

Strength of Lime-Cement Stabilized Tropical Lateritic Clay Contaminated by Heavy Metals

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Abstract

Cement and lime are considered as stabilizers of contaminated land since they can reduce the leachability of contaminants. The contaminated soils can generally have higher strength after stabilization. However, the presence of heavy metal contaminants in soil interferes with stabilizer hydration which inhibits strength development in treated soils. Stabilizing products also have different strength properties due to heavy metals that affect levels of chemical fixation in different contaminated soil mixes. This paper presents an experimental study that evaluates strength development in cement-lime stabilized/solidified soils contaminated with either copper or zinc. Unconfined compressive strength was used to determine the suitability of cement and lime stabilization of contaminated laterite clay soils. Control samples (cement-lime stabilized soils without heavy metals) were prepared for comparison. Results confirmed the interference of heavy metals in the process of cement and lime hydration as a direct reflection of varied strength developments in tested soil samples. It was found that metal concentration, stabilizer content, type of stabilizer, and heavy metal type were factors that affected stabilizer hydration and strength development. The most significant ones of these were the type of stabilizer used and heavy metal concentration.

Keywords: laterites, stabilization, cement, lime, contamination, heavy metals

1. Introduction

Protecting the environment from hazardous pollutants associated with waste generation and disposal is a major concern of today's heavily industrialized world. Thus far, various technologies have been developed to transform hazardous wastes to nontoxic substances or to reduce the potential release of toxic species into the environment. Chemical treatment for 'cement-lime based solidification and stabilization' (S/S) either binds a hazardous compound waste stream to a stable insoluble form (stabilization), or entraps the waste within a solid cementitious matrix (solidification) (Wiles, 1987). Chemical changes that arise from interaction of waste components with a solidifying binder play an important role that controls the quality of binder-based solidified waste products (Asavapisit *et al.*, 2005). This method remains preferential since it can be applied in-situ or ex-situ for contaminated soil remediation. This technique is popular because it is relatively cheaper than most alternatives and results in well qualified long-term physical and chemical stability, and also because resultant

products often possess superior mechanical and structural characteristics (Conner, 1990). In addition, such stabilized wastes often attain adequate stress-strain properties as higher strength end products that can be reused for engineering fills, highway construction or pavement subgrading, backfill and base material etc.

Many formulations have been developed for the S/S process according to types of wastes and heavy metals. One of these is modified Portland cement using fly ash, lime, slag and soluble silicates (Choon, 2000). Ordinary Portland Cement (OPC) is the most widely used binder as it is cost effective, readily available and also compatible with a variety of wastes (Spence *et al.*, 2004; USEPA, 1999; 2001; 2004).

However, several studies have reported that retardation and, in some cases, inhibition of cement hydration is likely caused by the addition of heavy metals to stabilized wastes (Hanna *et al.*, 1995; Hills *et al.*, 1993). Retardation is believed to occur primarily by adsorption of the retarding compounds onto hydration products. Adsorption results from the hydrogen bonding on the

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cement's surface by hydroxyl groups with oxygen atoms as well as by chemical bonding between carboxylic acid oxygen and calcium ions. The adsorption of these compounds forms an impervious coating of Calcium Silicate Hydrate (C-S-H) that inhibits further hydration by blocking water access to the cement grain. Furthermore, Trussel and Spence (1994) and Tashiro et al. (1977) reported that the hydration of cement can also be retarded in the presence of Zn, Pb, and Cu when double salts are formed between these heavy metals and early calcium ion dissolution from cement. Meanwhile, Tashiro and Oba (1980) found that the heavy metal oxides of Cr, Cu, Zn, As and Pb also influence cement's physical properties due to reactions with cement paste. More specifically, these oxides affect cement paste hardening and strength development during early stages of cement hydration.

Generally, the literature supports that heavy metals can retard cement reactions. Even so, their effect on reactions with lime has yet to be comprehensively studied. As reported by Kassim and Chern (2004), lime in the form of hydrated lime is relatively high in Malaysia, which means that lime is an economically viable option commonly utilized in the treatment of tropical soils. Hence, this study used lime as an alternative stabilizer with a view to compare the efficiency and suitability of both lime and cement as binders for S/S treatment of tropical laterite soils contaminated with heavy metals.

In this study, evaluated was the unconfined compressive strength of stabilized soil at different curing intervals to determine strength development for both cement and lime in contaminated stabilized soils.

2. Laboratory Experimental Works

2.1 Materials

The residual laterite soil used in this investigation was a reddish clayey soil with high amount of iron oxides commonly found in tropical regions. The chemical and physical properties of the natural soil are presented in Table 1.

A hydrated lime was used in this study. It works well with clayey soils, especially those with moderate to high plasticity

Table 1. Physical Properties and Chemical Composition for Laterite

Engineering & Physical Properties (Laterit)	Values	Chemical Composition Oxides	Values (%)
CEC (meq/100 g)	22.7	SiO ₂	21.55
pH (L/S = 2.5)	4.86	Al ₂ O ₃	24.31
Specific Gravity	2.75	Fe ₂ O ₃	29.4
Liquid Limit, LL (%)	72.8	Na ₂ O	0.07
Plastic Limit, PL (%)	35.6	K ₂ O	0.11
Plasticity Index, PI	37.2	P ₂ O ₅	16.71
(%)BS Classification	MH	SO ₃	3.98
ICL (%) 2.00 Soluble	5	CO ₂	3.65
Maximum dry density (Mg/m ³)	1.33		
Optimum moisture content (%)	34		
Unconfined compressive strength (kPa)	288		
Cc	0.24		

Note: ICL: Initial Consumption of Lime, Cc: Compression Index

index (PI > 15). In addition, the Ordinary Portland Cement (OPC) was used as the second stabilizers in this work. Both substances were in powder form, and they were obtained from a factory in Pasir Gudang, Johor. The reagents added to simulate inorganic metal contamination were copper nitrate trihydrate (Cu(NO₃)₂ × 3 H₂O, to provide the copper (II) ions (Cu²⁺), and zinc nitrate tetrahydrated (Zn(NO₃)₂ × 4 H₂O, to provide zinc (II) ions (Zn⁺²). Both of them were from Merck KGaA-Germany. The two reagents were chosen due to their prevalence at many contaminated sites.

2.2 Preparation of Specimens

Previous investigations conducted on laterite soil indicated that oven drying can significantly change the plasticity and compaction properties of the soil (Goswami and Mahanta, 2007). Therefore, in this study, all the soil samples were prepared from air-dried soil broken into smaller sizes and sieved through a 2 mm sieve. The sieving was done to ensure that the soil was of uniform grade.

The concentration of stabilizer ions has a great impact on the short and long term reactions during the initial modification and cementation of the treated samples, respectively. Based on Das (1990) and Maher *et al.* (2005), a lime concentration of between 2% and 3% of the soil's dry weight is sufficient for modification purposes, and for stabilization purposes, this typically ranges from 5% to 10%. The latter is more prominent for pozzolanic reactions. Kassim and Chern (2004) discovered that, for typical Malaysian cohesive soils, the optimum lime content for stabilization should be around 3% to 6%. However, its related studies on improving contaminated soils are relatively lesser. Thus, this has to be adjusted depending on the suitable percentages of stabilizers for pozzolanic reaction. For comparison purposes, two equivalent contents of stabilizers were used (5%, 10%) for both lime and cement in this study. The required amount of water or Optimum Water Content (OWC) depends on the nature of the soil and stabilizer content. In BS 1377: Part 4: 1990 (clause 3.3.4.1), five series of standard proctor compaction tests are mentioned to ascertain the optimum moisture contents for various lime and cement mixtures. In this study, the mix proportions (% lime, % cement) were (0,0), (5,0), (10,0) and (0,5), (0,10) in percentages by weight of dry soil. The optimum moisture contents were adopted in accordance to these mix proportions as the designed water content of contaminated soils specimens. The artificial heavy metals contaminated soil samples were prepared by mixing zinc and copper nitrate as the sources of pollutants into the natural laterite clay. Three percentages of heavy metals were selected, i.e., 0.1%, 5%, and 10% (dry soil weight basis). These different percentages were based respectively on the level of pollutants commonly found in naturally contaminated soil, industrially contaminated soil, and highly contaminated soil. Control samples (cement-lime treated soils without heavy metals) were also prepared for comparison purposes.

For contaminated soil, all laboratory ware and sampling apparatus were pre-soaked in a 5% nitric acid solution followed

by deionized water for a day prior to the sampling. This was done to remove traces of metals. During the actual sample preparation, lime and cement were first individually mixed with the dry soil to ensure homogeneous distribution of the two stabilizers in the soil. Then, the deionized water mixed with predetermined amount of copper nitrate or zinc nitrate was added into the mixture. For the control samples, only pure deionized water was used. Based on laboratory trials, an additional quantity of water (2% of the optimum water content) was added to all mix designs to take evaporation losses into account. After the mixing process, the soils were compacted in 38 mm × 76 mm cylindrical moulds. The preparation process was concluded by making sure that the designed optimum water content and maximum dry density according to clause 4.1.5 of BS 1924: Part 2: 1990b were achieved. After that, the specimen was cured for two hours, removed from the mould, put in a thin-walled PVC tube, wrapped with thin plastic cover, and sealed with rubber tight lids. The samples were then stored to cure in a temperature controlled room (27 ± 2°C) until experiments were done after 7, 14, 28, 100, and 200 days.

3. Results and Discussion

3.1 Unconfined Compressive Strength (UCS)

To evaluate the effectiveness of both lime and cement in stabilizing the lateritic clay contaminated by heavy metals, several factors were scrutinized.

3.1.1 Effect of Heavy Metals Content on UCS

The normalized strength index was the metric used to investigate and compare effects of heavy metal content on the strength of lime and cement samples. This index is defined as measured UCS divided by control sample UCS at the same curing time (Chen *et al.*, 2010).

In Figs. 1 and 2 below, the dashed line represents the UCS of

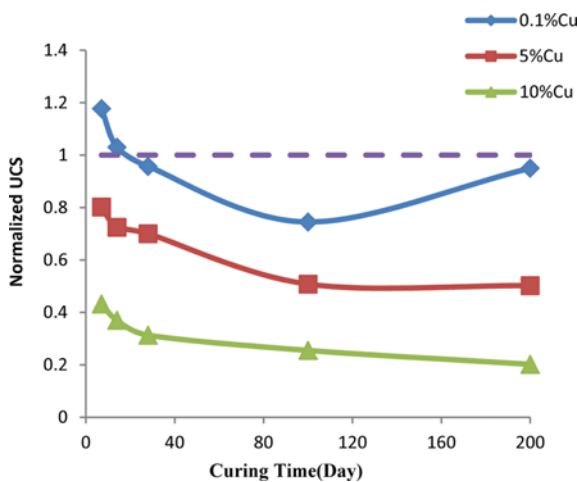


Fig. 1. Normalized Strength of 5% Lime Treated Lateritic Clay Contaminated by Different Percentages of Copper

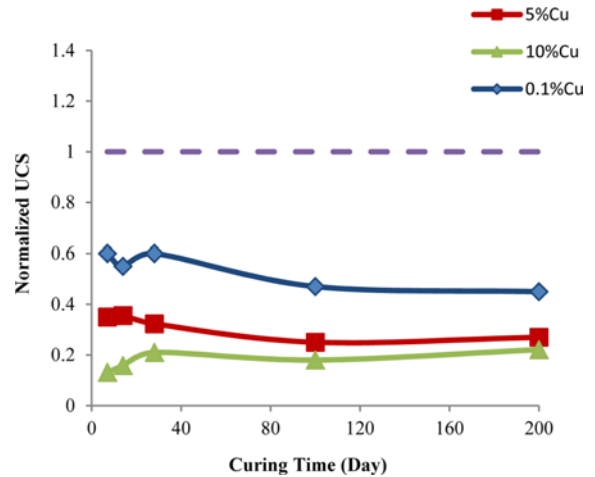


Fig. 2. Normalized Strength of 5% Cement Treated Lateritic Clay Contaminated by Different Percentages of Copper

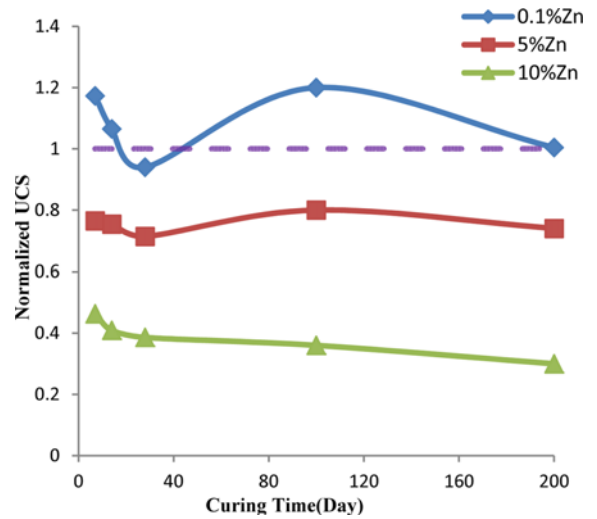


Fig. 3. Normalized Strength of 5% Lime Treated Laterite Clay Contaminated by Zinc

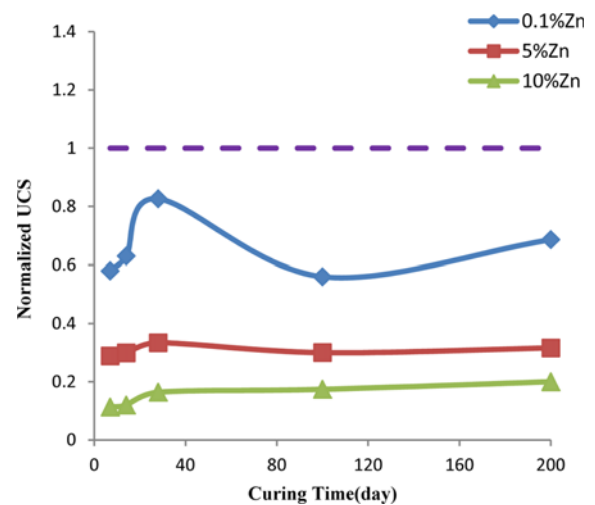


Fig. 4. Normalized Strength of 5% Cement Treated Laterite Clay Contaminated by Zinc

the control sample (normalized UCS = 1). This parameter was emphasized for comparison with respect to the presence of heavy metals and either improvement or inhibition of both cement or lime stabilization. Both Figs. 1 and 2 depict normalized strength of stabilizer-treated samples contaminated with different percentages of Cu. Fig. 1 shows that 7 and 14 day strengths were higher for lime-treated laterite clay contaminated with a lower heavy metal content (0.1%), than for samples with more heavy metal content (5 and 10% Cu). A similar result was observed for strength development of samples contaminated with 5% and 10% of copper, although the values were lower. The strength of copper contaminated soil (0.1%) improved by the day 200. Compared to Fig. 1, Fig. 2 shows that the samples strength remained far below that of the control sample regardless of copper concentration throughout the longer curing period. Hence, if purely focused on stabilizer type, it can be concluded that the strength of lime treated laterite clay soil contaminated with equal concentrations of heavy metals was higher than the soil treated with cement. This conclusion also affirmed that cement experiences more retardation with heavy metals than lime.

3.1.2 Effect of Heavy Metal Type on UCS

Figures 3 and 4 show the normalized strength of zinc contaminated laterite soil treated with lime and cement. These tests were done to compare results with copper contaminated laterite soil earlier. Generally, both figures show increased strength over longer curing periods (more specifically by day 200) for both stabilizer types at a lower zinc concentration (0.1%). For lime treated soil, strength development was greater than that recorded in Fig. 1. Furthermore, the strength values for cement treated zinc contaminated clay (0.1%) were also higher compared to Fig. 2 at 28 and 100 days. These results clearly indicated that heavy metal type affects strength development, especially at lower concentrations. However, both metals had greater retardant effects on cement stabilization than on lime stabilization

3.2.3 Effect of Stabilizer Content on UCS

Although the presence of heavy metals in soils can interfere with the stabilizer reactions and affect strength development in stabilized soils, the stabilizer's content can also play a contributing role in strength development. Figs. 5(a) and 5(b) compare differences in strength between samples treated with 5 and 10%

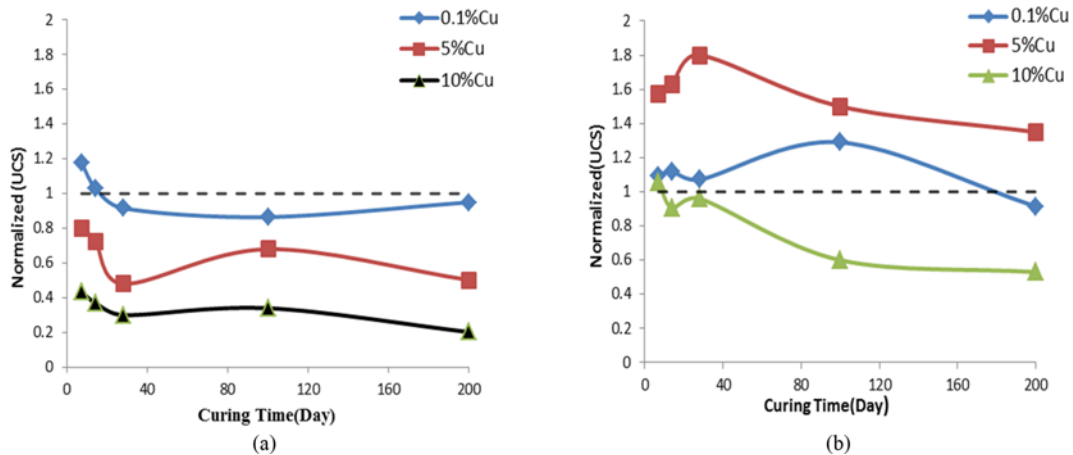


Fig. 5. (a) Normalized Strength of 5% Lime Treated Laterite Clay Contaminated by Different Percentages of Copper, (b) Normalized Strength of 10% Lime Treated Laterite Clay Contaminated by Different Percentages of Copper

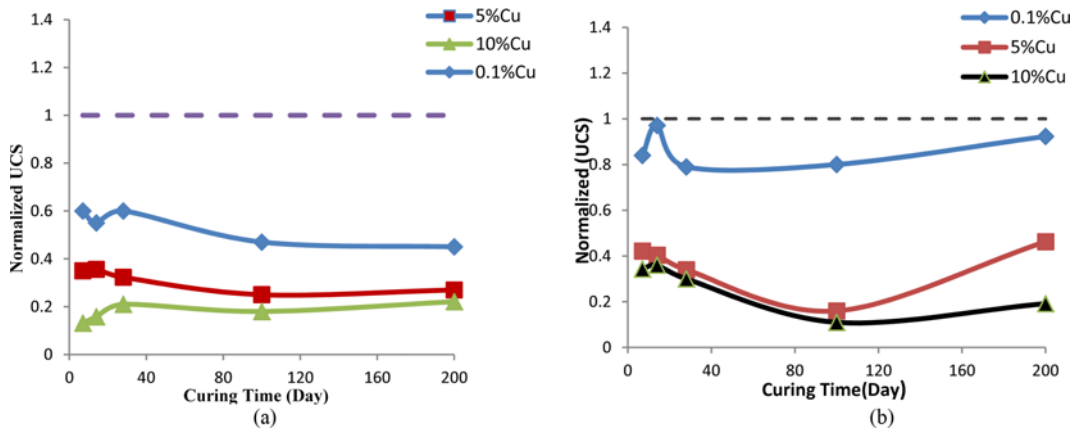


Fig. 6. (a) Normalized Strength of 5% Cement Treated Laterite Clay Contaminated by Copper, (b) Normalized Strength of 10% Cement Treated Laterite Clay Contaminated by Copper

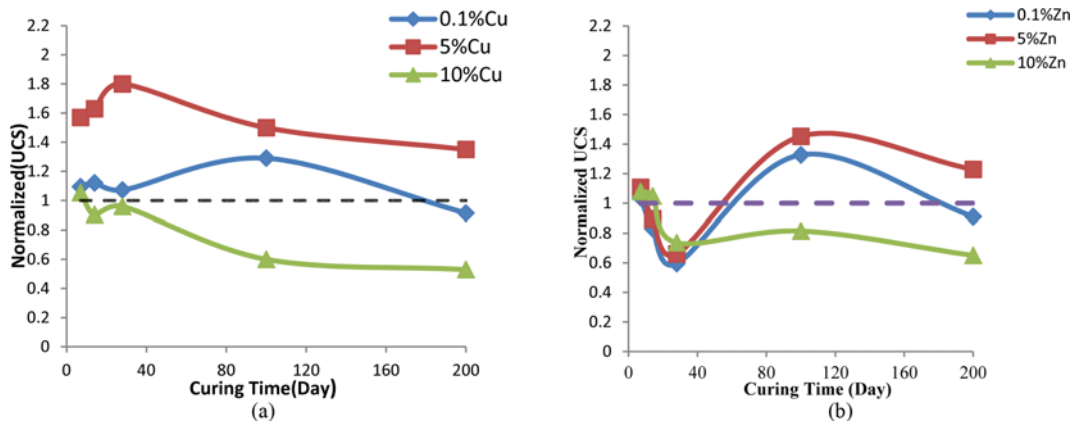


Fig. 7. (a) Normalized Strength of 10% Lime Treated Laterite Clay Contaminated by Copper, (b) Normalized Strength of 10% Lime Treated Laterite Clay Contaminated by Zinc

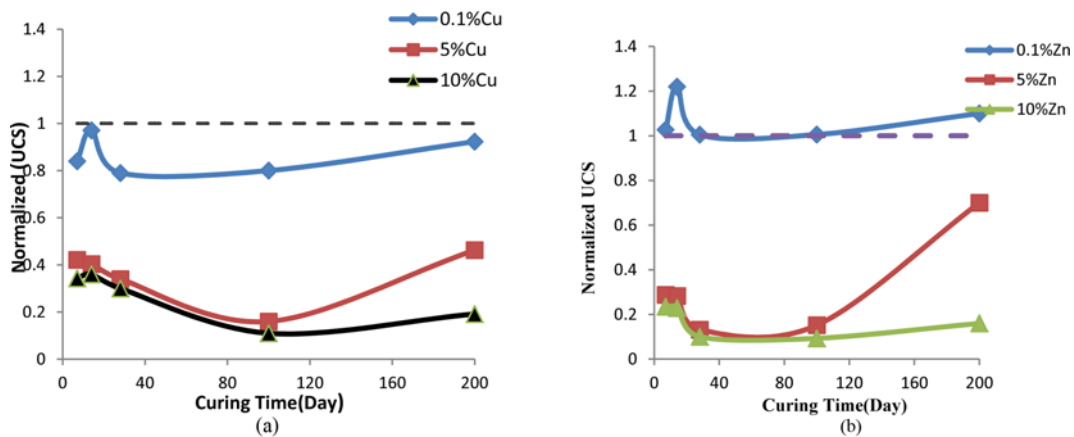


Fig. 8. (a) Normalized Strength of 10% Cement Treated Laterite Clay Contaminated by Copper, (b) Normalized Strength of 10% Cement Treated Laterite Clay Contaminated by Zinc

lime. Fig. 5(b) shows an obvious increase in strength for all percentages of copper, even at higher concentrations (5% and 10%) than results shown in Fig. 5(a) for soils treated with 5% lime. This indicated that regardless of the retarding effects of heavy metals, increased stabilizer content minimized the interference and promoted strength development in heavily polluted clay soils. A similar comparison was done for cement stabilizer and the results are as shown in Figs. 6(a) and 6(b). Fig. 6(a) shows improved strength development of cement stabilizer samples during early curing stages (which decreased over time) and also demonstrates minimal variance with normalized UCS. Fig. 6(b) shows that when cement content was increased strength development also increased for soils contaminated with 0.1% copper (dry weight). Soils contaminated with 5% and 10% copper (dry weight), showed negligible strength development during early curing but did increase after day 100. Despite the positive strength development, generally, the retarding effect of heavy metals was very obvious in soils treated with cement stabilizer.

Comparisons were also made for fixed amounts of both stabilizer types as shown in Figs. 7 and 8. Comparing results shown in Fig. 7(a) with those in 7(b), strength development was

clearly dissimilar by days 28, 100 and 200 for the different contaminants. This indicated that zinc may be less of an inhibitor in soil treated with 10% cement (dry weight), especially in the long-term. Hence, it appears that the effectiveness of stabilizer content is influenced by factors other than heavy metals.

4. Conclusions

Based on the laboratory tests, the following conclusions can be drawn:

1. The strength of the treated lateritic clay soil contaminated by heavy metals depends on metal concentration, type of heavy metal, stabilizer content, and the stabilizer type. These factors interfere with the stabilizer reactions and strength development.
2. In general, the strength development of stabilized heavy metals clay soils with a high metal concentration is much lower than that of control samples due to the significant retardation or inhibition effect on lime or cement reactions.
3. The difference in strength between control sample and heavy metal contaminated sample treated with lime is less than that of cement even with low stabilizer content. This

indicates that lime is less retarded than cement in treating tropical laterite clay soil contaminated with heavy metal.

4. With increasing stabilizer content for both lime and cement, the strength of contaminated laterite clay soil increases even with high concentration of metal. This is more obvious in soils stabilized by lime because such increase in cement treated contaminated soil only happened for low content of heavy metal (1000 mg/kg).
5. The strength difference between control samples and heavy metal contaminated samples decreases or increases with curing time depending on the type of metals. However, a reduction in this difference has been observed with increased stabilizer content.
6. The influence of heavy metals on strength development depends on the metal concentration. Generally, the retarding effect of heavy metals is more apparent in cement than lime.

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