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Production of mixed cement and lime mortars incorporating Beige – Bahia marble waste filler (RMBB) and construction and demolition waste (CDW)

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Abstract: The civil construction sector consumes large volumes of non-renewable raw materials, especially in the production of hydraulic binders such as Portland cement and lime. The cement industry is one of the main contributors to the worsening of the greenhouse effect due to the decarbonation of limestone and the use of fossil fuels, which intensively release CO_2 gas. At the same time, both the extraction and processing of ornamental rocks, as well as the various stages of construction, cause changes in the landscape and generate significant amounts of waste. One alternative to mitigate these impacts is the partial replacement of binders with alternative materials in the formulation of mortars, which are widely used in different phases of construction.This research aimed to evaluate the performance of mixed cement-lime mortars, in which lime was partially replaced by Beige Bahia Marble Waste (RMBB) and Construction and Demolition Waste (CDW) in proportions of 10% and 20%, analyzing the physical and mechanical behavior of the mixtures. First, the materials used (cement, lime, RMBB, and CDW) were characterized. Then, the water/binder ratio for the mixed formulations (1.00:0.5:6.90 — cement:lime:sand) was defined, using air-entraining and water-retaining additives, based on a flow spread of 260±5 mm. The results obtained were compared to the reference mortar (without RMBB and CDW), showing a reduction in the water/binder ratio with the increase in waste content, as well as greater cohesion of the mixtures.In the fresh state, the mortars showed a reduction in bulk density, a decrease in water retention (for the mortar with RMBB), and an increase in the same property (for the mortar with CDW) when compared to the reference mortar. It is expected that, in the hardened state, mortars with different percentages of waste filler will promote nucleation, improving the physical and mechanical properties.
Keywords: Binders. Mortar. Filler. Waste
Abbreviations: RMBB, Beige Bahia Marble Waste– Bahia. CDW, onstruction and Demolition Waste.

INTRODUCTION

Civil construction is responsible for the intensive use of raw materials from non-renewable sources and for the generation of waste, contributing significantly to environmental impacts. The production of hydraulic binders, such as Portland cement and lime, plays a prominent role in CO_2 emissions and the worsening of the greenhouse effect (Freitas, 2014 [1]). As a result, the partial replacement of hydraulic binders with industrial waste has become an increasingly common and promising strategy to make the construction sector more sustainable. Materials such as ornamental stone industry waste and construction and demolition waste have been studied due to their beneficial properties for cementitious matrices. Brazil holds a prominent position in the ornamental stone export sector. According to the Brazilian Center for Ornamental Stone Exporters (2024) [2], the state of Bahia ranks 4th in the national export ranking. The Beige Bahia marble, produced in the region of Ourolândia (BA), stands out for its beige coloration, fine grain, brecciated appearance, and the presence of small quartz veins and grains (Magalhães, 2007 [3]). All stages of the production of Beige Bahia marble pieces generate waste, from block extraction to slab processing (Mariani & Batalha, 2019) [4].

Another residue with significant environmental impact is construction and demolition waste (CDW), commonly known as rubble or debris. It results from activities such as construction, demolition, deconstruction, renovation, repair, paving, and correction works (ABRECON) [5]. The typical composition of CDW includes concrete, bricks, gypsum, wood, glass, metals, plastic, and excavated soil, allowing its reuse in various applications within the construction industry itself (Tinoco et al., 2024 [6]). According to ABREMA [7], Brazil produced around 45 thousand tons of CDW in 2022. Leite (2001) [8] highlights that challenges in waste management, scarcity of disposal areas, and urban cleanliness are factors that must be considered regarding the environmental impact.

Both RMBB and CDW have potential for use as fillers in cementitious mixtures. According to Neville (2016) [9], a filler is defined as a finely ground, chemically inert material that, through its physical effects, enhances the properties of cementitious mixtures. Hydrated lime, commonly used in mixed mortars, contributes properties such as plasticity, water retention, and durability (Guimarães et al., 2004) [11].

Therefore, in addition to reducing the demand for non-renewable raw materials, this practice promotes the reuse of waste in cementitious matrices and contributes to the mitigation of environmental impacts. In this context, this study aims to evaluate the production of mixed cement-lime mortars, with partial replacement of lime by RMBB and CDW.

EXPERIMENTAL PROCEDURE

The experimental program consisted of producing five formulations of mixed cement-lime mortars with partial replacement of lime by Beige Bahia Marble Waste (RMBB) and Construction and Demolition Waste (CDW) at replacement levels of 10% and 20%. The objective was to evaluate the physical behavior of the mixtures. The research was divided into three main stages: 1)Characterization of the materials used; 2)Production of the mortars; 3)Characterization of the mortars in the fresh state. Additionally, the characterization of the mortars in the hardened state will be carried out, focusing on tensile and compressive strength.

MATERIALS CHARACTERIZATION

The characterization of the materials used — CP II-F 32 cement, CH-I lime, RMBB, and CDW — was performed by determining the specific gravity, which were 2.98 g/cm³, 2.27 g/cm³, 2.68 g/cm³, and 2.60 g/cm³, respectively. Additionally, compacity was evaluated according to the method proposed by Larrard (1999a); the results are presented in Tables 1 and 2.

MORTAR PRODUCTION

In the mortar production stage, hydrated lime, RMBB, CDW, fine sand, an air-entraining admixture, and a water-retaining agent were used alongside cement. The proportions of the mixed formulations (cement:lime:sand — 1.00:0.50:6.90 by mass) were determined based on a flow spread of 260 ± 5 mm, according to ABNT NBR 13276:2005, and compacity, as presented in Tables 1 and 2.

Table 1. Mix proportions with RMBB by mass, and the results of compacity and consistency of the mortars

	C	Lime	RMBB	FS	w/b
REF	1,00	0,50	-	6,90	1,08
T10 RMBB	1,00	0,45	0,05	6,90	1,10
T20 RMBB	1,00	0,40	0,10	6,90	1,04
Nota:	C – cement; RMBB – Beige Bahia marble waste; FS – fine sand; w/b: water/binder ratio;				

	AEA	WRA	C compactness	Consistency ± Sd (mm)
REF	0,30	0,08	0,557	258±1,70
T10 RMBB	0,30	0,08	0,553	264±1,25
T20 RMBB	0,30	0,08	0,507	262±1,25
Note:	AEA: air-entraining agent; WRA: water-retaining agent; SD: standard deviation.			

Table 2. Mix proportions with CDW by mass, and the results of compacity and consistency of the mortars

	C	Lime	CDW	FS	w/b
REF	1,00	0,50	-	6,90	1,08
T10 CDW	1,00	0,45	0,05	6,90	1,11
T20 CDW	1,00	0,40	0,10	6,90	1,06
Note:	C – cement; CDW – construction and demolition waste; FS – fine sand; w/b – water/binder ratio;				

	AEA	WRA	Compactness	Consistency ± Sd (mm)
REF	0,30	0,08	0,557	258±1,70
T10 CDW	0,30	0,08	0,563	263±1,15
T20 CDW	0,30	0,08	0,560	265±0,58
Note:	AEA: air-entraining agent; WRA: water-retaining agent; SD: standard deviation.			

<u>MORTAR CHARACTERIZATION</u>

The mixed cement-lime mortars with partial replacement of lime by RMBB and CDW were characterized in the fresh state through tests of bulk density, air content, and water retention. The results are presented in Figures 2 and 4.

RESULTS AND DISCUSSIONS

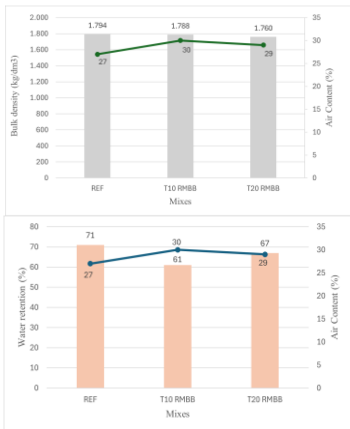
Figure 1: Flow spread of the mortars. a) REF; b) T10 RMBB; c) T20 RMBB

Regarding the qualitative evaluation of the mixed mortars with partial replacement of lime by RMBB, when comparing the REF, T10 RMBB, and T20 RMBB mixes, it was observed that the T10 RMBB mix exhibited higher fluidity. This behavior is attributed to the filling of intergranular voids previously occupied by water (SEQUEIRA and GHISLENI, 2020 [12]), resulting in good plasticity, although with increased bleeding due to the higher water-to-binder ratio, as indicated in Table 1. On the other hand, the T20 RMBB mix was less fluid, showing reduced plasticity. Nevertheless, all mixes presented good cohesion, a matte appearance, and satisfactory workability.

Figure 2: Results of fresh-state properties. a) Variation of bulk density and air content; b) Variation of water retention and air content.

a)

b)



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As observed in Figure 2.a, there was a slight reduction in bulk density with the increase in RMBB replacement content. According to Ruhnke (2024) [10], this phenomenon may be related to the saturation points in particle packing, where the filler begins to act as an internal lubricant, or to greater water retention — as also shown in Figure 2.b. Regarding the increase in entrained air content, the author associates this behavior with the same saturation effect, since the accumulation of particles can form agglomerates capable of trapping air bubbles.

Also, according to Figure 2.b, a decrease in water retention is observed in the mixes with partial lime replacement by RMBB compared to the REF mix. This is due to the fact that lime has a finer particle size than RMBB, resulting in a higher specific surface area, which favors water retention through adsorption on the particle surfaces.

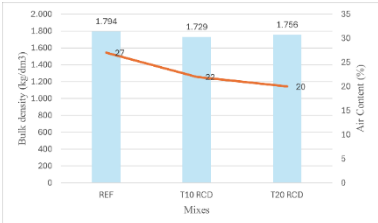
Figure 3: Flow spread of the mortars. a) REF; b) T10 CDW; c) T20 CDW

a) b) c)

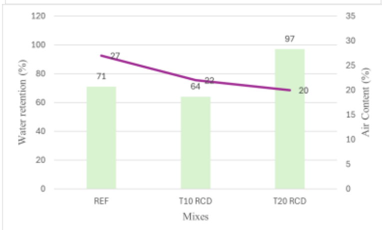
Regarding the mixed mortars with partial replacement of lime by CDW, qualitative analyses show that the mixtures behave similarly to the T10 RMBB and T20 RMBB mixes. When comparing the REF, T10 CDW, and T20 CDW mixes, it is also possible to notice greater fluidity in the T10 CDW mix, a behavior common to the T10 RMBB mix, which is explained by the filling of intergranular voids, resulting in higher workability; however, the increased water-to-binder ratio leads to greater bleeding. The T20 CDW mix was less fluid, similar to the T20 RMBB mix. According to Fortunato (2019) [13], this occurs because the particle shape of the waste is less rounded compared to the binder. Finally, both mixes containing CDW exhibited consistent workability, cohesion, and a matte appearance.

Figure 4: Results of fresh-state properties. a) Variation of bulk density and air content; b) Variation of water retention and air content.

a)



b)



As observed in Figure 4.a, there was a reduction in bulk density in the T10 CDW and T20 CDW mixes compared to the REF mix. This behavior is explained by the fact that the specific gravity of the waste is higher than that of lime; therefore, less material is needed to occupy the same volume previously filled by lime. The packing density of the mixtures also increased with the higher replacement levels of lime by the waste (10% and 20%), which justifies the reduction in air content in the T10 CDW and T20 CDW mixes, evidencing the packing effect in the cementitious matrix, reducing voids and air bubbles.

When comparing the T10 CDW mix to the REF mix, a decrease in water retention is observed due to lime having a larger specific surface area, thus retaining more water than CDW. Ferreira (2017) [14] incorporated fine CDW particles (<0.15 mm) in mortars and found high water absorption due to the material's porosity and very fine particles — overcoming the surface area effect — which increases the mortar's water retention capacity, an effect observed in the T20 CDW mix.

CONCLUSION

The study evaluated mixed cement-lime mortars with partial replacement of lime by RMBB and CDW, aiming at sustainable alternatives in civil construction and waste management. Based on the presented results, the T20 RMBB and T20 CDW mixes showed a lower water-to-binder ratio — a factor that, according to the literature, increases strength — while maintaining workability. Furthermore, although the T20 RMBB mix exhibited a reduction in bulk density, the air content also decreased compared to T10 RMBB, indicating better particle packing. Regarding the replacement with CDW, the improved compaction of the mixture and reduction of entrained air in the T20 CDW mix demonstrate a more effective filler effect of the material.

Therefore, the partial replacement of lime by RMBB and CDW in rendering mortars is feasible, provided that a prior analysis of the materials is conducted to ensure physical-mechanical performance. Thus, incorporating waste into construction contributes to sustainability by offering an alternative for proper waste disposal.

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LIST OF TABLES AND FIGURES

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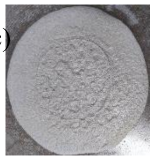
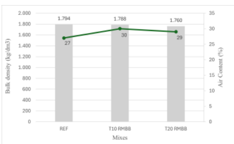
a)  b)  c) 

a)  b)