Study on Cohesion and Angle of Internal Friction of Copper Slag When Mixed with Lime

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Abstract

Waste generation in unpredictable amounts is a part of almost every metal and non-metal casting industry. These wastes can be converted to useful material if processed for ultimate recovery of valuables provided it is economical. Dumping of these wastes may lead to environmental problems. Therefore, the reuse of the waste materials in various fields is seen for quite some time. Copper slag is a waste product generated during the smelting process for the production of copper. It has been estimated that for every tonne of copper produced, about 1.8-2.2 tonnes of copper slag is generated as a waste. Due to increase in production capacity of copper, copper slag getting accumulated require additional dumping space and causing wastage of good cultivable land. The present paper discusses the laboratory test results of direct shear tests conducted on copper slag mixed with lime. The copper slag mixed with lime in various percentages were kept for curing and then tested after 7, 14, 28 days. Effective results are observed for the shear parameters like cohesion and angle of internal friction of copper slag on addition of lime from 4% and 6%. There is an increase in cohesion and decrease in angle of internal friction as the percentage of addition of lime increases and with the curing period.

Keywords – Copper Slag, Lime, Direct Shear test, Shear Parameters.

1. Introduction

Pure copper is rarely found in nature, but is usually combined with other chemicals in the form of copper ores. The process of extracting copper from copper ore varies according to the type of ore and the desired purity of the final product. Once the waste materials have been physically removed from the ore, the remaining copper concentrate must undergo several chemical reactions to remove the iron and sulphur. This process is called smelting. The recovery of sulphuric acid from the copper smelting process not only provides a profitable by-product, but it also significantly reduces the air pollution caused by the furnace exhaust. Copper slag (CS) is a waste product which comes out from the smelting process. It has been estimated that the production of one tonne of blister copper generates 2.2 tonnes of slag. Metal industry slag, mine stone and mining waste are generally suitable for recycling or reuse and the use of these inorganic wastes as alternative materials in building, road and geotechnical applications have been reported [1, 2, 3, 4, 5, 6].

Copper slag, upon mixing with soil, can be used as an effective stabilizing agent for the improvement of problematic soils for use in highway embankments, sub-grades and subbases. Also, by mixing it with fly ash, it becomes suitable for embankment fill material. Slag, when mixed with fly ash and lime, develops pozzolanic reactions [7]. Fly ash has been widely accepted as embankment and structural fill material [8, 9].

Copper slag along with binding material or an admixture can be used as an alternative material to that of sand in road construction. If the copper slag is mixed with calcium-based compound like lime, the silica and alumina present in copper slag may react chemically on hydration and it may be used for the improvement of sub-grades and sub-bases. The present paper discusses the shear parameters of the copper slag when admixed with lime with varying percentages added and tested after 7, 14 and 28 days of curing period.

2. Experimental Study

2.1 Materials Used

2.1.1 Copper Slag

Copper slag was collected from Sterilite Industries, Tuticorin, Tamil Nadu, India. The physical and chemical properties are presented in Tables 1 and 2 respectively.

Table 1 Physical Properties of Copper Slag

Property	Value
Hardness, Moh's Scale	6.5 – 7.0
Specific Gravity	3.6
Plasticity Index	Non-Plastic
Swelling Index	Non-Swelling
Granule Shape	Angular, Sharp edges
Grain Size Analysis	
Gravel/Size (%)	1
Sand/Size (%)	98.9
Silt & Clay/Sizes (%)	0.05
MDD (kN/m^3)	23.5
OMC (%)	6
Direct Shear test	
Cohesion (kN/m^2)	0
Angle of internal friction (degree)	40
Permeability(cm/sec)	15.43×10^{-3}
CBR (%)	3.5

Table 2 Chemical Composition of Copper Slag

Property	(% wt)
Iron Oxide, Fe_2O_3	55 – 60
Silica, SiO_2	28- 30
Aluminium Oxide, Al_2O_3	1 – 3
Calcium Oxide, CaO	3– 5
Magnesium Oxide, MgO	1.0– 1.5

2.1.2 Lime

Locally accessible hydrated lime which consists of 95% of Calcium hydroxide is used in the present study.

2.2 Tests Conducted

Compaction tests (11) were conducted for the copper slag mixed with lime, as the % of lime varies from 4% and 6%, the MDD values are slightly increasing. Direct Shear tests were conducted (12) for the copper slag mixed with lime of 4% and 6%. Copper slag and lime are mixed in various percentages of lime in dry condition and then water is added. The samples are kept for curing for 7 days, 14 days and 28 days. After the curing period the copper slag mixed with lime is tested for the cohesion and angle of internal friction.

3. Results and Discussion

3.1 Direct Shear Results

Direct shear tests were conducted on the copper slag samples mixed with lime in various proportions of 0%, 4% and 6% after 7days, 14days and 28 days of curing period. The results of the direct shear are presented below.

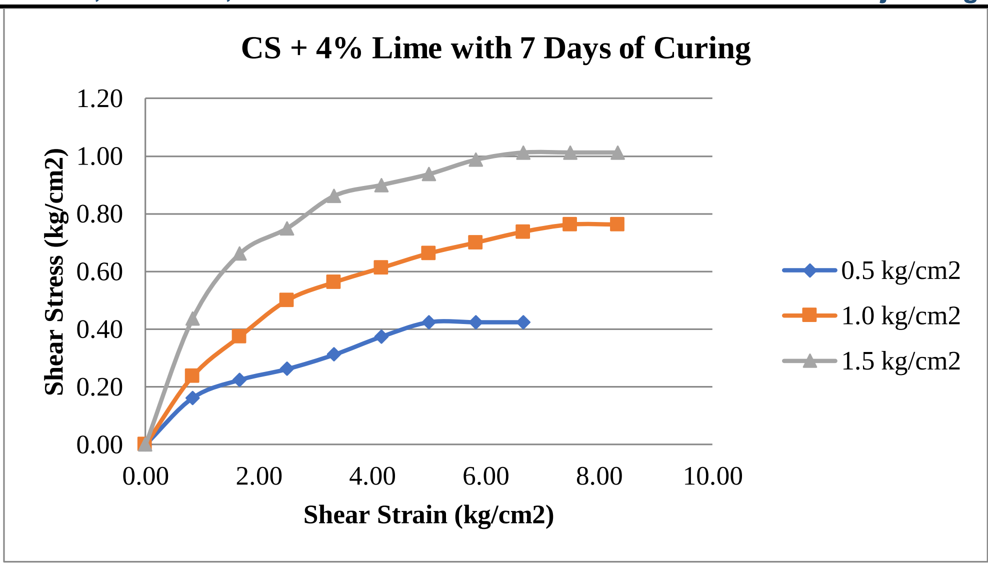

Fig. 1 Test results of Shear strain Vs Shear stress for copper slag mixed with 4% Lime after 7days of curing for the normal stress 0.5kg/cm^2, 1.0kg/cm^2 and 1.5kg/cm^2.

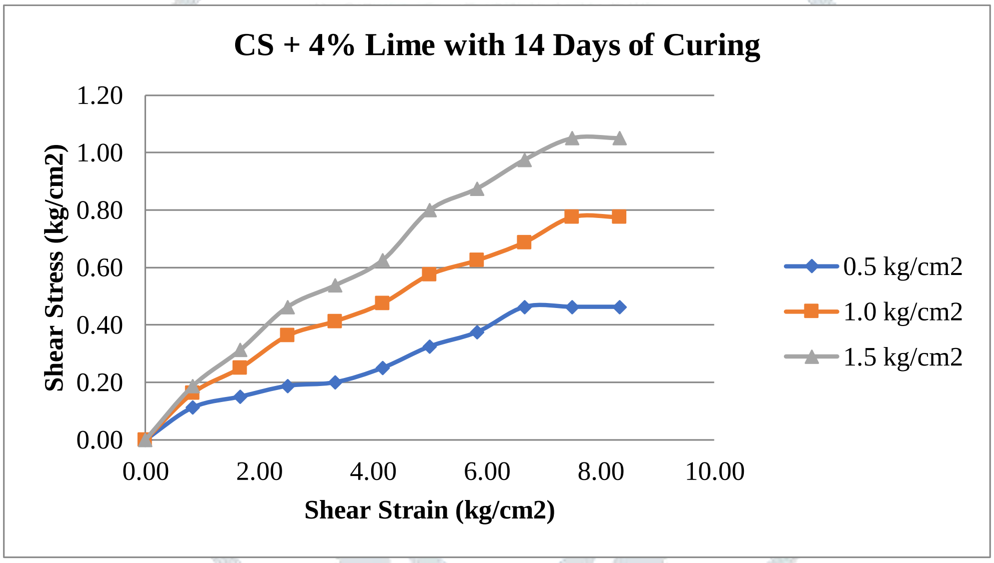

Fig. 2 Test results of Shear strain Vs Shear stress for copper slag mixed with 4% Lime after 14days of curing for the normal stress 0.5kg/cm^2, 1.0kg/cm^2 and 1.5kg/cm^2.

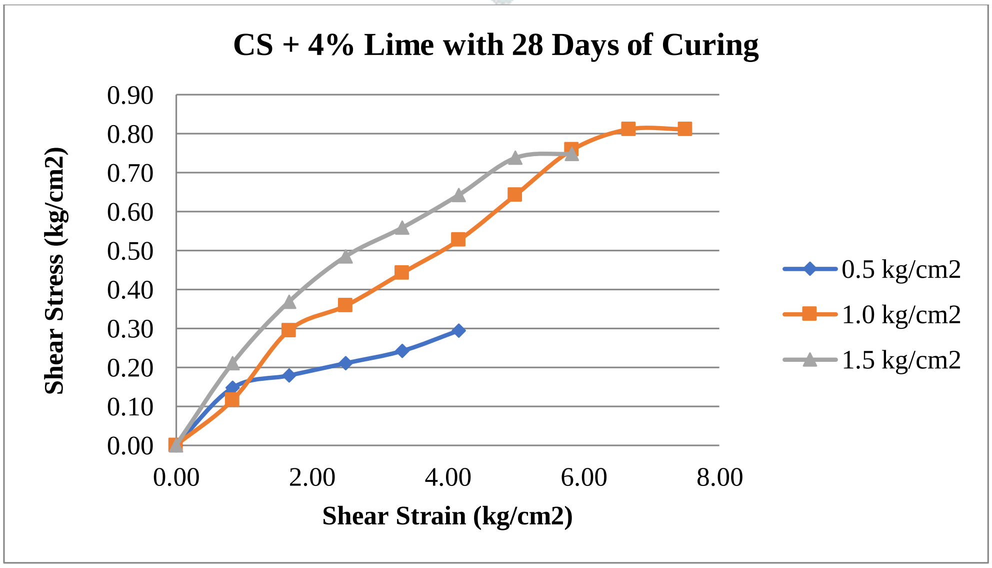

Fig. 3 Test results of Shear strain Vs Shear stress for copper slag mixed with 4% Lime after 28days of curing for the normal stress 0.5kg/cm^2, 1.0kg/cm^2 and 1.5kg/cm^2.

In fig 1, fig 2 and fig 3, the variation of shear strain with shear stress is shown for the normal stress of 0.5kg/cm^2, 1.0kg/cm^2 and 1.5kg/cm^2 when copper slag is mixed with 4% lime and is tested after 7days, 14days and 28days of curing. From these figures it can be seen that with increase in curing period there is an increase shear stress value.

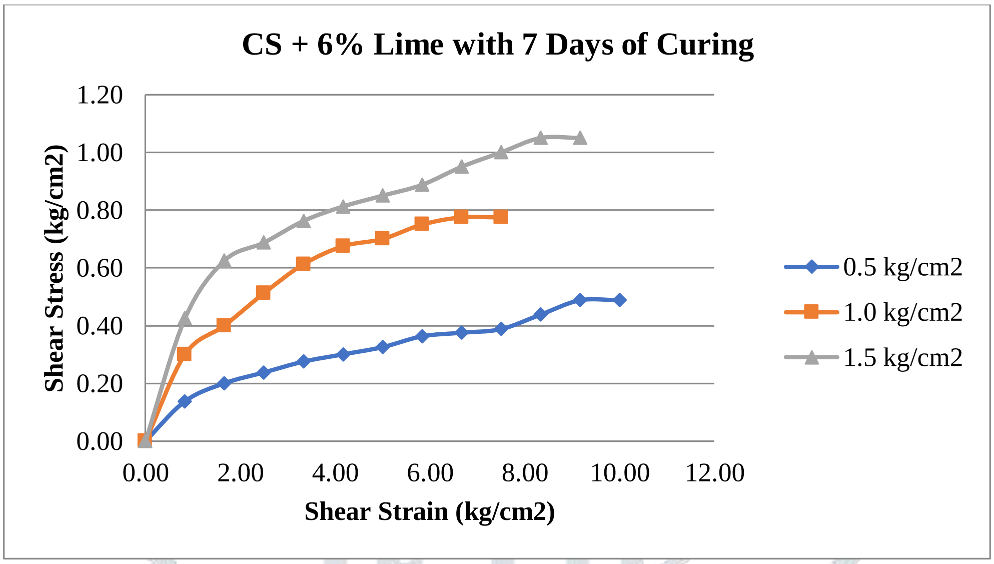

Fig. 4 Test results of Shear strain Vs Shear stress for copper slag mixed with 6% Lime after 7days of curing for the normal stress 0.5kg/cm^2, 1.0kg/cm^2 and 1.5kg/cm^2.

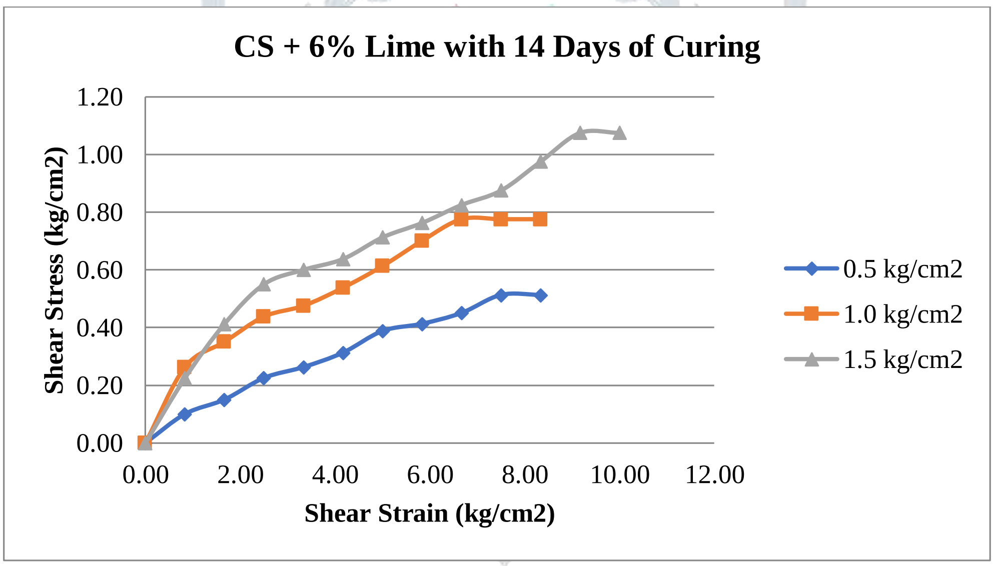

Fig. 5 Test results of Shear strain Vs Shear stress for copper slag mixed with 6% Lime after 14days of curing for the normal stress 0.5kg/cm^2, 1.0kg/cm^2 and 1.5kg/cm^2.

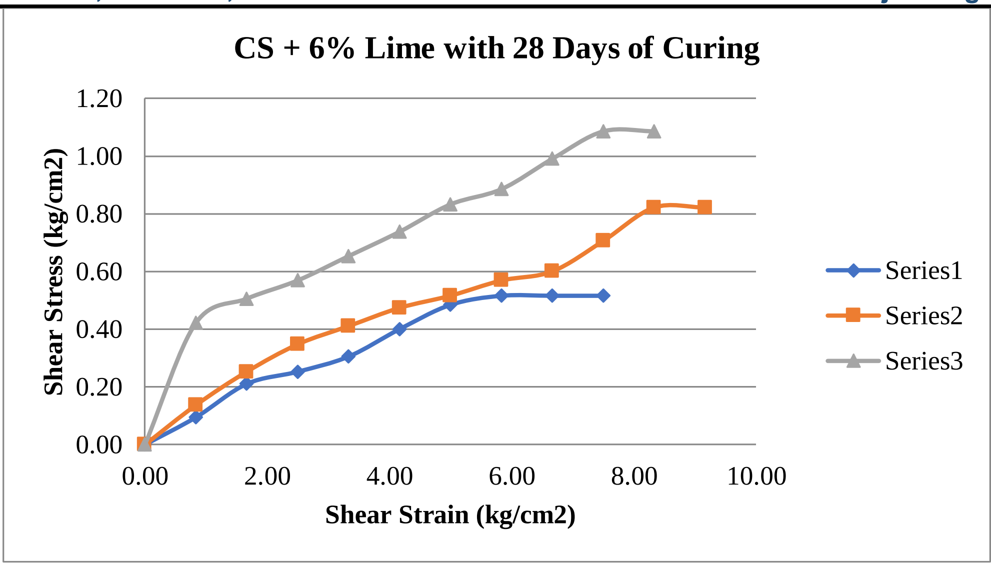

Fig. 6 Test results of Shear strain Vs Shear stress for copper slag mixed with 6% Lime after 28days of curing for the normal stress 0.5kg/cm^2, 1.0kg/cm^2 and 1.5kg/cm^2.

In fig 4, fig 5 and fig 6, the variation of shear strain with shear stress is shown for the normal stress of 0.5kg/cm^2, 1.0kg/cm^2 and 1.5kg/cm^2 when copper slag is mixed with 6% lime and is tested after 7days, 14days and 28days of curing. From these figures it can be seen that with increase in curing period there is an increase shear stress value.

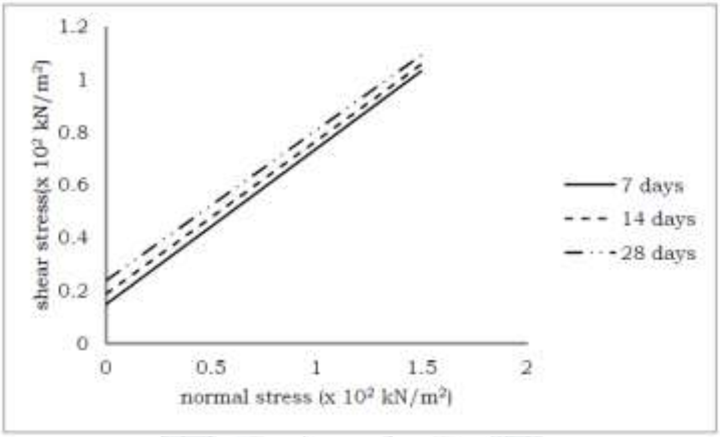

Fig. 9 Test results of Normal stress Vs Shear stress for copper slag mixed with 4% Lime after 7days, 14days and 28days of curing.

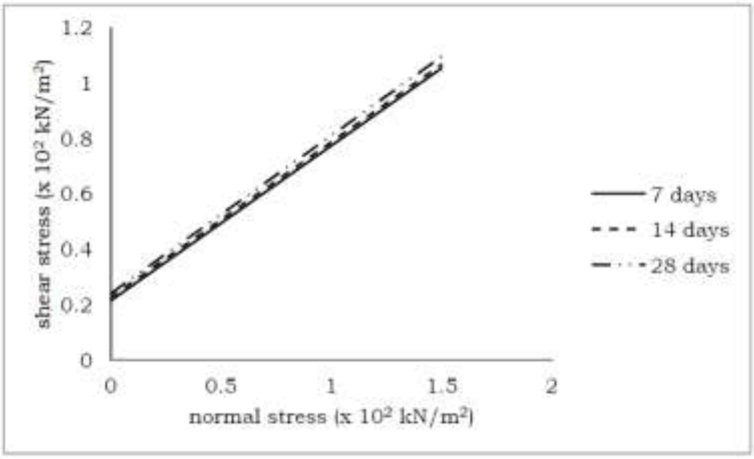

Fig. 10 Test results of Normal stress Vs Shear stress for copper slag mixed with 6% Lime after 7days, 14days and 28days of curing.

In fig 9 and fig 10, the variation of normal stress with shear stress is shown for 7days, 14days and 28days of curing when copper slag is mixed with 4% and 6% lime respectively. From these figures it is seen that with increase in curing period there is an increase in cohesion. The shear parameters are effectively changing with the increasing in curing period. Cohesion is increasing with increase in curing period and also with addition of 6% lime. Angle of internal friction is decreasing with increase in curing period and with addition of 6% lime.

4. Conclusions

Based on the above test results the below outlines are given.

- Lime admixed copper slag in various percentages gives effective and improved results of cohesion when compared to copper slag without any admixture.
- Copper slag when mixed with 4% lime and 6% lime, results increase in cohesion and decrease in angle of internal friction.
- From the results, it was noticed that cohesion increases with the addition of 6% lime to the copper slag for curing period of 7 days, 14 days and 28 days was about 1.4, 1.16 and 1.04 times respectively when compared with that with 4% lime.
- Lime admixed copper slag when tested after 7days, 14days and 28days of curing results improvement in cohesion and decrease in angle of internal friction as the curing period increases.
- When Lime mixed with CS along with soils may result in beneficial effects in terms of stabilization of clayey deposits.

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