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MECHANICAL AND DURABILITY PROPERTIES OF CONCRETE MADE BY REPLACING COPPER SLAG WITH FINE AGGREGATES: A REVIEW

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Abstract— **Concrete was widely used in buildings, large structures and other industrial structures, etc. as a building material. Growing demand for building materials, which have increases the need for alternative materials to be used in conventional concrete production. To reduce dependence on natural aggregates as the main source of aggregate in concrete, artificially produced aggregates and artificial aggregates produced from industrial waste provide an alternative for the construction industry. This review study encouraged the use of industrial waste copper slag as a substitute for natural concrete aggregates. Numerous research works has been conducted to assess concrete's mechanical properties such as compressive strength, flexural strength, and tensile strength. The durability properties of concrete such as rapid chloride penetration test, water absorption test and many more have been evaluated in numerous research works.**

This review study shows the results on the effects of different types of fine aggregate on the mechanical and durability properties of concrete obtained from experimental results by different researchers. This review study shows that when replaced with natural river sand, the performance of manufactured sand and copper slag as fine aggregate in concrete is better. The percentage of natural sand replacement with copper slag in concrete up to 40 percent increases concrete performance.

Keywords— **Copper Slag, Metakaolin, Fly Ash, Concrete**

I. INTRODUCTION

Many countries are witnessing a rapid growth in construction industries which involves the use of natural resources for the development of the infrastructure. To reduce the dependence on natural aggregates as the main source of aggregate, artificially manufactured aggregates and artificial aggregate generated from industrial wastes provide an alternative for the construction industries. The utilization of industrial waste or secondary materials has encouraged the production of cement and concrete in construction field. New by-products and waste materials are being generated by various industries, dumping or disposal of waste materials causes environmental and health problems. Therefore, recycling of waste materials is a great potential in concrete industry. Many by-products are in use over the years such as fly ash, silica fume and slag were considered as waste materials. Concrete prepared with such materials showed improvement in workability and durability compared to normal concrete and has been used in the construction of power, chemical plants and under-water structures. Many intensive research studies have been carried out to explore all possible reuse methods. Construction waste, blast furnace, steel slag, coal fly ash and bottom ash have been accepted in many places as alternative aggregates in embankment, roads, pavements, foundation and building construction, raw material in the manufacture of ordinary Portland cement pointed out by *luin et al. (2006).*

Copper slag is an industrial by-product material produced from the process of manufacturing copper. For every ton of copper production, about 2.2 tonnes of copper slag is generated. It has been estimated that approximately 24.6 million tons of slag are generated from the world copper industry *Gorai et al. (2003).* Copper slag possesses mechanical and chemical characteristics that qualify the material to be used in concrete as a partial replacement for Portland cement or as a substitute for aggregates. For example, copper slag has a number of favourable mechanical properties for aggregate use such as excellent soundness characteristics, good abrasion resistance and good stability reported by *Gorai et al. (2003).* The utilization of copper slag for applications such as Portland cement replacement in concrete, or as raw material has the dual benefit of eliminating the cost of disposal and lowering the cost of the concrete.

The use of copper slag in the concrete industry as a replacement for cement and as a raw material can have the benefit of reducing the costs of disposal and help in protecting the environment. Despite the fact that several studies have been reported on the effect of copper slag replacement on the properties of Concrete, further investigations are necessary in order to obtain a comprehensive understanding that would provide an engineering base to allow the use of copper slag in concrete.

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II. COPPER SLAG

Sterlite Industries India Limited (SIIL), Tuticorin, Tamil Nadu is the principal subsidiary of Vedantha Resources Public Limited Company (PLC), a diversified and integrated Financial Times Stock Exchange (FTSE)100 metals and mining company, with principal operations located in India and Australia.The annual turnover of SIIL, Tuticorin, India is Rs. 13,452 crores. SIIL, a leading producer of copper in India, pioneered the manufacturing of continuous cast copper roads and established India's largest copper smelting and refining plant for production of world class refined copper. SIIL is the producer of copper slag (Figure 1) during the manufacture of copper metal. Presently, about 2500 tons of copper slag is produced per day and a total accumulation of around 1.5 million tons.

Fig. 1. Appearance of Copper Slag Sample

This slag is currently being used by many purposes. It is a glassy granular material with high specific gravity particle sizes. The various myths about copper slag are shown in Table 1. The size of the particle is of the order of sand and can be used as a fine aggregate in concrete. To reduce the accumulation of copper slag and also to provide an alternative material for sand and cement, an approach has been done to investigate the use of copper slag in concrete for the partial replacement of sand and cement.

The chemical composition of copper slag is given in Table 2. Since the main composition of copper slag is SiO2 and Fe2O3, it has low melting point and could decrease the calcinations temperature for the manufacture of cement clinker. According to the results shown by *Nazari et al,* (2010) that the addition of nano- Fe_2O_3 particles blended concrete had significantly higher compressive strength compare to that of the concrete without nano- Fe_2O_3 particles. It is found that the cement could be advantageously replaced with nano-Fe_2O_3 particles up to maximum limit of 2.0% with average particle sizes of 15 nm.

Table -1 Concerns/ false belief over copper slag *(Brindha 2011)*

FALSE BELIEF OVER COPPER SLAG	PERFORMANCE IN REAL
Toxic material	**Non-toxic material**
Durability	**High durability**
Decreases concrete strength	**Improves concrete strength**
Bleeding	**No bleeding of concrete up to 40-50% replacement**
Leaching	**Leaching levels are insignificant**

Although, the optimal level of nano- Fe_2O_3 particles content was achieved with 1.0% replacement. Partial replacement of cement by nano- Fe_2O_3 particles decreased workability of fresh concrete; therefore use of super plasticizer is substantial. The performance test results indicated that strength and durability of cement made using copper slag performed better than using iron powder. The chemical composition of cement and copper slag is similar in many aspects; hence copper slag may be used as a supplementary cementing material as well.

Table -2 Chemical composition of copper slag used by various researchers

COMPONENTS(%)	WU ET AL, (2010)	AL-JABRI ET AL, (2009)	GEETHA ET AL, (2017)	MIRHOSSEINI ET AL, (2017)
Aluminum oxide (Al_2O_3)	**2.52**	**2.79**	**3.01**	**3.71**
Silicon oxide (SiO_2)	**31.92**	**33.05**	**35**	**28.83**
Sulfur trioxide (SO_3)	**1.34**	**1.89**	**-**	**3.26**
Calcium oxide (CaO)	**1.25**	**6.06**	**0.20**	**5.80**
Sodium oxide (Na_2O)	**1.40**	**0.28**	**0.95**	**-**
Magnesium oxide	**1.65**	**1.56**	**0.90**	**-**

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(MgO)				
Potassium oxide (K_2O)	**0.81**	**0.61**	**1.02**	**1.15**
Iron oxide (Fe_2O_3)	**59.11**	**53.45**	**55**	**46.37**

A. **Production of Copper Slag**

With increasing scarcity of river sand and natural aggregates across the country, construction sector is under tremendous pressure to explore alternative to these basic construction material to meeting growing demand of infrastructure demands. In states like Kerala, Maharashtra and Gujarat, sand mining in rivers has already been banned owing to its disastrous impact ecology. Therefore, slag has a big potential of getting developed as a suitable alternative material to these resources. It is a new business avenue for us and we are going to make revenue out of waste. Copper slag is a by-product obtained during the matte smelting and refining of copper has been reported by *Biswas and Davenport (2002)*. The major constituent of a smelting charge are sulphides and oxides of iron and copper. The charge also contains oxides such as Silicon Dioxide (SiO_2), Aluminium Oxide (Al_2O_3), CaO and Magnesium Oxide (MgO), which are either present in original concentrate or added as flux. It is Iron, Copper, Sulphur, Oxygen and their oxides which largely control the chemical and physical constitution of smelting system. A further important factor is the oxidation/reduction potential of the gases which are used to heat and melt the charge stated by *Gorai et al. (2002)*. As a result of this process copper rich matte (sulphides) and copper slag (oxides) are formed as two separate liquid phases. The addition of silica during smelting process forms strongly bonded silicate anions by combining with the oxides. This reaction produces copper slag phase, whereas sulphides from matte phase, due to low tendency to form the anion complexes. Silica is added directly for the most complete isolation of copper in matte which occurs at near saturation concentration with SiO_2. The slag structure is stabilized with the addition of lime and alumina. The molten slag is discharged from the furnace at 1000-1300ºC. When liquid is cooled slowly, it forms a dense, hard crystalline product, while a granulated amorphous slag is formed through quick solidification by pouring molten slag.

As per scientific estimate, for every tonne of copper metal produced, around 1.8-2.2 tonnes of slag is generated, according to Ramesh Nair, chief operating officer, SIIL. At present, across the world around 33 tonnes of slag is generated while in India three copper producers Sterlite, Birla Copper and Hindustan Copper produce around 6-6.5 tonnes of slag at different sites.

Utilization of copper slag in applications such as Portland cement substitution or as aggregates has threefold advantages of eliminating the costs of dumping, it can also be substituted with both sand and aggregates hence reducing the cost of concrete, and minimizing air pollution problems.

The slag is currently used in many applications and around 15-20% of the copper slag is utilized of the total slag generated as per *Madheswaran et al.(2014).* Remaining slag is being dumped as a waste, which requires large areas of land, a fast diminishing high value asset. Alternative use of it as partial or complete substitute for fine aggregates in concrete will eliminate these problems.

III. USE OF COPPER SLAG IN CONCRETE

Various research works have investigated the possible use of copper slag as a fine aggregate, coarse aggregate, and cement in concrete and its effect on the mechanical and durability properties of mortar and concrete.

Hwang and Laiw (1989) evaluated the compressive strength development of mortars and concrete containing fine copper slag aggregate with different water cement ratios. The strength of mixtures with % substitution of copper slag was having higher strength than that of control specimens. *Shoya et al. (1997)* reported that the amount and rate of bleeding increased by using copper slag fine aggregate depending on the water to cement ratio and also they recommended using less than 40% copper slag as partial replacement of aggregate to control the amount of bleeding to less than 5 l/m^2. Therefore copper slag can be replaced 40% with that of sand.

The pozzolanic activity of copper slag has been investigated by *Pavez et al. (2002).* The effect of copper slag on hydration of cement was investigated by *Mobasher et al. (1996) and Tixier et al. (1997).* Up to 15% by weight of copper slag was used as a Portland cement replacement together with 1.5% of hydrated lime as an activator to pozzolanic reaction. Result indicated a significant increase in the compressive strength. *Wu, Zhang and Ma (2010)* found that the smooth glassy surface texture and low moisture absorption, the excellent compressibility of CS can improve the workability and dynamic behavior of the concrete. Presence of excess water, the higher fineness and ferric oxide content decreases the quasi-static compressive, flexural and tensile splitting strength, and recommended that less than 40%.

Although there are many studies that have been reported by investigators from other countries on the use of copper slag in cement concrete, not much research has been carried out in

India concerning the incorporation of copper slag in concrete and also its durability effects.

Therefore to generate specific experiment data on the potential use of copper slag as sand and cement replacement in concrete, this research was performed.

A. Copper Slag Replacement for Sand

The use of slag from copper smelting as a fine aggregate in concrete was investigated by *Ayano et al. (2000)* as a fine aggregate in concrete. They described the strength, setting time and durability of concrete mixtures made with copper slag. To control the bleeding in concrete mixtures when incorporating copper slag as fine aggregates, *Ueno et al. (2005)* suggested a grading distribution of fine aggregate based on particle density. This review investigated the maximum size of slag fine aggregate that does not significantly influence the amount of bleeding and the required plastic viscosity of paste to control the amount of bleeding by the variation of water-to-cement ratios. *Shi et al. (2008)* presented a comprehensive review on the use of copper slag in cement, mortars and concrete. The paper was focused on the characteristics of copper slag and its effects on the engineering properties of cement, mortars and concrete. *Wu et al. (2010)* investigated the mechanical properties of copper slag and reinforced concrete under dynamic compression. The results showed that the dynamic compressive strength of copper slag reinforced concrete generally improved with the increase in amounts of copper slag used as a sand replacement upto 20%, compared with the control concrete, beyond which the strength was reduced. *Wu et al. (2010)* also investigated the mechanical properties of high strength concrete incorporating copper slag as a fine aggregate. The results indicated that the strength of concrete, with less than 40% copper slag replacement, was higher than or equal to that of the control specimen. The microscopic view demonstrated that there were limited differences between the control concrete and the concrete with less than 40%copper slag content.

Al-Jabri, Al-Saidy and Taha (2011) found 70% improvement in the compressive strength of mortars with 50% copper slag substitution in comparison with the control mixture and almost 5% increase in the concrete density, when copper slag was used as a sand replacement, whereas the workability increased substantially with an increase in copper slag content. This was attributed to the low water absorption and glassy surface of copper slag. The compressive, tensile and flexural strength of concrete were comparable to the control mix using up to 50% copper slag substitution for sand, but they decreased with a further increase in copper slag contents. The surface water absorption of concrete was reduced with up to 40% copper slag replacement for sand. The volume of permeable voids decreased with the replacement of up to 50% copper slag. Copper slag, in the range of 40–50%, replacement is having good results.

B. Copper Slag Replacement for both Sand and Cement

Copper slag has been replaced for both sand and cement in concrete. Based on investigations, optimum percentage replacement was achieved at 40% for fine aggregates and 15% for cement in concrete. Therefore one concrete mixture was prepared with 40% replacement of sand with copper slag and 15% replacement of cement with copper slag. In addition to this, 1.5% of hydrated lime also added with this mixture for activating pozzolanic reactions.

IV. RESULT AND DISCUSSION

Copper slag is considered as the waste material which has been investigated and has the promising future in the construction industries as a partial or full substitute of either cement or aggregates. Many researchers have already found that it is possible to use copper slag in concrete. Copper slag has been replaced with sand and cement and its effects on mechanical and durability properties have been studied. Therefore this review work is to investigate the mechanical and durability properties of the concrete made by replacing copper slag with fine aggregates. India is a developing country so the construction work is on large scale and it requires huge amount of money. Out of the total cost of any construction work material cost is much more in developing countries. Therefore the need of an hour is to replace costly and scarce conventional building materials by innovative, cost effective and environment friendly by alternate building materials.

Since copper slag concrete showed an enhanced mechanical and durable performance so it can be used as a building raw material. Therefore in this investigation, possibilities of using copper slag for various purposes were examined.

Copper slag has been replaced with sand and cement in concrete, as copper slag is a high density material containing more than 55% of Ferric Oxide (Fe_2O_3). As it is to be replaced by the major constituents of concrete so it must give good results as the concrete structures have to withstand the adverse effect of the environment. The research works have been carried out to investigate the mechanical and durability properties of a concrete made by using a by-product copper slag.

The effects of using several types of slag on mortar and concrete reactions, reinforcing steel corrosion, abrasion, workability and slump, shrinkage, and freezing and thawing characteristics were examined by various investigators. Copper slag was also used by *Ayano et al (2000)* as a fine aggregate in concrete. They described the strength, setting time and durability of concrete mixtures made with copper slag. It was investigated and concluded that the addition of copper slag to concrete results in an increase on the concrete's axial compressive, splitting tensile strength and decrease in the absorption rate by capillary suction, carbonation depth and hence improved its durability. The carbonated thickness, resistance to freezing and thawing, thermal resistance, shrinkage strain, creep and setting time of copper slag admixed concrete was examined by *Ayano and Sakata (2000).* Copper slag contains more than 55% of ferrous content. Hence corrosion and durability factors are necessary to find out, when replaced with sand and cement in concrete.

V. CONCLUSION

Based on the investigation following conclusions were drawn:

- Compressive strength of concrete made by replacing fine aggregate with copper slag is high as compared to the conventional concrete. It is high at 40% to 50% replacement of copper slag after which the strength reduces but still on a higher side as compared to the control concrete.
- Workability of concrete goes on increasing with the % of replacement. It is found that the smooth glassy surface texture and low moisture absorption, and the excellent compressibility of copper slag improve the workability and dynamic behavior of concrete.
- Flexural strength of concrete made by replacing fine aggregate with copper slag is high as compared to the conventional concrete. It is high at 20% to 30% replacement of copper slag and varies at other %.
- Split tensile strength of concrete made by replacing fine aggregate with copper slag is high as compared to the conventional concrete. It is high at 20% to 30% replacement of copper slag and varies at other %.
- Permeability of concrete with copper slag decreases at first 40% and then keeps on increasing till 100%.
- Density of concrete increases with the increase in copper slag %.
- Modulus of elasticity increases as the strength increases till 40% replacement of copper slag.
- The surface water absorption of concrete was reduced with up to 40% copper slag replacement for sand. The volume of permeable voids decreased with the replacement of up to 50% copper slag.
- The Rapid chloride permeability and ultrasonic pulse velocity test results are shows that the concrete are in good quality.
- The rate of initial surface absorption of water on the surface of the hardened concrete also decreased as the replacement levels of copper tailings increases.
- Nonetheless with the depletion of the natural aggregates the use of suitable alternative aggregates based on waste materials should be encouraged as a potentially more sustainable option overall.

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