

Production of Mixed Cement–Lime Mortars Incorporating Beige Bahia Marble Waste (BBMW) Filler and Construction and Demolition Waste (CDW)

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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 contributors to the worsening of the greenhouse effect due to the decarbonation of limestone and the use of fossil fuels, releasing large amounts of CO₂ into the atmosphere. At the same time, other stages of construction also cause changes in the landscape and generate significant amounts of waste in several segments, such as the extraction and processing of ornamental stones, which produce considerable waste ranging from block remnants to fine particulate material known as slurry. An 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 construction stages. Thus, this research aimed to evaluate the performance of mixed cement–lime mortars in which lime was partially replaced with Bahia Beige Marble Waste (BBMW) and Construction and Demolition Waste (CDW) at proportions of 10% and 20%, analyzing the physical–mechanical behavior of the mixtures. The materials used (cement, lime, BBMW, CDW, and sand) were characterized, and the water/binder ratio (w/b) was defined for the reference mixed mortar (1.00:0.5:6.90 — cement:lime:sand), using air-entraining and water-retaining additives, based on a flow of 260±5 mm. Subsequently, the w/b ratios were determined for each of the mixtures with lime replaced by 10% and 20% of BBMW or CDW. The results were compared with the reference mortar and showed a reduction in the water/binder ratio with the increase of waste content, in addition to greater cohesion of the mixtures. In the fresh state, mortars presented a reduction in bulk density with the use of both wastes. For water retention, there was a decrease with BBMW and an increase in this property in mixtures with CDW compared to the reference mortar. In the hardened state, the mortars showed improved flexural tensile strength and axial compressive strength. Therefore, based on the physical–mechanical results, both wastes, BBMW and CDW, demonstrated a predominantly physical effect of pore filling, favoring nucleation and improving physical–mechanical properties.

Keywords: Binders. Mortar. Filler. Waste.

Abbreviations: BBMW, Bahia Beige marble waste. RCD, construction and demolition waste.

The construction sector is responsible for the intensive use of raw materials from non-renewable sources and is a major generator of waste, contributing to significant environmental impacts. The production of hydraulic binders, such as Portland cement and lime, stands out in terms of CO₂ emissions and contribution to the worsening of the greenhouse effect, since the production process involves the decarbonation of limestone and the consumption of non-renewable energy [1].

In this context, the partial replacement of hydraulic binders with industrial wastes has become increasingly frequent and promising in order to make the construction sector more sustainable. Materials such as ornamental stone industry waste and construction and demolition waste (CDW) have been investigated for their beneficial properties to the cementitious matrix. Brazil holds a prominent position in the ornamental stone export sector.

According to the Brazilian Center of Ornamental Stone Exporters (2024) [2], the state of Bahia ranks fourth in exports. Bahia Beige Marble, whose main production is concentrated in the Ouro-lândia region (BA), is characterized by its beige coloration, fine grain, brecciated appearance, with small quartz veins and particles.

Its mineralogical composition consists of approximately 98% carbonate and only 2%

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quartz [3]. All production stages of Bahia Beige Marble pieces generate waste. The extraction of blocks for slab production results in a significant amount of coarse waste, originating from the breakage of pieces during cutting [4].

Another residue with significant environmental impact is Construction and Demolition Waste (CDW), popularly known as rubble. CDW is generated from construction, renovations, repairs, and demolitions in civil works [5]. Its composition generally includes concrete, bricks, gypsum, wood, glass, metals, plastics, and excavated soil, allowing for reuse within the construction industry itself [6]. According to the Brazilian Association of Waste and Environment (ABREMA) [7], the country generated around 45 thousand tons of CDW in 2022. As noted by Leite (2001) [8], issues related to waste management, the shortage of disposal areas, and urban cleaning are factors that must be considered when analyzing the environmental impact of CDW. Both BMW and CDW present potential for use as fillers in cementitious mixtures.

According to Neville (2016) [9], a filler is a finely ground and chemically inert material that, through its physical effects, enhances the properties of cementitious mixtures. The incorporation of fillers improves workability and matrix density, reducing porosity and increasing durability [10]. Hydrated lime, commonly used in mixed mortars, contributes to properties such as plasticity, water retention, and durability [11].

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

Experimental Procedure

The experimental program consisted of producing five mixes of cement–lime mortars with partial replacement of lime by Bahia Beige Marble Waste (BMW) and Construction and Demolition

Waste (CDW) at replacement levels of 10% and 20%, in order to evaluate the physical–mechanical behavior of the mixtures.

First, both wastes were subjected to crushing in a knife mill and subsequently sieved to obtain a particle size smaller than 150 μm . It is important to note that the CDW used consisted only of gray-colored material, predominantly mortar and concrete. The research was divided into three stages: 1) Characterization of the materials used; 2) Production of the mortars; 3) Characterization of the mortars in the fresh and hardened states.

Material Characterization

The characterization of the materials used — CP II-F 32 cement, CH-I lime, BMW, CDW, and sand — was carried out through the determination of their specific gravity, which were 2.98 g/cm^3 , 2.27 g/cm^3 , 2.68 g/cm^3 , and 2.60 g/cm^3 , respectively. Additionally, the packing density was evaluated according to the method proposed by Larrard (1999a). Table 1 presents the results.

Production Mortar

In the mortar production stage, the materials used included cement, hydrated lime, BMW and CDW, fine sand, 0.30 by mass of air-entraining additive, and 0.08 by mass of water-retaining additive. The water/binder ratios were determined based on a flow of 260 ± 5 mm, according to ABNT NBR 13276:2005, and the packing density, as presented in Table 1.

Mortar Characterization

The mixed cement–lime mortars with partial replacement of lime by BMW and CDW were characterized in the fresh state through tests for bulk density, entrained air content, and water retention, with the results shown in Figures 1 and 2. In the hardened state, the mortars were evaluated by flexural tensile strength and axial compressive strength tests.

Table 1. Mixes with BMW, by mass, and the resulting packing density and workability of the mortars.

	REF	T10 BMW	T20 BMW	T10 CDW	T20 CDW
Cement	1.00	1.00	1.00	1.00	1.00
Lime	0.50	0.45	0.40	0.45	0.40
RMBB	-	0.05	0.10	-	-
CDW	-	-	-	0.05	0.10
Fine sand	6.90	6.90	6.90	6.90	6.90
Water/binder	1.08	1.10	1.04	1.11	1.06
Compactness	0.557	0.553	0.507	0.563	0.560
Consistency $\pm$ Sd (mm)	258 $\pm$ 1.70	264 $\pm$ 1.25	262 $\pm$ 1.25	263 $\pm$ 1.25	265 $\pm$ 1.25

SD – standard deviations.

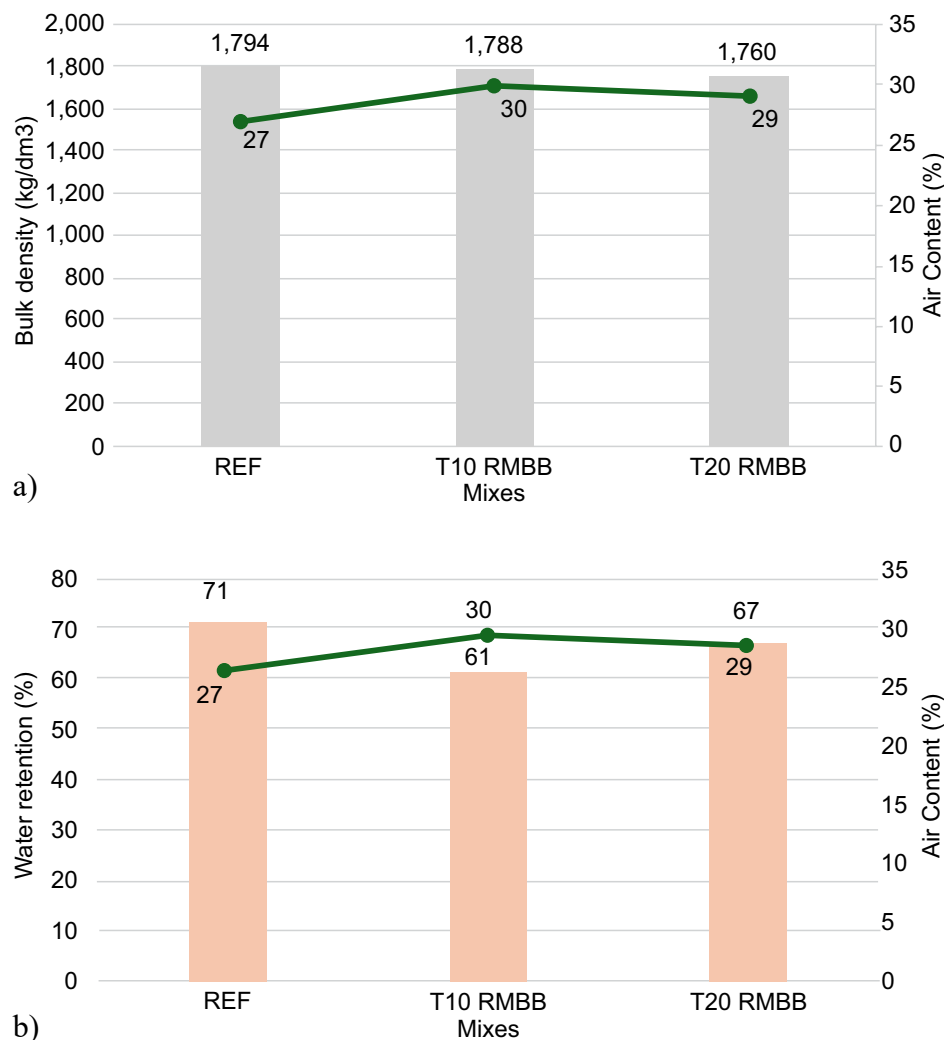
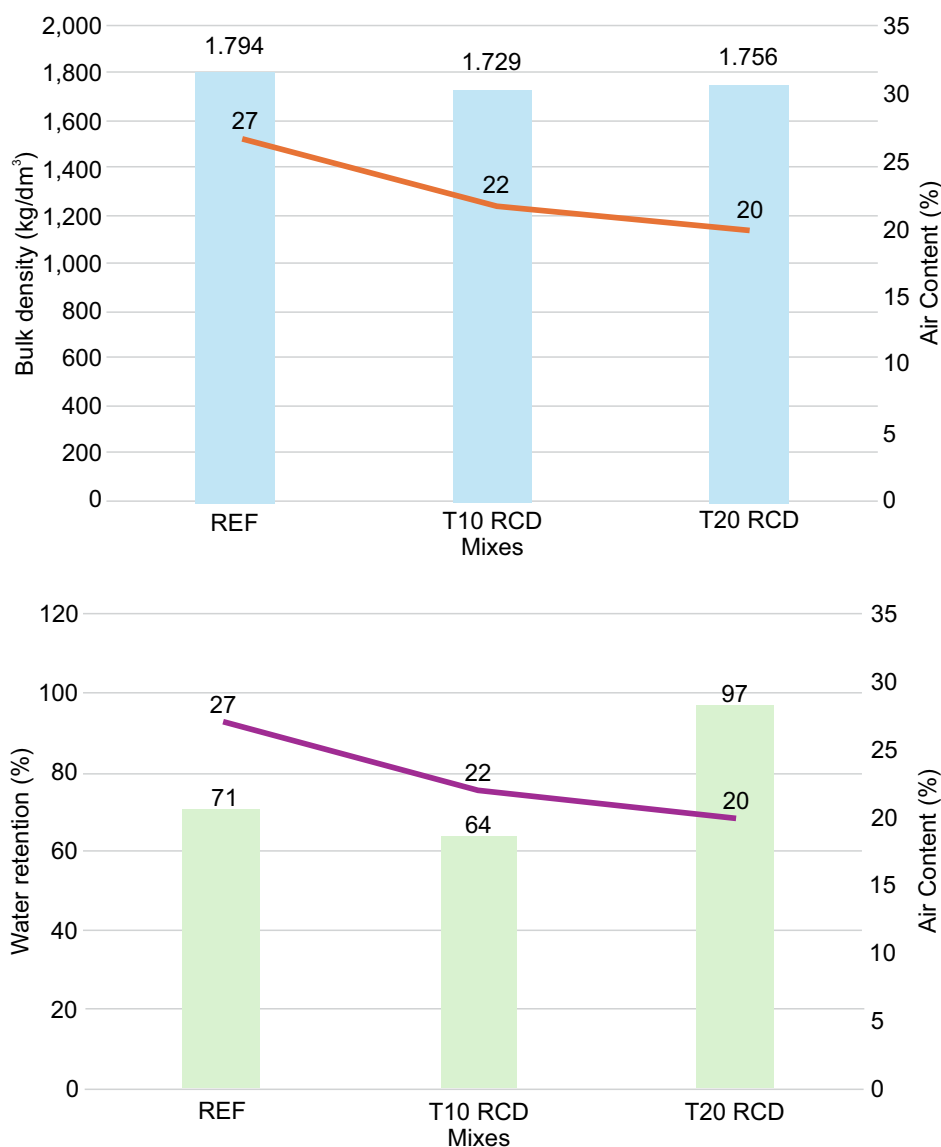
Figure 1. Results of fresh-state properties: a) Variation of bulk density and air content; b) Variation of water retention and air content.

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

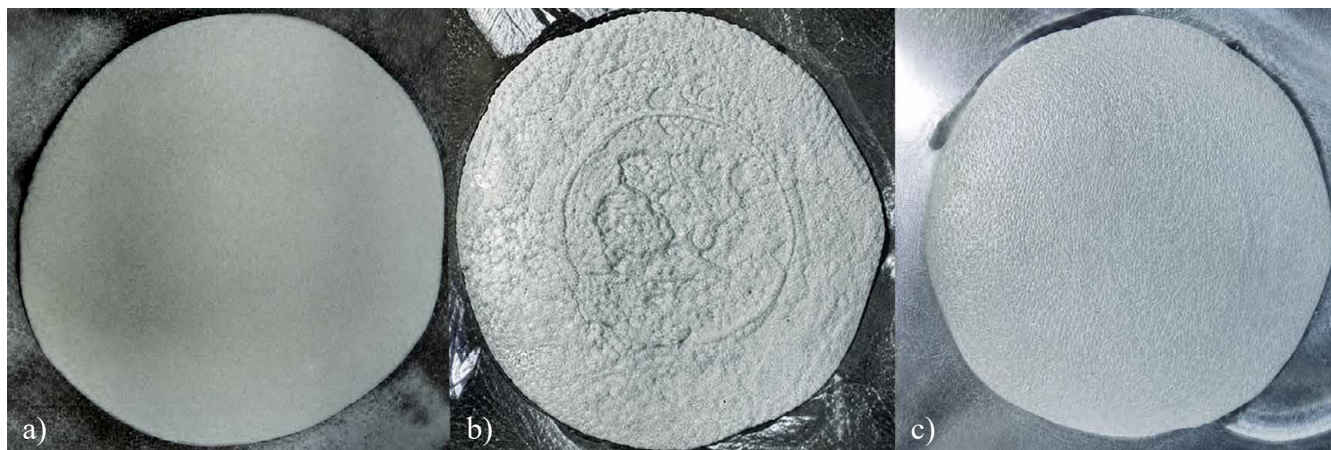


Results and Discussion

Regarding the qualitative evaluation of the mixed cement–lime mortars with partial replacement of lime by BBMW, when comparing the REF, T10 BBMW, and T20 BBMW mixes, it was observed that the T10 BBMW mix presented a flow value close to the upper limit (265 mm). This behavior is attributed to the filling of intergranular voids previously occupied by water [12], resulting in good plasticity, although with higher bleeding due to the increase in the water/binder ratio, as indicated

in Table 1. On the other hand, the T20 BBMW mix showed lower fluidity, with reduced plasticity. Nevertheless, all mixes exhibited good cohesion, a matte appearance, and satisfactory workability, as shown in Figure 3.

As observed in Figure 1.a, there was a slight reduction in bulk density with the increase in lime replacement by BBMW. According to Ruhnke (2024) [10], this phenomenon may be related to the saturation points of particle packing, in which the filler acts as an internal lubricant, or to higher water retention, as also

Figure 3. Mortar flow. a) REF; b) T10 BMW; c) T20 BMW.

evidenced in Figure 1.b. Regarding the increase in entrained air content, the author associates this behavior with the same saturation effect, since particle accumulation can form agglomerates capable of trapping air pockets.

According to Figure 2.b, a decrease in water retention is observed in mixes with lime replacement by BMW compared to the REF mix. This is due to lime having a finer particle size than BMW, resulting in a greater specific surface area, which favors water retention through adsorption on the particle surfaces.

For the mixed mortars with lime replaced by CDW, qualitative analyses showed that the mixture behavior is similar to the T10 BMW and T20 BMW mixes. When compared to the

REF mix, T10 CDW and T20 CDW, the T10 CDW mix exhibited higher fluidity, similar to T10 BMW, which can be explained by the filling of intergranular voids, resulting in higher workability; the increase in water/binder ratio causes greater bleeding in the CDW mixes. The T20 CDW mix showed lower fluidity, similar to T20 BMW. According to Fortnatto (2019) [13], this occurs because the particle shape of CDW is less rounded compared to the binder. Finally, both CDW mixes exhibited good workability, cohesion, and a matte appearance, as shown in Figure 4.

As observed in Figure 2.a, there was a reduction in bulk density in the T10 CDW and T20 CDW mixes compared to REF. This behavior can be explained by the fact that the specific gravity of CDW is higher

Figure 4. Mortar flow. a) REF; b) T10 CDW; c) T20 CDW.

than that of lime, meaning less material is needed to occupy the same space previously filled by lime. The packing density of the mixes increased with higher levels of lime replacement (10% and 20%), which also explains the reduction in entrained air content in T10 CDW and T20 CDW mixes, evidencing the effect of particle packing in the cementitious matrix, reducing voids and air bubbles.

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

Analyzing the mortars in the hardened state (Table 2), all mixes containing BMW and CDW showed improved flexural tensile strength, averaging 27% for mixes with BMW and 20% for CDW, compared to the REF mortar.

According to Gonçalves (2000) apud Apolinário (2014) [15], the filler effect is responsible for the strength gain due to its physical role in accelerating cement hydration at early ages. The same behavior was observed for axial compressive strength, with all mixes containing the wastes achieving higher results. According to Moraes (2001) apud Apolinário (2014) [15], the effect of BMW and CDW in mortars is predominantly physical, related to pore filling.

The high fineness of the fillers promotes cement hydration by acting as nucleation sites, stimulating the precipitation of hydrated products and accelerating early-age strength gain, resulting in a denser and more homogeneous paste due to better pore distribution.

Conclusion

The study evaluated mixed cement–lime mortars with partial replacement of lime by BMW and CDW, aiming to explore sustainable alternatives in civil construction and the management of waste generated by marble extraction and construction and demolition activities.

Based on the results obtained, the T20 BMW and T20 CDW mixes exhibited lower water/binder ratios — a factor that, according to the literature, increases strength — while maintaining workability. Furthermore, although the T20 BMW mix showed a decrease in bulk density, the air content was also reduced compared to T10 BMW, indicating better particle packing. In addition, water retention was not as significantly affected as in the 10% replacement mix. Regarding CDW replacement, the improved compaction of the mixture and the reduction in entrained air in the T20 CDW mix demonstrate the more effective filler action of the material.

The mixes containing these wastes showed improvements in both flexural tensile strength and axial compressive strength, once again evidencing the effect of pore filling and particle packing in the

Table 2. Average results, standard deviations, and coefficients of variation of the mechanical properties of mortars with BMW and CDW replacement at 7 days.

Mixing Sequence	Flexural Tensile Strength ft ± SD(CV%)	Axial Compressive Strength fc ± SD(CV%)
REF	1.60 ± 0.08(5.25)	3.67 ± 0.27(7.39)
T10 BMW	1.90 ± 0.09(7.00)	4.31 ± 0.11(2.65)
T20 BMW	2.15 ± 0.05(2.40)	4.49 ± 0.14(3.06)
T10 CDW	1.95 ± 0.28(14.46)	3.77 ± 0.66(17.58)
T20 CDW	1.72 ± 0.04(2.38)	3.73 ± 0.20(5.26)

cementitious matrix through the partial replacement of lime by BBMW and CDW.

In light of these findings, the partial replacement of lime by BBMW and CDW in coating mortars is feasible, provided a prior analysis of the materials is conducted to ensure adequate physical–mechanical performance. Moreover, incorporating waste into construction contributes to sustainability, offers better final disposal for various types of waste, and reduces environmental pollution from production to final deposition of the materials.

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