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Sustainable Alternative for the Production of Soil Cement Bricks

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Abstract

The construction industry plays a fundamental role in the economy of a developing country, representing, in most of them, approximately 3.7% to 10.5% of its Gross Domestic Product. However, it is extremely important to search for sustainable alternatives in this sector, aiming to reduce the environmental impacts generated by the production of inputs, waste generation, in addition to the inappropriate disposal of this activity in the environment. Therefore, the work aimed to evaluate the technical and economic feasibility of the incorporation of residues (Marble and Granite Cutting Waste—MW and Construction and Demolition Waste—CDW) in the production of soil cement bricks (SCB). For the development of the present work, physical and mechanical characterization of the soil, residues (CDW and MW), composites (Control, MW15%, MW25%, MW50%, MW100%, MW30%CDW70%) were performed. After manufacturing the bricks, the characterizations mentioned were carried out at 7, 28 and 60 days, in addition to the evaluation of the geometric characteristics, water absorption and strength of the bricks and microscopic analysis of the post-rupture fragments. Additionally, a cost analysis of the use of SCB was performed compared to two different construction systems (ceramic brick and concrete block). From the results of physical characterization, soil was classified as clayey-silty sand (SC-SM), while the CDW was well-graded sand and MW as sandy clay. Soil and composite plasticity characteristics ranged from weakly plastic (MW15% and MW30%CDW70%) to highly plastic (MW100%). In the compaction tests, composites with the addition of MW presented increasing values in terms of optimal moisture. The compressive strength test performed showed satisfactory results for all composites, especially for MW25%, which obtained the most significant result with 13.777 kPa at 28 days. Thus, it is concluded that the incorporation of CDW and MW for the production of SCB represents a sustainable application for civil construction.

Keywords: ecological brick, waste, sustainability, cement soil

1. Introduction

Civil construction plays a fundamental role in the economy of a developing country, and the economic impacts resulting from these activities are also of great importance, as they can represent approximately 3.7% to 10.53% of GDP (Gross Domestic Product) from most countries (Musarat, Salah, & Liew, 2021).

The pressure for the growth of this sector is constant, since engineering and construction services play an important role in the world's growing economy, generating employment opportunities for millions of workers and significantly impacting the country's GDP. However, due to the COVID-19 (SARS-CoV-2) pandemic, significant changes occurred, resulting in the need for improvements in the production systems (Rocha & Escobar, 2021).

According to Gupta, Vedika et al. (2022), the civil construction sector was directly affected by the pandemic, with services paralyzed and lack of supplies for service, activities were harmed and workers who usually receive per day had a reduction in wages, in addition to workers, companies and startups. Small businesses are also at risk of shutdown as financial capital has been impacted.

In Brazil, this sector is resuming its activities slowly, but with great significance given the global economic recession. In the first quarter of 2020, construction GDP fell by 2.4% compared to the last quarter of 2019. Results improved in the first quarter of 2021, representing a growth of 2.1% compared to the last quarter of 2020. Despite the optimistic result, the country is still recovering from the economic crisis that started in 2014 and worsened in 2019 by the COVID-19 pandemic (IBGE, 2019).

With the prospect of growth in civil construction, it is estimated that the consumption of materials will increase, with a direct impact on the need for inputs to meet such demand. The National Construction Cost Index – M (INCC-M) changed 1.24% in July 2021, accumulating a variation in the last 12 months of 29.03%. Among these, masonry stands out, which represents a significant percentage in constructions (approximately 4% to 12%) total budget (Mattos, 2019).

Most masonry constructions are made with conventional ceramic bricks, which, despite their low cost, require large amounts of mortar for laying, roughening, and plaster, thus increasing the cost per square meter (Mattos, 2019).

Since the beginning of the Industrial Revolution, an increase in the generation of waste from industrial production and consumption of natural resources has been observed. However, only in the last decades has society become aware of the impact caused to the environment by these actions (Marques, Santos, Cruz, & Torres, 2021).

The problem of the generation of Construction and Demolition Waste (CDW) involves its disposal, a process in which irregularities are frequently observed. Unfortunately, as a consequence, negative impacts on urban centers are commonly observed. Paz, Lafayette and Sobral (2020) mapped and evaluated 857 illegal dumping sites in the Metropolitan Region of Recife/Brazil, analyzing 7 municipalities and identifying the types of waste improperly deposited (Paz, Lafayette, &. Sobral, 2020).

Therefore, the present work aimed to evaluate the physical, mechanical and chemical performance of soil-cement composites and residues from marble and civil construction for the production of soil-cement bricks.

The present work had, as general objective, the evaluation of the viability of the incorporation of residue in the production of soil cement bricks, seeking eco-efficient alternatives for the applicability and inclusion of composites from marble and civil construction.

1.1 Solid Waste: Definitions and Legislation

Insufficient management, associated with a set of other factors, becomes one of the most significant problems faced by the environmental sector (Aguiar, Ribeiro, Viana, & Pontes, 2021). Since the lack of control over urban growth has been perceived, discussions and debates related to solid waste management have become increasingly common. This disorderly growth has resulted in actions promoted by governmental and non-governmental entities that aim to reduce problems related to the theme. This, in turn, has been possible through the implementation of norms and legislation that regulate the sector's guidelines (Silva, Santos, & Araújo, 2017).

Resolution No. 307 of the National Environment Council classifies waste into 4 classes (A, B, C and D) constituting the guideline for applying the 3Rs (reduction, reuse and recycling), in addition to describing the attributions and responsibilities on who generates and who is responsible for each waste (MMA, 2002).

A publication of the Global Waste Index discussed the assessment of 38 countries in relation to the generation of waste. Firstly, South Korea stood out, with 400kg of waste generated, 243kg/inhabitant recycled, 88kg/inhabitant incinerated, and 46kg/inhabitant disposed of in landfills. Peru ranked last, with 424 kg/inhab of waste generated, 47 kg/inhab recycled, 0 kg/inhab incinerated, 347 kg/inhab disposed in landfills and 176 kg/inhab dumped openly (TER, 2022).

With practices that divide its municipal waste into landfills, recyclables, composting and incineration, South Korea is known as a zero-waste country, where the disposal of food waste is also charged depending on the weight produced by each municipality, discouraging further waste in the country. By 2022, the South Korean government plans to halve the amount of single-use plastic used in the country and increase recycling by 70% (TER, 2022).

1.2 Marble Waste (MW)

Marbling waste (MW) is also known as ornamental stone cutting waste, which can be classified as to its origin, between natural and artificial, being the processing of marble and granite of natural origin and silestone, marmoglass and others of artificial origin (Figure 1, Santos, 2020).

Figure 1. Granite processing

Manhães and Holanda (2008) classified the residues as “Non-inert - Class II A”, and among the tests used, those of solubilization and diffraction by x-rays stood out, finding components such as Iron and Manganese in high indexes, surpassing the limits presented in the Annex G of NBR - 10004 (ABNT, 2004).

1.3 Construction and Demolition Waste (CDW)

The environmental impacts generated by the civil construction sector are significant when it comes to construction and demolition waste (CDW), so, in view of the importance of the sector when it comes to waste generation, it is necessary to develop studies that enable reuse and/or the recycling of that waste (Figure 2, Assunção, 2019).

Figure 2. Construction and demolition waste located at the Environmental Cycle Company

Services with execution failures are major causes of waste generation, with rework and material accumulation being observed. In many cases, the incompatibility of projects with the characteristics of the place or with the reality of the applicant and the inconsistency in standardized service procedures lead to the inadequate destination of waste at the construction site. In renovation situations, especially without adequate professional monitoring, the lack of knowledge about recycling and reuse, and also about the potential of materials, contributes to the generation of waste.

1.4 Efficiency of Composites in the Preparation of Soil Cement Bricks

To ensure the performance of composites, the materials under study must be known as to their characteristics. The cement dosage directly influences the strength of the soil-cement mixture, making the cement the main cause of the increase in the maximum apparent specific weight of the mixture. Cement acts, basically, as a filler, of considerable fineness, filling the various voids between the soil particles. However, such fill content is limited, and in some cases, the apparent dry weight of the soil becomes susceptible to reduction (Gonçalves, 2021).

Duarte and Souza (2020) substituted soil, cement and slag compounds in percentage proportions for the steel slag at 0%, 15%, 30%, 45% and 60% and Reis (2019) incorporated tailings from quartzite mining. In these situations, the authors obtained satisfactory results.

Barreto (2020) used the additions of CDW and MW in partial replacement of the soil in the traces 1:8, 1:10 and 1:12 with 10% and 20% of mass replacement by MW, evaluating, in addition to the mechanical properties, the acoustic and thermal performance. The author found similarities in acoustic and thermal performance to handcrafted solid earth bricks.

Finally, Silva et al. (2022) states that there are many studies on the feasibility of incorporating different residues or alternative products in cement soil. This incorporation can have a double objective, as an alternative for a more adequate destination and as the possibility of reusing these residues. In his study, this author also found that several authors have partially replaced the soil or the binder, and that in cases of cement replacement in the binder function, there is also a joint benefit in reducing cement consumption and disposing of the residue in a more appropriate way.

2. Method

The typology and details of the research will be described in this chapter. The first stage describes the collection of material, the second deals with the tests of physical and mechanical characterization of soils and residues, in addition to the statistical analysis, and later, a third stage describes the analysis of all the results.

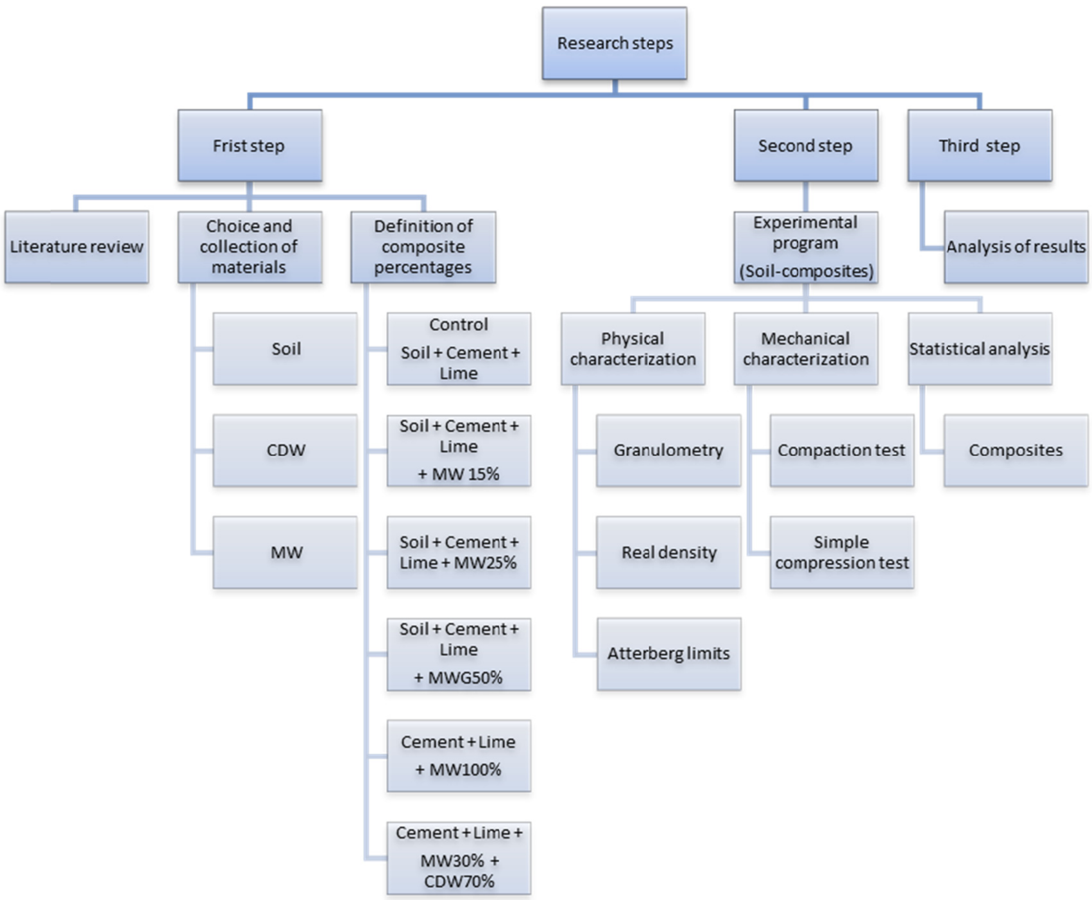

Figure 3. Research steps

2.1 Materials

Soil collection was carried out in the city of Jaboatão dos Guararapes/PE in natural deposits in the region, totaling 3600kg. The marble waste (MW) used was provided by the company Pedra Bonita Mármores e Granitos

Ltda, which is located in the city of Serra Talhada. A total of 600kg of residue were distributed in 50kg bags. The Civil Construction Waste (CDW) was obtained from the company Ciclo Ambiental, located in the city of Camaragibe, Metropolitan Region of Recife, with a total of 350kg of waste collected.

For the development of the research, Portland Cement of High Initial Strength (CP-V - ARI) marketed in 40kg bags (Stabilizer) and Hydrated Lime (CH-I) marketed in 20kg bags were used.

2.2 Experimental Program

1) Physical characterization

Physical characterization was performed following the NBR 7181 (ABNT, 2018), NBR 6459 (ABNT, 2016) and NBR 7180 rules (ABNT, 2016).

2) Mechanical characterization

In the tests, 60 specimens were molded with the reuse of the material and without the addition of binders, and with the addition of binders and without the reuse of materials. The determination of the simple compressive strength was performed according to NBR 12770 (ABNT, 2022), in which three curing ages were defined, 7, 28 and 60 days, and 90 PC's (Portland Cement) were molded.

3. Results and Discussion

3.1 Physical Characterization

Soil, residue (CDW and MT) and composite granulometric analysis tests were carried out, obtaining the granulometric curves, represented in Figures 4 and 5.

Following the Unified Soil Classification System (USCS) [25], the soil was classified as clayey-silty sand (SC-SM), while the CDW was classified as well-graded sand. MW presented sandy clay characteristics, as shown in Figure 4.

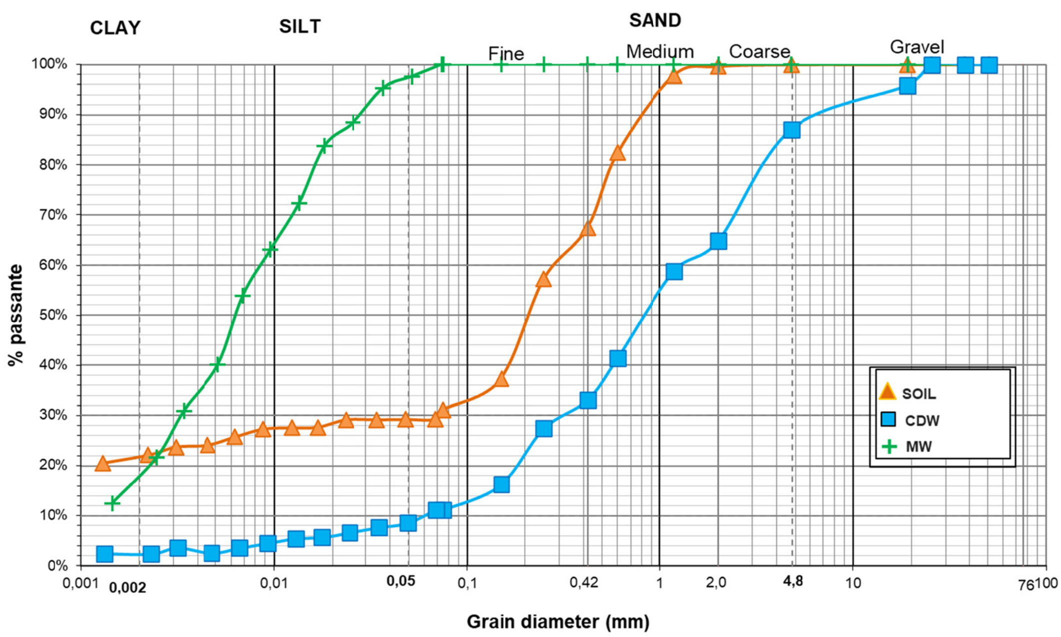

Figure 4. Soil granulometric curve, CDW and MW

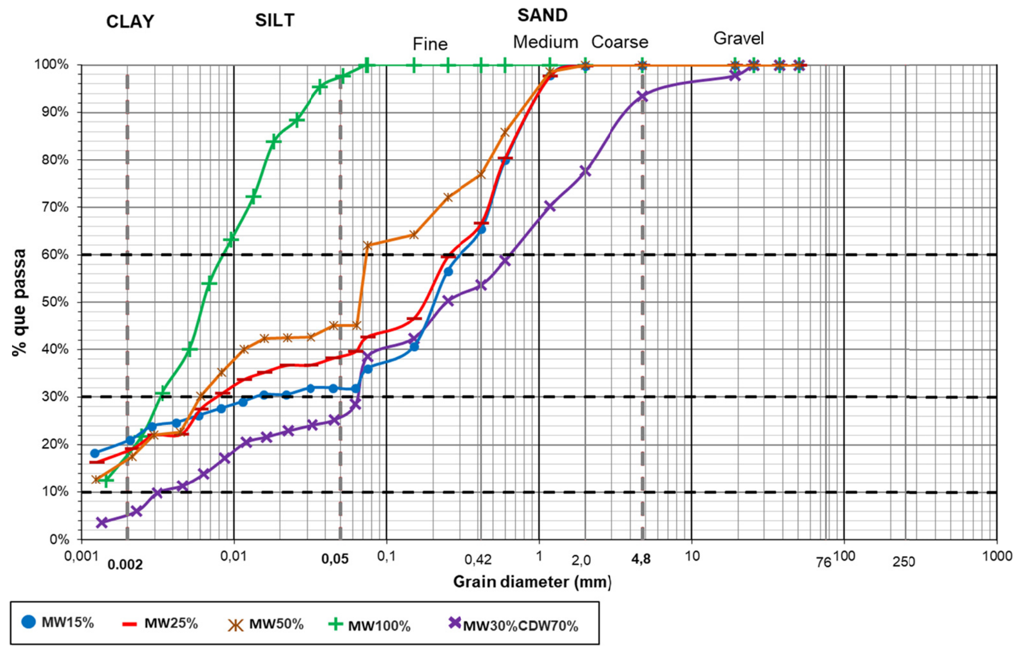

Figure 5. Grain size curve of composites

Only in the CDW and in the composite MW30%CDW70% it was possible to identify the coefficients of curvature (Cc) and uniformity (Cu), which for the CDW was 13.46 and 2.69, respectively, with the values classified as a well-graded soil (Figure 5). The soil and the other composites, as they are thin materials, did not present an effective diameter (d10), and it was not possible to calculate Cu and Cc.

The analysis of the shapes of the curves in Figures 4 and 5 indicate the irregularity or regularity in the texture of these materials, that is, when there is a bad distribution between their granulometric fractions, it is possible to analyze their behavior. In cases of bad graduation and abrupt changes in shape, the formation of voids and consequently the reduction of resistance can be favored.

It was also possible to observe the graduation variation in the behavior of the materials. As the MW residue was incorporated, the percentage of fines in the composites increased.

In addition to the requirements requested in the soil/cement standards, NBR 10833 (ABNT, 2012) was also used, which addresses the requirements for the production of soil cement bricks. Table 1 presents the values of the granulometric fractions referring to the studied samples.

Table 1. Fractions of granulometry

Sample ID	Clay	Silt	Sand			Gravel	Silt/Clay Ratio	NBR 10833:2012 Requirement
			Fine	Medium	Coarse			
Soil	17%	10%	14%	35%	22%	0%	0.60	• 100% passing #4,75 mm
CDW	4%	5%	24%	31%	22%	14%	1.25	
MW15%	26%	8%	30%	35.5%	0.5%	0%	0.31	
MW25%	24%	16%	23.5%	36%	0.5%	0%	0.67	• Passing fraction in #0,075mm de 10% a 50%;
MW50%	24%	20%	32%	23.5%	0.5%	0%	0.83	
MW100%	24%	76%	0%	0%	0%	0%	3.17	
MW30%CDW70%	12%	16%	26%	24%	16%	6%	1.33	

It was verified that the granulometric fractions of the studied soil have 72% of sand, while the CDW contains 66% of sand and 6% is considered gravel, being characterized as sandy soils. Nascimento et al. (2018) evaluated the same CDW of the company Ciclo Ambiental and the characteristics found were 77% of sandy soil.

The evaluation of granulometric fractions allows the analysis of the criteria stipulated by NBR 10833 (ABNT, 2012) which proposes a more sandy soil characterization. Gonçalves (2022) describes that fine soils with clayey characteristics can hinder the process of demolding the brick as soon as it leaves the press, and also emphasizes that high plastic shrinkage can occur during drying. Soil correction was carried out with washed sand with a coarser granulometric portion, approaching its production soil to the requirements of NBR 10833 (ABNT, 2012) in 70% of sandy soil.

Regarding the production of soil cement bricks following the guidelines of NBR 10833 (ABNT, 2012), it is also noteworthy that all composites met the criteria of that standard, and only the CDW residue did not meet the minimum required, which is 10 at 50% passing through the 0.075mm sieve, with a result of 9%. N. Dantas (2020) used the coarse sandy characteristic of CDW to correct the soil with clayey characteristics used in his study. The chosen CDW had 67.83% sand, 11.5% clay and 20.65% silt.

For Barreto (2020), MW should be added in smaller amounts to evaluate the possibility of contribution as a filler, with the objective of filling the voids of the mixture in the cement soil. Besides this, the author also cites the example of the use of filler in Portland Cement composite CP II-F.

The tests to obtain the specific weight of particles related to soil, waste and their mixtures are shown in Table 2.

Of the values obtained, the soil that presented density of 2.64 g/cm³ stands out, representing 3% more than the composite MW30%CDW70%. The MW100% composite had a density of 2.65 g/cm³, while the CDW had 2.66 g/cm³.

Table 2. Real density of soil particles, residues and composites

Sample ID	Real density
SOIL	2.64
CDW	2.66
MW	2.65
MW15%	2.62
MW25%	2.65
MW50%	2.64
MW100%	2.65
MW30%CDW70%	2.55

Barreto (2020) found a value of 2.54 for CDW, while for MW the value was 2.66. This value can be justified according to the minerals present in the material, in which the presence of crystalline phases of Quartz and Calcite was identified. The Atterberg limits indicate samples of weak and medium plasticity, as shown in Table 3.

Table 3. Consistency limits

Sample ID	LL (%)	PL (%)	PI (%)	Classification	NBR 10833 Requirement
SOIL	28	18	10	Moderately plastic	Liquidity limit
CDW	NL	NP	-	Non plastic	≤ 45%;
MW15%	30	23	7	Weakly plastic	
MW25%	32	24	8	Moderately plastic	Plasticity index
MW50%	35	25	10	Moderately plastic	≤ 18%.
MW100%	27	26	1	Weakly plastic	
MW30%CDW70%	24	19	5	Weakly plastic	

Note. *NL – Non-Liquid / NP – Non-Plastic.

It was possible to observe that the MW15%, MW100% and MW30%CDW70% composites were classified as weakly plastic. In the case of MW15%, the value of the Plasticity Index approached the threshold that defines the state as weakly plastic and moderately plastic with a PI of 7, while soil and composites with intermediate additions MW25% and MW50% were classified as moderately plastic.

Only for CDW it was not possible to perform the classification of consistency because it did not present sufficient characteristics to perform the test, being considered as non-plastic and non-liquid. Nascimento (2018) in his study also classified CDW as non-liquid (NL) and non-plastic (NP).

3.2 Mechanical Characterization

The compaction tests performed with information related to the addition of binders and/or without the addition of lime and cement, as well as the results of Maximum apparent specific weight (γmax) and optimal moisture content (h ót.) are presented in Table 4.

Table 4. Maximum apparent specific weight (γmax) and optimal moisture content (h ót.) of composites, soil and residues with and without binders

Sample identification	No binders		With binders	
	γmáx (g/cm³)	Optimal humidity (%)	γmáx (g/cm³)	Optimal humidity (%)
SOIL	1.88	11%	1.953	12%
CDW	1.87	12%	-	-
MW15%	1.96	12%	1.926	12%
MW25%	1.93	13%	1.918	12%
MW50%	2.09	18%	1.8	16%
MW100%	2.33	26%	1.523	21%
MW30%CDW70%	1.81	9%	1.847	12%

The tests with the incorporation of the binders showed a slight reduction both in the specific weight and in the optimal moisture content, except in the test referring to the soil, in which with binder there was an increase of 1.11%.

The compaction curves of all mixtures and components were divided into without binder and with binder. In Figures 6 and 7 it is possible to observe the nonconformity between the composites, highlighting MW100.

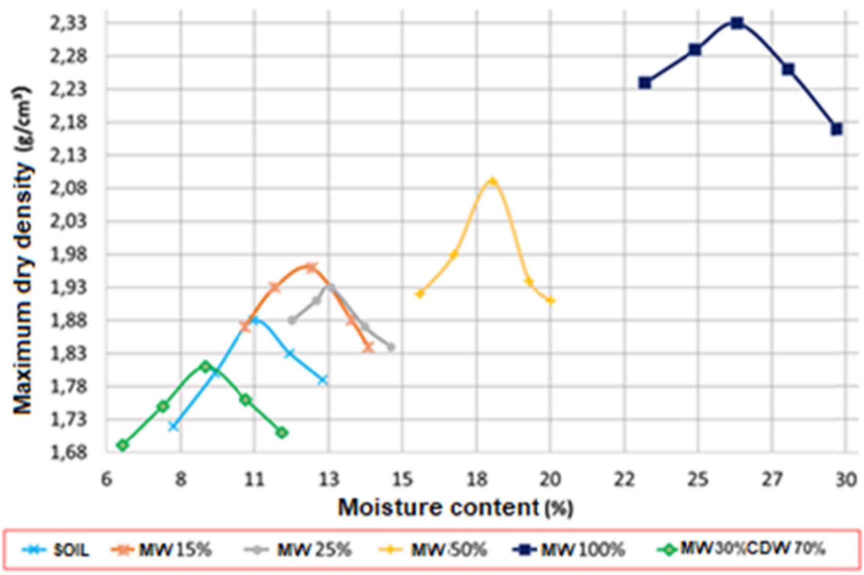

Figure 6. Binder-free compaction curves

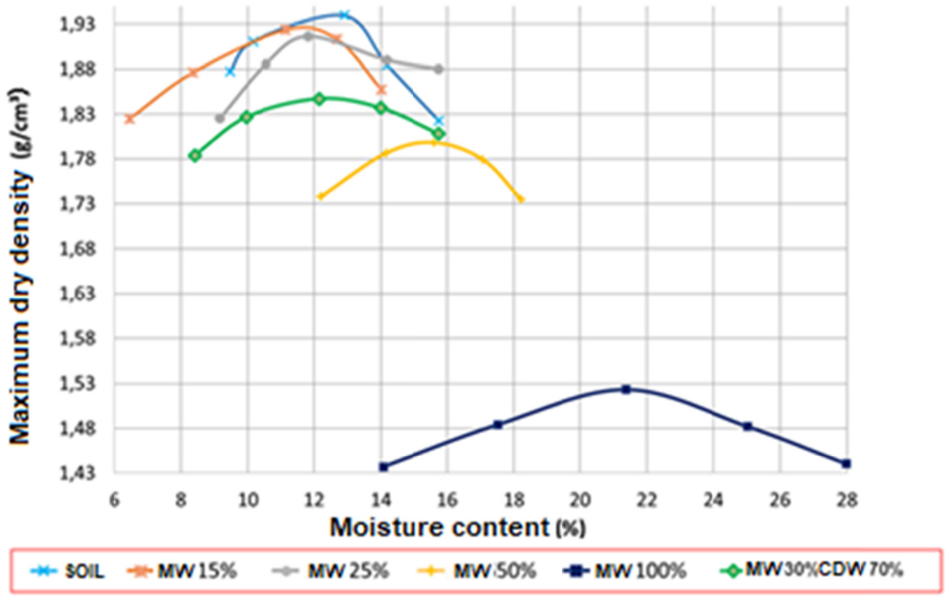

Figure 7. Compaction curves with binder

It is noteworthy that, in both curves presented in Figures 6 and 7, the MW100% composite was more distant from the other curves, while the MW50% composite was associated with them. It is worth mentioning that the materials behave differently mainly due to each specific mass of the soil grains, which presents differences.

According to Nascimento (2018), was CDW was incorporated into the mixtures, the maximum dry density increased, and a reduction in optimal moisture was observed. The author justifies that this result can be explained by the improvement in soil grading.

In relation to simple compression, Figure 8 shows the results of the test of resistance to simple compression of the composites at 7, 28 and 60 days of age, and considering a maximum deformation of 15mm.

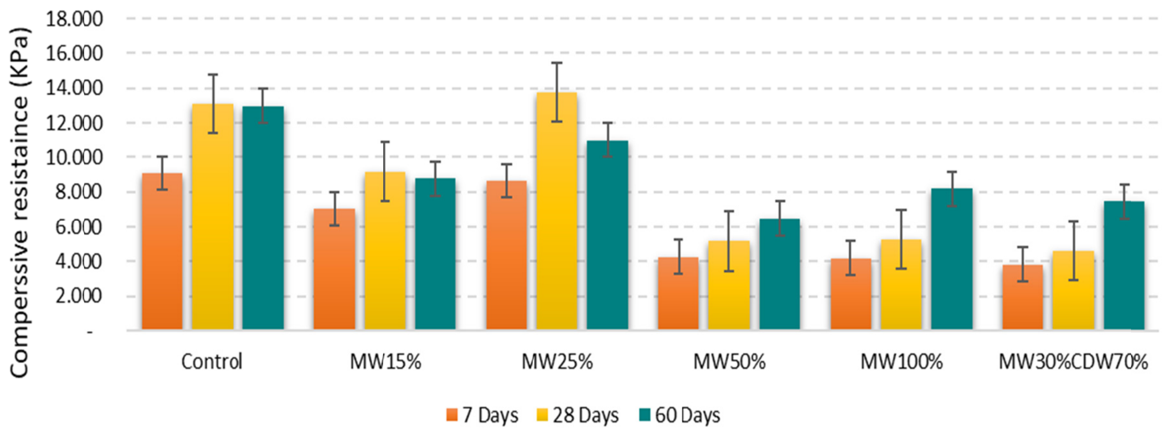

Figure 8. Comparison of compressive strengths of soil and composites

The results of resistance at 28 days in the control mixtures, MW15% and MW25% showed higher values than the results at 60 days of age, 31%, 24% and 37%, respectively. On the other hand, the MW50%, MW100% and MW30%CDW70% composites showed the best performance at 60 days of age (Table 5).

Table 5. Compressive strength of specimens

Sample identification	Average of values		
	7 Days (kPa)	28 Days (kPa)	60 Days (kPa)
Control	9,077	13.117	12,966
MW15%	7,013	9,177	8,750
MW25%	8,630	13,777	11,011
MW50%	4,283	5,177	6,457
MW100%	4,203	5,273	8,195
MW30%CDW70%	3,843	4,627	7,439

At 7 days of age, the control mix obtained the best result with 9,077kPa, while the composite with the lowest performance was MW30%CDW70%, with 3,843 kPa, representing a 42% reduction in its strength. The result with greater expressiveness was at 28 days of the composite MW25% with 13,777 kPa, representing 34% more than the result with less expressiveness at this age, MW30%CDW70%, with 4,627 kPa.

For analysis at 60 days of age, it was possible to observe that the best performance was of the control mix with 12,966 kPa and the composite with the greatest difference was MW50% which obtained 6457 kPa, showing a difference of approximately 50% between them (Figure 9).

Figure 9. Broken specimens

3.3 Statistical Analysis

Regarding the evaluation of the information obtained in the analyzes related to the soil compression test, a significant difference was observed between the simple compressive strength (SCS) and the treatments (ANOVA, df = 5; F = 17.5612; p-value = 2.714 e-10) by curing time (ANOVA, df = 2; F = 10.2452; p-value = 0.000169) alone, but there was no interaction between them. Figure 10 demonstrates the means and standard deviations of SCS between treatments by time of cure and the difference between them.

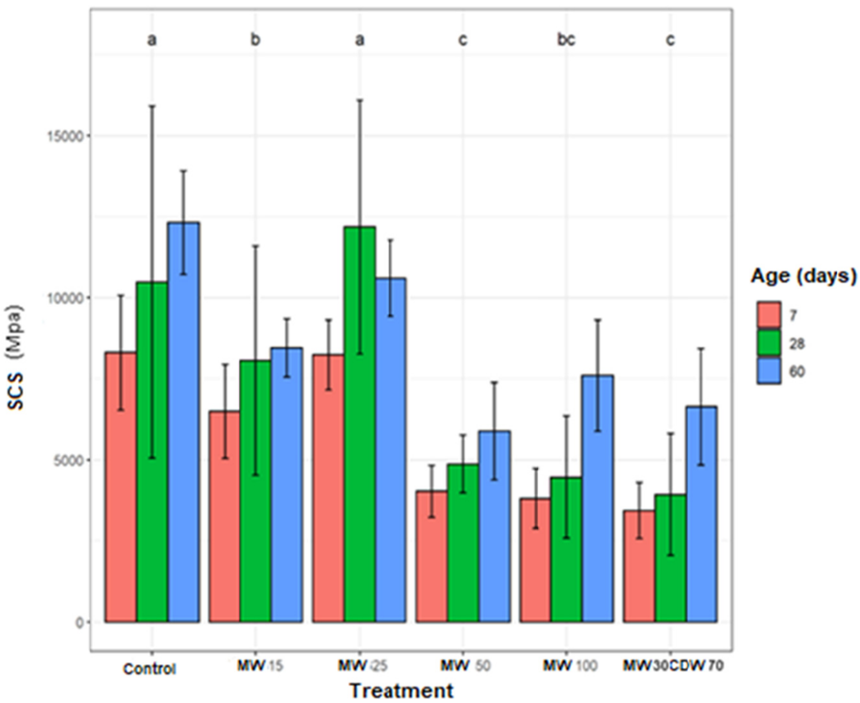

Figure 10. Comparison between SCS by treatment and curing time of PC

Defined by letters the contrasts (a, b and c), it was possible to observe that the significantly different groups, the composite MW25% and the Control obtained the same contrasts "a" representing a statistical similarity, the same happened with the residues MW50% and MW30%CDW70% represented by the contrast "c".

Table 6. Means and standard deviations (sd) between treatments and curing time (CT) of the specimens

Treatment	CT	Mean	Standard deviation
Control	7	8.30	1.77
Control	28	1.04	5.42
Control	60	1.23	1.59
MW15%	7	6.49	1.44
MW15%	28	8.05	3.53
MW15%	60	8.45	8.99
MW25%	7	8.23	1.08
MW25%	28	1.21	3.92
MW25%	60	1.06	1.16
MW50%	7	4.03	7.97
MW50%	28	4.87	8.86
MW50%	60	5.87	1.49
MW100%	7	3.80	9.25
MW100%	28	4.46	1.88
MW100%	60	7.59	1.72
MW30%CDW70%	7	3.43	8.64
MW30%CDW70%	28	3.92	1.87
MW30%CDW70%	60	6.63	1.79

4. Conclusion

After the analysis, it was possible to conclude that the physical characterization of the soil used for the production of soil cement bricks was classified as clayey-silty sand (SC-SM), while the CDW was well-graded sand. MW, on the other hand, presented a sandy clay characteristic. The studied soil had 72% of sand, while the CDW contains 66% of sand and 6% is considered gravel, being characterized as sandy soils, which are within the requirements requested both in the soil/cement standards, and for the production of cement soil brick. The actual density results obtained for the soil, residues and their mixtures were within the normative requirements.

For the plasticity characteristic of soil and composites, they ranged from weakly plastic to moderately plastic, except for the CDW considered non-plastic non-liquid. The composites MW15%, MW100% and MW30%CDW70% were classified as weakly plastic and the others were considered moderately plastic. In addition to the classification by its plasticity, requirements necessary for the production of bricks were also evaluated, with the information of the plasticity index, only the composite RCMG100% did not meet with a percentage of 1% of PI.

The mechanical behavior of the soil and composites was obtained through compaction tests and simple compression of the specimens, and the characteristics obtained in the compaction test highlighted that the composites presented increasing values in terms of optimal moisture as the percentage of fines in the MW were added. In addition, the optimal moisture value using binders with greater relevance was 21.30% for the MW100% composite.

The simple compressive strength performed on the composites showed results that prove the feasibility of incorporating waste, especially the MW25% composite that obtained the most significant result with 13,777 kPa at 28 days of age. Furthermore, all results were considered satisfactory, since the minimum reached at 7 days of age was 3,843 kPa for the composite MW30%CDW70%.

The results obtained in the present work indicate the technical and economic feasibility of using recycled waste from construction and demolition, as well as waste from cuts of marble and granite in the incorporation for the production of ecological bricks, indicating a sustainable alternative for civil construction.

Future studies should be developed in order to improve the percentages of waste addition in the production of ecological bricks, in addition to evaluating possible reductions in environmental impacts in the process produced and in construction.

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