Utilization of waste copper slag as a substitute for sand in vertical sand drains and sand piles

Utilisation des scories de cuivre en tant que substitut pour le sable dans des drains et des colonnes de sable

Nawagamuwa U.P.
University of Moratuwa, Sri Lanka

Senanayake A.
University of Texas at Austin, USA

Rathnaweera T.
University of Calgary, Canada

ABSTRACT: Vertical sand drains are used as a method of expediting consolidation for ground improvement projects. Unfortunately, the installation of vertical sand drains have become less economically viable due to the high costs and limited availability of good quality sand. Particle size distribution analyses done on samples of waste copper slag obtained from the Colombo dockyard revealed that its gradation was similar to that of sand, which meant that waste copper slag could potentially be used as a substitute for sand, provided that it did not adversely affect the hydraulic conductivity of the resulting mixture. In this study, constant head permeability tests were done on "sand-copper slag" mixes of varying proportions and it was shown that up to 50% copper slag by weight could be added to sand without an appreciable loss in permeability. The performance of sand piles is dependent on strength and settlement characteristics of the sand. Hence, consolidation tests and direct shear tests were also carried out on the "sand-copper slag" mixes to explore how the mechanical properties of sand were affected by the copper slag.

RÉSUMÉ : Sable drains verticaux sont utilisés en tant que méthode d'accélérer la consolidation des projets d'amélioration des sols. Malheureusement, l'installation de drains verticaux sable sont devenues moins rentables en raison des coûts élevés et une disponibilité réduite de sable de bonne qualité. Analyses granulométriques effectuées sur des échantillons de scories de cuivre obtenu à partir des déchets du chantier naval Colombo a révélé que sa gradation était semblable à celle du sable, ce qui signifie que scories de cuivre des déchets pourrait être utilisé comme un substitut pour le sable, à condition que cela ne nuise pas la conductivité hydraulique du mélange résultant. Dans cette étude, des essais de perméabilité constants ont été réalisés sur la tête "sable-laitier de cuivre" mélange des proportions variables et il a été montré que jusqu'à scories de cuivre 50% en poids peuvent être ajoutés au sable sans perte notable de la perméabilité. La performance des piles de sable dépend des caractéristiques de résistance et de règlement du sable. Ainsi, des essais de consolidation et essais de cisaillement direct ont également été menées sur le sable-laitier de cuivre mélange d'explorer la façon dont les propriétés mécaniques de sable ont été affectés par les scories de cuivre.

KEYWORDS: waste copper slag, vertical drains, sand piles,

1 PARTICLE SIZE GRADATION

Laboratory sieve analyses were conducted on the waste copper slag. The material was first sieved through the No.4 (4.75mm) sieve to remove coarse particles which do not fall within the particle size range of sands. The results showed that the copper slag had a very small range of particle sizes. The material could be categorized as "poorly graded" according the USCS (C_u= 2.5 and C_c = 0.9).

The waste copper slag was mixed with a poorly graded sand (C_u =3, C_c =1.1) in proportions of 10%, 20%, and 40% by weight and tested how the geotechnical engineering properties of the sand would be affected.

The results of sieve analysis test conducted on the copper-sand mixes are shown in figure 1. It can be observed that the gradation curve is not greatly affected by the addition of waste copper slag. The only apparent change is a slight shift in the curves towards the right.

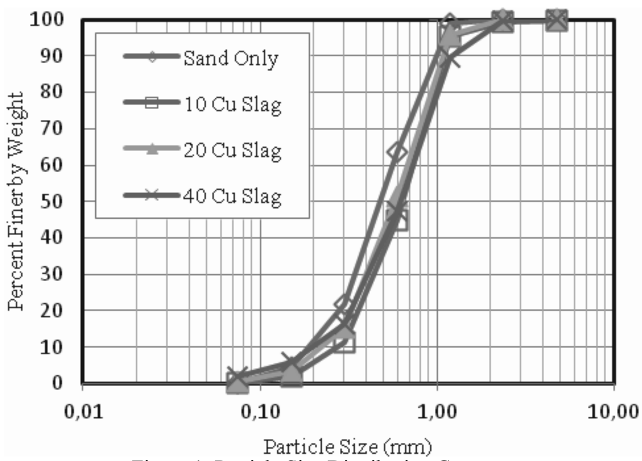

Figure 1: Particle Size Distribution Curves

2 HYDRAULIC CONDUCTIVITY

A poorly graded material will have a high void ratio as compared to a well graded material. Whilst this may be a undesirable attribute in many engineering applications, it can be an advantage if the material is to be used for sand drains. The purpose of sand drains is to provide a mechanism to expediting the dissipation of excess pore water pressures created in soil masses by acting as outlets for ground water to flow out. A key attribute of sand drains is to have very high hydraulic conductivities so that there is minimal resistance to water flowing them. High void ratios generally translate into high hydraulic conductivity thus, a material with high void ratio would be ideal for used in such drains.

The particle size gradation curves suggest that the hydraulic conductivity of the mixes should not deviate too much from that of the original sand. A series of constant head test were carried out on the each mix in order to check if this was true.

The permeameter was filled with air dried samples of the copper-sand mix by dropping the material through a funnel from a fixed height. Special care was taken during the preparation of the specimens in order to ensure that they were comparable and consistent among all the different copper-sand mixes. The funnel used in this case was one from a "Sand Cone" test used in estimating field compaction values and it was placed on top of the permeameter. The funnel was first filled to the brim and the tap was opened to let all the material fall in to the permeamter in a single step. This method could be estimated to produce samples slightly denser than those specified in ASTM D 4254. The unit weight of the specimen was found by weighing the permeameter and calculating the volumes occupied by the material.

Specific gravity of the waste copper slag was found to be 3.7 and that of the sand was around 2.65. The specific gravity of the copper-sand mixes were calculated as a weighted average based on the proportions of each component. The void ratio of each mix was then calculated .As expected, the void ratio are tightly grouped together, ranging between 0.7 – 0.8. There is a trend showing a peak void ratio at a mix proportion of 20% copper slag. However, these small differences in void ratios are not significant enough to affect the hydraulic conductivity of the materials as can be seen from **Figure 2**.

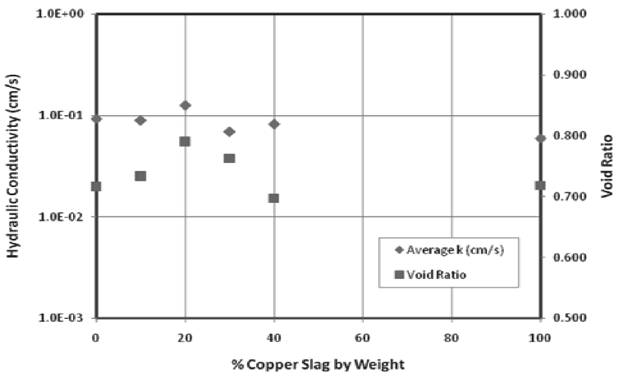

Figure 2: Hydraulic Conductivities and Void Ratios for Copper-Sand Mixes

3 SHEAR STRENGTH

The samples which were tested in the direct shear apparatus were prepared in 'loose condition' with no compacting. As expected, the plots on **Figure 3** are typical of 'loose' sand as they show a gradual gain in shear strength and then flatten out with no pronounced peak. It can also be seen that the axial strain required mobilizing maximum shear strength increases with the increase in the applied normal stress. Figure 6 shows the summary of Mohr Coulomb failure envelopes for various copper sand mixes and Table 1 provides friction angles those mixes.

The direct shear test results show that the addition of waste copper-slag does not affect the shear strength of the sand. A friction angle of 30 degrees is typical for a 'loose' sand and if need be, the friction angle can be increased further by densifying the material.

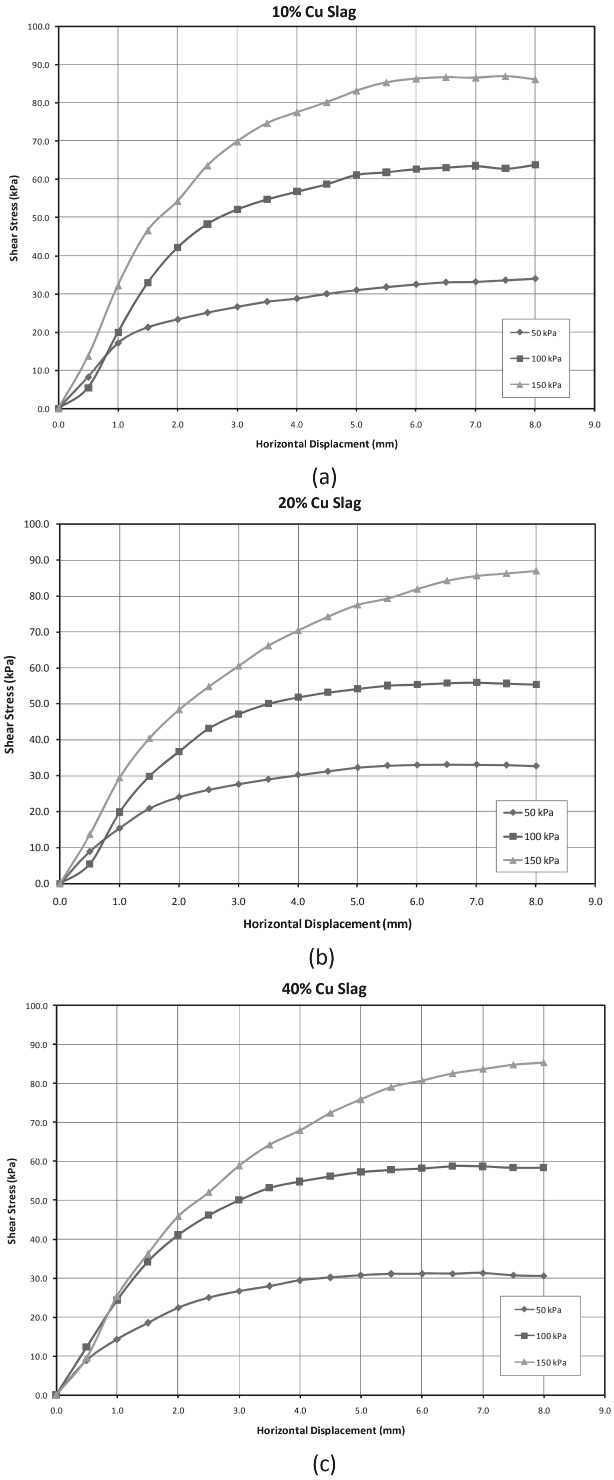

Figure 3: Direct Shear Test Results on Copper-Sand Mixes

Table 1: Friction Angles of Copper-Sand Mixes in 'Loose' State

% of Copper Slag by Weight	Friction Angle (degrees)
10	31.4
20	30.4
40	30.4

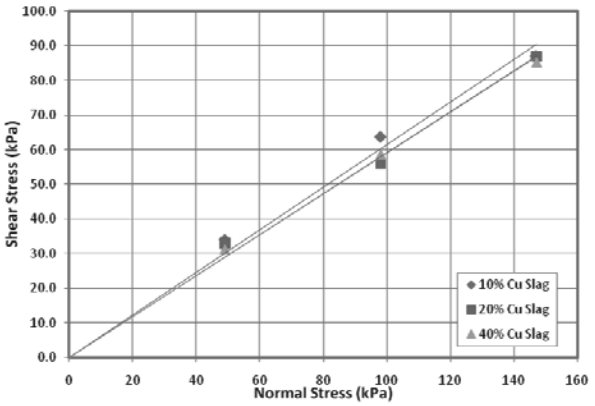

Figure 4: Mohr-Coulomb Failure Envelopes for Copper-Sand Mixes

4 STIFFNESS

The most significant effect of the addition of waste copper slag to sand was observed in confined compression tests. Dry specimens were tested in a consolidation apparatus to ascertain settlement and stiffness properties of the material. Standard consolidation tests with fully saturated samples were not warranted as the material had a very high hydraulic conductivity and consolidation would have occurred at a rapid rate. Strains were measured for different stress changes by applying loads on to the sample. **Figure 5** shows the results in the form of a typical strain vs log stress plot. There is clear distinction between the behavior of the sand and the copper-sand mixes. The addition of just 10% of waste copper slag drastically increases the stiffness of the material. All three curves for copper-sand mixes are tightly grouped which suggest that increasing the proportion of copper slag more than 10% does not have any further effect.

Figure 5: Compression Characteristics of Copper-Sand Mixes

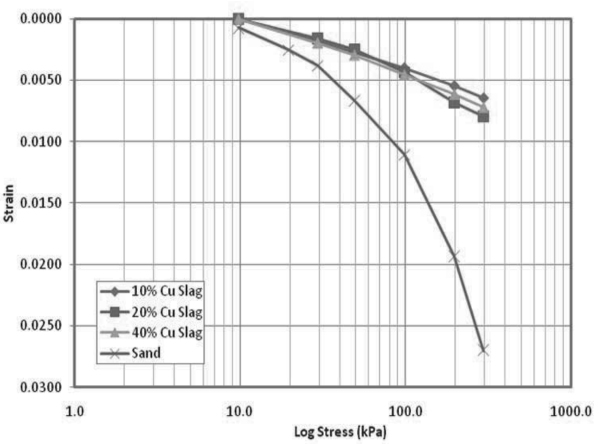

figure 6: Compression characteristics of copper-sand mixes

5 GEOCHEMICAL CHARACTERISTICS OF USED THE COPPER SLAG

Chemical properties of the used copper slag as a percentage of total weight are Iron Oxide-Fe_2O_3 55%, Silica-SiO_2 35%, Aluminium Oxide-Al_2O_3 3.01%, Calcium Oxide-CaO 0. 20%, Magnesium Oxide-MgO 0. 90%, Copper-Cu 0.42%, Titanium Di-oxide 0.60%, and Potassium Oxide 1. 02% (Hammarstrom et al.1999). The geochemical characteristic of used copper slag can be analyzed for its element content, pH, acid neutralization capacity (ANC), redox potential (Eh), and electrical conductivity (EC). According to the previous research done by Lim et al. (1997), it is clear that the pH of leachate generated from the used copper slag is around 8.4. This pH value is within the common pH range for soils and groundwater. Figure 6 shows the variation of pH- acid titration curves for used copper slag and natural soils (Moyer et al. 2000).

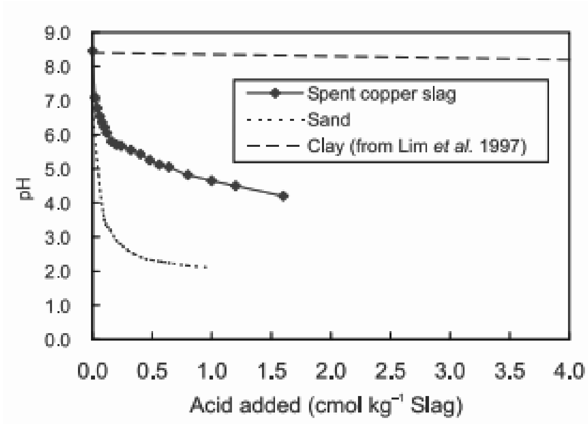

Figure 7: pH- acid titration curves for used copper slag and natural soils (After Moyer et al. 2000)

Figure 7 clearly illustrates that the used copper slag has a rather low ANC in comparison with the clay. Sand has practically negligible ANC. The low ANC value indicates that the spent copper slag is not resistant to acid attack. The concentration of Pb, Cd, Cr, Ba, As, Ag, Se, Cu, Zn, Ni and Hg in the used copper slag leachate are fairly low. The leachabilitie of Cu and Zn metals are much higher when compare with Cd, Pb, Cr and Ni. The impact of the heavy metals leachability would be nullified by dilution process under larger water: slag ratio. Another important property of the used copper slag is the Eh value. The initial Eh value for the used copper slag is 171 mV at a solid: water ratio of 1:1. The Eh would continue to decrease rapidly days after placing the copper slag. Due to the presence of sulphide minerals, the used copper slag can be oxidized under oxic condition and release H^+ into the pore water. As a result, there is a marginal drop in pH. The reduction can be expressed by the following reactions such as reactions of pyrite and ferrous. The amount of H^+ generated from this reaction is very low and do not have enough reaction power to make significant changes in double layer of clay minerals.

Pyrite oxidation:

$$4FeS_2 + 14O_2 + 4H_2O \longleftrightarrow 4Fe^{2+} + 8H^+ + 8SO_4^{2-}$$

Fe (11) oxidation:

$$4FeSO_4 + O_2 + 10H_2O \longleftrightarrow 4Fe(OH)_3 + 8H^+ + 4SO_4^{2-}$$

The variation in pH due to present of heavy metals can be affected to the groundwater pollution scenario. According to the previous research done on used copper slag, it is clear that the effect of groundwater pollution scenario is very unlikely to occur (Lim et al. 1997).

6 CONCLUSIONS

Results have show that the hydraulic conductivity of the tested sand was hardly affected by the addition of waste copper slag due to the void ratio and the hydraulic conductivity of the waste copper slag itself being very similar to that of the sand. Investigation of the geochemical characteristics of the used copper slag alleviates the concern of possible groundwater pollution by its use. Therefore, it can be concluded that used copper slag can safely and effectively be used as a replacement for sand in vertical drains.

The shear strength of properties of the tested sand-copper slag mix was found to be very insensitive to the amount of waste copper slag in the mix. In a "loose" state the sand-copper slag mix shows friction angles of 30.4° – 31.4°, which is a deviation of only 1°, even when the percentage by weight of waste copper slag changes from 0 to 40.

The stiffness of the sand was found to be clearly improved by the addition of waster copper slag. The addition of waste copper slag substantially reduced the settlement of the mix when tested in a conventional consolidation apparatus. This shows potential of waste copper slag to be successfully used as a replacement for sand in "sand piles" with the added advantage of improved performance.

It was puzzling to find that the stiffness of the sand-copper slag mix was insensitive to increases in the amount of waste copper slag beyond 10% by weight. However, the authors feel that shear strength and stiffness behavior holds the greatest potential for the use of waste copper slag hence, further testing is already underway.

7 ACKNOWLEDGEMENTS

Officials of Colombo Dockyard for providing waste copper slag for this research.

8 REFERENCES

Hammarstrom, J.M., Meier, A.L., Jackson, J.C., Barden, R., Wormington, P.J., Wormington, J.D., and Seal, R.R., II., 1999, Characterization of mine waste at the Elizabeth copper mine, Orange County, Vermont: U.S. Geological Survey OpenFile Rep. 99-564, 74 p.

Lim, Teik-Thye, and J. Chu. "Assessment of the use of spent copper slag for land reclamation." *Waste Management & Research*, 2006.

Lim, T. T., J. H. and Tech, C. I. (1997) Sorption and speciation of heavy metals from incineration fly ash in a marine clay. Journal of Environmental Engineering, 123 (11), 1107- 1115.

Moyer, T.C., Jourdan, R., Taylor, M., and Mozingo, J.T., Jr., 2000, Challenges of restoring an environment impacted by a century of copper mining: the Copper basin mining district, Tennessee: Geological Society of America, Abstracts with Programs, v. 32, no. 7, p. 476-477.