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Adherence of Brazilian dimension stones by mortar adhesion: influence of temperature

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ABSTRACT

The influence of temperature variation on the adherence of granite slabs was simulated by a set of TBS tensile bond strength tests carried out using three types of rocks of established commercial use and with good technological qualities, known as “Branco Desireé”, “Vermelho Capão Bonito” and “Cinza Andorinha”. Specimens of these materials were fixed with two types of adhesive mortars, one commercial and the other produced in the laboratory, with white cement CPI. After the standardized cure, 186 TBS tests were carried out in 5 temperature ranges laboratory-controlled, ranging from 23 °C to 60 °C. The test results showed the temperature increase implies the loss of tensile strength. The commercial mortar presented TBS final values lower or nearby to 1 MPa, the standard threshold for ceramic slabs. The mortar prepared with white cement showed better performance, with adherence values above the 68% mentioned limit. This expressive result recommends the continuation of research with other types of rocks fixed with mortar prepared with white cement. The microstructure behavior of the material sets subjected to adherence tests was also investigated. The inspections showed clear contact between the stone plates (with both rough and smooth contact surfaces), without the occurrence of reaction edges or pervasion of the mortar in the stone. Anchoring, therefore, took place only in the contact between the standard substrate and mortar.

1. Introduction

The increasing use of rocks in floors and cladding of buildings is known to increase the consumption of laying mortars, requiring more detailed studies on their compositions to qualify them against the wide variety of lithological types currently available on the market [1–8].

Regarding the fixing of rock plates with adhesive mortars, this is a subject that is still little known, unlike ceramics

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where the most important chemical reactions that influence the adhesion resistance develop internally in the mortar itself. As for dimension stones, which are natural materials made up of "phases" with different chemical/mineralogical compositions, in addition to the aforementioned chemical reactions, there is also the possibility of chemical reactions occurring between minerals and mortar phases [9,10].

Facades of buildings suffer several physical and mechanical demands caused by temperature variations during the day, resulting from sunlight, wind, and rainfall. Studies in the literature report the importance of temperature on the adherence of adhesive mortars with ceramics [11–16]. Studies by Sá (2005) on the alterability of facades with ceramic coating [14] proved through soundness by artificial weathering that the temperature strongly influences the adherence strength. The sets (substrate + mortar + ceramic) were subjected to a nine-step cycling. The first lasted 1 min, serving only to start the test cycle so that the chamber reached the desired humidity and moisture. The second step was the rain simulation; the third, the transition from rain to freezing; the fourth, the freezing; the fifth, the transition from freezing to high temperature and moisture; the sixth, at high temperature and moisture; the seventh, the transition to radiation; the eighth step, radiation, and the last step, the transition to the initial phase. The soundness tests caused a drop in the cement-glue performance, showing an important decrease in the TBS tensile bond strength values.

In turn, Bortoletto (2004) carried out pullout tests on ceramics laid with industrialized adhesive mortars heated at different temperatures in an oven (from 23 to 70 °C) for 30–60 min. The results indicated that the adhesive mortars tested suffered a loss in adherence strength with increasing temperature, which was responsible for the detachment of ceramic tiles, when applied on facades [15]. According to the author, the increase in temperature proved to be more influential compared to the time of exposure to heat on the adherence strength of the adhesive mortars studied.

Perez (2003) evaluated the behavior of industrialized adhesive mortars subjected to thermal shock cycles in laboratory and field tests, using masonry of ceramic blocks [16]. ACII, AC III, and ACIII E adhesive mortars were studied. The results showed that, after 4 cycles of thermal shock, the tensile bond strength of adhesive mortars had a decrease between 30% and 76.9%, and the ACII mortars showed the greatest reduction in adherence strength (60%), below the established by the Brazilian Standard. The ACIII E mortar showed the smallest decline in bond strength (30%). In terms of thermal shock cycles, these did not influence the flexibility of mortars subjected to temperatures of up to 70 °C. In ACIII mortars, there was a 22% increase in flexibility; while in the others, the results remained stable compared to values in which the samples did not suffer the thermal shocks. As for shear, the ACIII E and AC III mortars present much better results than the ACII mortar. Therefore, considering the shear, AC III and AC III E mortars are the most suitable for application when building facades, as structural variations may deform the mortars with less chance of producing cracks.

On the facades covered by rocks, detachments similar to those of ceramic tiles are also observed. In this case, among other factors, the weight of rock slabs must be considered, which is about three times greater than that of ceramics. With the wide array of dimension stones available today in a very demanding market, detachment has to be investigated, taking into account the knowledge already acquired for ceramic material.

In this context, Ribeiro et al. (2015) examined the action of temperature variation on the adhesion of stone slabs laid with mortars in the outside cladding of floors and walls [17]. As an example, samples of a syenogranite of great commercial acceptance were fixed using two types of mortars (commercial and laboratory-made). The results showed that adherence decreases with temperature variations from 23 to 60 °C (Fig. 1). However, adherence values were still higher than 1 MPa, the limit required by the standard for ceramic tiles. In microstructural analysis, no evidence of reactions or anchoring of the mortar was observed.

The similarity between these results and those verified in previous studies on ceramic materials encouraged the continuation of studies relating the loss of adherence of slabs of other three types of rocks with the temperature measured at the interface between adhesive mortars and rocks, including further studies on the behavior of the

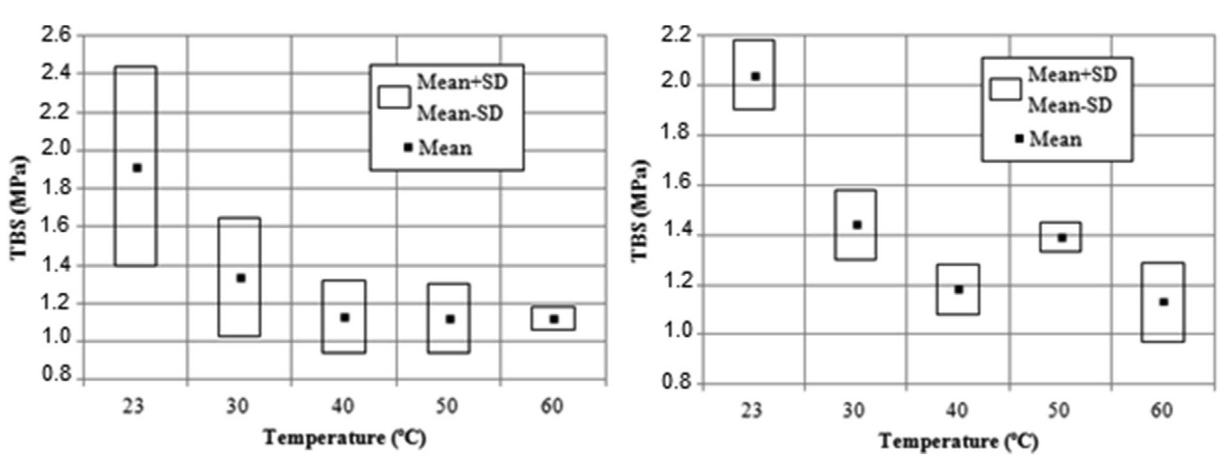

Fig. 1 – Box plots of the tensile bond strength (TBS) results for commercial mortar CM (LEFT) and mortar developed in the laboratory, M3 (RIGHT). Modified from [15].

microstructure of rock/mortar interfaces subjected to different temperatures, through routine petrographic analysis combined with microscopic observations with reflected light.

2. Material

The main materials for the present study were: stone slabs, used to make the specimens; mortars, used to fix the specimens; and standard substrates, used as a basis for fixing specimens and adhesion tests.

2.1. Stones

The three types of rock chosen for sampling were the BD Branco Desireé leucogneiss, the VCB Vermelho Capão Bonito syenogranite, and the CA Cinza Andorinha monzogranite. These are materials with adequate physical-mechanical

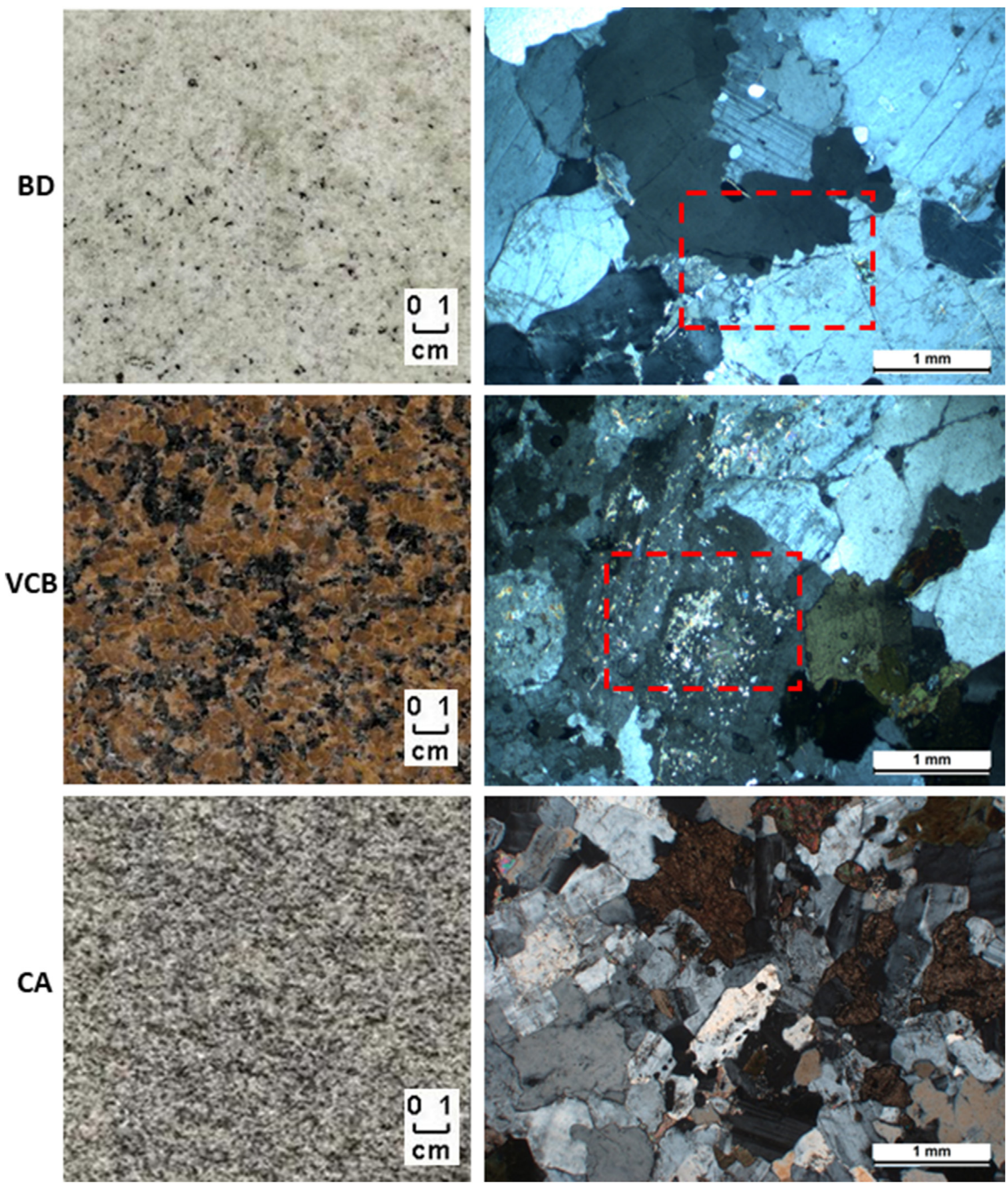

Fig. 2 – LEFT- Visual aspect in macroscopic observation of the studied materials. RIGHT- Microscopic feature of the rocks: BD leucogneiss-quartz-feldspar matrix with minerals exhibiting interlobed contacts (in detail); VCB syenogranite-in the central portion (in detail) more intense processes of saussuritization in plagioclase crystals; CA monzogranite-equigranular textural arrangement between felsic (most abundant) minerals and biotite. Crossed Nicols.

qualities and alterability, with consolidated commercial acceptance, and have been used in previous studies from sawing blocks and polishing slabs to their application in engineering works, especially in fixing tilestones with non-adherent systems (metallic inserts and raised floors) and adhesive mortars [18–20].

The commercial BD Branco Desireé metamorphic rock is a light-colored, anisotropic, fine to medium-grained (grain size ranging from 1 mm to 10 mm) leucogneiss. The essential minerals are perthitic to mesoperthitic microcline (42%), quartz (30%), oligoclase (25%), and garnet (3%). Its use is recommended for exterior and interior cladding [21]. The VCB Vermelho Capão Bonito syenogranite has medium to large grain size (ranging from 0.3 mm to 50 mm or more, with a predominance between 0.5 and 30 mm) and sparse feldspar megacrysts, orange-red. The main minerals are microcline, quartz, plagioclase, and biotite (45%, 35%, 15%, and 5% in composition, respectively). It is a rock widely specified for exterior claddings of tall buildings' facades in the main Brazilian cities [22]. The CA Cinza Andorinha monzogranite is a rock classified as with "medium hardness" in the polishing process. It has a light gray color, with an isotropic structure and an equigranular phaneritic texture, with a finer grain size than the other rocks, between 0.5 and 5 mm, predominating crystals with dimensions of 1–2 mm. At a microscopic level, it consists of microperthitic microcline (31%), quartz (30%), oligoclase (25%), biotite (12%), and 2% accessory minerals (opaque, titanite, zircon, apatite, allanite). Its use is recommended for exterior, and interior coverings, and floors [21].

Macro- and microscopic aspects of the three rocks studied are shown in Fig. 2, while synthesis of the technological characterization of these materials is listed in Table 1, highlighting that the information serves only as a reference in the selection of materials for cladding (floors, walls, and facades). In specifications, results of petrographic analysis and physical–mechanical properties referring to the batch of material to be applied on site must be used.

2.2. Mortars and standard substrate

In this study, two types of mortar were used: a CM commercial mortar and an "M2" mortar developed in the laboratory based on previous studies [9,10,27]. The M2 mortar is composed of 5% silica fume, 20% latex, total water/cement ratio = 0.4; the cement/sand ratio is 1:1.5 by mass, and 1% superplasticizer. The cement used is white cement and the sand has a characteristic maximum diameter of 0.6 mm. This laboratory-prepared mortar was selected for having shown low loss of adherence strength in soundness tests of rocks (freezing and thawing).

The standard substrates used in this research were purchased directly from the manufacturer, whose production meets the guidelines and requirements of the NBR 14081-2 standard [28]. Table 2 presents the characterization tests of the ABCP standard substrates. These characteristics refer only to new slabs, as their reuse is not recommended in the aforementioned standard, due to changes that might occur in their initial characteristics.

Table 1 – Basic characterization tests of the studied rocks.

Properties	Material		
	BD	VCB	CA
Bd (kg/m^3) [23]	2630	2635	2703
AP (%) [23]	0.67	0.56	1.01
WA (%) [23]	0.26	0.21	0.38
UCS (MPa) [24]	107.1	191.2	151.5
RA (mm/1000m) [25]	1.11	0.65	0.63
CLTE (mm.10^{-3}/m°C) [26]	4.9	10.0	7.1

CAPTIONS: Bd- Bulk density; AP- Apparent porosity; WA- Water absorption; UCS- Uniaxial compressive strength; RA- Resistance to abrasion and CLTE- Coefficient of linear thermal expansion. Material: BD- "Branco Desireé" leucogneiss; VCB- "Vermelho Capão Bonito" syenogranite and CA- "Cinza Andorinha" monzogranite.

3. Methodological procedures

3.1. Preparation and settlement of stone specimens

Disc-shaped specimens, with 30 mm diameter, were cut using a diamond drill from the commercial tiles with dimensions of 400 × 400 mm and a thickness of 20 mm. Some BD, VCB, and CA slabs available in the research collection were used. The TBS assays were carried out on the polished (smooth) face of the specimens, thus avoiding the action of the surface roughness on the adherence values obtained [29].

To study the effect of temperature variation on the adherence of stone plates fixed with adhesive mortar on external flooring and external cladding, the tests were carried out in 5 temperature ranges, from 23 to 60 °C. Ten specimens were placed on each standard substrate, 01 of them as a reference sample where thermocouples were installed to measure the actual temperature at which the rock/mortar interfaces were in each temperature range to which the materials were subjected, totaling 186 specimens. This is a laboratory simulation closer to the real conditions of sunlight on facades covered with stone slabs, starting from initial conditions that represent one-week daytime heating and so on.

Regarding comparisons, the sets were kept at a temperature of 23 °C and relative humidity of 65% for 28 days. At the other temperatures, the sets were placed in an oven and subjected to a heating time between 90 and 120 min (Figs. 3–1, 3–2, 3-3), then the TBS tests were immediately performed for each set of samples.

3.2. Determination of tensile bond strength

Using a manual dynamometer with a loading capacity of 250 ± 50 N/s (Figs. 3–4 and 3–5), the TBS tests were performed according to the NBR 14081-4 standard [30], including the evaluation of the type of rupture that occurred in the rock/mortar/substrate sets.

Considering the mineralogical and textural heterogeneity of the rocks and also the conditions for obtaining specimens with a diamond drill from tiles, the standardized statistical criteria for ceramic materials were disregarded. Aiming at statistical representativeness, between 5 and 9 specimens of each rock (BD leucogneiss, VCB syenogranite, and CA

Table 2 – Characterization tests of ABCP standard substrates.

Parameter	Volume of water absorbed in 4 h (cm^3)			Surface tensile adhesion strength (MPa)					
	Area 1	Area 2	Area 3	S1	S2	S3	S4	S5	S6
Individual value	0.3	0.2	0.3	2.13	2.16	2.22	2.08	2.13	2.16
Mean	0.3			2.1					
Specification of the NBR 14081-2 standard [26]	<0.5 cm^3			≥2.0 MPa					

LEGEND: S- Sample.

monzogranite) were tested under different conditions and an average variation of around 30% was adopted.

Especially when dealing with heterogeneous material and experimental scope, it is important to emphasize that all laboratory procedures were carried out under the same conditions, in terms of equipment, and sample preparation, including the same specialized technician in the execution of all TBS tests.

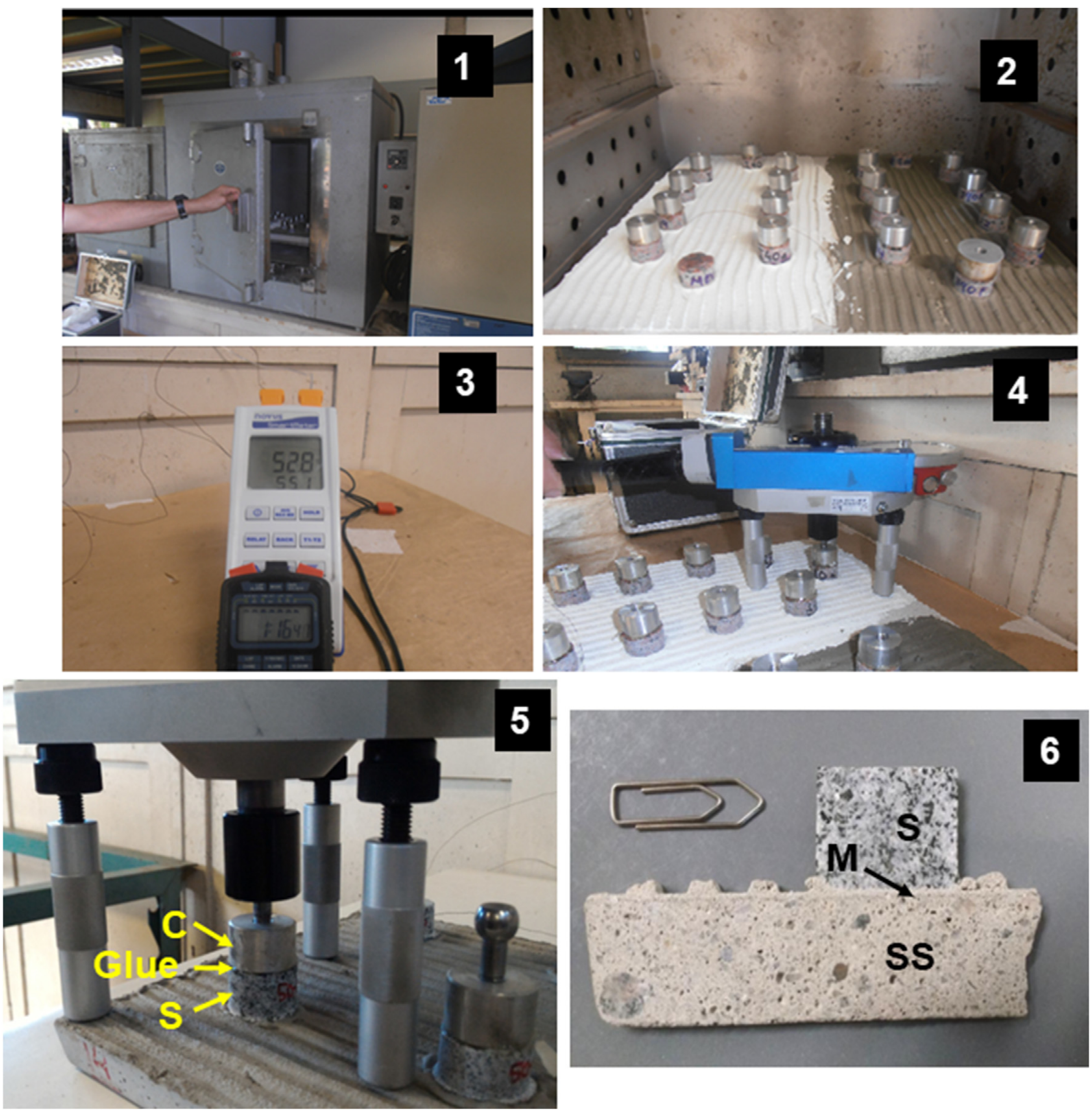

Fig. 3 – (1) Oven; (2) Detail showing substrate/mortar/rock sets and metallic adapters inside the oven; (3) Equipment for continuous control of temperature and heating time of sets in oven (4–5) Details of the equipment used for TBS tests showing the connection between the "C" metal cap glued to the stone and the equipment; (6) Vertical profile (4 mm thick) of a set of rock (S) – mortar (M) – standard substrate (SS) cut with a diamond disk for microstructural analysis.

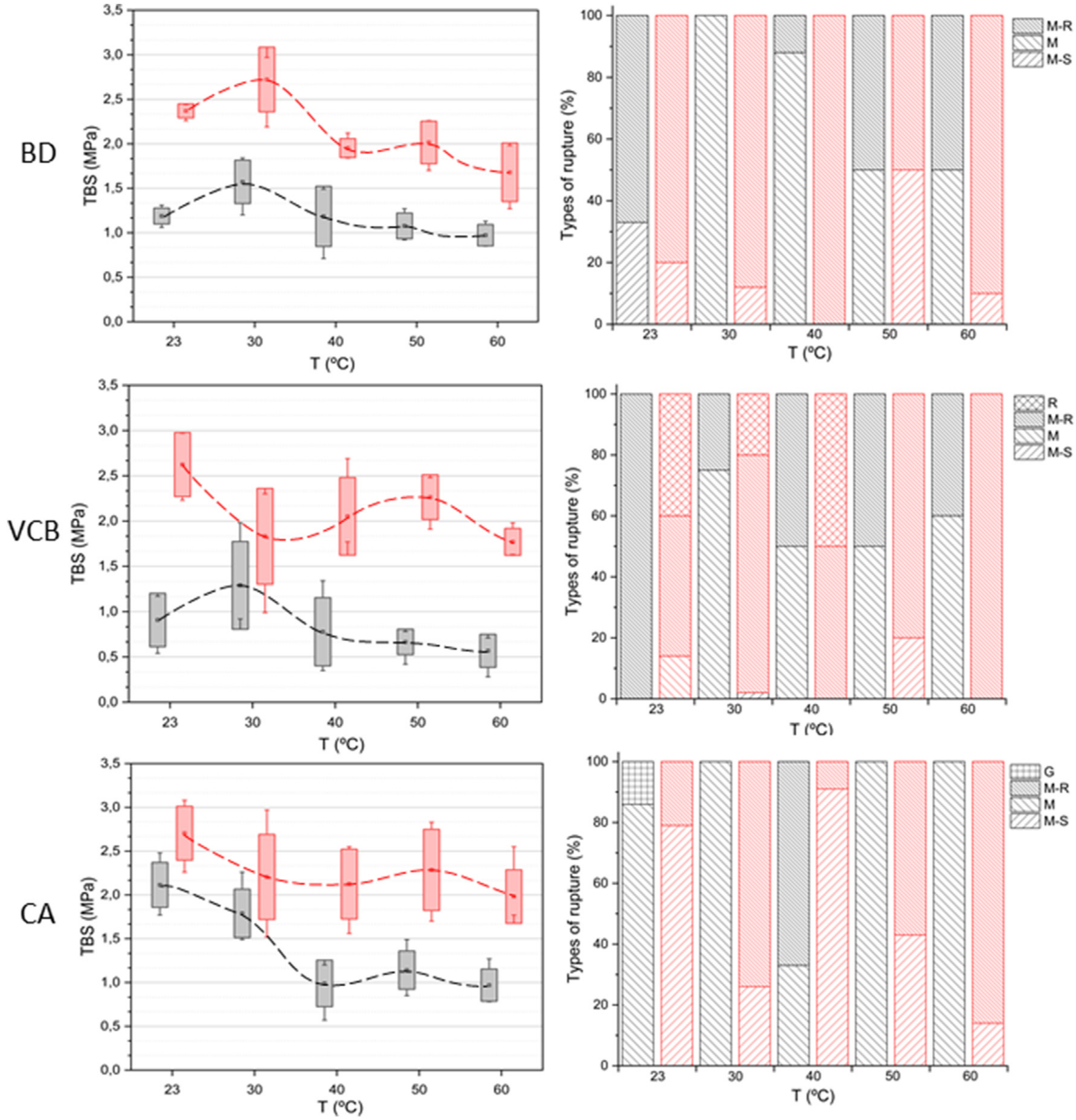

Fig. 4 – LEFT- Box plots of the TBS tensile bond strength results. Commercial mortar (in gray) and M2 mortar (in red). RIGHT-Failure (%) resulting TBS tests: G-glue, R-rock, M-R- mortar/rock interface, M–mortar, M–S mortar/standard substrate interface, and S- standard substrate.

3.3. *Study of the microstructure of rock/mortar interface*

For the microstructural analyses, an extra specimen, here called a "reference sample", was placed in each group of TBS tests. By making post-test perpendicular sections for microscopic observations with reflected light (Figs. 3–6), the objective was to examine the occurrence of adherence by anchorage, chemical reactions, or air bubbles between the rock and the mortar, corroborating data from the literature. More details on methodological procedures and statistical/microstructural analysis can be found in related works [9,10,17,29] (see Fig. 7).

4. Results and discussion

4.1. *Influence of the temperature variation on the adherence of "granite" slabs*

The results of the 160 valid tests performed were grouped according to the two types of mortars used to fix the BD leucogneiss, VCB syenogranite, and CA monzogranite specimens, individualizing the following information by temperature range: TBS tensile bond strength, type of failure and statistical data. The most general trends are discussed, since they

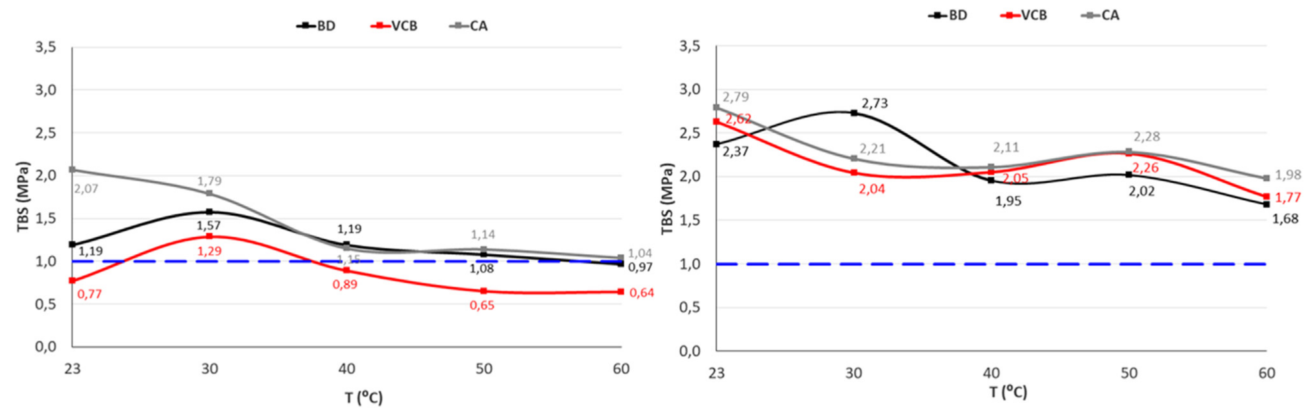

Fig. 5 – Mean adherence values obtained with the CM commercial mortar (LEFT) and the M2 mortar (RIGHT). In dashed (blue), minimum adherence strength recommended for ceramic material [31].

involve 3 types of rocks laid using 2 types of mortar and with the sets subjected to 5 different temperatures.

Considering the increase in temperature, the results of TBS tests presented in Table 3/4 and Fig. 3 revealed that in the CM and M2 mortars, there was a relevant decrease in adhesion, in agreement with studies carried out with ceramics [12,14–16].

The temperature increase in the tests with commercial CM mortar reduced the adhesion values from 17% to 50% (Table 3). This is an important practical aspect as it causes damage to the transition between rock and mortar, with the percolation of water and possible dislocations and pathologies. Among the three rocks studied, the VCB syenogranite presented the lowest values of adherence, ranging from 0.77 to 0.64 MPa. It is a coarse-grained rock, with more quartz, a higher quartz/feldspar ratio (QFR of 0.68), and lower apparent porosity (fewer pores, less anchoring) compared to other rocks; and in adherence tests, smoother and more polished failure surfaces were more common and, in some cases, CPs did not adhere well to the mortar. As for the types of failure in the TBS tests of the VCB syenogranite, the following conditions were observed: 23 °C: failures occurred at the rock-mortar interface (R-M); in other temperatures (30 °C, 40 °C, 50 °C, and 60 °C) predominated the failures in the mortar layer (M) and at the R-M interface. In general terms, patterns of failures similar to those described above were found in the BD leucogneiss, with mixed ruptures at the interface R-M and M. In the CA monzogranite, the ruptures occurred in mortar layer M and, subordinately, with mixed ruptures at the interface R-M and M. Hence, in these cases, the bond strength between the stone and mortar was lower than the bond between the mortar and substrate. Considering as a reference the minimum adherence limit recommended by ABNT for ceramic materials (1 MPa) and the RAT values according to the temperature increase (from 23 °C to 60 °C), it appears that BD gneiss and VCB syenogranite do not meet the requirements, the CA monzogranite was just above this limit.

In the M2 mortar, the temperature increase in the TBS tests reduced the adhesion values from 29% to 32% (Table 4). A comparative evaluation between the two mortars tested (Fig. 5) showed that the M2 mortar (prepared with white cement) clearly showed better adherence, confirming experimental research [31,32], which reported that this mortar was the most suitable in tests with more severe temperature variations (freezing and thawing). Even with an average decrease

Fig. 6 – Partial view of substrates with application of "M2" mortars, after TBS tests of CA monzogranite specimens with 30 mm diameter (LEFT, CENTER) Detail showing failure in the mortar-standard substrate interface (tests at temperatures of 23 °C and 40 °C, respectively) (RIGHT) Detail showing mixed failure (part in mortar and part in substrate) common in tests at temperatures of 60 °C.

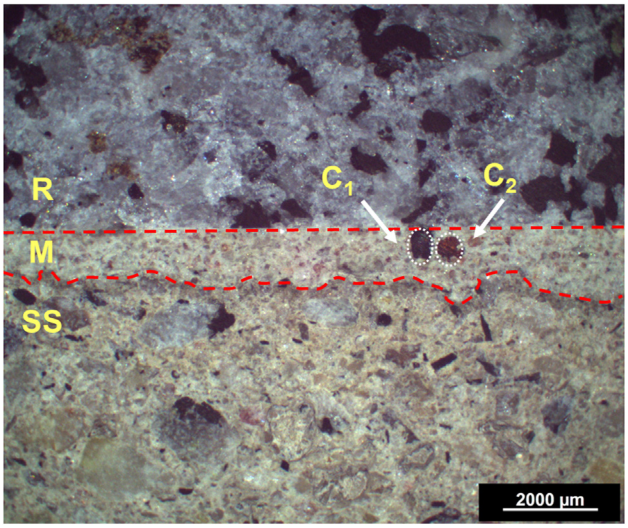

Fig. 7 — Rock/mortar/standard substrate set (R) rock: Cinza Andorinha monzogranite (M) A2 mortar (SS) Standard substrate made by the Brazilian Portland Cement Association (C1 and C2) thermocouple conductors.

of 30% in adherence values with increasing temperature, the tested rocks showed that the TBS remained expressive, with values of 68%, almost twice the minimum adherence limit (1 MPa) recommended for ceramic materials, the reference used here because there is no specific technical standard for stone cladding. As for the rocks studied, the CA monzogranite, a less quartzous and finer-grained rock, presented the highest adherence values, ranging from 2.79 MPa to 1.98 MPa for the M2 mortar. The predominant types of failure at all temperatures tested in VCB syenogranite and BD leucogneiss were mixed ruptures in the rock-mortar R-M and mortar-substrate M–S interfaces. In the case of CA monzogranite, there was a predominance of ruptures at the M–S interface, as shown in Fig. 6. This demonstrates that in tests performed with the M2 mortar, the bond strength between the stone and mortar was higher than the bond between the mortar and substrate.

The aspect verified in the tests carried out by Ribeiro et al. [17] was repeated in the present study with stone slabs fixed with laboratory mortars: despite the general trend of decreasing bond strength with increasing temperature, it was observed a slight increase in resistance at a temperature of 50 °C, compared to resistance values obtained at 40 °C and 60 °C. Research results [15] showed that the increase in temperature was more influential compared to the time of exposure to heat on the adhesion strength of the studied mortars. Related to the changes of the rock-mortar-standard substrate interface at different temperatures, the author also inferred that one of the pathologies in the detachment of plates, when applied on facades, may be related to the temperature at which the ceramic tile fixing system is exposed and the "Tg" glass transition temperature of the additive used in the mortar. It is possible that temperatures higher than the Tg of additives normally used by manufacturers are being used. In this way, theoretically the additives would have a very low viscosity to act in the reinforcement of the adherence resistance, modifying its initial characteristics [33]. This is a very open subject, requiring more detailed studies and a much more representative number of different types of dimension stones.

Finally, high standard deviation values in adherence tests with rocks must be considered, which is even predictable in the case of very heterogeneous materials from the mineralogical and textural point of view.

4.2. *Microstructure studies (standard rock–mortar–substrate interface)*

In terms of analysis, the inspections carried out always showed clear contact between the stone plates (with both

Table 3 — "TBS" tests valid for the BD leucogneiss, VCB syenogranite, and CA monzogranite specimen fixed with the "CM" Commercial Mortar.

T	Material	TBS, in MPa (type of failure)	N	TBS Statistics (MPa)			
				M	SD	MIN	MAX
23 °C	BD	1.31; 1.20 (MR) - 1.20 (MS) - 1.17; 1.06 (MR/MS 15–50%)	5	1.19	0.09	1.06	1.31
	VCB	0.54; 0.64; 1.13 (MR)	3	0.77	0.32	0.54	1.13
	CA	1.77; 1.92; 1.98; 2.12; 2.48; 2.12 (M) - 2.41 (RG)	7	2.07	0.26	1.77	2.48
30 °C	BD	1.63; 1.20; 1.49; 1.84; 1.70 (M)	5	1.57	0.24	1.20	1.84
	VCB	1.98; 1.27 MR/M (50%) – 0.99; 0.92 (M)	4	1.29	0.48	0.92	1.98
	CA	1.77; 1.77; 2.05; 1.56; 1.49; 1.63; 2.26 (M)	7	1.79	0.28	1.49	2.26
40 °C	BD	1.34; 1.20; 1.49 (M) - MR/M (50%)	4	1.19	0.34	0.71	1.49
	VCB	0.57; 1.34; 0.92; 0.71 MR/M (50%)	4	0.89	0.38	0.35	1.34
	CA	0.92; 0.64; 0.64; 1.13; 0.92; 0.85 (MR) - 0.78 (MR/MS 20%)	7	0.84	0.18	0.64	1.13
50 °C	BD	1.06; 0.92; 1.27; 1.06 (MR/M 50%)	4	1.08	0.15	0.92	1.27
	VCB	0.71; 0.78; 0.42; 0.71; 0.71 (MR/M 50%)	5	0.65	0.16	0.42	0.78
	CA	1.06; 0.85; 0.78; 0.71; 1.13; 0.92 (MR) - 0.57 (MR/M 15%)	7	0.86	0.20	0.57	1.13
60 °C	BD	1.13; 0.99; 0.85; 0.92 (MR/R 50%)	4	0.97	0.12	0.85	1.13
	VCB	0.28 (MR) – 0.50; 0.64; 0.71; 0.71 (MR/M 50%)	5	0.64	0.10	0.28	0.71
	CA	0,78; 1.06; 1.13; 1.20 (MR) – 0.92; 1.20 (MR/M 10–20%) - 0.85 (R)	7	1.02	0.17	0.78	1.20

LEGEND: TBS - tensile bond strength; Types of failure (G: glue; R: rock, RM: rock-mortar interface, A: mortar, MS: mortar-standard substrate interface, S: standard substrate); N- number of tests; M-mean; SD: standard deviation; MIN: minimum and MAX: maximum. Some tests were not validated due to poor gluing or inefficient adhesion of the specimen.

Table 4 – "TBS" tests valid for the BD leucogneiss, VCB syenogranite and CA monzogranite specimen fixed with the "M2" Mortar.

T	Material	TBS, in MPa (type of failure)	N	TBS Statistics (MPa)			
				M	SD	MIN	MAX
23 °C	BD	2.26; 2,41 (RM) - 2.44 (RM/MS 20%) - 2.37 (MS/RM 40%)	4	2.37	0.08	2.26	2.44
	VCB	2.90 (M/RM 30%) - 2.23; 2.76 (RM) - 2.97; 2.26 (R)	5	2.62	0.35	2.23	2.97
	CA	2.69; 3.08; 2.69; 2.41 (MS) - 3.08 (RM) - 2.26; 2.72 (MS/MR 15–30%)	7	2.79	0.26	2.26	3.08
30 °C	BD	2.19; 2.94; 2.79 (RM) - 2.97 (RM/MS 50%)	4	2.72	0.36	2.19	2.94
	VCB	2.02 (RM/MS 10%) - 1.66; 2.30; 2.19 (RM) - 0.99 (R)	5	2.04	0.28	0.99	2.30
	CA	1.87; 2.79 (RM) - 2.37; 1.52; 1.91 (RM/MS 30-40-20%) - 2.05; 2.97; 2.16 (MS/RM 10-45-50%)	8	2.21	0.49	1.52	2.97
40 °C	BD	1.91; 1.98; 1.84; 2.12; 1.91 (RM)	5	1.95	0.11	1.84	2.12
	VCB	1.77; 1.91 (R) - 2.69; 1.84 (RM)	4	2.05	0.43	1.77	2.69
	CA	2.12; 1.56; 2.48; 2.48 (MS) – 1.70; 1.98; 2.55 (MS/RM 30-15-20%)	7	2.12	0.40	1.56	2.55
50 °C	BD	1.70; 1.98; 2.26 (MS/RM 50%) – 2.12 (MS/RM 30%)	4	2.02	0.24	1.70	2.26
	VCB	1.91 (RM/MS 25%) - 2.33 (RM) – 2.48; 2.48; 2.12 (RM/MS 20-40-15%)	5	2.26	0.25	1.91	2.48
	CA	1.77 (RM) – 1.70; 2.83; 2.83 (RM/MS 15-30-40%) – 2.05; 2.41; 2.41 (MS/RM 15-30-40%)	7	2.28	0.46	1.70	2.83
60 °C	BD	1.98; 1.91 (RM) – 1.56; 1.27 (RM/MS 15%)	4	1.68	0.33	1.27	1.98
	VCB	1.84; 1.63; 1.63; 1.77; 1.98 (RM)	5	1.77	0.15	1.63	1.98
	CA	1.77; 1.77; 2.55; 1.77 (RM) - 1.84; 1.91; 2.26 (RM/MS 40-40-15%)		1.98	0.31	1.77	2.55

LEGEND: TBS - tensile bond strength; Types of failure (R: rock, RM: rock-mortar interface, A: mortar, MS: mortar-standard substrate interface, S: standard substrate); N- number of tests; M-mean; SD: standard deviation; MIN: minimum and MAX: maximum. Some tests were not validated due to poor gluing or inefficient adhesion of the specimen.

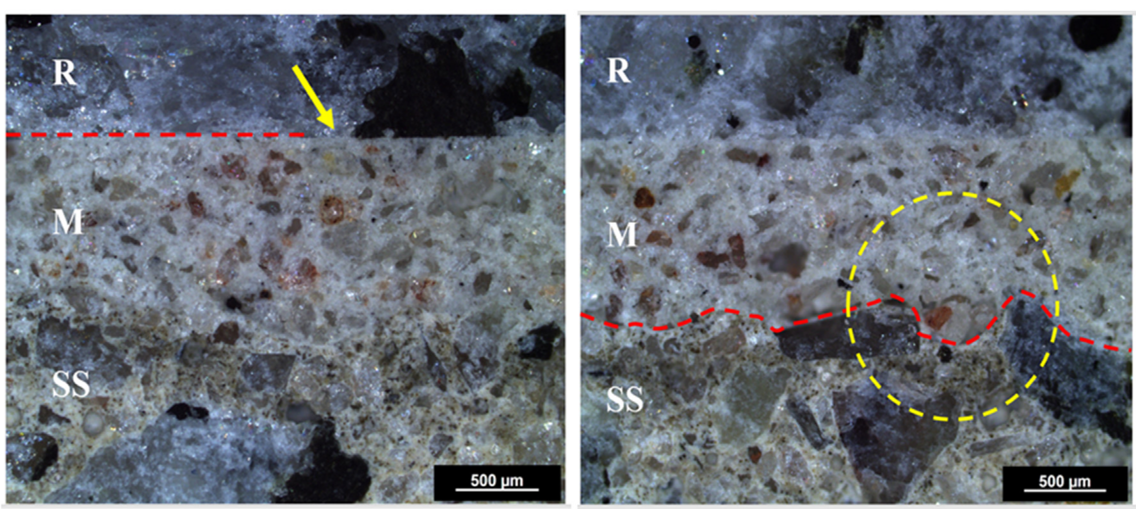

Fig. 8 – Details of the sets rock/mortar/standard substrate (R) rock: Cinza Andorinha monzogranite (M) A2 mortar (SS) Standard substrate. LEFT (arrow): clear contact between rock and mortar with no reaction edges. RIGHT (circle): detail showing anchoring at the standard substrate/mortar interface.

rough and smooth contact surfaces), without the occurrence of reactions or pervasion in the stone. Anchoring only took place in the contact between the standard substrate and the mortars. The studies were carried out under a stereo microscope with reflected light.

As can be seen in Fig. 8, showing a vertical profile of the rock set "Cinza Andorinha"/"M2" mortar/substrate, obtaining a TBS mean value of 1.98 MPa, after subjecting the set to a temperature of 60 °C. Also, observe the C1 and C2 thermocouple conductors used for monitoring the temperature of the set (see Fig. 7).

This level of information was decisive to better understand microstructural relationships of rock-mortar-standard substrate interfaces. In addition to TBS values, the importance of the type of failure was also observed for an integration of the roughness of stone plates, the mineral constituents, and the mortar components.

5. Conclusions

- As an example of the behavior shown by ceramic materials, the test results showed that temperature plays an important influence on the loss of tensile strength.
- This is important information since they seem to indicate a common phenomenon in cementitious mortars subjected

to temperature variations, similar to natural conditions of insolation and humidification, which may lead to detachment and pathologies in external claddings of floor and walls with stone plates.

- In tests with commercial adhesive mortar, the final TBS values were lower or close to 1 MPa, the standard threshold for ceramic tiles. On the other hand, the mortar prepared with white cement showed better performance where, even after the tests, values of adherence of the rocks remained much higher (>68%) than the limit mentioned above. These are expressive results that recommend the continuity of research testing this mortar with other types of rocks, however, the industrial cost of processing and obtaining more expressive white cement must be considered.
- The influence of mineralogy and textural aspects of rocks on adherence values obtained by TBS tests using the two types of mortars is also highlighted. The rock with the highest adherence values was the "Cinza Andorinha" monzogranite, a more homogeneous rock, with a lower percentage of quartz and relatively smaller grain size of minerals compared to the other two materials.
- The microstructure of the material sets subjected to adherence tests with adhesive mortars was also investigated. The procedures adopted proved to be adequate with the joint evaluation of TBS values, the type of failure, the roughness and mineralogy of the rock, as well as the mortar components.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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