Research, Society and Development, v. 10, n. 6, e0210615412, 2021
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v10i6.15412

Soil-cement bricks with insertion of scheelite-tailings: Mechanical behavior and physico-chemical evaluation of kneading water

Tijolos de solo-cimento com inserção de rejeito da scheelita: Comportamento mecânico e avaliação físico-química da água de amassamento

Ladrillos suelo-cemento con inserción de relaves de scheelita: Comportamiento mecánico y evaluación físico-química del agua de amasadura

Received: 04/24/2021 | Reviewed: 05/03/2021 | Accept: 05/04/2021 | Published: 05/18/2021

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Abstract

Through the environmental perspective of producing new construction materials with the inclusion of tailings or residues that improve their properties and, at the same time, promote a practice that mitigates environmental impacts, the objective of this work is to diagnose the effect of incorporating scheelite- tailings as recycled aggregate in soil-cement bricks, partially replacing the soil, seeking to make its use feasible in interlocking pavements, as well as studying the physical-chemical properties of the mixing water used in the making of soil-cement bricks, originating from drains air conditioning system at IFPB Campus Campina Grande. The bricks produced used CP II Z-32 class cement, landfill cut-off soil for disposal, scheelite-tailings, and kneading water from air conditioning drains at the IFPB Campus Campina Grande. Conformation was performed manually with the aid of a hydraulic press, with subsequent curing at room temperature and periodic wetting during the first 7 days of cement hydration (alkaline stabilizer), until the ages of laboratory tests of compressive strength reached (28 days) and direct flexion (180 days). It was noted that the results of compressive strength exceeded the minimum limits of ABNT NBR 10834:2013, as well as the results of the flexion test demonstrated that the mechanical strength of the bricks is superior when incorporating the mineral tailings, a phenomenon also noticed through of the compressive strength test. The quality of the water used to manufacture the bricks, in addition to ensuring better chemical potential in the hydration reaction based on the state of the art, promotes a reduction in the use of water from the public supply, which comes from a relatively low water source.

Keywords: Soil-cement; Scheelite-tailings; Ecological bricks; Interlocked pavement; Air conditioning drain water.

Resumo

Através da perspectiva ambiental em produzir novos materiais de construção com inclusão de rejeitos ou resíduos que melhorem suas propriedades e, ao mesmo tempo, promovam uma prática mitigadora dos impactos ambientais, objetiva-se com esse trabalho diagnosticar o efeito da incorporação do rejeito da extração da scheelita como agregado reciclado em tijolos maciços de solo-cimento substituindo parcialmente o solo, buscando viabilizar seu uso em pavimentos intertravados, bem como, estudar as propriedades físico-químicas da água de amassamento utilizada na confecção dos tijolos de solo-cimento, oriunda dos drenos de ar condicionado do IFPB Campus Campina Grande. Os tijolos produzidos utilizaram cimento de classe CP II Z-32, solo de recorte de aterro para descarte, rejeito mineral da scheelita, e água de amassamento proveniente de drenos de ar condicionado do IFPB Campus Campina Grande. A conformação foi realizada manualmente com o auxílio de prensa hidráulica, com posterior cura à temperatura ambiente e molhagem periódica durante os 7 primeiros dias de hidratação do cimento (estabilizador alcalino), até atingirem as idades de realização dos testes laboratoriais de resistência à compressão axial (28 dias) e flexão direta (180 dias). Notou-se que os resultados de resistência à compressão axial superaram os limites mínimos da ABNT NBR 10834:2013, como também, os resultados do teste de flexão demonstraram que a resistência mecânica dos

tijolos é superior quando incorporado o rejeito mineral, fenômeno também notado através do teste de compressão axial. A qualidade da água utilizada para fabricar os tijolos, além de assegurar melhor potencial químico na reação de hidratação com base no estado da arte, promove a redução do uso da água do abastecimento público, que advém de manancial com aporte hídrico relativamente reduzido.
Palavras-chave: Solo-cimento; Rejeito da scheelita; Tijolos ecológicos; Pavimento intertravado; Água do dreno de ar condicionado.

Resumen
Mediante de la perspectiva ambiental de producir nuevos materiales de construcción con la inclusión de relaves o residuos que mejoren sus propiedades y, al mismo tiempo, promuevan una práctica que mitigue los impactos ambientales, el objetivo de este trabajo es diagnosticar el efecto de incorporar residuos de la extracción de scheelita como agregado reciclado en ladrillos sólidos suelo-cemento, reemplazando parcialmente el suelo, buscando viabilizar su uso en pavimentos entrelazados, así como estudiando las propiedades físico-químicas del agua de amasado utilizada en la fabricación de ladrillos suelo-cemento, procedente de los desagües del sistema de aire acondicionado de la IFPB Campus Campina Grande. Los ladrillos producidos utilizaron cemento clase CP II Z-32, tierra de corte de relleno sanitario para eliminación, desechos minerales de scheelita y agua de amasado de los desagües de aire acondicionado en el IFPB Campus Campina Grande. La conformación se realizó manualmente con ayuda de una prensa hidráulica, con posterior curado a temperatura ambiente y humedecimiento periódico durante los primeros 7 días de hidratación del cemento (estabilizador alcalino), hasta alcanzar las edades de los ensayos de laboratorio de resistencia a la compresión axial (28 días) y flexión directa (180 días). Se notó que los resultados de resistencia a la compresión axial excedieron los límites mínimos de ABNT NBR 10834:2013, así como los resultados del ensayo de flexión demostraron que la resistencia mecánica de los ladrillos es superior al incorporar el residuo mineral, fenómeno también notado a través de la prueba de compresión axial. La calidad del agua utilizada para fabricar los ladrillos, además de asegurar un mejor potencial químico en la reacción de hidratación basada en el estado de la técnica, promueve una reducción en el uso de agua del suministro público, que proviene de un agua relativamente baja fuente.
Palabras clave: Suelo-cemento; Relaves de scheelita; Ladrillos ecológicos; Piso entrelazado; Aire acondicionado drenaje de agua.

1. Introduction

The strands of studies for unconventional materials nowadays emerge from the need to seek to cover, through laboratory studies, the creation of mechanisms that favor the realization of such a claim. Civil construction is characterized as the sector that best supports the ecological initiative to improve this technological segment, producing materials that are in harmony with the environment without affecting the environment through these innovative studies (Srivastava & Kumar, 2018).

It can be noted that the civil construction industry has shown itself, in a promising way, as an alternative in the correct destination of several industrial by-products, when compared to more traditional methods of disposal (Rodrigues & Holanda, 2015), due to the potential in incorporate tailings as constituents of construction materials, reducing the use of inputs of natural origin, and raising the concept of sustainability in one of the industrial sectors that most consumes non-renewable raw materials.

The construction materials that are available today, carry enormous environmental expenditure for releasing carbon dioxide, carbon monoxide and other particulate materials into the atmosphere at the time of manufacture, and this occurs because they demand burning as an essential mechanism in production, such as steel, Portland cement-based materials, and burnt ceramic blocks (Tran, Satomi & Takahashi, 2018).

It is undeniable the fact that the burnt ceramic blocks have always produced intense effects on the consumption of raw materials and energy consumed through burning, and it can be observed that for each ton of bricks produced, an estimated 706 kWh of energy consumed, in addition to the emission of 150 kg of carbon dioxide, becoming a contradiction in the current concept of sustainable development (Zhang, Wong, Arulrajah & Horpibulsuk, 2018).

The use of soil-cement, as a building material, is applied in various construction stages, ranging from the production of bricks to the correction of soils in superficial layers for direct foundations. With emphasis on bricks, it is possible to reduce the volume of tailings using them as a complementary constituent, so that pollution is reduced and raw materials are protected from depletion (Al-Fakih, Mohammed, Liew & Nikbakht, 2019).

According to Tosello, Tamashiro, Silva, Antunes and Simões (2021), due to the search for models that have less impact on the environment, there is an interest in the construction process with the use of raw earth, and the current technology allows the incorporation of raw earth in buildings with some improvements, in order to guarantee greater safety and durability of the constructions through the stabilization of the soil with binders. According to França *et al.* (2018), massive blocks of soil-cement are currently standing out and gaining space in civil construction.

Soil-cement technology is widespread in the world, and has gained greater attention for the best cost benefit that the technique has, in addition to denoting ecologically correct potential for reducing energy consumption (Tran, Satomi & Takahashi, 2018). Traditionally, clays used as inputs in the production of burnt bricks consume a significant amount of fertile soils used in agriculture (Singh, Kulkarni, Kumar & Vashistha, 2018), and thus, soil-cement is an alternative in the production of ceramic materials and cement-based without using excessive volume of this raw material, since the required quantity is minimal.

This minimum amount of clay acts as a dimensional stabilizer at the moment of forming, which often occurs manually, as there is no need for specialized labor or modern machinery, which makes the final product even cheaper. However, as time goes by, the initial cohesion force conferred by the clay is lost as the contact with water becomes more present (Murmu & Patel, 2018). Thus, it is necessary to use alkaline stabilizers for the soil, which in large part is more sandy than clayey, and among the many available, cement has become the most used for conferring the gain of resistance to the brick after the period initial cure (Tran, Satomi & Takahashi, 2018).

In the search to cohesively combine the use of raw material from tailings and/or residues with the improvement of the physical-mechanical properties of the materials, studies such as the use of rice husk ash to stabilize the soil in materials that involve the soil-cement strand perform properties similar to the use of Portland cement (Fundi, Kaluli & Kinuthia, 2018), ratified by the standards that attest durability in terms of resistance to compression and absorption.

The technology of soil-cement also makes possible the viability of incorporating products of residual origin to the material, contributing, under the sustainable aspect, with the correct targeting of industrial by-products that act as aggressive mechanisms to the environment. The tailings, from the fine processing, from the scheelite extraction, due to its granulometry similar to the soil used in this technology, becomes possible to be used as recycled aggregate, advocating environmentally correct advantages that are directly linked to the brick production practice of soil-cement with recycled raw materials (Castro, Costa, Borba, Fagury-Neto & Rabelo, 2016).

Scheelite-tailings are configured, in the aspect of the final disposal, inappropriately due to open discard around the mining company in Currais Novos-RN, where it is estimated that 4.5 to 5 million tons are improperly disposed of mineral waste, only for fine processing (Machado, 2012).

The correct disposal of industrial by-products, with regard to the class of solids, is made difficult by the traditional disposal mechanisms that are available, since within the social, economic and environmental bias, the inadequate disposal leads to irreversible impacts, requiring of a permanent and sustainable system (Siqueira & Holanda, 2013). However, the concept of sustainability advances gradually in the conventional design and construction scenarios (Rimal, Poudel & Gautam, 2019), considering recycling as a crucial factor in the development of the sector.

In parallel, the alternative of enabling sustainable action in the manufacture of soil-cement bricks enters and questions, replacing the fine aggregate with construction and demolition waste, which significantly improve and enable the use of the material, meeting the normative prerequisites, reducing the areas of waste disposal and producing a material with

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environmentally friendly potential (Reis *et al*. 2018).

Rolim, Freire and Beraldo (1999), emphasize that the soil-cement constitutes one of the main elements of constructions with earth, standing out, also, for the potential of involving in its mixture diverse residues, because according to Cunha Oliveira (2020), the construction industry has great potential to be able to absorb its own wastes and the wastes of other industrial spheres.

According to Helene (1999), the mixing water used in the materials based on soil and cement, is a factor that directly interferes in the final quality of these materials, either in the composition itself or in the water/cement ratio. The water/cement ratio is a factor that influences the susceptibility of these materials to the entry of external agents, as they interfere with porosity, permeability and water absorption capacity. ABNT NBR 15900-1:2009 determines that regarding the civil construction activities, the mixing water, used to mix the cement with the aggregates, cannot have a pH below 5.0 (acidic water) and sulfate content greater than 2,000 mg/L.

The objective of this work is to diagnose the effect of using scheelite tailings as recycled aggregate in soil-cement bricks, partially replacing the soil, for application in interlocking pavements, through mechanical tests of compressive strength and flexural strength, as well as to evaluate the physico-chemical properties of the of kneading water originating from drains air conditioning system at IFPB Campus Campina Grande Library.

2. Materials and Methods

The study was developed at the Construction Materials, Geotechnical and Analytical Chemistry Laboratories, at the Federal Institute of Paraíba - Campus Campina Grande (-7° 14' 24.845”; -35° 54' 54.651”, 498 m).

2.1 Composition and Manufacture of Soil-Cement Bricks

The compositions fixed for making the specimens were determined from the amount of cement, composing 10% by weight (Ferreira & Cunha, 2017), with the 90% consisting of soil previously sieved in ABNT mesh n° 4 (4.76 mm) and depleted, seeking to disaggregate the larger grains to give clay properties to the soil by increasing the content of fines.

The homogenization water originating from drains air conditioning system at IFPB Campus Campina Grande Library, varying between 5 and 10% in total weight of the dry material, defined at the end of the planning to have 2.0 kg. The insertion of the scheelite-tailings was carried out in fractions of 9% (Table 1).

Table 1 – Formulations applied in the development of soil-cement bricks.

Formulations	**Percentages**		
	Cement	***Soil***	***Scheelite-Tailings***
B	10%	90%	0%
B1	10%	81%	9%
B2	10%	72%	18%
B3	10%	63%	27%
B4	10%	54%	36%
B5	10%	45%	45%

Source: Authors.

The scheelite-tailings come from the Brejuí Mine, located in the municipality of Currais Novos-RN. The soil comes

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from a cut-out cut, that is, land for disposal, from a closed condominium located on the banks of the BR-104 in the city of Campina Grande-PB, and the cement was purchased in local stores and comes from the manufacturer Elizabeth Cimentos, class CP II Z-32 (Portland Cement Composed with Addition of Pozzolana and Resistance to 28 days of 32 MPa).

The reference formulation, after planning, resulted in 1:9:1 (cement, soil and water) for the manufacture of the reference trace and the others with the addition of tailings. The procedure adopted began with mixing the materials dry with the aid of plastic bags, and then homogenizing the mixing water, manually, with a step of 1 brick at a time in a hydraulic press (Figure 1).

Figure 1 – Dry, wet homogenization and hydraulic press making, respectively.

Source: Authors.

After the conformation stage, the bricks remained at room temperature until they reached the ages foreseen for the tests. During the first 7 days of air curing, periodic moistening was carried out twice a day to ensure the perfect production of the hydrated phases of Portland cement, taking into account the loss of moisture from the material to the environment associated with heat. hydration of the binder, which occurs through an exothermic process (Figure 2).

Figure 2 – Visual presentation after pressing, and bench setting during curing.

Source: Authors.

2.2 Evaluation of the Properties of Soil-Cement Bricks

To perform the direct flexural strength test, an age of 180 days was adopted for breaking the bricks, justifying the waiting period due to the low presence of cement in the mixture, which has lower strengths when compared to strokes with greater percentage of the binder. In addition, flexural test results correspond to up to 5% of the value obtained in the compressive strength test for conventional Portland cement-based materials.

ABNT NBR 13279:2005 was adapted to perform the test, and it determines that the surfaces of the prototypes are flat and parallel, and that the speed of the breaking load is at the rate of 50 N/s. The EMIC Line DL hydraulic press with a 100 kN load cell was used, equipment belonging to the Materials Characterization Laboratory (LCM/UAEMa/CCT) of UFCG - Campus Campina Grande (Figure 3), for bricks to break.

To perform the compressive strength test at 28 days, a SHIMADZU Model ServoPulser hydraulic press with a capacity of 10 Tons was used, equipment belonging to the Pavement Engineering Laboratory (LEP/DEC/CTRN) of UFCG - Campus Campina Grande (Figure 3). As recommended by ABNT NBR 10836:2013, to perform the test, the surfaces of the specimen must be flat and parallel, and the speed of the rupture load must be uniform at a rate of 500 N/s, or 50 Kgf/s.

Figure 3 – Conducting tests of compressive strength (left), and flexion (right).

Source: Authors.

2.3 Physico-Chemical Evaluation of Water

The kneading water was collected from the air conditioning drains of the IFPB - Campus Campina Grande Library, which destines the water produced by the climatic conditioners to a semi-earthed reservoir made of polyethylene (Figure 4). After collecting the sample, the water was destined to perform the tests of: pH, Temperature (°C), Electric Conductivity (μS/cm), Total Dissolved Solids (TDS) (ppm at 25°C), Ashes (% at 20°C), Alkalinity (mg/L), Chlorides (mg/L), Color (uH), Carbonic Acidity (mg/L $CaCO_3$) and Hardnesses of Calcium (mg/L), Magnesium (mg/L) and Total (mg/L $CaCO_3$), covering titrometry and direct immersion as techniques for this study, comparing the results obtained with ABNT NBR 15900-1:2009.

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Figure 4 – Drainage scheme for the air conditioners of the IFPB Campus Campina Grande Library.

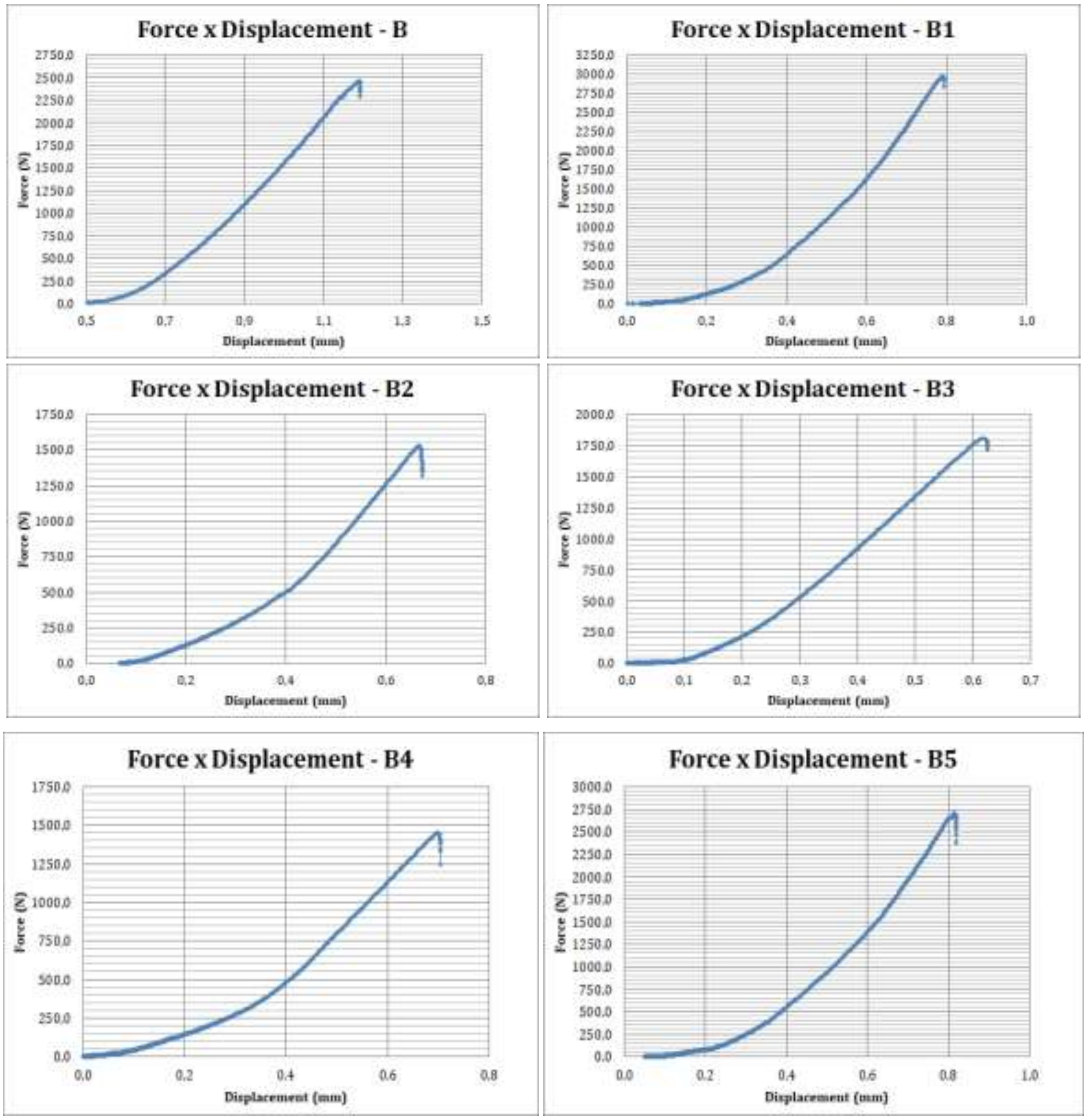
Source: Authors.

3. Results and Discussion

3.1 Flexural Strength

Through the evaluation of the flexural strength in 3 points of the soil-cement bricks, Figure 5 below shows the force x displacement curves of each studied soil-cement composition. It could be understood that the soil-cement brick is characterized as a fragile material, as it does not advance to the elastic zone and stabilizes its rupture at the limit of proportionality and close to the flow limit. Table 2 shows the results corresponding to each composition, obtained through the TESC operating software from EMIC, according to the instrumentation used and the spacing of 140 mm between the lower supports of the tested specimens.

Figure 5 – Force x displacement curves obtained in the direct flexion test at 180 days.



Source: Authors.

Table 2 – Flexural strength values of the tested compositions.

Formulations	**B**	**B1**	**B2**	**B3**	**B4**	**B5**
Strength	0.18 MPa	0.21 MPa	0.11 MPa	0.13 MPa	0.10 MPa	0.19 MPa

Source: Authors.

It was observed that the B1 trait with 9% scheelite tailing positively outperformed the control trait (B), as well as the B5 trait, which incorporates half the amount of natural aggregate as recycled aggregate. The maximum displacements of each tested formulations were also measured (Table 3), in the same way that the curves already shown in Figure 4 show a little sinuous behavior and absent slower deformations, with abrupt breaks at the end of each peak.

Table 3 – Approximate maximum displacements of the tested compositions.

Formulations	B	B1	B2	B3	B4	B5
Displacement	±1.20 mm	±0.80 mm	±0.67 mm	±0.62 mm	±0.70 mm	±0.81 mm

Source: Authors.

The composition that had the least displacement was mix B3, with 27% of incorporated tailings, 0.62 mm, clearly exceeding the control mix B, which reached 1.20 mm. It is also noted that, in addition to the B3 mix with the lowest recorded value, all the others had displacements below the reference mix, with a value closer to 0.81 mm for B5 compared to B.

3.2 Compressive Strength

For the compressive strength test, performed at 28 days of age, ABNT NBR 10834:2013 emphasizes that the rupture load speed is in the order of 500 N/s, as well as that, for the tested samples, an average is presented of mechanical resistivity values equal to or greater than 2.0 MPa, and none of the individual values must be less than 1.7 MPa, with a minimum age of 7 days. Table 4 below shows the average of the values measured in the laboratory.

Table 4 – Compressive strength values of the tested compositions.

Formulations	B	B1	B2	B3	B4	B5
Strength	6.86 MPa	6.63 MPa	6.65 MPa	5.88 MPa	6.33 MPa	5.55 MPa

Source: Authors.

It was observed that all values obtained, in arithmetic mean, exceed the minimum of 2.0 MPa established by ABNT NBR 10834:2013, with all compositions exceeding the value 3 to 4 times. Formulation B remained the most resistant, followed by formulation B2 with 18% tailings in its composition, which positively exceeds the norm almost 4 times with 6.65 MPa. The formulation that showed the lowest value was B5, with a resistance of 5.55 MPa with 45% of tailings in its composition. The difference between the best formulation with tailings and the reference one is only 0.21 MPa, or 3.06%, and it can be said that the use of scheelite-tailings is possible. Through the ruptures, it was possible to produce the stress x deformation curve, making it possible to identify that the material, facing this parameter, behaved like ductile, absorbing in a balanced way the stresses received during the test (Figure 6).

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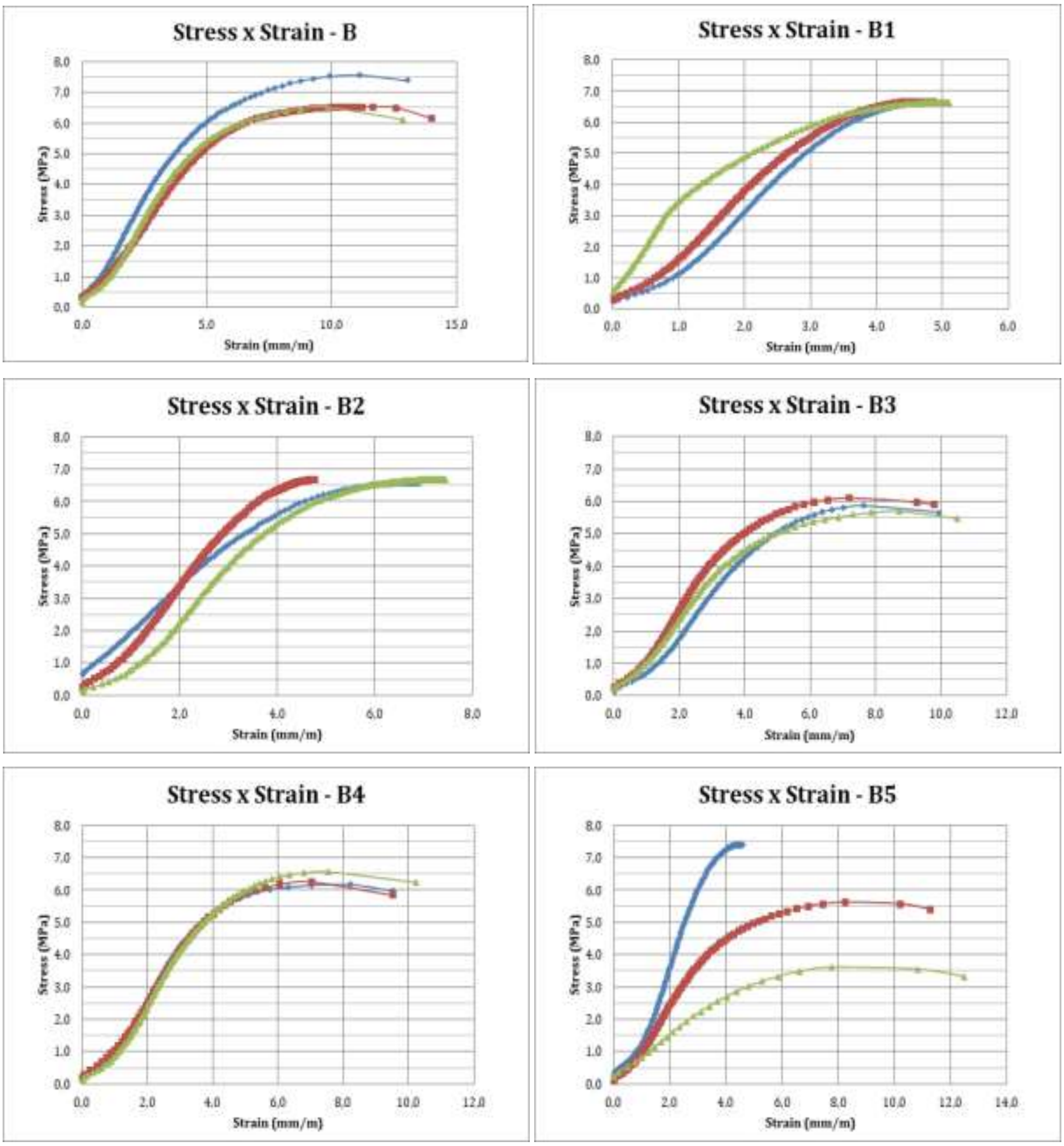
Figure 6 – Stress x strain curves obtained in the compression test at 28 days.



Source: Authors.

3.3 Physico-Chemical Evaluation of Water

Supported by ABNT NBR 15900-1:2009, which determines the quality of the mixing water for concrete and mortar (materials that contain cement in its composition), it can be observed that the values obtained for the physical-chemical tests with the water used in the manufacture of soil-cement bricks did not exceed, under any parameter, the Maximum Allowable Values (MAV) (Table 5).

It also emphasizes that the pH, the contents of alkalinity and chlorides are the most important for an evaluation of the behavior of the material during and after the mixing and shaping process, where they can give the composite changes in porosity, resistance to compression and water absorption, favoring the appearance of pathologies, such as efflorescence.

Table 5 – Physico-chemical determinations of water in the air conditioners of the IFPB Campus Campina Grande Library.

Analyzed Parameters	Air Conditioning Water	MAV
Hydrogen Potential	6.33	≥ 5
Temperature (°C)	25.46	
Electric Conductivity (μS/cm)	27.16	
TDS (ppm at 25°C)	12.77	
Ashes (% at 20°C)	0.0132	
Alkalinity (mg/L)	2.83	1,500
Chlorides (mg/L)	4.444	4,500
Color (uH)	11.66	
Carbonic Acidity (mg/L $CaCO_3$)	0.3	
Total Hardness (mg/L $CaCO_3$)	Absent	
Calcium Hardness (mg/L)	Absent	
Magnesium Hardness (mg/L)	Absent	

Source: Authors.

The hydrogen potential was within the minimum limit allowed by the standard, with a value higher than 26.6%. Alkalinity exposed an excessively low value in relation to ABNT NBR 15900-1:2009, being able to characterize this water as pure, due to the little existence of substances that neutralize acidic agents. The chloride content also showed a value much lower than the maximum allowed by the standard, and the limit of 4500 mg/L is for simple concrete (without reinforcement), with two other limits: for reinforced concrete (1000 mg/L), and for prestressed or grouted concrete (500 mg/L), being usable for all cases, in addition to the soil-cement brick (cementitious matrix material), the water originating from drains air conditioning system at IFPB Campus Campina Grande library. The total hardness was shown to be absent, and as a consequence, the magnesium and calcium contents were also absent.

4. Conclusion

The results of the bending test showed that the mechanical strength of the bricks is superior when mineral tailings are incorporated, since, while formulation B of control registered 0.18 MPa, B1 with 9% of tailings exposed 0.21 MPa, and the B5 with 45% tailings surpassed with 0.19 MPa, confirming that for this parameter, the recycled aggregate improves the mechanical behavior.

Through the compressive strength test, it was observed that all formulations manufactured exceed the minimum established by the norm of 2.0 MPa, however, none of the formulations with tailings exceeded the mark measured with formulation B with 6.86 MPa , but exposed similar values, such as composition B2 with 18% tailings with 6.65 MPa, followed by formulation B1 with 9% tailings with 6.63 MPa, very small values when analyzed globally, ratifying the potential of tailings as recycled aggregate in soil-cement bricks. The lowest value obtained was 5.55 MPa for formulation B5, differing from the reference formulation by 1.31 MPa, lower by 19%.

Correlating the two parameters evaluated, in the bias of application of the technology in interlocking pavements, formulation B5, with 45% of incorporated tailings, manages to adapt the variables studied in both tests. Despite the reduced value in its mechanical resistivity when compared to the control formulation, the compliance with the concept of sustainable development is strongly ratified by using the recycled aggregate in half of its soil content, that is, 45%.

The mixing water used in the study confirms, through physical-chemical evaluation, its full application in the development of this unconventional technology, as well as attesting the possible use in other cement matrix composites for being in compliance with the regulations.

Acknowledgments

To CNPq for granting the scholarship, in PIBITI modality, to the first author. To IFPB - Campus Campina Grande for the laboratory structure. To the Pavement Engineering Laboratory (LEP/DEC/CTRN) at UFCG - Campus Campina Grande, in particular to Professor Lêda C. de F. L. Lucena, for assisting in the performance of the compressive strength tests. To the Materials Characterization Laboratory (LCM/UAEMa/CCT) at UFCG - Campus Campina Grande, in particular to Renato Correia dos Santos for his support in carrying out the flexion test. The authors also thank Yokiny Chanti Cordeiro Pessoa for providing the hydraulic press used in making the bricks.

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