation period of five to seven days, the Proctor compaction tests were conducted on the soil samples to achieve the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC).

3.22 Unconfined compression test

This test involves compressing a cylinder of earth without lateral support until failure occurs while applying continual strain. Unconfined Compressive Strength (UCS) (IS 2720-Part 10 (1991)) of the soil is the compressive load per unit area necessary to fail the specimen. The weight of the dry soil was calculated by using volume of the UCS specimen and compaction characteristics of the soil. In the current experimental work, samples of natural and reinforced soils were compacted in split moulds to the appropriate OMC and MDD.

4. Results and Discussions

4.1 Index properties of soil with addition of Steel Dust and Bagasse Ash

The percentage of reinforcement shown in Figures 1 through 16 refers to the percentage of admixtures in different proportions. The admixtures (steel dust and sugarcane bagasse ash) have been replaced by gravimetric concept to have a uniform mix proportion for the experimental study.

Figures 1 through 7 demonstrates the variation of index properties with percentage variation of steel dust and bagasse ash of soils having different liquid limit range.

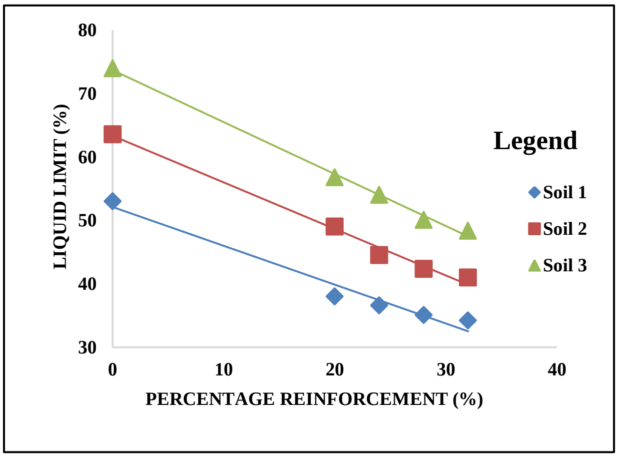


Fig. 1. Liquid Limit variation in Reinforced Soils

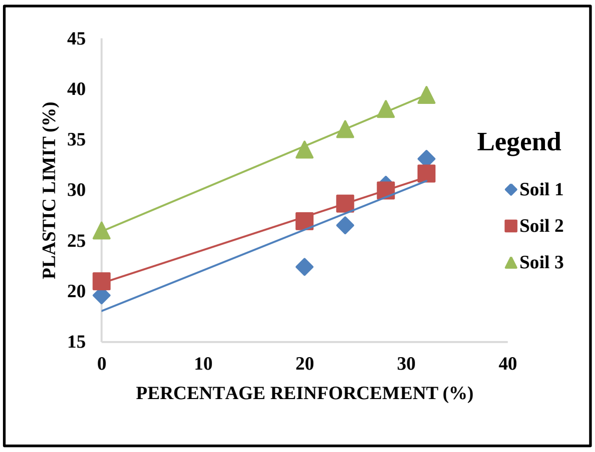


Fig. 2. Plastic Limit variation in Reinforced Soils

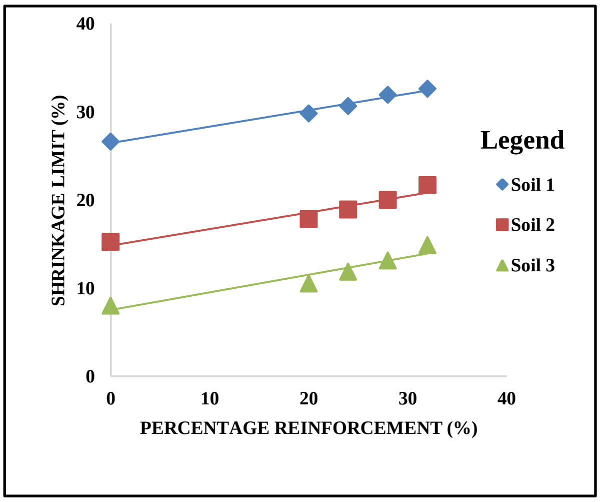


Fig. 3. Shrinkage Limit variation in Reinforced Soils

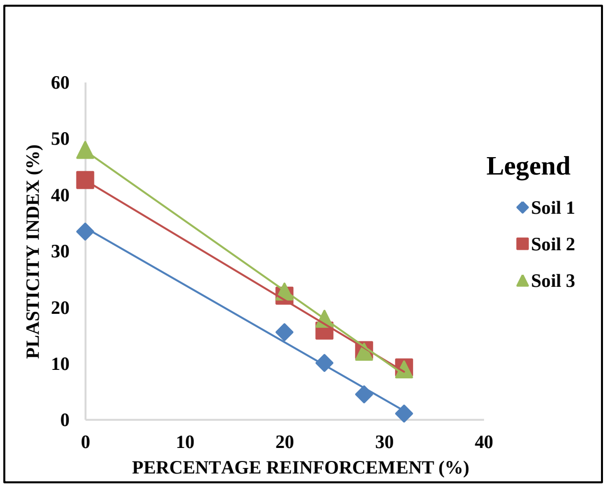


Fig. 4. Plasticity Index variation in Reinforced Soils

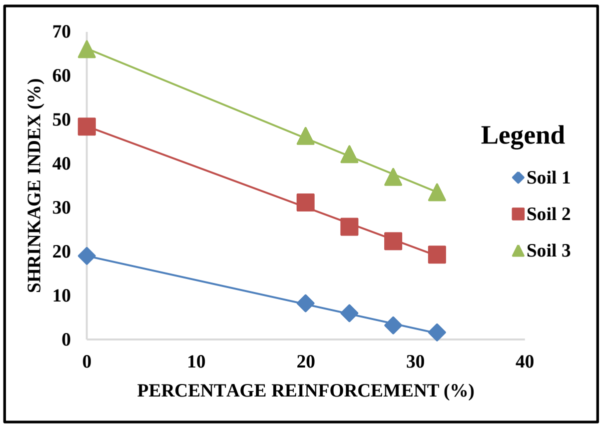


Fig. 5. Shrinkage Index variation in Reinforced Soils

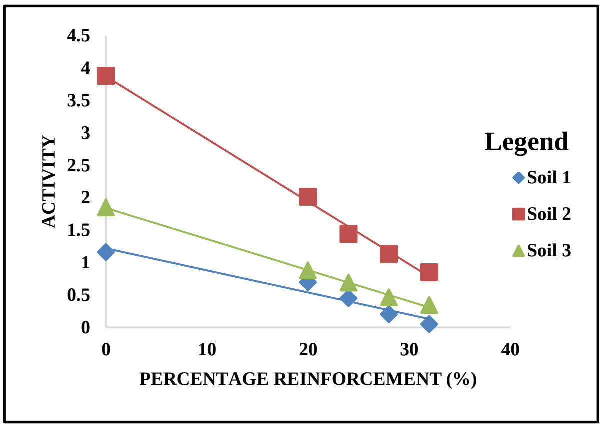


Fig. 6. Variation of Activity in Reinforced Soils

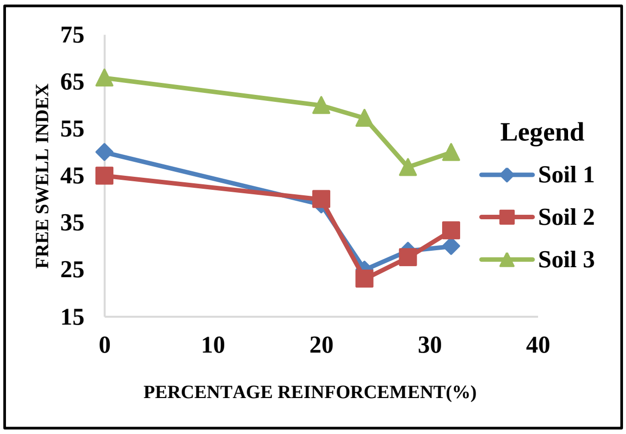


Fig. 7. Variation of Free Swell Ratio in Reinforced Soils

It is evident that as the percentage of steel dust and bagasse ash increases in expansive soils, their liquid limit gets reduced. This demonstrates unequivocally that, the capacity of these soils to be compressed and the swell potential is getting reduced. The amount of water that can be entrapped within the voids of soils, increases with increase in percentage of admixtures. As shown by the fact that the plastic limit of these soils is observed to be increasing with increase in the percentage of admixtures added to them, indicating that the soils will experience lower magnitude of volumetric changes when in contact with moisture. The shrinkage index and activity of these soils were observed to decrease with increase in percentage of admixtures, illustrating the lesser degree of swelling and shrinking behavior. The amount of swelling that emerges is influenced by a number of environmental parameters, including dry density, initial water content, surcharge loading and others. It was observed that 24% of admixtures (8% of steel dust + 16% of sugarcane bagasse ash) for Soil 1 and Soil 2 whereas for soil 3 it is 28% (8% of steel dust + 20% of sugarcane bagasse ash) is the optimum replacement and the free swell ratio of the soils reduces upto a significant extent providing the ideal mix proportion in respective case

Table 4 shows the Linear and Regression equations developed using the relationship between Percentage Reinforcement and Index Properties.

Table 4: Linear Relationship between Percentage Reinforcement and Index Properties

Variation of Percentage Reinforcement with	Linear Equation		
	Soil 1	Soil 2	Soil 3
Liquid Limit	$W_L = -0.6119P_R + 52.106$, $R^2=0.96$	$W_L = -0.7346P_R + 63.36$, $R^2=0.98$	$W_L = -0.8207P_R + 73.722$, $R^2=0.98$
Plastic Limit	$W_P = 0.4026\ P_R + 18.036$, $R^2=0.81$	$W_P = 0.3277\ P_R + 20.801$, $R^2=0.98$	$W_P = 0.4026\ P_R + 18.036$, $R^2=0.81$
Plasticity Index	$I_P = -1.0168\ P_R + 34.132$, $R^2=0.98$	$I_P = -1.0623\ P_R + 42.559$, $R^2=0.98$	$I_P = -1.2425\ P_R + 47.82$, $R^2=0.98$
Shrinkage Limit	$W_S = 0.1866\ P_R + 26.442$, $R^2=0.98$	$W_S = 0.1875\ P_R + 14.835$, $R^2=0.92$	$W_S = 0.2001\ P_R + 7.5151$, $R^2=0.92$
Shrinkage Index	$I_S = -0.5506\ P_R + 19.027$, $R^2=0.98$	$I_S = -0.9221\ P_R + 48.525$, $R^2=0.98$	$I_S = -1.0208\ P_R + 66.207$, $R^2=0.98$
Activity	$A = -0.0341\ P_R + 1.2192$, $R^2=0.94$	$A = -0.0966\ P_R + 3.869$, $R^2=0.98$	$A = -0.0478\ P_R + 1.8392$, $R^2=0.98$

- P_R – Percentage Reinforcement

From Table 4, it is evident that the relationship between Index properties and percentage reinforcement for the above soils having liquid limit range of 50% to 75% respectively is linear which can be generalized for all expansive soils. Based on this, characteristic behavior of soils with different liquid limit and percentage reinforcement can be predicted with respect to their index properties.
Table 5 shows the correlation between the variation of P_R and index properties

Table. 5: MLRA between Percentage Reinforcement and Index Properties

Soil 1	Soil 2	Soil 3
$P_R = 9.68\ W_L + 4.67W_P + 0.10FSR - 536.51$, $R^2 = 0.96$	$P_R = -0.83\ W_L + 1.30W_P + 0.12FSR + 25.32$, $R^2 = 0.98$	$P_R = -2.34\ W_L - 0.83W_P + 0.33FSR+194.13$, $R^2 = 0.97$
$P_R = -102.43\ I_P + 3.35\ I_S + 2252.34\ A - 1.31$, $R^2 = 0.97$	$P_R = 33.09\ I_P - 2.45\ I_S - 352\ A + 70.39$, $R^2 = 0.94$	$P_R = -4.29\ I_P - 1.45\ I_S + 125.62\ A + 71.04$, $R^2 = 0.98$

Table 5 shows the relationship between the Index properties and percentage reinforcement for the soils having liquid limit range of 45% to 75% respectively, which is obtained through Multiple Linear Regression Analysis. It also provides relationship between Index properties with respect to Percentage reinforcement making it easy in the practical implementations at site when some of these properties are unknown.

4.2 Results of Compaction characteristics with varying percentage of Steel Dust and Bagasse Ash

Figures 8 through 13 shows that the variation of compaction characteristics (Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) with addition of different percentage of reinforcement for the soils having different liquid limit range.

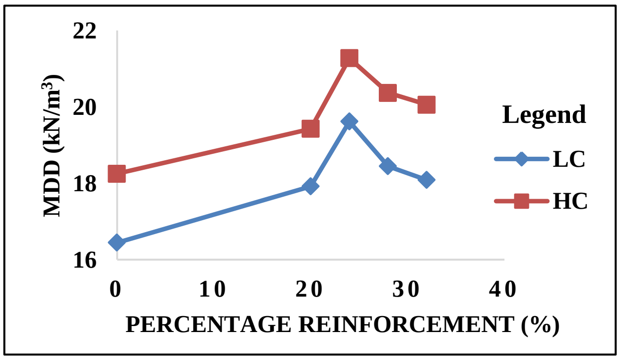


Fig. 8. Variation of MDD with Percentage Reinforcement (Soil 1)

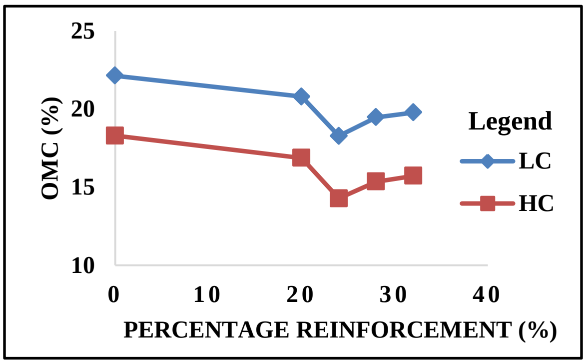


Fig. 9. Variation of OMC with Percentage Reinforcement (Soil 1)

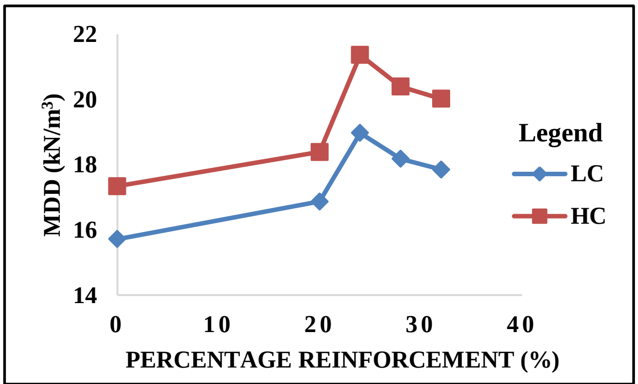


Fig. 10. Variation of MDD with Percentage Reinforcement (Soil 2)

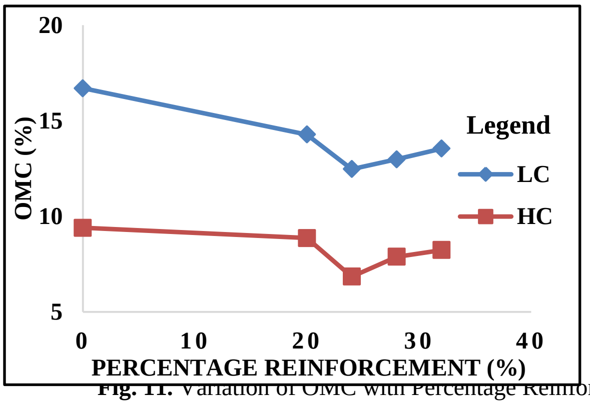


Fig. 11. Variation of OMC with Percentage Reinforcement (Soil 2)

Figures 8 and 9 show that, the magnitude of maximum dry density was achieved at 24% reinforcement (steel dust and sugarcane bagasse ash) for both Standard Proctor compaction (LC) and Modified Proctor compaction (HC) of the soil having liquid limit 53%.

Figures 10 and 11 shows that, the magnitude of maximum dry density was achieved at 24% reinforcement i.e,8% Steel dust and 16% Bagasse ash for Standard Proctor compaction (LC) and Modified Proctor compaction (HC) of the soil having liquid limit 64%.

From the figures 12 and 13, it can be observed that, the magnitude of maximum dry density was achieved at 28% reinforcement i.e,8% Steel dust and 20% Bagasse ash for both Standard (LC) and Modified Proctor compaction (HC) tests of the soil having liquid limit 74%.

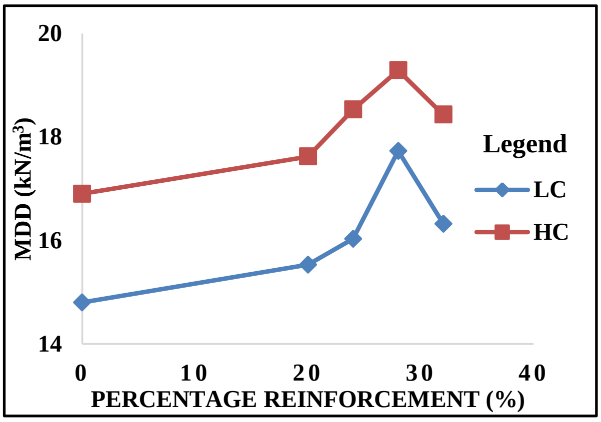


Fig. 12. Variation of MDD with Percentage Reinforcement (Soil 3)

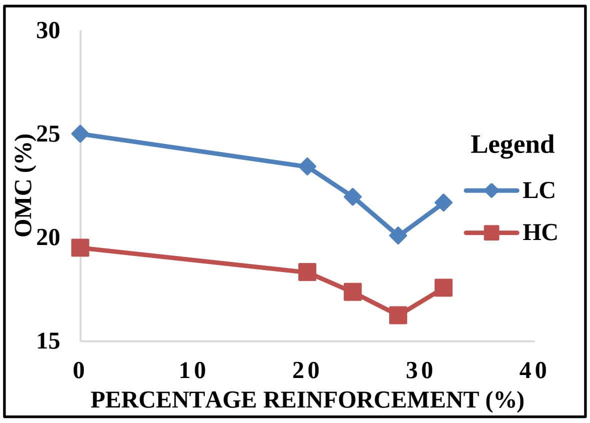
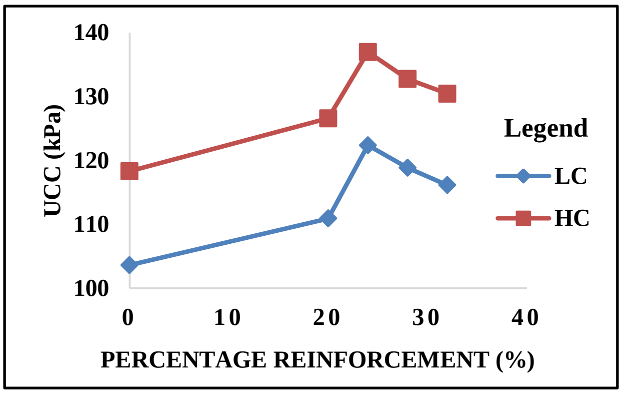


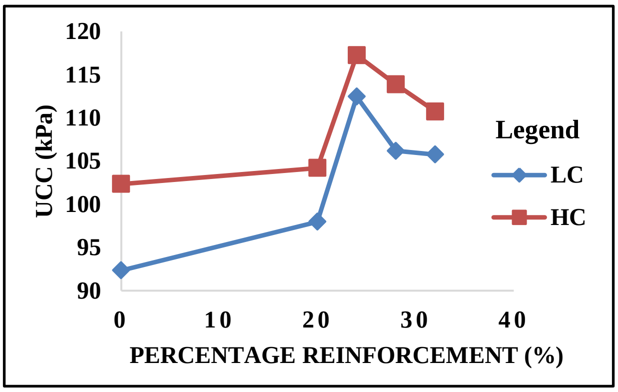
Fig. 13. Variation of OMC with Percentage Reinforcement (Soil 3)

Expansive soils typically showing higher void ratio due to higher degree of expansion in the soil particles by repulsive force domination (Diffuse Double Layer Theory), which is troublesome for building foundations during loading and unloading. From the experimental study, it can be observed that the OMC decreases up to the optimum reinforcing percentage (Steel dust and Bagasse ash). This is due to strengthened particles filling in gaps which reduces the attraction between soil particles and water, thereby stabilizing the voids within these soils. The Maximum Dry Density of reinforced soils is observed to be 21.28 kN/m^3 and 21.36 kN/m^3 at 24% of reinforcement for soil 1 and soil 2 respectively. While for Soil 3 it is 19.29 kN/m^3 at 28% reinforcement which is reasonably higher than the MDD of plain soil.

4.3 Variation of Unconfined Compression Strength (UCS) with varying percentage of Steel Dust and Bagasse Ash

Figures 14 through 16 illustrate the variation in UCS with different percentage of admixtures of soils having different liquid limit range. It has been observed that as percentage of admixtures added to the soil increases the intensity of the unconfined compressive strength increases. The unconfined compressive strength of these compacted soils reaches its peak at a replacement of 24% to 28% of admixtures (steel dust and sugarcane bagasse ash) with the weight of soil for both the energy levels. Hence 8% steel dust and 16% sugarcane bagasse ash make up the ideal proportion of replacement of admixtures for Soil 1 and Soil 2, while 8% steel dust and 20% sugarcane bagasse ash can be considered as the ideal percentage of replacement of admixtures for Soil 3 respectively. It is clear that the liquid limit of each soil affects the maximum magnitude of unconfined compressive strength that can be attained by the soil i.e, for Soil 1 having the lower liquid limit attaining the maximum strength possible whereas Soil 3 having the higher liquid limit attaining the minimum compressive strength in relative comparison to Soil 2.





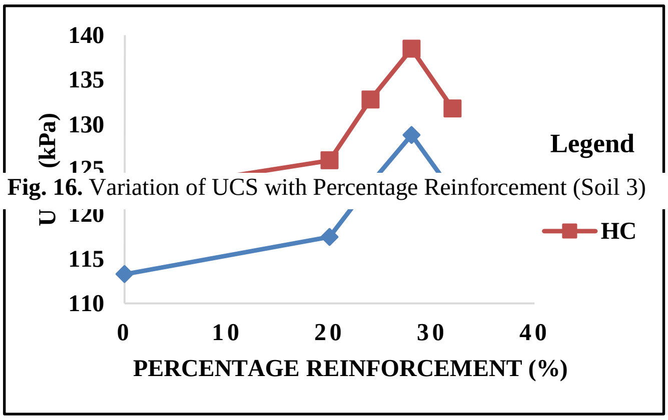


Fig. 16. Variation of UCS with Percentage Reinforcement (Soil 3)

The blending of the soil with exclusively steel dust, no appreciable increase in unconfined compressive strength was seen. Sugarcane bagasse ash acts as a catalyst and enhances steel dust as a stabilizer. The safe and economical disposal of sugarcane bagasse ash can be thought of by blending it with soil in construction activities of compacted earth fill.

5. Conclusions

The following conclusions can be made from the present experimental study:

- The plasticity characteristics of soils increases with increase in percentage of reinforcement irrespective of the liquid limit of soils.
- The percentage of reinforcement increases with increase in the liquid limit of the soil.
- The correlations between the percentage of admixtures and index properties of soils with various liquid limit ranges are reliable as R values ranges from 0.9 to 1.
- The equations developed using MLRA can be used to determine the percentage of reinforcement required.
- The optimum admixture percentage was found to be 24% for soil 1&2, whereas for soil 3 it is 28% (at the maximum magnitude of MDD and UCS).

6. References

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