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Soil Stabilization Using Pine Needles and Marble Dust: An Experimental Study

Muhammad Zeeshan Ahmad *[a], Irfan Jamil *[b], Umar Zafar *[c]

**a Master Research Student, Department of Civil Engineering, UET Peshawar,Peshawar and 25120 ,Pakistan*
**b Lecturer, Department of Civil Engineering, UET Peshawar, Peshawar and 25120, Pakistan*
**c Master Research Student, Department of Civil Engineering, UET Peshawar, Peshawar and 25120, Pakistan*

A B S T R A C T

Soil stabilization is a crucial practice in civil engineering, aimed at enhancing soil properties to support infrastructure development. This study investigates the potential of using pine needles and marble dust as eco-friendly stabilizers for soil improvement. By integrating these natural and industrial waste materials, this research explores their combined effect on soil properties, such as compaction, unconfined compressive strength, and load-bearing capacity. Laboratory tests were conducted to assess the feasibility of pine needles and marble dust in stabilizing expansive soils. The findings demonstrate that this combination can improve the soil's mechanical properties, contributing to more sustainable construction practices.

Keywords: Soil stabilization, pine needles, marble dust, sustainable construction, expansive soils, and mechanical properties.

INTRODUCTION

Soil is a heterogeneous material that varies in qualities across different locations, often requiring stabilization, especially for construction purposes. Clayey soil, common in Pakistan, is particularly challenging due to its high water retention and swelling properties, which can damage infrastructure.

To mitigate these issues, soil stabilization and reinforcement are essential. Stabilization controls volumetric changes and improves shear and tensile strength.

Soil stabilization and reinforcement techniques are crucial in geotechnical engineering to enhance the physical properties of soil, making it more suitable for construction. Common methods include the use of additives like lime, cement, and fly ash to improve soil strength and reduce permeability (Bhuvaneshwari, Robinson, & Gandhi, 2005). Geosynthetics, such as geogrids and geotextiles, are also widely used for reinforcement, particularly in road construction and slope stabilization, as they distribute loads and prevent soil erosion (Koerner, 2012). Additionally, techniques like mechanical stabilization, which involves the compaction of soil layers, are often employed to increase the density and bearing capacity of the soil (Holtz, Kovacs, & Sheahan, 2011). These methods are essential for ensuring the long-term stability and durability of infrastructure projects. This study explores using pine needles and marble dust for soil treatment due to their abundance and cost-effectiveness. Additionally, this approach helps reduce environmental pollution from marble dust disposal.

OBJECTIVES

The objectives of this research are to:

a. Evaluate the potential of pine needles and marble dust in improving soil properties.

b. Determine the optimal proportions of pine needles and marble dust for maximum stabilization effect.

c. Analyze the environmental and economic impacts of using these materials for soil stabilization.

LITERATURE REVIEW

Soil stabilization is a critical aspect of geotechnical engineering aimed at enhancing the physical and mechanical properties of soil to meet the requirements of construction projects. This process is essential for ensuring the stability and durability of infrastructure built on naturally weak or variable soil conditions. Various stabilization methods have been developed, with chemical stabilization being among the most widely researched and applied.

Chemical stabilization involves the use of additives such as lime, cement, and other industrial by-products to improve soil properties. Lime stabilization, in particular, has been extensively studied and applied to clayey soils. According to Bell (1996), lime treatment improves the workability, strength, and durability of clay soils, making it a popular choice for stabilizing road bases, embankments, and foundations. The lime reacts with the soil to reduce plasticity, increase bearing capacity, and enhance resistance to environmental factors like freeze-thaw cycles.

Cement stabilization, another common method, is particularly effective in increasing soil compressive strength and reducing plasticity. Ingles and Metcalf (1972) emphasize that cement treatment is well-suited for stabilizing subgrade and sub-base layers in pavements, where increased strength and durability are required. Cement reacts with water and soil minerals to form a rigid matrix that binds the soil particles together, resulting in improved load-bearing capacity.

In recent years, the use of industrial by-products such as fly ash and ground granulated blast furnace slag (GGBFS) in soil stabilization has gained traction due to their cost-effectiveness and environmental benefits. Fly ash, a by-product of coal combustion, has been successfully used to stabilize expansive soils. Research by Bhuvaneshwari, Robinson, and Gandhi (2005) demonstrated that fly ash significantly reduces the swell potential of expansive soils and improves their bearing capacity, making it an attractive option for stabilizing problematic soils. Similarly, Senol et al. (2006) found that GGBFS, a by-product of the steel industry, enhances the compressive strength and durability of treated soils, particularly in pavement construction.

Mechanical stabilization methods, such as compaction and the use of geosynthetics, are also widely employed to improve soil properties. Compaction involves mechanically rearranging soil particles to increase density and strength. Holtz, Kovacs, and Sheahan (2011) highlight that compaction is a well-established technique for improving the load-bearing capacity of soils and reducing settlement. Geosynthetics, including geogrids and geotextiles, are materials placed within the soil to reinforce it, enhance load distribution, and prevent erosion. According to Koerner (2012), geosynthetics are particularly effective in road construction, slope stabilization, and retaining wall applications.

As the demand for sustainable and eco-friendly construction practices grows, alternative soil stabilization materials are being explored. Natural fibers such as coir, jute, and bamboo have been investigated as potential reinforcements for soil stabilization. Studies by Kumar and Walia (2006) suggest that these fibers can improve the shear strength and reduce the settlement of sandy soils, offering a greener alternative to synthetic materials. Additionally, enzyme-based stabilization methods, which involve the use of biological processes to alter soil properties, have shown promise in recent research. Khattab and Al-Amoudi (2011) found that enzyme-treated soils exhibit improved strength and stability, although the widespread application of this technique is still in its early stages.

METHODOLOGY

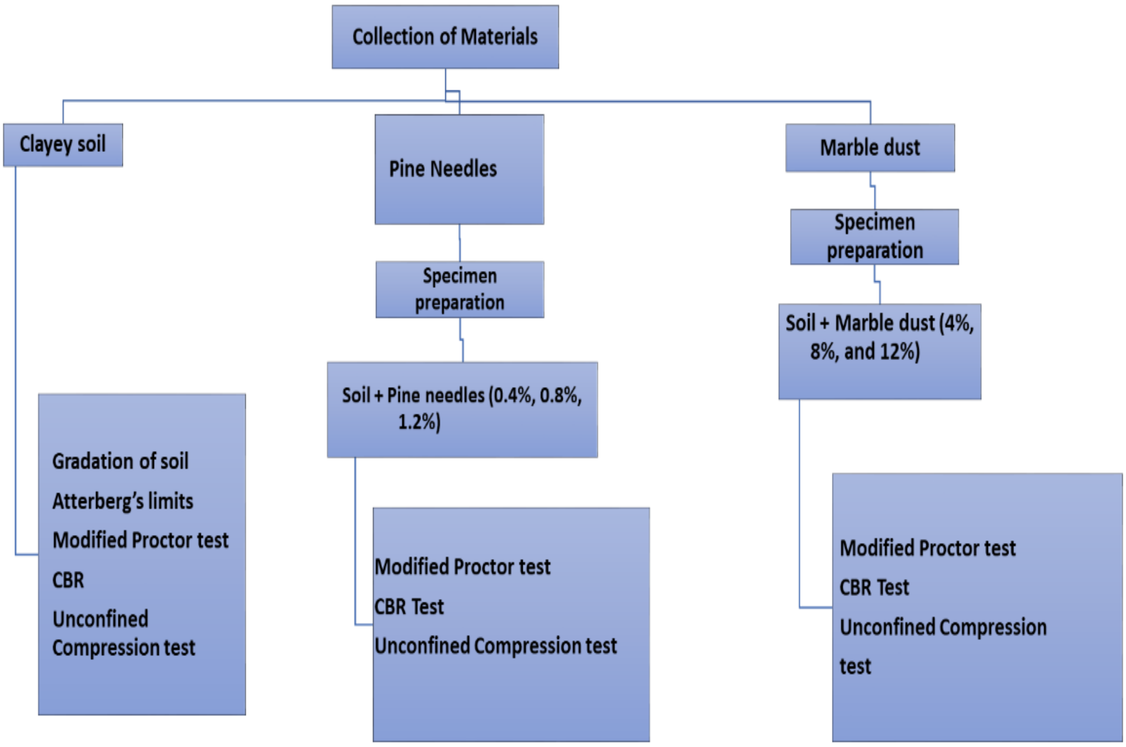
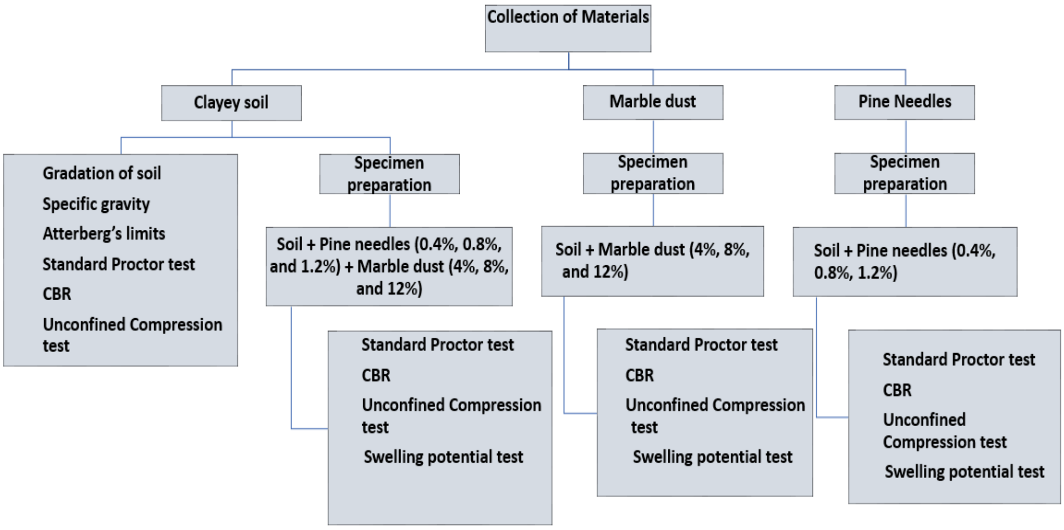


Fig. 1 – hierarchy of methodology



Soil sample has been collected from the site and its virgin properties have been found by gradation, specific gravity, Atterberg's limit, proctor test etc. At the same time Marble dust have been collected from different factories where cutting and polishing of marble stone are carried out. Pine needles (tree of pine trees like kail, chire etc) in dry form have been collected from Murree area where these trees are found easily. Now different proportion of Pine needles and marble dust as mentioned in above hierarchy were mixed and tested.

Table 1 – Virgin Properties of soil

S.NO	PROPERTIES	VALUES/DETAILS
1	Soil Type	Clayey Soil
2	Color	Greyish Brown
3	Optimum Moisture Content (%)	12.6
4	Maximum Dry Density (g/cc)	1.83
5	Liquid Limit (%)	30.2
6	Plastic Limit (%)	14.5
7	Permeability (cm/day)	2.6
8	CBR (%)	3.9

Table 2 – Properties of pine needles

S.NO	PROPERTIES	VALUES/DETAILS
1	Specific Gravity	0.651
2	Color when dry	Brown
3	Length used (mm)	10-12

Results and Discussion

Compaction test:

Modified proctor test was performed for Pine needles and marble dust. This test involve compaction of sample in a mold in five layers through 10 lb hammer dropped from 18 inches height. Different samples of pine needles (0.6%,1.2%,1.8%) and marble dust (6%,12% and 18%) were used. After testing it was revealed that by adding Pine needles its MDD increased to 1.86g/cc at 1.2%, and become 1.9g/cc at 12% of marble dust. The Optimum moisture content was also decreased from 12.6% to 10.3% for pine neeles and 9.2 % marble dust.

Unconfined compression test:

This test was performed on soil with varying percentages of Pine needles and marble dust. Same ratio/percentages of both the additives were used.

The Unconfined compression strength of soil was increased to 4100l b/ft^2 at 0.6% Pine neeles and 4040 lb/ft^2 at 12% marble dust from 3750 lb/ft^2 of parent soil.

Table 3 – Unconfined Compression test at 0.6% Pine needles

S.No.	***Unit Strain (%)***	***Load per Unit Area (psf)***
1	0	0.0
2	0.492125984	1053.9
3	0.984251969	1685.1
4	1.476377953	2265.5
5	1.968503937	2598.7
6	2.460629921	3009.4
7	2.952755906	3444.9
8	3.44488189	3919.6
9	3.937007874	4100.3
10	4.429133858	3951.0
11	4.921259843	3275.4
12	5.413385827	2998.3
13	5.905511811	2895.1
14	6.397637795	2771.9
Maximum Stress (lbs/ft^2)		4100.3

Table 4 – Unconfined Compression test at 12% Marble dust

S.No.	***Unit Strain (%)***	***Load per Unit Area (psf)***
1	0	0.0
2	0.472143532	595.4
3	0.944287063	949.4
4	1.416430595	1256.2
5	1.888574127	1500.6
6	2.360717658	1846.1
7	2.83286119	2208.8
8	3.305004721	2419.4
9	3.777148253	2635.9
10	4.249291785	2860.4
11	4.721435316	3068.3
12	5.193578848	3394.6
13	5.66572238	3637.5
14	6.137865911	3778.3

15	6.610009443	3878.1
16	7.082152975	3957.9
17	7.554296506	4034.7
18	8.026440038	4044.5
19	8.498583569	4050.8
20	8.970727101	4011.5
21	9.442870633	3892.8
22	9.915014164	3729.8
23	10.3871577	3605.3
Maximum Stress (lbs/ft2)		4050.8

California bearing ratio test:

This test was performed for both the additives and it was revealed that CBR for pine needles was increased to 6% at 1.2% Pine needles and upto 8% at 12% marble dust.

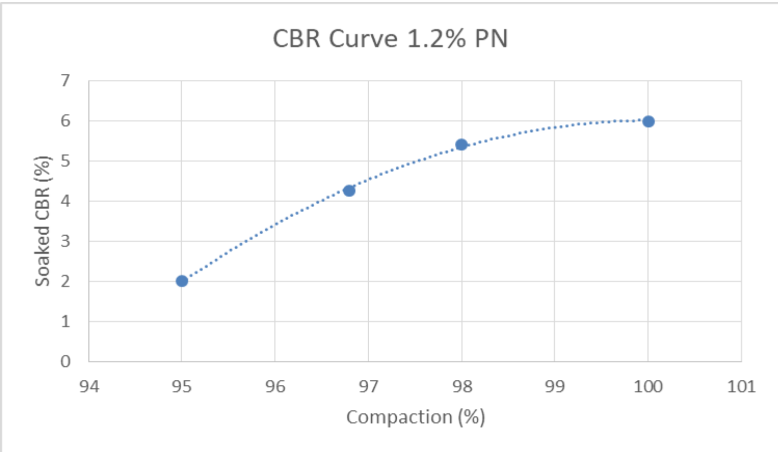


Figure: 1 – CBR of soil having 1.2% pine needles

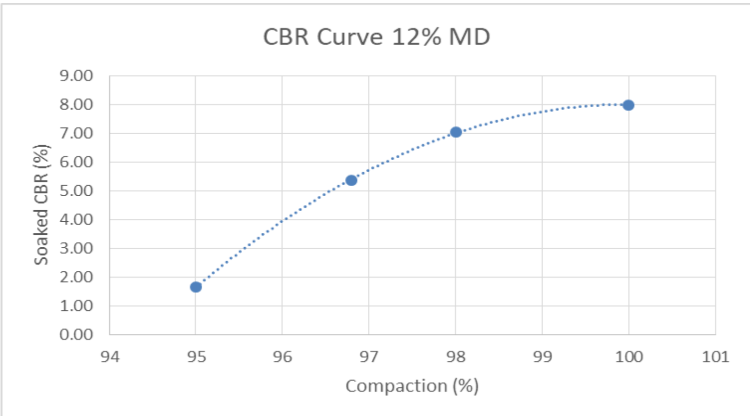


Figure: 2 – CBR of soil having 12% marble dust

Conclusions

- This study demonstrates that Pine needles and marble dust have significantly increased the strength of soil. The optimum percentage of Pine needles and marble dust was found as 1.2% and 12 % for CBR, and MDD.

- UCS was maximum at 0.6% Pine needles and 12% Marble dust show 10% increase in strength.

Recommendations

Future research is recommended to explore long term behaviour of soil stabilized with Pine needles and Marble dust.

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