

# Comparative study of the tensile bond strength of rendering mortars in ceramic and concrete structural blocks

## Estudio comparativo de la resistencia a la tracción del mortero de revestimiento en bloques estructurales de cerámica y hormigón

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### Abstract

The tensile bond strength is one of the main properties of rendering mortars. It represents the adhesiveness ability between the mortar itself and the substrate. This property depends on several factors, such as the proportion and characteristics of the mortar materials and the substrate, along with the mode of application and climate conditions. The purpose of this paper was to analyze the tensile bond strength between three rendering mortar proportions in volume – 1: 1: 6, 1: 2: 9, and 1: 6 (with plasticizer additive) – each one applied on two substrates, ceramic structural blocks with roughcast and concrete structural blocks. The rendering mortars had their physical properties evaluated in fresh and hardened stages, as well as their compressive and tensile strengths in flexure. The tensile bond strength was determined by a pullout test on ceramic and concrete masonry walls exposed to external weather. The results showed that the 1: 1: 6 mixed mortar exhibited higher tensile bond strength in both substrates of ceramic blocks with roughcast and concrete blocks without preparation. Besides, among 1: 2: 9 and 1: 6 mortars there is no significant difference in tensile bond strength considering both substrates. Another conclusion was that the substrate type did not affect the final bond strength between the mortars.

**Keywords:** Rendering mortar; Tensile bond strength; Masonry walls

### Resumen

La adherencia a la tracción es una de las principales propiedades de los morteros de revestimiento. Esta representa la capacidad de adhesión entre el mortero y el sustrato. El objetivo de este trabajo fue evaluar la resistencia de adherencia de tres mezclas de mortero de recubrimiento (1: 1: 6, 1: 2: 9 y 1: 6, en volumen) aplicados a dos tipos de sustratos, uno de bloques cerámicos revestidos con mezcla gruesa, y otro de bloques de hormigón. Los morteros tuvieron sus propiedades físicas evaluadas en estado fresco y endurecido y su resistencia a la compresión y a la tracción en flexión. La resistencia de adherencia a la tracción se determinó mediante pruebas de extracción en las paredes de mampostería expuestas al clima externo. Los resultados mostraron que el mortero con la proporción de 1: 1: 6 mostró mayor resistencia a la adherencia a la tracción, tanto en bloques cerámicos como en bloques de hormigón. También se observó que entre los morteros 1: 2: 9 y 1: 6 no existe una diferencia significativa en la resistencia de adherencia para ambos sustratos. Otra conclusión es que el tipo de sustrato no afectó la fuerza de unión final entre los rasgos estudiados.

**Palabras clave:** Revestimiento de mortero; Fuerza de Tensión; Muros de mampostería

## 1. Introduction

In buildings, rendering mortars perform an important role as an insulating element of the structure. They are applied on masonry and concrete bases, both internally and externally, with the function of regulating, waterproofing, and improving the thermoacoustic conditions in the environments.

According to (Carasek et al., 2016), rendering mortars are commonly applied in ceilings and wall panels that will receive a final finish, such as painting, ceramic coating, among others. Thus, to guarantee the complete connection between the substrate and the finishing, some properties become important to the mortar, such as workability, adhesion, mechanical resistance, deformability, and durability.

Among the properties listed above, adherence, the ability of the coating to remain attached to the substrate after it has hardened, depends directly on the characteristics of the mortar, the substrate, the application technique, and the climatic conditions (Kazmierczak et al., 2007).

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According to (Carasek and Scatezini, 2001), the mortar's adhesion mechanism depends on the occurrence, in the plastic stage, of the mixing water and the binder penetration by capillarity inside the cavities of the substrate's absorbent surface. Inside these cavities, a blocking occurs through precipitation and curing of cement hydration products. Therefore, the composition of the mortar, particularly, its mix proportions and the surface characteristics of the base, have a determining role in the coating's bond strength.

Bond strength is measured by tensile bond strength, shear bond strength and bond length (ratio between the contact area and the total possible wet area), these are derived from the properties and contact of mortar and base materials (Carasek et al., 2016).

The tensile bond strength, focus of this work, defined in NBR 13528: 2010 as the main method used to quantify the bond strength of rendering mortars. It is an easy and simple test, but with high variability that depends on several factors.

Numerous researchers, such as (Antunes and Masuero, 2016), (Stolz and Masuero, 2018), (Kabagire et al., 2017), (Jiao et al., 2017), (Zanelatto et al., 2013) concluded that there are determining factors in the tensile bond strength of rendering mortars. Those are the characteristics of the mortar (proportion of materials, granulometry, rheology and presence of additives), the substrate (capillarity, water absorption, and surface roughness), the executive process (surface treatment, application energy, quality of the mixture, type of application and curing process), in addition to the climatic conditions the coating system is subjected (temperature, relative air humidity, and wind). The materials proportions used in the rendering mortar directly influence the bond strength: a high cement content creates greater adhesion but produces rigid coatings, which tend to crack. Besides, lime-rich mortars have a greater extent of adhesion due to the fineness of the particles. However, this same factor causes the clogging of the substrate pores and compromises the mortar anchorage. The use of high amounts of sand, as well as greatly coarse or fine sands, affects its adherence, so the use of medium sands with good granulometric distribution is the recommendation (De Freitas and Gonçalves, 2008).

Some researches that analyzed the influence of materials on tensile bond strength indicated traits that would improve this property. (Gattesco et al., 2015) recommend that under general conditions, the generally used proportions for rendering mortars are 1: 1: 6 and 1: 2: 9 in volume. The mentioned dosage proportions represent an average of 20% of agglomerate (cement and lime) and 80% of aggregate. In the same way, according to (Gallegos, 1995), the mortar proportion indicated for renderings must be 1: 2: 8-9 in volume. For the author, the proportion of sand should be the maximum possible as long as the cement and lime fill their voids.

Regarding the substrate influence, (Paes et al., 2005) analyzed that for the same mortar applied in ceramic and concrete blocks, it has greater bond strength in the last ones, as they have greater porosity. According to the authors, the ceramic block has a more compact and smooth surface, which can decrease water transportation from the mortar mixture. Considering this factor, the mortar close to the block-mortar interface can have a greater porosity, leading to lower values of bond strength. The concrete block has greater surface roughness, which increases the contact area between it and the mortar and allows better penetration of the agglomerate inside the block, improving bond strength.

(Sarhosis et. al., 2015) state that water absorption occurs immediately after the mortar / absorbent base contact. The water begins to flow from the mortar towards the base until the balance between capillary suction and the physicochemical retention forces of mortar water is reached. In this sense, the water suction capacity, or IRA (Initial Rate of Absorption), which means the mass of water absorbed by one of the block faces for one minute, is also one of the most studied parameters. Therefore, given the importance of compatibility between mortar and substrate for the tensile bond strength and the properties variability from materials produced on different circumstances, it is important to define the proportions of rendering mortars, composed with supplies from Palmas – TO, that presents better behavior. The research has the general objective of evaluating the tensile bond strength of rendering mortars using a pullout test on walls of ceramic and concrete structural masonry.

## 2. Materials and methods

### 2.1. Materials

The mortar components were Portland cement CII - Z 32 Ciplan brand, hydrated lime CH-I Fortex brand, and natural sand of medium granulometry provided by Mineradora Capital located in the city of Palmas-TO.

(Table 1) shows the results of the sand characterization. The granulometry was determined according to NBR NM 248. Unit weight and bulk specific gravity were determined according to NBR NM 45 and NBR NM 52, respectively. The water absorption test was performed under NBR NM 30 and the powdery material test according to NBR NM 46.



**Table 1.** Results of fine aggregate characterization

CHARACTERISTICS	RESULTS
Fineness modulus	2,25
Maximum aggregate size	2,4 mm
Unit weight (g/cm <sup>3</sup> )	1,638
Bulk specific gravity (g/cm <sup>3</sup> )	2,662
Water absorption (%)	0,5
Powdery material (%)	1,3

The mortar dosages were among the most used in local constructions. Three proportions, in volume, were defined, the first two with hydrated lime and the last one with the addition of plasticizer.

- Proportion 1 (T1) - 1:1:6 (cement: lime: sand)
- Proportion 2 (T2) - 1:2:9 (cement: lime: sand)
- Proportion 3 (T3) - 1:6 (cement: sand)

For T3, the chosen plasticizer additive was Quartzolit from Weber Company, which is widely used in constructions in the city of Palmas-TO. It is an air incorporator indicated to increase cohesion and consistency of mortars. The additive rate was 0.2% of the cement mass, in consonance with the manufacturer's specification, placed in the mixing water just before blending it with the aggregate and agglomerates.

Ceramic and concrete structural blocks measuring 29x19x14 cm and 19x19x14 cm half blocks from the manufacturers Cerâmica Tecil (ceramic blocks) and Nova Precil (concrete blocks) were chosen to compose the masonry walls. These blocks are widely used by the construction companies and they are standardized products. The characterization consisted of water absorption determination and compressive strength under NBR 15270-2 and NBR 12118, respectively. The results are shown in (Table 2).

**Table 2.** Results of the characterization of ceramic and concrete blocks

BLOCKS	WATER ABSORPTION (%)	COMPRESSIVE STRENGTH (MPa)
Ceramic	16,94%	8,53
Concrete	7,45%	5,65

## 2.2 Application of the rendering mortar

The masonry walls construction was externally in the open air to subject the mortar to the real conditions an external rendering is subjected to in Palmas-TO. It includes the action of wind and high temperatures, which tend to result in lower bond strengths.

The ceramic and concrete walls were constructed in five rows, 1 cm laying joints, and staggered configuration following the specifications of NBR 15961-2: 2011. The joints mortar was in the proportion in volume 1: 1: 6 (cement: lime: sand). In this case, it was adopted a proportion specified in the ASTM C 270 86b, class N, considering medium compressibility mortars and indicated for walls in high heat regions.

Smooth substrates generally lead to lower bond strength values, requiring the base preparation on-site to adequate its roughness, such as the application of roughcast. Thus, to create a similar roughness to the concrete blocks on the ceramic blocks and to perform a better comparison of the rendering mortar tensile bond strength, roughcast with a proportion in volume 1: 3 was applied to the ceramic blocks.

The preparation of the rendering mortar was based on NBR 7200 and applied to both types of walls as shown in (Figure 1).





**Figure 1.** Rendering mortar on walls with ceramic and concrete block

The mortar was characterized in its fresh stage for specific gravity, entrained air content, and rheology by the squeeze flow method, following NBR 13278 and NBR 15839, respectively.

In the hardened stage, the specific gravity tests were executed according to NBR 13280, water absorption by capillarity, and the capillarity coefficient by NBR 15259. For the mechanical behavior evaluation, flexural and compressive strength were determined as prescribed by NBR 13279.

The execution of the tensile bond strength test followed the guidelines defined by NBR 13528: 2010 as shown in (Figure 2). The equipment was the Contenco brand hydraulic handheld adherometer that applies the traction force perpendicular to the coating surface.



**Figure 2.** Execution of the tensile bond strength test

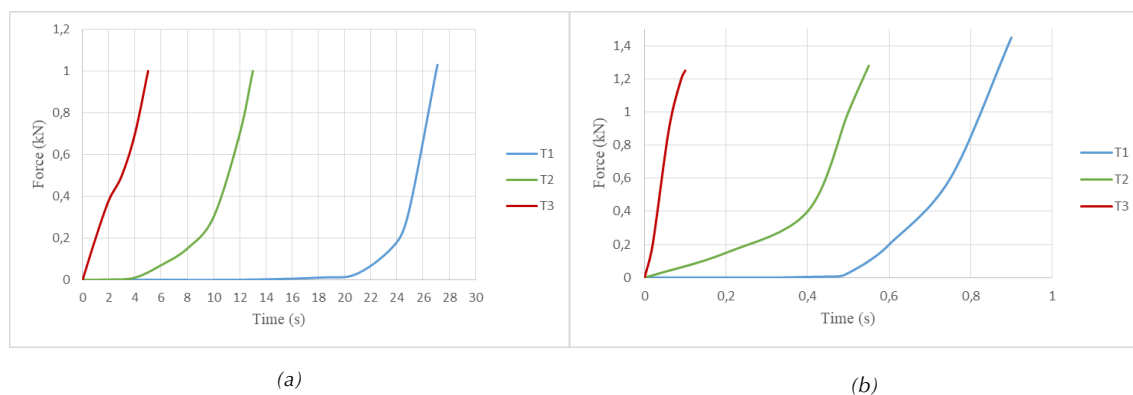
### 3.1 Fresh rendering mortar tests

(Table 3) presents the results for the specific gravity and entrained air content. The proportion T3, with plasticizer additive, obtained a higher content of entrained air and less specific gravity, presenting a behavior contrary to T1.

**Table 3.** Specific gravity and entrained air content in the rendering mortar fresh stage

PROPORTIONS	SPECIFIC GRAVITY (g/cm <sup>3</sup> )	ENTRAINED AIR CONTENT (%)
T1	1,97	8,52
T2	1,95	10,08
T3	1,71	21,78

(Figure 3) presents the results for the rheological test by the Squeeze Flow method. The test consisted of load rates of 0.1 mm / s and 3 mm / s applied 10 and 15 min after the mortar preparation, respectively, until reaching a displacement of 9 mm or a maximum load of 1kN



**Figure 3.** Rheological test by Squeeze Flow method: a-) Test at the rate of 0.1 mm / s and b-) Test at the rate of 3 mm/s

Each mortar has a characteristic curve, and comparatively, it is possible to determine the mortars that have the highest viscosity. Greater times indicate mortars with higher viscosity since it took more time to obtain a maximum displacement. Shorter times indicate, on the contrary, mortars with less viscosity. In general, the rheological behavior expected for mortars, over the test time, is to increase the compression time (as observed with the mortars understudying), as the mortar gradually loses water due to evaporation, becoming more rigid.

Initially, for the load applied at the 0.1 mm / s rate, T3 shows greater fluidity, followed by T2 and finally Proportion 1, because the time to reach the maximum limits is less. The same behavior happened in 15 min, with the test at 3 mm / s rate, in which T3 shows greater fluidity. The results demonstrate the workability of the mortars understudy, T1 mortar presents a greater difficulty for spreading, behavior corroborated on its application on the panels.

The results present that the higher the content of entrained air, the greater is the mortar's workability. This behavior is in line with previous research on the topic, such as (Calhau and Tristão, 1999) and (Farinha et al., 2015).

### 3.2 Hardened rendering mortar tests



(Table 4) represents the results for specific gravity, water absorption, tension strength in flexure, and compressive strength.

**Table 4.** Results of the rendering mortar characterization tests in the hardened stage

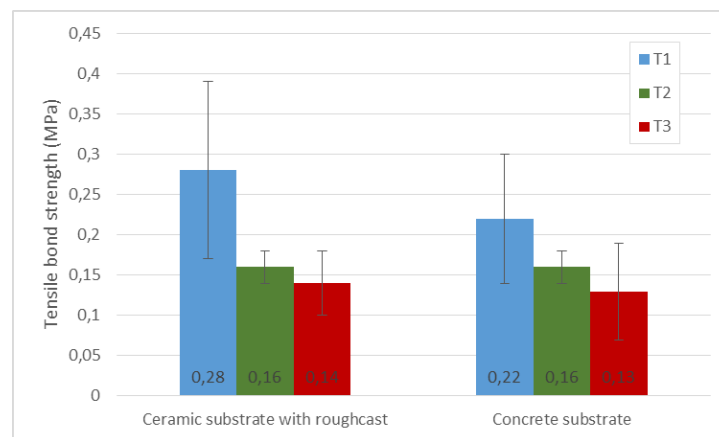
PROPORTION	SPECIFIC GRAVITY (g/cm <sup>3</sup> )	WATER ABSORPTION (%)	TENSION STRENGTH IN FLEXURE (MPA)	COMPRESSIVE STRENGTH (MPA)
T 1	1,77	12,73	0,80	2,17
T2	1,68	15,77	0,52	1,07
T3	1,67	9,57	0,58	1,31

Analyzing T1 and T2 proportions, produced with the same sand, as the lime content increased, the specific gravity decreased and the water absorption increased. Therefore, the mechanical performance was better for the mortar T1, with a greater tensile in flexion and compressive strength. According to (Silva et al., 2005), mortars with a greater amount of fines in their mixture require more water to guarantee workability because part of the water hydrates the cement and the other part is absorbed by the aggregate particles. As mortars lose water in the hardened stage, a greater lime proportion rate creates a greater amount of voids, which decreases the specific gravity in the hardened stage and, consequently, their mechanical properties.

T3 mortar had less water absorption by capillarity. The same behavior was observed by (Calhau and Tristão, 1999) and (Farinha et al., 2015) in which the higher the content of entrained air, the lower the absorption by capillarity.

### 3.3 Tensile bond strength.

(Figure 4) presents the average tensile bond strength results. Similar behavior takes effect between the two substrates (concrete blocks and ceramic blocks). T1 mortar showed higher values of tensile bond strength, followed by T2 and T3. Besides, T1 and T3 have slightly higher tensile bond strengths in ceramic blocks with roughcast. T2, on the other hand, has no differences in the adhesion property concerning the type of substrate.



**Figure 4.** Representation of the bond strength resistance of the proportions

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The results of the tensile bond strength are below the values defined for external coating in NBR 13279, 0.3 MPa. However, (Silva et al., 2005), who studied the same proportions T1 and T2 analyzed in this paper, in ceramic substrates with roughcast, had results with a variation of only 0.02 MPa concerning this research. Noticeably, in the mentioned work, the coating curing was inside a covered environment, unlike this research, in which the panels were subjected to wind action of and direct sunlight, which influences the reduction of tensile bond strength.

Considering only the fine aggregate factor, with the increase in sand content on T2 there is a reduction in tensile bond strength compared to T1, which is consistent with the conclusions of (Carasek y Scartezini, 2001). In this study, an increase in the cement/aggregate ratio from 0.11 to 0.17 resulted in a decrease in strength for about 43% for ceramic substrate and 27% for the concrete substrate.

According to (Agopyan et. al., 2005), who studied the performance of mixed rendering mortars with additive and lime, in most tests, the replacement resulted in the loss of tensile bond strength. This behavior was also observed in this research, in which T3 has the lowest average strength values for both substrates.

Besides, the entrained air content in the mortars, shown in (Table 3), despite favoring their workability, acts negatively on the tensile bond strength. A result following (Costa et al., 2010) and (Silva et al., 2005). The previous authors explain this behavior by a large number of microscopic air bubbles at the substrate interface, which reduces the contact surface and, consequently, the connection bridges between mortar-base.

Finally, analyzing the results, T1 proportion (1: 1: 6 in volume) shows greater tensile bond strength compared to the other mortars for both substrates.

A statistical study using the ANOVA method for the averages and standard deviations of the mortars' tensile bond strength presented a better interpretation of the results. For a 95% reliability level, there was a significant difference in the results; consequently, the mortar mixture proportion influenced the tensile bond strength of the rendering system. The Tukey test was applied to identify which proportions differ from each other and it was concluded that T2 and T3, which represent in volume 1: 2: 9 and 1: 6 (with plasticizer additive), do not differ between themselves regarding final tensile bond strength.

## 4. Conclusions

Given the comparative study of the rendering mortars tensile bond strength, the following conclusions can be reached:

- For ceramic and concrete blocks substrates submitted to the Palmas-TO climate, mixed rendering mortars with T1 proportion (1: 1: 6 in volume) presented greater tensile bond strength compared to T2 and T3 - 1 : 2: 9 and 1: 6 (with plasticizer additive Quartzolit), respectively. This result was possibly due to the higher cement content in the mixture since the results of the mechanical tests, such as flexural tensile strength and compressive strength were higher for this mortar. T1 presented less workability and less content of entrained air concerning the other two;
- Mixed rendering mortars with lime addition (T1 and T2) showed greater tensile bond strength in comparison to mortar T3 with the addition of the plasticizing additive. This could be justified by air bubbles forming in the adhesion area, decreasing the mortar bond with the substrate.
- Mix Proportions T2 and T3 do not present statistically significant differences concerning the final tensile bond strength. On the other hand, the rheology of T3 showed greater fluidity, and therefore, better workability in the application of this type of mortar, which may bring advantages such as greater service productivity.
- Regarding the type of substrate, the rendering mortar applied to ceramic structural blocks with roughcast showed similar values of tensile bond strength compared to concrete structural blocks without roughcast. In this case, considering the statistical analysis of variances, T1 showed better results. Therefore, in constructions with ceramic blocks, it is advisable to place roughcast on the substrate surface to increase the tensile bond strength of the rendering mortar.

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