ABSTRACT: Use of waste materials in road construction has been in vogue in India for quite sometime. This is particularly necessitated by the problems of disposal associated with it. Otherwise, these materials would cause problems to the environment. Copper slag is one of the waste materials that are being used extensively in the civil engineering construction industry. Copper producing units in India leave thousands of tonnes of copper slag as waste every day. Large quantities of the accumulated slag is dumped and left on costly land, causing wastage of good cultivable land. Based on U.S. environmental protection agency regulations, governing solid waste characteristics, copper slag can be classified as a non-hazardous material. Granulated copper slag is more porous and, therefore, has particle size equal to that of coarse sand. In this paper, a review of the previous research studies carried out by various researchers on utilization of copper slag in geotechnical applications is discussed and presented.

INTRODUCTION
Copper is one of the basic chemical elements which is a soft and ductile metal, known for its high thermal and electrical conductivity and has a reddish-orange surface in its pure state. It is commonly used in electrical, construction and transportation industries. 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. Each process consists of several steps in which unwanted materials are physically or chemically removed, and the concentration of copper is progressively increased.

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 byproduct, but 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, then if world smelter copper production was 15,900,000 metric tonnes as of Nov 2010, about 34,980,000 metric tonnes of slag was generated in the world (Copper Statistics, U.S. Geological Survey). 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 [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, subgrades and sub-bases. 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 mixed with fly ash and local soils (available near Delhi) in different proportions showed effective results with the suitability in embankment, sub base and base of a road pavement [10]. Comparison of values shows that the behaviour of copper slag is similar to that of medium sands and that it can be used as a construction material in place of sands, such as backfill of retaining walls and landfill for the construction of shallow foundations. Copper slag has high angularity and friction angle (up to 52°) of aggregates contribute to the stability and load bearing capacity. Also copper slag aggregates tend to be free draining and are not frost-susceptible. Copper slag can be used as an alternative aggregate in bituminous mixes [11]. Mroueh et al [12] carried out life-cycle analysis for the use of industrial waste slag in road and earth constructions which yielded effective conclusions for the reuse of waste by-products.

Also, other than geotechnical applications the effect of copper slag can be even seen effectively by replacing a part of the cement content in concrete. Copper Slag can also be utilized as fine aggregate in cement concrete. The study conducted by CRRI, New Delhi [10,13] showed that fine sand with slag up to 40 percent can be used as fine aggregate in pavement quality concrete as well as in dry lean concrete. Also, Central Electro Chemical Research Institute [14] studied the efficacy of blended CS with concrete and showed that the CS can be used as a fine aggregate in concrete mix. Transportation Research Board of Washington (TRBW) [15] also investigated the use of CS as fine aggregate in concrete and found that the mortar
strength ratio with cement, slag and water of 1:2:0.55 has higher strength properties.

Copper slag can be used as fine aggregate in concrete describing the strength, setting time and durability of concrete mixtures made with copper slag [16, 17]. Also, up to 15% by weight of copper slag was used as Portland cement replacement together with up to 1.5% of hydrated lime as an activator to pozolanic reactions and the results indicate that there is an increase in the compressive strength for up to 90 days of hydration [18, 19, 20].

The siliceous and silica-aluminous substances available in copper slag are considered pozzolanic; they react chemically with calcium hydroxide in presence of water at normal temperature to form cementitious products in the form of a gel. Therefore, if lime or cement is added to copper slag, the calcium present in it will react with the alumina and silica present in the latter, to form calcium-alumina-silicates which are cementitious products.

**TYPICAL PROPERTIES OF COPPER SLAG**

<table>
<thead>
<tr>
<th>Property</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness, Moh’s Scale</td>
<td>6 – 7</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>3.51</td>
</tr>
<tr>
<td>Plasticity Index</td>
<td>Non-Plastic</td>
</tr>
<tr>
<td>Swelling Index</td>
<td>Non-Swelling</td>
</tr>
<tr>
<td>Granule Shape</td>
<td>Angular, Multifaceted</td>
</tr>
<tr>
<td></td>
<td>Sharp edges</td>
</tr>
<tr>
<td>Grain Size Analysis</td>
<td></td>
</tr>
<tr>
<td>Gravel (%)</td>
<td>1.00</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>98.90</td>
</tr>
<tr>
<td>Silt + Clay (%)</td>
<td>0.05</td>
</tr>
</tbody>
</table>

(Ref. Birla Copper Unit, Hindalco’s Industries Ltd, Dahej, Gujarat, India)

**Effect of CS on Plasticity Index**

Copper slag, when mixed with locally available soil in a proportion of 30% CS and 70% soil, the plasticity index of the soil was reduced by 40% [24]. Copper slag with fly ash and local soil (available near Delhi) mixes were found to be non-plastic in nature [10]. Decrease in plasticity index shows that the copper slag when mixed with soil and the additives like fly ash and cement reacts on hydration and is considered to be pozzolanic.

**Effect of CS on Free Swell Index**

Free swell Index decreases from 122% to 70% for the local soil (available at Anna Nagar, Chennai) when mixed with 30% of CS with the addition of 2% cement [25]. There is a considerable reduction in the free swell index with copper slag when mixed with local soil (available at Anna Nagar, Chennai) due to the coarse fraction present in it. Copper slag can be used in controlling the swelling properties of expansive clays. The reduction in free swell index was observed to be 70% to 80% when solid wastes like fly ash, quarry dust and marble powder were used in expansive soils [26].

**Effect of CS on Compaction Properties**

Maximum dry density of the copper slag and fly ash were observed to be 26 kN/m³ and 11kN/m³. The soil mixed with CS and fly ash showed increased MDD and decreased OMC [10]. Voids of Coarser particles are filled by the finer particles and the unit weight increases as a result causing an increase in the maximum dry density and a decrease in the optimum moisture content which can give effective results for the sub-grade and sub-base applications. The soils treated with Portland cement showed that the maximum dry density decreased by 1% and optimum moisture content increased by 0.6%. When the same soil was mixed with copper slag and 2% cement, it showed an increase in MDD and a decrease in OMC [27].

**Effect of CS on California Bearing Ratio (CBR)**

CBR test results reviewed from the published data on copper slag-treated soil showed good increase in the CBR value with an increase in the copper slag content for all mix proportions. The CBR values of cement mixed soil with copper slag are 3 to 7 fold higher than that of the soil with copper slag waste without the presence of the Portland cement. Soaked CBR with 2% addition of cement has a drastic increase in the CBR value [25]. There is a reduction in swelling characteristics and increase in density results in an increase in the CBR values. Increase in CBR values is

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**Table 1 Chemical Composition of Copper Slag**

<table>
<thead>
<tr>
<th>Property</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron Oxide – Fe₂O₃</td>
<td>42 – 48</td>
</tr>
<tr>
<td>Silica – SiO₂</td>
<td>26– 30</td>
</tr>
<tr>
<td>Aluminium Oxide – Al₂O₃</td>
<td>1– 3</td>
</tr>
<tr>
<td>Calcium Oxide – CaO</td>
<td>1.0– 2.0</td>
</tr>
<tr>
<td>Magnesium Oxide – MgO</td>
<td>0.8– 1.5</td>
</tr>
</tbody>
</table>

(Ref. Birla Copper Unit, Hindalco’s Industries Ltd, Dahej, Gujarat, India)
essential in poor sub-grade soils and for the application in rigid pavements laid in problematic soils.

**Effect of CS on UC Strength**

Shear strength of the soil is one of the most important properties in geotechnical applications. The effect of CS on shear strength was studied by conducting the unconfined compressive strength test on mix of local soil (available at Anna nagar, Chennai) along with 2% addition of cement at optimum moisture content. The UC strength of the mix increases up to 50% when CS is added and there after decreases [25]. The increase in the unconfined compressive strength is because of the high internal friction of the copper slag.

**CONCLUSIONS**

From the aforementioned review, the following conclusions are presented.

1. Copper slag has the potential to use as admixture to improve the properties of problematic soils.
2. Copper slag with 30% to 50% can be mixed with problematic soils to improve or modify the soil characteristics.
3. Copper slag can also be mixed with fly ash and cement to enhance the strength effectively.
4. Copper slag can be recommended for sub-grade, sub-base, bitumen mixes. Engineering behaviour of expansive soils can be improved by utilizing 40% of the copper slag along with 2% Portland cement for embankment construction, land reclamation and for improving sub-grade soil conditions.
5. The grain size distribution and properties of copper slag are similar to that of medium sand and it can be used as a construction material in place of sand used in backfill for retaining walls and shallow foundations.
6. By utilizing and reusing the industrial waste product, namely, copper slag, wastage of good cultivable land can be avoided when large quantities of the accumulated slag is dumped and left on costly land.

**REFERENCES**

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24. Tandel Yogendra.K., Utilization of Copper Slag as a Sub grade.