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Strength and Microstructural Behavior of Expansive Soil Treated with Limed Leather Waste Ash

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Abstract*: Expansive clays are one of the most widely found soil type across the globe known for their low strength behavior. A number of studies have been conducted in the past few decades to stabilize such soils using various additives. The traditional stabilizers such as cement and lime not only prove quite costly due to their high industrial demands but also result in exhaustion of the available natural resources. This study is based on admixture of a waste originating from leather industry known as limed leather waste which can be utilized as a potential stabilizer and strength enhancer for expansive clays at the construction sites as a replacement to conventional additives. The utilization of the waste besides treating the problematic soil will also solve the dumping issue of the waste itself and will reduce the environmental hazards. It is found from the study that the waste when used in the ash form is capable of improving the compaction and strength characteristics of the expansive soil substantially. A comprehensive increase in soil strength is also achieved through curing. The SEM results are used to explain the microstructural changes in the soil and agglomeration and generation of silicate gel compounds responsible for increase in strength of the soil-ash mixture.

Keywords: Expansive soil, Limed Leather waste, UCS, Curing, SEM.

I. INTRODUCTION

The expansive clays are one of the most widely found soils across the globe. Expansive clays have produced various challenges to the civil engineers due to their unfavorable engineering characteristics such as high swelling and low strength behavior. The expansive clays are also known to produce cracks and deformation in the superstructure as they settle down heavily on account of their low bearing capacity. The engineering anomalies of expansive soils originate from their mineralogical structure. Most of the highly expansive soils contain a high proportion of vermiculite or smectite minerals.

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Montmorillonite is the most common of smectite group clay minerals having high exchange capacity due to their ability of undergoing isomorphous substitution which increase their affinity towards water and give rise to expanded structure having lower intersheet strength. Past researches show that the affinity of soil towards water may be reduced by supplement of various cationic admixtures [23-25, 33].

Industrial wastes on the other side have given rise to various environmental hazards by polluting the land, air and water resources besides their dumping issues and costly land demands. Leather industry is also one of the most commonly found and pollution causing industries giving rise to a variety of wastes with a minimal or no utility thereafter. Around 20000 tonnes of solid waste is produced by leather tanneries per day and about 6 million tonnes annually around the globe of which 0.3 million tonnes is generated from India itself [30]. Majority of these wastes are either dumped into a landfill without or after incineration [1, 21] or are sent to treatment plants for digestion [26]. But the chemical processes at various stages involved in preparation of tanned leather impart calcium, chromium, iron, potassium, sodium, aluminium and other elements into the waste materials which make these wastes difficult to handle and readily digestible [22]. The open dumping of waste in raw or ash form pollutes the air and water resources and requires costly land acquisitions. The present study is based on the utilization of a tannery industry by-product called limed waste as an expansive soil stabilizer produced after lime soaking process of the hides. It is established from the study that the limed waste after incineration possess the stabilizing characteristics of lime and can be used for strength enhancement of expansive soils.

II. LITERATURE STUDIES

Soil stabilization has emerged as an important part of ground improvement technique. The efficiency of additives as physical and chemical stabilizers have been well proven by various past researches [20,29] due to their ability to modify the soil at microstructural level. The initial methods of chemical stabilization included blending of cement[28] or lime[2-3,15-17] or both[23,37] with the expansive clays which are now partially or fully replaced by various agricultural and industrial by-products due to high industrial demands and increasing cost of conventional stabilizers. In the recent past, a number of additives have been tested and recognized as soil stabilizers which are industrial wastes or by-products [14].

A number of researches are available in the literature based on calcium and silica based industrial and agricultural wastes used as soil stabilizers. Solanki and Zaman (2012) [35] treated the expansive soil with a variety calcium based stabilizers such as hydrated lime, Portland cement, cement kiln dust (CKD) and class-C fly ash(FA).

The study concluded that the emergence of cementitious products demands containment of silica in the soil and their content is dependent on the amount of free lime present in the additive which is maximum in case of lime. Sabat (2014) [31] used an agricultural waste called rice husk ash (RHA) as a pozzolanic additive rich in amorphous silica along with a paper manufacturing waste called lime sludge as a binder for stabilization of soil. The CBR of soil was found to increase to 2.82% from 1.92% for 10% RHA mix which further enhanced to 8.71% with the addition of 15% lime-sludge post 28 days curing. It was established from Consolidated Undrained triaxial test that RHA decreased the cohesion of clay and increased its angle of internal friction whereas lime sludge increased both the parameters with the increasing curing period. Kumar and Janewoo (2016) [24] tested two different stabilizers, cement kiln dust(CKD) and RBI Grade 81 to treat the expansive soil at subgrade level. It was observed that simultaneous use of both the stabilizers increased the UCS from 88.3 to 976 kN/m^2 and CBR from 1.65 to 21.7%. The UCS also increased multifold post curing at various mix proportions of the additives. The formation of cementitious products like Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH) were explained through SEM and EDS spectra. Shukla and Parihar (2016a) [34] used a calcium containing granulated blast furnace waste called micro-fine slag with black cotton soil and tested the mix with respect to various soil parameters. The study showed that the waste reduced the liquid limit, plasticity index and swelling potential of the soil substantially and modified the soil from a highly plastic, high swelling material to a low plastic, low swelling material. It also increased its unconfined compressive strength and CBR values to almost 400% of the initial one.

III. MATERIALS AND METHODS

The soil procured for the testing is a black cotton soil (BCS) taken from Guna, Madhya Pradesh located in Central India. The soil was brought after being dug from a depth of 50 cm to reduce any contamination from surroundings. The soil properties tested as per Indian standard codes [4-13] are shown in Table 1.

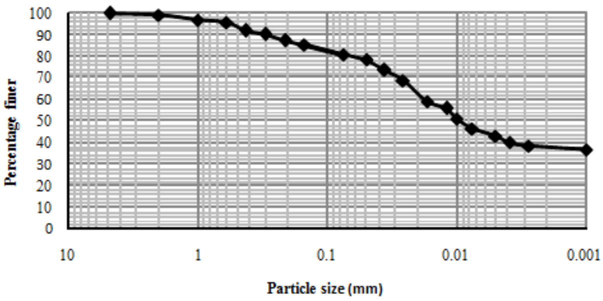

Fig. 1. Grain size distribution of untreated soil

Fig.1 shows the grain size distribution of the soil as obtained from wet sieve and hydrometer analysis. More than 80% of the soil particles are finer than 75 micron and almost 38% of the soil particles belong to clay fraction. The soil was classified as highly plastic silt (MH) as per IS classification system. The soil can be referred to have a low bearing capacity and high swelling potential based on the unconfined strength, plasticity index and clay fraction [36].

Table- 1: Engineering properties of untreated soil

Properties	Value	Properties	Value
Liquid limit (%)	69	Sp.Gravity	2.65
Plastic Limit (%)	40	MDD (g/cc)	1.80
Shrinkage limit (%)	9.37	OMC (%)	21.78
Plasticity Index (%)	29	UCS (kN/m^2)	114
Unsoaked CBR (%)	10.83	Soaked CBR(%)	2.36
Free Swell Index	40-50%	Swell Pressure (kN/m^2)	420

The limed leather industry waste also known as liming waste or lime fleshing waste [27] was procured from drying landfills at Jalandhar tannery area in Punjab. The limed waste was initially heated under a high temperature gas flame for achieving the fire point to imitate the burning conditions at the boiler or incineration site and then the waste is left to burn on its own under open oxic conditions until its conversion to ash form. Due to containment of high amount of organic matter, the waste releases large amount of heat energy during self exothermic burning of 15 to 20 minutes. Previous studies on the waste have also mentioned its efficiency as a good fuel material [18-19]. The waste lost about 75% of its initial weight on burning as oxidized organic matter. The cooled off ash was pulverized and passed through 600 micron sieve to eliminate any unburnt material.

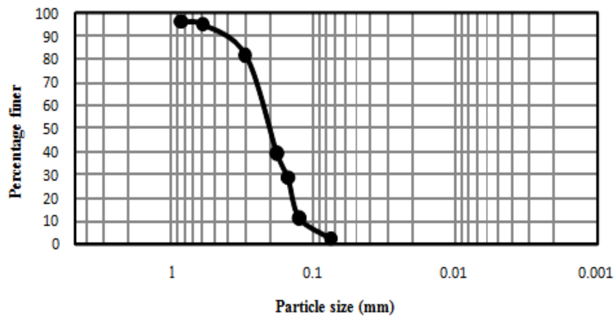

Fig. 2. Grain size distribution of LLWA

The grain size distribution of the used ash (Fig.2) indicates the granularity of the ash particles. The major chemical components of the ash as determined from X-ray Fluoroscence (XRF) are given in Table 2 which shows that the ash contains a good proportion of both lime and silica components required for stabilization of soil.

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The objective of the study is to utilize the leftover waste ash as soil stabilizer after incineration of raw limed waste as a fuel material which at present is dumped into the landfills along with other tannery waste after extracting their calorific heat [32, 38].

Table- 2: Major chemical components of LLWA

Components	Concentration
CaO	21.12%
SiO_2	17.74%
Na_2O	35.29%
Fe_2O_3	1.12%
MgO	1.0%

IV. EXPERIMENTAL PROGRAM

The procured expansive soil was kept in close containers to preserve its natural state. The soil has been initially tested at original state for its compaction parameters and unconfined compressive strength (UCS) and same tests were repeated with the waste-soil mix with limed leather waste ash(LLWA) mixed in proportions of 2% to 10% with additive increments of 2%. The waste ash was mixed with the soil in dry state in the required proportions of the dry weight of the soil until the attainment of uniform texture and color before performance of the tests. The water was then added to the dry mix as per the requirement of the test to form a workable slurry. All the tests were conducted as per Indian Standard codes. The optimum moisture contents (OMC) were obtained through proctor compaction test for various mix proportions before conduction of the strength tests. For UCS tests, the test samples were derived through steel tubes after proctor compaction in three equal layers of plain soil and soil mix keeping the moisture level at respective OMC of the mix to have uniformity in the compaction effort of various samples. The UCS tests were performed at a strain rate of 1.25 mm/min immediately after obtaining the samples and after 4 and 28 days of sample curing. An average value of maximum compressive strength of the two tested samples at same mix proportion was referred as unconfined compressive strength of the mix. Scanning Electron Microscope (SEM) analysis of the plain soil and ash mixed samples is shown at the end for the realization of the transformation in the soil at the microscopic level.

V. RESULTS AND DISCUSSION

A. Compaction Parameters

The proctor compaction was performed for various proportions of waste ash content. The variation of dry density with moisture content is shown in Fig. 3. It can be observed that the slope of the graph at dry side of optimum has became flatter with the increasing proportion of waste ash and is nearly flattish for 10% LLWA content which shows the decreasing role of water for densification of mix. The variation of optimum moisture content (OMC) and maximum dry density (MDD) are given in Table 3. The maximum dry density (MDD) of the mix showed enhancement till LLWA content of 6% where it attained the highest value of 1.98 g/cc from initial MDD of 1.8 g/cc for plain black cotton soil but the trend reversed with further addition of additive. The immediate increase in MDD is due to the agglomeration and cementation effect produced by the waste ash containing high concentration of calcium oxide.

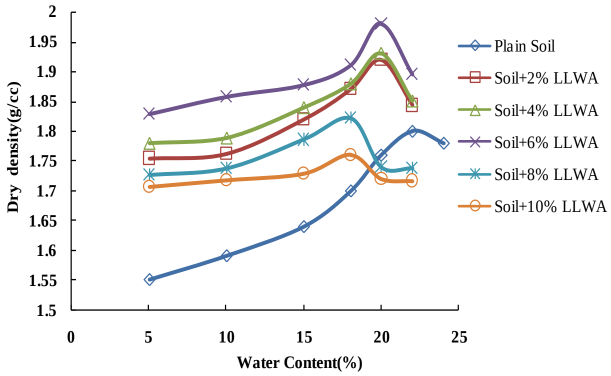

Fig. 3. Variation of dry density with moisture content for different LLWA contents

Table- 3: Variation of compaction parameters with LLWA content

Sample	MDD (g/cc)	OMC (%)
Plain Soil	1.87	21.78
Soil+2% LLWA	1.92	20.75
Soil+4% LLWA	1.93	20.65
Soil+6% LLWA	1.98	20.4
Soil+8% LLWA	1.82	18.92
Soil+10% LLWA	1.75	18.78

Diamond and Kinter (1965) [17] reported the decrease of dry density of soil during addition of lime due to deposition of calcium hydroxide in the soil voids. The initial increase of density with LLWA therefore may be attributed to packing effect of ash particles with clay which might have helped to form a dense cohesive matrix. The SEM image also clarifies the densification of mix due to reduction of voids in the soil. Though, addition of low specific gravity waste ash beyond 6% lowered the combined density of the mix. The excessiveness of calcium hydroxide might also be a cause for such reduction. The OMC showed a receding trend throughout despite the increasing hydration requirements to form calcium hydroxide and at 8% of the LLWA content, the OMC attained a minimum value of 18.9% compared to OMC of 21.78% for plain soil.

B. Strength

The test samples for UCS test were derived through proctor compaction method as explained earlier and were tested immediately after preparation of sample and after 4 and 28 days curing under controlled humid conditions. The stress and strain relationship for the uncured and cured samples derived through UCS test is shown in Fig.4 and Fig.5 for 4 day and 28 day curing period respectively and the peak compressive strengths thus obtained are shown in Table 4. It is noticeable that the both the peak stress and peak strain are delayed with the increasing content of LLWA due to continuous increase in the elastic modulus of the mix.

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The compressive strength also enhanced with the rise in additive content and an increase of 40% was achieved with 10% content of the additive immediately after mixing. The failure strain further increased with the curing of the samples.

There was also a significant rise in UCS post curing on account of formation of Calcium Silicate Hydrate (CSH) gel and calcium hydroxide promoting agglomeration of the soil particles and hence increased shear strength. The CSH gel is formed by the reaction of calcium hydroxide present in the waste ash with the silicates present in the soil minerals and the waste itself in the presence of water. An increase of about 77% in UCS was observed with 10% additive post 4 days curing which further enhanced to 150% after 28 days of curing. Although, the relative rise of strength post curing was not significant beyond 6% concentration of additive for both the curing periods.

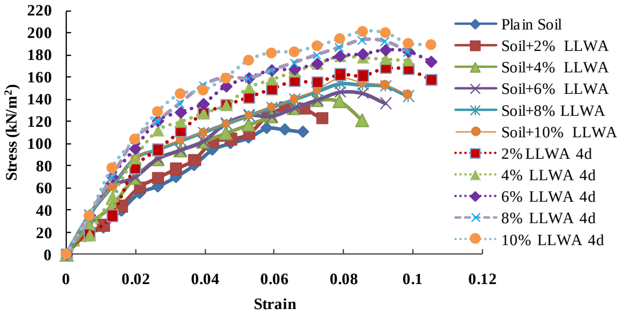


Fig. 4. Stress vs strain relation for uncured and 4 day cured soil mix

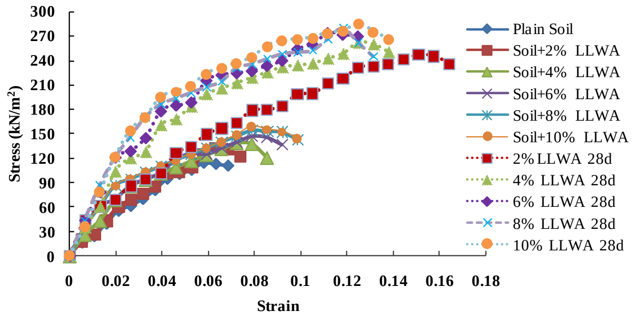


Fig. 5. Stress vs strain relation for uncured and 28 day cured soil mix

Table- 4: UCS of uncured and cured LLWA treated samples

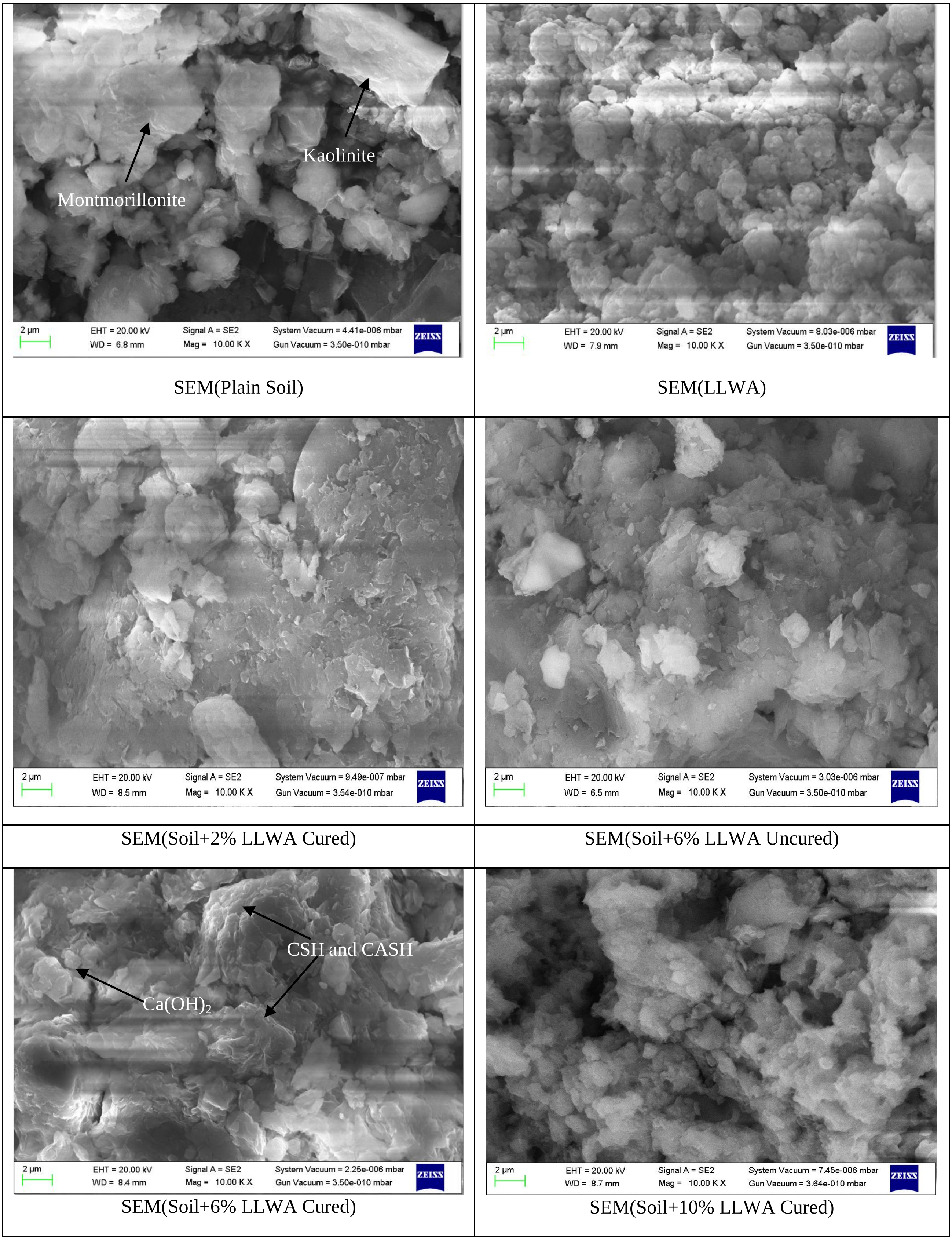
Sample	UCS (kN/m^2)		
	Uncured	4 d cured	28 d cured
Plain Soil	114		
Soil+2% LLWA	124	168	247
Soil+4% LLWA	132	179	262
Soil+6% LLWA	138	184	274
Soil+8% LLWA	147	194	280
Soil+10% LLWA	149	202	285

C. Microstructure

The SEM study(Fig.6) was conducted on plain expansive soil samples and the waste mix samples in cured and uncured state. The SEM analysis of plain soil shows the presence of montmorillonite with flat and thin sheets and kaolinite having hexagonal sheets as the major minerals in soil. The micro image of waste ash display the appearance of polygonal particles of calcium hydroxide in the waste. It can be observed that the orientation of particles in plain soil is random with presence of large volume of voids. The same transforms to a more oriented and dispersed pattern with continuous reduction in the voids with the increase in additive content. The formation of silicate gel can be observed as the formation of cloud like patterns which increases with the increase in LLWA content and also with the curing effect.It may be noticed that the original structure of soil has dissolved to a new transformed and compacted matrix due to the action of calcium hydroxide particles and generation of CSH gel.The structural transformation and agglomeration increased both with the additive content and the curing time. The 10% cured sample SEM presents excessiveness of calcium hydroxide and ash particles which is not evident at 6% cured and uncured sample images. This might be the reason behind achievement of maximum density of the mix at 6% LLWA concentration.

VI. CONCLUSIONS

The study shows the potential of limed leather waste ash for improvement of compaction and strength of the expansive soil.It is found that the waste ash has the capability to form a compact matrix with the expansive clayey soils which helped to improve the density of the mix.The maximum dry density increased initially on LLWA mixture contrary to the trend of lime treatment.The soil mix attained its maximum density at 6% additive content which decreased with the excessiveness of the ash particles in further additions of the waste ash. The OMC of the mix also experienced a continuous downfall despite the hydration requirements of the mix.There was a substantial increase in the unconfined compressive strength with and without curing of the mix with the maximum strength achieved at 10% additive concentration in both cases. The immediate compressive strength rose by almost 40% in uncured state and by 77% and 150% for curing periods of 4 and 28 days respectively as compared to the UCS of the plain soil sample.The primary reason behind rise of the strength was generation of the CSH gel resulting in agglomeration of the particles of the soil mix. The SEM analysis showed the presence of montmorillonite and kaolinite as major minerals in the soil.The SEM results further confirmed the formation of CSH gel due to reaction of lime present in the ash and silica content of the clayey soil which increased with the additive content and also with the curing of mix. Therefore, it may be estabilished from the study that the LLWA contains stabilization characteristics of lime and it can be well utilized to counter the low strength of expansive soils which will also reduce the major dumping problems of the leather industry.



SEM(Plain Soil) | SEM(LLWA)

SEM(Soil+2% LLWA Cured) | SEM(Soil+6% LLWA Uncured)

SEM(Soil+6% LLWA Cured) | SEM(Soil+10% LLWA Cured)

Fig. 6. SEM results

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