Obtaining and evaluation of abrasive materials

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Abstract

During the manufacture of flats and terrazzo, grinding and polishing operations are compulsory, which are carried out with abrasive wheels. The work deals with the obtaining and evaluation of abrasive materials from aluminothermic processing of solid industrial waste and Cuban minerals. 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 by-product. The results of the process are evaluated from the metal and slag yields. The behavior of the ceramics as an abrasive material is evaluated by means of scratch tests on glass, and the behavior of the powders during setting with P-350 cement is also evaluated. Finally, an assessment is made for the possible assembly of a Pilot Plant for the manufacture of abrasive powders, which guarantees the possibility of producing these materials on a pilot plant scale where all the construction and logistical aspects for their subsequent exploitation are assessed.

1. Introduction

Abrasive materials are substances whose purpose is to act on other materials with different kinds of mechanical stress (crushing, grinding, cutting and polishing), they are of high hardness and are used in all types of industrial and craft processes where hardness, grain size, composition and structure are of fundamental importance for the choice of the appropriate material [5].
They can be found on the market in multiple forms (wheels, discs, paper, powders, pastes, etc. [8].
The structure of these materials is generally divided into three parts: backing, mineral (abrasives) and the adhesive or binder [2].
The combination of logistics and quality assurance creates the conditions for a change in production and services [4]. In order to work in this direction, the country's management prioritizes science and technology work, which is carried out by increasing university-industry links in order to obtain concrete results.
Similarly, the choice of type of infrastructure and the way in which it is designed, regulated and the services provided over it are operated, determine the price, timing and quality of products [2].
In Cuba, the polishing of floor and terrazzo elements is carried out with grinding wheels, which are manufactured using abrasive powders imported at high costs on the international market. The absence in the country of an industrial process to obtain abrasive materials with national raw materials for use in the manufacture of grinding wheels used in the polishing of floor and terrazzo elements, together with the cost of importing these materials, are aspects that limit the fulfilment of the production plans of the Villa Clara Construction Materials Company, affecting the social and economic development of the territory. This makes it necessary to develop an economically

feasible alternative for the manufacture of these materials.

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

The proposed methodology constitutes a scientific novelty for the country, since the process uses Cuban industrial waste and minerals as raw materials [3].

2. Methods or experimental part:

2.1. Raw materials

The raw materials used in aluminothermic processing are as follows:

- Mill scale, from the Acinox-Tunas company.
- Aluminum shavings, from the Empresa de Recuperación de Materias Primas de Villa Clara.
- Limestone (stone dust), from the El Purio deposit, belonging to the Villa Clara Construction Materials Company.

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

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

<table>
<tr><th colspan="9">Aluminum shavings</th></tr>
<tr><td>Si</td><td>Fe</td><td>Mn</td><td>Cu</td><td>Mg</td><td>Zn</td><td>Cr</td><td>Ti</td><td>Al</td></tr>
<tr><td>0,5</td><td>0,2</td><td>0,1</td><td>0,1</td><td>0,2</td><td>0,2</td><td>0,1</td><td>0,1</td><td>report</td></tr>
<tr><th colspan="9">Mill scale</th></tr>
<tr><td>Fe_2O_3</td><td>Fe_3O_4</td><td colspan="2">FeO</td><td>Fe</td><td>Fe</td><td colspan="2">O_2</td><td>Impure</td></tr>
<tr><td>20-30</td><td>40-60</td><td colspan="2">15-20</td><td>2-5</td><td>70,3</td><td colspan="2">24,1</td><td>5</td></tr>
<tr><th colspan="9">Limestone</th></tr>
<tr><td>CaO</td><td>MgO</td><td colspan="2">SiO_2</td><td>Al_2O_3</td><td colspan="2">Fe_2O_3</td><td colspan="2">Ignition loss</td></tr>
<tr><td>55,20</td><td>0,68</td><td colspan="2">0,34</td><td>0,23</td><td colspan="2">0,17</td><td colspan="2">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.

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

Limestone ($CaCO_3$) is marketed in Cuba 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.

2.2. Formulation of the loads

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 (g)

	Mill scale	shavigs	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, charge 1 was reproduced 20 times to obtain a larger amount of ceramic, 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

Mill scale	shavigs	Limestone
3000g	1040g	300g

2.3. Obtaining the abrasives

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: aluminum chips, limestone and mill scale. Mixing is carried out for 30 minutes. Subsequently, each mixture was preheated in an oven between 250 and 300 °C for 1 h, 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 1.

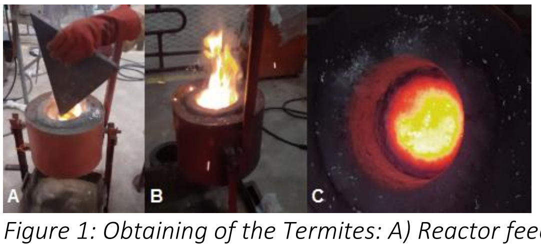

Figure 1: Obtaining of the Termites: A) Reactor feed and ignition of the reaction, B) Self sustainability of the reaction, C) Cooling of the termite

3. Results and Discussion:

3.1. 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 aluminum (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.

$$\mathbf{Fe_2O_{3(s)} + Al_{(s)} \rightarrow Fe_{(s)} + Al_2O_{3(s)}} \quad (1)$$

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].

Accumulation = Input - Output + Generation - Consumption (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.

3.2. 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 [7], results that allow the prediction of the feasibility of self-sustaining the aluminothermic reaction. These results are shown in Table 4.

Table 4: Amount of heat generated by the charges (cal/g)

	0	**1**	**2**	**3**	**4**
Qr	-930,9	-867,2	-811,4	-762,5	-719,19

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, and all mixtures are above 650 cal/g, which guarantees the adequate separation between metal and slag [7].

3.3. Results of the metallurgical processing of the small batches

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 separated adequately.

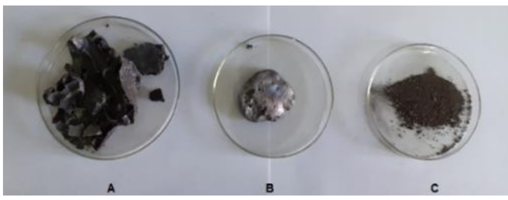

Figure 2: A) slag, B) metal, C) unreacted mixture

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 5, showing also the yield values, which are determined from the ratio between the actual amount obtained and the theoretical amount determined from the mass balance.

Table 5: Masses of molten metal, slag and unreacted mixture of the termites small

	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.

3.4. Processing of the large charge

The ignition process went smoothly, with a good reaction rate, resulting in metal with a uniform and smooth appearance (see Figure 3).

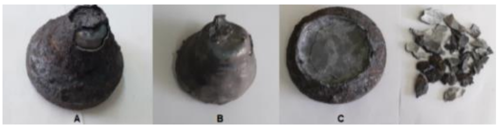

Figure 3: A) products obtained, B) metal, C) slag

The results of the processing of the large charge in terms of metal and slag quantity are shown in Table 6.

Table 6: Results of the processing of large thermite

Product	**Theoretical mass (g)**	**Actual mass (g)**	**(%)**
Metal	2124,95	1995	93,9
Ceramic	2082,83	2120	101,8

Table 6 shows that the aluminothermic processing of the large charge yielded more than 2 kg of ceramic and more than 1 kg of metal, which represents 102 and 94 % yield respectively. Comparing these results with those obtained in casting 1, it can be seen that when the amount of metal processed increases, the metal yield increases significantly and the ceramic yield decreases slightly, with a marked decrease in the amount of mixture that stops reacting, which contributes to improving the pyrometallurgical processing results. These results allow the possibility of scaling up the process to be assessed.

3.5. Evaluation of abrasives

3.5.1. 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 [3], see Figure 4.

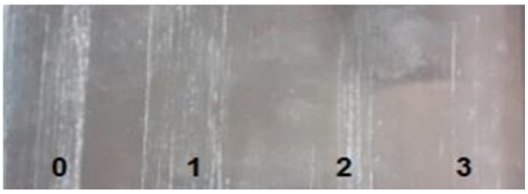

Figure 4: Abrasive action on glass

As shown in Figure 4, all ceramics have a higher hardness than glass, with the hardness of glass on the Mohs scale being 5.5 [6], which validates their use for the manufacture of abrasive powders.

3.5.2. 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 classified granulometrically, being manually crushed in a mortar until a grain size of less than 0.315 mm was achieved. 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 7 shows the results of the granulometric classification of the crushed ceramics and the average grain number, according to the granulometry obtained.

Table 7: Results of the granulometric classification process of the crushed ceramics

	Grain size fraction	Number. Grain	Mass (g)	%	% Accumu-lated
1	-0,315 +0,21	60	540	30,3	30,3
2	-0,21 +0,16	80	188	10,5	40,85
3	-0,16 +0,08	100	715	40,1	80,97
4	-0,088 +0,05	180	230	12,9	93,88
5	-0,053	240	109	6,12	100

The results shown in Table 7 show that it is possible to obtain abrasives with different grain sizes, which makes it possible to manufacture the grinding wheels needed to carry out the grinding and polishing operations on floors and terrazzo.
When the test specimens shown in Figure 5 were made, it was confirmed that they behaved satisfactorily, and the problems presented in previous studies [8] were not observed, which was achieved by substituting limestone for ceramic in the composition of the mixtures.

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

3.6. Production strategy

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 SICTE SA and Materiales de la Construcción de Villa Clara 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 6 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.

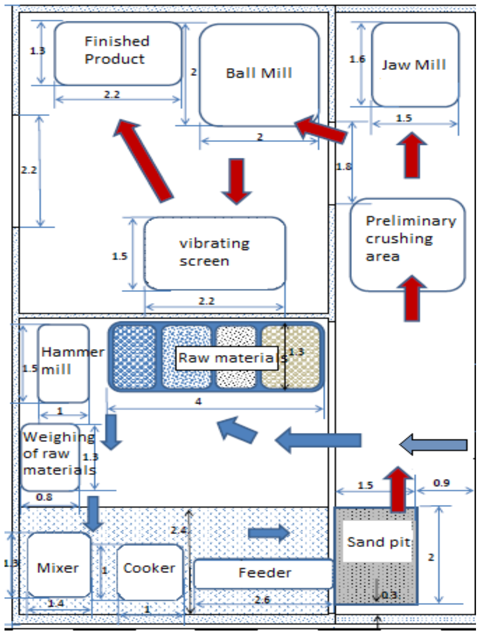

Figure 6: Distribution of equipment used for the manufacture of abrasive powders within the plant.

Figure 7 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.

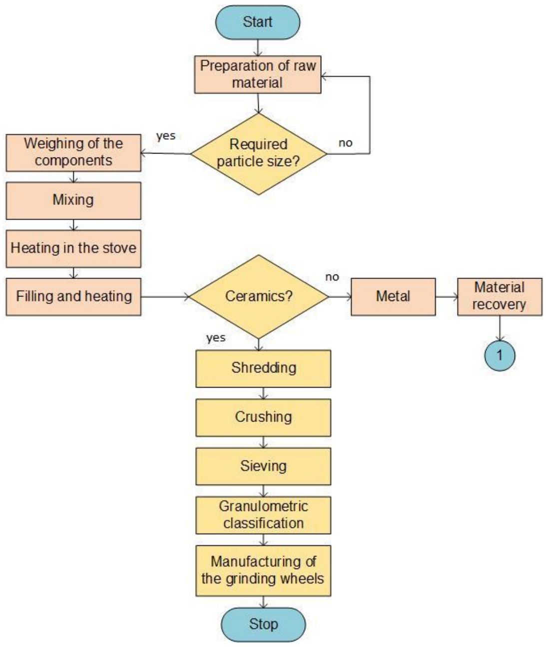

Figure 7: Flow diagram of the process of obtaining abrasive materials at the plant

Table 8 shows the forming of some aluminothermic casts which were processed, during the scale-up in the plant using the plant equipment. The pyrometallurgical performance was excellent which confirms the preparation of the workers. The results of the evaluation are given in Table 9.

Table 8: Forming of two casts in the Pilot Plant (in kg)

Casts	**Husk**	**shavings**	**Limestone**
1	76	26,4	7,6
2	136	46,2	13,3

Table 9: Results of the Pilot Plant scale evaluation

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

Pilot plant scale-up 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.

3.7. Results of the crushing and sieving process of a sample of abrasives obtained at the Cifuentes Pilot Plant.

Two samples obtained from the initial crushing and grinding process of the abrasive powders obtained at the Pilot Plant were subjected to a sieving process in an electric sieve for ten minutes, obtaining the results shown in Table 10.

Table 10: Results of the sieving of the abrasive obtained in the ball mill and retained between the two large sieves at the Cifuentes Abrasive Plant

Coarse grain (mm)	**Retain-ed mass (g)**	**Re-tained (%)**	**Accu mulat ed (g)**	**Gri nd**	**%**	**%**
-1	62	9,2	62	18		
+1-0,84	109	16,2	171	20		
+0,84 -0,5	348	51,6	519	25, 30, 35	74,2	90,4
+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 10, 90 % 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. From the results of the grinding and sieving process, the final process scheme is drawn (Figure 7).
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, which were evaluated under real working conditions and their performance was verified.

3.8. Project Considerations

3.8.1. Economic and market aspects (for technological innovation projects involving a large investment)

The Empresa de Materiales de Construcción de Villa Clara carries out artisanal production of grinding wheels made with imported abrasive grains and Portland p-350 cement, so having a technology that allows these products to be obtained in the country, with 100% national components, guarantees total sovereignty for these productions, as well as valuing the possible insertion of these products in the national market and in the Latin American region.

3.8.2. 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.

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

3.8.4. 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 %).

3.8.5. Location of the Pilot Plant
For the construction of the pilot plant, the Empresa de Materiales de la Construcción decided that it should be located within the facilities of the UEB Combinado de Hormigón ¨Rolando Morales Sanabria¨ in the municipality of Cifuentes, Villa Clara, in order to minimize transportation costs, since the grinding wheels are manufactured in this factory. It was decided to name the plant Dr. Sc. Rafael Quintana Pichon.

3.8.6. 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.

3.9. Impact of the results studied

3.9.1. Scientific
Obtaining an abrasive grain that can be used in the manufacture of grinding wheels and a high-quality iron alloy that can be used in the manufacture of steel, through the use of a non-conventional technology.

3.9.2. Technological
The procedure for obtaining the abrasive powders is based entirely on the use of Cuban industrial waste and minerals, allowing the manufacture of grinding wheels with 100% national components. A technology, not previously used for these purposes, is proposed that does not generate other solid waste.

3.9.3. Economic
A process is developed and evaluated to obtain abrasive powders from Cuban minerals and industrial waste, which can be used in the manufacture of grinding wheels for polishing floors and terrazzo, thus avoiding the importation of these powders.

3.9.4. Environment

- Reduction of the pollutant load
- Use of waste materials
- Development of cleaner production

4. Conclusion

- The characteristics and chemical composition of the selected raw materials, as well as the proportions in which they were mixed, allowed the generation of heat quantities between 719.19 - 930.6 call/g, which guaranteed 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, aluminum 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 Pilot Plant Dr, Sc, Rafael Quintana Puchol set up in the UEB Combinado de Hormigón ¨Rolando Morales Sanabria¨ de Cifuentes, allows the production of the abrasive powders required by the Empresa de Materiales de Construcción de Villa Clara to satisfy its demand for grinding wheels for floor and terrazzo polishing.
- The technological proposal evaluated represents a contribution to the preservation of the environment and contributes to the substitution of imports, making the company totally independent from the international market.

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