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Contents

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Effect of Curing on Compressive and Shear Strength Parameters of Liming Waste Ash Stabilized Expansive Soil

Niraj Singh Parihar and Ashok Kumar Gupta

Abstract The expansive soils are known for their low compressive and shear strength and they present numerous challenges to geotechnical engineers during infrastructural development. The study is an effort to examine the utility of a leather industry waste product known as liming waste ash for enhancement of the compressive and shear strength of the soil. The effects of different curing periods on the relative parameters of strength have also been discussed. It was found that the curing of the soil-ash (LLWA) mix promotes the development of bond strength through formation of pozzolanic cementitious products and augments the shear strength parameters and the unconfined compressive strength (UCS) of the soil. An improvement of 270 and 380% was found in the UCS and cohesion of the soil respectively post 28 days of curing period along with substantial rise of internal friction angle up to 7 days of curing. The influence of LLWA and curing duration on the soil fabric and its relative effect on various strength parameters have also been explained at the microstructural level through SEM analysis on the uncured and cured soil samples.

Keyword Expansive soil · Liming leather waste ash · Chemical stabilization · UCS · Shear strength · SEM

1 Introduction

Expansive soils are one of the most found soils across the globe known through various names such as black cotton, vertisol, udert, etc. and they have been one of the most problematic soils to be used as foundation and subgrade material in building and road construction due to their high expansive mineral content such as montmorillonite. A high proportion of such minerals give rise to high electronegativity and

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water absorption capacity to the soil leading to its reduced bearing capacity and high swell-shrink characteristics. In India, the huge land masses layered with the weathered basaltic plateaus and lava traps have resulted in formation of the black cotton soil which covers more than one-fifth of the geographical area and is abundantly found in central, western and southern Indian states [1, 2]. Such large areas covered by expansive soil when brought under infrastructural development, offer very less alternatives of costly base-soil replacement and soil stabilization proves as one of the best techniques to make these soils fit as a decent bearing material.

Chemical stabilization is a widely practised technique to counter the unwanted characteristics of expansive soils. A number of industrial and agricultural by-products have emerged as useful products in the recent past with capability to stabilize expansive soils. These waste products contain similar pozzolanic or binding characteristics as are found in the conventional chemical soil stabilizers such as lime and cement and their use as a soil stabilizer not only creates an alternative for replacement of the costly and pollution causing conventional construction material but also solves the dumping and environmental related issues related to these wastes. A wide number of researches have been done on the utility of these wastes as chemical modifiers of soil including industry originated wastes such as phosphogypsum [3], cement kiln dust [4, 5], marble dust [6], silica fume [7], fly-ash [5, 8], slags [2, 9], quarry dust [10], lime-soda glass powder [11], lime sludge [12, 13], etc. and silica containing agricultural wastes such as corn ash [14], groundnut shell ash [15], bagasse ash [16], rice-husk ash [12], wheat-husk ash [17], etc. or a combination of both [18, 19].

The leather processing industry is one of the oldest in the world. The leather industry has seen an overwhelming growth in the recent past due to increase in demands for its finished products. It is also among the top export industries in India with Indian leather exports crossing 5.5B USD [20]. With more than 6 million tonnes of leather waste production worldwide, India and China together share more than 25% of this waste produce [21]. It is one of the industries with the highest waste to raw product fraction of 60–80% containing numerous environmental pollutants originating from its chemical processes. However, the waste originating from the industry finds no or little use and has to be either dumped or sent for digestion [22, 23]. The earlier researches have shown their concerns on these methods of waste disposal as this waste dumping is environmentally hazardous and the waste matter is not easily digestible and generates greenhouse gases [24]. The incineration of this waste has therefore been suggested as the adaptable method by many of the researchers due to high calorific value of the waste [25, 26] and the same is practised by many countries nowadays. But despite the volume reduction of the waste after burning, a lot of waste ash still has to be disposed of in the landfills with or without treatment which can promote degradation of land and water table.

Liming waste coming from beam-house operations in the leather processing industry accounts for a sizeable proportion of the total produced waste and is only scarcely utilized for making glue and gelatin-like products. Parihar and Gupta [27, 28] conducted research over the utilization of lime-fleshing or liming leather waste ash (LLWA) for stabilization of expansive soil and established that the residual waste

3 Experimental Program

The black cotton soil dug from the open field was collected and sealed in airtight containers to conserve its native state till the time of testing. The virgin soil was first subjected to laboratory determination of engineering properties such as unconfined compressive strength (UCS) and shear strength parameters and the same tests were repeated through various soil-LLWA mix proportions under different curing periods. The LLWA was mixed in the proportions of 2, 4, 6, 8 and 10% by weight of the soil. The soil and waste ash were first dry mixed to uniformity until formation of a homogenous mix followed by addition of a requisite amount of water for slurry formation and sample preparation for all tests. All the experiments for plain and LLWA mixed soil were conducted as per the recommendations of Indian standard codes. The samples for UCS and unconsolidated undrained triaxial test were simultaneously prepared by using same slurry mixture in the previously defined mix proportions as per IS: 2720 (Part X)-1991 [30] and IS: 2720 (Part XI)-1993 [31] respectively. The soil samples for both the tests having 38 cm diameter and 76 mm height were derived through sampling tubes driven in the proctor mould compacted under standard proctor compaction procedure recommended by IS: 2720 (Part VII)-1980 [32] for equality in imparted energy levels. The moisture content during proctor compaction of soil-LLWA mixes was kept a little above the optimum moisture level of the mix to compensate for the water required for hydration reaction. The obtained samples were divided into four groups for examining the effects of different periods of curing. The first set was tested immediately after the derivation of samples whereas the other three sets were tested after curing the samples for a period of 4, 7 and 28 days respectively under very high humid conditions as explained by Parihar and Gupta [28]. A strain rate of 1.25 mm/min was followed for all the compressive and shear strength tests. An average value of at least two UCS samples tested for each mix type has been taken as final. The SEM study has been conducted on the readily mixed samples, uncured samples and samples derived after various curing periods to examine the effect of additive proportion and curing time on soil structure at a microscopic level.

4 Results and Discussion

4.1 Uncured and Cured Compressive Strength

The behaviour of soil strength with respect to curing period is accessed through an unconfined compressive strength test. The samples of dimension 38 mm diameter and 76 mm height derived through proctor compaction test were used for the study. Samples of plain black cotton soil were tested immediately after extrusion of soil samples while the LLWA mixed samples were tested both immediately after derivation and also after different curing periods of 4, 7 and 28 days. The curing periods were decided on the grounds of time required for electronegative charge stabilization of soil, generation of compounds of cementation and initial gain of strength respectively. The effect of curing on UCS of soil with different LLWA contents is shown in Fig. 2a and the respective increase in UCS(ΔUCS) with respect to the UCS of untreated soil specimen (UCS_i) is shown through a dimensionless ratio ($\Delta UCS/UCS_i$) in Fig. 2b.

It was observed that the strength increase was continuous both with the addition of LLWA and with the progression of the curing period. A nominal strength gain was also noticed immediately after mixing the waste ash which was mainly due to the formation of cohesive matrix and particle packing effect as the soil and the waste ash exhibit different grain size characteristics. Further, with the increment of the curing duration, the calcium silicate compounds (calcium silicate hydrate (CSH) and calcium aluminate silicate hydrate (CASH)) continued to form with the chemical reaction of silica and aluminium in the soil and ash and calcium oxide in the ash in

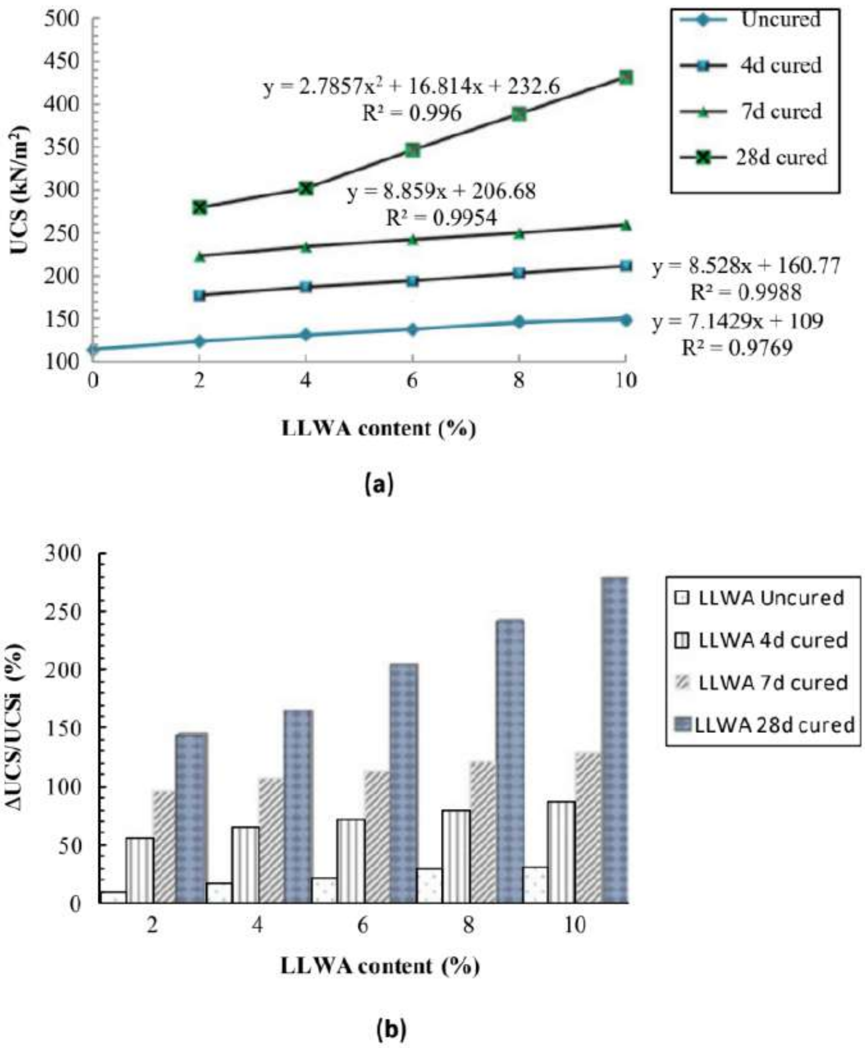

Fig. 2 **a** Relationship of UCS with LLWA content and curing period, **b** % rise in cured UCS w.r.t. untreated UCS

the presence of moisture which substantially increased the strength, particularly after 7 days of curing. A more than 270% increase in the UCS was observed with highest additive addition post 28 days of curing. It is interesting to note that the behaviour of UCS with LLWA content is almost linear with a high degree of correlation coefficient for uncured UCS specimens and cured specimens of 4 and 7 days whereas a parabolic increase in strength was observed for 28 days cured specimen. The extreme rise in this strength gain is due to complete formation of the silicate gels after 7 days of curing which provided the bonding between particles thereafter.

4.2 Shear Strength Parameters

The undrained shear parameters, i.e. cohesion and internal friction angle for each sample mix and for all defined curing periods were derived from the failure envelope obtained through unconsolidated undrained (UU) triaxial test performed at low confining pressures of 50, 100 and 200 kPa. The effect of waste addition and curing on angle of internal friction and cohesion are shown in Fig. 3a, b respectively. It is clear that the LLWA addition has an incremental effect on both the parameters as a consequence of the combined effects of granular material addition and its capacity to produce agglomeration between particles. This agglomeration is generated on account of the chemical reaction between calcium ions and electronegative silica mineral sheets and the bonding provided by silicate gel which increased both cohesion and internal friction. It can also be noticed that the effect of waste on cohesion is more pronounced as the cementation between particles enhanced progressively with the addition of waste and higher curing time. The rate of cohesion rise also increased after 7 days of curing due to full establishment of strength yielding calcium silicate gel and peak cohesion of 260 kPa was achieved as compared to 54 kPa of untreated soil cohesion post 28 days of curing time. However, the effect of waste on internal friction angle was limited to a certain extent as addition of LLWA beyond 6% concentration decreased this parameter at all curing periods. This may be due to cationic repulsion and lack of frictional effect between the ash particles in case of their excessiveness. It was also observed that the internal friction stabilized after 4 days of curing time and reduced beyond 7 days of curing. This probably has occurred due to the achievement of full electroneutrality till the former period which would have helped coalescence of the particles leading to maximum increase in the internal friction angle. Although, the presence of excessive gel formation between soil and ash particles at the latter period would have led to the reduction of particle to particle contact and hence the internal friction did not experience much appreciation at this curing period and beyond. But overall, cementation and cohesion had a dominating effect at even highest concentrations of additive and at all curing periods which also led to a continuous gain of UCS despite the decrease in the internal friction.

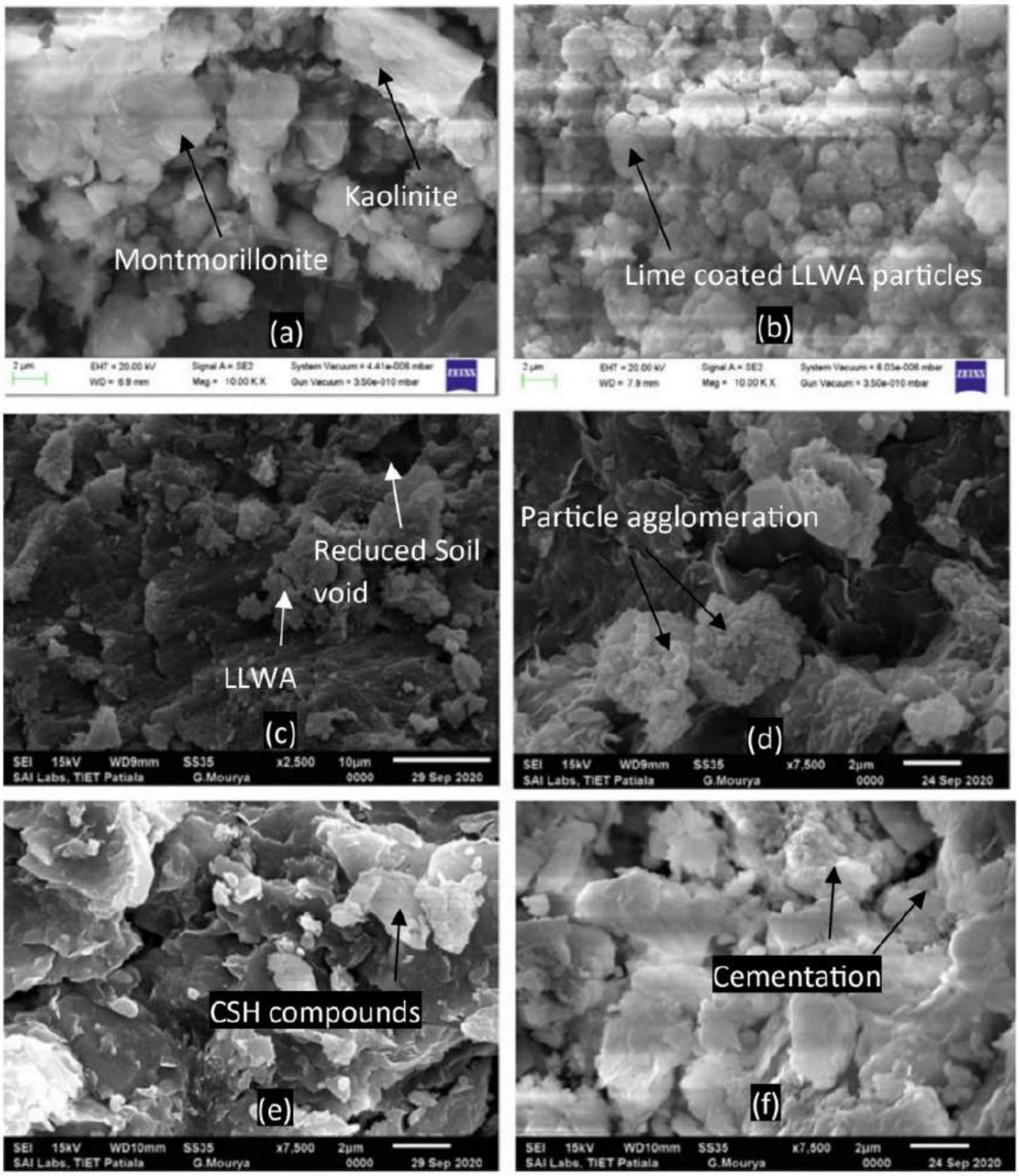

Fig. 4 SEM images for **a** untreated soil, **b** LLWA, **c** uncured mix, **d** 4 day cured mix, **e** 7 day cured mix, **f** 28 day cured mix

particularly beyond 4 days of curing period where the original crystalline structure of the soil was modified and dissolved into the compact cementitious structure of CSH and CASH gel formation. A well-developed silicate gel formation was visible after 28 days of curing period with the particle void spaces completely filled with cementitious compounds. This improved gel formation was the reason behind a sharp increase in UCS and cohesion of the mix at late periods of the curing led by an increased bond strength and cementation between particles. However, the gel structure reduced the particle to particle contact and decreased the overall friction which appeared as a reduced internal friction angle in the UU test results.