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Study of Shear Stress in Ceramic Tiling Systems

Rodolfo Rabelo Neves[1], Guilherme Augusto Martins Moreira[2], Matheus Marques Fernandes Aguiar[3]
[1]Department of Materials Engineering and Construction, Federal University of Minas Gerais, Brazil
[2]Pontifical Catholic University of Minas Gerais Gerais, Brazil
[3]Pontifical Catholic University of Minas Gerais, Brazil
([1]rodolforabelon@gmail.com, [2]guilhermemoreirabh@gmail.com, [3]mmfa.civil@gmail.com)

Abstract- The present paper aims to carry out a bibliographic study the shear stress in coating systems. Ceramic tiling system has been widely used in buildings currently mainly for their thermal comfort, safety against infiltration and better aesthetics for buildings. This system suffers from several internal interferences that affect its performance, such as climatic conditions, conditions of use and execution. These interferences generate tensile, compressive and shear stresses on the plate that compromise its useful life and may even cause its displacement. As a system, these interferences are transmitted to each element according to its degree of adhesion. The tensile stresses occur when the parts expand, being mainly due to the greater absorption of water, causing them to move away from each other. The compressive stresses are mainly due to the retraction of the base, being it due to the decrease of the relative humidity of the air, movement of the structure and hygroscopic dilatation. Being one of the major influences in displacement, the shear stress occurs with the collaboration of the tensile and compression stresses. The perpetuation of these tensions causes fatigue in the material that generates the rupture of the mechanisms of adhesion, through the shear, between the plate and the substrate. Considering the importance of these tensions in the useful life of the system, the execution of a ceramic plates must conform to known and widely used standards. The tests used by the ASTM C482, MR14 and MR20 standards are internationally used and of great benefit for the works in Brazil, considering that there is no standardization for tests of resistance to shear adhesion.

Keywords- *Shear Stress, Ceramic Tiling, Adhesive Mortars*

I. INTRODUCTION

Ceramics is a very old material whose production process has been incorporating technology through the centuries [19]. Ceramic tiling has a long history as an inner and outer building coating, mainly because of its versatility in terms of colour, dimension and texture. Adhesive ceramic tiling systems have advanced significantly lately, due to technological innovations in the ceramic tiles and laying materials industry. Simultaneously, the range of applications where this cladding is used has grown [21].

External wall tile structures normally consist of concrete substrate, adhesive mortar, and tiles [14]. In order to study the behavior of coating's tensions, it is necessary to understand that this layer of elements is connected to each other and may have a greater or lesser degree of adhesion. This adhesion has a great influence on the transfer of tensions and is influenced by the care of workforce that performs it and also by the preparation of the surfaces to receive the posterior layers [8].

Ceramic tiling system undergoes various external and internal interferences that affect its performance, such as seating, conditions of use and climatic factors [19]. With the layers attached, the deformation of any of them, due to endogenous causes or external forces, will result in tensions acting on each layer. With different behaviors between the elements of the coating system, tensions of compression, tensile, tensions due to retraction and shear stresses are generated [8].

It is relevant to mention that these tensions can occur quickly but in most cases of displacement of ceramic coatings they occur gradually and alternately. This cyclic effect leads to fatigue in the material and, consequently, favors the detachment of the ceramic plates [8].

II. STRESS DEFINITION

Stress can be defined as a load that is applied to a material object and also a force resistance within any solid body against alteration of form [24].

Being derived from a fundamental physical quantity (force) and a purely geometrical quantity (area), stress is also a fundamental quantity, like velocity, torque or energy, which can be quantified and analyzed without explicit consideration of the nature of the material or of its physical causes [5].

Stress can be classified as compressive, tensile, shear, bending, torsional and fatigue stresses - Fig. 01. Compressive stress is related to a stress that resists a force attempting to crush a body. Tensile stress is the maximum unit stress that a material is capable of resisting under axial loading, based on the cross-sectional area of the specimen before loading. Shear stress is related to a stress component acting tangentially to a plane. Bending stress is a force causing a deflection in shape or position of any member of a structure. Torsional stress is a shear stress on a transverse cross-section resulting from a twisting action. Fatigue is related to repeated or alternating load or from vibration [25].

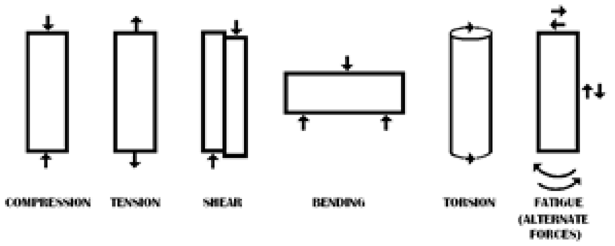

Figure 1. Different types of stress, Almazi (2016)

In mechanics, compression is the application of balanced inward ("pushing") forces to different points on a material or structure, that is, forces with no net sum or torque directed so as to reduce its size in one or more directions. It is contrasted with tensile stress or traction, the application of balanced outward ("pulling") forces; and with shearing forces, directed so as to displace layers of the material parallel to each other. The compressive strength of materials and structures is an important engineering consideration [10].

Another simple type of stress occurs when a uniformly thick layer of elastic material is firmly attached to two stiff bodies that are pulled in opposite directions by forces parallel to the layer. As it is shown in Fig. 02, let *F* be the magnitude of those forces, and *M* be the mid-plane of that layer. Just as in the normal stress case, the part of the layer on one side of *M* must pull the other part with the same force *F*. Assuming that the direction of the forces is known, the stress across *M* can be expressed simply by the single number, calculated simply with the magnitude of those forces, *F* and the cross sectional area, *A*.

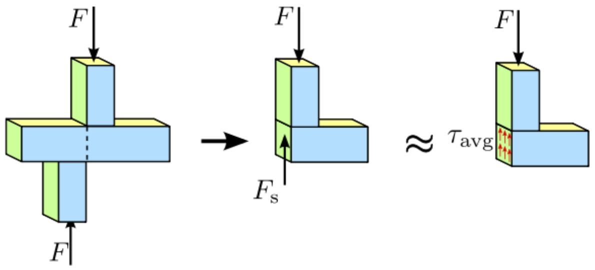

Figure 2. Shear stress in a horizontal bar loaded by two offset blocks, Sanpaz (2009)

Bending, which is also known as flexure, characterizes the behavior of a slender structural element subjected to an external load applied perpendicularly to a longitudinal axis of the element [13].

Torsion is the twisting of an object due to an applied torque. Torsion is expressed in newton per square metre (Pa) or pounds per square inch (psi) while torque is expressed in newton metres (N·m) or foot-pound force (ft·lbf). In sections perpendicular to the torque axis, the resultant shear stress in this section is perpendicular to the radius [23].

Often, mechanical bodies experience more than one type of stress at the same time; this is called combined stress. In normal and shear stress, the magnitude of the stress is maximum for surfaces that are perpendicular to a certain direction, and zero across any surfaces that are parallel to a particular direction. When the shear stress is zero only across surfaces that are perpendicular to one particular direction, the stress is called biaxial, and can be viewed as the sum of two normal or shear stresses. In the most general case, called tri-axial stress, the stress is nonzero across every surface element [11].

In this paper we will talk about the influence of compressive, tensile and shear in coating tile coating systems.

III. CERAMIC TILING SYSTEMS REQUIRED BY TENSILE STRESS

Consider the coating portion showed in Fig. 03 which, to exemplify, is at an initial temperature *T*, gradually moving to a temperature $T_1 > T$.

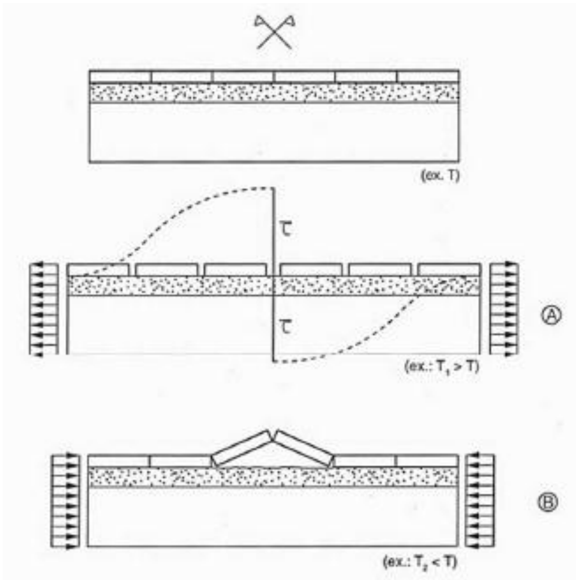

Figure 3. Ceramic coating required by tensile stress, Fiorito (2013)

In this case, lining parts tend to move away from each other. Joints tend to open, and a simple shearing process is then performed between pieces' base and the material used in the laying (Fig. 03-A). When the rupture is reached, pieces are simply released from the base [8].

Following a shortening due, for example, to a gradual drop in temperature $T_2 < T$, the loose parts would take the shape of an inverted "V" - Fig. 03-B [8].

Although there have been studies about this behavior, it has never been observed in practice. Fiorito (2013) in his publication "Manual of Mortars and Coatings: Studies and Execution Procedures" notes that shear rupture tests showed values of the order of 10 kgf/cm^2 (1,0 MPa) for common cement paste, and 12 kgf/cm^2 (1,2 MPa) for adhesive mortar, following American standard test procedure. These are high values and, before being achieved, ceramic pieces detach from base due to a tensile force acting perpendicular to the plane of the coating.

According to Silvestre and Brito (2008), cladding components' cracking of adhesive ceramic tiling systems results from the occurrence of tensile stress in the tiles layer greater than the tensile strength of the tiles. The cracking of the tiles occurs each time the adhesion strength between the tiles and the mortar is high. When that adhesion strength is low, the tensile stress in the tiles layer causes the detachment of this element [24].

IV. CERAMIC TILING SYSTEMS REQUIRED BY COMPRESSIVE STRESS

The compression of the ceramic coating can occur due to several factors, such as the reduction of the base mortar due to climatic factors, such as the decrease of relative humidity and thermal variations, due to the slow deformation of the concrete of the structure, hygroscopic expansion of ceramic coatings and deformation originated by the performance of accidental loads. In these situations there is the shortening of the base and the approach of the ends of the ceramic part, causing a possible buckling in the material [8].

Buckling is characterized by a pulling tension of direction perpendicular to the plane of the coating with external direction (leaving the ceramic part) and opposing the force of adhesion of the part to the mortar. When this tensile stress which tends to pull the baseplate from its base is less than the adhesion caused by the mortar, compression will occur on the part but it will remain stable. When this tensile stress is greater than the possible poor adherence, the ceramic pieces will be released from the base, causing the piece to slip and its subsequent collapse. Fig. 4 illustrates a coating requested for compression [8].

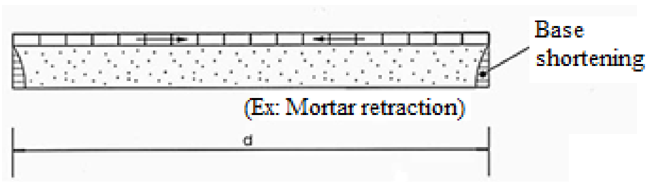

Figure 4. Ceramic coating required by compressive stress, Fiorito (2013)

Compression in coatings occurs because of retraction. In conventional method, the initial bond between coating, mortar and the support of concrete or masonry is made with fresh and plastic mortars. Thus, as the mortar dries, its retraction will have increasing values, and its modulus of elasticity will change from zero to a final value that depends on the trait [8]. As the retraction increases, an increasing compression will appear in the coating and in the support, and by reaction, also increasing traction in mortar itself. The forces will always be in balance. It establishes a process of interaction between these forces [8].

V. CERAMIC TILING SYSTEMS REQUIRED BY SHEAR STRESS

Ceramic tiling systems generally consist of several layers of different materials bonded together. Thus, any deformation in one of these layers will result in the appearance of tensions throughout the assembly. These tensions depend on the physical characteristics of each layer [8] and also on climatic factors, structural movements and factors related to the form of settlement and conditions of use of the site [20].

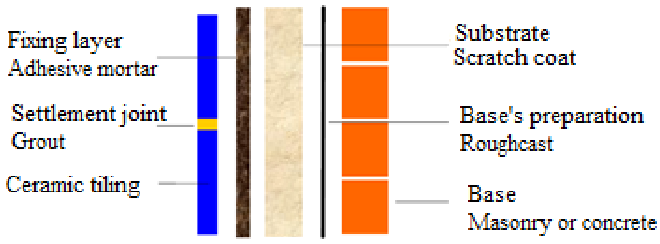

Figure 5. Usual layers of coating system, Medeiros e Sabbatini (1999)

Layers of different materials that make up the ceramic tiling system present varying strengths, moduli of elasticity, deformation capacities and coefficients of thermal expansion and when exposed to external actions, will determine dimensional variations of the set [8].

It is observed that in relation to base/mortar interface's shear strength, this conditioners the spacing between cracks, and increase in spacing increases the risk of detachment [6]. The detachment of the ceramic pieces may also occur when the movements break the physical bonds produced by the adhesion phenomenon, both by tensile stresses and by shear stress [3].

The different modulus of elasticity and material's coefficients of expansion that make up a coating system allow differential deformations to occur, leading to the emergence of tensions at the interfaces. These tensions may cause cracks to appear internally in each material and in the adhesion interfaces between the different layers [6].

An important aspect to consider in assessing compatibility and selection of an adhesive is the difference between the adhered materials' shear modulus characteristics. In an adhered tile assembly, the tile has a much greater shear modulus than a cementitious substrate, therefore the tile-adhesive interface is often more susceptible to concentration of shear stress and potential failure. As a result shear strength becomes the dominant design characteristic, despite the capability of an adhesive to deform [9].

So, it is important to select an adhesive with balanced flexibility or rigidity characteristics that are compatible with the adherends, such as the tile and the type of substrate. It is a well-known phenomenon that shear stress is uniformly distributed at the adhesive interface with more rigid adhesives, whereas shear stress is concentrated at the perimeter of the adhesive interface with more flexible adhesives. Engineering data also demonstrates that higher shear modulus adhesives exhibit a much more linear shear vs. strain behavior over a large range of stresses, and that lower modulus adhesives exhibit non-linear behavior, and consequently exhibit greater strains. So while highly flexible polymer-modified adhesives are better able to absorb differential movement between components of a composite tile assembly, their behavior is less mathematically predictable [9].

Therefore, deformation capability alone is not an indication of ultimate performance of a tile adhesive. As a result, testing and determination of shear strength and shear modulus characteristics, together with flexibility characteristics, can enable a more accurate assessment of a polymer-modified cement adhesive's performance under adverse conditions [9].

In order to perform the shear bond strength tests on adhesive mortar, there is no standardization in Brazil. However, there are standards that specify which trials to follow and which are widely used. Among them, the following standards can be highlighted: ASTM C482, RILEM - MR 14 - Determination of the bond yields by shear tests and RILEM MR-20.

VI. TESTING METHODS STANDARDS

A. ASTM C482 - Standard Test Method for Bond Strength of Ceramic Tile to Portland Cement Paste

American standard considers the construction of a substrate of mortar in which the ceramic of square format will be glued. The application of the load occurs by the same method of compression tests, being applied directly to the top of the ceramic causing the shear in relation to the mortar [20]. This method is presented in Fig. 06.

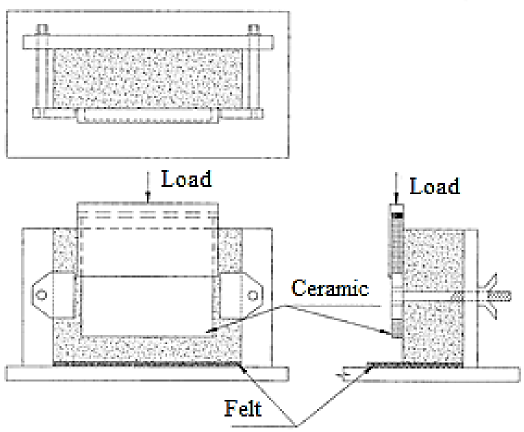

Figure 6. Test Method for Bond Strength of Ceramic Tile to Portland Cement Paste – ASTM C482, ASTM (2014)

As Sagave (2001) observed, this method may present dispersions in its results due to the error in its execution. At the time of application of the load, if it is not in parallel with the ceramic and the substrate, it can generate tensile and compressive stress.

B. RILEM - MR 14 - Determination of the bond of renderings by shear tests

In this test method, two blocks are coated with mortar on their opposite sides and the ceramic to be tested. After curing, a metal plate is glued joining the two blocks, leaving a space between them (Fig. 07). Thus, the specimen is subjected to a compression load parallel to the face of the ceramic, but is applied directly to the block [4].

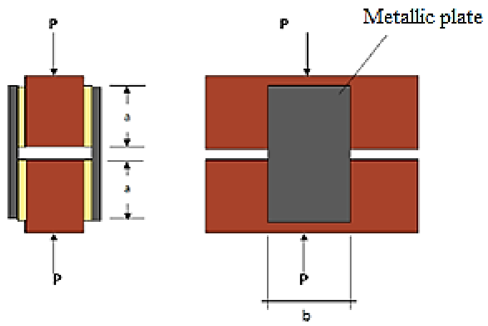

Figure 7. Shear Test – MR-14, RILEM (1993)

With the breaking load P, the shear stress is obtained by the formula:

$$\tau = \frac{P}{4ab} \quad (1)$$

Where:

τ = shear bond strength in MPa

P = burst load, in Newton

a, b = lateral dimensions of the coating, in mm

C. RILEM - MR 20 - Determination of the bond strength of renderings by torsion tests

This method for determination of shear strength is by the application of a torsional force. A metal ring plate is glued to the ceramic surface under the block. By means of a torque wrench the torsion is performed on the axis perpendicular to the plane of the ceramic plate, thus obtaining the bursting load.

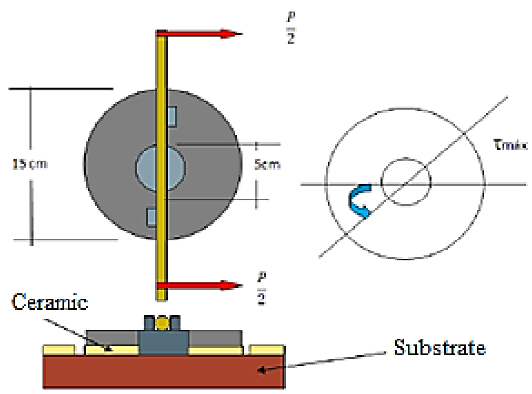

Figure 8. Torsion Test – MR-20, RILEM (1994)

The shear stress will be calculated by:

$$\tau = \frac{\frac{P}{2}\times 2a}{A\times r} \quad (2)$$

Where:

P = load applied by the torque wrench (N)

a = length of the lever arm (mm)

A = area of the metal ring (mm²)

r = mean ring radius (mm)

It should be noted the difficulty of performing this test mainly in relation to the applied load. If loads of different orders are applied at both ends, as occurs in manual applications, the sliding of the part will occur, compromising the results [20].

VII. FINAL CONSIDERATIONS

Observing that the ceramic tiling system has been widely used, it is necessary to have a better knowledge of the stresses acting from internal and external effects. Considering that the climatic factors that contribute most to the tensile and compression stresses in the ceramic plates and can hardly be predicted, the control in the execution and also in the manufacture of the materials must be stimulated to perform better, thus increasing the useful life of the system.

The shear stresses are those that exert the greatest influence on the displacement of ceramics and, in Brazil, are little studied and not yet standardized. Considering the international norms, one can obtain good results, however, in view of the widely used tests, it is perceived the difficulty of accomplishing them. It is therefore necessary to develop new, accessible and better-performing methods that address and consider climatic factors, construction methods and Brazilian feasibility.

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