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Comparison Between Cement With The Addition Of Ground Crushed Granite And A Commercial Pozzolanic Cement In The Amazon Region

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Abstract
This study aims to compare the properties of a cement mixture produced by partially replacing clinker with crushed granite powder to a commercial pozzolanic cement, evaluating the possibility of using this new composition in accordance with national regulatory criteria and within the context of the construction industry in the Amazon region. Based on procedures prescribed in the technical standards applicable in the national scenario, the article characterized cement mixtures with the partial replacement of clinker by crushed granite residue (RBGM), in different proportions (10% RBGM, 20% RBGM, 30% RBGM, 40% RBGM and 50% RBGM), observing good performance of the compositions, in accordance with the established parameters and regulatory limits. From the analysis of the compressive strength levels verified, it was possible to observe that all samples reached values required for Strength Class 25, and with all mixtures qualified for Strength Class 40, except for 50% RBGM, which fell into Class 32. From the above, it is concluded that ground granite gravel residue has the potential to be used as a pozzolanic addition in cement mixtures, as a partial replacement for clinker.

Keywords: *Mineral addition. Residue of crushed granite. Cement.*

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I. Introduction

Professionals working in civil construction management must have broad knowledge of the materials used, understanding their potential and shortcomings, since the performance of production processes in this market is dependent on the availability of raw materials in large quantities [1], [2]. One of the main elements in this array of inputs is Portland cement, a construction material manufactured by mixing limestone and clay, or minerals with similar properties, in a rotary kiln (which results in an element called clinker), with subsequent addition of gypsum to delay the hardening of the cement paste [2], [3].

The main advantages of using Portland cement are the pervasive availability of the materials used in its manufacture, which makes it essential for concrete production, and the development of high compressive strength after being mixed with water [2]. The concrete industry consumes around 1.6 billion tons of Portland cement every year, in addition to sand, water and rock, making it the largest consumer of natural resources in the world [3]. A sustainable future for this industry will require reducing the use of these materials, as well as reducing energy consumption for manufacturing concrete, which can be achieved by adding materials with properties similar to those of cement to concrete, since the manufacture of clinker in the rotary kiln involves the burning of large quantities of fossil fuels [1], [3].

In the mining industry, a series of materials to which no commercial value has yet been attributed are treated as waste, which determines their disposal. The use of these materials is required due to the need to reduce the impact of mining exploration, but also due to the advantage of using available resources with low acquisition costs [4].

In this sense, this work seeks to compare the properties of a cement mixture produced with the partial replacement of clinker by crushed granite powder with a commercial pozzolanic cement, evaluating the possibility of using this new composition considering national normative criteria, and within the context of the construction industry in the Amazon Region.

II. Methodology

Materials

This work advances the research produced by [5] on the influence of the addition of by-products from rock mining activities in cement matrices, specifically as a partial replacement for Portland cement, through

chemical and physical characterization and determination of the pozzolanic activity index of clinker samples and granite crushed stone powder, "in natura" and ground, in order to identify the potential of this crushing by-product as a Supplementary Cementitious Material, that is, pozzolanic addition.

As described by [5], the granite stone powder, as it is commercially known, originating from a crushing plant in the northeastern region of the state of Pará, was dry ground, with grinding times of 15, 30 and 45 minutes, to produce material with an average particle size close to that of cement. This material was then called Granite Crushed Stone Powder Residue – RPBG15, RPBG30 and RPBG45, according to the grinding time used of 15, 30 and 45 minutes, respectively. Through tests to determine pozzolanic activity, with lime and Portland cement, it was found that the longer the grinding time, the greater the activation of the material, and the sample that demonstrated the best performance, meeting the requirements proposed by NBR 12653 [6] was RPBG45, which was renamed RBGM.

According to the parameters established in NBR 16697 [7], cement with a composition consistent with the standardized designation CP IV was used, in relation to which cements produced with the partial replacement of clinker by ground granite crushed stone residue were compared. Gypsum and clinker were supplied by a company located in the city of Ananindeua, Pará, and their characteristics are presented in Tables 1 and 2.

Table 1 – Chemical and granulometric characteristics of Gypsum

Species / Factor	Quantities
SO_3	40.22%
CaO	32.85%
SiO_2	4.64%
P_2O_5	2.31%
Al_2O_3	0.92%
Fe_2O_3	0.34%
K_2O	1.58%
Retained # 11.00 mm	54.70%
Retained # 4.75 mm	7.60%
Retained # 3.35 mm	7.20%
Retained # 3.35 mm	26.93%

Source: Author, 2025

Table 2 – Chemical Characteristics of Clinker

Species / Factor	Quantities
Insoluble Residue (%)	0.11%
Loss on Ignition	0.50%
Free lime	3.38%
SO_3	0.11%
SiO_2	19.49%
Al_2O_3	4.94%
Fe_2O_3	3.45%
CaO	66.20%
MgO	3.85%
C_3S	69.97%
C_2S	2.78%
C_3A	7.25%
C_4AF	10.50%
Lime Saturation Factor	104.32

Source: Author, 2025

Cements produced with partial replacement of clinker by ground granite gravel residue are designated CP IV, as established in NBR 16697 [7]. Prototypes with six compositions were produced, one with standard cement, without the addition of RBGM, and five compositions with replacement of 10%, 20%, 30%, 40% and 50%, respectively called 10%RBGM, 20%RBGM, 30%RBGM, 40%RBGM and 50%RBGM. Table 3 shows the compositions, in mass percentage, of the prototypes produced.

Table 3 – Characteristics of the Prototypes

Cement Type	**Class**	**Strength Class (MPa)**	**Composition (mass percentage)**			
			Clinker + Gypsum	**Blast Furnace Slag**	**Pozzolanic Material**	**RBGM**
Standard	CP IV	32	80	0	20	0
10%RBGM	CP IV	32	72	0	20	8
20%RBGM	CP IV	32	64	0	20	16
30%RBGM	CP IV	32	56	0	20	24
40%RBGM	CP IV	32	48	0	20	32

50%RBGM	CP IV	32	40	0	20	40

Source: Author, 2025

Methods

Insoluble Residue Content

The insoluble residue content of the samples was determined according to the method described in NBR 17806-4 [8]. First, 25 mL of cold water were added to a 250 mL beaker containing a sample in the range (1.000 0 ± 0.001 0) g. After the cement dispersion, 5 mL of HCl were added while the sample was stirred. The solution was then diluted with water close to boiling temperature until it reached approximately 50 ml. After this, the steps of filtering the solution and washing the utensils in hot water were performed, tearing the filter paper over 100 mL of a NaOH solution at a temperature close to the evolution temperature. After the addition of the red solution and acidification, a new filtering was performed, and the residue was washed, transferred to a crucible and dried in an oven. After this, the residue was calcined according to the normative parameters, cooled and weighed. The percentage of insoluble residue was calculated to the nearest 0.01% using (1):

$$\%RI = \frac{m_1 - m_2 - m_3}{m} \times 100$$

where:

%RI is the insoluble reside content (%);
m is the mass of the sample, expressed in grams (g);
m_2 is the tare weight of the crucible plus the mass of the insoluble residue, in grams (g);
m_1 is the mass of the crucible, expressed in grams (g);
m_3 is the mass of the residue due to the blank test, when performed, expressed in grams (g).

Loss on Ignition

The determination of the loss on ignition of the samples was performed according to the method described in NBR 17806-6 [9]. First, in a crucible of known mass, a sample was weighed in the range (1.000 ± 0.0010) g, and then calcined, cooled and weighed again, according to normative parameters. The percentage of loss on ignition was calculated by (2):

$$\%PF = \frac{m_1 - m_2}{m} \times 100$$

where:

%PF is the percentage of Loss on Ignition;
m is the mass of the sample used in the test, expressed in grams (g);
m_2 is the mass of the crucible plus the mass of the sample tested, in grams (g);
m_1 is the mass of the crucible plus the sample, after calcination, in grams (g).

Magnesium Oxide and Sulfuric Oxide Content

The magnesium oxide and sulfuric oxide contents were determined according to the procedures of NBR 17086-2 [10] and 17086-5 [11], respectively. For magnesium oxide, after SiO_2 filtration according to the prescribed procedure, 20 mL of the filtrate were transferred to a beaker, to which 10 mL of triethanolamine solution and approximately 50 mL of water were added. After adjusting the pH of the solution with NH_4OH, the mixed indicator was added and titration was performed with EDTA-Na_2, with constant stirring, until colorless color was achieved, after which the percentage of MgO was calculated. The determination of Sulfuric Oxide, in turn, used the filtrate collected in the insoluble residue determination test, diluting it until it reached 250 mL and bringing it to the boil. After adding a hot $BaCl_2$ solution and standing for 24 hours, the chlorides were filtered and washed, the filter paper with the precipitate was burned in a crucible of known mass and calcined, cooled and weighed. The percentage of SO_3 was calculated to the nearest 0.01% by (3):

$$\%SO_3 = \frac{(m_2 - m_1 - m_3)}{m} \times 0{,}343 \times 100$$

where:

m is the mass of the sample, expressed in grams (g);
m_2 is the mass of the crucible plus the mass of the $BaSO_4$ precipitate, in grams (g);
m_1 is the mass of the tared crucible, expressed in grams (g);
m_3 is the mass of the residue obtained in the blank test, when performed, expressed in grams (g).

0.343 is the molar ratio between SO_3 and $BaSO_4$.

Determination of Normal Consistency Paste

The normal consistency of the cement paste for the samples was determined according to the procedure prescribed in NBR 16606 [12]. First, the mold supported on the base plate was filled, removing the excess paste. The assembly was positioned under the Vicat apparatus, centering it under the rod, which was lowered until the end of the probe met the surface of the paste, with its subsequent fixation. After 45s from the end of the mixing, the rod was released. The paste is considered to have normal consistency when the probe is located at a distance of (6 ± 1) mm from the base plate after 30 s from the moment it was released.

The amount of water necessary to obtain the normal consistency of the cement paste is calculated by (4):

$$A = \frac{m_a}{m_c} \times 100$$

where:

A is the quantity of water, expressed as a percentage (%);
m_a is the mass of water used to obtain the normal consistency of the cement paste, expressed in grams (g);
m_c is the mass of cement used in the test, expressed in grams (g);

Determination of Setting Times

Setting times were determined according to the procedure prescribed in NBR 16607 [13]. After the needle had been in contact with the paste in the Vicat apparatus for 2s, the needle was released and the reading was taken after 30s, recording the time lapse since the mixing of the water and cement (zero instant). The test was repeated in conveniently separated positions, at least 10 mm from the edge of the mold and between them. The results of all penetrations were recorded and the time at which the distance between the needle and the base plate would reach (6 ± 2) mm was determined by interpolation. The needle for determining the start of setting time was replaced by the Vicat needle for determining the end of setting time, whose annular accessory facilitates the exact observation of small penetrations, and the tests for determining the end of setting were performed on the opposite side of the test specimen.

Determination of Fineness by Sieve Number 200 and by the Air Permeability Method

For the samples analyzed, the percentage of material retained on the 200 Sieve was determined according to the procedure described by ABNT NBR 11579 [14], while the fineness determination test by air permeability (Blaine method) was performed according to the methods prescribed in NBR 16372 [15]. The fineness, from the measurement obtained in the Blaine equipment, was calculated according to (5):

$$blaine = \frac{k\sqrt{T}.\sqrt{\epsilon^3}}{\rho.\ (1-\epsilon).\sqrt{0{,}1n}}$$

where:

ρ is the specific mass (g.cm-3);
∈ is the porosity of 0.5 as a starting point;
blaine is the specific area (Cm2.g-1);
k is the calibration constant of the device (Pa1/2. cm-1);
T is the test time (s);
n is the dynamic viscosity of the air (Pa.s).

The values obtained for Fineness using Sieve No. 200, for each of the compositions, can be seen in Table 4, while the values obtained by Blaine are presented in Table 5.

Table 4 – No. 200 Mesh Fineness

Cement	#200 mesh fineness (%) Normative Limit ≥ 1	#325 mesh fineness (%) Normative Limit ≤ 10
Standard	1.6	9.0
10%RBGM	0.7	9.1
20%RBGM	1.5	9.3
30%RBGM	0.7	9.1
40%RBGM	0.9	9.0
50%RBGM	1.2	9.1

Source: Author, 2025

Table 5 – Fineness by the Air Permeability Test

Cement	Specific Area (cm^2/g) Normative Limit ≥ 2600
Standard	8690
10%RBGM	8770
20%RBGM	9390
30%RBGM	9200
40%RBGM	8310
50%RBGM	9610

Source: Author, 2025

Water absorption by immersion, void index and specific mass

The procedure established in NBR 9778 [16] was followed to determine water absorption, void index and specific mass. Portions of mortar produced from the mixtures 10%RBGM, 20%RBGM, 30%RBGM, 40%RBGM and 50%RBGM were subjected to drying in an oven at a temperature of (105 ± 5)°C for a period of 72 h, and their mass in the dry condition (ms) was subsequently determined. The samples were also immersed in water at a temperature of (23 ± 2)°C and kept in this condition for 72 h. After completing the saturation stage in water at a temperature of (23 ± 2)°C, the samples were placed in a container filled with water, which was gradually brought to the boil between 15 min and 30 min before the start of heating. The boiling was maintained for a period of 5 h, keeping the water volume approximately constant. The water was then allowed to cool naturally. The mass was measured using a hydrostatic balance (m_i), and, after removing it from the water and drying it with a damp cloth, its mass was recorded again (m_{sat}). Water absorption was calculated using (6):

$$A = \frac{m_{sat} - m_s}{m_s} \times 100$$

where

A is the water absorption, expressed as a percentage (%);
m_{sat} is the mass of the sample saturated in water after immersion and boiling, in grams (g);
m_s is the mass of the oven-dried sample, in grams (g);

The void index was calculated using (7):

$$I_v = \frac{m_{sat} - m_s}{m_{sat} - m_i} \times 100$$

where

Iv is the void index, expressed as a percentage (%);
m_i is the mass of the saturated sample immersed in water after boiling, in grams (g);

The actual specific mass (ρr) was calculated using (8):

$$\rho_r = \frac{m_s}{m_{sat} - m_i}$$

The values obtained in the specific mass determination tests are presented in Table 6.

Table 6 – Specific Weight

Cement	Specific Weight (cm^2/g)
Standard	2.91
10%RBGM	2.84
20%RBGM	2.84
30%RBGM	2.81
40%RBGM	2.78
50%RBGM	2.74

Source: Author, 2025

Compression Strength Test (MPa)

For the mechanical test on the samples produced, the guidelines of NBR 5739 [17] were followed. The test specimens were molded as established in NBR 5738 [18], and broken under compression at specified ages,

counted from the moment of molding, with time tolerance set out in Table 8. The machine used to perform the test was equipped with two steel plates with contact surfaces with the test specimen proportioned in relation to the diameter of the test specimens within the normative limits.

Table 8 – Time Tolerance for Compressive Strength Testing

Age of Testing	Tolerance (h)
24h	0.5
3 days	2
7 days	6
28 days	24

Source: Author, 2025

The test load was applied continuously and without shocks, with a loading speed of (0.45 ± 0.15) MPa/s. The loading speed was kept constant throughout the test, ceasing only when the force dropped, indicating the rupture of the test specimens.

The compressive strength was calculated using (9):

$$f_c = \frac{4F}{\pi \times D^2}$$

where

f_c is the compressive strength, expressed in megapascals (MPa);
F is the maximum force achieved, expressed in newtons (N);
D is the diameter of the test specimen, expressed in millimeters (mm).

III. Analysis Of Results

Determination of Loss on Ignition and Setting Times

According to [19], the importance of the test for determination of loss on ignition lies mainly in verifying the levels of deterioration of cement products in storage. In Brazil, the minimum performance parameters regarding loss on ignition are established in NBR 16697 [7]. Table 9 presents the Loss on ignition values verified for the tested mixtures.

Table 9 – Loss on Ignition (%)

Cement	Normative Limit ≤ 6,5
Standard	5.03%
10%RBGM	5.23%
20%RBGM	5.01%
30%RBGM	5.02%
40%RBGM	5.01%
50%RBGM	5.08%

Source: Author, 2025

From the analysis of Table 19, we can see that all the tested compositions are within the normative limits regarding Loss on Ignition, with the mixtures with partial replacement of clinker presenting similar performance to the reference material in all proportions.

In Brazil, the minimum performance parameters regarding Setting Times are established in NBR 16697 [7]. Table 10 presents the Setting Time values verified for the tested mixtures.

Table 10 – Setting Times

Cement	Initial Setting Time (h) Normative Limit ≥ 1	Final Setting Time (h) Normative Limit ≤ 10
Standard	01h35	03h00
10%RBGM	03h10	04h10
20%RBGM	03h05	04h05
30%RBGM	03h20	04h40
40%RBGM	02h55	04h00
50%RBGM	03h15	04h25

Source: Author, 2025

From the analysis of Table 10, we can see that all the tested compositions are within the normative limits regarding Setting Times, with the mixtures with partial replacement of clinker showing the start of setting at around 3h, above the minimum of 1h, and the end of setting at around 4h, below the maximum of 10h, and close to the Setting Time of the reference mixture (3h).

Magnesium Oxide and Sulfuric Oxide Content

In Brazil, the normative limits regarding Magnesium Oxide and Sulfuric Trioxide contents are prescribed in NBR 16697 [7]. Table 11 shows the percentages verified for the mixtures tested.

Table 11 – Magnesium Oxide and Sulfur Trioxide Contents (%)

Cement	MgO (%) Normative Limit ≤ 6,5	SO_3 Normative Limit ≤ 4,0
Standard	2.46%	2.15%
10%RBGM	2.33%	2.17%
20%RBGM	2.16%	2.13%
30%RBGM	2.06%	2.13%
40%RBGM	2.06%	2.12%
50%RBGM	1.80%	2.15%

Source: Author, 2025

From the analysis of Table 11, we can see that all the tested compositions are within the normative limits in relation to both the Magnesium Oxide Content and the Sulfuric Trioxide Content, with the mixtures with partial replacement of the clinker presenting contents very close to the reference mixture. It is also possible to see that the MgO concentration decreases as the replacement of clinker by RBGM increases, while the SO_3 concentration remains stable in all clinker replacement ranges.

Determination of Insoluble Residue Content

In Brazil, the normative limits regarding Insoluble Residue Content are prescribed in NBR 16697 [7], and for the CP-IV category, there are no maximum levels required. Table 12 shows the contents verified for the mixtures.

Table 12 – Determination of Insoluble Residue Content (%)

Cement	Verified Content
Standard	2.365%
10%RBGM	2.909%
20%RBGM	3.576%
30%RBGM	4.056%
40%RBGM	4.768%
50%RBGM	5.357%

Source: Author, 2025

From the analysis of Table 12, we can see the directly proportional variation of the Insoluble Residue Content in relation to the level of replacement of clinker by RBGM. According to [19], the determination of insoluble residue verifies the presence of impurities and non-reactive materials, although this test can indicate the presence of pozzolanic substances as insoluble residue, which can explain the trend observed in Table 12.

Determination of Normal Consistency Paste

According to [19], the Normal Consistency Paste test is primarily a starting point for other tests, although some of its most interesting applications are the verification of the compatibility between mineral additions and cement, or determining the effects of a mineral addition on the percentages of water required. In Brazil, the performance parameters related to Normal Paste Consistency are prescribed in NBR 16606 [12]. Table 13 presents the values verified for the mixtures.

Table 13 – Determination of Normal Consistency Paste (%)

Cement	Consistency (%)
Standard	30.60%
10%RBGM	31.00%
20%RBGM	32.80%
30%RBGM	33.20%
40%RBGM	33.20%
50%RBGM	33.60%

Source: Author, 2025

From the analysis of Table 13, we can see that all the tested compositions have consistency percentages very close to the reference mixture.

Water Absorption by Immersion and Void Index

According to [19], the level of water required in cement mixtures can vary considerably depending on the properties of the materials added. In Brazil, the parameters related to water absorption by immersion are prescribed in NBR 9778 [16]. Table 14 presents the values verified for the mixtures.

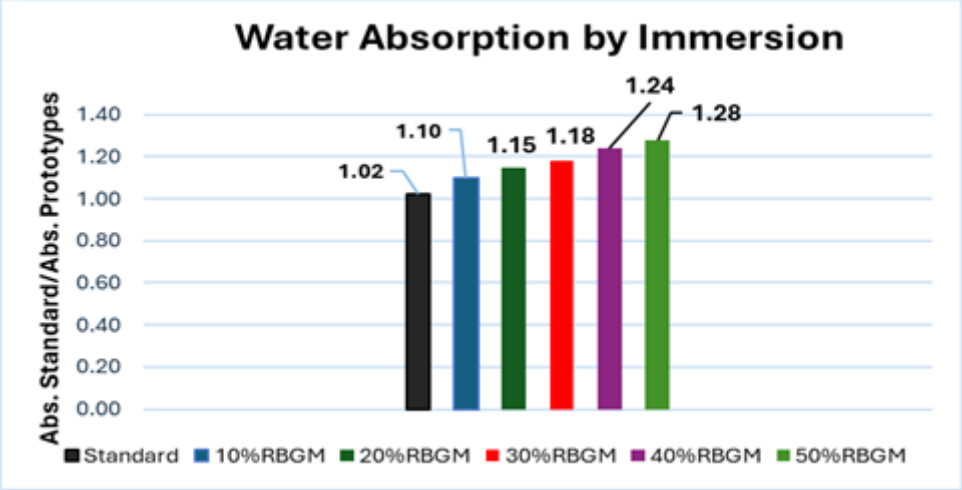
Table 14 – Water Absorption by Immersion

Cement	Water Absorption by Immersion
Standard	1.02
10%RBGM	1.10
20%RBGM	1.15
30%RBGM	1.18
40%RBGM	1.24
50%RBGM	1.28

Source: Author, 2025

From the analysis of Table 14, we can see that the water absorption index by immersion increases as the partial replacement of clinker by RBGM increases. Fig. 1 shows the plot of the values found in a bar graph in which this trend is clear.

Fig. 1 – Water Absorption by Immersion



Source: Author, 2025

In Brazil, the parameters relating to the void index are prescribed in NBR 9778 [16]. Table 15 presents the values verified for the mixtures.

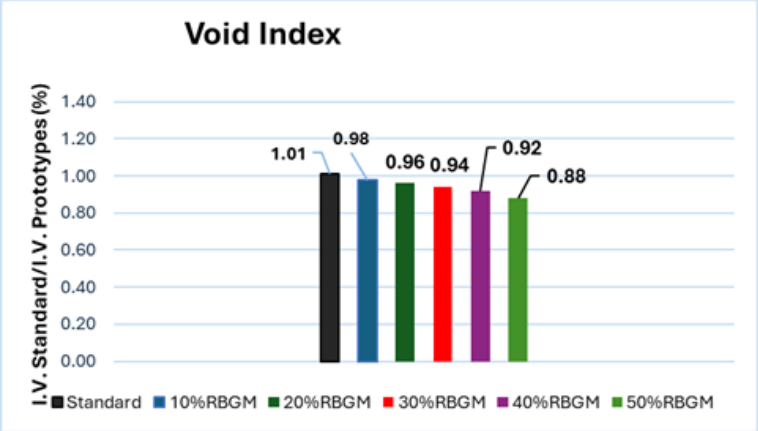
Table 15 – Void Index

Cement	Void Index
Standard	1.01
10%RBGM	0.98
20%RBGM	0.96
30%RBGM	0.94
40%RBGM	0.92
50%RBGM	0.88

Source: Author, 2025

In Table 15, we can observe the indirect proportional variation of the void index in relation to the partial replacement of clinker by RBGM, with the 10% RBGM mixture presenting an index very close to the reference value, and the lowest index having been verified for the 50% RBGM sample. Figure 2 presents the plot of the values found in a bar graph in which this trend is clear.

Fig. 2 – Void Index



Source: Author, 2025

Compressive Strength (MPa)

According to [20], the consistency of compressive strength levels is an important criterion in the quality control of the production of cementitious mixture products. For [19], the attention given to compressive strength is due, in most cases, to the fact that this is the most effective quality control tool, even when high levels of compressive strength are not the priority.

In Brazil, the parameters related to the void index are prescribed in NBR 16697 [7]. Table 16 presents the values verified for the mixtures.

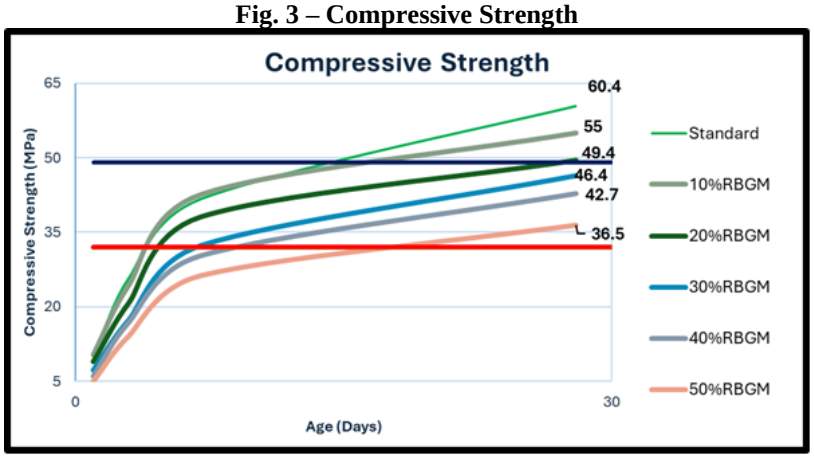
Table 16 – Compressive Strength (MPa)

Cement	Compressive Strength (MPa)			
	1 day	3 days	7 days	28 days
	-	≥ 10	≥ 20	≥ 32
Standard	10.1	26	41.7	60.4
10%RBGM	10.4	24.5	42.6	55
20%RBGM	8.9	20.8	38	49.4
30%RBGM	7.2	17.4	32.3	46.4
40%RBGM	6	16.9	30.2	42.7
50%RBGM	5	14.2	26.3	36.5

Source: Author, 2025

In Table 16, we can see that all samples reached levels that were adequate to the normative limits, above the values required for Strength Class 25, and with all mixtures qualified for Strength Class 40, with the exception of 50%RBGM, which was classified as Class 32. A proportional variation in the compressive strength was observed in an indirect direction in relation to the partial replacement of clinker by RBGM, with the 10%RBGM mixture presenting values very close to the reference value, and the lowest compressive strength value having been verified for the 50%RBGM sample. Fig. 3 shows the plot of the values found in a bar graph in which this trend is clear.

Fig. 3 – Compressive Strength



Source: Author, 2025

IV. Conclusions

Based on procedures prescribed in the technical standards applicable in the national scenario, the article characterized cement mixtures with partial replacement of clinker by ground granite gravel residue (RBGM), in different proportions (10% RBGM, 20% RBGM, 30% RBGM, 40% RBGM and 50% RBGM). The feasibility of using RBGM as a mineral addition was verified considering the performance of the compositions at levels suitable to produce cement mixtures, given the established parameters and normative limits.

Through the results obtained, it was observed that the proportion of replaced clinker influences the properties of the mixture produced, with emphasis on the variations in indirect proportion of the void index, the water absorption index by immersion and the levels of compressive strength, in which the 10% RBGM sample presented behavior very similar to the reference material. The variation in direct proportion of the insoluble residue content and the determination of the normal consistency paste was also observed, again with the %50RBGM mixture behaving in the most different way from the reference material. Finally, the Sulfuric Oxide content proved to be stable throughout the range of partial replacement of the clinker. From the analysis of the compressive strength levels verified, it was possible to observe that all samples reached levels appropriate to the normative limits, above the values required for Strength Class 25, and with all mixtures qualified for Strength Class 40, except for 50% RBGM, which fell into Class 32. A proportional variation in the compressive strength was verified in an indirect sense in relation to the partial replacement of clinker by RBGM, with the 10% RBGM mixture presenting values very close to the reference value, and the lowest compressive strength value having been verified for the 50% RBGM sample.

From the above, it is concluded that ground granite gravel residue has the potential to be used as a pozzolanic addition in cement mixtures, as a partial replacement for clinker.

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