Effect of type cement on the mechanical strength of copper slag mortars

Efeito do tipo de cimento na resistência mecânica de argamassas de escoria de cobre

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Resumo

A escória de cobre é um resíduo metalúrgico massivo e reconhecido como um passivo ambiental. A geração anual de escória de cobre é de 24,6 milhões de toneladas, aproximadamente, e os principais impactos ambientais, derivados da disposição da escória, é o uso de grandes extensões de solo e a contaminação visual da paisagem. Nas últimas décadas, as escórias de cobre têm sido utilizadas na fabricação de concretos e argamassas de cimento. Nesse estudo, com o objetivo de verificar a influência do tipo de ligante na dureza final de argamassas, foram utilizados dois tipos de cimento: cimento normal e cimento de alta resistência. A escória de cobre foi caracterizada por análise química, mineralógica e granulométrica. Regras chilenas de construção foram utilizadas na metodologia aplicada para a determinação de alguns parâmetros importantes das escórias. Ensaios de resistência à compressão e flexão foram realizados em argamassas de cimento, em laboratórios especializados. Os resultados obtidos mostraram que as argamassas preparadas com escória de cobre e cimento normal apresentaram melhor resistência à compressão e flexão do que as argamassas preparadas com a areia normal, e os resultados obtidos com cimento de alta resistência inicial foram ainda melhores. Pode-se concluir, a partir desse trabalho, que a escória de cobre tem boas características mecânicas, para ser usada na fabricação de argamassas de cimento, constituindo-se em uma adequada alternativa para uso na indústria da construção.

Palavras-chave: Escória de cobre, argamassa, resistência à compressão, resistência à flexão, construção.

Abstract

Copper slag is a massive metallurgist waste. Annual production rises up to 24.6 million tons, approximately, and the main environmental impact derived from slag disposal is the usage of great soil extensions and the resulting visual contamination of the landscape. Along time, copper slag has been used in the manufacture of concrete and cement mortars. Thus, with the aim of verifying binder-type influence in the final hardness of mortars, two types of cement were used: regular cement and high initial resistance cement. Copper slag was characterized from the chemical, mineralogical and grading viewpoints. Official Chilean regulations were used in the applied methodology for the determination of some important slag parameters. Compression and flexural strength trials were carried out on cement mortars in specialized laboratories. The obtained results showed that mortars manufactured *with copper slag presented a better resistance to compression and flexural strength than mortars manufactured with normal sand, and those made with high initial resistance cement were even better. It can be concluded from this work that copper slag offers optimal mechanical characteristics to be used in the manufacturing of cement mortars, becoming a sustainable and adequate alternative material for usage in the construction industry.*

Keywords: *Copper slag, mortar, compression strength, flexural strength, construction.*

1. Introduction

Copper slag is a massive metallurgist waste and it is recognized as an industrial passive. It is obtained from the transformation of cooper concentrates, to metallic copper (anode) in smelters. Slag is then deposited in tailings that occupy large soil surface designated for this purpose. A great portion of these residuals is poured with no suitable recycling (Oman Daily Observer, 2009). Physical and mechanical characteristics of slag will depend directly on the cooling speed that is submitted to. Copper slag is, in general, air-cooled, favoring a partial crystallization of the held oxide, resulting in a mixture of crystalline and vitreous components. Its chemical composition is rich in iron oxide, silicon and aluminum. On the other hand, regarding the mineralogical composition, it is frequent the presence of fayalite and magnetite, among other components (Gorai et al., 2003).

According to Gorai et al (2003), it is estimated that for each ton of metallic copper produced, 2.2 tons of copper slag are generated and 24.6 mill tons of slag are generated worldwide annually. In Chile, during 2002, the existing seven copper smelters produced 2,360,000 metric tons of copper slag (Goonan, 2005).

The great amount of slag production and the subsequent deposit of these in the tailings results in environmental issues, along with high transportation and dumping costs. The main environmental impacts derived from slag disposition are soil usage and visual contamination of landscape. On the other hand, under certain climatic conditions, leaching may occur, depending on the solution characteristics, and the composition and crystalline final structure of solid slag (Demetrio et al., 2000).

In Chile, this massive metallurgic residual is indefinitely deposited as hard soil, with no industrial utility. However, experiences on the usage of these residuals in many sectors of production have been carried out, with very good published results, particularly on the usage of copper slag in the construction industry. This residual has been used as raw material in cement production, as a substitute for arid, both in concrete and cement mortars (Zain et al. (2004), Goñi et al. (1994), Resende et al. (2008), Al-Jabri et al. (2006), Shi et al. (2008), Wu et al.(2010a), Wu et al.(2010b), Moura et al. (1999)). Mortar is a material regularly used as both decorative coating or as a means of waterproofing of surfaces, and as a merger of prefabricated cement elements and clay bricks in building work. Mortar is comprised by a mixture of cement, sand and water. Initially, it is fluid, which after a period of cement and water reactivity, acquires resistance until its final hardening. On the other hand, copper slag have also been used as raw material for the polishing and cleaning by abrasive blast of metallic structures (Kambham et al., 2007), (Resende et al. 2008) and as gravel in road work (Douglas & Mainwaring, 1985), among other commercial applications.

During the last two decades, articles presenting results for the usage of copper slag in cement mortars have been published. Moura et al. (1999) and Moura et al. (2009) concluded that copper slag can be used as an alternative to sand in mortar mix and cement concrete. A major headway motivating the usage of these metallurgic residuals can be appreciated in China with the publishing of a technical manual for the usage of copper slag in mortars and concrete (SPCSA, 1999 in Shi et al. 2008). Tang et al. (2000) in (Shi et al. 2008), reported that copper slag usage as sandstone aggregates in cement mortars increases its resistance to abrasion. On the other hand, Resende et al. (2008) assessed feasibility of mortar manufacturing incorporating recycled copper slag in the blasting of metallic structures as a partial substitute of sand. Shi et al. (2008) studied the characteristics and effects of copper slag in the properties of cement, mortars and concrete. An Australian company has manufactured concrete using copper slag aggregate (ASA, 2000). The various experiences carried out throughout the world aim at seeking for a suitable use of copper slag in cement concrete and mortars, giving a chance for recycling to a massive metallurgic passive. In this direction, the current work develops a comparative experimental study with the purpose of determining usage possibilities for copper slag as a substitute for traditional sand in the manufacturing of cement mortars, and, for this end, using slag from a copper smelter located in the Atacama Region, Chile.

2. Materials

Cement

For the mortar elaboration from copper slag, two types of cement, manufactured according to the NCh 148, Of.1968 (INN, 1968) standard, on the basis of clinker, pozzolana and plaster, were used. One type of cement belongs to the Pozzolana class, regular rate, and the other cement is classified as Pozzolana Portland, High Resistance rate. According to ASTM C595 standard (2008), the latter corresponds to IP type.

Fine Aggregate

Rolled, polished sand that complies with the NCh 163.Of79 standard, bought from a provider of normal arid, near to the city of Copiapó, Chile, was used.

Copper slag

Discarded copper slag, solidified by slow air- cooling in outdoor conditions, obtained from Hernán Videla Lira smelter, located in the Atacama Region, Chile, was used. The smelter dumps in open air a daily average of 600 tons of slag containing 0,8 % copper, approximately.

3. Methodology

Laboratory samples preparation

Both copper slag and sand were characterized in the material resistance laboratory at Universidad de Atacama, and in the laboratory of cement mixes at the Inacesa Company, Antofagasta. The chosen proportion for the mix in this study is shown in Table 1. For all the essay samples, the use of a relation cement/sand of 1/3 was established, according to the NCh 2260.Of1996 standard, and the consistency of the mortar was determined by the procedure outlined in the NCh 2257/1. Of1996 standard. Mortar test samples were manufactured, according to the NCh2260.Of1996 (INN, 1996a) standard, in shapes of prism rods with measures 40x40x160 (width, height, length) and a cement, water and sand mixture.

The reference mortar was manufactured with 100% normal sand, while the study mortar was manufactured with 100% copper slag. The compounds were separately, weighted, and afterwards were kneaded on an electric mortar mixer to ensure its homogeneity. This mixture was poured into metallic molds and it was later compacted on a table according to the NCh158.Of1967 (INN, 1967). 24 hours later, the hardened mix forming the prism rods was unmolded and underwent a process of curing, that consists of immersion in saturated lime water at 23°C, until the moment of its compression and flexural strength trials, according to the NCh158.Of1967 (INN, 1967) Chilean standard.

Table 1
Mix proportions, consistency and water/cement ratio (W/C ratio) of mortars for a test sample manufactured with river sand and copper slag.

Mix	Sand (%)	Slag (%)	Total weight (g)	Cement weight (g)	Regular consistency (mm)	W/C ratio
Regular Cement / 100% Slag	0	100	2,350	783	210	0.44
High resistance Cement/100%Slag	0	100	2,350	783	211	0.44
Regular Cement/ 100% Sand	100	0	1,550	517	210	0.55
High resistance Cement/100% Sand	100	0	1,550	517	210	0.53

Laboratory tests

After the curing, each sample was identified, measured and weighted in the scale. Thirty six test samples were tested to compression, and thirty six to flexural strength; in both cases, twelve were tested at day 3, twelve at day 7 and twelve at day 28. Compression and flexural strength trials, tripled, were performed according to the NCh158.Of1967 (INN, 1967) Chilean standard. All testing was performed in a hydraulic press.

4. Results

Chemical characterization of copper slag

The chemical composition of the main components of copper slag is presented in Table 2. The most present components are iron (Fe) and silica (SiO_2).

Mineralogical characterization of copper slag

The mineralogical study performed on copper slag showed the presence of the following phases: 51% $2FeO.SiO_2$ (fayalite), 10.2% $2MgO.SiO_2$ (magnesian fayalite) and 38.8% magnetite.

Chemical Composition	Cu	Cr_2O_3	Fe_T	Fe_3O_4	SiO_2	Al_2O_3	CaO	MgO	Cl	Pb
(%)	0.75	0.05	41.45	5.14	27.89	2.91	2.10	0.88	0.12	0.11

Table 2
Chemical composition of the main components of copper slag

Copper slag density

Regularly, the aggregate used in mortars and concrete shows a real density between 2,000 and 3,000 kg/m3. Heavy aggregate is the one having a real density above 3,000 kg/m3, while light aggregate presents a real density below 2,000 kg/m3. For the specific case of copper slag used in this work, a real density of 3,817 (kg/m3) was showed, which is why slag is considered as a heavy aggregate.

Grading characterization of copper slag

Grading of copper slag sand was prepared in laboratory taking into consideration the grading requirements stated in the NCh163.Of1979 (INN, 1979) Chilean standard, used in the aggregates of the construction industry.

Other physic and mechanical characteristics of slag

- Fineness Modulus, NCh 165 Of.1977 (INN, 2009). Fineness modulus obtained for the classified slag sands was 2.78.
- Friable particles, NCh1327 Of.1977 (INN, 1977). Standard requirements for friable particles in sands indicate values should not be over 3%. The obtained value for slag sand was 0,20 %, which meets the needs of the standard.

Compression resistance of mortars manufactured with copper slag and normal sand

Figure 1 displays the results of compression resistance obtained with copper slag and normal sand mortars, for ages 3, 7 and 28 days.

Flexural strength of cooper slag and normal sand mortars

Figure 2 shows the results of flexural strength obtained from copper slag and normal sand mortars, for the ages 3, 7 and 28 days.

5. Discussion

According to the obtained resistance to flex-traction and compression results of normal sand mortar samples, which served as reference for comparison with copper slag mortars, it could be observed that copper slag mortars resistance is higher than the values reached in normal sand mortars. This was demonstrated at days 3, 7 and 28, ages at which slag mortars displayed a higher flex-traction resistance in 51.4%, 43,2% and 31.7%, respectively, when using regular and superior cement, and 39.6%, 40,6% and 33.8%, respectively, when using high resistance cement, compared with the resistance reached by normal sand mortars. Likewise, slag mortars were found to have a higher resistance to compression at 3, 7 and 28 days, by 70.5%, 58.0% and 40.4%, respectively, when using a regular cement, and higher in 43.5%, 28.7% and 18.4% when using high resistance cement, compared with the resistance reached in normal sand mortars.

Very encouraging results on the use of copper slag in mortars were reported by Nazer et al. (2012), when working with regular pozzolana cement, at the same ages (3, 7 and 28 days), but with raw grading copper slag samples, i.e. not adjusted to grading distributions stated in the NCh 163.Of1979 (INN 1979) Chilean standard. Studies on copper slag mortars yielded at the ages 3, 7 and 28 days a flex-traction higher in 97%, 44% and 35%, and a resistance to higher compression in 114%, 66% and 44% respectively, compared with the resistance reached in normal sand mortars. Authors pointed out that the great differences of reached resistances in the earlier age (3 days), suggested its usage in hot geographic areas and/or works requiring a fast hardening of the mortar.

Regarding size distribution of this metallurgic sludge, when comparing the grading of raw copper slag with the requirements of sand standards, slag did not comply with it on some size ranges, which is the reason why in this work copper slag was classified and adjusted, so that it complied with the standard grading requirement. It must be kept in mind that grading characterization of the Chilean standard of sand for mortar usage states that it applies to real densities between 2,000 and 3,000 kg/m^3 and copper slag used in this work expressed a value of 3,817 kg/m^3. Taking into account this background regarding the real density of slag, and given the large variety of copper slag existing in the country, either in active and abandoned tailings, it seems advisable to study and propose a new standard, prepared specifically for copper slag mortars. In the same context, documents leading to the suitable use of copper slag in mortars and concrete for construction (Shi et al., 2008). This study does not consider the environmental classification of copper slag. This study does not consider the environmental classification of copper slag. This will be of great interest to investors wishing to manufacture construction sector cement mortars with copper slag, especially to quantify the degree of leaching.

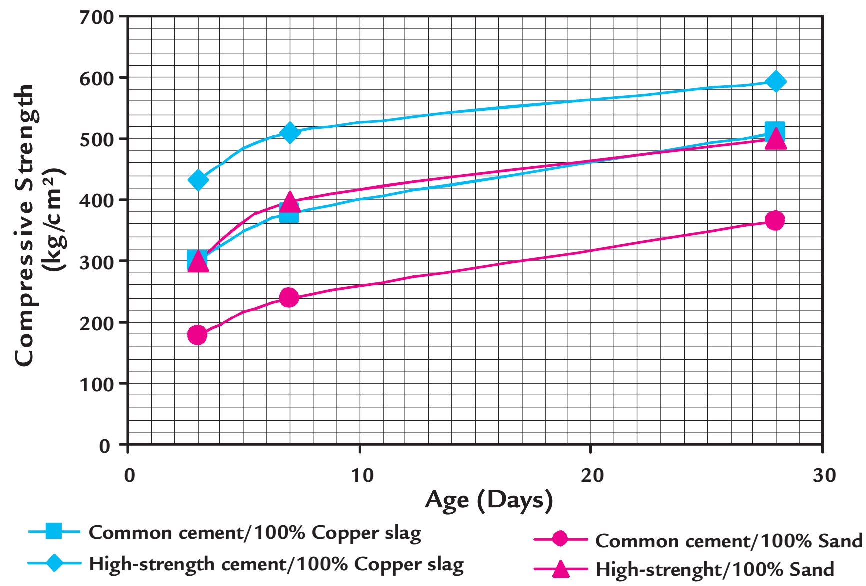

Figure 1
Compressive strength of tested mortar.

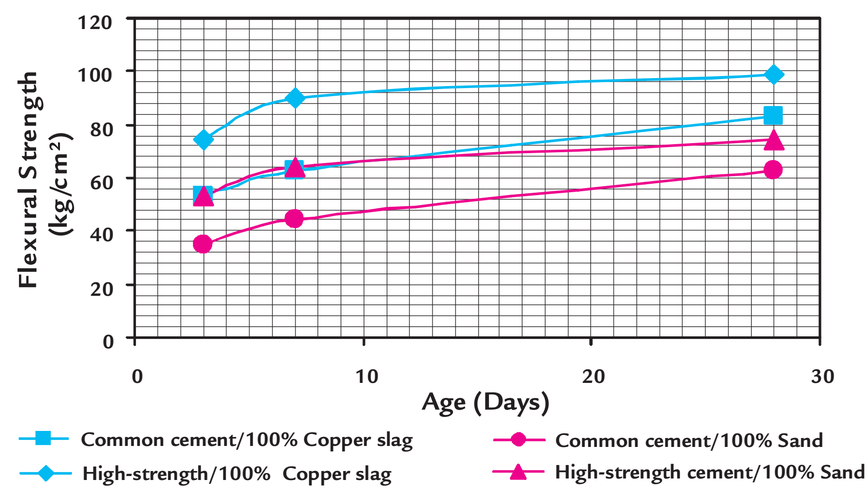

Figure 2
Flexural strength of tested mortar.

6. Conclusions

Copper slag sand mortars presented higher resistances both for compression and flex-traction, compared to normal rolled sand mortars. This was checked with both types of cement used, at different ages: 3, 7 and 28 days.

The obtained results in this study indicate that copper slag use in mortars as a substitute for normal sand, provide with options for the use of this massive metallurgist waste as an alternative, adequate for the construction industry.

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