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CHARACTERIZATION OF COPPER SLAG FOR ITS UTILIZATION IN THE CONSTRUCTION INDUSTRY

O. Pavez [(1)], F. Rojas [(1)], J. Palacios [(1)], C. Aguilar [(1)], A. Nazer [(2)]
(1) Departamento de Metalurgia – Universidad de Atacama – Av. Copayapu 485, Copiapó.
(2) Instituto Tecnológico – Universidad de Atacama – Av. Copayapu 485, Copiapó.
E-mail: opavez@uda.cl

ABSTRACT

In Chile, 3.2 millions metric tons of copper slag is produced every year by seven copper smelters, and they are dumped as solid waste. Thus, in order to use the slag as construction materials, a copper slag from cleaning electric furnace was characterized. A sample of air-cooled slag from the H.V. Lira Smelter was analyzed chemically and mineralogically, and physical and mechanical properties were also determined. The obtained results showed the construction industry is an interesting alternative for using copper slag as aggregate for concrete.

KEY WORDS: copper slag, characterization, arid, concrete, residues.

1. INTRODUCTION

During last years, Chile has been the largest copper producer in the world with 5,320 metric tons of copper produced in 2005. Since, copper sulfides are the main mining resources in the country; the metal is produced using the classical processes of flotation followed by pyrometallurgical extraction. Thus, the smelter production is approximately 1.6 millions tons of blister copper with more than 3.2 millions tons of slag per year, and it produced in seven copper smelter plants extended from the northern Atacama Desert to the central part of the country with a notorious environmental impact due to the great amount of slag produced (COCHILCO, 2006).

Currently, there is concern about the generation of mining residuals, and the environmental authorities have considered slag as a hazardous solid waste. Thus, companies have been forced to invest in new technologies regarding clean production processes and efficient residual management searching for alternative usages of the produced slag during copper production (Demetrio et al., 2000).

Non-ferrous slag is usually produced away from potential markets, and they are usually dumped with no further utilization. However, copper and nickel slag have been used as material for road construction, abrasive materials for cleaning metallic surfaces, mine filling materials, granulated materials for roofing and aggregate for cement fabrication (Piret, 2000). Additionally, copper slag has been applied in soils with copper deficiency (Joseph, 1999).

Additionally, the effectivity of using copper slag, cement, Blast Furnace slag and slag-cement mix on reducing the swelling potential and plasticity of expansive soils has been reported, and these results show that copper slag increases significantly the swelling potential, while it decreases with the other stabilizers and also the soil plasticity was reduced (Al-Rawas et al., 2002).

Although, non-ferrous slag has been successfully used as admixture in concrete in Canada, Europe and Australia, the American construction industry has not adopted the use of slag as constructing material. However, there is some interest in the southwest part of United State in using copper slag as partial substitute of Portland due to the cost decreasing of the concrete (Ariño and Mobasher, 1999). In addition, the cost of slag disposing and the accumulation of dumped materials are reduced as well as the solid pollutant emission (Tixier at al., 1997 and Escalante, 2002).

Therefore, a characterization of copper slag produced and disposed in the H.V. Lira Smelter, located in the Third Region in Chile, is done in order to analyze the possibility of using it as arid in the construction industry.

2. EXPERIMENTAL

Three samples of 1,500 Kg of air-cooled copper slag, from the slag cleaning electric furnace, were taken from the slag dump according to the Chilean standard NCh 164. E Of 76 (1976). After preparation, the sample was sent to the laboratory for its characterization.

The slag chemical analysis was run by using volumetric and gravimetric methods, and the mineralogical characterization was done by X-Ray diffraction by using a Siemens SRS 3000 Spectrometer with copper radiation of $K\alpha_1$=0.15418 nm at 40 Kv and 30 mA.

The physical and mechanical characteristics of the slag were determined according to Chilean standards for coarse and sand NCh 164. E Of 76 (1976), NCh 1116. E Of 77 (1977), NCh 1239. Of 77 (1977), NCh 1117. Of 77 (1977), NCh 1369. Of 78 (1978), NCh 165. Of 77 (1977), NCh 163. Of 79 (1979), NCh1223. Of 77 (1977), NCh 1327. Of 77 (1977), NCh 1511. Of 80 (1980), NCh 1444. Of 80 (1980), NCh 166. Of 52 (1952), ASTM standard ASTM C 33 (1990) and EN 1744-1 (1999).

3. RESULTS

The slag composition and the mineralogical components are shown in Table I and Table II, and the mayors components are iron and silica with minor amounts of lime alumina and magnesia.

Table I. Chemical composition of copper slag from cleaning electric furnace in wt%.

Cu	$Fe_{(T)}$	Cr_2O_3	Fe_3O_4	SiO_2	Al_2O_3	CaO	MgO	S	Cl	Sb	As	Pb
0.77	43.38	0.05	5.06	28.31	2.94	2.00	0.75	0.89	0.10	0.01	0.01	0.11

In Table II, it can bee observed that the slag is essentially iron silicate containing mainly fayalite and magnetite with low content of iron-magnesium fayalite.

Table II. Mineralogical composition of copper slag from cleaning electric furnace

Compounds	wt (%) in the slag
Fayalite	51.0
Iron-magnesium fayalite	10.2
Magnetite	38.8

The high iron content provides high density, giving the copper slag a higher specific gravity than natural sand, with a value ranging from 3.3 to 3.8 for coarse and sand respectively, as shown in Table III.

Table III. Density, absorption and porosity of the copper slag.

Property	Coarse	Sand
Density real (kg/m^3)	3,318.8	3,817.06
Density apparent (kg/m^3)	2,240	2,480
Absorption Coefficient	0.43	2.03
Porosity	1.70	----

This table also shows that copper slag can be considered as heavy arid since its density is higher than 3,000 kg/m^3, which is the higher density limit for a normal arid according to Chilean Standards NCh 1116. E Of 77 (1977) and NCh 1239. Of 77 (1977).

The absorption coefficient is lower than the standard limit for coarse (NCh 1117. Of 77, 1977) and is within the normal limits for sands (NCh 1239. Of 77, 1977) suggesting that the copper slag could be used for concretes. The air-cooled copper slag is glassy and more compact, so that, it is more compact and has lower absorption capacity and higher specific gravity than granulated slag.

The "*Los Angeles*" coefficient shows the abrasion resistance of the arid, and the copper slag *LA* coefficient is 18% which is almost a half of the upper limit of 40% according to the Chilean standard NCh 1369. Of 78 (1978). Therefore, the slag is very resistant to wearing by abrasion.

The following physical properties of the copper slag were measured according to Chilean standards; NCh 163. Of 79 (1979) for Fines Module, NCh 1223 Of. 77 (1977) for particles smaller than 0.08 mm, NCh 1327 Of 77 (1977) for breakable particles and NCh 1511 Of. 80 (1980) for the volumetric coefficient.

The Fines Module obtained for coarse is 3.65 which is within the acceptable range, and it is 3.20 for sand which is higher than 2.54 value required for lime to be used in concretes and this high value is due to the obtained size distribution of the sand which is over the range required for concrete. The particles smaller than 0.08 mm in copper slag is 1.68% which is suitable for low water absorption and the coarse aggregate is not covered by fine particles in concretes. The obtained values for breakable particles of the slag are 0.01% for coarse and 0.20% for sand, which are within the range required for ordinary aggregate, 5% for coarse and 3% for sand according to Chilean standards, suggesting that copper slag is stable to particles friction. The copper slag volumetric coefficient is 0.31, and it fits the standard values required by the Chilean standard. Thus, copper slag can be used as arid for the cement industry adjusting the particles size distribution during the grinding process.

The particle size distribution of the arid and it fractions over 5 mm mesh, coarse, and under 5 mm mesh, sand, is determined by using the procedure established in the standards for concretes and mortars (ASTM C 33, 1990, NCh 165. Of 77, 1977, and NCh 163. Of 79, 1979). The results of the particles size analysis are shown in Figures 1, 2, and 3.

Figure 1 shows the size distribution of the over 5mm fraction of the copper slag, and it can be observed that the coarse fraction presents a size distribution within the limits for concretes established by the Chilean standard NCh 165. Of 77 (1977).

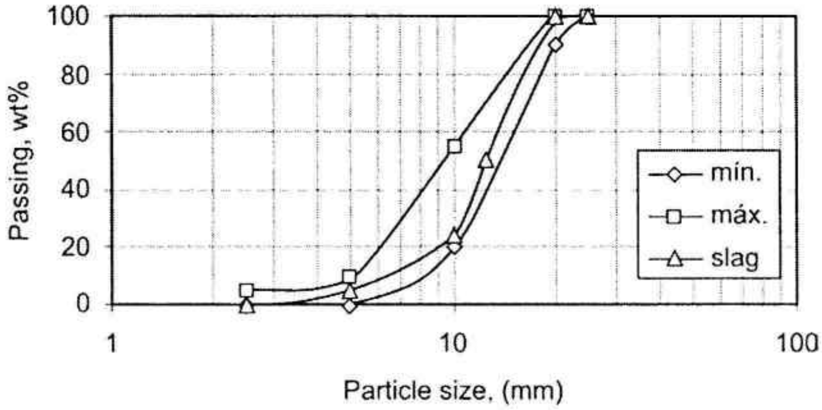

Figure 1. Particles size distribution of the coarse fraction of the copper slag compared with the Chilean standard NCh 165. Of 77 (1977).

The size distribution of the fraction under 5 mm of the copper slag is presented in Figure 2, and this figure shows a wide range of over size between 0.6 mm and 2.3 mm suggesting that the copper slag sand can not be used like it is in concrete fabrication.

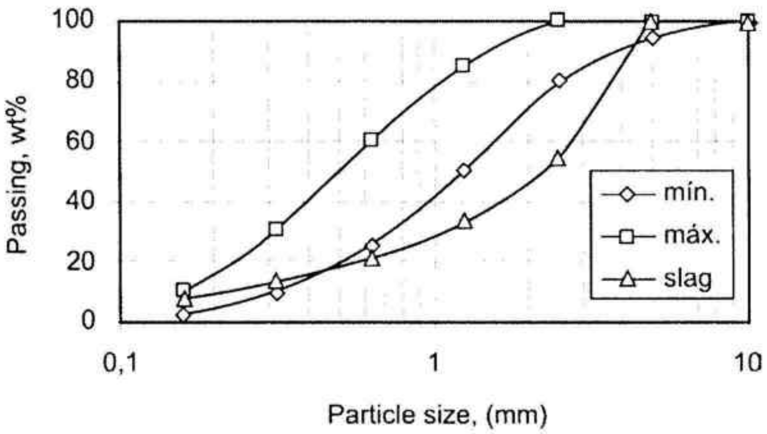

Figure 2. Particles size distribution of the sand fraction of the copper slag compared with the Chilean standard NCh 165. Of 77 (1977).

The total copper slag distribution is shown in Figure 3, and it can be observed the effect of the oversize of the sand fraction on the particles size distribution which is over the upper limit in the whole size range. Therefore, a proper control of the granulation process shall allow the production of a consistent size distribution for fitting the standard requirements of concrete fabrication (NCh 165. Of 77, 1977).

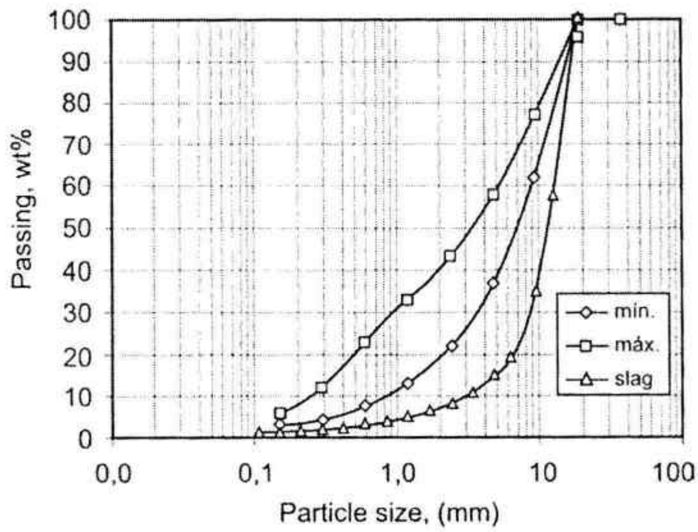

Figure 3. Particles size distribution of the total sample of copper slag compared with the Chilean standard NCh 165. Of 77 (1977).

Table IV shows the chemical analysis of the copper slag for harmful substances for concretes, and the results are compared with the Standard values required for concrete fabrication.

Table IV. Chemical analysis of harmful substances contained in the copper slag.

Component	(%)	Limits
Sulfates (SO_4^{-2})	0,04	< 0,6 sulfate soluble in water
Total Sulfur	0,89	1,0
Chlorides (Cl^-)	0,01	< 1,20 for Concrete < 0,25 for Mortar

The presence of these substances in the slag is less than the limits allowed for concrete fabrication established required by the standards (NCh 1444. Of 80, 1980). Therefore, the copper slag does not contain any harmful component for the concrete fabrication.

Additionally, organic impurities were not detected in copper slag, and the iron compounds are stable according to the standards NCh 166. Of 52 (1952) and EN 1744-1 (1999).

4. FINAL REMARKS

According to this characterization of slag, the obtained results suggest that copper slag shows a high potential in concrete applications.

The amounts of harmful components contained in the copper slag are less than the maximum allowed for the concrete fabrication.

Air-cooled copper slag has a black color and glassy appearance, and its unit weight is somewhat higher than that of conventional aggregate and its absorption capacity is typically very low therefore it is suitable to be used in the construction industry.

Since the slag production and the stock are both very high in Chile, the interest of application for this solid residual has increased, and it use in the construction industry is been explored. Thus, the preliminary study on copper slag obtained in the electric cleaning furnace show promising results on physical and chemical properties for construction applications.

5. ACKNOWLEDGEMENTS

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