RECYCLING OF SOLID WASTER IN THE PRODUCTION OF CERAMIC FLOOR TILES

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ABSTRACT

Scrap from the selection of finished ceramic tile products is a solid waste originating in the manufacturing process. The bulk of these solid wastes is usually deposited in landfills. In the traditional double firing process (wall tile), the arising ceramic tile solid wastes are normally recycled by wet grinding, with other raw materials, forming the ceramic body. This is possible because double-fired ceramic tiles are thinner (from 4.0 to 6.5 mm) and are fired at temperatures up to 1090°C. Moreover, being highly porous, they are more brittle. In the case of solid wastes generated by the single firing process, recycling is not possible without suitable previous processing, since the products are thicker than those obtained by double firing (from 6.5 to 11.0 mm) and are harder. Consequently, grinding these products becomes difficult by the process normally employed in ceramic tile industries. With this purpose, the objectives of this work are to enable recycling solid wastes (scrap arising in the selection of the final product) by the using a suitable dry milling process, and establish the influence of the addition of different amounts of these solid wastes in a ceramic body (used for the production of ceramic floor tiles) prepared by wet-grinding.

1. INTRODUCTION

The manufacture of utensils in ceramics is one of the oldest human activities. Clay dishware has been found dating back to 15000 B.C. and manufacture was well developed in Egypt ten centuries later. This occurred due to some very simple practical reasons: it is easily shaped or moulded, the raw materials are the most common in the earth's crust and production does not require advanced knowledge. The need for materials with better properties to the existing ones has led mankind to develop ceramic technology, that is the science applied to several manufacturing processes of ceramic products, including ceramic floor and wall tiles, which are of great interest in the engineering area and are widely used for covering the most varied environments.

In the ceramic tile industry, the raw materials are extracted from natural mines (and contain significant degrees of impurities and physical, chemical and mineralogical variability) and processed by means of sintering, in which bulk powders are prepared and physically and thermally treated, giving them shape and mechanical properties, and consolidating them[1]. This process essentially involves the stages of raw materials weighing, milling, spray-drying, pressing, drying, glazing, firing and selection of the final product, as shown in figure 1.

It is important to point out that in this context, the wastes generated in the course of the process (shown in the figure 1) are currently reincorporated into the process, being used as raw material. The solid wastes generated during final product selection are characterized by the presence of a defect in the fired product, making them unsuitable for use. These solid wastes are not frequently used because they are hard materials and, consequently, difficult to mill. At this moment, they are usually deposited in landfills.

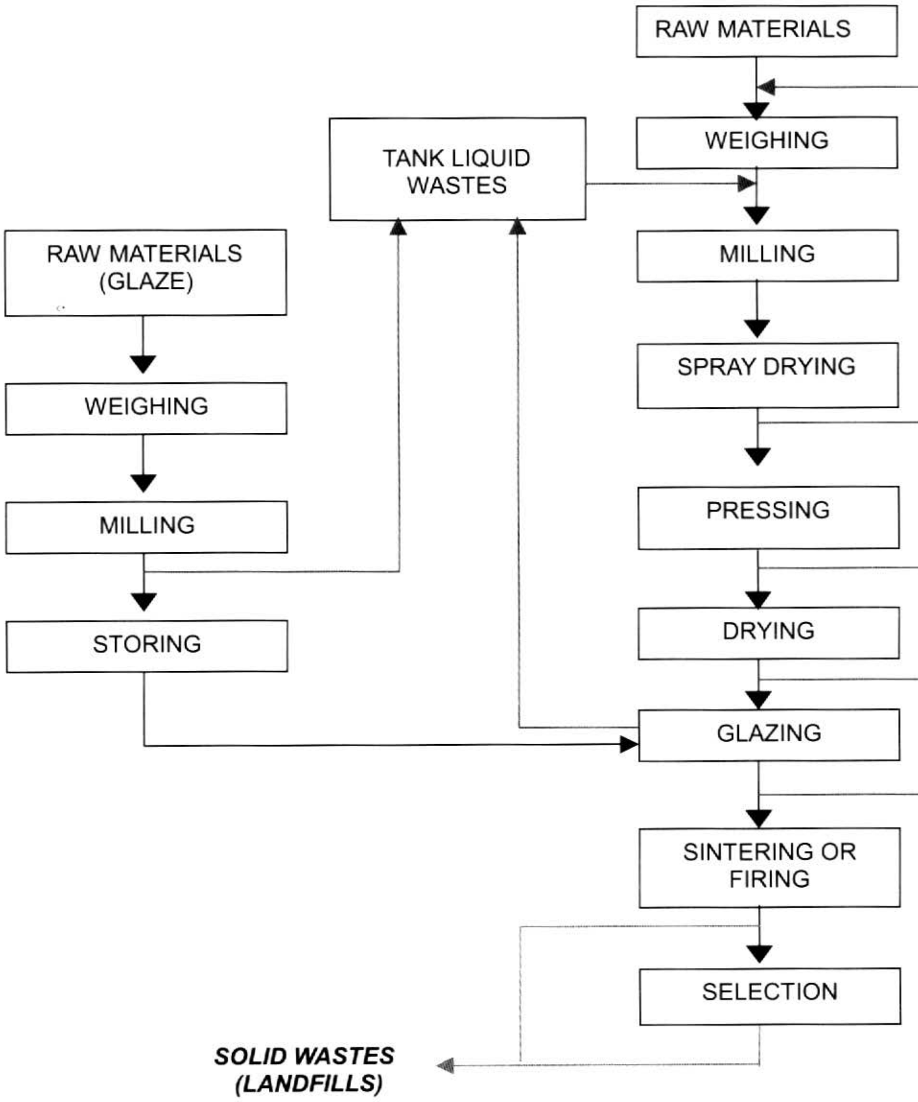

Figure 1. Flowchart of the ceramic floor tile production process.

Throughout all this evolution, mankind became used to taking advantage of the natural sources of the planet and generating wastes without any concern: sources were abundant and nature used to accept all the refuse without complaining. According to Toffler[2], after the 18^{th} century, with the spread of the industrial revolution, the development model or strategy of the nations has consolidated their social and technique bases. The main objective was short term economic growth, using new production processes and intense exploration of energy and raw materials, whose sources were considered limitless. This model generated impressive excesses of economic wealth, but it has also brought great social and environmental problems, including wastes.

In the Brazilian ceramic tile industry the volume of the material discarded by breakage represents on average 3.0% of all national production. Correlating this percentage with an effective production in 2000 of 452.7 million square meters, according to ANFACER[3], we have approximately 200 thousand tons a year of this waste being used as landfills. And the feature of concentrating this material in a specific area (landfill) constitutes a palliative but also harmful measure. Palliative because with this quantity of rejected material 80 square kilometres are occupied annually. Harmful because these materials possess water-soluble constituents in their vitreous coating, such as Lead, Cadmium and other harmful metals, which represent a great danger for human health[4].

In this context, the objectives of this work are to enable recycling these solid wastes by using an appropriate milling process to obtain a powder to be added in the milling step of a wet milling process in floor tile manufacturing and to verify the influence of this addition on the characteristics of the final product.

2. EXPERIMENTAL PROCEDURES

Solid wastes were separated in sufficient amounts to carry out the tests considered on a lab scale. These materials were put through a crusher mill (Hazemag APS-0604B), and dry milled with the aid of a hammer mill unit (Hazemag Novorotor 650/500 II), both these facilities belonging to a recycling trial plant as shown in figure 2. The powder obtained was sieved using a 35 mesh sieve.

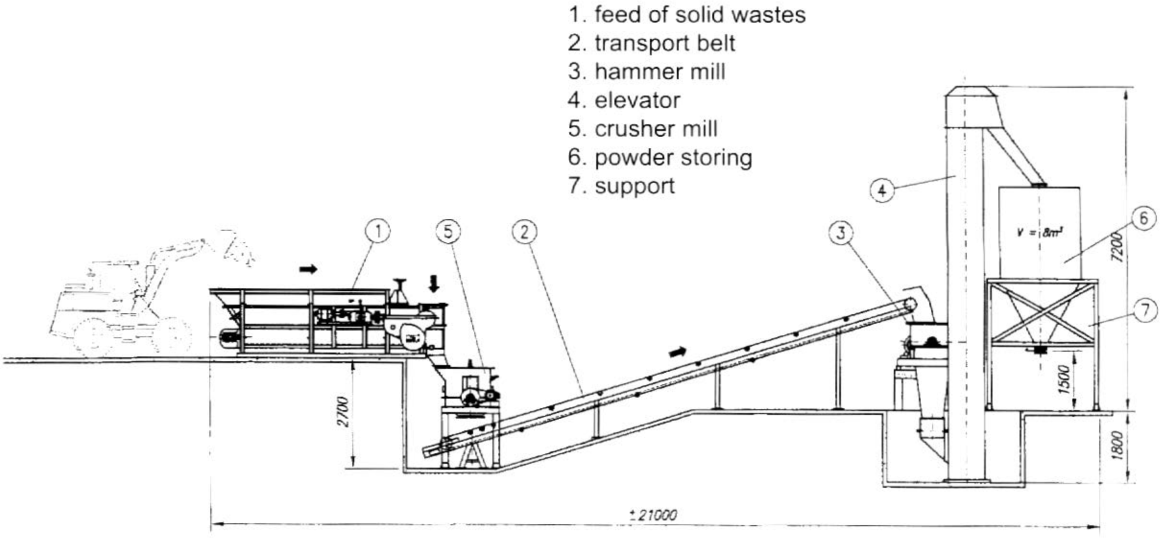

Figure 2. Recycling plant lay out.

The other raw materials making up the composition were dried and deaggregated manually, with the aid of a mortar, up to a particle size lower than 2.8 mm (7 mesh).

The raw materials powders and solid wastes were processed according to the flowchart shown in figure 3. Each powder was weighed in accordance with the standard formulation, containing three distinct clays, two argillites and one talcum. To the standard formulation, identical to the one used in a ceramic tile company, we added 1, 3, 5, 10 and 30 wt% rejects or solid wastes, respectively. The six different resulting formulated batches were separately milled in a wet process, in a 5,000 cm^3 ball mill for 40 minutes. The milling reject was found to vary from 5.8 to 7.2 wt% on a 325 mesh sieve, while density ranged from 1.66 to 1.69 g/cm^3. The flow time varied from 25 to 35 seconds in a number 4 Ford cup. Subsequently, the ceramic suspension (slurry) resulting from the milling process was dried in an oven for 24 hours at 110 °C (± 10 °C) and humidified to 7 wt%. The wet powder was passed through a 16 mesh sieve for granulating and pressing.

Each powder was compacted in a lab hydraulic press (model Gabrielli 24/110A) with a specific pressure of 25 MPa. The compacted samples were sintered in a kiln (model Schaly LAB 44) at 1150 °C, using a heating rate of 10 °C/min from room temperature to 1000 °C and 5 °C/min from 1000 °C to 1150 °C, with a holding time of 10 minutes at 1150 °C. After sintering, the samples were air-quenched to room temperature.

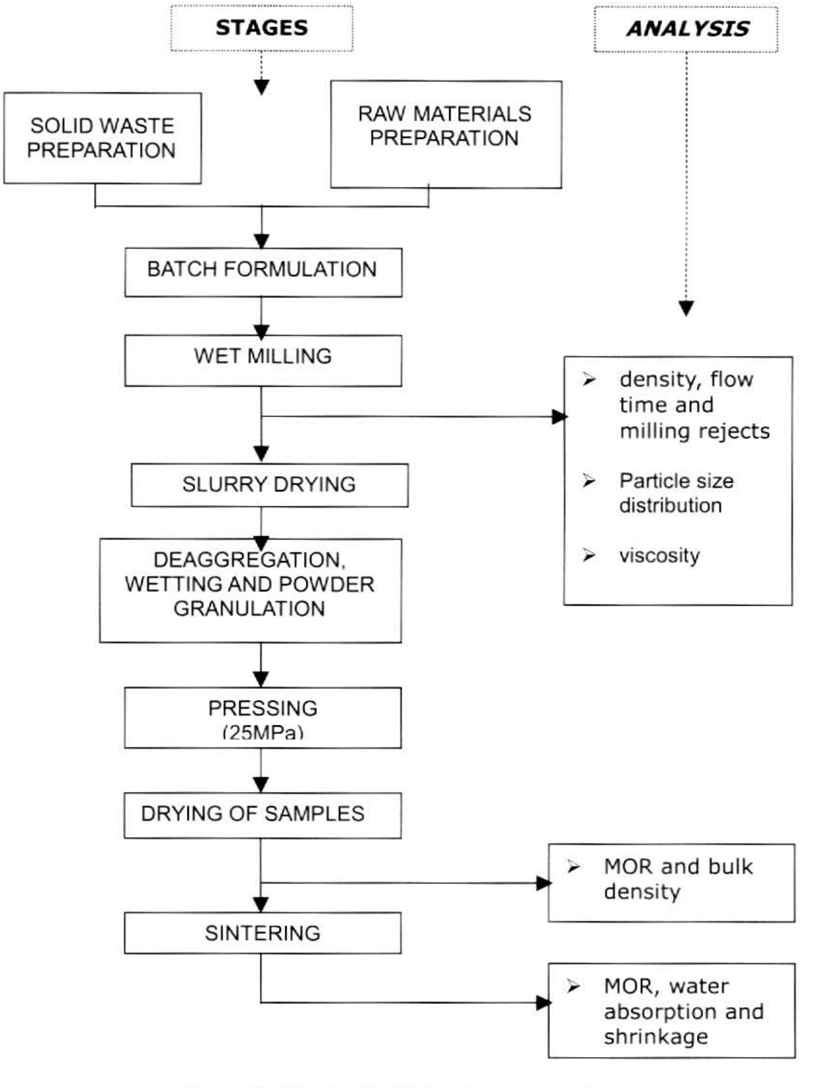

Figure 3. Flowchart of laboratory processing.

Slurry samples of each milled batch were also collected and subjected to the laser scattering particle size analyzer (model Cilas 1064L) for determination of the particle size distribution. The flow curve of each sample was determined using a viscometer (model Bohlin 88 BV). The chemical composition of each powder was determined in a XRF spectrometer (model Phillips PW2400). The dry compacted bodies were subjected to bending strength tests and bulk density measurements according to the Archimedes principle with mercury immersion method. The sintered bodies were also subjected to bending strength tests, water absorption and linear thermal shrinkage measurements.

3. RESULTS AND DISCUSSION

The standard composition of the studied floor ceramic tile was obtained using three different kinds of clay, two argillites and a talcum, according to the formulation shown in table 1.

Raw materials	% wt
Argillites A	30.0
Argillites B	20.0
Clay 1	20.0
Clay 2	10.0
Clay 3	13.0
Talcum	7.0
Total	100.0

Table I. Standard ceramic body composition.

Table II shows the chemical compositions of the standard ceramic body, before firing, and the solid waste after firing. It can be observed that the main meaningful difference is the values of loss on ignition (L.O.I.), besides the acceptable variations inherent to the raw materials and to the manufacturing process. Although the solid waste has a vitreous glaze layer, the similarity between the chemical compositions of the standard ceramic body and the solid waste suggests there should not be any interference in the final formulations, after addition of any amounts of solid waste.

COMPOUNDS	STANDARD CERAMIC BODY wt%	SOLID WASTE wt%
SiO_2	68.3	69.4
Al_2O_3	16.4	17.1
Fe_2O_3	3.3	3.5
CaO	0.6	0.9
Na_2O	0.8	0.8
K2O	2.9	3.3
MnO	0.0	0.0
TiO_2	0.3	0.7
MgO	2.4	2.7
P_2O_5	0.1	0.1
ZnO	0.2	0.5
ZrO_2	0.1	0.7
L.O.I.	4.6	0.3

Table II. Chemical analysis.

Table III shows a comparison of the particle size distribution between the standard ceramic body and the solid waste, while table IV shows a comparison of the particle size distribution between the standard ceramic body and other ceramic bodies with solid waste additions.

CUMULATIVE VALUES	STANDARD CERAMIC BODY (μm)	SOLID WASTE (μm)
Diameter at 10%	0.93	3.56
Diameter at 50%	7.49	44.60
Diameter at 90%	31.54	268.89
Diameter at 100%	75.00	500.00

Table III – Standard ceramic body and solid waste particle size distribution.

In table III It can be observed that the solid waste has a higher particle size than the standard ceramic body; therefore it must be added to the standard mass, together with the composition's raw materials in the milling step.

The utilization of a crusher mill and a hammer mill, available technologies at an accessible cost, is sufficient to reduce the solid waste to a powder with an average particle size lower than 500 μm (32 mesh). This powder, when added to the composition of the ceramic body that originated it, in percentages that vary from 1 to 30 wt% and subjected to the wet milling process, does not significantly affect the particle size distribution of the resulting suspension, as shown in table IV.

CUMULATIVE VALUES	STD	F1	F3	F5	F10	F30
Diameter at 10%	0.93	0.97	0.95	0.87	0.98	1.05
Diameter at 50%	7.49	7.75	9.88	8.09	8.44	9.65
Diameter at 90%	31.54	32.25	32.04	32.59	33.49	35.68

Table IV - Particle size distribution of the formulations obtained.

Where:

STD = Standard ceramic body composition

F1P = Standard ceramic body composition with solid waste addition of 1 wt%

F3P = Standard ceramic body composition with solid waste addition of 3 wt%

F5P = Standard ceramic body composition with solid waste addition of 5 wt%

F10P = Standard ceramic body composition with solid waste addition of 10 wt%

F30P = Standard ceramic body composition with solid waste addition of 30 wt%

In table IV it can be observed that the solid waste was well incorporated into the ceramic body composition, showing that the comminution process was enough to make the particle size suitable of the added solid waste. That happens due to the fact that the ceramic materials possess high shear resistance, which leads to high compression strength, together with notch sensitivity and low fracture resistance, or they are brittle materials[5].

Table V, shows the results regarding the physical tests for the studied formulations.

Samples	Bulk density (g/cm^3)	MOR Green Dry Sample (N/mm^2)	Viscosity (Pa.s)	Linear Thermal Shrinkage wt%	Water Absorption wt%	MOR Fired Sample. (N/mm^2)
STD	1.93	3.9	0.15	3.9	9.0	28.1
F1	1.95	3.7	0.17	3.9	8.6	28.6
F3	1.95	3.8	0.17	3.9	8.9	26.7
F5	1.93	4.3	0.13	3.7	8.8	25.2
F10	1.93	4.1	0.13	3.8	9.1	24.7
F30	1.85	2.1	0.10	3.9	10.1	20.2

Where: MOR = Modulus of Rupture

Table V. Results of the physical tests.

The influence of the addition of milled solid waste, in a ceramic floor tile body, in percentages varying from 1 to 10 wt% does not affect properties such as: slurry viscosity, linear thermal shrinkage, water absorption and bending strength (green and sintered). This assures a very good safety margin in utilization in the standard ceramic body, without meaningful effects on the characteristics of the final product. On the other hand, it is an interesting way of using this waste, since the current demand corresponds to about 3 wt% of the production.

By adding 30 wt% of the solid waste, a significant increase is noticed in water absorption. This can be explained by a lower densification of the compacted bodies due to the low plasticity of the solid waste. This same fact explains the significant reduction in their bending strength. However, this effect can easily be reverted with the addition of larger amounts of plastic raw materials (clay), without any additional cost[6].

4. CONCLUSIONS

The laboratory studies demonstrate the perfect feasibility of reusing ceramic floor tile solid wastes as a raw material source, to be fed back into the same production process in the milling stage. From an economic point of view, this material can place the ceramic floor tile manufacturer in a strong competitive position in the market. Moreover, it diminishes the ambient liabilities of the company, at the same time preserving the environment and the health of the population. For example, some glasses contain lead; depending on the frit used, which could be sodium-based for example, this dissolves in the presence of water and contaminates the soil.

The solid wastes, after transforming them into powder, can be used for other specific applications currently in development by the authors.

The developed reuse process has been shown to be technically and economically feasible for the companies of the sector, while the technology involved is compatible with current production demands and with the lay-outs of the ceramic plants, which further reinforces the feasibility of this procedure.

The basic principle of the process can be extended to the handling of solid wastes in other sectors, such as civil construction, metallurgic industries (casting sand) and thermoelectric plants (fly ashes), among others.

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