Thermal characterization of lime stabilized soils

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Abstract
In this paper, the time-dependent changes induced in the thermal properties of lime treated bentonite comprised mainly of montmorillonite mineral and a tropical lateritic soil rich in iron oxide were investigated. The thermal gravimetric analysis (TGA) indicated that evaporation of the adsorbed surface water was the main reason responsible for the weight losses observed in the lower temperature regions. Nevertheless, in 8 months cured bentontie samples, a new drop at around 285ºC due to the evaporation of moisture encapsulated into the reaction products was evident. Also, it was found that in laterite clay mix designs, lime treatment had a marginal impact on the thermal properties of the soil. From geotechnical point of view, the stabilization technique was far more effective in improving the strength properties of bentonite soil over the 8 months curing period.

Key Words
Bentonite, lateritic soil, lime stabilization, thermal properties

Introduction
Thermal analysis involves a dynamic phenomenological approach to the study of soils by observing its response to a change in temperature. The results for this type of analysis can be obtained in three different ways, i.e., thermal gravimetric analysis (TGA), differential thermal analysis (DTA), and derivative thermal gravimetric (DTG) analysis. For clays, endothermic reactions involve desorption of surface H_2O, dehydration at low temperatures, dehydroxylation and eventually melting at more elevated temperatures. Exothermic reactions are related to recrystallization at high temperatures that may be nearly concurrent with or after dehydroxylation and melting (Guggenheim and van Groos, 2001).

Throughout these years considerable research has been carried out in studying the effect of traditional stabilizers such as lime on engineering properties of the soil (Locat *et al*., 1990; Bell, 1996; Narasimha Rao and Rajasekaran, 1996). However, publications on the thermal characteristics of lime treated soils have been limited. In the present paper an attempt was made to study the effects of curing time on the thermal properties of lime stabilized soils.

Materials and experimental programme

Materials
In this research, a native tropical soil (i.e., laterite clay) was used for laboratory experiments. The more important features of this soil are as follows:

a) Noticeable acidic nature (pH= 4.86).

b) High amounts of free iron oxides (The main cause of its reddish colour).

c) High specific surface area value.

d) Presence of kaolinite as the dominant clay mineral.

In addition, bentonite comprised mainly of sodium-montmorillonite was used in this investigation as reference sample. The bulk soil was purchased in 50 kg bags from Wyoming (United States). The engineering properties and chemical composition of untreated soil are presented in Table 1.

Table 1. The engineering properties and chemical composition of the natural soil.

ENGINEERING PROPERTIES	**VALUES**		**CHEMICAL COMPOSITION (Oxides)**	**VALUES (%)**	
	LC*	**GB***		**LC**	**GB**
CEC (meq/100 g)	14.88	78.79	**SiO_2**	21.55	60.79
pH (L/S = 2.5)	4.86	9.03	**Al_2O_3**	24.31	21.20
Specific Gravity	2.75	2.64	**Fe_2O_3**	29.40	6.46
Liquid Limit, LL (%)	75.8	301.60	**Na_2O**	0.07	6.14
Plastic Limit, PL (%)	39.60	41.80	**K_2O**	0.11	(-)
Plasticity Index, PI (%)	36.20	259.80	**P_2O_5**	16.71	(-)
BS Classification	MH	CE	**SO_3**	3.98	(-)
ICL (%)	5.00	7.00	**CO_2**	3.65	1.19
Maximum dry density (Mg/m^3)	1.33	1.27	**MgO**	(-)	3.26
Optimum moisture content (%)	34.00	37.70	**CaO**	(-)	0.96
UCS (kPa)	288.10	281.30	**Soluble P (ppm)**	0.40	0.50
Loss of ignition (%)	6.32	(-)*	**Soluble Al (ppm)**	0.05	250
* LC: Laterite Cay, GB: Green Bentonite			**Soluble SiO_2 (ppm)**	0.10	40
(-): not detected.			**Soluble Ca (ppm)**	0.10	0.04

Preparation of specimens

The full-scale testing samples were prepared and cured in a similar manner to that described in the British Standard (BS 1924: Part 2: 1990). Based on the previous studies conducted on lime stabilized soils (Bell, 1996), two percentages of lime (i.e., 3% and 7%) by weight of the dry soil were chosen for this investigation.

Testing program

A TGA/SDTA851 instrument which is a modern device for TGA and simultaneous difference thermal analysis (SDTA) of materials was used in this study. This technique is based on monitoring the weight loss of the material during a controlled heating process in a defined gas atmosphere. Hence, small amounts of the sample was placed in an aluminum crucible under N_2 gas atmosphere with a flow rate of 10 mL/min and analyzed up to 850ºC at a rate of 10ºC/min.

Results and discussion

Figure 1 shows the thermal gravimetric curves of natural and 8 months cured lime treated bentonite and lateritic soil. As can be seen, soil dehydration covered the lower temperature regions. This weight loss was due to the evaporation of the adsorbed water on the surface and inter-layer of clay minerals. In laterite clay samples, considerable amount of organics were also present. The weight loss at temperatures around 300°C was due to this phenomenon. The losses at temperature ranges between 450ºC and 650ºC observed in all mix designs was due to the dehydroxylation of clay minerals (Guggenheim and van Groos, 2001). On the other hand, evaluation of the TGA results for the 8 months cured lime mix designs revealed a new drop at around 285ºC for bentonite samples. The latter was caused by the evaporation of moisture encapsulated into the cementitious compounds. In Fig. 2, the unconfined compressive strength of 3% and 7% lime treated soils after 1, 4, and 8 months of curing are shown. As can be seen, an increase of approximately 11-fold in the strength of lime treated bentonite in comparison to the natural soil was obtained.

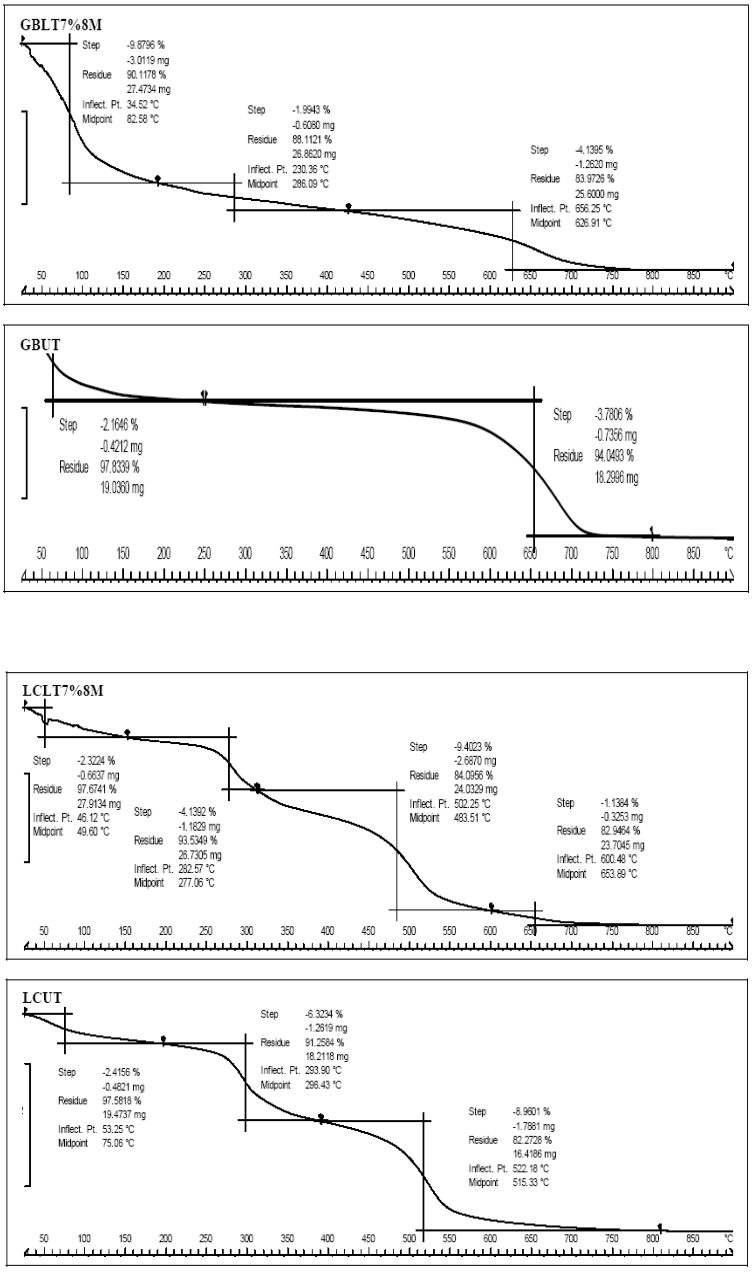

Figure 1. TGA spectrums of natural and 7% lime treated bentonite (Top) and laterite (Bottom) after 8 months of curing.

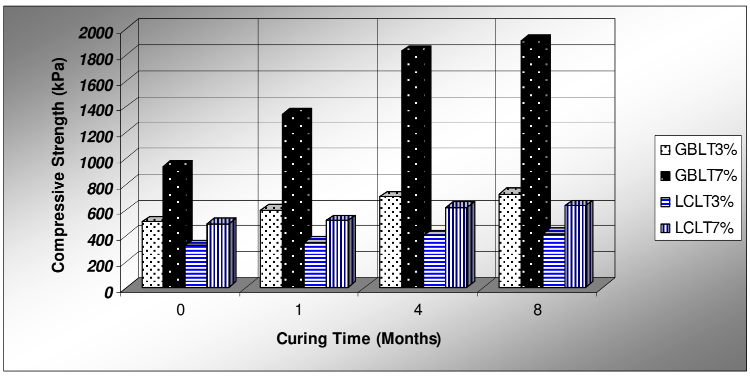

Figure 2. Strength development for Green Bentonite (GB) and Laterite Clay (LC) mix designs with curing time.

Conclusions

In this paper, an analytical technique that was linked to the thermal characteristics of soil was conducted at different time intervals. This was carried out in an attempt to further elucidate the effects of lime on soil's properties. In lime treated bentonite samples, after 8 months of curing, new weight losses due to the evaporation of moisture encapsulated into the crystallized reaction products was seen. Also, it was found that the application of lime as a soil stabilizer had a marginal impact on the thermal properties of lateritic soil. From geotechnical point of view, lime treatment was more beneficial in enhancing the engineering properties of montmorillonite-rich soil (bentonite) over the 8 months time interval.

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