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Review on Usage of Copper Slag For Pavements

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Abstract- Copper slag generated during smelting and refining of copper from its ore is an industrial byproduct. The storage and proper disposal of copper slag is an issue to be addressed as a priority. Considerable research has been undertaken on this subject all over the world. In this paper, utilization of copper slag as a construction material for sub grade and sub base layers of pavements is discussed. It is found that copper slag can be used as partial replacement for conventional aggregates in pavements. The study also revealed that copper slag can be used with additives like lime, fly ash, and cement, granulated blast furnace slag to improve the bearing strength, unconfined compressive strength and stabilize the poor subgrade. Research findings indicate that copper slag is stable, does not undergo leaching even under extreme weather conditions, non- toxic and environmentally safe.

Keywords — Copper slag, applications, CBR, pavement, soil, industrial waste material

I. INTRODUCTION

Copper slag is produced during pyro metallurgical manufacturing of copper from its ores. For every tonne of metal production, about 2.2 ton of slag is generated. At present, across the world if 33 tonnes of slag is generated then in India three copper producers Sterlite copper, Birla Copper and Hindustan Copper produce around 6-6.5 tonnes of slag at different sites. The production of copper slag is 120-130 lakh ton per annum. Copper producing units in India leave thousands of tons of copper slag as waste every day. Dumping of huge quantities of slag is an environmental challenge. However, good physio mechanical characteristics of copper slag makes it useful as an input for cement, structural fill, ballast, abrasives, aggregates, roofing granules, glass, and tiles., Copper slag is an economical and the most suitable alternative to the natural aggregate (sand, crushed from natural rocks)[15].It is finding increasing wide acceptance in ready-mix concrete manufacturers and in government road projects for concrete applications as prescribed by BIS IS 383:2016 (Bureau of Indian Standards) for past many areas. Recently many corridor projects used these alternatives, thereby avoiding deplete the precious natural resources contributing to save the environment and sustainability. India is expected to be the sixth largest copper market by 2020 with Electrical, Transport and Telecommunications as major consumption sectors. The utility of copper slag as alternative material for other industrial and sectoral application has been vastly explored in the last one decade. Research on the use of copper slag as a replacement for coarse or fine aggregates shows its suitability as a construction material. This paper reviews use of copper slag in stabilization of sub grades, sub base, embankments, land reclamation and other applications for pavements.

ADVANTAGES OF USING COPPER SLAG

The benefits of copper slag are as follows,

- Use of copper slag in the road construction helps in reducing environmental impacts due to quarrying.
- Using copper slag for construction reduces dumping of huge quantities, minimising environmental concerns such as leaching of metals into soil, ground water contamination and addresses the problem of landfill space for its disposal.
- Copper slag used as an alternative material can address the increased demand on natural aggregates for construction. Utilizing such Industrial waste products leads to sustainability and economy in construction.
- In states like Kerala, Maharashtra and Gujarat, sand mining in rivers has already been banned owing to its disastrous impact on ecology. Therefore, slag has a big potential of getting developed as a suitable alternative material to these resources.
- Concrete Applications – Copper slag can replace river sand in fine aggregate up to 50% (as per IIT , Kanpur study report titled "Durability of Cement Concrete using Copper Slag").It is used as partial replacement for fine aggregate in cement mortar and cement concrete.

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- Its innovative use for stabilising is found to increase the strength of soil.
- Copper slag is also suitable as a fill material for land reclamation.

CHARACTERISTICS OF COPPER SLAG

The general physical and chemical properties of copper slag are shown in Table 1 and Table 2.

Table 1 Physical properties of copper slag

Properties	Copper Slag
Appearance	Black and Granular
Shape	Irregular
pH	6.6 – 7.2
Fineness Modulus	3.4-4.8
Specific Gravity	3.5 – 3.8
Bulk Density	1.8-1.9 kN/m^3

Table 2 Chemical properties of copper slag

Composition	Percent by weight
Fe_2O_3	55-60 %
SiO_2	27-33 %
CaO	1-3.5 %
Al_2O_3	3%
MgO	0.9%
K_2O	1.02%
Na_2O	0.95%
TiO_2	0.6%
Cu	Traces - 1%

Table 3 Available Sizes of copper slag

Size, mm
0.2 - 0.5
0.2 - 0.85
0.2 - 1.4
0.5 - 1.4
0.2 - 2.5 0.5 - 2.5
0.8 - 2.2
1.0 - 3.0
2.0 - 3.0

Copper slag is available in different sizes ranging from 0.2mm to 3mm as shown in Table3

Table 4 Typical Grain size distribution

Sieve Size, mm	% Finer
4.75	99.79
2.36	98.02
1.18	77.30
0.6	24.56
0.425	7.30
0.3	4.07
0.15	1.47
0.075	0.91

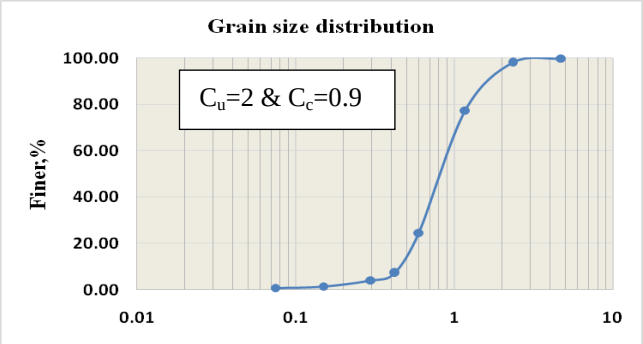

Fig 1 Typical Grain size distribution of copper slag

Fig 1 shows typical grain size distribution curve of copper slag with uniform coefficient is 2 and coefficient of curvature is 0.9. It is similar to that of sand, ideal for pavement construction, land reclamation. The mean diameter was around 0.5mm which was larger than that of sand. Generally fill material with larger mean size is preferred. It is known that larger the mean size, greater will be the hydraulic conductivity and greater the shear resistance.[12]

II. EXPERIMENTAL STUDIES

Few recent studies conducted using copper slag for pavements are given below:

Kavisri et al., (2018) [1] conducted experiments to study the effect of stabilization of clayey soil by copper Slag and granulated blast furnace slag. Soil samples mixed with 10%, 20%, and 30% of individual stabilizers were tested for compaction characteristics, unconfined compressive strength and California bearing ratio. It was concluded that 70% clay soil and 30% copper slag or 30% granulated blast furnace slag was the stabilization ratio to meet sub grade requirements.

Rajendra Kumar et al., (2017) [2] studied the effect of copper slag and fly ash on black cotton soil with liquid limit of 86%. Soil treated with various percentages of additives were tested for Modified proctor compaction and California bearing ratio . Copper slag was added in percentages varying from 5% to 35%. The optimum percent was found to be 30% copper slag with 70% expansive soil with soaked CBR of about 6.3%. Further studies were conducted with addition of flyash in percentages varying from 2% to 10% and addition of 8%

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flyash found to exhibit the maximum CBR of 45.5%. It was found that optimum moisture content decreased and maximum dry density increased upon addition of copper slag or fly ash to soil. There was significant increase in CBR for treated soil upon the addition of flyash.

Jaber Shahiri et al., (2016) [3] investigated the effect of adding cement and copper slag to clay soil with a liquid limit of 37%. The soil cement mix were prepared by adding various percentages of cement 2%, 4%, 6% to soil and tested for compaction characteristics. Maximum dry density reduced and optimum moisture content increased. The unconfined compressive strength after curing was found to increase from 2.4 Mpa to 11.9 Mpa after 90days of curing with 6% cement. The clay soil was mixed with copper slag varying from 5% to 20%. The MDD increased and OMC decreased with addition of copper slag to soil. The percentage of copper slag was identified as 20% to carry out further tests with cement, copper slag and soil mixtures. Unconfined compressive strength of soil with 6% cement and 20% copper slag after 90days of curing was found to be 13.4 Mpa. Further an Artificial Neural Network model was developed with 8 input parameters such as copper slag content, cement content, water content, dry density, liquid limit, plastic limit, pH and curing age. ANN was used for analysis. A network composed of 10 neurons in a hidden layer was considered. The proposed model was efficiently applied to predict elastic modulus of stabilized soils with the input parameters. The results proved that the model was efficient in prediction.

Parvathi et al., (2016) [4] evaluated the effect of copper slag on Lime stabilized clay. Soil samples with different percentages of copper slag 2%, 4%, 6%, 8%, 10% were prepared and unconfined compressive strength tests were conducted. It was reported that 6% copper slag exhibited the maximum value of 44.4kPa. Further to that optimum percentage of copper slag of 6%, lime was added in varying percentages 2%, 4%, 6%, 8%, 10% and tested for unconfined compressive strength, California Bearing Ratio and Scanning Electron Microscopy. Test results indicated that unconfined compressive strength after adding 6% lime was maximum with a value of 306kPa after 28days curing period. The California bearing Ratio of soil –copper slag – lime mix was found to be 18%. The CBR value of untreated soil was 2.1%. It was concluded that copper slag is effective in increasing the CBR and UCC of lime stabilized clays. Also Reduction in pore spaces was observed indicating change in micro structure of soil with addition of lime and copper slag when compared to untreated soil.

Jinka Chandrshekar et al.,(2015) [5] experimented on the use of Waste Material such as Copper Slag in geotechnical Applications. Copper slag was found to be coarse grained material with around more than 95% sand size particles. Test samples with 60% copper slag with 40% soil were prepared. Free swell test, California Bearing ratio test, Compaction test were conducted on the samples. Test results showed that plasticity index reduced by 40%, free swelling index also reduced to be 20% to 30% when expansive soil was compacted with copper slag .Also the Maximum dry density increased with highest value being 1.9 KN/m3 while the Optimum Moisture Content decreased. From the results it was also found that there is a decrease in swelling characteristic and increase in California Bearing Ratio due to addition of copper slag. From the test results it was concluded that copper slag in the range of 30% to 60% can be mixed with problematic soils to improve its characteristics and recommended for sub grade, sub base and bitumen mixes. Further by utilizing 60% of copper slag with 40% of soil can be used for embankment construction, land reclamation and sub grade soil improvements. The grain size distribution and properties of copper slag are similar to medium sand and can be used as replacement for sand used in back fill for retaining walls and shallow foundations.

Ramesh Chandra Gupta et al .,(2013) [6] investigated the experimental studies on the optimum moisture content and maximum dry density of sandy and clayey soil stabilized by copper tailings .Samples with varying percentages of copper such as 10%, 20%,30% up to 100% with soil were adopted. The maximum dry density of sandy soil and clayey soil stabilized by copper tailing was determined using Modified proctor test and triaxial test. As the percentage of copper tailing increases the dry density increases to a maximum of 1.83gm/cm^3 for sandy soil and the maximum dry density for clay soil was 1.93gm/cm^3. The variation in dry density with water content for standard proctor test did not follow normalize curve as the material having higher percentage of copper tailings needs more compaction energy. From the tests it was reported that the mix range of 70% clay with 30% of copper tailings to 30% clay with 70% copper tailings resulted in good strength improvement.

Mahesh et al., (2013) [7] studied the effect of fly ash on the properties of Expansive soil with liquid limit 65%and identified fly ash as a potential admixture to improve the engineering properties of expansive soil as it improves the California Bearing Ratio and reduces swelling. Test Samples with 5%, 10%, and 15% up to 40% of fly ash were mixed with expansive soil. Tests such as standard Proctor, consistency limits, Free Swell, California Bearing Ratio were performed on the samples. From the results it was observed that the liquid limit decreased and plasticity index also reduced by 30-40% with an addition of 10-15% flyash. Free swell and swelling pressure also reduced by 40-50% by adding 20%of flyash. Maximum dry density increased by 15-17% and optimum moisture content reduced by 30-35%.California bearing ratio for expansive soil also increased by 70-75% with an addition of 25-30% of fly ash. Further increase in the addition of fly ash for 25-30% had no significant improvement in the engineering properties. It

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was concluded that the penetration resistance of expansive soil improved by the addition of flyash. Also the plasticity characteristics and expansiveness of soil reduced by the addition of flyash.

Patel et al., (2012) [8] investigated feasibility of Copper Slag – Fly Ash Mix as a Road Construction Material and adopted Copper slag Fly ash Mix for use in Sub Base course of pavement . Test samples of soil with different percentages of fly ash such as 10%, 20%, 30%, and 40% were tested for different curing periods of 0, 7, 14, 28 days. Geotechnical properties of trial mixes were tested for unconfined compressive strength, California Bearing Ratio, Tri axial shear Strength. The Unconfined compressive strength increases with addition of flyash upto 30% and decreases thereafter .The value also increases with increase in the curing period for all mixes. The California bearing ratio also increases with the curing period and the mix with 30% flyash and 70% copper slag was up to 78 after 28 days of curing and satisfies the criteria for sub base course as per IRC37-2001.From the experimental findings it was concluded that 30% fly ash and 70% copper slag was found to be optimum for use in sub base layers of flexible pavements.

Lavanya et al., (2011) [9] reviewed the use of Copper Slag in Geotechnical Applications. It has been concluded that the copper slag in the proportion of 30% to 50% enhances the soil characteristics. The Grain size distribution and property of copper slag are similar to that of medium sand and it is also stated that copper slag mixed with 2 % cement increases the unconfined compressive strength of the mix up to 50% .When fly ash is added to copper slag soil mixes it decreases the plasticity index and free swell index. Upon addition of flyash to copper slag –soil mix, the maximum dry density increases and optimum moisture content decreases. California bearing ratio of cement mixed soil with copper slag is 3-7 times higher than that of soil copper slag mixes. Hence copper slag has the potential to modify the soil characteristics and when mixed with cement or flyash it can be used for improving sub grade soil condition, embankment construction and land reclamation.

Pundhir et al., (2005) [10] conducted experimental studies with Copper Slag as fine aggregate (up to 30%) in the design of bituminous mixes like Bituminous Macadam, Dense Bituminous Macadam, Bituminous Concrete and Semi-Dense Bituminous Concrete. Mechanical properties of mix such as Marshall Stability, Indirect Tensile Strength were determined. It was observed that addition of Copper Slag as fine aggregate in various bituminous mixes provided good interlocking and eventually improved the volumetric and mechanical properties of bituminous mixes. It was concluded that copper slag can be used as fine aggregate or as replacement for crusher dust.

LEACHING AND TOXICITY ASPECTS OF COPPER SLAG

P. Shanmuganathan et al., (2007) [11] conducted detailed studies on the toxicity and long-term stability of copper slag of varying heavy metal concentration generated over a 14-week period in an Indian copper plant through the ISASMELT process was carried out using toxicity characteristic leaching procedure, multiple extraction procedure and sulfuric acid leaching of granulated and mechanically activated slag as a function of pH at two different temperatures. The test samples of varying compositions derived from the use of several copper concentrates indicate poor leachability of the heavy metals and assure long-term stability even in extreme atmospheres. Leaching tests on mechanically activated samples showed the resistance to leaching of the heavy metals even upon weathering. The leaching tests indicate that the heavy metals present in the slag are stable and are not likely to dissolve significantly even through repetitive leaching under acid rain in a natural environment. The highest concentration of all the elements is far below the prescribed limits.

Teik-Thye Lim et al., (2006) [12] experimented on the use of spent copper slag for land reclamation. The physical and geotechnical properties of the spent copper slag were assessed by Hydraulic conductivity and shear strength tests. These properties were compared with conventional fill materials such as sand. The potential environmental impacts associated with the use of spent copper slag for land reclamation were also evaluated by conducting tests such as pH and Eh measurements, batch leaching tests, neutralizing capacity determination and monitoring of long term dissolution of the material. From the test results it was concluded that the engineering properties of copper slag is suitable for land reclamation. It was also found that the copper slag is weather resistant as there is no generation of acidic leachate or toxic heavy metals into soil which makes the copper slag environmentally safe. This aspect highlights the safe use of copper slag as a subgrade material.

Saraswathy et al., (2014) [13] conducted the Corrosion and Leaching Studies in Blended Copper Slag Mortar. In this the effect of copper slag leaching was evaluated using Atomic Absorption Spectroscopy immersed in three aqueous media such as tap water, sea water, and synthetic/artificial rain water. The mechanical and corrosion resistance properties of copper slag admixed concrete was evaluated using compression test, electrochemical tests. Sand was totally replaced with copper slag in making the concrete specimens. From the investigations it is observed that the copper slag leaching was found to be very less even after 180 days of exposure in aqueous media. Tests showed that the addition of copper slag increased the compressive strength of the concrete. Rapid Chloride Penetration Test and other electrochemical tests indicated that copper slag

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admixed mortar performed equal to the sand mortar in sea water environments. From investigations it was concluded that copper leaching is very less even after 150 days of exposure in all aqueous media. .Compressive strength measurements showed increase in the compressive strength of the copper slag concrete. Rapid Chloride Penetration test revealed that after 90 days curing period the total charge passed was found to be very less when compared with the sand mortar. Gravimetric weight loss measurements indicated that negligible corrosion was observed after 150 days of exposure in sea water. .Open circuit potential and impedance measurements were also conducted. From the result it was clear that copper slag can be used as an alternative material for coarse and fine aggregate, since it gives better performance in all the corrosion tests conducted and permeability is less when compared with control concrete. Hence Copper slag can be utilized as sand replacement material without affecting the durability properties of concrete. Copper slag can be used as a potential alternative to coarse aggregate/ fine aggregate used in concrete and mortar

III .OTHER FINDINGS

Copper slag behaves as sandy soil since percentage of sand size particle is high in copper slag. Granulated copper slag is more porous and, therefore, has particle size equal to that of coarse sand. Copper slag is a non-hazardous, non-toxic and non-leachable material, thereby facilitating its suitability in such applications. It does not seep into the ground water and is not a pollutant. Some of the research findings by reputed institutions ease many myths about the material.

Here are a few of them

1. Industrial Toxicology Research Centre (ITRC), Lucknow,(2004) conducted Leach ability & Toxicity Test, Seed Germination Test and concluded copper slag is Found safe for aquatic fauna and flora. It does not affect early growth of seedling [16]
2. Highways Research station (HRS), Chennai conducted suitability test for Road construction and found copper slag to be suitable material for use as an alternative material for road construction.[Tamilnadu state highway wing][17]
3. Central Electrochemical Research Centre (CECRI), Karaikudi conducted Corrosion and Leaching Studies on Blended Copper Slag in Concrete and Concluded non-leach ability & low conductivity of concrete made of copper slag [18]
4. National Council for Cement and Building Material (NCCBM), New Delhi (2005) conducted Technical Suitability Study of Copper Slag in Cement Manufacturing Process and found its suitability in manufacturing ordinary Portland cement (OPC) and Portland slag cement (PSC). Contributes in energy saving [19]
5. Central Road Research institute (CRRI), New Delhi (2006) conducted a detailed Study for 2 Years on Usage of copper slag as an alternative for Aggregate Material for Road Construction Applications. Study recommended utilization of slag in various layers of road including sub base, sub-grade and pavement layers. [20]
6. NHAI issued a policy letter for promoting usage of Copper Slag in road construction[21]
7. Structural Engineering Research Centre (SERC), Chennai conducted Application of Copper Slag in Concrete Manufacturing and concluded that slag possesses properties like river sand and can be used as a partial replacement of sand in ready-mix concrete for better strength and workability in addition to resisting abrasion[22]
8. National institute for Oceanography (NIO), Goa, conducted Impact Assessment Studies on Utilization of Copper Slag as Reclamation Material for Berthing Facility on Marine Flora and Fauna and concluded that usage of copper slag would not alter the water quality and biological productivity of coastal water.[23]

FIELD APPLICATIONS

Road Application - Replacement of fine aggregates up to 20% in all layers of the road and embankment construction (Evident from CRRI, New Delhi study titled "Feasibility Study on Use of Copper Slag in Road and Embankment Construction,")

Various roads also have been constructed in India using copper slag as mentioned below.

1. It is being currently employed in the Madurai Tuticorin industrial corridor project, thereby eliminating the need to deplete the existing natural topography of the region.

2. In the Kerala-Tamil Nadu border, L&T is constructing a four lane concrete road using copper slag.

TYPICAL MICROGRAPHS

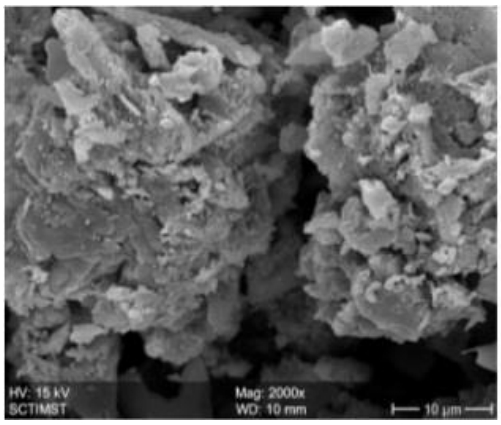

Fig 2. SEM of clay [4]

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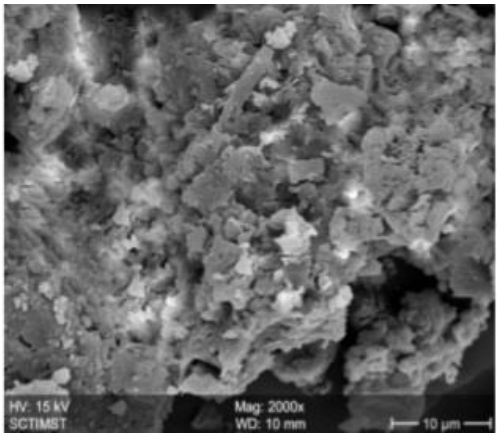

Fig 3. SEM of Soil treated with copper [4]

IV. CONCLUSION

Based on the review of literature, the following conclusions are drawn:

Copper slag is an industrial by product with high specific gravity and available in sizes varying from 3mm to 0.2mm. It can be used as replacement for conventional aggregates in roads. Addition of copper slag to soil reduces the optimum water content and increases dry density of the mix. California bearing ratio increases with the addition of copper slag to soil. Various additives such as lime, cement, fly ash, GGBFS are added to copper slag to improve the bearing strength for its use as sub grade, sub base, base course material. Because of the improved engineering behavior Copper slag is recommended for embankment construction, land reclamation and pavements. It is environmentally safe since there is no risk of toxins leaching in to the soil.The use of copper slag as an alternative to conventional materials is economically significant in regions near the slag source Utilizing copper slag in pavements is a sustainable way to solve the problem of storage and disposal faced by copper smelting industries which generate million tonnes of copper slag every year.

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