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EXPERIMENTAL INVESTIGATION ON BONDING CHARACTERISTICS OF LOW-STRENGTH MORTARS USED TO REPOINT THE JOINTS OF THE DAMAGED HISTORICAL MASONRY STRUCTURES

BY

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Abstract. Masonry represents the oldest building material in the history. The rehabilitation of a damaged building involves knowledge about the building material's properties, the execution technology, the elaboration of the rehabilitation project and, also, theoretical knowledge about the strength calculus of the rehabilitated structure. All these are required in order to assess the bearing capacity. With the view to determine the strength and deformability characteristics of the old masonry (made from bricks and "bound" with low-strength mortars), this paper proposes an analysis concerning the mechanical characteristics of the component materials and proposing a new method for testing the mortar adhesion to the "masonry stone" (bricks). The test method involves determining the maximum tensile stress applied by a direct load at right angles to the surface of the mortar. The strength of a mortar can vary. If mixed with higher amounts of portland cement, a harder mortar is obtained. The more lime that is added, the softer and more plastic the mortar becomes, increasing its workability. A mortar strong in compression might be desirable for a hard stone, whereas a softer, more permeable lime mortar, would be preferable for a historic wall of soft bricks. Three different mix proportions were considered in the experimental investigation, made with different binders (lime based, clay based, combination between lime and cement) and one standard cement mortar (for comparison).

Key words: mortar; masonry; adhesion; pull-out strength; shear strength.

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1. Introduction

Masonry is one of the oldest building material in history. In antiquity, the masonry was the base material of masonry building for foundations, walls and vaulted roofs, etc. In present days the use was restrained but, taking into account all the progresses realized in the field of building materials. However masonry remains an unreplaced material, especially for exterior walls at the civil structures (Covatariu, 2001; Covatariu, 2005).

Old buildings, heritage of old times, give an individualization aspect to our habitat and, in most cases, become the city's symbol (for instance, Culture Palace from Iaşi, Ştefan cel Mare Church from Piatra Neamț, Black Church from Braşov, Precista Church from Galați, etc.). These uninestimable urban values must be saved from the unfavourable aging and environmental damaging processes. "Saving" mean not only bringing them back to their initial functionality and interior /exterior architecture but especially, *structural restoration and rehabilitation*. By changing the interior structure and preserving/restoring the façades in old style (which has a pleasant aspect, comparing with the "industrial building" aspect of the modern structures) are assured the strength requirements. Unfortunately for the civil engineer, structural rehabilitation of a historical building in this radically manner is quite impossible (Budescu *et al.*, 1982; ENV-1-1, 1996; Covatariu, 2001).

The building with a long exploitation period (more than 100 years) has the constitutive materials more or less damaged and its initial mechanical characteristics are affected. At the masonries were used, as a rule, the low-strength mortars (about M2, M4 and rarelly M10) which, sometimes, were depreciated in time. The massive industrialization years enhanced the physical-chemical aggressiveness of the environment. On account of these specific factors, most of the old buildings suffered many degradations and damages comparing with the "new" buildings, because its resist to many earthquakes (affecting the structural integrity) (Metodologie MP007-99; Maurenbrecher *et al.*, 2007).

Rehabilitation and consolidation of the historical buildings represent a complex problem and, also, require a different approach compared to a new building. The approach involves a good understanding of the material characteristics (in old stages), of the rehabilitation technology, and solid knowledge about the structural design.

The present paper brings its contribution to the investigation and testing methods of the low-strength mortar adherence to the old masonry stone (brick). It also proposes a new method of testing the shear strength (Luque *et al.*, 2010; Knöfel & Huesmann, 1993).

We must remind two of the Wien Chart's principle (1964) namely

a) ***The reversibility of the applied methods to preservation and/or restoration.*** Presuming that the future will bring more viable technologies, it is necessary to impose those methods which lead to results easily removed in the future, if new and innovative techniques will be discovered.

b) ***The compatibility of the new materials used in conservations /restoration's process***: We must use only those "new" materials that have same/adequate characteristics as the "old" ones, preferable from the same source, because the major incompatibilities resulted from the usage of the original (old) material and a new one, often produce an ulterior faster degradation. For this reason, the materials chosen for the structural rehabilitation for old masonries will preserve (as much as possible) the original recipe used at the initial construction, keeping the initial mechanical characteristics and, also, having other characteristics which could concede compatibility with structural materials.

The difference of the deformability under pressure, of the masonry block (stone, brick) and of the mortar's layer represent the main cause of the complex stages of stresses in masonry. The transversal strains (as a result of the basic components deformation) superposed with the relative displacements between the components, exerts an important influence of the masonry strength. The mortar has higher deformation capacity than the masonry block and it tends to expand through the joints. This tendency is restrained by the adherence and adhesion forces of the masonry blocks. Consequently, this transversal deformability difference produces tensile stresses in the masonry block (Budescu *et al.*, 1982; ENV-1-1, 1996). The failure of the masonry can occur through bounded and un-bounded joints (Fig. 1).

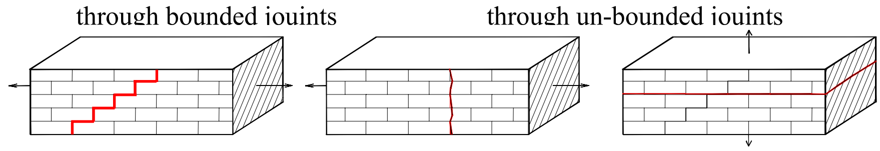

Fig. 1 – Different failure patterns of masonry subjected to tension.

Failure of *unbounded* joints due to tensile stresses is determined by the adherence at the contact surface between the bricks and the mortar. Failure on *bounded* joints depends on the bond strength of the mortar (in case of the failure through horizontal joints). If the failure occurs on the bricks and/or on vertical joints depends on the bricks compression strength. Therefore it is very important to know the adherence forces between the mortar and the bricks, this being influenced, mostly, by the material characteristics (ENV-1-1, 1996).

The mortar homogeneous mixture made from binder, sand and water (sometimes additional materials), is used in order to connect the masonry blocks or in order to protect/finish some building elements. The mixture has a good workability which, after a specific time, hardens and strengthens. The mortar transmits and distributes uniformly the stresses internal forces in masonry and, also, decreases the permeability to athmospheric agents (wind, rain) by filling the joints between the bricks.

2. Experimental Study

2.1. Preliminary Remarks

The experimental program has in view the determination of the bond strength between the constituent materials of the masonry: ordinary bricks (M50) and low-strength mortars. Therefore the only parameter considered in this study was the type of mortar.

All three mortar mixes fulfil the initial characteristics (the "original old recipe") of the constituents and, also, the characteristic imposed by the actual standards. The aim was, also, to observe the influence of different additional material in mortar's recipe (ENV-1-1,1996; Covatariu, 2005; SR EN 197-1, 2002).

Three mortar mix proportions were used with different mineral binder and one additional standard recipe namely

1. *R*1 – Standard recipe (M50 Z): cement (1 part), sand (4 parts).
2. *R*2 – Recipe 2 (M4Z): lime (1 part), sand (3 parts).
3. *R*3 – Recipe 3 (M4Z): clay (1 part), sand (3 parts).
4. *R*4 – Recipe 4: lime (1.5 parts), cement (0.5 parts), sand (6 parts).

2.2 Mortar's Adherence at the Support Layer; Bond Strength of the Mortar to the Support Layer Test

The test was performed with the help of a modified Frühling – Michaelis device (Fig. 2 *b*). Five specimens were tested for each recipe (Fig. 2 *a*).

Observations to the adherence determination at pull-out test:

a) For *R*1 recipe (cement mortar) – the separation took place through mortar, at the interface between the plate and the mortar layer. It results a very good adherence, so the adherence to the support is superior to the strength obtained at the determination (Fig. 3).

b) For *R*2, *R*3 and *R*4 recipes – the separation took place during the calibration of the apparatus. It was caused by the self-weight of the ensemble plate–brick–mortar (Fig. 2 *c*). For some of the tested samples the debonding took place immediatelly after the calibrating, leading to a very small values of the adherence force).

a

b

c

Fig. 2 – *a* – Specimen's preparing; *b* – aspects from the pull-out test; *c* – aspects from the pull-out test.

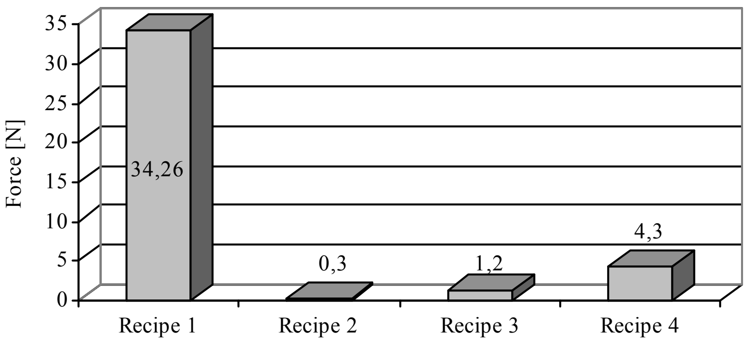

Fig. 3 – Variation of the pull-out force for different types of mortar.

2.3. Mortar's Adherence at the Suport Layer; Bond Strength of the Mortar in Shear Test

The method is not a standardized one. It was derived from the pull-out test method based on the same Frühling – Michaelis apparatus (Fig. 4). The device was modified so that it subjects the brick-mortar assembly to shear force in order to determine the bond strength in shear of the mortar. It was attached a metallic trimmer (in order to support the brick on the apparatus base) and an ensemble steel ring + adjusting screew (to transmit a shear force from the apparatus lever perpendicular to the support interface – brick-mortar) (Fig. 5).

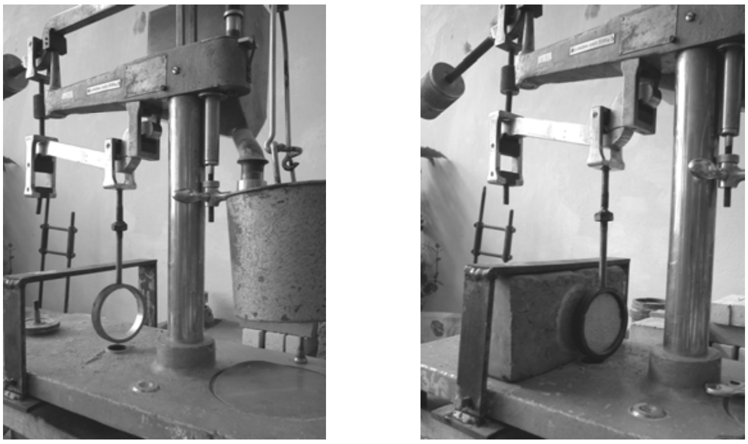

Fig. 4 – Frühling - Michaelis apparatus modified for shear force determination.

Fig. 5 – Testing aspects.

This test was performed also on five specimens for every mortar mix.

The obtained values are very small but are relevant by comparison. The greatest values were obtained for the *R*1 recipe (cement mortar). A weak adherence between the mortar and the bricks was observed for the other specimens. A cement supplement (of 25%) to the lime based mortar (*R*4 recipe) results in an increased strength in shear compared to *R*2 recipe (lime based mortar). The lowest strength was obtained for the *R*3 recipe (clay mortar).

Moreover, it is interesting to observe that the adherence forces, obtained for the shear test were smaller compared with those from the pull-out test. It is known that for the strength of the masonry subjected to the earthquake actions, is more relevant to test in shear compared with the pull-out test.

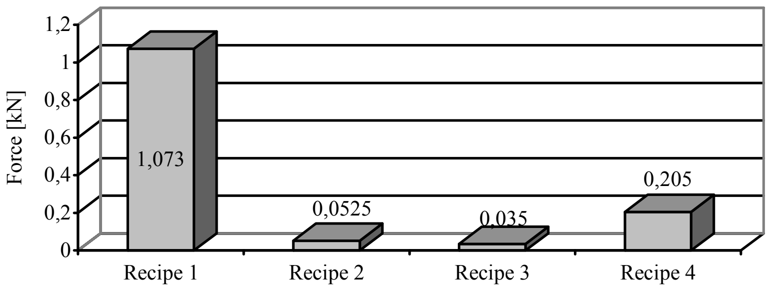

Fig. 6 – Variation of the shear force for different types of mortar.

Observations concerning the adherence determination from shear test (Fig. 6):

a) For *R*1 recipe (cement mortar) – very good adherence (a single specimen cracked in brick layer).

b) For *R*2, *R*3 recipes – very weak adherence.

c) For R4 recipe – better adherence in comparison with the *R*2 recipe (depending on the cement quantity).

3. Conclusions

The results obtained from the testing procedures lead to the following conclusions:

1. The best behavior has the *R*4 recipe (75% cement + 25% lime) having an elasticity reserve (because of the lime–cement mortar), compared with the *R*1 recipe (only cement mortar).

2. Cement fraction (25%) in the *R*4 recipe (cement + lime) leads to a three fold increase in the failure force compared to the recorded value of the failure force of the *R*2 recipe (lime based mortar).

3. Cement based mortar has a friable behavior, and doesn't contribute to the elasticity of the structure.

4. The weakest structure is the one using clay mortar (*R*3), due to the small adherence between the brick and the mortar.

Therefore, taking into account the obtained results it is necessary to continue the experimental investigation in order to enhance the quality of the low-strength mortars used to re-joint the old masonries (based on clays and limes). The aim is to obtain mortars stronger to the pull-out forces and to shear forces. This may be achieved by using anhydrous calcium sulphate as a replacement for the original binder – clay or lime.

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INVESTIGAȚII EXPERIMENTALE ASUPRA ADERENȚEI MORTARELOR DE REZISTENȚĂ INFERIOARĂ UTILIZATE LA REABILITAREA STRUCTURILOR VECHI DIN ZIDĂRIE ALE MONUMENTELOR ISTORICE

(Rezumat)

Zidăria este unul din cele mai vechi materiale de construcții. În prezent aria de utilizare a zidăriei a fost restrânsă dar, cu toate progresele realizate în direcția diversificării materialelor şi sistemelor de construcții, zidăria rămâne de neînlocuit la realizarea pereților exteriori la clădirile social-culturale. Consolidarea unei construcții avariate impune cunoaşterea proprietăților materialelor de construcții, a tehnologiei de execuție, a elaborării şi realizării proiectului de consolidare cât şi temeinice cunoştințe teoretice pentru efectuarea calculului de rezistență al construcției consolidate în vederea stabilirii capacității de rezistență. Pentru determinarea caracteristicilor de rezistență şi deformabilitate ale zidăriilor vechi, alcătuite din cărămizi şi „legate" cu mortare de rezistență scăzută, prezentul studiu îşi propune o analiză aprofundată asupra caracteristicilor materialelor din care au fost realizate acestea, aducând contribuții la perfecționarea metodelor de testare referitoare la aderența „liantului" (mortarul de zidărie) la piatra de zidărie, dezvoltând in acest sens o metodă nouă de testare a aderenței mortarelor de rezistență scăzută la piatra de zidărie.