Copper tailings in stucco mortars

http://dx.doi.org/10.1590/0370-44672015690148

Osvaldo Pavez
Profesor
Universidad de Atacama
Departamento de Ingeniería en Metalurgia
Copiapó – Región de Atacama – Chile
osvaldo.pavez@uda.cl

Luis González
Profesor
Universidad de Atacama
Instituto Tecnológico
Copiapó – Región de Atacama – Chile
luis.gonzalez@uda.cl

Hernán Vega
Profesor
Universidad de Atacama
Instituto Tecnológico
Copiapó – Región de Atacama – Chile
hernan.vega@uda.cl

Eduardo Rojas
Alumno de pregrado
Universidad de Atacama
Instituto Tecnológico
Copiapó – Región de Atacama – Chile
eduardo.rojas@alumnos.uda.cl

Abstract

This investigation addressed the evaluation of the use of copper tailings in the construction industry in order to reduce the impact on the environment. The evaluation was performed by a technical comparison between stucco mortars prepared with crushed conventional sand and with copper tailings sand. The best results were achieved with the stucco mortars containing tailings. The tailings presented a fine particles size distribution curve different from that suggested by the standard. The values of compressive strength, retentivity, and adherence in the stucco mortars prepared with copper tailings were much higher than those obtained with crushed sand. According to the results from this study, it can be concluded that the preparation of stucco mortars using copper tailings replacing conventional sand is a technically feasible alternative for the construction industry, presenting the benefit of mitigating the impact of disposal to the environment.

Keywords: copper tailings, stucco, compression strength, construction, environment.

1. Introduction

In the construction industry, the use of solid wastes generated in mining and metallurgical activities becomes attractive, i.e., the use of tailings and slags (Onuaguluchi and Eren, 2012a; Nazer, *et al*., 2012; Nazer *et al*., 2013). Tailings deposits are considered environmental liabilities. Therefore, the possibility of an alternative use in the construction industry could reduce the undesirable impact.

Different types of tailings have been used in the construction industry: copper tailings (Sultan, 1979; Mahmood and Mulligan, 2007), iron ore tailings (Kumar *et al*., 2014; Shetty *et al*., 2014; Zhao *et al*., 2014; Uchechukwu and Ezekiel, 2014), gold mine tailings (Roy *et al*., 2007; Malatse and Ndlovu, 2015), scheelite tailings (De Araújo, 2013), quartzite waste (Russo, 2011).

Regarding the use of copper tailings in the construction industry, Oluwasola *et al*., (2014) reported that the potential uses of copper mine tailings and steel slag require studies and the negative impact of mine tailings should be reduced by exploring potential uses of these waste materials in the construction industry. Prahallada and Shanthappa (2014) studied the suitability of using copper ore tailings as an admixture in the preparation of concrete by replacing the cement in different percentages viz., 0%, 10%, 20%, 30%, 40%, and 50%. Zhang *et al*., (2014) prepared standardized mortar specimens, where cement was replaced by 55, 10, 15, 20, 25, 30, and 35 % of copper tailings. They reported that copper tailings can be used as cement admixture to solve the problem of environmental pollution. Thomas *et al*., (2013) used copper tailing in cement concrete as a partial replacement of natural river sand. They concluded that the copper tailings may be utilized as partial replacement of fine aggregates up to the proportion of 60%. Onuaguluchi (2012) studied the possibility of using copper tailings either as a cement replacement or additive material in pastes, mortars and concretes at 0.65, 0.57 and 0.50 w/b ratios. The mechanical properties investigated were compressive strength, flexural strength, splitting tensile strength and abrasion resistance. Mortar and concrete mixtures containing copper tailings as an additive have greater mechanical strengths compared to the control samples. Onaugulushi and Eren (2012b) reported that copper tailings have a slightly negative impact on the slump, setting time and porosity of mixtures. However, in comparison with the control specimens, improved mechanical strengths, abrasion resistance, and reduced chloride penetration are observed in mixtures incorporating copper tailings. Sultan (1979) determined the feasibility of using stabilized copper mill tailings in road construction. The results indicated that there is excellent potential for using tailings as compacted fill in embankments, compacted foundation and subgrade material, cement lining canals, ponds, and reservoirs.

In order to evaluate the use of tailings in the construction industry and thus reduce the impact on the environment, this article presents a technical comparison between stucco mortars prepared with crushed natural sand (conventional) and with copper tailings collected at the Manuel Antonio Matta plant, Chile.

2. Materials and methods

2.1 Materials

The cement, Pozzolana Portland (special INACESA), was manufactured according to the NCh148 standard. The sand utilized was obtained from the MCR Áridos plant. The sample of copper tailings sand was collected at the Manuel Antonio Matta plant, located in the Atacama Region, Chile. The plant processes 150,000 tons of copper sulfide ore per month, yielding 4,500 tons of concentrate and 145,500 tons of tailings. Drinking water was used in the stucco mortars.

2.2 Methods

The experimental program considered a study with the following materials:

a) Dry stucco mortars (exterior stucco DryMix) as a reference for comparison;

b) Stucco mortars with crushed conventional sand for comparison; and

c) Stucco mortars with copper tailings sand. The tests were performed in different specialized laboratories according to Chilean standards (INN NCh). Mechanical testing of compressive strength and flexural strength at ages 1, 3, 7 and 28 days were conducted at INACESA-Antofagasta. Assays of chlorides and sulfates were conducted at SESMEC laboratories. Weight dosage and volume dosage for copper tailings sand and crushed conventional sand were conducted at theWBS SERVILABHOR laboratories. Assays of adherence and retentivity were performed at the Printec laboratories. Chemical analyzes of the copper tailings were conducted at the Manuel Antonio Matta plant.

According to NCh 2256/1.Of 2001, mortar is defined as the mixture of cement, sand and optionally other binder material that reacts with the addition of water and acquires resistance. The mixture may also have some other product to improve its properties whenever this complies with the requirements for use. When water is added to cement, it gives rise to the cement paste, which passes through an initial stage, in which the cement hydration process is developed, during which it has a plastic consistency. Subsequently, it starts a progressive hardening process that transforms the plastic consistency material into a solid. During this process, the properties of the mortar gradually evolve over time. The dosing used are: Cement/sand = 1/3; Cement/tailings = 1/3; Water/cement = 0.65. Cement: 400 kg/m^3, Arid: 1200 kg/m^3, and Water: 260 kg/m^3.

The sand was crushed to obtain a particle size as close as possible to that required by the standard. The reduction in size of the sand was performed in a cone crusher laboratory of setting 5 mm. On the other hand, the tailings that had a finer grain size than required by the standard, were not crushed.

In the measurement of the mechanical strengths, 3 samples of 40x40x160 mm for each type of mortar and age were prepared. Iron molds of 3 compartments with the inside dimensions indicated were used. For these tests the NCh 2261. Of1996 was applied. In measuring the compressive strength and flexural strength, the molds after having been filled with cement mortars, compacted in compaction table and smoothed for removal of mortar in excess, were sent to humid chambers by 24 hours and then demoulded and immersed in a water bath saturated with lime until their breakup in ages 1, 3, 7 and 28 days. In the case of the flexural strength, the resulting resistance value corresponds to the average of three specimens tested resistance to its rupture. On the other hand, the compressive strength is the average resistance of each piece tested that it come from the flexural test.

For testing adherence, the direct drive method is used according to NCh 2471. Of2000 standard. The assay for direct drive is effected by means of a steel disc attached to the surface of the coating to be tested, on which a separating force perpendicular to the surface is applied using a calibrated equipment, which is gradually increased to produce takeoff between the coating and the substrate or breakage in another area. Before placing the fixing disc, make sure that the surface of the specimen is clean and free of surface moisture. If needed, surface moisture must be removed with an absorbent material such as a blotting paper. With regard to process traction, it must connect the applicator equipment traction to the fixer disc, ensuring that the tensile force is applied perpendicular to the surface and with the appropriate speed according to the expected adherence until takeoff or breakage occurs in some area.

The retentivity, ability of mortar to retain water for kneading, is determined by the NCh 2259. Of1996 standard. The following equipment is used: a water suction device, a vacuum that is controlled by a column of mercury and a pressure regulator; a ruler of length 200 mm and thickness 2.5 mm; a filter paper of diameter 150 mm; a rammer of non-absorbent material of 150 mm in length, that has the base face of compacting with a rectangular section of 13 by 25 mm, flat and smooth. The procedure begins by connecting the water suction device to the vacuum and adjusting the mercury column to a vacuum of 51 mm by the pressure regulating equipment. The mortar is constructed and its consistency is measured on a shaking table, which obtained the result (A) in mm. Once applied the entire procedure with the mortar, again the consistency is measured on a shaking table, and the result obtained is B in mm. The operation must be done in less than 11 minutes, counted from the time of mixing the cement with water. The retentivity is calculated with the percentage of the final spread mortar sucked by the vacuum (B) relative to the initial spread mortar (A).

Chemical analysis of the samples were carried out by using different techniques: chemical elements (Cu, Zn) were analyzed in an atomic absorption spectrophotometer GBC; volumetric technique (volumetry) was used in the determination of S and chemical compounds (SiO_2, Al_2O_3, Fe_2O_3, others); a hydride generator coupled to the atomic absorption spectrophotometer was applied in the determination of As; and to determinate Hg, the cold vapor technique was used with a mercury analyzer.

3. Results

The particle size distribution of the copper tailings does not comply with specifications of the NCh2256/1 standard, and is completely outside the limits of the size recommended. The particle size of the copper tailings sand is quite fine (91% -0.315 mm and 55% -0.16 mm). Moreover, sand tailings have a fineness modulus of 0.54, a very low value. The limit values for fineness modulus are 1.40 to 2.38. The particle size of the crushed sand does not comply with the specifications recommended by the NCh2256/1 standard, for sizes above 2.00 mm. Moreover, the crushed sand presented a fineness modulus of 3.05 that is within the required limits (2.15 to 3.38). The particle size of the tailings and crushed sand are presented in Table 1.

Size (mm)	Crushed sand Cumulative passing (%)	Tailings Cumulative passing (%)	Crushed sand Lower limit – Upper limit Cumulative passing (%) NCh 2256/1. Of2001	Tailings Lower limit – Upper limit Cumulative passing (%) NCh 2256/1. Of2001
10	94		100	
5	78		95 – 100	
2,5	69		80 – 100	100
1,25	61		50 – 85	95 - 100
0,63	51	100	25 – 60	50 - 100
0,315	30	91	10 – 30	15 - 40
0,16	12	55	2 - 10	2 - 20
Fineness Modulus	3,05	0.54	3.38 – 2.15	2.38 – 1.4

Table 1
Granulometry of the tailings and crushed sand. Also the tableshows the lower and upper limits and the cumulative passing percentage according to NCH standard 2256/1.Of2001.

The quantitative chemical analysis of the copper tailings sand indicated the presence of: SiO_2 (54.30%), FeO (12.10%), Al_2O_3 (9.21%), Fe_3O_4 (3.60%), MgO (2.26%), S (1.94%), CaO (1.14%). These chemical species are characteristic of copper tailings produced at the concentrators located in the Atacama Region. Moreover, the chemical analysis of crushed sand showed the presence of: SiO_2 (45.23%), Fe_2O_3 (16.34%), Al_2O_3 (11.37%), CaO (8.53%), MgO (7.66%), Na2O (1.75%), K_2O (1.42%), MnO (0.83%), P_2O_5 (0.64%), Cu (0.02%), As (0.003%), Zn (0.02%), and Hg(1 ppm).

Table 2 shows the contents of chlorides and sulfates in the copper tailings sand. The figures comply with the maximum values recommended by the NCh1444 standard for concrete, 1.20 $kgCl^-/m^3$ and 0.60 kg $SO_4^=/m^3$.

Assay	Unit	Value
Chlorides	$kgCl^-$/kg arid	2.3×10^{-5}
Sulfates	$kgSO_4^=$/kg arid	5.8×10^{-3}

Table 2
Contents of chlorides and sulfates in the copper tailings sand, according to the NCh1444 standard.

Figure 1 shows the results for thecompressive strength of stucco mortars with crushed sand and copper tailings sand for ages 1, 3, 7 and 28 days. The best results were achieved with copper tailings. Also, the compressive strength was determined for exterior stucco DryMix for age 28 days; the value obtained was 60.0 kgf/cm^2, which it is very similar to that of stucco mortars of crushed sand for the same age.

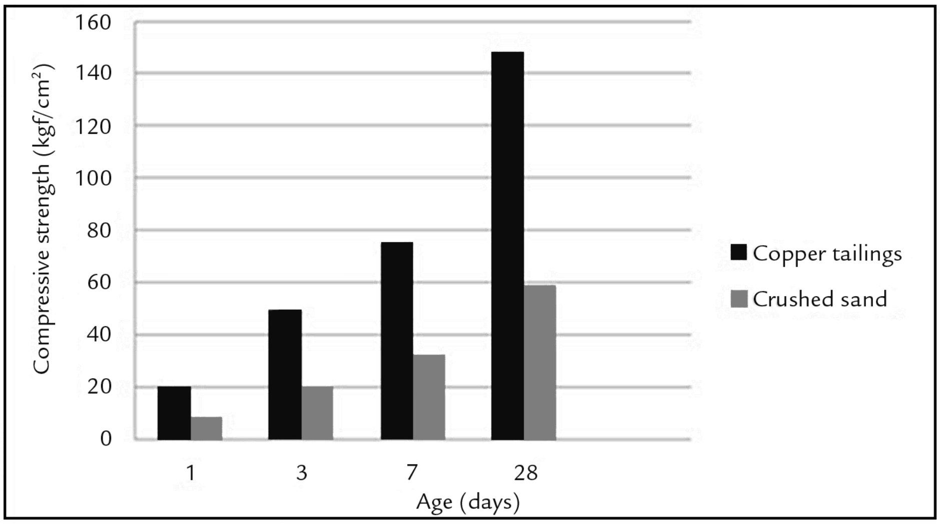

Figure 1
Compressive strength of stucco mortars with crushed sand and copper tailings sand for ages 1, 3, 7 and 28 days.

Moreover, Figure 2 shows the results obtained of the flexural strength for stucco mortars with crushed sand and copper tailings for ages 1, 3, 7 and 28 days. It is observed that with copper tailings the values increase from 5 kgf/cm^2 to 36 kgf/cm^2 at the ages 1 day and 28 days respectively, while with crushed sand the values increase from 3 kgf/cm^2 to 26 kgf/cm^2 at those ages.

Table 3 presents the values of retentivity for exterior stucco DryMix, stucco with crushedsand and stucco of copper tailings. It is appreciated that the value obtained for copper tailing is 87%, which is 45% and 40.3% greater than thatachieved with the exterior stucco DryMix (60%) and with the crushedsand (62%) respectively.

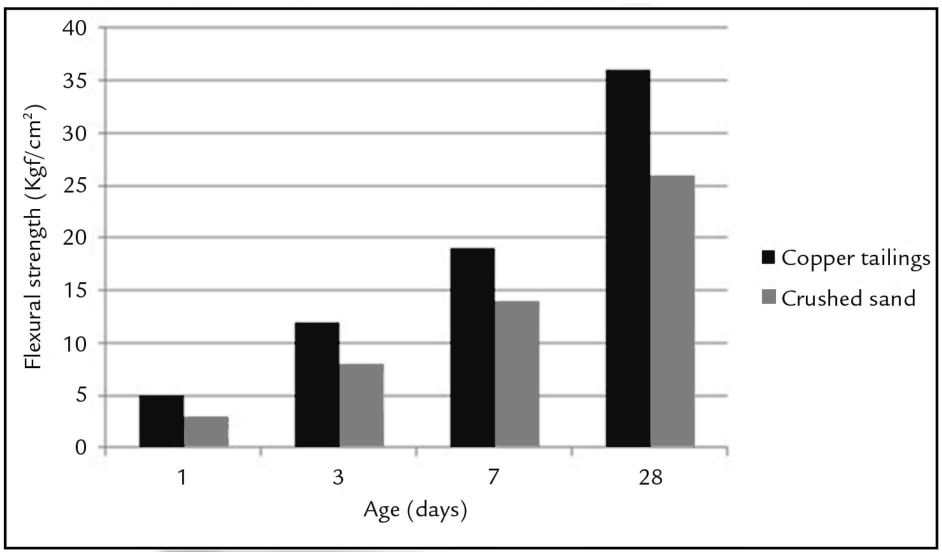

Figure 2
Flexural strength obtained for stucco mortars with crushed sand and copper tailings sand for ages 1, 3, 7 and 28 days.

Material	Retentivity(%)
Exterior stuccoDryMix	60
Stuccowithcrushedsand	62
Stucco with copper tailings sand	87

Table 3
Retentivity values for exterior stucco DryMix, stucco with crushed sand and stucco with copper tailings sand.

Table 4 shows the values of adherence for stucco exterior DryMix, stucco with crushed sand and stucco with copper tailings sand for age 28 days. The stucco mortars must have a minimum adhesion of 2.0 kgf/cm^2 at 28 days when they are placed on new surfaces (INN(2000) NCh2471. Of2000). The value of adherence for stucco with copper tailings (7.0 kgf/cm^2) is 250% higher than the minimum value required at that age.

Table 4
Values of adherence for stucco exterior DryMix, stucco with crusher sand and stucco with copper tailings sand for age 28 days.

Material	Age (days)	Adherence (kgf/cm^2)
Exterior stucco DryMix	28	3.0
Stucco with crusher sand	28	2.8
Stucco with copper tailings sand	28	7.0

4. Discussion

The size distribution of the copper tailings sand presented 55% passing 0.1 mm. These tailings do not comply with the specifications of the standard and the size distribution curve is completely outside the recommended limits. However, despite this, the results obtained using copper tailings were very good. The literature indicates that the copper tailings used in construction contain a high proportion of fine particles. Onuaguluchi and Eren (2012b) reported that the copper tailings used in their experiments contained 50% passing 0.1 mm. In the case study reported by Mahmood and Mulligan (2007), the copper tailings fraction passing 0.075 mm reached 56.9%. Moreover, Oluwasola *et al.* (2014) reported that the size analysis of a sample of Malaysian copper tailings contained 60% passing 0.9 mm and 10% passing 0.2 mm.

The compressive strength of stucco mortars prepared with copper tailings sand was greater than the values obtained with crushed sand at all ages(1,3, 7 and 28 days). The requirements for compressive strength are 25 kgf/cm^2 for exterior stucco and 10 kgf/cm^2 for interior stucco. Figure 1 shows that the stucco mortars with copper tailings comply very quickly with the requirements of compressive resistance; at age 3 days, it reached a value of 49.0 kgf/cm^2. Furthermore, the compressive strength obtained with stucco mortars of copper tailings at 28 days was 148.0 kgf/cm^2. This value would be 150% higher than the compressive strength obtained with exterior stucco DryMix and with stucco mortars of crushed sand of the same age. It is also important to mention that with copper tailings at the age of 7 days, a compressive resistance of 75.0 kgf/cm^2 was achieved, this value being 27% and 25% higher than the values obtained at 28 days with crushed sand (58.9 kgf/cm^2) and exterior stucco DryMix (60 kgf/cm^2), respectively. Higher values of compressive strength of stucco mortars with copper tailings indicate that this stucco has a good internal cohesion and a high capacity to support pressure without disintegrating. Onuaguluchi and Eren (2012a) reported that the compressive strength was increased by the addition of copper tailings to concrete, leading to higher strengths compared with the control concrete at the 7th, 28th and 90th days. Similarly, all the concrete mixtures incorporating copper tailings recorded higher flexural strengths compared to the control at all test ages. Zhang *et al.*, (2014) showed that when copper tailings are added at a proportion lower than 15 %, it can increase the compressive strength,the flexural strength, and improve the cement performances, while additions above 15 % would decrease the strength. Moreover, Prahallada and Shanthappa (2014) reported that: a) strength of concrete blocks decreases with increase in the percentage of tailings (the cement can be replaced by copper tailings up to 30%); b) the addition of copper tailings replacing ordinary Portland cement causes reduction in the compressive strength of concrete; and c) the replacement of ordinary Portland cement by copper tailings is safe up to 20% considering average minimum field strength.

The retentivity is an important property of the stuccos. The NCh2259. Of1996 standard recommended that the value of the retentivity must be greater than 60% to ensure the operation of the continuous coatings. In the case of constructions that are built under extreme weather conditions, the values may be higher to cover the effect that may be caused by the water retention capacity of the mortar. According to the retentivity value obtained in the stucco with copper tailings (87%), this stucco would comply with the requirements of retentivity for high standards (for example, very rigorous environment).

The adherence obtained at 28 days for the copper tailing stucco was 250% higher than the value required by the standard, and 130% and 150% higher than that achieved by the exterior stucco DryMix and crushed sand stucco, respectively. These results confirm that the tailings easily adhere to the elements with which they have contact. In the copper concentrator plants, it can be seen that the tailings adhere to the elements and structures of the place, rendering it difficult to clean equipment and machines, since the tailings are strongly adhered.

5. Conclusions

The results obtained with stucco mortars prepared with copper tailings were better than those achieved with stucco mortars prepared with crushed sand. The particles of the copper tailings were finer than the recommended standard. However, the results obtained using these tailings in stucco mortars were very good. The values of compressive strength in stucco mortars prepared with copper tailings were better than those obtained in stucco prepared with crushed sand at all examined ages (1, 3, 7 and 28 days). According to the retentivity value obtained in the stucco with copper tailings (87%), this stucco would comply with the requirements of retentivity for high standards (for example, very rigorous environment). The adherence obtained at 28 days for the copper tailings stucco was 250% higher than the value required by the standard and 130% and 150% higher than that achieved by the exterior stucco DryMix and crushed sand stucco, respectively. These results confirm that the tailings easily adhere to the elements with which they have contact. According to the results obtained in this study, the preparation of stucco mortars using copper tailings replacing conventional sand is a technically feasible alternative for the construction industry, which would reduce the impact of this environmental liability.

6. References

DE ARAÚJO, J.E. ***Estudo de caso: uso de resíduo de scheelita em argamassa e concreto.*** (Case study: use of scheelite residue in concrete and argamassa). Monografia para obtencão do título de Bacharelem Ciëncia e Tecnologia, Universidade Federal Rural do Semi-Árido, RN, 2013. 50p.

INN (2010) NCh1444. Of2010. Áridos para morteros y hormigones. Determinación de cloruros y sulfatos (Aggregates for mortars and concretes. Determination of chlorides and sulfates). INN, Instituto Nacional de Normalización, Chile.

INN (2001) NCh2256/1. Of2001. Morteros - Parte 1: Requisitos generales (Mortars - Part 1: General requirements). INN, Instituto Nacional de Normalización, Chile.

INN (1996) NCh2259. Of1996. Morteros. Determinación de la retentividad – Método de la succión de agua por vacío (Mortars. Retentivity determination - Method of water succión by vacuum). INN, Instituto Nacional de Normalización, Chile.

INN (1996) NCh2261. Of1996. Morteros. Determinación de las resistencias mecánicas de probetas confeccionadas en obra (Mortars. Determination of the mechanical strength of specimens prepared on site). INN, Instituto Nacional de Normalización, Chile.

INN (2000) NCh2471. Of2000. Morteros. Ensayos de adherencia – Método de tracción directa (Mortars. Adhesion tests - Method of direct traction). INN, Instituto Nacional de Normalización, Chile.

KUMAR, B.N.S., SUHAS, R.,SHET, S.U., SRISHAILA, J.M. Utilization of iron ore tailings as replacement to fine aggregates in cement concrete pavements. ***International Journal of Research in Engineering and Technology,*** v. 3, n. 7, p. 369-376, 2014.

MAHMOOD, A. A., MULLIGAN, C.N. Investigation of the use of mine tailings for unpaved road base.In: ANNUAL INTERNATIONAL CONFERENCE ON SOILS, SEDIMENTS, WATER AND ENERGY, 2007, Massachusetts, Proceedings…(Proceedings…). Massachusetts, 2007. v. 12, Article 11, 2007.

MALATSE, M., NDLOVU, S. The viability of using the Witwatersrand gold mine tailings for brick making. ***The Journal of The Southern African Institute of Mining and Metallurgy,*** v. 115, p. 321-327, 2015.

NAZER, A., PAVEZ, O., ROJAS, F. Use of copper slag in cement mortar. ***REM - Revista Escola de Minas,*** v. 65, n. 1, p. 87-91, 2012.

NAZER, A., PAVEZ, O., TOLEDO, I. Effect of type cement on the mechanical strength of copper slag mortars. ***REM - Revista Escola de Minas,*** v. 66, n. 1, p. 85-90, 2013.

OLUWASOLA, E.A., HAININ, M.R., AZIZ, M.M.A., YAACOB, H.,WARID, M.N.M. Potentials of steel slag and copper mine tailings as construction materials. ***Materials Research Innovations,*** v. 18, n. S6, p. S6-250 - S6-254, 2014.

ONUAGULUCHI, O. ***Properties of cement based materials containing copper tailings.*** Turkey: Eastern Mediterranean University, 2012. (These Doctor of Philosophy).

ONUAGULUCHI, O., EREN, O. Cement mixtures containing copper tailings as an additive: durability properties. ***Materials Research,*** v. 155, n. 6, 2012a.

ONUAGULUCHI, O., EREN, O. Copper tailings as a potential additive in concrete: consistency, strength and toxic metal immobilization properties. ***Indian Journal of Engineering & Materials Science,*** v. 19, p. 79-86, 2012b.

PRAHALLADA M.C., SHANTHAPPA B.C. Use of copper ore tailings – as an excellent pozzolana in the preparation of concrete. ***International Journal of Advanced Research in Engineering and Applied Sciences,*** v. 3, n. 3, 9p., 2014.

ROY, S., ADHIKARI, G.R., GUPTA, R.N. Use of gold mill tailings in making bricks: a feasibility study. ***Waste Management and Research,***v. 25, n. 5, p. 475-482, 2007.

RUSSO, M.L.C. ***Waste reciclagem obtained from extraction of quartzite.*** Belo Horizonte, MG: Universidade Federal de Minas Gerais, 2011. 174p. (Doctoral Thesis).

SHETTY, K.K., NAYAK, G., VIJAYAN, V. Use of red mud and iron tailings in self compacting. ***International Journal of Research in Engineering and Technology,*** v. 3, n. 6, p. 111-114, 2014.

SULTAN, H.A. Stabilized copper mill tailings for highway construction. In: ANNU-

AL MEETING OF THE TRANSPORTATION RESEARCH BOARD, 58, 1979. Washington, Proceedings… (Proceedings…). Washington, 1979. p. 1-7.

THOMAS, B.S., DAMARE, A., GUPTA, R.C. Strength and durability characteristics of copper tailing concrete. ***Construction and Building Materials,*** v. 48, p. 894-900, 2013.

UCHECHUKWU, E. A., EZEKIEL, M.J. Evaluation of the iron ore tailings from Itakpe in Nigeria as concrete material.***Advances in Materials,*** v. 3, n. 4, p. 27-32, 2014.

ZHANG, C.S., ZHOU, T.T., WU, Q.S., ZHU, H.J., XU, P. Mechanical performances and microstructures of cement containing copper tailings. ***Asian Journal of Chemistry,*** v. 26, n. 5, p.1371-1375, 2014.

ZHAO, S., FAN, J., SUN, W. Utilization of iron ore tailings as fine aggregate in ultra-high performance concrete. ***Construction and Building Materials,*** v. 50, n. 15, p. 540-548, 2014.

Received: 19 September 2015 - Accepted: 04 April 2016.