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Industrial Waste Application with Silicon as an Aggregate in Ceramic Products

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Abstract

Experiments show that the reuse of waste in addition to reducing production costs also contributes to the environment. This study points out the industrial waste sludge containing silicon that comes from the cutting, lapping, silicon plates polishing, and individual chips cutting process from the semiconductor industry, with the proposal to reuse this as an aggregate material in the ceramic products industry. There are also sludge toxicity tests which show that the sludge can be reused as material added to the clay traces. Tests done right after the specimen burn containing silicon waste indicated the possibility of using the waste due to its nanometer features. Even though it is a preliminary study, it emphasizes the applicability of the silicon industrial waste sludge addition in the mixture with clay for ceramic artifact composition.

Keywords: Experimental; Silicon; Industrial Waste Sludge; Clay; Ceramic

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1. Introduction

The chemical element used for semiconductor and microelectronic production is silicon (SI), which is also a component found in ceramic materials. During the cutting, lapping, silicon plate polishing and individual chip cutting process for the semiconductor production, an extremely fine particle residue is that composes the industrial

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waste sludge. As it is a very fine granular material, the silica particles (silicon oxide) are spherical with diameter 100 times smaller than the cement particles and as they are thinner than the cement, such particles compose a framework with greater homogeneity reducing the spaces in the structure (interstitial) [1].

Due to these special features, the waste can be a different and innovative aggregate when mixed with the ceramic artifact traces.

According to the Brazilian Ceramic Association (ABCERAM), what distinguishes mineral clay from others is the kind of structure andthe substitutions that can occur inside the structure, mainly from aluminum to magnesium or iron, from silicon to aluminum or iron.Consequently, the residual charges are neutralized by different ion electric charges of some cations. This way, there is no replacement in the kaolinite, but there is in the illite and the neutralizing cation is the potassium; there are also replacements in the montmorillonite and the neutralizing cations can be the sodium, calcium, potassium and others. It illustrates the differences in the characteristics of interest for several technological applications. For example, clays that are made up of the mineral kaolinitemainly are the most refractory clays, as they are mostly made up of silicon (SiO_2) and alumina (Al_2O_3), and the others are less refractory due to the presence of potassium, iron and other elements [2].

The proposal of reusing industrial waste can be taken into account as a business opportunity, as the search for ways to reduce the environmental impact created by waste is in the organization’s strategic management as a new innovation line and industrial entrepreneurship. Following this philosophy, we see that with the waste flow designed strategically it’s possible to get to a cycle closing which can be reached by the industrial ecosystem formation in which the power and material consumptionis optimized and the waste from a production process can be used as raw material for other processes [3].

In addition to the economic opportunities that come from reuse, reprocessing, and recycling, the sustainable businesses will lead their strengths in favor of their corporate and business image while societies will defend themselves by means of specific legislation and regulations [4].

2. Objective

In Brazil, this proposal comes with guidelines applicable to solid waste, in Chapter I of the Introductory provision in the National Solid Waste Policy (PNRS), Law No. 12,305/2010, Article 13, for law enforcement purposes, among the industrial waste we can list the industrial waste generated by the production processes and industrial facilities [5].

With regard to industrial waste, there is the concern about the toxicity level of these elements. Ecotoxicology tests must be done to evaluate the contamination risk level to humans and the environment. Tests with industrial waste sludge from the semiconductor industry were carried out to evaluate the possibility of acute toxicity using the bio-indicator Eisenia Andrei organism in which no individual death was noted in the concentrations used, stating lack of acute toxicity for these organisms for 14 days [6].

Toxicity refers to the potential of a certain substance, product, or set of substancesto cause harmful effects in the organisms in which they are in contact with. These effects can be from behavioral changes, growth changes, or reproduction changes, evento theorganisms’ death. In order to evaluate the degree of impact that a certain effluent can cause on the receptor body, toxicity tests are carried out and the purpose is to simulate in laboratories the effects that could be noted in the receptor body after the release of the effluent. Toxicity and Ecotoxicological tests are synonyms to set up the main ecotoxicology tool to evaluate effluents toxicity [7].

To evaluate the addition of industrial waste sludge possibility as value-added material to the ceramic artifact traces, tests with the addition of sludge were carried out in laboratories and empirically added in a proportion of 20% from 0 to 100% for clay and for dehydrated silicon waste.

In a study carried out by Ramos regarding clay characterization used for structural ceramics it was noted that most of the samples presented particle-size distribution suitable for structural ceramics production and the samples showed high plasticity level and the materials analyzed are mainly composed of quartz, smectite clay mineral, kaolinite, mica, feldspar and an aluminum silicate hydroxide that concluded that the physical mineralogy is very important to understand the clay processing behavior and evaluate its suitability for the use of industrial ceramic [8].

It’s noted that the ceramic artifacts studies have been increasing in the science field and in academic research from the primary inputs to the recycling.

Ceramic waste can be turned into aggregate ground rocks instead of rough aggregate and the experimental study showed that the ceramic waste recycling is feasible as a gross aggregate for the nonstructural concrete artifacts production [9].

In another research ceramic coating waste in the cement production as tile waste shows pozzolanic properties and chemical and physical properties of the cement and they are in conformity with the cement standard to the addition of 35% of tile waste [10].

As the purpose of this study is to evaluate the performance and dimensional characteristics of mass and resistance for the reuse of waste that comes from the semi-conductor production as a ceramic aggregate, this possibility of reuse can reduce the environmental impact regarding disposal and contribute as new ceramic aggregate materials.

3. Methodology

This research proposal was to evaluate changes in the dimensional characteristics of mass and resistance of the samples for the ceramic artifacts production with the addition of silicon waste from the semiconductor production process. The tests were carried out in May 2016 in the Laboratory of Processing and Material Characterization from the Technology College in São Paulo and the experiment steps were divided as follows:

a. Industrial waste sludge moisture drying and measurement,
b. Test specimen production and burn,
c. Specimen bending tests.

a– Industrial waste sludge moisture drying and measurement

In the sludge drying process two approaches were used (oven and humidity scale) the high content of moisture in the sludge of approximately 92% is seen in Table 1 and Table 2. The sludge dehydration operation occurred for 7 days at 90 ºC in a Digital timer multiprocessor oven and the dehydration operation occurred for 30 minutes at 118 ºC in the moisture scale.

Table 1. Industrial Waste Sludge drying in oven

Industrial waste sludge drying (Si)	Loss of mass humidity	Humidity (%)
Wet net mass = 0.546kg	0.505 kg	92.50%
Dry net mass = 0.041kg		

Table 2. Industrial waste sludge drying in moisture scale

Industrial waste sludge drying (Si)	Loss of humidity in mass	Moisture (%)
Wet net mass = 5.120g	4.725g	92.30%
Dry net mass = 0.395g		

b – Test specimen production and burn

For theproduction of the testspecimen, there were 2.5 kilograms of silicon industrial waste sludge in the Digital Timer microprocessor oven Sterilifer at 90 ºC for 48 hours for dehydration. After drying, there was a gain of 0.250 kilograms that were ground until obtaining a very fine aggregate as it's shown in Figure 2.

Fig. 1. Silicon industrial waste sludge

Fig. 2. Dehydrated silicon powder

Table 3 shows the mixture proportions of clay and silicon powder for the production of 18 rectangular testpieces in a scale from 0 to 100% of clay and silicon that were produced in a hydraulic press Shimadzu model and 120 kN capacity. The samples were pressed at 40 kN with the following dimensions described in Table 4 and noted in Figure 3.

Table 3. Clay and silicon proportion in test specimen

Elements in %		Proportion in grams	
Clay	Silicon	Clay	Silicon
100	0	10	0
80	20	8	2
60	40	6	4
40	60	4	6
20	80	2	8
0	100	0	10

Table 4. Dimensions of test specimen

Sample	Elements in %		Dimensions before the burn (E, C, L) in mm	Quantity
	Clay	Silicon		
1	100	0	5 x 61 x 21	3
2	80	20	5 x 61 x 21	3
3	60	40	10 x 61 x 21	3
4	40	60	9 x 61 x 21	3
5	20	80	9 x 61 x 21	3
6	0	100	12 x 61 x 21	3

E = thickness C = Length L = Width

Fig. 3. Test specimen after pressing

The test specimenwere wrapped in an oven as a muffle furnace for 24 hours at an increasing temperature from 0 to 1000 ºC with one hour rest after the burnwas complete, as it’s shown in Figure 4. According to the Brazilian Ceramic Association, after drying, the pieces must undergo a thermal treatment at high temperatures and for most of the products, the temperature is between 800 ºC to 1700 ºC, in continuous or intermittent ovens.

Fig. 4. Test piece burn

c- Bending test

After the cooling of the test specimen as seen in Figure 5, these were subjected to bending test in the universal machine for traction mechanical tests, compression and bending; model EMIC DL-10000, maximum capacity of 100 kN as shown in Figure 6.

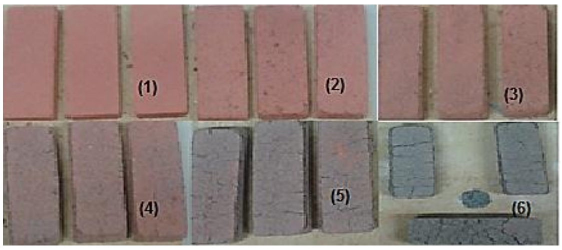

Fig. 5. Test specimens after burn procedure

Fig. 6. Bending test in test specimen

4. Results

It was seen that the industrial waste sludge is composed of high humidity reaching 92% in a mass of water. This result may influence in water saving to preparing ceramic mass traces.

Even empirically, the burn process of the test specimens suggested a considerable change in the masses. Table 5 shows that as some proportions of residual were added to clay, the average mass has had an important reduction achieving a difference of 2.38 grams, which represents 30.8%.

Table 5. Difference in mass and percentage

Sample	Elements in %		Proportion in grams		Average mass before the burn	Average mass after the burn	Average mass difference	Average difference %
	Clay	Silicon	Clay	Silicon				
1	100	0	10	0	10.5	9.53	0.97	10.1
2	80	20	8	2	10.2	8.80	1.40	15.9
3	60	40	6	4	10.9	8.95	1.95	21.7
4	40	60	4	6	10.9	8.72	2.18	25.0
5	20	80	2	8	10.1	7.72	2.38	30.8
6	0	100	0	10	10.6	7.67	2.93	38.2

Table 6 shows a variation in the dimensions of the samples after burn which is compatible with the drying process of the mass.

Table 6. Mass and dimensions before and after the samples burn

Sample	Elements in %		Proportion in grams		Dimension before the burn (E, C, L) in mm	Dimensions after the burn (E, C, L) in mm	Dimensional differences of the samples in mm
	Clay	Silicon	Clay	Silicon			
1	100	0	10	0	5 x 61 x 21	5 x 58 x 20	0 x 3 x 1
2	80	20	8	2	5 x 61 x 21	5 x 58 x 20	0 x 3 x 1
3	60	40	6	4	10 x 61 x 21	7 x 57 x 19	3 x 4 x 2
4	40	60	4	6	9 x 61 x 21	7 x 56 x 19	2 x 5 x 2
5	20	80	2	8	9 x 61 x 21	9 x 53 x 18	0 x 8 x 3
6	0	100	0	10	12 x 61 x 21	10 x 49 x 17	2 x 12 x 4

Table 7 bending tests have shown a significant reduction of the mechanical resistance when residues were added to the clay.

In case of ceramic blocks width smaller than 90 mm, the least demanded compressive strength is 2.5 MPa. [11].

To the test specimen with their own dimensions shown in Table 6, after mechanic bend tests, maximum bend load (critical) was obtained as shown in Table 7. We see that as the silicon proportion increases in the traces of materialcomposition of the testspecimen, the mechanical resistance to bending is reduced.

Table 7. Bending Test in Newton (N)

Elements in %		Proportion in grams		Bending Tests (Maximum force in N)
Clay	Silicon	Clay	Silicon	
100	0	10	0	91.34
80	20	8	2	17.31
60	40	6	4	15.76
40	60	4	6	12.92
20	80	2	8	11.89
0	100	0	10	0

5. Conclusion

In the ceramic artifacts industry, the basic material used is clay, which has silicon in its composition. Recyclingindustrial waste sludge as an aggregate will lead to the sanitation of two environmental problems: sludge disposal at the end of the semiconductors production chain, and the obtainment of feedstock to the beginning of the ceramic artifact production chain.

We understand that using industrial waste sludge, especially in the ceramics sector, depends on larger studies and research for the production of artifacts. In this regard, it is necessary to perform more mechanical tests following the parameters imposed by Instituto Nacional de Metrologia, Qualidade e Tecnologia (INMETRO). In addition, toxicity tests suggest the possibility of reuse of residue as an opportunity of feedstock to ceramic sector.

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