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SOIL-COOPER WASTE RESIDUE AS MINERAL ADDITIVE FOR MORTAR OR CONCRETE USED IN SUSTAINABLE CONSTRUCTION

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ABSTRACT
In this research the possibility of using soil-cooper residue (known in Mexico as Jales of cooper) as a mineral additive for producing concrete was studied. This industrial waste comes out from a plant in the state of Sonora, Mexico, here 75,000 metric tons of the waste residue accumulates daily during cooper production. Physical and chemical characteristics of the waste product were verified and compared with ASTM standards of interest. It was found that this material has pozzolanic reactivity as determined with compression tests ran in the laboratory with Portland cement mortars (strengths are better than the minimum established by ASTM C 618-91). Although some of the ASTM requirements are not fully satisfied, it is considered that this material can be useful for manufacturing mortar and concrete for non-structural purposes. Because of its pozzolanic reactivity this industrial waste can reduce the cement consumption, alleviating its dangerous accumulation while providing a sustainable resource for our construction industry.

KEYWORDS
Soil-cooper Residue, Puzzolanic Reactivity, Mortar, Concrete

1. INTRODUCTION

It is important to do research in all possible uses of any industrial waste generated in Mexico, in fact, it should not be permitted to operate any industrial complex without a plan to avoid any possible contamination. This paper will focus particularly in the study of a waste generated during cooper production.

In the State of Sonora, Mexico, it is located a large plant that produces cooper, its name is Mexicana de Cananea, this plant generates daily 75,000 metric tons of a waste material known as Jales of cooper. The waste material can be define as some sort of soil-cooper residue, which is being accumulated in a huge sedimentation dam built to avoid that the material gets away from the confined area. Particularly this dam mantains the Sonora river free of contamination, this river is the largest in the state. Despite the efforts of the mining corporation, the contamination of the large area that forms the reservoir is inevitable, and water infiltration is always a potential hazardous for groundwater aquifers.

The objective of this work was to investigate and analize the physical and chemical properties of the soil-cooper waste residue, with the purpose of determine if this industrial waste is useful as a mineral additive with pozzolanic reactivity in Portland cement mortar or concrete. It is well known that the use of cement alone to make mortar or concrete (including water and aggregates, of course) is no longer a truly sustainable application, since when cement hydrates, two things are produced, namely: gel (calcium silicate hydrates) and calcium hidroxide $Ca(OH)_2$ (free lime), this last product does not provide strength and can be easily carried away by water when the paste is subjected to wetting and dry cycles. The calcium hidroxide is not only the cause of those white and dusty spots on the concrete surface, but also a weak link in the concrete to undergo carbonation.

2. LABORATORY WORK

The behaviour of the Jales of cooper was analized taking into account three areas of interest, they are the physical composition, and chemical and mineralogical compositions. Part of the laboratory work was carried out processing the waste residue in question, the rest was performed on mortar mixes including the Jales of cooper as mineral additive. In any case the mortar was made with type I cement, standard sand and water.

2.1 Physical Properties

The physical properties were analized using as a guide the norm ASTM C31 “Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for use as a Mineral Admixture in Portland Cement Concrete”. Results were compared with specifications included in ASTM C618 “Standar Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Concrete”.

Some of the tests ran to determine the physical properties of the Jales of cooper included: specific gravity (ASTM C188), fineness, drying srinkage with mortar bars (ASTM C157), sanity (expansion in autoclave, ASTM C109).

2.2 Chemical Analysis

Tests for the chemical analysis were done according to ASTM C311. To determine the presence of oxides, 174 different samples were processed. A private laboratory in the city of Hermosillo, Sonora, performed the chemical analysis. Mexicana of Cananea provided data. It was detected the presence of the next oxides: SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O, Na_2O and CaO. The lost by ignition was done according to ASTM C114.

2.3 Mineralogical Analysis

The mineralogical analysis was done by x ray diffraction, the purpose was to detect qualitatively the presence of either a crystalline form or an amorphous form of the Jales of cooper.

3. RESULTS AND DISCUSSION

3.1 Definitions

Norm ASTM C618 defines three types of mineral additives, they are:

Type N. Raw or calcined pozzolans, some diatomaceous earths, opaline cherts and shales, tuffs and volcanic ashes or pumicites.

Type F. Fly ash as a byproduct of the combustion of anthracite or bituminous coal.

Type C. Fly ash normally as a byproduct of the combustion of lignite or subbituminous coal, some ashes may contain more than 10% of lime.

According to the previous definition, it is considered that the Jales of cooper can be classified as a mineral additive type N, since the other types are byproducts of the combustion of grinded coal, normally used to generate electricity in the power industry.

3.2 Chemical Analysis

Results of the chemical analysis showing the oxides present and the loss by ignition is presented in Table 1. ASTM requires a minimum of 70% for the total percentage for silica (SiO_2), alumina (Al_2O_3) and ferric oxide (Fe_2O_3), and a maximum of 10% for loss by ignition. As it can be seen from Table 1, the total for the mentioned oxides for the Jales of cooper is 83.47%, meanwhile the percentage for loss by ignition is 11.44. According to these results, the Jales of cooper doesn not comply with the requierement for loss by ignition, this indicates that contains soft particles that may affect in some degree its reactivity.

Table 1. Chemical Analysis of the Jales of Cooper

SiO_2	63.50%
Al_2O_3	16.17%
Fe_2O_3	3.80%
MgO	0.56%
K_2O	3.84%
CaO	0.14%
Na_2O	0.22%
Loss by ignition	11.44%

3.3 Mineralogical Analysis

Results of the mineralogical analysis obtained by x ray diffraction are shown in Figure 1. The purpose of this analysis was to detect the presence of amorphous material, particularly silica. According to ASTM the presence of amorphous silica indicates a possible highly reactive material. Figure 1 shows no amorphous products, since the base line of the x ray diffraction spectrum is parallel to the horizontal axis. If amorphous materials were present, then the base of the x ray spectrum (both sides of the pike) would show a convex shape raising from the horizontal axis. In this analysis an estimation of the concentration of major crystalline minerals present in the Jales of cooper is as follows: quartz (55%), muscovite (30%), kaolinite (10%) and pyrite (5%).

"There are no amorphous minerals"

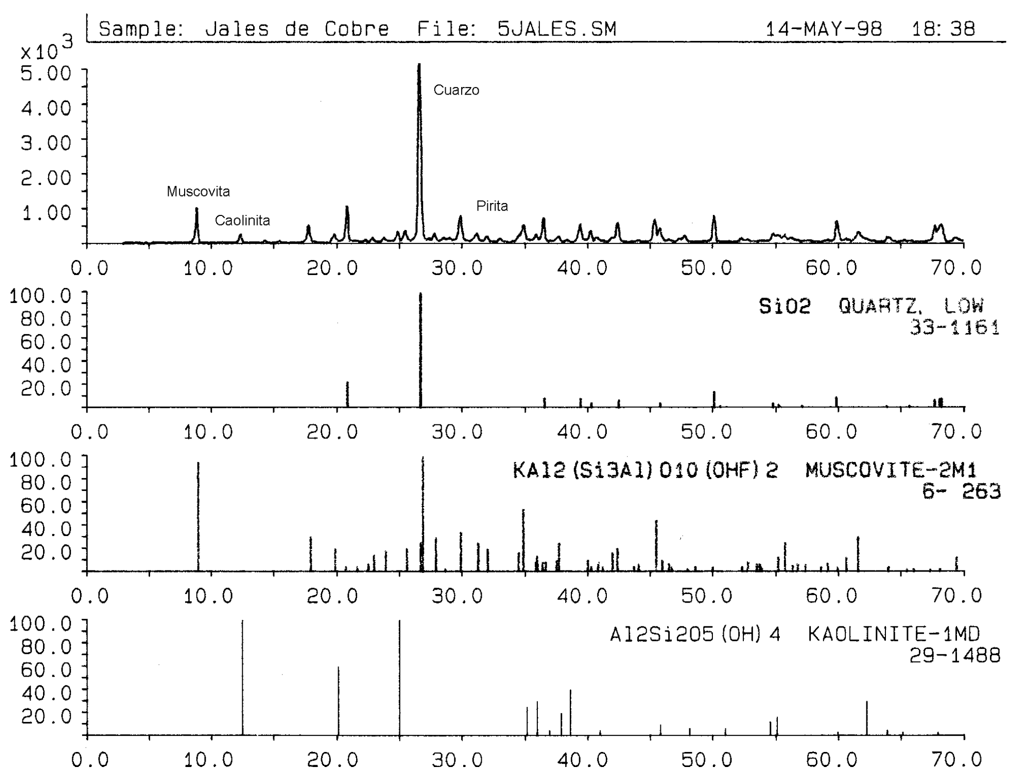

Figure 1. X Ray Diffraction Analysis of the de Jales of Cooper

3.4 Physical Tests

If it is true that on one hand the absence of amorphous material indicates a possible low pozzolanic reactivity, on the other hand, it is necessary to verify such a fact by means of physical tests. Next, the results of physical tests considered not only simple but also of major interest for the construction industry are presented.

Specific gravity
Three samples were processed, the average specific gravities obtained were: 2.75, 2.72, and 2.73, the variations against the average were well below the maximum specified of 5%.

Sanity
Two sets of samples were processed to run autoclave expansion. Mortar bars were fabricated with 100 parts of cement and 25 parts of the Jales of cooper. Bars from sample one presented a 0.14% expansion, while bars from sample two presented a 0.10% expansion, both results are well below the maximum 0.8% allowed.

Water requirement
ASTM C618 also establishes a specification for the variation in water requirement when making comparisons with a control mix. In this test, a control mix (with no Jales of cooper) labeled as control 1 was used. Results of the optimum amount of water required and mixes used are shown in Table 2. From this table, it can be seen that the percentage of water required for the different mixes with respect to the control mix is less than the 115% maximum allowed.

Table 2. Water Requirements

Mix	Optimum water (ml)	% Related to Control 1	ASTM C 618
100% Cement (control 1)	242.5	100	115% Maximum
90% Cement+10% Jales	250	103	
80% Cement+20% Jales	257	106	
70% Cement+30% Jales	263	108	
80% Cement+20% Filler (control 2)	240	99	

Table 2 indicates that the use of the Jales of cooper does not influence the need for more water than the maximum specified. It is well known that wet mixes tend to yield low strength. Considering this fact, probably the mix made with 80% cement and 20% Jales looks promising for good strength results.

Fineness
Fineness was verified with a sieve analysis according to ASTM C618. Sieves used were: Nos. 48, 65, 100, 150, 200, 325 and 400, however the norm only specifies the percentage retained in sieve No. 325. The percentage retained in sieve No. 325 was 47.14%, while the specification requires a 34% as maximum. Certainly the Jales of cooper are coarser than specified, and this will have a detrimental effect in its potential pozzolanic reactivity.

Drying shrinkage
Drying shrinkage was obtained testing three mortar bars according to ASTM C618, the percentage of contraction was 0.02%, which is lower than the 0.03% maximum allowed.

Pozzolanic reactivity with Portland cement

To detect the degree of pozzolanic reactivity of the Jales of cooper, tests for compressive strength with mortar cubes (5x5x5 cm) were carried out. Five mixes were tried, two for control with no additive and three using the Jales of cooper as a partial cement replacement. Trial mixes are shown in Table 3. In this table, besides control mix 1 already referred to, control mix 2 was added. Control mix 2 includes a 20% cement replacement with a mineral filler with zero reactivity with the cement.

Table 3. Mix Proportions to Detect Pozzolanic Reactivity

	Control 1	Trial	Trial	Trial	Control 2
W/C	0.485	0.555	0.514	0.751	0.6
Cement	500 g	450 g	400 g	350 g	400 g
replacement	0 g	50 g	100 g	150 g	100 g
Sand	1375 g	1375 g	1375 g	1375 g	1375 g
Water	242.5 ml	250 ml	257 ml	263 ml	240 ml
Fluidity	89.5	91	91.5	91	93

It should be mentioned that all mixes were proportioned to yield a similar fluidity. Mixes presented in Table 3 are identified from left to right as follows:

- 100% cement (control 1)
- 90% cement + 10% Jales of cooper (trial)
- 80% cement + 20% Jales of cooper (trial)
- 70% cement + 30% Jales of cooper (trial)
- 80% cement + 20% filler (control 2)

Results from compression tests at 7 and 28 days are presented in Figures 2 and 3. From figures it can be seen that there is a significant difference in strength between trials and mix control 1. Considering that the minimum strength specified by ASTM C618 should be 75% of that of control mix 1, probably the best mix for construction applications would be the one with 80% of cement plus 20% of Jales. For this last mix, it should be pointed out that when comparing strength results with control mix 2, it seems that the Jales of cooper really improved strength since control mix 2 was made with an inert filler.

The pozzolanic reactivity of the Jales of cooper is apparent since it complies with the minimum requirements of ASTM C618. The question is, can the Jales of cooper develop in the long-term strength closer or in excess of that of control mix 1? This question requires research on the long-term performance of this waste material.

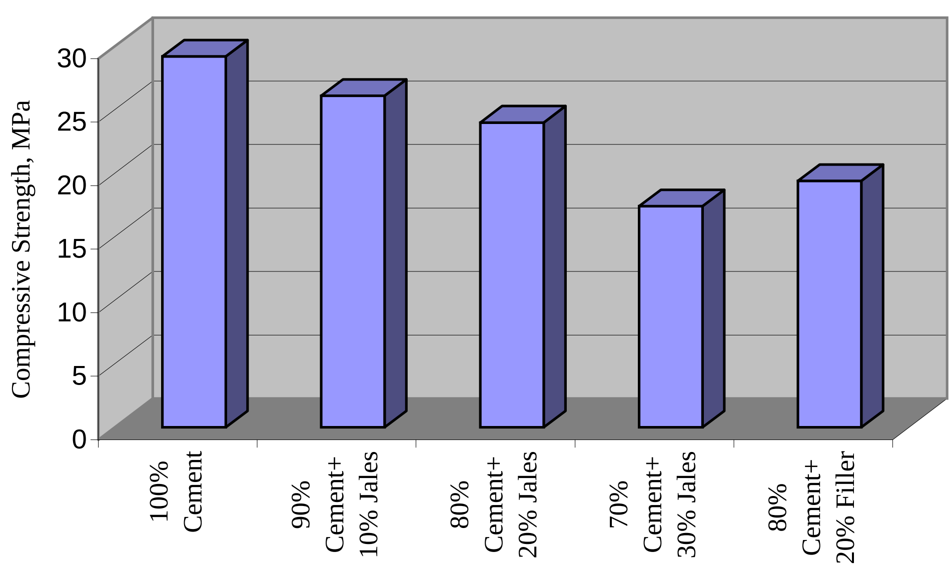

Figure 2. Compressive Strength of Mortar Cubes, 7 days

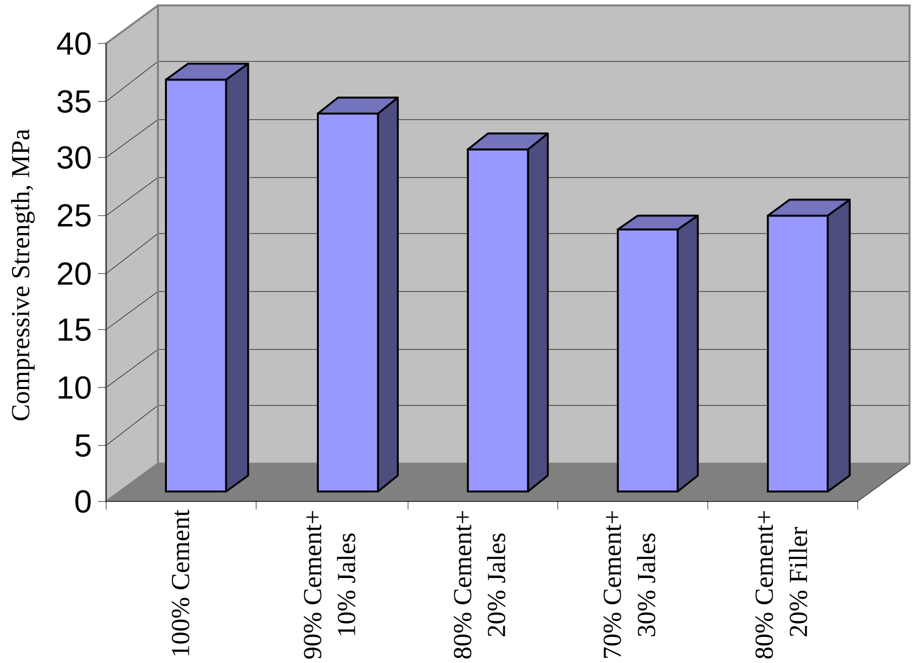

Figure 3. Compressive Strength of Mortar Cubes, 28 days

4. CONCLUSIONS

The present work permits to conclude that the Jales of cooper exhibit a pozzolanic reactivity with Portland cement, since the minimum specified for strength development by ASTM C618 is satisfied, although not all the requirements of the norm were met. The benefit in strength when using the Jales of cooper can be verified when comparing mixes with the same percentage of replacement, consider the mixes with 20% of Jales on one hand and 20% of filler on the other hand.

As it can be seen from the results, it is not enough that the total of silica, alumina and ferric oxide exceeds the 70% minimum required by ASTM C618, but also that some other characteristics are needed to have an excellent pozzolanic material, among them, an amorphous structure and high fineness.

The Jales of cooper could be very useful as a cement replacement in a wide variety of mortars and concretes required in the construction industry, always as result of a program to detect better applications. If used in this way, this material can not only save money when using less cement, but also may become a good alternative to get ride of an industrial waste that can contaminate the environment.

5. REFERENCES

ASTM C109, “ Compressive Strength of Hydraulic Cement Mortars”.

ASTM C151, “Autoclave Expansion of Portland Cement”.

ASTM C157, “Length Change of Hardened Hydraulic Cement Mortar and Concrete”.

ASTM C188, “Specific Gravity of Hydraulic Cement”.

ASTM C311, “Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete”.

ASTM C618-91, “Fly Ash and Raw or Calcined Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete”.