Investigation on the Stabilization of High Compressibility Soil with Wood Ash and Cement.

Ipsita Rahman[1*], and Hossain Md. Sayem[1]

[1] Department of Geological Sciences, Jahangirnagar University, Savar, Dhaka, Bangladesh

(*Corresponding E-mail: ipsitarahman0@gmail.com)

Abstract: Weak and soft soils pose serious problems in many areas, especially in Bangladesh, and frequently lead to the structural failure of roads, pavements, embankments, and other crucial infrastructures underscoring the vital role of geotechnical engineering in fostering sustainable and resilient construction. This study explores the effectiveness of wood ash (WA) and cement (C) as stabilizing additives for enhancing the engineering characteristics of highly compressible silty clay soils. XRF analysis confirmed the presence of reactive oxides conducive to pozzolanic reactions. Laboratory investigations were performed on soil samples incorporating varying proportions of WA (0%, 4%, 8%, 12%, and 16%) and equivalent WA contents supplemented with 2% C. The findings indicated that specific gravity decreased progressively with increasing WA content but exhibited a slight increase when C was incorporated. Both the liquid limit and plastic limit rose with WA and WA–C additions, whereas the plasticity index and linear shrinkage declined consistently. The unconfined compressive strength (UCS) demonstrated an upward trend with increasing WA, achieving further enhancement upon C inclusion. Consolidation test results showed a reduction in the volume compressibility (m_V) and compression index (C_C) with higher WA content, which further decreased upon the addition of 2% C. These findings suggest that combining WA and C significantly enhances soil performance, providing an economic and environmentally sustainable method for stabilizing weak subgrade soils.

Keywords: ***Compressibility, Stabilization, Additives, Pozzolan, Sustainability.***

Introduction

Soils such as expansive soil, organic soil, or high compressibility clay are often considered problematic because of their tendency to exhibit low strength, excessive settlement, and poor workability which make them unsuitable for construction. The treatment and subsequent compaction of perceived weak soils to enhance their strength and durability, such that they become viable for a specific engineering purpose beyond their original classification, is known as stabilization (Koteswara et al., 2012).

Stabilization can be achieved through physical as well as chemical methods. Chemical stabilization is where chemical additives such as cement, lime, and other binders stabilize the soil through chemical reactions such as cation exchange, flocculation, and agglomeration. The high cost of production, depletion of natural resources, contribution to global warming, and adverse health effects of workers associated with the use of conventional materials have driven research towards alternative and sustainable stabilizing agents conducted by individuals, companies, and institutions especially in developing, underdeveloped countries. Domestic and agricultural wastes such as sawdust, rice husk, bamboo leaf ash, and sugarcane straw ash that are generated in large quantities are being studied as potential chemical additives. Wood ash, a by-product of biomass combustion, has emerged as a promising additive in soil stabilization due to its pozzolanic properties (Blayi et al., 2024).

As a developing country with a growing population, it is of great importance for Bangladesh to explore and implement methods to guarantee the resilience, safety and sustainability of infrastructure. This research is intended to systematically investigate the effectiveness of various wood ash contents, in combination with cement, in stabilizing high compressibility soil by a series of laboratory tests supporting two of the interconnected Sustainable Development Goals, SDG 9 and SDG 11.

Materials and Methods

The materials used in this study primarily include soil collected from Haor area, wood ash (0.063 mm) and locally bought portland cement. Based on the particle size distribution curve ASTM-D422 (2007), the natural soil was determined to be fine-grained, with approximately 54.12 % of its composition being clay, 43.24% silt and 2.64% sand particles. The studied clayey soil has shown high plasticity (CH) in nature.

The required amounts of wood ash (WA) and cement (C) were weighed based on predetermined percentages by the dry weight of the soil and mixed with the soil while maintaining a fixed moisture content. Nine samples were prepared by thoroughly mixing varying percentages of additives (Soil, Soil + 4% WA, Soil + 8% WA, Soil + 12% WA, Soil + 16% WA, Soil + 4% WA + 2% C, Soil + 8% WA + 2% C, Soil + 12% WA + 2% C and Soil + 16% WA + 2% C) and cured for 15 days before the tests were performed. X-ray fluorescence (XRF) was used to assess the elemental composition of the original soil, WA and C. The geotechnical properties were performed on treated and untreated soil according to ASTM (1974) and BS 1377 (1990).

Results and Discussion

The XRF analysis revealed that the soil was siliceous containing 48.6% SiO_2, 18.15% Al_2O_3, 9.47% CaO whereas the WA comprised of high CaO content (25.1%), moderate Al_2O_3 (14.6%) and low SiO_2 (2.7%). The SiO_2, Al_2O_3, CaO content in C was 16.82%, 6.77% and 63.38% respectively.

The specific gravity (*Gs*) of soil decreased with increasing WA content due to the lower *Gs* (2.27) of WA, though the value increased slightly with the addition of cement (*Gs*=3.16). However, the overall trend remained declining. The liquid limit (LL) and plastic limit (PL) value increased with increasing WA content. However, incorporation of 2% C caused a slight reduction of LL that of WA induced samples, but the PL experienced a gradual rise with the inclusion of increasing percentages of WA and 2% C (Table 1). The plasticity index (PI) and linear shrinkage (LS) values showed decreasing trend with increasing WA content and the corresponding values further decreased with the addition of 2% C.

Table 1, Basic geotechnical properties.

Sample	G_s	Atterberg Limit (%)			LS (%)
		LL	PL	PI	
0% WA (Pure Soil)	2.68	57.05	25.23	31.82	13.48
Soil+4% WA	2.63	60.87	30.63	30.24	12.14
Soil+8% WA	2.59	64.25	35.83	28.42	11.02
Soil+12% WA	2.53	66.53	39.44	27.09	9.82
Soil+16% WA	2.48	67.93	42.06	25.87	8.97
Soil+4%WA+2%C	2.65	59.82	32.14	27.68	11.51
Soil+8%WA+2%C	2.62	62.73	36.77	25.96	10.26
Soil+12%WA+2%C	2.57	65.16	41.35	23.81	9.13
Soil+16%WA+2%C	2.52	66.74	44.15	22.59	7.84

According to the plasticity chart (BS 5930, 1981), all samples except the pure soil and 4% WA mix plotted below the 'A' line, indicating a transition from high-plastic clay to silt with the addition of WA and WA–C. This transformation results from clay particle agglomeration caused by calcium silicate gel formation (Okagbue, 2007).

From the UCS test, the stress increased rapidly with strain until reaching a peak, after which it declined for all samples (Figure 1). UCS values rose with higher WA content, indicating reduced ductility, with a maximum increase of about 192.88% at 16% WA compared to the pure soil. Adding 2% cement further enhanced UCS. This improvement is attributed to hydration and pozzolanic reactions forming calcium silicate and aluminate hydrates, which strengthen the soil matrix. Consolidation results showed reductions in settlement, volume compressibility (m_V), and compression index (C_C), producing a denser and more stable soil. Overall, WA proved to be an effective stabilizer for enhancing the engineering properties of soft clay soils.

Conclusion

In conclusion, this study investigated the stabilization of highly compressible soil using wood ash (WA) and cement. The addition of WA increased LL and PL while reducing PI and LS, indicating lower plasticity and improved stability. The highest UCS was achieved at 16% WA + 2% cement, with mV and CC showing a decreasing trend. XRF analysis confirmed reactive oxides in both additives, verifying pozzolanic activity responsible for the observed improvements. Overall, the WA–cement blend proved to be an effective and sustainable option for soil stabilization.

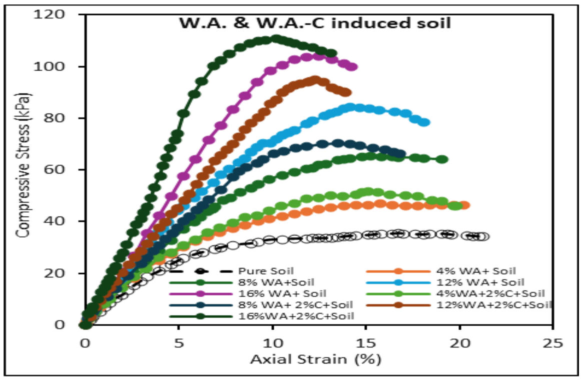

Figure 1, Variations in UCS.

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