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Feasibility of using a vibrating machine for laying ceramic tiles

Abstract

Inadequate practices are still present in the day-to-day of the works when performing the ceramic tile laying service. The coating laying machine comes as a proposal to improve the execution process of this service, guaranteeing higher quality. The general objective of this work is to verify the quality of the ceramic tile laying service using a vibrating laying machine. Eight pieces of porcelain tiles measuring 60x120 cm were laid in order to verify the differences in the quality of laying the pieces using the vibrating machine and the rubber hammer. The quality was verified following two requirements, mortar compaction and the adherence resistance of the pieces. The use of a vibrating machine for installing ceramic tiles improves the quality of the service, as well as makes its application viable in laying coatings. The mortar compaction was better in the pieces settled using the vibrating machine. Adherence to the pieces laid using the vibrating machine was, on average, twice that stipulated by the regulatory standard, whether using one or two layers of mortar. It is noteworthy that there were no cases of rejected values. The use of the vibrating machine proved to be high compared to the traditional laying method, which makes it legitimate to lay pieces with surface area dimensions greater than 900 cm², using only a single layer of mortar. Adherence to the pieces laid using the vibrating machine was, on average, twice that stipulated by the regulatory standard, whether using one or two layers of mortar. It is noteworthy that there were no cases of rejected values. The use of the vibrating machine proved to be high compared to the traditional laying method, which makes it legitimate to lay pieces with surface area dimensions greater than 900 cm², using only a single layer of mortar. Adherence to the pieces laid using the vibrating machine was, on average, twice that stipulated by the regulatory standard, whether using one or two layers of mortar. It is noteworthy that there were no cases of rejected values. The use of a vibrating machine proved to be high compared to the traditional laying method, which makes it legitimate to lay pieces with surface area dimensions greater than 900 cm², using only a single layer of mortar.

Keywords: vibrating machine, ceramic coating, traditional settlement, gri, quality

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Gabriel Dal Ross, Francielle Coelho dos Santos

Department of Civil Engineering, Federal Institute of Education, Science and Technology of Goiás - Campus Jataí, Brazil

Correspondence: Francielle Coelho dos Santos, Department of Civil Engineering, Federal Institute of Education, Science and Technology of Goiás - Campus Jataí, Jataí, Goiás, Brazil, Email francielle.santo@ifg.edu.br

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Introduction

The coatings market

According to the National Association of Manufacturers of Ceramics for Coatings, Sanitary Ware and Related Products (ANFACER), Brazil is the third largest producer of ceramic coatings in the world and the second largest consumer of the material, and in 2019 production reached 909 million square meters.[1] Based on this high consumption of ceramic material, it is understood that there is a need for specialized labor to carry out the laying service.

The lack of adequate labor leads to an incorrect execution of the coating laying service, which may cause damage to property owners. One of the main causes of problems with coatings is erroneous practices when laying the piece, such as not using the double layer of adhesive mortar on pieces larger than 900 cm², as described in item 5.7.7 of NBR 13.753:1996 - Internal or external floor covering with ceramic tiles and using adhesive mortar – Procedure. The absence of this practice generates productivity gains, due to the lesser movement required by the performer, but it can cause pathologies such as the ceramic piece coming off or the hollow sound of poorly fixed coating.

In legal instances, specifically in the Court of Justice of the Federal District and Territories (TJDFT), there are lawsuits related to defects in the service of installing coatings in new buildings, as reported by the applicant, in which "the coating had cracks and cracks, with infiltrations at several points, causing detachment, requiring immediate repair. In addition, the floor had ripples, which generated water retention, with a risk of insect proliferation".[2] The judge's opinion in this case is as follows: "The judge of the 16th Civil Court of Brasília condemned the construction company RV LTDA to pay the owner of a new apartment in the construction company's building the amount of R$ 21,501.44 for reimbursement of expenses with problems in the immovable".[2]

These flaws in the executive practices of the laying method of ceramic tiles were analyzed by Hoffman and Longo[3] in external areas under the execution and management of two different civil construction companies, in which the authors verified that it existed in both laying processes, nonconformities with the recommendations and requirements made by the NBR 13.753 standard.[4]

With regard to improving the technique for laying coatings, several brands have developed products that aim to deliver practicality and speed to the performer, maintaining the quality standards required by the NBR's. The brands Quartzolit, Portokoll and Votorantin are today the main suppliers of adhesive mortars in the Brazilian market. Portokoll's special single-layer fluid mortar promises to deliver adherence that satisfies regulatory requirements, dispensing with the practice of using a double layer on parts with an area greater than 900 cm², as mentioned in NBR 13,753.[4]

At the same time, in the Brazilian market, the company Khaata Tools has introduced equipment that vibrates the piece to generate the density of the adhesive mortar and perform a quality fixation, seeking to maintain the high productivity index without infringing the normative recommendations, as shown in Figure 1A. In this research, a similar equipment imported from China by the YS-H brand (Figure 1B) will be used, due to the unavailability of the Brazilian version.

Figure 1 (A) Machine for laying ceramic tiles, brand Khaata Tools and (B) equipment used for the development of this research, brand YS-H.

Success story of new executive methods in civil construction

Havingin view of the gain in productivity and quality due to the type of equipment used in this study, it is possible to cite some successful occurrences of other modernized models of executive systems for civil construction services, which demonstrate the importance of implementing technologies in the construction site.

Among them, we can mention the study carried out by Souza (2018), who analyzed the service of coating walls executed in industrialized projected mortar, the commonly known projected plaster, which is a mechanical system for executing the plastering service of masonry in a modern and productive. Similar to the conventional procedure where the employee sprays the mortar on the wall in small amounts, manually as seen in Figure 2A, the mechanical system uses a machine that works as a kind of mortar jet, projecting the mortar on the wall, continuously, exemplified in Figure 2B.

Figure 2 (A) Exemplification of the practice of manual plastering and (B) illustration of the mechanized process of projected plastering.

Souza[5] proved that the most modern method of execution, the designed plastering system, was 2.5 times more productive and 15.22% more economical.

Another case of technology implementation at the construction site that resulted in gains in productivity, quality and economy was the use of self-levelling subfloor technology, reported in the study carried out by Araújo and Ramires.[6]

The subfloor is the smoothing layer that precedes the ceramic coating on floors, and its conventional method of execution is the use of a dry mortar, called "farofa" on site, due to its heterogeneous appearance, seen in Figure 3. It is evenly mirrored through the base where the regularization will be carried out, and compacted in order to thicken and promote resistance.

Figure 3 Exemplification of the dry and heterogeneous aspect of conventional subfloor mortar.

Seeking gains in the executive process, the self-levelling subfloor system was developed, in which a fluid and homogeneous mortar is used, exemplified in Figure 4, which, when thrown under the base, spreads easily and evenly, providing an already leveled and uniform layer. at the end of the service, promoting productivity and service quality. The main difference between traditional subfloor mortar and self-levelling mortar is the special additives in its composition, which control the viscosity and increase the fluidity of the material.

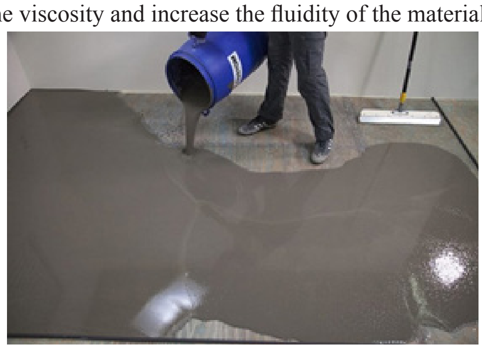

Figure 4 Example of self-levelling subfloor mortar.

Araújo and Ramires[6] analyzed the two execution processes in three towers, from which they measured the cost of executing the service.

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In tower A, where the conventional subfloor was used, the cost was R$118,270.46, and the execution cost in tower B, which used the self-leveling subfloor system, was R$62,546.88. Based on this data, there is a reduction in costs that borders on the margin of 45%, that is, the use of the more modern system reduced the total price of the service by almost half, when compared to the conventional system. The self-leveling subfloor system was adopted in tower C.

Research hypotheses

The chancesthat supported the development of this article were:

Hypothesis 1: The use of this equipment can standardize the execution of the coating installation service, thus guaranteeing greater reliability, since the mechanical process presents adjustment of the applied consolidation force, a factor absent in the manual procedure recommended by NBR 13.753.[4]

Hypothesis 2: The possibility of using only one layer of mortar in pieces with dimensions greater than 900 cm² is speculated, based on the fact that with better consolidation of the mortar, adhesion can be obtained with just a single layer, equal or greater to that achieved by the conventional method with manual consolidation and double layer, thus generating more speed in service and material savings.

Justification

The use of new, more modern and technological construction systems generate gains in production, quality and cost reduction, as seen in the two models presented, projected plaster and self-leveling subfloor.

Also, as found in the study by Hoffman and Longo,[3] inadequate practices are still present in the day-to-day work of the works when performing the ceramic tile laying service. The machine for installing coatings, like the one used in this research, comes as a proposal to modernize the execution process of this service, in the same segment of the new construction methods mentioned above, projected plaster and self-leveling subfloor, which aimed at productivity, quality and reduction of costs by implementing a new technology.

The interest in proposing an analysis of the laying method with the use of the studied equipment is therefore justified, in view of the large market for coating services, the success story of other innovative methods and the established hypotheses for improvement. Therefore, the general objective of this work is to verify the quality of the ceramic tile laying service using the vibrating laying machine and to determine its viability regarding the possibilities of improving the service.

Installation of ceramic coating

Normative method

As a theoretical basis for the elaboration of any research in the field of the executive process of ceramic coating, there is NBR 13.753.[4] It is the norm that prescribes the appropriate practices for the execution of such service. It specifies which tools and which executive practices must be adopted during the service.

In a light way, the standard determines a sequence of steps for laying pieces with dimensions greater than 900 cm², called in this work as large format pieces, which are visualized from item 5.7.7.1 onwards as:

1. Spread and comb the adhesive mortar on the subfloor and on the back of the ceramic tiles
2. Apply each ceramic tile slightly out of position, in order to cross the cords of the back and subfloor and then press it, dragging it to its final position
3. Once the final position is reached, apply high frequency manual vibrations, transmitted through the fingertips, trying to obtain the greatest possible accommodation that can be seen when the adhesive mortar flows on the edges of the ceramic tile

In item 5.7.8, the standard complements by determining that "in the application of ceramic tiles, the mortar cords must be completely undone, forming a uniform layer, configuring total impregnation of the back by the adhesive mortar".[4] This process is illustrated in Figure 5.

Figure 5 Exemplification of broken mortar cords promoting impregnation of the piece.

In a similar way to what is determined by the standard, the use of a rubber hammer is found in the day-to-day work, used to replace manual vibrations, so that the impact caused by the action of the hammer acts to densify the mortar and crush the cords.

Failures present in the execution of the coating laying service

In a study developed by Andrade,[7] there was a monitoring of the installation of porcelain tiles with dimensions greater than 900 cm² in seven different cases, with different professionals in charge of the service. At the end of the analysis, it was possible, according to Andrade,[7] to verify the lack of care and techniques on the part of the professional settlers, proven through the tests, where the ceramic pieces were erected after their laying and it was possible to observe that in all seven cases the mortar cords had not been completely crushed. In all seven cases, the author identified that traditional consolidation practices were used, through percussion with a rubber hammer.

With such data in hand, a certain flaw in the traditional method of laying using a rubber hammer is noticeable. There are other factors that also led to the inconsistencies reported in the study by Andrade[7] at the time of checking the service, but the use of a rubber hammer was present in all cases, and proved to be an inefficient method, in the case of parts of large sizes.

Adherence

Definitions and forms of measurement

The factor that measures the effectiveness of the laying process, whether manual or mechanical, is adherence. Simply put, according to Oxford Languages (2020), adhesion means "the union of one thing with another", which in this research will be understood as the union between the ceramic piece and its substrate, the subfloor. This union is promoted by the adhesive mortar.

According to Carasek,[8] the adhesion between a porous substrate such as the subfloor and the adhesive mortar occurs through an essentially mechanical phenomenon. This phenomenon is characterized by the transfer of water that occurs between the mortar and the substrate, allowing the entrance of the cement paste into the pores of the substrate, which promote the anchoring of the coating. The author identified through microscopy the morphology and nature of the products formed in this region, and stated that the interlocking of crystals in the pores of the substrate was mainly responsible for the adhesion resistance. Still according to Carasek[9] a possibility of increment of adherence is related to the impact energy applied at the moment of the execution of the laying of the ceramic pieces.

The measurement of this bonding factor, adherence, is instrumentally determined by the test described in the NBR 13,753 standard – Annex A.[4] The test uses equipment that continuously applies a traction force to a metal tablet glued under the surface of a coating specimen, in order to verify the force required to pull this specimen out. The execution is due in stages, and begins with the choice of specimens, which according to the standard, must be established 6 specimens per test. Then, they are instructed to prepare the test specimens, where it is determined that the test specimens should be cut, since they have dimensions of 100x100 mm, be cleaned in order to remove loose particles of dirt and then perform the bonding of the metal insert on them. After gluing the tablets, the traction equipment can be positioned and the test can be performed, verifying the force necessary to pull out the specimen. Figure 6 presents a diagram of this tablet-glue-test piece system.

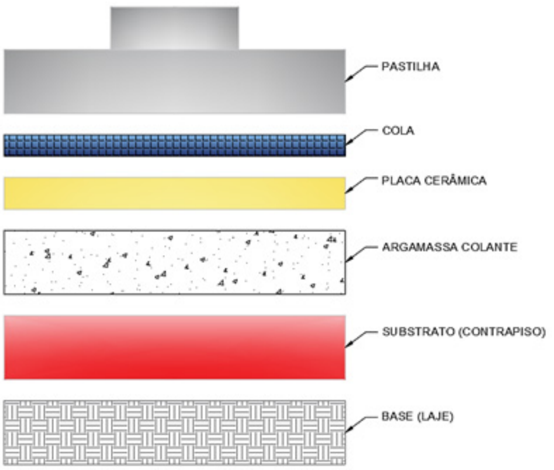

Figure 6 Schematic section of the system used in the adhesion resistance test.

After carrying out the test, the force must be observed on the equipment display, and the form of rupture. The force on the dial (P) is given in newtons, and must be divided by the surface area (A) of the insert, in square meters, to determine the bond strength (R) in megapascals (Equation 1). The minimum resistance established by standard is 0.3 MPa.

$$R = \frac{P}{A} \tag{1}$$

Regarding the form of rupture, it can occur in 7 different ways, illustrated in Figure 7:

1. Rupture at the ceramic tile/adhesive mortar interface
2. Rupture inside the adhesive mortar
3. Rupture at the adhesive mortar/substrate interface
4. Rupture inside the substrate mortar
5. Rupture at the substrate/base interface
6. Rupture inside the base
7. Rupture at the tablet/glue interface or
8. Rupture at the glue/ceramic plate interface

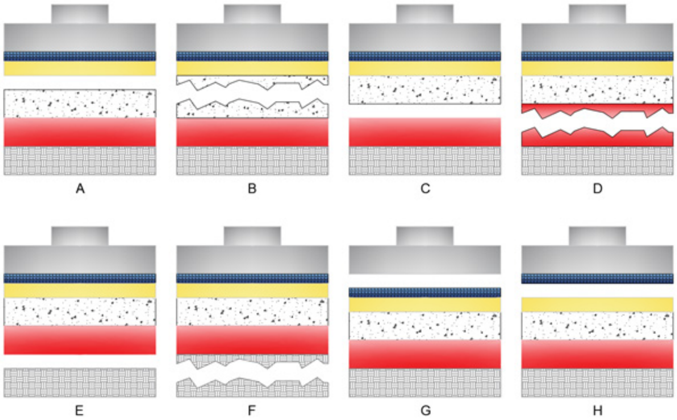

Figure 7 Forms of rupture in the bond strength test of ceramic tiles laid with adhesive mortar.

Coating laying machine

General description: The vibrating machine for installing coatings aims to optimize the execution of this service, meeting the requirements established in NBR 13,753.4 This equipment consists of a set of suction cup and motor, which generates controlled vibrations in the coating. In its operation, the suction cup works under the action of the lever present in the equipment, exerting suction force on the piece, facilitating handling when picking up and positioning the piece under the base. With the piece placed under the base, the motor vibration intensity is adjusted, then the motor is pressed against the piece, activating the vibration function, which will thicken the mortar by crushing the cords, replacing the force applied by the hands or by the rubber mallet used in the normative method.

Brazilian version with patent registration: Searching for the possible origins of this equipment, a patent application was found in Brazil by a group of 5 people[10] regarding equipment very similar to the one that will be used in this research. The version of the equipment from this group was designed as a portable tool powered by a power cable, consisting of a rotary engine system that transferred vibrations to the ceramic piece through a rubberized dampening base, shown in Figure 8. The title of the patent application was "Mechanical vibrator for ceramic laying", and the order number was BR1020120211408A2. The patent application describes the functions of the equipment and clarifies that the equipment provides simple handling, as it does not require practice or skill from the operator, guarantees the reduction of time spent in the service.

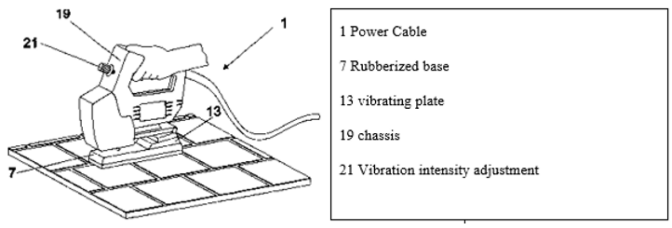

Figure 8 Mechanical vibrator for laying ceramic cadar under patent application BR1020120211408A2.

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Version sold in Brazil: In Brazil, the company Khaata Tools sells a version similar to that found in the aforementioned patent application, but with differences such as the power supply, in which the Khaata model (Figure 9) is powered by a portable and rechargeable battery, whereas the patent model is powered by power cord. Another difference is the fact that the Brazilian model has a suction cup in its contact area, contrary to the patented one, which only has a rubberized base plate.

Figure 9 Machine for laying ceramic tiles sold by the brand Khaata Tools.

Comparison between the version marketed in Brazil and the one used for analysis

The commercially available coating laying machine models are comprehensive, but for the most part they are only available in the foreign market. As seen so far, there is only one model sold in Brazil, sold by Khaata Tools. However, due to the unavailability of this model at the time of purchase, it was decided to import equipment from the YS-H brand (Figure 10), sold in the Chinese market and available for purchase on the Banggood website.

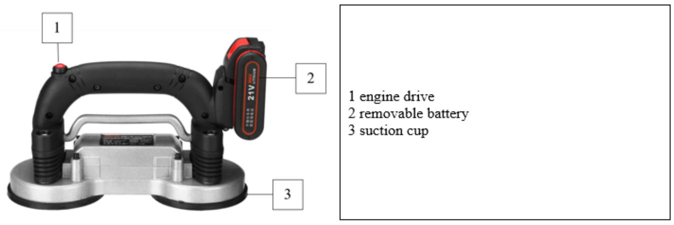

Figure 10 Variant of the YS-H ceramic tile laying machine marketed in Brazil by the Banggood website.

Comparing both versions one finds subtle but important differences between them. The chosen model (Figure 9) presents better characteristics in relation to the Brazilian model (Figure 8), such as, for example, the chosen model is equipped with two suction cups with a total load capacity of 200 kilograms and a battery of five thousand milliamps, whereas the version Brazilian has only one suction cup with a total load capacity of 25 kilograms and a battery of two thousand five hundred milliamps.

Methodology

An experimental research was carried out in this work, seeking to achieve the above objectives. As a guide for the activities to be developed, NBR 13753:1996 was the normative basis.

The delimitation of this research is reserved for the interval defined by the moment of application of the mortar on the piece, until the moment after the mortar has cured, in which the coating is released for transit, or in this case, released for carrying out the pull-out test, and under the caveat , in the case of pieces with dimensions greater than 900 cm² of surface area and excluding the grouting procedure. What precedes the beginning of the service, such as the curing period of the subfloor, cleaning the site, preparing the mortar and the like were not part of the scope of this research. The focus was entirely on laying the piece, as this is what the equipment described in the work proposes to do.

The materials used were:

1. Toothed steel trowel 10mm x 10mm x 10mm
2. Trowel
3. Rubber hammer
4. Coating laying machine (YS-H brand model, imported by the Banggood sales site – acquired by the author of this work)
5. Mortar container
6. Mortar mechanical mixer
7. Traction equipment
8. Tablet
9. Coating cutting device
10. Spatula
11. Polished Porcelain Tile 120cm x 60cm

The execution parameters will follow a basic executive flow, based on NBR 13753 (ABNT, 1996), which comprises the following sequence:

1. Laying the ceramic piece to the substrate
2. Verification of the state of compaction of the mortar
3. Laying new pieces to measure adherence
4. Performance of the adhesion resistance determination test

Eight samples were defined for the test, four samples for visualizing the kneading of the mortar beads still in the fresh state and four for the adhesion resistance test. Regarding the executive procedure for laying the pieces, the following order was followed in both the two checks carried out:

Laying the piece using a single layer of mortar and compaction by percussion with a rubber hammer

1. Placement of the piece using a double layer of mortar and consolidation by percussion with a rubber hammer
2. Laying the piece using a single layer of mortar and compaction by mechanical vibration using the equipment
3. Laying the piece using a double layer of mortar and compaction by mechanical vibration using the equipment

It should be noted that items a and c deviate from the norm, since they were executed with a single layer of mortar in large format pieces1.

After laying the first four pieces, using a rubber hammer and also a vibrating machine, a visual check was made of the state of consolidation of the mortar and a photographic record of each sample was made.

Once the verification of mortar compaction was finished, the other four pieces were laid, these destined to be tested to determine the adherence resistance. After 46 consecutive days from the laying date, the pullout test was performed by a qualified professional, working in a specialized laboratory.

The design of this research can be better visualized in the flowcharts of Figure 11 and Figure 12 respectively.

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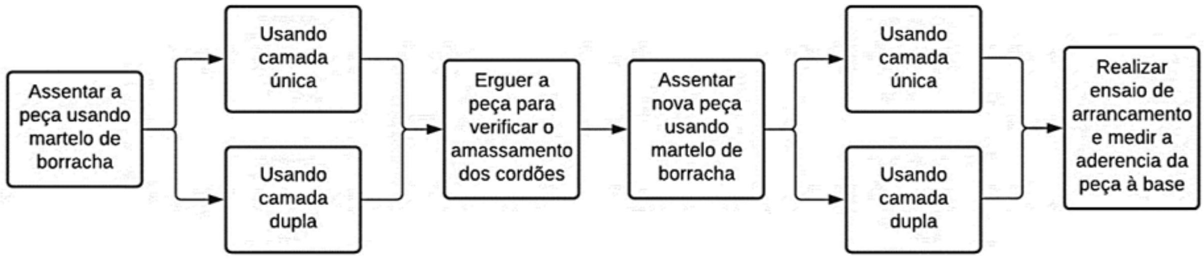

Figure 11 Flowchart of the executive process using the method of consolidation by percussion with a rubber hammer.

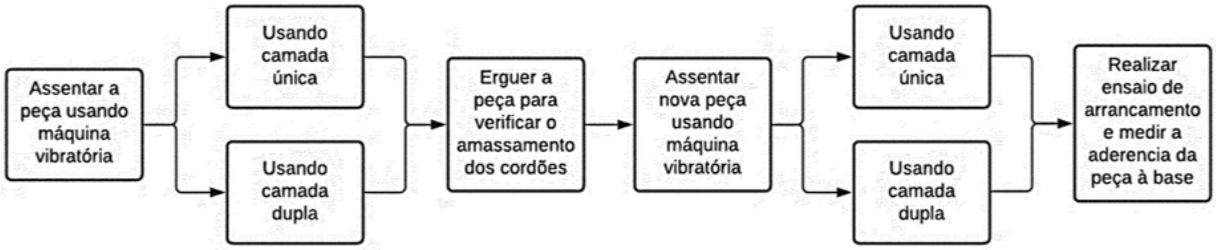

Figure 12 Flowchart of the executive process using the method of compaction by vibration with a machine for laying ceramic tiles.

The delimitation of this research is reserved for the interval defined by the moment of application of the mortar on the piece, until the moment after the mortar has cured, in which the coating is released for transit, or in this case, released for carrying out the pull-out test, and under the caveat , in the case of pieces with dimensions greater than 900 cm² of surface area and excluding the grouting procedure. What precedes the beginning of the service, such as the curing period of the subfloor, cleaning the site, preparing the mortar and the like were not part of the scope of this research. The focus was entirely on laying the piece, as this is what the equipment described in the work proposes to do.

The materials used were:

1. Toothed steel trowel 10mmx10mmx10mm
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5. mortar container
6. Mortar mechanical mixer
7. Traction equipment
8. Tablet
9. Coating cutting device
10. Spatula
11. Polished Porcelain Tile 120cmx60cm

The execution parameters will follow a basic executive flow, based on theNBR 13753,[4] which comprises the following sequence:

1. Laying the ceramic piece to the substrate
2. Verification of the state of compaction of the mortar
3. Laying new pieces to measure adherence
4. Performance of the adhesion resistance determination test

Eight samples were defined for the test, four samples for visualizing the kneading of the mortar beads still in the fresh state and four for the adhesion resistance test. Regarding the executive procedure for laying the pieces, the following order was followed in both the two checks carried out:

1. Laying the piece using a single layer of mortar and compaction by percussion with a rubber hammer
2. Placement of the piece using a double layer of mortar and consolidation by percussion with a rubber hammer
3. Laying the piece using a single layer of mortar and compaction by mechanical vibration using the equipment
4. Laying the piece using a double layer of mortar and compaction by mechanical vibration using the equipment

It should be noted that items a and c deviate from the norm, since they were executed with a single layer of mortar in large format pieces[1]. After laying the first four pieces, using a rubber hammer and also a vibrating machine, a visual check was made of the state of consolidation of the mortar and a photographic record of each sample was made.

Once the verification of mortar compaction was finished, the other four pieces were laid, these destined to be tested to determine the adherence resistance. After 46 consecutive days from the laying date, the pullout test was performed by a qualified professional, working in a specialized laboratory.

Once the experimental phase was concluded, data were collected from another 82 tests of adhesion resistance in floor coverings, installed in different works using the traditional method with a rubber hammer, in order to promote a comparative analysis with the results obtained by the author.

After all data collection, both those obtained directly via own tests and data obtained through third-party tests, the results were analyzed in order to determine the viability of using the machine for laying ceramic tiles.

[1]Parts with a surface area greater than 900cm².

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Results

The results of this research were obtained through the stipulated methodological processes and are presented below.

Kneading of mortar cords

After laying, the four pieces of polished porcelain tile measuring 60x120 cm were lifted to visually verify that the mortar cords had been crushed. Two pieces laid using the vibrating machine were used, one with a single layer (Figure 13A) and the other with a double layer (Figure 13B) and two other pieces laid using the rubber hammer, also with one piece using a layer mortar layer (Figure 14A) and another with a double layer (Figure 14B).

Visually analyzing the samples, a higher level of mortar impregnation was noticed in the pieces applied using the vibrating machine, and in the pieces laid with only one layer of mortar, the higher level of kneading of the cords was more evident. The difference in consolidation in the pieces laid with a double layer was more subtle, but it was still possible to see greater impregnation in the piece in Figure 13B.

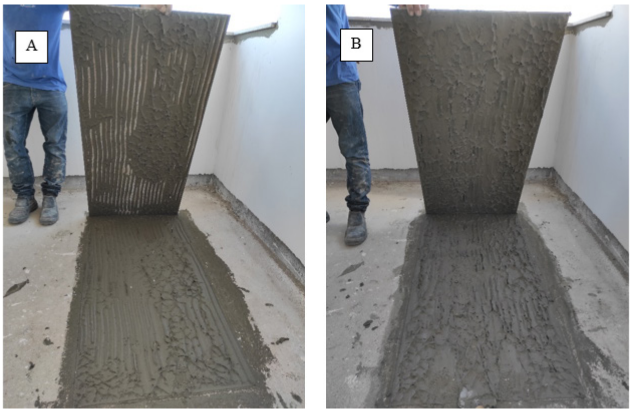

Figure 13 (A) View of the kneading of the mortar cords of the 60x120 cm porcelain tiles laid using the vibrating machine with a single layer of mortar and (B) a double layer.

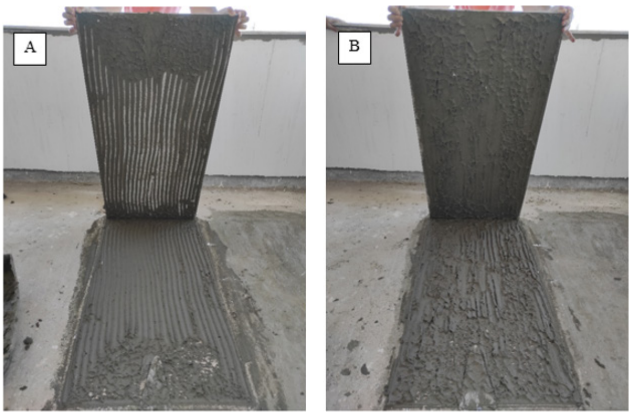

Figure 14 (A) View of the kneading of the mortar cords of the 60x120 cm porcelain tiles installed using a rubber hammer with a single layer of mortar and (B) a double layer.

Adhesion resistance test

Following the verification of the quality of laying by visualizing the kneading of the mortar cords, another four new pieces were laid, following the established methodological process.

Preparation of parts and performance of the test: After 46 days from the laying date, the bond strength test determined by NBR 13.753 – Annex A[4] was carried out. The assay was administered by a specialized laboratory. The values obtained, as well as the form of rupture, are recorded in Tables 1 and 2, with respective averages of 0.63Mpa and 0.56Mpa in the pieces laid with the vibrating machine and 0.45Mpa and 0.38Mpa in the pieces laid with rubber mallet. The form of rupture of each specimen was recorded photographically and are visualized in Figures 15 and 16.

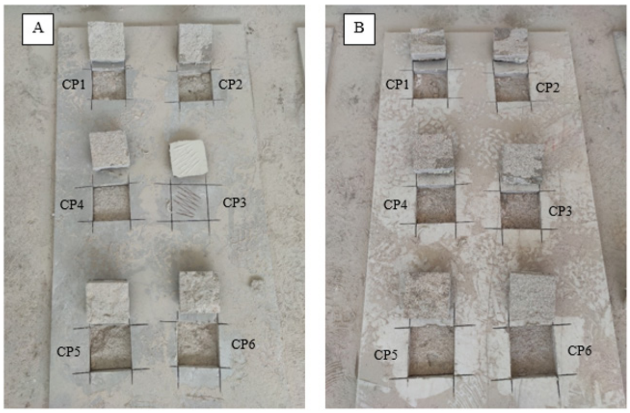

Figure 15 (A) Specimens extracted from porcelain tiles laid using a vibrating machine with a single layer of mortar and (B) a double layer.

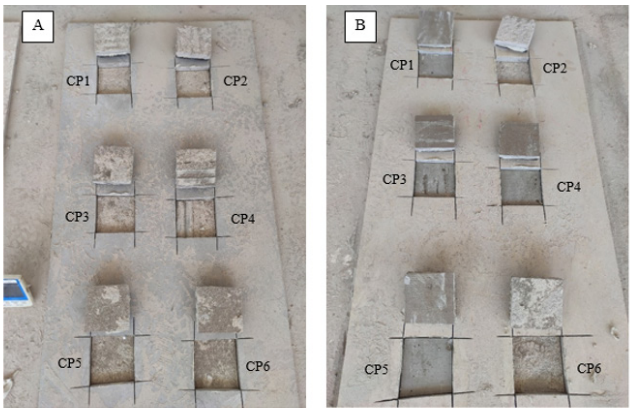

Figure 16 (A) Specimens extracted from porcelain tiles laid using a rubber hammer with a single layer of mortar and (B) a double layer.

Table 1 Results of breaking stresses of specimens settled using the vibrating machine

Single Layer - Machine			Double Layer - Machine		
CP	Voltage (Mpa)	Break	CP	Voltage (Mpa)	Break
I	0.79	D	I	0.59	W
two	0.74	D	two	0.62	D
3	0.63	H	3	0.61	D
4	0.56	D	4	0.59	D
5	0.5	D	5	0.32	D
6	0.6	D	6	0.65	D

Table 2 Results of the rupture tensions of the specimens settled using the rubber hammer

Single layer - Hammer			Double Layer - Hammer		
CP	Voltage (Mpa)	Break	CP	Voltage (Mpa)	Break
I	0.43	W	I	0.3	A
two	0.49	W	two	0.48	D
3	0.55	W	3	0.28	A
4	0.22	W	4	0.36	A
5	0.6	W	5	0.38	A
6	0.41	W	6	0.49	D

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The forms of rupture are described according to the following nomenclature:

A – Rupture at the ceramic tile/adhesive mortar interface

B - Rupture inside the adhesive mortar

C – Rupture at the adhesive mortar/substrate interface

D – Rupture inside the substrate mortar

E – Rupture at the substrate/base interface

F – Rupture inside the base

G – Rupture at the tablet/glue interface

H – Rupture at the glue/ceramic plate interface

Discussion

There were different ways of rupture of the specimens, indicating which was the point of least resistance, for example, if the rupture occurred inside the substrate, this was the point of least resistance of the system. It is understood that in this case, both the tile glue, the ceramic piece/mortar interface and the mortar/substrate interface resisted the force and the subfloor mortar did not resist, breaking.

This specific case, of breakage inside the substrate, leaves the real value of adhesion resistance open, since the force supported by the ceramic tile/mortar interface was not measured in its entirety, after all it resisted the applied force, and who broke it -if it was the substrate, being it the limiting factor. Therefore, in this case, it can be admitted that the strength of the adhesion resistance of the porcelain tile with the substrate would actually be even greater than the registered value. It was observed that the resistant tension results of the parts laid using the vibrating machine were mostly double the minimum value specified by the standard of 0.30 MPa, in addition to the coatings laid with a single layer obtained a value greater than 0.30 MPa minimum, even though this is a practice considered incorrect by current legislation.

Still on the results referring to the pieces laid using the vibrating machine, when analyzing the forms of rupture, it is noticed that in 9 of the 12 specimens, the rupture occurred in the mortar of the substrate, that is, the maximum value of adhesion resistance was not effectively measured, as the subfloor was the limiting factor, since it was the least resistant point of the system. This fact makes it clear that the actual resistance results of the adherence of the parts to the substrate would be even greater than those measured if the substrate resistance had not limited the test.

In turn, the results of resistant tension of the parts settled using the rubber hammer had in both models, single and double layer, one of the test specimens with values in disagreement with the minimum stipulated by standard, the CPs 4 (single layer) and 3 (double layer), highlighting the failures of the method, after all there was no complete and efficient bonding of the ceramic piece. However, the average resistance values of the pieces laid with a single and double layer, respectively 0.45 Mpa and 0.38 Mpa, meet the standard stipulation of 0.30 Mpa.

Analyzing the forms of rupture of the pieces settled with a rubber hammer, it is verified that the rupture in the single layer system, happened mostly at the mortar/substrate interface. Such ruptures did not have a limiting factor, that is, the measured value was effectively the adherence resistance of the pieces. In the double layer system, most of the breakages were at the ceramic tile/mortar interface, where in this type of breakage the value found is also not limited, representing the maximum value of the adhesion obtained. Above all, there were two specimens with rupture inside the substrate, so in this case, the real values were limited by the type of rupture, making possible the fact that the real average of the resistant stresses in this system was greater than the measured one.

A collection was made, together with a specialized laboratory, of data from 82 specimens of adhesion resistance tests, carried out by third parties in several works with ceramic pieces laid by the traditional method using a rubber hammer. These data are presented in Table 3 and Table 4, where the resistance and rupture results found in all tests are presented, as well as the percentage of each type of rupture that occurred. In none of the tests was there a specification whether a single or double layer of mortar was used, however, all parts tested had dimensions with a surface area greater than 900 cm². All tests were performed on porcelain tiles.

Table 3 Results of rupture tensions and rupture form of specimens of ceramic pieces tested by third parties

0.38	W	0.47	H	0.8	W	0.42	W	0.52	A	0.02	A	0.23	A
0.52	W	0.51	B	0.38	A	0.32	A	0.58	H	0.71	A	0.43	B
0.34	D	0.47	A	0.5	A	0.57	A	0.72	H	0.41	A	0.46	D
0.24	W	0.47	H	0.51	A	0.45	W	0.67	H	0.75	A	0.45	W
0.19	W	0.4	W	0.5	A	0.46	W	0.76	H	0.7	A	0.05	A
0.41	W	0.36	H	0.45	A	0.3	W	0.85	H	0.72	A	0.33	A
0.37	B	0.39	B	0.56	B	0.4	W	0.37	B	0.37	H	0.53	A
0.36	A	0.41	W	0.63	H	0.48	W	0.4	H	0.42	H	0.63	A
0.51	H	0.4	D	0.5	H	0.37	W	0.34	B	0.32	B	0.68	H
0.29	A	0.48	B	0.48	H	0.29	W	0.38	H	0.23	W	0.52	A
0.33	A	0.37	B	0.44	H	0.27	W	0.4	H	0.36	A		
0.51	B	0.29	B	0.53	B	0.31	W	0.42	H	0.09	A		

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Table 4 Percentage of each type of rupture that occurred

Percentage of types of rupture	
Type of Rupture	**% occurrence**
A	31.71%
B	15.85%
W	24.39%
D	3.66%
AND	0.00%
F	0.00%
G	0.00%
H	24.39%

Checking the percentages of the types of rupture, it appears that 24.39% ruptured at the glue/ceramic plate interface. This type of rupture does not allow the measurement of the real adhesion value between the ceramic tile and the substrate, as the glue was the limiting factor, being the least resistant point.

Moving on to the other values, the average of the resistant stresses was 0.44 MPa, so in general the average of the results is within the minimum established by the regulations, of 0.30 MPa. However, it is observed that 11 of the 82 results were below the required standard, such as the extremely low values of 0.02 MPa and 0.09 MPa, which showed a break between the ceramic piece/mortar, which shows the flaws present in the traditional method. Laying with a rubber mallet.

Still referring to the restricted analysis of the collected data, it was observed that 56.10% of the ruptures occurred at the mortar interfaces, ruptures whose values reflect the scenario in which the zones of least resistance were between the ceramic piece/mortar and the mortar/substrate, that is, the system paste zones.

In general, such data confirm the integrity of the tests carried out by the author, with no negative discrepancies between the results of the own tests and those of third parties, since the author's tests showed through their results a correct placement of the pieces with the use of the hammer of rubber, both applied with a single layer, which obtained an average stress of around 0.45 MPa, and with a double layer, which had an average of 0.38 MPa.[11–18]

Conclusion

This study pointed out that the use of the vibrating machine for laying ceramic tiles improves the quality of the service, as well as makes its application viable in laying tiles. This fact became clear after making a comparison between the porcelain tiles laid using a vibrating machine and those laid using the traditional method with a rubber hammer.

The consolidation of the mortar, verified through the kneading of the cords, was better in the pieces laid with the use of the vibrating machine, either using a single or double layer of mortar. Adherence to pieces laid using the traditional method with a rubber hammer was good, obtaining average results that satisfy regulatory standards, using one or two layers of mortar. However, some individual values of the tests performed were rejected, showing that even following the normative instructions, the process is liable to failures.

Adherence to the pieces laid using the vibrating machine was, on average, twice that stipulated by the regulatory standard, whether using one or two layers of mortar. There were no cases of rejected values.

The data collected from the pullout tests carried out by third parties in different works attested to the integrity of the values obtained in the author's tests, as well as reinforced the terms proposed in the research justification, where it was mentioned that the traditional laying method has numerous flaws.

The efficiency of using the vibrating machine in the laying process was such that it becomes legitimate the possibility of laying pieces with surface area dimensions greater than 900cm², using only a single layer of mortar, thus promoting savings of 50% in material costs, attesting to the veracity of the hypotheses established for the research.

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Conflicts of interests

Author declares there are no conflicts of interests.

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