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OBTAINING A CERAMIC BY ALUMINOTHERMIA FOR USE AS AN ABRASIVE MATERIAL

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Abstract: Polishing operations are mandatory in the manufacturing of floors and terrazzo, which are performed with grinding wheels. This study is carried out in two main stages, a laboratory study and later a study in the experimental pilot plant where the obtaining of abrasive materials from the aluminothermic processing of solid industrial wastes and Cuban minerals is approached. Different mixtures composed of mill scale and aluminum chips to which different proportions of limestone are added are studied. As a result of the process, a high hardness ceramic is obtained as the main product and a metal as a byproduct. The results of the process are evaluated on the basis of the metal and slag yields. The behavior of the ceramic as an abrasive material is evaluated by means of scratch tests on glass, as well as the behavior of the powders during setting with p–350 cement. Finally, a real working test of the abrasive obtained is carried out, achieving good results, which justifies the production on a larger scale of the abrasive materials with the objective of substituting the imported abrasive. The proposed technology constitutes a great step towards sustainability, since it would allow to substitute the importation of this product, minimizing its price and using Cuban industrial waste and minerals as raw materials.

Keywords: aluminothermia, ceramics, castings, abrasive wheels, sustainability

INTRODUCTION

An abrasive is a material of a certain hardness and density that allows other materials to be processed by removing the material itself [9]. Hardness, grain size, composition and structure are of fundamental importance [5].

Each of these variables affects the final result. Choosing the right abrasive is essential to achieve the desired result [9]. They can be found on the market in multiple forms (wheels, discs, paper, powders, pastes, etc. [7].

The combination of logistics and quality assurance (management) creates the conditions for a change in production and services [6]. To work in this direction, the country's leadership gives priority to scientific and technological work, which is carried out by increasing university–industry links to obtain concrete results.

Likewise, the choice of the type of infrastructure and the way in which the services provided over it are designed, regulated and operated, determine the price, times and quality of the products [2].

In Cuba, the polishing of floor and terrazzo elements is done with grinding wheels, which are manufactured using abrasive powders imported at high costs in the international market. The absence of an industrial process for obtaining abrasive materials represents a major constraint to the economic development of the island. This makes it necessary to develop an economically feasible alternative for the manufacture of these abrasive materials, since they are used in numerous tasks.

From a mixture consisting of: mill scale, aluminum shavings and the addition of limestone, it is possible to obtain by aluminothermia a ceramic with high alumina content and high hardness, which can be used in the production of grinding wheels. The pyrometallurgical processing is carried out using the energy generated by the redox reactions that take place, being more than 90 % of the materials used industrial waste.

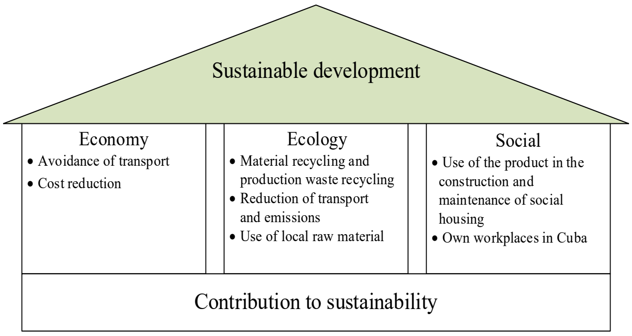

Figure 1. Effects on sustainability through the research results achieved

The proposed methodology constitutes a scientific novelty for the country Cuba, since the process uses Cuban industrial wastes and minerals as raw material [3]. This is also a contribution to sustainability, Figure 1. Sustainability is an essential trend of the present [4]. This leads to the use of waste and reduction of transportation expenses. This technology may be interesting for other countries with similar conditions.

MATERIALS AND METHODS

Figure 2 shows the scientific approach and methods of the work, applied in the research.

RAW MATERIALS

The raw materials used in aluminothermic processing are as follows:

- Mill scale, from the company A.
- Aluminium shavings, from company B.
- Limestone (stone dust), from company C deposit.

Table 1 shows the chemical composition of the raw materials to be reacted.

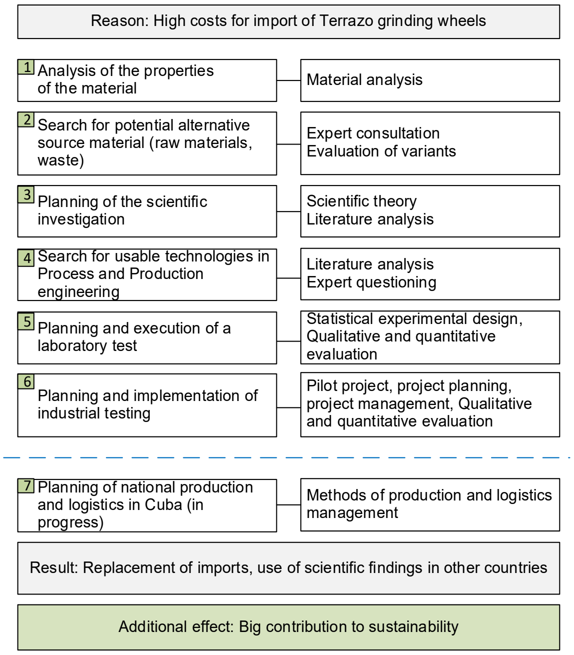

Figure 2. Scientific approach and methods of the research work

Table 1. Chemical composition of the raw materials to be used

<table>
<tr><th colspan="36">Aluminium shavings</th></tr>
<tr><td colspan="4">Si</td><td colspan="4">Fe</td><td colspan="4">Mn</td><td colspan="4">Cu</td><td colspan="4">Mg</td><td colspan="4">Zn</td><td colspan="4">Cr</td><td colspan="4">Ti</td><td colspan="4">Al</td></tr>
<tr><td colspan="4">0,5</td><td colspan="4">0,2</td><td colspan="4">0,1</td><td colspan="4">0,1</td><td colspan="4">0,2</td><td colspan="4">0,2</td><td colspan="4">0,1</td><td colspan="4">0,1</td><td colspan="4">report</td></tr>
<tr><th colspan="36">Mill scale</th></tr>
<tr><td colspan="4">Fe_2O_3</td><td colspan="4">Fe_3O_4</td><td colspan="4">FeO</td><td colspan="4">Fe</td><td colspan="4">Fe</td><td colspan="4">O_2</td><td colspan="12">Impurities</td></tr>
<tr><td colspan="4">20–30</td><td colspan="4">40–60</td><td colspan="4">15–20</td><td colspan="4">2–5</td><td colspan="4">70,3</td><td colspan="4">24,1</td><td colspan="12">5</td></tr>
<tr><th colspan="36">Limestone</th></tr>
<tr><td colspan="6">CaO</td><td colspan="6">MgO</td><td colspan="6">SiO_2</td><td colspan="6">Al_2O_3</td><td colspan="6">Fe_2O_3</td><td colspan="6">Ignition Lose</td></tr>
<tr><td colspan="6">55,20</td><td colspan="6">0,68</td><td colspan="6">0,34</td><td colspan="6">0,23</td><td colspan="6">0,17</td><td colspan="6">44,38</td></tr>
</table>

Mill scale is a solid residue generated during hot rolling processes in the steel industry. The iron oxide (mill scale) has a very variable grain size, therefore, it was crushed and sieved until all the residue had a grain size of less than 2 mm.

Aluminothermia requires the use of aluminium with low granulometry, so the shavings used were sieved below 3 mm.

Limestone ($CaCO_3$) is marketed in different grain sizes, according to the requirements for its use, using in this case the fraction called stone dust, which has a grain size of less than 1 mm.

FORMULATION OF THE LOADS AND OBTAINING THE ABRASIVES

— EXPERIMENTAL STUDY

The research strategy consisted of formulating five charges, from 0 to 4, according to the amount of heat generated per unit mass of each charge, so that the amount of heat released by the reactions would be sufficient to ensure the self–sustainability of the process and the adequate separation of the metal from the ceramic. The data are shown in Table 2.

Table 2. Conformation of aluminothermic charges (in g)

	Mill scale	Shavings	Limestone
0	150	52	0
1	150	52	15
2	150	52	30
3	150	52	45
4	150	52	60

Once the melting process is finished, the mixture is left to cool in the reactor for its later extraction in a tray, leaving the metal in the lower part and the ceramic in the upper part, which are separated manually.

Finally, load 1 was selected and reproduced 20 times to obtain a greater quantity of ceramics, which will be evaluated in the manufacture of abrasive materials. Table 3 shows the charge conformation for the large casting.

Table 3. Conformation of the aluminothermic caster large (in g)

Mill scale	Shavings	Limestone
3000	1040	300

The different components of the load, once weighed on a balance technical, are introduced into a drum mixer in increasing order according to their density: aluminium shavings, limestone and mill scale. The components are mixed for 30 minutes. Subsequently, each mixture was preheated in an oven between 250 and 300 °C for one hour, then it was placed, hot, in the graphite reactor, starting the reaction by the action of the electric arc. The process of obtaining the termites is shown in Figure 3.

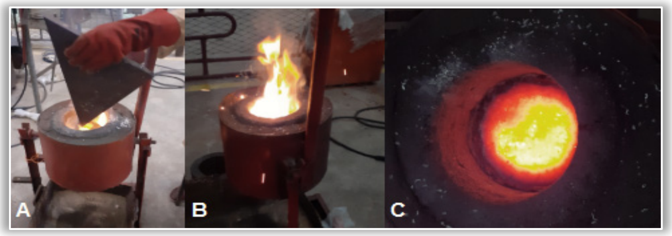

Figure 3. Obtaining of the Termites: A) Reactor feed and ignition of the reaction, B) Self–sustainability of the reaction, C) Cooling of the termite

— STUDY AT THE EXPERIMENTAL PILOT PLANT

In the laboratory study, the best performing mixture was selected, which reproduced at a higher volume and behaved favorably. For the study in the experimental pilot plant, two large–volume mixtures (Table 4) were developed with the objective of obtaining the largest possible amount of ceramic to evaluate them under real working conditions in the factory. The process of obtaining the termites is shown in Figure 4.

Table 4. Forming of two casts in the Pilot Plant (in kg)

Casts	Mill scale	Shavings	Limestone
1	76	26,4	7,6
2	136	46,2	13,3

The reactions developed satisfactorily, the ignition of the process was adequate, guaranteeing that the mixture to react completely in a self–sustaining manner, allowing an adequate metal–ceramic separation.

Figure 4. Obtaining oh the termites at the experimental pilot plant level: A) Ignition of the reaction, B) Self–sustainability of the reaction, C) Cooling of the termite

RESULTS AND DISCUSSION

MASS BALANCE

From the charge conformation data shown in Table 2 and 3, the chemical composition of each of the raw materials (Table 1) and the fundamental chemical reaction to occur between Fe_2O_3 and aluminium (Equation 1), a mass balance is performed to estimate the potential outputs of each of the charges, assuming that all the iron present in the scale is in the form of Fe_2O_3.

$$Fe_2O_3(s) + Al(s) \longrightarrow Fe(s) + Al_2O_3(s) \qquad (1)$$

The balance is carried out on the basis of the principle of Conservation of Mass, the general expression of which is shown in Equation 2, [1].

$$\text{Accumulation} = \text{Input} - \text{Output} + \text{Generation} - \text{Consumption} \qquad (2)$$

From the results obtained in the mass balances, the theoretical quantity of metal, ceramics and gases to be obtained in each of the loads is determined.

CALCULATION OF HEATS OF REACTION

The determination of the heats of reaction allows the assessment of the feasibility of occurrence of the chemical reactions that develop during metallurgical processing [8], results that allow the prediction of the feasibility of self–sustaining the aluminothermic reaction. These results are shown in Tables 5 and 6.

Table 5. Amount of heat generated by the charges in the experimental study (cal/g)

	0	1	2	3	4
Reaction heat	–930,9	–867,2	–811,4	–762,5	–719,19

Table 6. Amount of heat generated by the loads in the study of the experimental pilot plant (cal/g)

	1	2
Reaction heat	–852,9	–859,0

These values for all loads are above 700 cal/g of pyrometallurgical mixture, which guarantees the self–sustainability of the aluminothermic process without the supply of additional external energy, which guarantees the adequate separation between metal and slag [8].

METALLURGICAL TREATMENT RESULTS IN THE EXPERIMENTAL STUDY

— SMALL LOADS

In general, the small casts behaved satisfactorily, the ignition process went smoothly, good ignition of the reaction developed in a self–sustained way until the end of the process. Metal and ceramics are adequately separated, Figure 5.

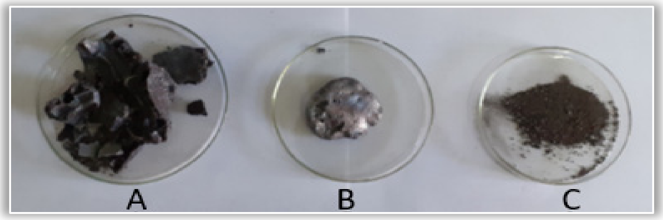

Figure 5. a) slag, b) metal, c) unreacted mixture

The quantitative results of the processing of all small loads in terms of: amount of metal, slag and unreacted mass of mixture are shown in Table 7, also the yield values, which are determined from the ratio between the actual amount obtained and the theoretical amount determined from the mass balance, are also shown.

Table 7. Masses of molten metal, slag and unreacted mixture of small termites

	Metal		Ceramic		Unreacted
	Mass (g)	(%)	Mass (g)	(%)	Mass (g)
0	93	87,5	97	101,4	5
1	91	85,6	108	103,7	6
2	85	79,9	116	103,1	16
3	80	75,2	128	105,7	18
4	58	54,6	131	101,1	47

To evaluate the process on a larger scale, charge 1 is selected because of its good pyrometallurgical behavior, good yield and lower amount of limestone incorporated into the mixture.

— PROCESSING OF THE LARGE CHARGE

The ignition process went smoothly, with a good reaction rate, resulting in metal with a uniform and smooth appearance (Figure 6).

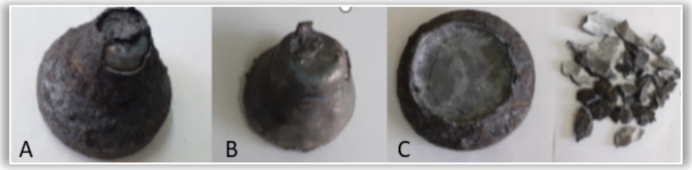

Figure 6. A) Products obtained, B) Metal, C) Slag

The results of the processing of the large charge in terms of metal and slag quantity are shown in Table 8.

Table 8. Results of the processing of large thermite

Product	Theoretical mass (g)	Actual mass (g)	(%)
Metal	2124,9	1995	93,9
Cerámic	2082,8	2120	101,8

Table 8 shows that the aluminothermic processing of the large charge yielded more than 2 kg of ceramic and more than 1,9 kg of metal, which represents 102 and 94 % yield respectively.

Comparing these results with those of casting 1, we find the following:

- with increasing amount of the mixture to be processed, the metallic yield increases significantly and the ceramic yield decreases slightly,
- while at the same time the amount of unreacted mixture decreases significantly.

This leads to an improvement in the results of pyrometallurgical processing.These results make it possible to evaluate the possibility of scaling up the process.

EVALUATION OF ABRASIVES

— VALUATION OF THE SCRATCH TEST

The objective of the test is to evaluate and compare the quality of the ceramics obtained in terms of their hardness. The test consists of scoring a crystal by the action of the abrasive with a constant load of 2 kg, following the principles of tribology [5], see Figure 7.

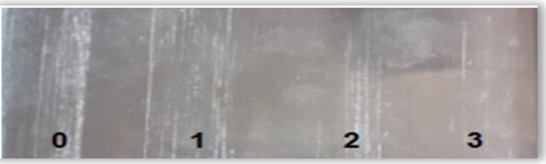

Figure 7. Abrasive action on glass

As shown in Figure 7, all ceramics have a higher hardness than glass, with the hardness of glass on the Mohs scale being 5.5 [7], which validates their use for the manufacture of abrasive powders.

— PRODUCTION OF GRINDING WHEEL SPECIMENS

When casting 1 was selected as the one with the best results, it was necessary to evaluate the behavior of the different granulometric fractions during setting, as these ceramics will be used for the development of grinding wheels, using P–350 cement as a binder.

The aim of this test is to evaluate the possible reactivity of the abrasive grains (ceramics obtained) with Portland P–350 cement.

Therefore, all of the ceramics obtained in the load large were manually crushed and granulometrically classified. The product obtained was then sorted into 5 fractions so that they could be grouped according to the particle size requirements of the grinding wheels.

Table 9 shows the results of the granulometric classification of the crushed ceramics and the average grain number, according to the granulometry obtained.

Table 9. Results of the granulometric classification process of the crushed ceramics

	Grain size fraction	Number of grain	Mass (en g)	%	Accumulated in %
1	–0,315 +0,21	60	540	30,3	30,3
2	–0,21 +0,16	80	188	10,5	40,9
3	–0,16 +0,08	100	715	40,1	81,0
4	–0,088 +0,05	180	230	12,9	93,9
5	–0,053	240	109	6,1	100

Table 9 shows that it is possible to obtain abrasives with different grain sizes.

This makes it possible to produce abrasive discs required for carrying out grinding and polishing work on floors and terrazzo. When the test specimens shown in Figure 8 were made, it was confirmed that they behaved satisfactorily, and the problems presented in previous studies [10] were not observed.

Figure 8. Test tubes manufactured with the 5 particle size fractions obtained

RESULTS OF METALLURGICAL TREATMENT IN THE STUDY OF THE EXPERIMENTAL PLANT PILOT

The results of the evaluation carried out at the experimental pilot plant level are presented in Table 10, Figure 9 shows a picture of the products obtained.

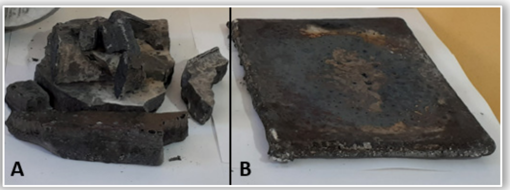

Figure 9. Products obtained at experimental pilot plant level. A) Slag, B) Metal

Table 10. Results of the Pilot Plant scale evaluation

Casts	Metal		Ceramics	
	Mass (kg)	(%)	Mass (kg)	(%)
1	55	104,7	44	87,4
2	94	101,2	80	89,0

Experimental pilot plant scale tests scaling were satisfactory, with a tendency for the metallic yield to increase and the ceramic yield to decrease as the amount of charge processed increases.

Two samples obtained from the crushing and grinding process of the abrasive powders obtained at the Pilot Plant were subjected to a sieving process for ten minutes, obtaining the results shown in Table 11.

Table 11. Results of the sieving of the abrasive obtained in the ball mill and retained between the two large sieves at the company C

Coarse grain (mm)	Retained mass (g)	Retained (%)	Accumulated (g)	Grind	%	%
–1	62	9,2	62	18		
+1 –0,84	109	16,2	171	20		90,4
+0,84 –0,5	348	51,6	519	25; 30; 35	74,2	
+0,5 –0,315	152	22,6	671	40; 45; 50		
+0,315 –0,2	3	0,5	674	60; 70		
Total	674	100				

As can be seen in Table 11, 9 % of the abrasive powder is concentrated between 0.1 and 0,315 mm, of which 74 % is between 0,315 and 0,84 mm, a range that corresponds to a particle size range, with which different grinding wheels can be produced, mainly for roughing, the rest can be used for polishing and finishing operations.

The study of the grinding and sieving process of the abrasives obtained in the plant allows us to affirm that with the appropriate use of the existing equipment in the plant, it is feasible to obtain all the particle size fractions required to cover the demand for grinding wheels used in the roughing and polishing operations of floors and terrazzo. The selected particle size fractions were used for the manufacture of grinding wheels Figure 10, which were evaluated under real working conditions and their performance was verified.

Figure 10. Abrasive wheels made from the abrasive powders obtained

Once the grinding wheels have been made from the abrasive obtained, the wheel must be left to set for approximately 20 days. Finally, the wheels are used for grinding and polishing operations.

The same were evaluated in real working conditions giving a performance very close to the imported abrasive, even superior in some specific granulometric fractions, in the Figure 11 you can see a series of finished terrazos.

Figure 11. Polished terrazzo tiles available for use

PRODUCTION STRATEGY IN EXPERIMENTAL PLANT

On the basis of the previous studies, an economic evaluation is carried out to determine the techno economic feasibility of the possible setting up of a pilot plant for the manufacture of abrasive powders. The evaluation allows us to determine that it is feasible from an economic point of view to carry out these productions, as all the indicators are favorable.

In order to materialize the research, a technology transfer contract is signed between the companies D and company C for the installation of the Pilot Plant. It is proposed to install a plant with a production capacity of 22,3 t/year of abrasive powders and 14 t/year of metal, for a total of 36,3 t/year of products, obtaining these production levels from the realization of 20 castings per month.

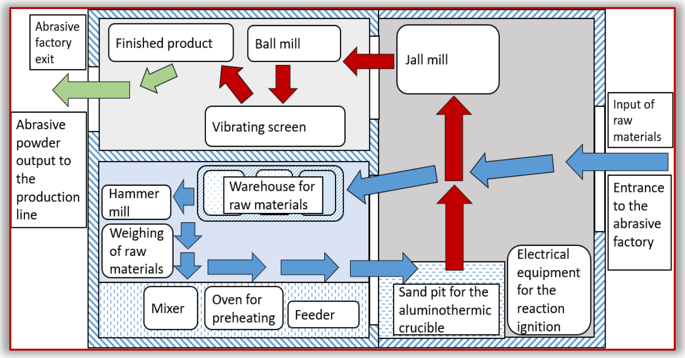

Figure 12. Layout and material flow (intralogistics) used for the manufacture of abrasive powders

Figure 12 shows the layout of the equipment to be used within the plant, which is built in an old building that was refurbished to meet the proposed requirements.

Figure 13 shows the processing scheme of the abrasives plant, which must be complied with for the proper functioning of the process and the production of good quality ceramics.

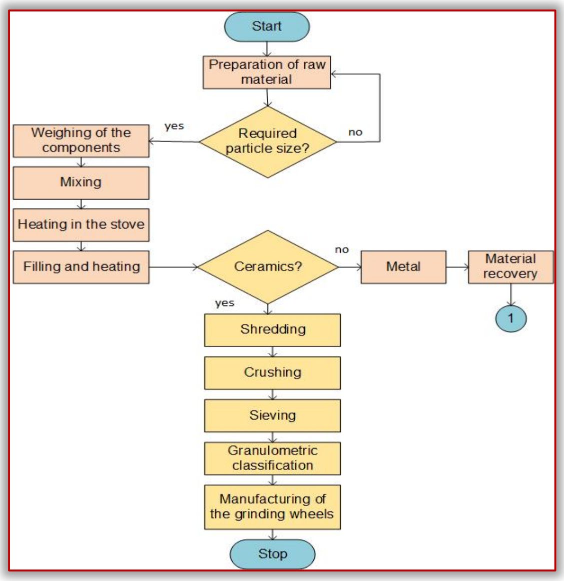

Figure 13. Flow diagram of the process of obtaining abrasive materials at the plant

CONSIDERATIONS ON EXPERIMENTAL PILOT PLANT

— ECONOMIC AND MARKET ASPECTS

Company C manufactures grinding wheels by hand with imported abrasive grains and Portland cement p–350. The new technology that makes it possible to manufacture these products in Cuba with 100% domestic components, guarantees full sovereignty for this production in the future and helps to introduce these products in the national market and also in the Latin American region.

— ASSIMILATION AND DEVELOPMENT CAPACITY

The processing technology does not have a high degree of complexity and can be assimilated by the company's technical staff from the advice offered by the CIS, so that workers and technical staff can be trained in a relatively short time.

— ENERGY

The proposed technology, unlike traditional methods, is based on the energy released by a chemical reaction between a metal oxide and aluminium, which is highly exothermic.

— RAW MATERIALS AND NATURAL RESOURCES

All the raw materials involved in the abrasive powder production process are industrial residues [3] (> 90 %) and Cuban minerals (< 10 %).

— LOCATION OF THE PILOT PLANT

Company C decided to build the experimental pilot plant within a facility of the same, since the powders obtained would be used there minimizing transportation costs, the construction was in the municipality of Cifuentes, Figure

14, since it is located a distance of 32 km from the Central highway, which allows a distribution throughout the whole country.

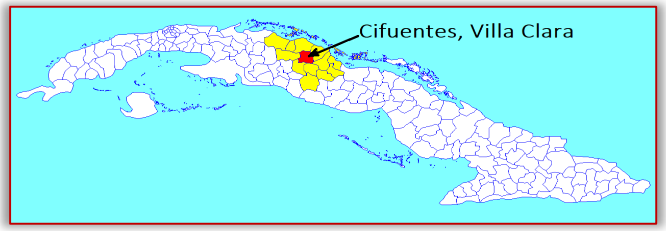

Figure 14. Location of the pilot plant in the municipality of Cifuentes Villa Clara in Cuba

— MANPOWER

As this is a small pilot plant for the manufacture of abrasive powders, in addition to the interlinking of the processes within the plant, only three workers will be employed to carry out all the tasks.

CONCLUSIONS

- The characteristics and chemical composition of the selected raw materials, as well as the proportions in which they were mixed, allow the generation of heat quantities between 719,19 – 930,6 cal/g, which guarantee the self–sustainability of the process and the adequate separation of the metal and the slag, ensuring the proper development of the aluminothermic processing.
- The charges made up of mill scale, aluminium chips and limestone allowed obtaining metal yield values between 54,6 – 87,5 % and slag yield values between 101,1 – 105,7 %, with an adequate technological behavior during pyrometallurgical processing for all the mixtures, where the reproduction of charge 1 (larger volume) allowed considerably reducing the amount of unreacted mixture, obtaining a metal yield of 94 % and slag yield of 102 %, considerably improving the results of the process.
- The abrasiveness tests carried out with the abrasive grains obtained showed that they all have a hardness higher than glass, making it possible to use them to manufacture the grinding wheels used for polishing flats and terrazzo. On the other hand, no deformations were observed in any of the samples evaluated during the setting of the mixtures of abrasive powders with P–350 cement.
- The Experimental Pilot Plant installed in Cifuentes, allows the production of abrasive powders required by Company C, to satisfy its demand for abrasive wheels for polishing floors and terrazzo.
- The technological proposal constitutes an impact on sustainability since it allows savings in the import costs of abrasive materials, also allows to take advantage of industrial and mineral waste to obtain an abrasive material, not generating more polluting waste.

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