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Comparative Study of Geotechnical Properties of Fly Ash and Bio Soil Mixed with Low Plastic Clay

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Abstract:

Bio soil is a byproduct obtained from the biomining of legacy waste, which typically contains over 50% of this inert material. Currently, its primary applications are limited to agriculture and filling low-lying areas. However, since bio soil is considered a waste material, this study explores its potential use in geotechnical structures, particularly as a subgrade material for highways. Fly ash is commonly used as a filling or subgrade material in highways and expressways. This research investigates whether bio soil can serve a similar purpose. For designing subgrades, the California Bearing Ratio (CBR) and compaction characteristics are crucial properties. This study compares the geotechnical properties of fly ash with those of a mixture of bio soil and low plastic clay. Laboratory tests were conducted to evaluate the compaction characteristics and CBR values of the bio soil-clay mixtures, focusing on the effect of different mixing ratios on strength improvement. Proctor compaction tests were used to analyze the compaction behavior, while CBR tests were conducted to assess strength characteristics. The study examined the impact of adding varying proportions of low plastic clay (0%, 20%, 40%, 60%, and 80%) to bio soil. Results showed that the optimal improvement in CBR and Maximum Dry Density (MDD) was achieved with a 60:40 ratio of bio soil to clay when compared to fly ash. Consequently, the findings suggest that bio soil, despite being a waste product, can be effectively utilized as a subgrade material in highways when mixed with low plastic clay.

Keywords: Legacy Waste, Bio soil, Fly ash, Clay

1 Introduction

Many developing nations struggle with proper Municipal Solid Waste (MSW) management, often resorting to open dumping due to insufficient resources and lack of governmental support. For instance, in India, more than 90% of MSW ends up in open dumpsites [1]. This practice has led to urban areas being overwhelmed by overflowing waste sites containing substantial amounts of accumulated refuse. These locations typically lack proper infrastructure to effectively handle the liquid and gaseous waste decomposition products [2]. As a consequence, harmful substances are released into the environment, contaminating soil, air, and water sources, and creating significant health hazards [3]. The expansion of urban areas in India has resulted in waste disposal sites becoming incorporated within city limits, negatively impacting public health, environmental quality, and urban aesthetics [4]. The increasing population has heightened the need for landfill space to accommodate MSW, presenting sustainability challenges due to the constrained capacity of urban land [5]. Research indicates that legacy waste dumpsites occupy more than 10,000 hectares of urban land, creating substantial challenges for urban local bodies and municipal corporations in managing waste disposal safely [6]. In response to these issues, the Indian government initiated the Swachh Bharat Mission (SBM) to enhance public health and sanitation. A key component of this program is the remediation of abandoned dumpsites through Landfill Biomining (LFBM), also referred to as landfill mining. This process involves digging up, stabilizing, and sorting waste into various recyclable materials. The Central Statistics Office (CSO, 2021) reports that India produces about 152,076 metric tonnes of MSW daily, with approximately 98% being collected. Roughly 37% of this waste undergoes treatment, while the remainder is sent to landfills or dumpsites. Nevertheless, the majority of these sites have surpassed their capacity but continue to function due to limited space and other challenges [7]. Moreover, these waste sites present considerable environmental hazards, such as contamination of air and water, due to their lack of proper management and sanitary controls. Considering these issues, it is essential to investigate methods for repurposing the accumulated waste in these dumpsites. The stockpiled refuse at these locations comprises various materials, including plastics, wood, textiles, metals, glass, stone, and others, which can be utilized as secondary resources. A substantial portion of this waste consists of a soil-like substance referred to as the fine fraction (FF) or bio soil. This material is composed of decomposed organic matter, soil particles, sediment, woody debris, and other inert components. Bio soil constitutes approximately 40% to 80% of the total waste in landfills, varying based on the cut-off diameter. However, the potential reuse of this material is complicated by the presence of contaminants such as micro plastics, heavy metals, and organic pollutants.

The use of bio soil as a building material presents an opportunity to recycle waste resources back into the human-constructed material cycle, aligning with circular economy objectives in developing nations. This strategy can simultaneously aid in the restoration of dumpsites while addressing the increasing need for construction materials in urban environments.

The objective of this research is to examine the geotechnical characteristics of bio soil to determine its potential as a construction material. Various combinations of bio soil and other soil types will be tested to identify the optimal blend for construction purposes. The study will also compare the geotechnical properties of these bio soil mixtures with those of fly ash, a material frequently employed in subgrade construction for highways and other infrastructure. Essential tests, including the California Bearing Ratio (CBR) and Proctor compaction tests, will be conducted to evaluate the strength and compaction qualities of the bio soil mixtures. Through comparison with fly ash, this investigation aims to ascertain whether bio soil can serve as a viable alternative in subgrade construction. If proven successful, this approach could provide a sustainable solution to address waste management issues and construction material shortages, thereby contributing to environmental conservation and urban growth.

2 Sample preparation and materials used

An experimental investigation has been done using Bio soil, soil (low plastic clay) & fly ash. Bio soil is added to soil (low plastic clay - CL soil) in a varying percentage (100%, 80%, 60%, 40% & 20% by dry weight) and compared with geotechnical properties of Fly Ash respectively. Total 6 samples are prepared by mixing Bio soil and low plastic clay and have been compared with Fly ash after investigating the geotechnical properties of both. Table 2.1 shows different samples.

Table 2.1 Details of Samples

Sr. No.	Details of Sample	Name of Sample	Nomenclature
1.	Bio soil	Sample 1 (100:0)	S1
2.	Soil	Sample 2 (0:100)	S2
3.	80% Bio soil + 20% CL soil	Sample 3 (80:20)	S3
4.	60% Bio soil + 40% CL soil	Sample 4 (60:40)	S4
5.	40% Bio soil + 60% CL soil	Sample 5 (60:40)	S5
6.	20% Bio soil + 80% CL soil	Sample 6 (20:80)	S6
7.	Fly Ash	Sample 7 (FA)	S7

2.1 Materials Used

The materials utilized in this study are as follows:

2.1.1 Bio Soil

The Bio soil used in this study is sourced from Biomining work, Baswar Dumpsite, Naini, Prayagraj, Uttar Pradesh. Fig.2.2 shows the particle size distribution (PSD) analysis of used Bio soil following IS: 2720-Part-4-1975. According to the Indian Standard Classification System (ISCS), this soil is classified as Poorly Graded Sand (SP).

Figure 2.1 Bio Soil

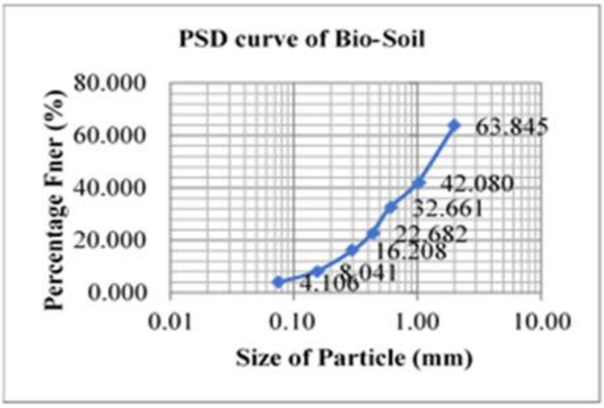

Figure 2.2 Particle Size Distribution curve of Bio Soil

Table 2.2 Properties of Bio Soil

Specific Gravity	2.042
Coefficient of Curvature, C_c	0.7097
Coefficient of uniformity, C_u	10.502
Classification	Poorly Graded Sand (SP)
D_{50}(mm)	1.089
Water content (%)	25.12
Maximum dry Density (MDD), γ_d (g/cc)	1.37
Optimum Moisture Content (OMC), %	25.12

2.1.2 Soil

The Soil used was sourced from Kurebhar, Sultanpur, Uttar Pradesh. Fig.4.3 shows the particle size distribution (PSD) analysis of used soil following IS: 2720-Part-4-1975. According to the Indian Standard Classification System (ISCS), this soil is classified as Low Plasticity Clay (CL).

Figure 2.3 Soil

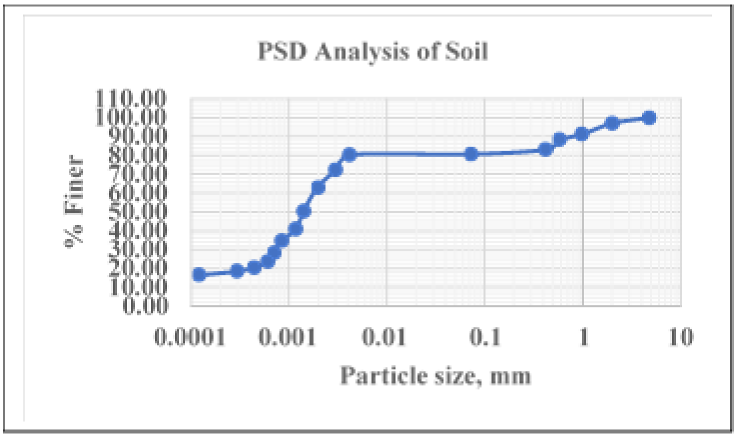

Figure 2.4 Particle Size Distribution curve of Soil

Table 2.3 Soil properties

Specific Gravity	2.742
Liquid Limit, W_L (%)	30
Plastic Limit, W_P (%)	23
Plasticity Index, I_P (%)	7
Classification	Low Plastic Clay (CL)
Water content (%)	11.45%

2.1.3 Fly Ash

The used Fly Ash was sourced from NTPC Tanda, Uttar Pradesh. Fly ash is fine, powdery material that is a byproduct of burning coal in power plants. It is carried away in the exhaust gases and collected using electrostatic precipitators or other methods. Fly ash is commonly used as a supplementary cementitious material in concrete and construction due to its pozzolanic properties.

Figure 3.1 Fly Ash

3 Results and Discussions

3.1 Specific Gravity

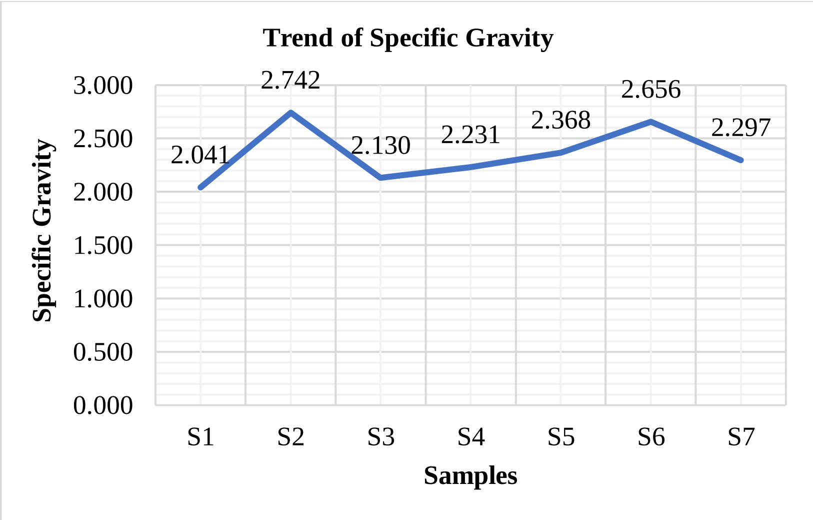

Figure 3.1 Trend of Specific Gravity

From figure 3.1 following result is deduced,

- For all types of the mixture samples studied, the specific gravity of samples is increasing as proportion of CL soil in Bio soil is increasing

3.2 Compaction Characteristics

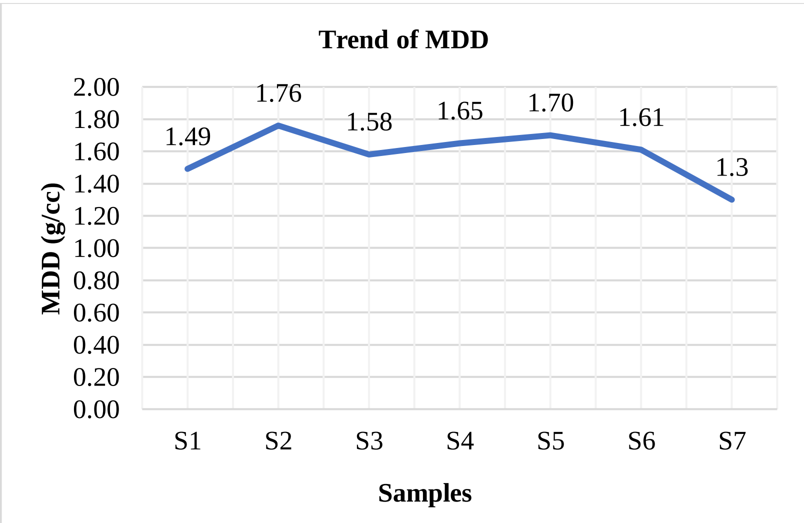

Figure 3.1 Trend of MDD

From figure 3.2 following results are deduced,

- For all types of the mixtures studied, the MDD increases as the proportion of CL soil increases (upto 60%).
- It is also found that, MDD of Sample 5 (40:60) is more than MDD of Fly Ash.

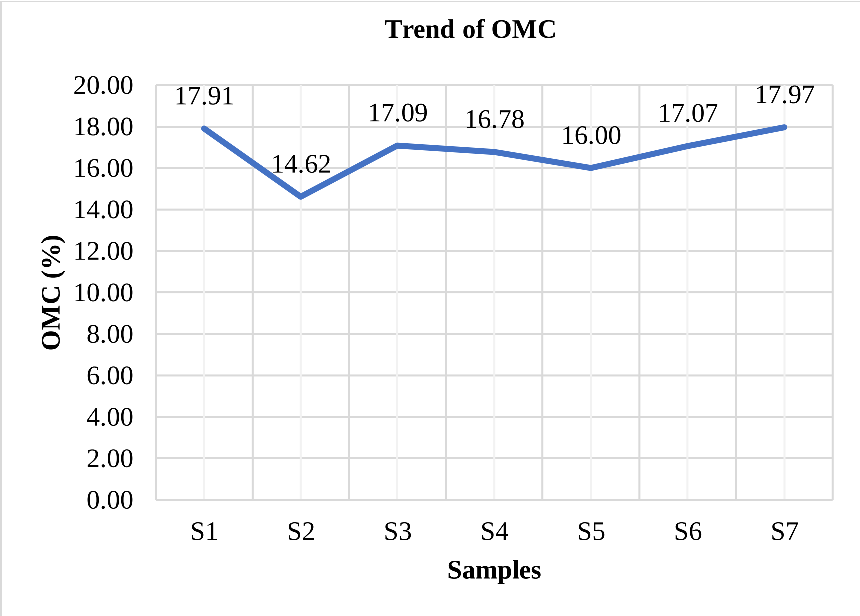

Figure 3.2 Trend of OMC

From the figure 3.3, shows the variation of OMC of various proportions of Bio soil & CL soil.

Following figure 3.4 shows comparison of MDD of Bio soil, CL soil, Fly Ash & different samples prepared by mixing bio soil and CL soil.

From figure, it is found that, bio soil when mixed with CL soil in proportion of 40:60 respectively, then its MDD is more than that of Fly Ash & OMC of it is also less than that of Fly Ash.

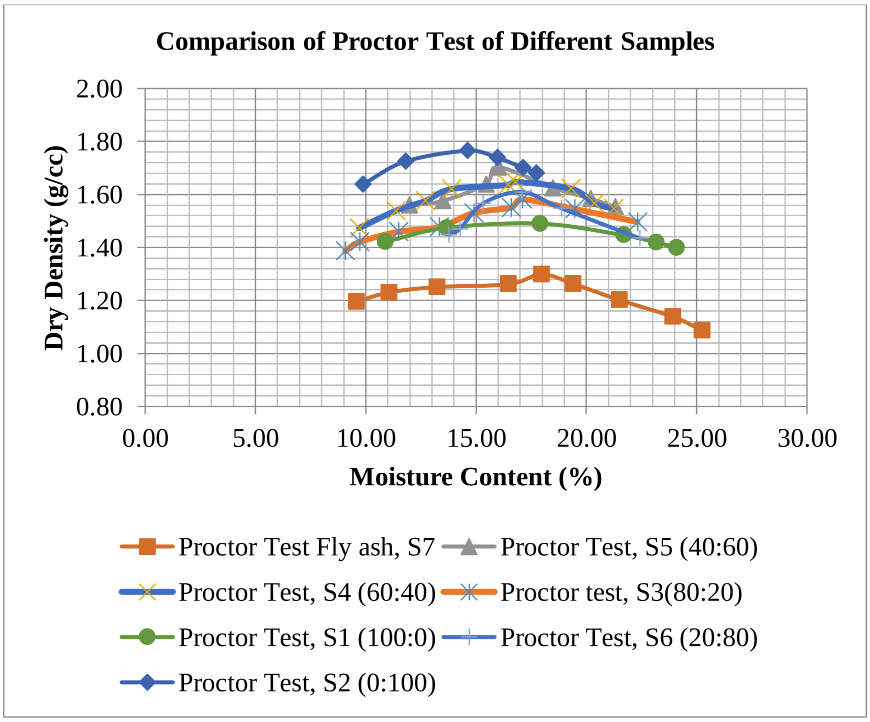

Figure 3.3 Comparison Proctor test of different Samples

3.3 California Bearing Ratio (CBR) Test

a) CBR of Unsoaked Samples

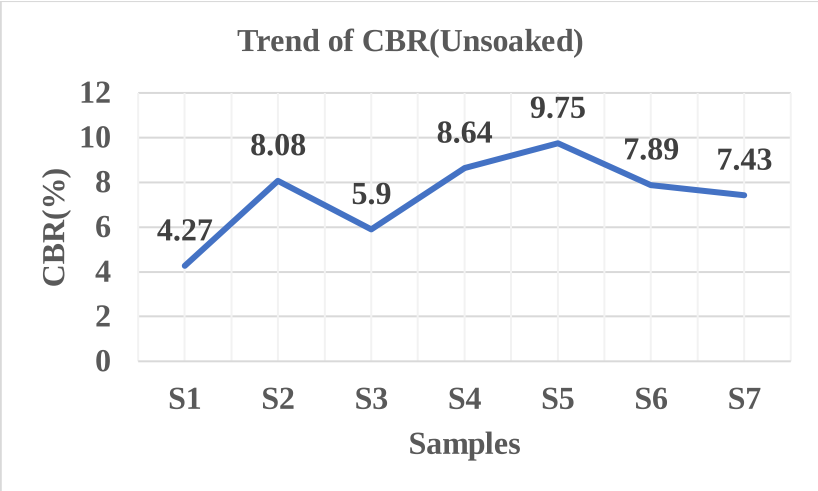

Figure 3.4 Trend of CBR values of different Unsoaked Samples

From figure 3.5 following results are deduced,

- For all types of the mixtures studied, the CBR increases as the proportion of CL soil increases (upto 60%).
- It is also found that, CBR of Sample 5 (40:60) is more than CBR of Fly Ash.

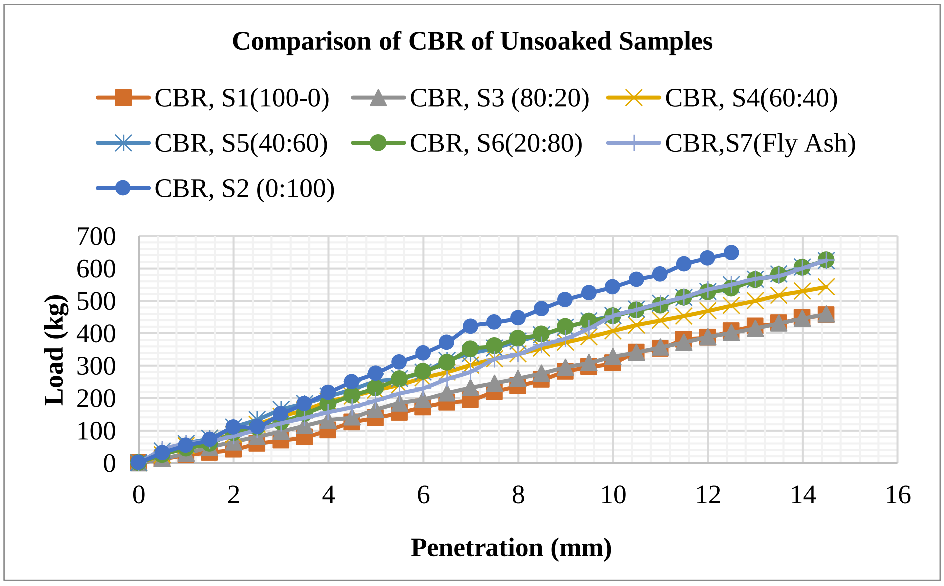

Figure 3.5 Comparison of Load Vs Penetration Curves of different Unsoaked Samples

Above figure 3.6 shows comparison of CBR of Unsoaked Bio soil, CL soil, Fly Ash & different samples prepared by mixing bio soil and CL soil.

From figure, it is found that, bio soil when mixed with CL soil in proportion of 40:60 respectively, then its CBR is more than that of Fly Ash.

b) CBR of Soaked Samples

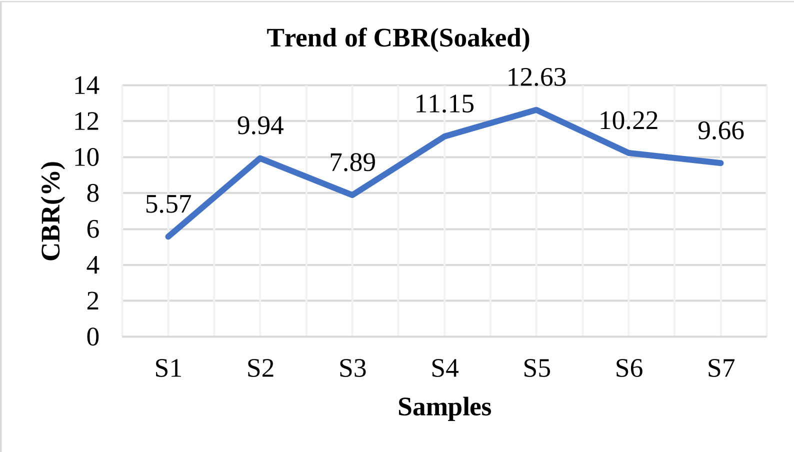

Figure 3.6 Trend of CBR values of different Soaked Samples

From figure 3.7 following results are deduced,

- For all types of the mixtures studied, the CBR increases as the proportion of CL soil increases (upto 60%).
- It is also found that, CBR of Sample 5 (40:60) is more than MDD of Fly Ash.

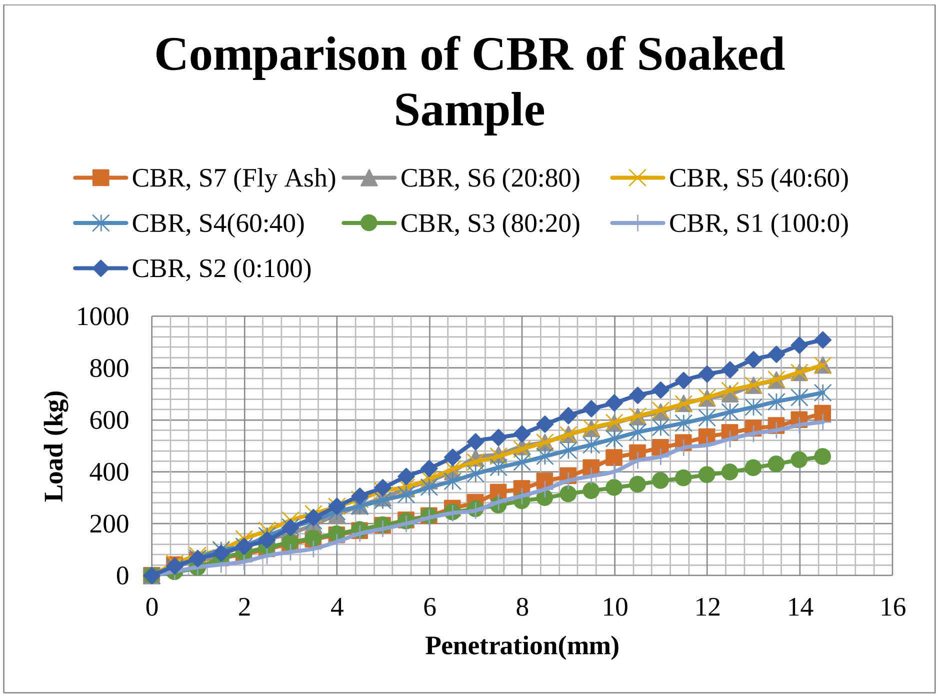

Figure 3.7 Comparison of Load Vs Penetration Curves of different Soaked Samples

Above figure 3.8 shows comparison of CBR of Soaked Bio soil, CL soil, Fly Ash & different samples prepared by mixing bio soil and CL soil.

From figure, it is found that, bio soil when mixed with CL soil in proportion of 40:60 respectively, then its CBR is more than that of Fly Ash.

3.4 COMPARISON OF RESULTS

Following table shows the comparison of geotechnical properties of bio soil, CL soil, Fly ash and Sample 5

Table 3.1 Comparison of Properties

Properties	Bio Soil	CL soil	Fly ash	S5
Specific Gravity	2.041	2.742	2.297	2.368
MDD	1.49	1.76	1.30	1.70
OMC	17.91	14.62	17.97	16
CBR(Soaked)	5.57	9.94	9.66	12.63
CBR (Unsoaked)	4.27	8.08	7.43	9.75

4 Conclusions

A series of the following tests: Specific Gravity test, Standard Compaction test & California Bearing Ratio tests were carried out on Bio soil, Soil, fly ash & different mixtures of bio soil & soil (in the proportions (80:20), (60:40), (40:60), (20:80); to explore the impact of soil variation in Bio soil and elucidate the trends of change in these characteristics concerning fly ash, an investigation is conducted.

Drawing from the results and discussions derived from the Specific Gravity test, Standard Compaction test, and California Bearing Ratio tests, the following conclusions are drawn:

1. For Bio-soil only

a. The specific gravity of bio-soil used in the work is 2.041 and has been classified as Poorly Graded Sand (SP) with OMC & MDD are 17.91% & 1.49g/cc

b. The value of Unsoaked & Soaked CBR for bio soil is 4.27% & 5.57% respectively

2. For CL soil only

a. The specific gravity of soil used in the work is 2.742 and has been classified as low plastic clay (CL) with OMC & MDD are 14.63% & 1.76g/cc

b. The value of Unsoaked & Soaked CBR for soil is 8.08% & 9.94% respectively

3. For Fly ash only

a. The specific gravity of fly ash used in the work is 2.297 with OMC & MDD are 17.97% & 1.30g/cc.

b. The value of Unsoaked & Soaked CBR for fly ash is 7.43% & 9.66% respectively

4. For Bio soil mixed with CL soil in different proportions

a. For all types of the proportions studied, the specific gravity increases as the proportion of clay particles increases in bio soil because bio soil particles are replaced by clay particles.

b. For all types of the proportions studied, the maximum dry unit weight increases as the proportion of soil (upto 60%) increases and decreases for 80% soil. Also, it has been observed and investigated that MDD of Sample 5 (40:60) is more than that of Fly Ash.

c. For all types of the proportions studied, it has been found that the CBR of Unsoaked samples increases as the proportion of soil (upto 60%) increases and it gets decreased for 80% soil. Also, it has been seen that CBR of Unsoaked Sample 5 (40:60) is more than that of Fly Ash.

d. For all types of the proportions studied, it is investigated that the CBR of Soaked samples increases as the proportion of soil (upto 60%) increase and decreases for 80% soil. Also, it has been investigated that the CBR of Soaked Sample 5 (40:60) is more than that of Fly Ash.

5. From the results, it is concluded that bio soil which is a waste material has also its utility in Subgrade of highways when it is mixed with soil.

6. Bio soil possesses good subgrade properties than fly ash when it is mixed with soil.

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