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Chemical Analysis of Reinforced Stabilized Soil

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Abstract

Objectives: This study aims at investigating lime and wheat straw as a chemical approach to improve clayey soils as an alternative to the traditional physical process of soil improvement. **Methods/Statistical Analysis**: A series of tests were conducted on clayey soils mixed with various percentages of lime and wheat straw. The readings were taken on the daily, weekly and monthly basis. The soil and water sample testing was based on pH, TDS, water hardness, Organic Content (OC) and Electrical conductivity (EC). **Findings:** The test results suggest that there are significant chemical changes resulting due to the addition of lime and/or wheat straw into the water and soil. An increase in pH, TDS and organic contents and a decrease in the electrical conductivity of soil was noticed both in short-term and long-term effects. The results indicate that by knowing chemical process some of the undesirable chemical changes could be seized to only permit the useful chemical changes in a particular process of the addition of soil stabilizing agents. Moreover, it has been noticed that a single soil stabilizing agent may not be sufficient to improve several engineering properties; therefore, combined soil stabilization techniques might be adopted for a wider range of soil improvement where necessary. **Application/Improvements:** The outcomes of present study would be of potential applications in the ground improvement field. The outcomes provide useful information about the chemical changes involved in process of ground improvement.

Keywords: Chemical Analysis, Decomposition, Reinforced Soil, Soil Stabilization

1. Introduction

The reinforcement and stabilization of soil are generally assessed by mechanical processes, for instance; cement, lime or fibre effects into the soil are measured through compressive strength, shear strength, and other mechanical properties. However, there are some chemical and biological changes involved in the process of soil improvement as well. For example, the addition of chemicals such as lime and fibres such as wheat straw into the soil may also be accompanied by chemical and biological changes. The chemical and biological effects in water and soils due to the lime and wheat straw are very vast. For example, the objectives of[1] were to investigate the response of wheat straw decomposition to increasing nitrogen availability[2], focused on wheat straw exposed to anaerobic and aerobic decomposition in the soil mass[3]. Investigated the effect of available C and N on the rate of wheat straw decomposition. The objective of the study by[4] was to investigate the effects of residue particle size on the decomposition of wheat straw. Carbon and nitrogen transformations during wheat straw and root decomposition were investigated by[5] there are several studies conducted only on the decomposition process of wheat straw and the subsequent chemical and biological changes.

Similarly[6], determined the effects of lime on organic matter content of the soil[7–10] and others investigated the effect of lime on the pH of the soil. According to[11] in expansive soils, the immediate initial strength gains are due to the cation exchange and flocculation of clay particles in the presence of lime. The Electrical Conductivity (EC) of soils varies depending on the amount of moisture held by soil particles, subsequently, the Electrical Conductivity is low, medium and high in sands, silt and clay respectively and therefore, EC correlates strongly to soil particle size and texture[12,13]. According to[13] the electrical resistivity of soil is going to decrease as well as the water content of the soil is increasing. The EC measurement of soils mainly

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depends upon soil chemical properties, salinity, porosity, temperature, CEC, the integrity of the chemical in soil, and depth of topsoil[14-17]. Therefore, the significance of chemical reactions that bring about soil stabilization and reinforcement during ground improvement could not be overlooked for most of the civil engineering works. The long-term behaviour of reinforced soils is strongly influenced by the chemical compatibility between construction materials and neighbouring components[18,19]. Otherwise, in the absence of chemical compatibility in the long term, various chemical reactions may take place (where organic acids high calcium or gypsum contents may adversely interact with the fibre materials). The chemical changes will also be dependent upon the type of soil stabilizing agents because different soil stabilizing agents having different chemical impacts on the soil pH, TDS, Hardness and electrical conductivity of the soil. These chemical properties, are usually investigated while using water for drinking, agriculture or industrial purposes. How much is the contribution to the chemical changes in the ground improvement and how the unnecessary chemical changes are controlled for achieving the targeted goals are of the key interest? The previous studies have not given adequate attention to this aspect. The main reason of the present study was to investigate the contribution of chemical and biological changes in the ground improvement and their role in controlling the ground improvement process. In this study, some chemical and biological parameters of soil which change due to the addition of soil stabilizing agents were investigated. A reverse approach to considering chemical and biological changes as a source of soil stabilization is applied. For this purpose, various percentages of lime and wheat straw were added into the soil, their effects as a function of time were investigated.

2. Materials

2.1 Soil

The clayey soil was used as a base material; the index properties of the base material were measured and are given in Table 1. As per USCS classification, the soil may be classified as low plastic clay.

2.2 Wheat Straw

Threshed wheat straws were used as a reinforcement agent, which is commonly available after separating the wheat from the straw using thresher machines. Wheat Straw (WS) is the agricultural by-product. WS is rich in cellulosic fibres, hemicelluloses, proteins, lignin and ash[20]. The index properties of wheat straw were determined and are summarized in Table 2.

2.3 Lime

Powdered lime is used, which is obtained after crushing lumps of limestone. For a selection of lime, it is very important to know its chemical composition. The chemical composition of the lime studied in this manuscript is being presented in Table 3.

Table 1. Index and physical properties of soil

Description	Value
Percentage Passing No. 10	99.2
Percentage Passing No. 40	98.2
Percentage Passing No. 200	96.5
Plasticity Index, (IP)	7.77
Liquid limit (LL)	23.85
Plastic limit (PL)	16.08
Shrinkage limit(SL)	13.14
Specific Gravity	2.600
USCS Classification	CL-ML
Percentage of sand between No. 4 to No. 200 sieve	3.45%
Silt size, 0.074 to 0.005 mm	48.88%
Clay size, smaller than 0.005 mm	37.98%
Colloids, smaller than 0.001 mm	9.70%
Maximum dry density (KN/m3)	18.02
Optimum moisture content (%)	16

Table 2. Index properties of wheat straw

Average diameter, D (mm)	Average length, L (mm)	Specific gravity (G_s)	Water absorption ratio (WAR)	Tensile strength (MPa)
3.1	18.4	0.34-0.38	300% (After 24 hours)	10.13

Table 3. The chemical composition of lime

Constituent	Quantity
Insoluble in hydrochloric acid	0.03%
Substitutes not precipitate by NH4.ox(an SO_4)	2.5
chloride	50 mg/kg
Sulfate	500 mg/kg
Cu	5 mg/kg
Fe	500 mg/kg
Pb	2 mg/kg
Zn	5 mg/kg
CaCO3	3%

3. Experimental Setups

3.1 pH Meter for Water

PHep5 is a water pH tester with a 0.01 pH resolution and an accuracy of ±0.05 pH. This accurate pH tester features 0.01 resolutions with automatic two-point calibration and temperature compensation in a single, portable, pocket device. The testing was conducted as per ASTM D1293-18. This test method covers the precise measurement of pH in water utilizing at least two of seven standard reference buffer solutions for instrument standardization. After calibration, the pH meter is dipped into the water sample taken in a 50 ml beaker until to get a stable reading displayed.

3.2 pH Meter for the Soil

Digital soil pH meter 4 in 1 Soil Survey instrument. The instrument can test moisture of soil, pH value and temperature and environment sunlight intensity using a probe with the length of 200 mm. The unit can easily display with oversize LCD. The testing was conducted as per ASTM D4972 – 13. The test method covers the precise measurement of pH value in soil within the range of 3.5 to 9.0. The probe was pushed vertically into the soil for pH measurement. The reading displayed on screen was recorded as pH of the soil.

3.3 Muffle Furnace for Organic Content Determination

Thermolyne-Type-1300-Furnace with chamber size 4” wide, 3.75” height and 4.5” diameter and built-in control working temperature of 1900°F was used. The testing was conducted as per ASTM D2974–14. For the determination of the effect of decomposition of wheat straw on the Organic Content (OC) of soil, 100 g of wheat straw was added into 2 litres of water and a workable paste of soil was prepared. Samples from the prepared paste stored in an airtight container were taken at various time intervals to measure the organic content. For Organic Content determination, the oven dried weight was taken first and then kept in the furnace by gradually raising the temperature to 440 ± 40°C for 24 h. the sample was then taken out from the furnace and burned weight was measured. The organic content was taken as (oven dried weight-burnt weight)/oven dried weight.

3.4 TDS Meter for Water

TDS-EZ water quality tester device was used. The device is Factory Calibrated with a 342 ppm NaCl solution and designed to stay consistent having Range: 0–9990 ppm (mg/L). The testing was conducted as per ASTM D5907–10. 100 g wheat straw submerged in 2 litres of water and the TDS values of the mixture were taken on daily, weekly and monthly bases. The TDS meter was dipped in the solution and the reading was then taken after fully stabilization (taken less than 30 seconds).

3.5 Titration Test for Water Hardness

HI 3812 Hardness Test Kit was used. The hardness level was measured as mg/L (ppm) $CaCO_3$ by an EDTA (ethylene-diamine-tetra-acetic acid) titration.The low range is from 0.0 to 30.0 mg/l (ppm) $CaCO_3$ and the higher range is from 0 to 300 mg/L (ppm) $CaCO_3$. The testing was conducted as per ASTM D511–14. Test Method A-Complex Metric Titration is adopted for determination of hardness of water. The complete procedure usually comes with the catalogue.

3.6 Electrical Conductivity Test of Soil

Victor VC 60 B^+ insulation tester device modified with electrode plates of 50 mm diameter and surcharge weight of 1 kg was used. The modifications were indigenously made for the determination of electrical conductivity of soil samples. The testing was conducted as per ASTM G187-12a. Soil specimen of 50 mm diameter and 20 mm thickness was placed between the electrodes connected with the megger device. A surcharge weight of 1 kg was applied for proper seating. Working voltage of 250 V, 500 V, 1000 V, AC-750 V was selected appropriately to get the electrical resistance value in mega ohm (MΩ). The electrical resistance value was taken after stabilization (usually taking less than two minutes).

4. Results and Discussion

4.1 Decomposition of Wheat Straw

Wheat straws were placed in water and soil-water mixture for decomposition in airtight and open containers. The change in colour and odour level was observed. By the passage of time colour darkness and increase the odour level was noticed during visual observations and smelling tests respectively. The darkness in colour and increase in odour level, in turn, suggests the decomposition of wheat straw which could be due to some chemical and biological changes. Biodegradation and growth of fungal and bacteria could be one of the reasons for the change in colour and of pungent smell. From a biological perspective, this may be termed as decomposition. The other reason according to[21] could be the carbon dioxide emissions and transformation of soil carbon and nitrogen which occurs during wheat straw decomposition. According to[22] the rate of decomposition of straw is dependent on the rapid colonization by fungal species with the necessary enzyme capabilities to break down constituent compounds. The rate of decomposition and odour level also depends upon aeration which is noticed by the comparison of the samples kept in airtight and open containers. The samples kept in airtight containers indicates a higher rate of decomposition and odour generation level; similar results were reported by[23] as well.

4.2 Wheat Straw Decomposition Effects on pH of Water and Soil

A known amount of wheat straw was mixed in fully saturated soil and water for the determination of its effects on the pH value. The results of pH for water and soil were taken on daily, weekly and monthly basis. The summarized variation of pH results for water and soil are shown in Figures 1 and 2. The pH of the soil gradually increased from 5.0 to 6.6 and the pH of water gradually increased from 7.0 to 8.6 in the duration of six (06) months. Similar trends of increase in pH value were also reported in the previous studies as well[23–26]. The increase in pH is generally thought to be the result of volatilization and microbial decomposition of the organic acids and subsequent release of ammonia through mineralization of organic nitrogen sources (which are basic in nature and results in neutralization of acidic properties of water and soil); subsequently resulting to an increase in the pH of water and soil[25,26].

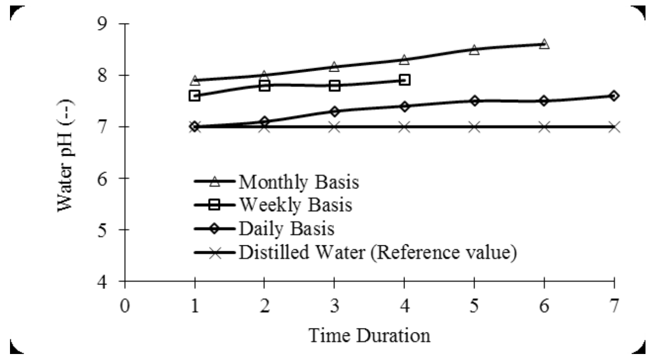

Figure 1. Effect of wheat straw on pH value of water with time duration.

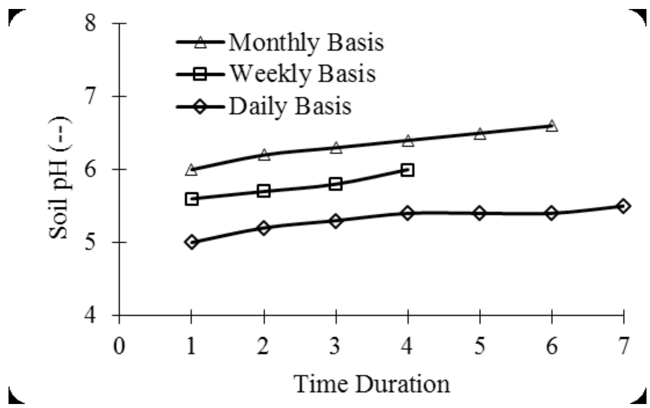

Figure 2. Effect of wheat straw on pH value of soil with time duration.

4.3 Effect of WS Decomposition on the TDS Value

Wheat straws were added to water and allowed for soaking and decomposition. The TDS value of water as a function of time was taken on daily, weekly and monthly basis. The TDS variation with respect to time is shown in Figure 3. From the figure, it can be seen that there is a gradual increase in the TDS value. The increase in TDS might be due to the decomposition and fermentation process as decomposition results in the mineralization of organic nitrogen sources[25,26]. Previous studies by[27] also reported an increase in the TDS value.

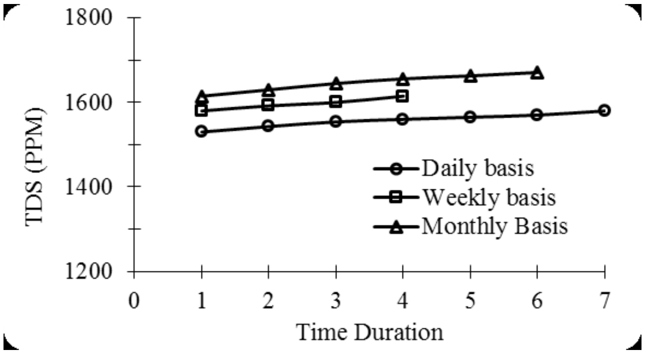

Figure 3. Effect of wheat straw on TDS value of water with time duration.

4.4 Effect of WS Decomposition on the Organic Matter Content of the Soil

The variation of organic content as a function of time is shown in Figure 4. The results indicate that there is a gradual increase in the organic content of the soil as a function of time; for example, the organic content of a soil added with wheat straw resulted to an increase of 5.7% to 8.29% in organic content for a period of six (06) months. Similar trends of increase in organic content value were also reported in the previous studies as well[28–30]. The increase in the organic content might be due to the decomposition of wheat straw; because, after decomposition the organic matters becoming the part of soil; as fundamentally, soil solids consist of minerals and organic compounds. From a mechanical behaviour perspective, increase in organic content may have adverse effects on the shear and compressibility characteristics of soil; as organic soils have the low shear strength and high compressibility[31].

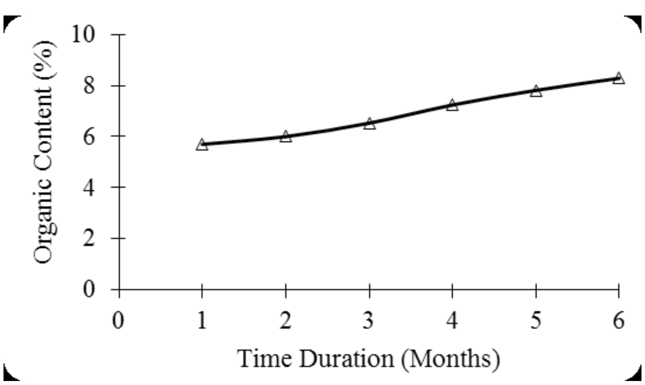

Figure 4. Effect of wheat straw on organic content of soil with time duration.

4.5 Effect of Lime on the pH of the Water

Various percentages of lime were added to tap water and pH values were observed. The results were plotted as shown in Figure 5. The results show that the rate of increase in pH is high up to 2% lime content; however, further increase in the lime resulting to no significant increase in the pH value; i.e. maximum pH saturation of water is being attended at around 2% lime content. Increase in the pH value due to the addition of lime content was also reported by[32–35]. From pH scale lime is basic in nature; therefore, resulting in the neutralization of the acidic effects that might be the reason for an increase in the pH of water. From previous literature review and present investigations, it can be seen that minimum 2% lime is required for stable water. According to[36] "Stable" water has tendency neither precipitate nor dissolves calcium carbonate ($CaCO_3$) (i.e., saturated) with respect to calcium carbonate.

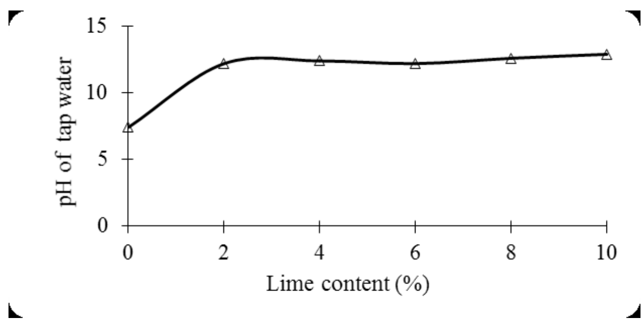

Figure 5. Effect of lime content on pH of tap water.

4.6 Effect of Lime and WS on Water Hardness

Effect of lime and WS were investigated on the water hardness, as there is little information available in the literature regarding the effect of fibres and lime on the water hardness. For this purpose, wheat straw was decomposed in water and hardness test was conducted on it; however, using titration process the hardness could not be determined, as there were no colour changes noticed during titration process. Therefore, alternative methods such as soap test kit and hard water tests were used where the titration process not worked.

Addition of lime in water resulted to decrease in the water hardness. The hardness of 100 mg/l decreased to 25 mg/l due to the addition of 2% lime in water approximately. The decrease in the water hardness might be due to the precipitation of soluble carbonates and bicarbonates to non-soluble ones. Historically lime softening has been an effective technique to remove hardness (calcium and magnesium) ions by precipitation, nevertheless, according to[37] the total hardness stays stable between 0% and 20% of lime addition and begins to decrease significantly with the increase of lime dose.

4.7 Wheat Straw and Lime Effect on Electrical Conductivity

Various percentages of lime and wheat straw were added to the soil and moulds of 50 mm diameter and 20 mm thickness were prepared. After curing and subsequent oven drying the samples were tested for electrical conductivity. For this purpose, an indigenously developed experimental setup was used as discussed in the experimental setups. The graphical representation of the test results is shown in Figure 6 and observed that the effect of lime and wheat straw on the electrical conductivity and electrical resistivity. The results suggest that there is a gradual decrease in the electrical conductivity of soil due to the addition of lime and/or wheat straw. The rate of decrease is high up to 6% lime and wheat straw contents each; however, thereafter, the rate of decrease is comparatively low. For instance, the electrical conductivity of clayey soils decreased from 1.4 mS to 0.38 mS and from 1.4 mS to 0.135 mS for lime and wheat straw contents respectively. Decrease in the electrical conductivity of soil due to the addition of lime was also reported by[38,39]. The decrease in electrical conductivity is associated with a simultaneous increase in strength and also the number of dissolved minerals hence there is a possibility of developing a correlation between strength and electrical conductivity.

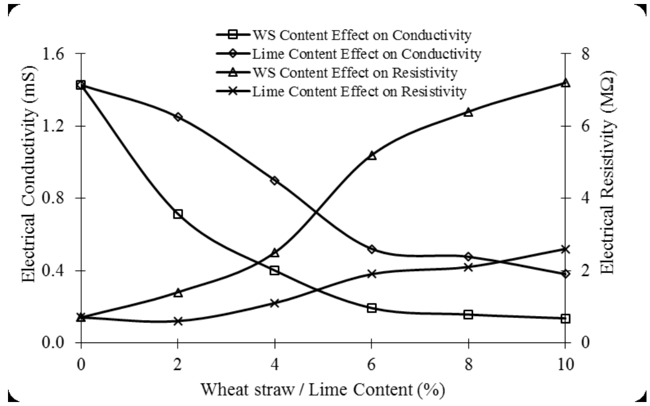

Figure 6. Wheat straw and lime effects on electrical conductivity and electrical resistivity characteristics.

5. Conclusions

From the results the following conclusions were drawn:

- There is a significant effect of lime and wheat straw (used as soil stabilizing and reinforcing agents respectively) on the chemical and biological properties of water and soil. This is evident from an increase in odour level and colour darkness due to decomposition of wheat straw in water and soil, increase in pH due to lime and wheat straw, increase in the TDS of water due to wheat straw decomposition, decrease in the water hardness due to lime, an increase in the organic matter content due to addition of wheat straw into soil.
- As soil stabilization is a physical, chemical, biological or combined method of changing a natural soil to meet an engineering purpose, hence apart from physical changes the chemical and biological changes are supposed to be the major factors controlling the stabilization mechanism. Therefore, the stabilization process may also be controlled through chemical and biological changes.
- A single soil stabilizing agent may not be sufficient to improve several engineering properties; because stabilization does not necessarily improve all engineering properties for better as is seen in present studies. Therefore, combined soil stabilization techniques might be adopted for a wider range of soil improvement where necessary.

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