Maximization of the use of casting sand residue in the production of fired ceramic bricks

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Abstract

In this study, a red ceramic was developed with the addition of sand residue from deburring and finishing processing of cast iron molds, replacing a variable fraction of the clay. The formulated masses were shaped by pressing and firing at different temperatures (850, 900 and 1000 ºC) at a heating rate of 180 ºC/h and 2-hour level. The bodies were characterized for their density prior to firing, and after firing, for mechanical strength, linear retraction, water absorption and porosity. From these results, tests were carried out with the purpose of evaluating the possible release of pollutants from the ceramic pieces produced by leaching tests according to Brazilian standards. The use of smelting sand residue, a low plasticity component, has been shown to be feasible with a few adjustments in the processing parameters and environmentally safe, as demonstrated by the experimental results.

Keywords: foundry, red clay, casting sand, residue.

1. Introduction

In the last century, the sources of natural resources on the planet were considered abundant and used indiscriminately, generating large amounts of solid waste. However, this practice has caused serious environmental problems. Solid waste is generated in a large number of industrial processes. Recycling or reusing these in some processes becomes a necessary alternative to preserving the environment. Recycling has become a usual activity in the globalized world. In Brazil many industries producing waste with high potential for reuse still need specific studies for its correct use in a manufacturing process. Ceramic materials are still the most efficient way to store a residue, making it inert, according to Menezes *et al.* (2002).

At this juncture, a casting sand residue to be used depends on the approval of federal, state and municipal environmental laws and regulations. Federal Law 9,605, promulgated on

February 12, 1998 - "Environmental Crime Law" and regulated by Federal Decree 3,179 of September 21, 1999, provided an additional boost to the legal protection of the environment, establishing serious penalties against natural and legal persons who commit environmental violations. In the civil sphere, according to the provisions of Law 6,938 / 81, polluters (individuals or legal entities) are obliged, irrespective of the existence of fault (objective liability), to indemnify or repair damages caused to the environment and to third parties, affected by its activity, or rather, for civil liability for environmental damage. It is sufficient to demonstrate the existence of the damage and the causal link between the activity carried out and the damage caused.

The strategy of this study, however, is based on the fact that every production process generates by-products and waste with quality and differentiated value of the main product. This waste constitutes, in the current legal and ecological perspective, as the responsibility of the generating entity. Regardless of the volume of waste generated, the industry needs to recognize it as being its responsibility. However, only with the entry into force of Law 12,305 / 2012 that created devices for the control and disposal of solid waste, are these now deposited in controlled industrial landfills that generate high financial costs for their proper disposal, which is not definitive, because the environmental liability is transferred to future generations. Since this date, the foundries have begun to look for solutions to the waste generated by them. Another reason for the development of new products using waste is the high cost of extraction of raw materials and associated environmental damages, as well as the depletion of reserves and the conservation of non-renewable sources. It is in this context that the use of the waste generated in the manufacture of metal parts through the casting process is inserted.

The mold casting process consists of raising the temperature of a metal or metal alloy to its melting point and from there pouring it into the cavity of a mold having the desired shape. This type of process is used when the shape of the part is complex so that any other process is impracticable, for example, in pieces having internal cavities, whose solution by casting is to add a core to have the desired empty part.

The use of the casting process leads to the generation of waste, *e.g.*, sand powder used in molds, cores and finishing of castings. Sand incorporated with phenolic resins and sand of granulometry below the pre-established fineness pattern must be discarded. In this way the research for the reuse of this sand has been growing because the generation of this residue is significant.

In the industry, the residual sands of a foundry can be separated into two groups: green sand, also known as process sand, and core sand, which is sand bonded with resins. There are four core systems: cold-box, cold-cure, hot-box and warm box. In Brazil these systems generate processed sand wastes that add up to approximately 2.8 million tons per year (ABIFA 2009).

Biolo (2005) investigated in an industrial process, the use of a percentage of 10% of casting sand in substitution of the plastic clay used in the production of ceramic blocks. Chegatti (2004) and Toledo (2006) studied the use of processed red cast iron sand by varying the concentration, temperature and addition of blasting powder and glass microspheres. They concluded that a maximum of 10% of sand can be added in the ceramic mass without decreasing the technological properties of the ceramic blocks produced. As of 2010, there has been a growing interest in these wastes, as well as, the appreciation of these. Santurde *et al.* (2010) studied the environmental behavior of ceramic blocks produced with contents of 5 to 50% of foundry sand that was fired at 1020 and 1030 °C. Andrés *et al.* (2011) simulated, in laboratory, industrial conditions to manufacture bricks by adding casting sand, cellulose sludge in varying proportions with plastic clay and fired at temperatures of 800, 850 and 900 °C. Casting sand and zinc plating were used in partial replacement of plastic clay to make bricks fired at 850 °C by Quijorna *et al.* (2012) and demonstrated that the SO_2 released upon burning reacts with alkaline and earth alkaline metals, forming salts that remain within the ceramic block. In a study published by Huan-Lin Lud *et al.* (2012), who studied the influence of the concentration variation of a foundry sand residue on tile production, it was observed that for a maximum concentration of 15% of the residue, the highest mechanical strength was found. Vsévolod *et al.* (2016) produced red ceramics from foundry sand, water treatment sludge, glass residues and automotive battery acid neutralization sludge containing heavy metals such as Pb, Cr, Sn, Zn, Cu and Sb. The fired temperatures used were 900, 950, 1000, 1050 and 1100 °C. Velasco *et al.* (2014) demonstrated that reducing waste is not the only reason to investigate the addition of this residue into a clay matrix, although traditionally it has been the main purpose of research on this topic. Another reason may be considered. Wastes may save energy in the manufacturing process in a tunnel kiln. Their higher heating values are added by self-combustion within the clay matrix, so less energy is needed to fire the bricks.

The last survey of processed sand of foundry ABIFA (2015) reported a decrease to 2,300,000 tons, in the production of this one, due to two parameters:

1- The introduction of processes of regeneration of processed sand with a greater number of steps.

2- The retraction of the market due to the economic crisis that settled down in the country.

In the research developed by Biolo (2005), the sand casting discarded had an average particle size of 184.81 µm. Since that time, the processes of sand regeneration have become more effective and with this, there has been an increase in the percentage of residue concentrates in the stage of polishing and finishing of the castings. The generation of these residues is due to the exhaust system of the finishing process, where there is a decrease of the particle size, now within the silt fraction of this residue. In this perspective, a new investigative study is necessary. In this process, the technological properties are evaluated for the blocks produced with this fraction of residue.

The objective of this study was to produce ceramic blocks, within the temperature range of the firing process of the industries that benefit red ceramics, and to verify at these temperatures, the maximum percentage of plastic clay substitution by the discarded sand casting residue. This residue is formed by the fines from the exhaust of the regeneration system of sand casting, and the sand out of specification to be reincorporated to the regeneration system. The study deals with the behavior of mechanical properties, retraction and water absorption. For this purpose, green sand and core sand (all of these classified as non-inert class II waste, according to NBR 10004) were used as a substitute for a percentage of clay used in the manufacture of ceramic parts.

2. Material and method

For the development of this study, the following sequence was adopted: preparation and characterization of the raw materials, formulation of the ceramic masses and conformation of ceramic blocks, drying and firing at different temperatures. The ceramic bodies thus obtained were then characterized for their physical and mechanical properties. In addition, the stability of its chemical constituents was evaluated in lixiviation and solubilization tests according to the Brazilian technical standard.

2.1 Raw materials

The raw materials were prepared by a horizontal ball mill grinding process. After milling for 12 hours, these materials were sieved in ABNT 270 mesh (53 µm aperture). The objective of this stage is the comminution of the raw materials, as well as the homogenization of the granulometric distribution of the materials. Next, the raw materials were characterized by mineralogical analysis (X-ray diffraction model Philips Xpert MPD with Cu emission RX), chemical (X-ray fluorescence model Shimadzu-1800 model) and granulometric (laser diffraction Cilas model 1180).

Gravataí Valley Clay: this clay comes from the Gravataí River RS and has a reddish-brown color due to the presence of iron oxide. This material was used in the ceramic masses tested due to its high plasticity, as well as its red burning color, indicated for ceramics and stoneware

The processed casting sand (PCS) employed in the study was obtained from the fabrication of molds in a foundry. The sand used in these molds consists of high-quality silica sand (85% to 95%); bentonite clay (4% to 10%), which acts as a binder; sea coal (2% to 5%), which facilitates the process and water (2% to 5%), which is used to activate the clay.

2.2 Methods

Formulations: the formulated ceramic masses are presented in Table 2. The formulation AF00 is that formed only by plastic clay; successively, the percentage of processed sand casting was varied. The formulations were homogenized in a paraffin mill for 5 minutes and humidified (addition of 10 % water). After that, the masses were granulated in 20 ABNT sieve (850 µm aperture) to be formed.

Conformation, drying and fired: formulations were initially dry-mixed, and water was subsequently added to humidify the mixture. The conformation method consisted of uniaxial pressing at 40 MPa pressure in a hydraulic press. The specimens were obtained in a mold with the dimensions of 60x20x6 mm (length x width x thickness). After pressing, the specimens were dried at room temperature for 24 hours and then dried in an oven at 110 °C for another 24 hours. Sintering of the pressed specimens was performed at temperatures of 850, 900 and 1000 °C with a heating rate of 180 °C/h and a firing time of 2 hours.

Characterization of the final product: The ceramic bodies were characterized according to their physical properties (density, linear retraction and water absorption) and four-point bending strength tests were performed. The water absorption test compiled with standard American Society for Testing and Materials (ASTM) C 373/94-88. The mechanical strength of the formulated materials was analyzed according to the ASTM C 133/97 standard. The bodies were tested in a universal testing machine (Applied Test Systems (ATS), 1105 C) with a 50 kN load cell, a speed of 0.5 mm/min in the compression direction and a test start at 2 N.

3. Results and discussion

3.1 Characterization of raw materials

Table 1 shows the results of the main oxides in all the raw materials used to form bricks. The Gravatai clay consisted of SiO_2 (68.03%), Al_2O_3 (17.86%), Fe_2O_3 (8.46%) and K_2O (3.30%). The PCS contained significant level of SiO_2 (49.16%), Al_2O_3 (12.99%), Fe_2O_3 (7.78%) and MgO (1.03%).

Table1 - Chemical composition of raw materials.

Oxide (%)	Clay	PCS
SiO_2	68.03	49.16
Al_2O_3	17.86	12.99
Fe_2O_3	8.46	7.78
MgO	0.73	1.03
CaO	0.33	0.90
TiO_2	0.83	0.48
K_2O	3.30	0.29
BaO	---	0.08
SO_3	---	0.68
Na_2O	---	0.38
MnO	0.24	0.16
ZnO	0.06	---
LOI	3.30	25.65

The X-ray diffraction analysis shown in Figure 1, demonstrates that Gravataí clay consists mainly of kaolinite ($Al_2Si_2O_5\ (OH)_4$), and quartz (SiO_2) also showing hematite (Fe_2O_3). The granulometer analysis, after milling, showed that the Gravataí clay had a diameter of 90% <15.21 μm and a mean particle diameter of approximately 5.39 μm. Figure 2 shows the particle size distribution data of this raw material.

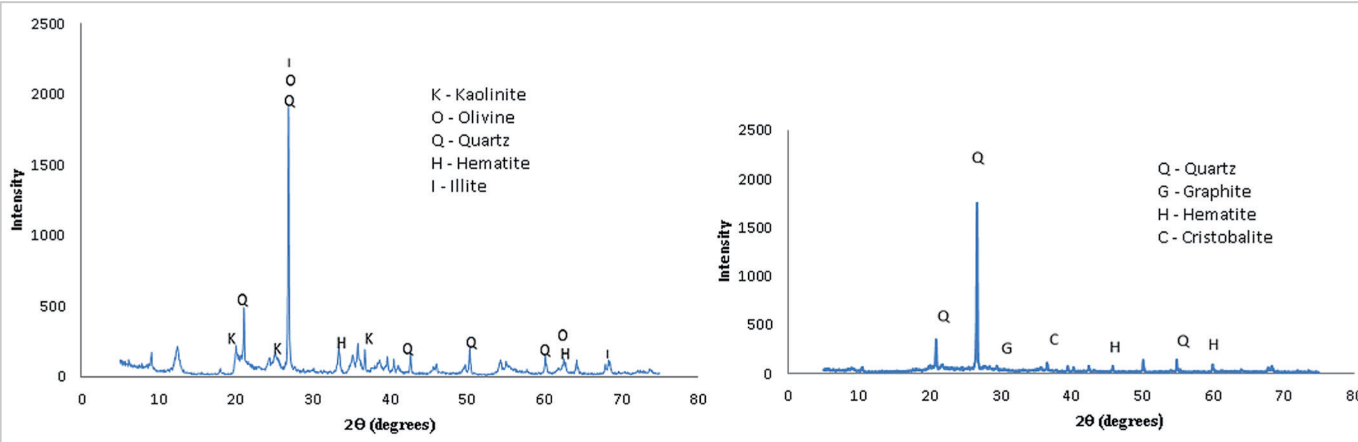

Figure 1 - X-ray diffractogram of plastic clay and PCS.

The processed casting sand (PCS), according to the mineralogical analysis, has quartz (SiO_2) as its main constituent, and contaminants like graphite (G), hematite (H) and cristobalite (C). The particle size analysis showed that this residue had a diameter of 90% <103.74 μm and a mean diameter of 44.6 μm. Figure 1 shows the mineralogical analysis of this raw material.

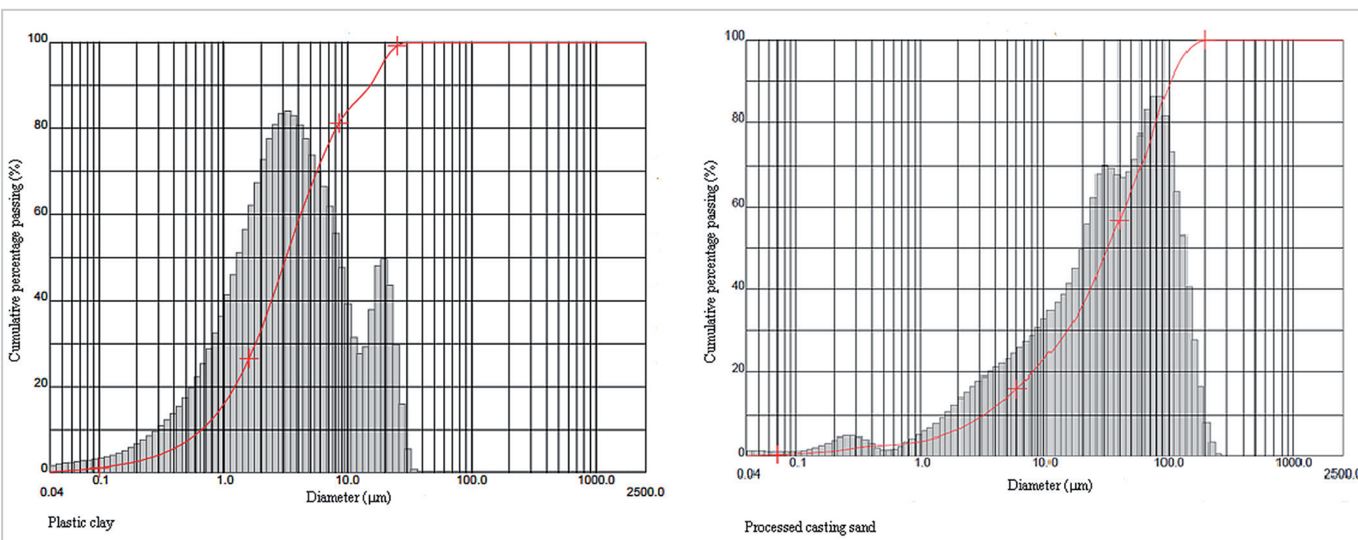

Figure 2 - Granulometry analyses of particles plastic clay and processed casting sand.

3.2 Formulations

The formulated ceramic masses are presented in Table 2. The formulation AF00 is that formed only by plastic clay, whereby the percentage of processed sand of the casting was successively varied. The formulations were homogenized in a paraffin mill for 5 minutes and humidified (addition of 10 % water). Then, the masses were granulated and sieved (850 μm aperture) to be formed.

Table 2 - Formulated ceramic masses.

Materials	AF00	AF20	AF30	AF40	AF50
Clay	100	80	70	60	50
PCS	0.0	20	30	40	50

3.3 Shrinkage test

Shrinkage is one of the primary phenomena observed upon firing a ceramic body and reflects possible increases in the numbers of contact points or surfaces among the particles and increase or decrease of the number of pores within the ceramic body. Table 3 shows that the retraction decreases as the percentages of the PCS increase. This is due to the presence of quartz that does not react at the temperatures studied, remaining static in the ceramic body.

Table 3 - Linear retraction, of bodies.

Linear Retraction (%)	85ºC	900ºC	1000ºC
AF00	1.50±0.16	1.65±0.01	1.97±0.36
AF20	1.38±0.03	1.27±0.07	2.07±0.11
AF30	1.00±0.08	1.10±0.67	1.90±0.01
AF40	0.66±0.08	1.01±0.07	1.67±0.07
AF50	0.31±0.42	0.84±0.15	1.68±0.14

3.4 Firing curves

Figure 3 shows the firing curves (relating to water absorption (WA) and linear retraction (RL) with the firing temperature) of the ceramic bodies formulated from the processed sand smelter and plastic clay as a function of the firing temperature. In the analysis of the firing curves, it can be observed that with the increase of the firing temperature, a decline of the water absorption for all the ceramic bodies of the formulations tested occurs. This occurs due to the presence of Fe_2O_3, MgO and CaO that act as flux, promoting the development of the liquid phase, inducing a reduction of the firing temperature.

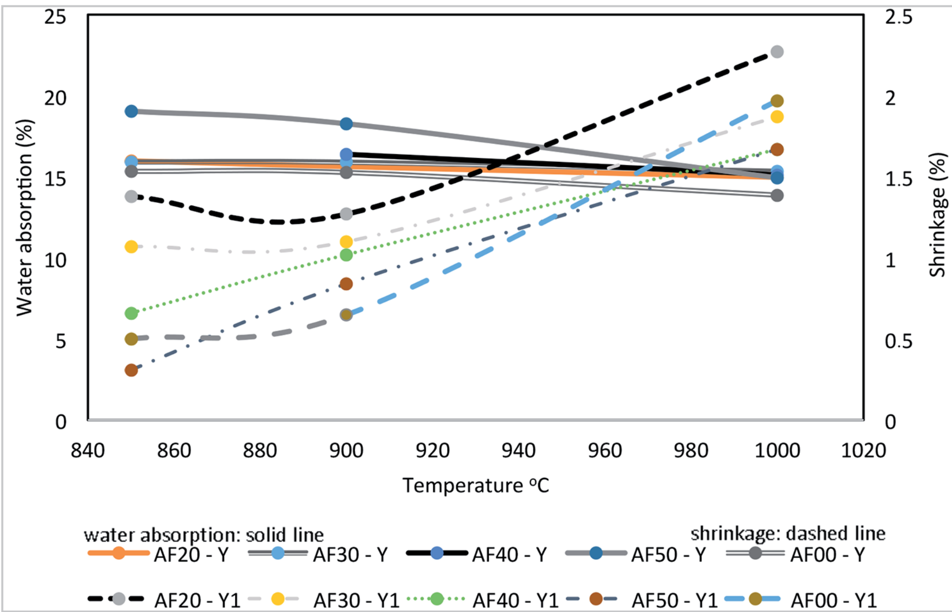

Figure 3 - Firing curves of the ceramic bodies formulated.

3.5 Density and mechanical strength

Table 4 presents the data for the density for the formulations studied. In this, it is verified for formulations with waste foundry sand that the density of the specimens at the same temperature decreases as the concentration of PCS increases. This fact is due to the composition (silica, bentonite and coal) of the sand; the coal is burnt and consequently there is a loss of mass of the ceramic body. Hossiney *et al.* (2018) concludes that the reduction in density can be attributed to the poor packing ability of bricks containing a higher content of waste foundry sand.

Table 4 - Density of green and fired test specimens.

Density (g/cm³)	Green	850ºC	900ºC	1000ºC
AF00	1.94	1.81	1.89	1.90
AF20	1.93	1.78	1.79	1.82
AF30	1.99	1.73	1.71	1.74
AF40	1.93	1.68	1.64	1.70
AF50	1.90	1.63	1.56	1.63

In the graph of Figure 4, notice that the mechanical strength of the ceramic bodies increases with temperature up to a limit of the percentage of sand added in the ceramic mass, from which the decrease of this property occurs. This temperature range varies between 850 °C and 1000 ºC, for formulations AF00, AF20, AF30, AF40 and AF50.

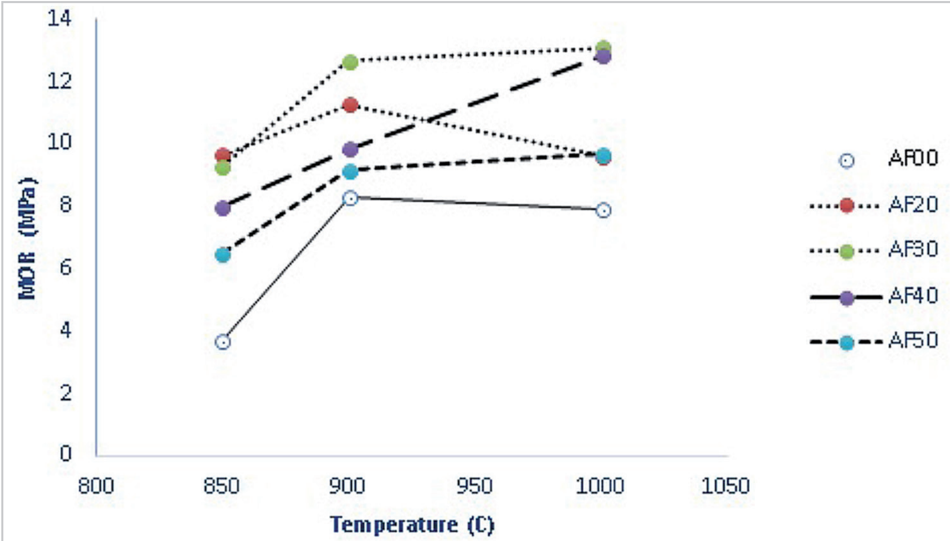

Figure 4 - Mechanical resistance of formulations at different firing temperatures.

3.6 Emissions of contaminants

In order to analyze the environmental aspect of the ceramic bodies of the AF30 formulations, burned at 900 °C, the emission of contaminant via leaching was evaluated. This procedure was based on Brazilian standards.

The results are presented in Table 5. Analyzing it, it is verified that the ceramic bodies produced with plastic clay and processed sand from casting can be classified as inert. No parameters were exceeded during leaching. With this result we can conclude that both the clay and the sand from casting do not undergo leaching in the sintered ceramic bodies.

Table 5 - Leaching of the processed sand and the ceramic bodies of the AF30 formulation, according to NBR-10005.

Parameters analyzed	Ba	Cr	Al	Fe
NBR 10005 (mg/L)	100	5	4	6
Casting sand	0.95	< 0.004	1.4	0.47
30 AF	0.90	< 0.004	< 0.001	< 0.002

4. Conclusions

This study investigated the replacement of plastic clay by a percentage of processed sand from the casting. From the obtained results, the following conclusions can be inferred:

- The foundry sand residues studied are silica (49.16%) and alumina (12.99%) as the main constituent. It is indicated for use in ceramics, since these two compounds are the main constituents in the ceramic pieces. However, the high iron content (7.78%) should be considered, which restricts its use to the production of stoneware and semi-stoneware ceramics, due to the dark firing color conferred by iron oxide.

- The shaped ceramic bodies presented sufficient quality for the production of ceramic bricks. The highest mechanical resistance with a percentage of 30% of residues was presented at temperature of 900 °C. It should be noted that particles size is an essential factor in the use of foundry sand.

- For formulations with percentages above 30% of processed casting sand (PCS), the reduction in the mechanical strength of fired parts is observed, but there is a resistance superior to that recommended by the standard that defines the brick as structure still prevails.

- When comparing the resistance of pure clay to that mixed with PCS at 900 °C, a significant improvement in this technological property is observed.

- The smaller the grain size of this residue, the greater the percentage of this added in the ceramic brick, providing a greater sintering in the firing temperature. The addition of this allows the production of bricks with greater mechanical resistance, due to the decrease in the porosity of the ceramic bodies, by the presence of ferruginous complexes and alkaline oxides added to the ceramic mass.

- The ceramic bricks using the PCS, because they have lower leaching contents than those established by the standard, allow their use in the production of environmentally safe bricks. In this way, these blocks can be commercialized and used in the construction without causing environmental impacts.

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