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Micro Level Analysis of Weak Soils Stabilized with Locust Bean Waste Ash (LBWA)

Samaila Saleh

Department of Civil Engineering, Hassan Usman Katsina Polytechnic, Katsina State, Nigeria

Email address
samailasaleh2003@yahoo.com

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Abstract
Many ground improvement techniques have been evolved in the past decade in order to reduce the potential of severity of the weak soils. Out of those techniques, soil stabilization is the most effective technique. This paper presents the results of a laboratory investigation of the use of Locust Bean Waste Ash (LBWA) as a material for stabilization of weak soils. Two types of soils were treated with varying quantities of LBWA under laboratory condition. To determine the effectiveness of LBWA as a stabilizer, general geotechnical soil properties including free swell index, Atterberg limits, specific gravity, grains sizes analyses, moisture density relationship, Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) tests have been investigated. X-Ray Diffraction analysis (XRD), Scanning Electron Microscopy (SEM) and X-Ray Fluorescence spectroscopy (XRF) were carried out in order to determine the improvement in strength of the soils at micro level. It's revealed that the LBWA improved the UCS of two soils samples by 69 % and 124 % for the CI and CH soils respectively during 21 days curing. Results of the XRD, SEM and XRF have shown changes in the peaks of XRD pattern, decreases in the pores in the SEM images and changes in the chemical compositions.

1. Introduction

Soil may be separated into three broad categories which are cohesionless, cohesive and organic soil. Cohesionless soils are gravel, sand and silt. This type of soil particles do not tend to stick together. Organic soil is described as soil containing a sufficient amount of organic matter to affect its engineering properties. Cohesive soils are characterized by very small particle size where surface chemical attractions are predominant and in other words, the particles tend to stick to others.

In many instances subgrade soils that are unsuitable in their natural state can be altered by admixtures or by the addition of aggregates or by the proper compaction and thus made them suitable for subgrade construction. In its broad sense, stabilization implies improvement of soil so that it can be used for subbase, bases and in some rare instances, surface course [1]. The prospect of this research is to try the use of Locust Bean Waste Ash (LBWA) for soil stabilization.

Use of LBWA as a single additive for the purpose of soil stabilization has received very little attention in the relevant literature. However, [2] have made effort in this direction and find the effect of LBWA on the strength of weak soil. In their research, they discovered that the CBR values increased from 8 to 54 % within the 12 % stabilizer content. And the UCS of the stabilised soil increases from 5.6 to 541.8 kN/m^2. Similarly, [3] investigated the effect of LBWA on the Compaction Characteristics of Weak Subgrade Soil. They concluded that LBWA had effect on the compaction characteristics of the soils by increasing its OMC from 10.4 to 11.5 %, 18.0 to 19.5 % and 12.03 to 18.50 % respectively. And it reduced the MDD from 1.68 to 1.62 g/cm^3, 1.33 to 1.304g/cm^3 and 1.62 to 1.50 g/cm^3 respectively for the various soil samples. The above studies and many more like that of [4], [5] and [6] lead to the further investigation on morphology and change in micro structure of the stabilized soil. The present investigation includes micro-level studies such as X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and X-Ray Florescence Spectroscopy (XRF) in addition, in order to study an enhancement of strength property of weak soil using Locust Bean Waste Ash (LBWA).

2. Materials and Properties

Two types of soil samples (S1 and S2) were used in this investigation, collected from Kanabur village, Kanchipuram district, Chennai India. The soil samples were collected from a depth of about 1 m below the ground level in order to avoid the vegetation and organic matter. A series of laboratory tests [7], [8], [9], [10], [11], [12] and [13] were conducted on the soil samples after drying them in a proper manner. The two soil samples were respectively identified as the clays of intermediate compressibility and clays of high compressibility as per [14]. The chemical composition and geotechnical properties of soils are shown in Table 1 and 2 respectively. The LBWA was obtained by incinerating of locust bean pod which is an Agricultural waste product collected from Yargoje village of Kankara L.G.A. Katsina State Nigeria.

Table 1. *Chemical composition of soil samples.*

Compounds	Concentric unit of the compounds (cps)		
	LBWA	Soil sample 1	Soil sample 2
Al – KA	109.364	337.27	341.907
Si – KA	741.711	3429.946	3228.253
Ca – KA	13620.50	3531.665	3957.285
Fe – KA	2610.11	22964.82	24652.85

Table 2. *Geotechnical properties of soil samples.*

Characteristics	Values		
	Symbol	Soil sample 1	Soil sample 2
Specific gravity	G_S	2.69	2.68
Particle Size distribution			
a) Gravel (%)	G	Nil	0.18
b) Sand (%)	S	35	31.20
c) Silt (%)	M	17.69	31.14
d) Clay (%)	C	47.31	36.96
Liquid limit (%)	LL	43.6	53.2
Plastic limit (%)	PL	19.6	18.13
Plasticity index (%)	PI	24.3	35.07
Free Swell Index (%)	FSI	75	100
Classification of soil		CI	CH
Maximum dry density (g/cm^3)	MDD	1.74	1.67
Optimum moisture content (%)	OMC	17.5	18.0
Unconfined Compressive Strength (Kg/cm^2)	UCS	1.5	2.0
Un-soaked CBR (%)	CBR	5.4	4.8

3. Sample Preparation and Testing

Examinations were carried out to study the strength property of the untreated and weak soil treated with LBWA to correlate the same with micro level analysis. Unconfined Compression (UCC) test and micro level analysis were carried out with Scanning Electron Microscopy (SEM), X-ray fluorescence Spectroscopy (XRF) and X- Ray Diffraction (XRD).

The UCC test was conducted on LBWA treated soil at various proportions of 0, 2, 4, 6, 8, 10 and 12 % for curing periods of 0, 3, 7 days, 21 days respectively. The UCC samples were prepared by static compaction using a split mould at Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) that were obtained from by standard proctor compaction test. The prepared samples were cured, by placing them in air - tight polythene covers which in turn were placed over wetted rice husk base and the whole assembly was covered with wet gunny bags, in order to prevent moisture loss. SEM, XRF and XRD tests were carried out on the samples collected from the middle section of the UCC specimen, for untreated as well as for LBWA treated specimens. The soil samples were dried completely before commencing the tests.

4. Results and Discussions

4.1. Unconfined Compression Test

Unconfined compression test was conducted on prepared sample of 3.8 cm diameter and 7.6 cm height at various dosages of LBWA and the samples were cured for a period of 0, 3, 7, 14 and 21 days before testing. Table 3 shows the variation in Unconfined Compressive Strength (UCS) values for untreated and LBWA treated soil samples 1 and 2. Effect of percentage stabilizer and curing period on both the soil samples 1 and 2 were studied. The UCS values reveal an increasing trend with the increase in percentage stabilizer and curing period. From the result it can be seen that, soil sample 1 at 8 % LBWA content when cured for 3, 7 and 21 days show highest improvement in the UCS result. Similarly soil sample 2 treated with 6 % LBWA content under same curing periods of 3, 7 and 21 days attained highest improvement in the UCS result. The optimum dose of 8 % and 6 % was selected for the soil sample 1 and soil sample 2 respectively. And those optimum dosages of LBWA were used to prepare the specimen for the California bearing ratio (CBR) tests.

Table 3. *Percentage increase in unconfined compressive strength of soil sample S1 and S2 at varying percentages of LBWA and varying curing periods.*

Soils	**LBWA (%)**	**Percentage increase in UCS (%)**			
		Curing periods (days)			
		0	**3**	**7**	**21**
Sample 1	0	-	N/A	N/A	N/A
	4	2	11	18	42
	6	9	18	33	49
	8	11	28	46	69
	10	9	25	33	58
	12	8	23	26	51
Sample 2	0	-	N/A	N/A	N/A
	4	36	64	88	102
	6	38	86	102	124
	8	33	79	89	98
	10	19	43	64	74
	12	17	25	40	70

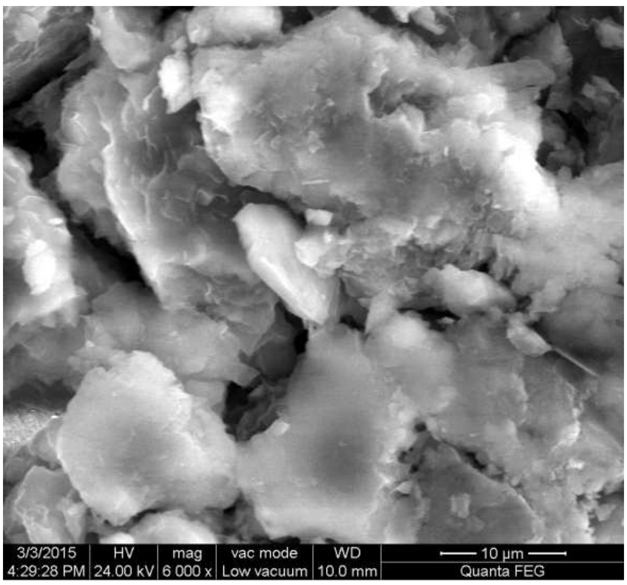
4.2. Micro level Studies on Soils

In order to compare and explain the strength development in the treated soil, micro level studies such as SEM, XRF and XRD were carried out.

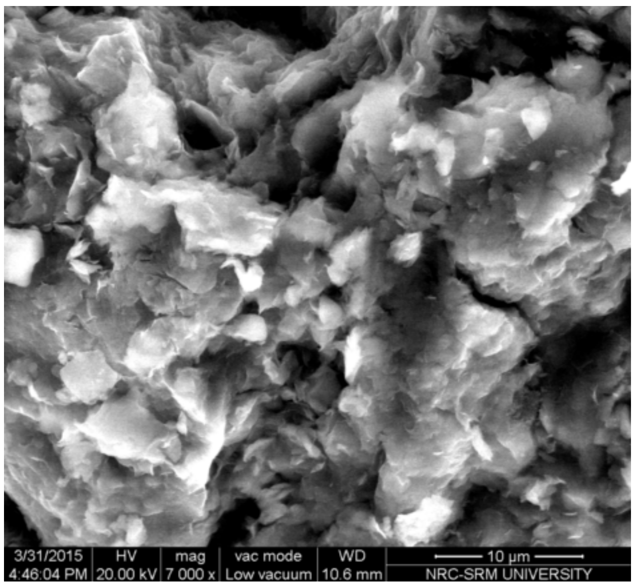
4.2.1. Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) analysis was carried out on the LBWA, untreated and treated soil samples 1 and 2 (figure 1 (a) through (e)).

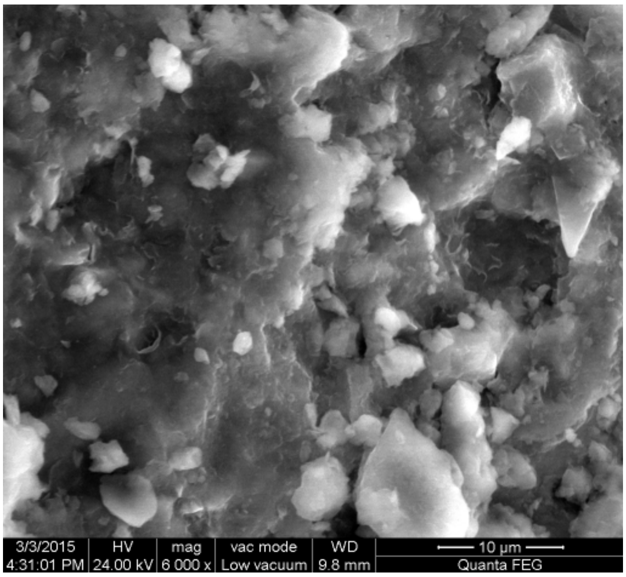
Figure 1 (a) and (b) shows SEM images of untreated and treated samples 1 respectively, while figure 1 (c) and (d) shows SEM images of untreated and treated soil sample 2. Soil sample 1 was treated with 8% LBWA while soil sample 2 was treated with 6% LBWA and both of the samples were cured for 7 days. The SEM images show some reduction in pore spaces and change in microstructure of the two soils on treatment with LBWA.



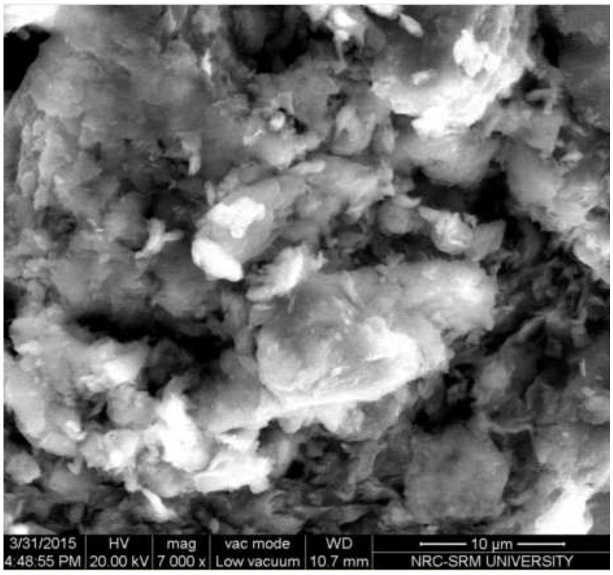
(a) Untreated soil 1



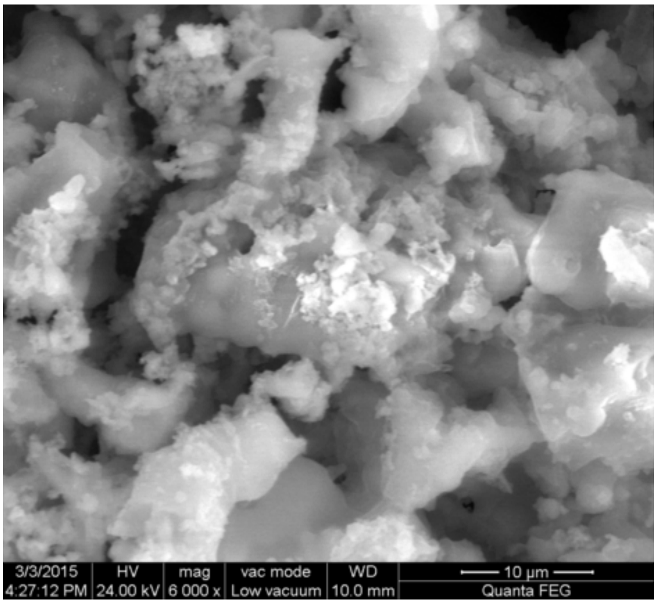
(b) Soil 1 + 8 % LBWA – 7days



(c) Untreated soil 2



(d) Soil 2 + 6 % LBWA – 7days



(e) LBWA

Figure 1. *SEM of LBWA, untreated and treated soil sample 1 and 2.*

4.2.2. X-Ray Fluorescence Spectroscopy (XRF)

XRF analysis was performed for the LBWA, untreated and treated soil samples to determine their chemical composition. Table 4 below show the concentration of the compound observed in the XRF analysis of the LBWA, untreated and treated soil samples 1 and 2.

A variation in composition of elements was observed from XRF results of untreated and treated samples. This change in elemental composition indicates the change in chemical composition of soil as well as the soil structure.

Table 4. *Result of XRF analysis of LBWA, untreated and treated soil samples 1 and 2.*

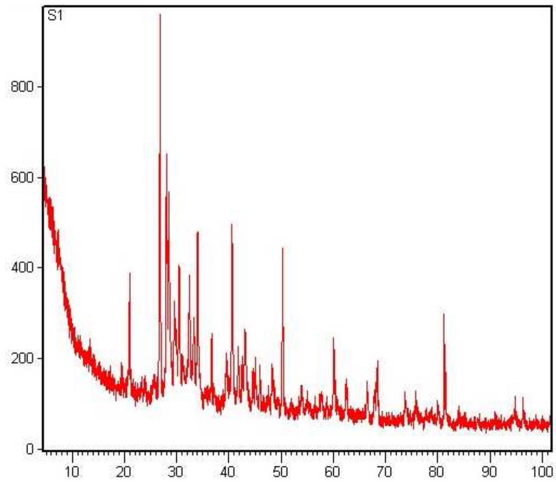
Compounds concentration (ppm)	LBWA	Untreated Soil 1	Untreated Soil 2	Soil 1 + 8 % LBWA - 7 days	Soil 2 + 6 % LBWA - 7 days
Al-K	2.19	6.75	6.84	6.78	6.75
Si-K	14.83	68.60	64.57	65.53	62.13
Ca-K	272.41	70.63	79.15	100.46	126.81
Fe-K	52.20	458.10	493.06	369.62	396.50

It is observed that the Fe percentage is high in raw soil sample. The percentage of Ca which is responsible for strength characteristics is high in the LBWA. Once the LBWA was introduced in to the raw soil in the presence of moisture and allowed to undergo curing period, there was a formation of hydration products such as calcium-silicate-hydrates (C-S-H), calcium-aluminate-hydrates (C-A-H) and calcium-aluminium-silicate-hydrates (C-A-S-H).

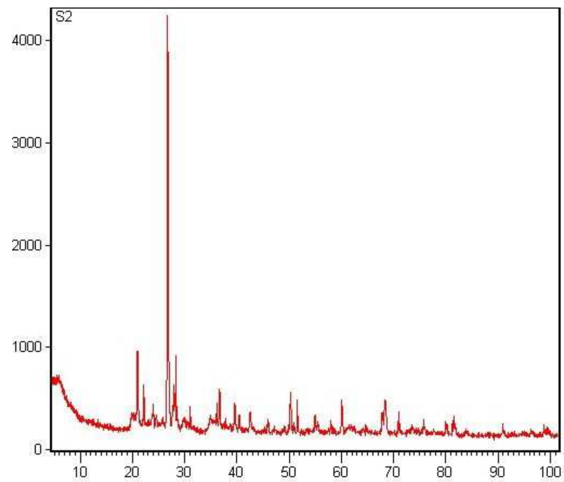
4.2.3. X – RAY Diffraction (XRD)

XRD analysis is conducted on the untreated and LBWA treated soil sample in order to identify the change in microstructure and mineralogical composition with the help of diffraction pattern. A plot has been drawn, by taking position of 2 theta angles along abscissa and the intensity in terms of counts along ordinate. The XRD gives different peaks for the different basal spacing. An increase in the number of peak was observed (Figure 2) due to addition of LBWA as well as curing period. This change in peak indicates the change in morphology of the soil on treatment with LBWA

Intensity counts

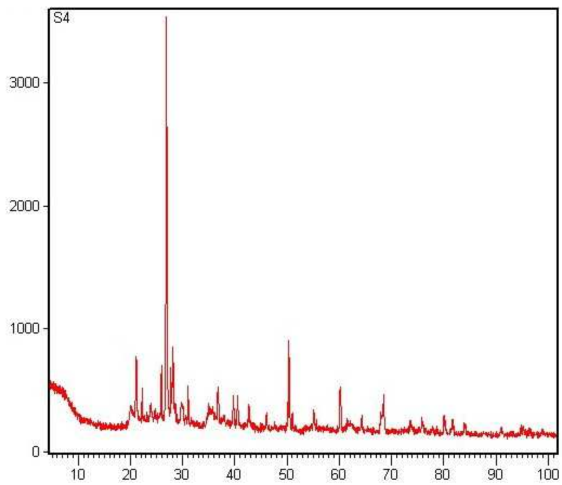


2 theta (degrees)
LBWA

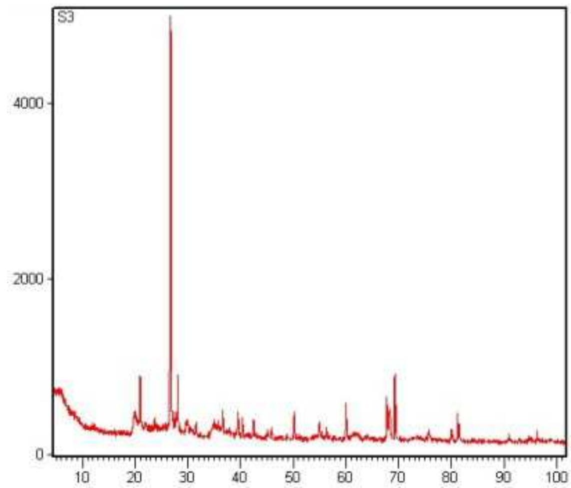


2 theta (degrees)
Untreated soil 1

Intensity counts

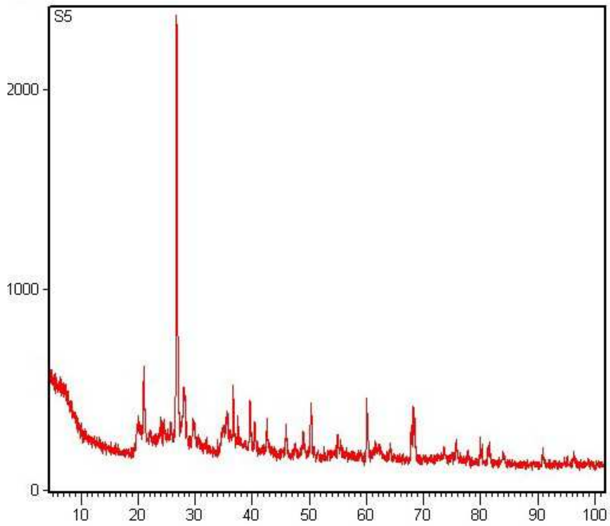


2 theta (degrees)
Soil 1 + 8 % LBWA + 7 days curing



2 theta (degrees)
Untreated soil 2

Intensity counts



2 theta (degrees)
Soil 2 + 6 % LBWA + 7 days curing

Figure 2. *XRD pattern for LBWA, untreated and treated soil sample 1 and 2.*

5. Conclusion

1. Both the soil samples S1 and S2 used in this investigation were identified as Intermediate and Highly compressible Clay (CI and CH) respectively, as per [14].
2. Both the soil samples show an improvement in UCS values due to treatment with LBWA. The optimum dose of LBWA for the treatment of soils S1 and S2 were 8 % and 6 % respectively
3. SEM, XRF and XRD analyses justified the experimental observations of UCC test. SEM micrographs reveal the change in microstructure of the treated soil and reduction in pore spaces which explains the increase in strength.
4. The changes in elemental composition of LBWA treated soil is found favourable, compared to untreated soil as depicted in XRF spectra which confirms the chemical reaction between soil and LBWA.
5. Formation of hydration products is confirmed by SEM and XRF results. Change in peak intensity gives an indication for the change in morphology of the soil sample up on treatment with LBWA stabilizer.

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