A MULTI-PHYSICS APPROACH APPLIED TO MASONRY STRUCTURES WITH NON-HYDRAULIC LIME Mortars

Mateus A. Oliveira
Federal University of Pará, Brazil
mateusengcivil@gmail.com

Miguel Azenha
University of Minho, Portugal
miguel.azenha@civil.uminho.pt

Paulo B. Lourenço
University of Minho, Portugal
pbl@civil.uminho.pt

Bernardo N. M. Neto
Federal University of Pará, Brazil
bnmn@gmail.com

Abstract: This work presents the summary of the PhD study developed for five years. The work had as the main objective the simulation and the achievement of parameters for the multi-physics modeling of masonry structures based in aerial lime mortar.

Keywords: Aerial lime, Historic Buildings, Multi-Physics, Carbonation, Finite Difference Method

Area: Technologies (Civil Engineering)

1 General information

Historical masonry structures have important cultural, social, archaeological, aesthetic, economic, political, architectural and technical aspects (Oliveira, 2015). In this sense, the preservation of historical constructions is a very important subject for society and for future generations (Warren, 2000). These constructions may have significant tourism potential (Lourenço et al., 2006, Adriano et al., 2009). These facts make the conservation and study of ancient structures an important issue (Binda and Saisi, 2001, Garavaglia et al., 2006, Lourenço et al., 2006, Oliveira et al., 2016, Oliveira, 2015).

Historical constructions suffer damage over time, such as earthquakes, soil settlements, material degradation and lack of maintenance (Oliveira, 2002). These phenomena are some of the main reasons for structural damage (Macchi, 1998).

Damage and collapses of monumental buildings, over the last years, have produced records noting the measurements of internal movement in masonry (Gimbert, 2008, Anzani et al., 2005, Anzani and Binda, 2013), more information can be seen in literature (Gimbert, 2008, Anzani et al., 2005, Anzani and Binda, 2013, Oliveira, 2015)

The long term behavior of masonry may present very important consequences, particularly with respect to historical buildings (van Zijl, 2000,
Accordingly, careful and periodic inspections may be considered necessary in order to evaluate the actual structural safety of this kind of construction (Rabun, 2000, Oliveira, 2002).

However, performing the structural analysis of a historical masonry construction is, general terms, a quite complex task (Lourenço, 2001, Lourenço et al., 2011). In ancient masonry structures mortar generally only represents a small (or moderate) part of the structure volume (Lourenço, 1996, Lourenço, 2002).

Nevertheless, mortar has been acknowledged as the principal cause for deformations or movements (Binda et al., 2003). Therefore, it is clear the necessity for a detailed analysis of the role of mortar. These studies of ancient masonry structures are demanded by the society and frequently supported by governmental funding agencies.

There is a significant quantity of historic constructions comprehending binders based on aerial lime mortars around the world (Oliveira, 2015, Oliveira et al., 2016). The work developed during the PhD is focused in the study of this binder.

Masonry structures can be considered the oldest and the most used structural system (Lourenço, 1996), more information about the modeling of masonry structures can be seen in literature (Lourenço and Rots, 1997, Lourenço, 1996, Lourenço, 2002, Lourenço, 2006, Oliveira, 2015).

Aerial lime is one of the most ancient binders discovered and used in construction (Oliveira, 2015, Oliveira et al., 2016). The aerial lime is produced from relatively pure limestone in kilns with high temperatures (Oliveira, 2015, Oliveira et al., 2016). Mortars based in such binder, after placement, harden gradually from the surface to their interior, due to reaction with carbon dioxide present in atmosphere, reaction usually denominated as carbonation (Lawrence, 2006).

The carbonation is a natural process and occurs in different materials, such as different mortars (Oliveira, 2015, Oliveira et al., 2016) or cementitious based material (Papadakis et al., 1991). For aerial lime mortar, this process has important structural effects, modifying the material mechanical properties.

Currently, with the constant attention of the governmental agencies and the society in the conservation and restoration in the conservation of the heritage and because of its compatibility with traditional materials, the necessity of a detailed study about the material became even more relevant.

It should be mentioned that only one work has been found in literature about the multi-physics modeling of masonry structures based in aerial lime mortar (Ferretti and Baz˘ant, 2006, Ferretti and Bažant, 2006), without any experiment.

Considering this increasing of interest, and the scarcity of studies in this subject, the work developed during the PhD presented an experimental and numerical approaches, they have been adopted in the studying of aerial lime mortar, in view of multi-physics modeling. For this purpose a hygro-carbo-mechanical model has been developed. For the numerical aspects, a software capable to simulate the coupled hygro-carbo fields over time has been implemented using the Finite Difference Method (FDM) (LeVeque, 2007) using the MATLAB®.
The obtained results from the implemented algorithm are then exported for a recognized software based in the Finite Element Method, TNO-DIANA® (TNO-DIANA-BV, 2007), that processes the mechanical analyses. These analyses is capable for instance to simulate the varying the elastic modulus over time. This framework can be considered very important, because such kind of structures last for long ages, and the mechanical analysis by itself may not be enough to reproduce the complicated behavior of them (Oliveira, 2015).

In terms of experiments, the initial step was the characterization of the raw material, followed by the definition of a suitable mixture. In sequence the drying process has been investigated through specific measurements. Mechanical properties have been measured since early ages and coupled with considerations regarding the evolution of carbonation.

The evolution of carbonation (reaction field) has been investigated using thermogravimetric analysis (Bakolas et al., 1998, Oliveira, 2015) and phenolphthalein indicator (Parrott and Killoh, 1989, Oliveira, 2015, Oliveira et al., 2016).

From the set of experiments and simulations, continuing with the study, and using the previous acquired experience, the different experiments are simulated. Numerical simulations are prepared to obtain the set of parameter to replicate the experimental data, from the simplest to the most complex modeling. The first simulation is related to the humidity field.

The experiments of humidity diffusion process are simulated with the decoupled humidity model. A unified pair of diffusivity and boundary coefficients is obtained. With these parameters, which best reproduce the experimental data in terms of humidity results, the carbonation process is in sequence simulated. Finally, the hygro-carbo model is coupled with TNO-DIANA® to simulate the evolution of elastic modulus experiments. A mathematical formulation that correlates the reaction (carbonation) and the humidity with the increase of elastic modulus is proposed.

The results obtained demonstrated that numerical models could reproduce reasonably well the experimental behavior of the mortar.

Experimentally, some innovative procedures regarding the tests in aerial lime mortar are done.

2 Conclusions

The thesis presented a methodology for hygro-carbo-mechanical analyses of aerial lime, based on the initial proposal of Ferretti and Bažant (2006). The originality of the presented work is related to the pioneering connection between experimentation and multi-physical simulation for aerial lime mortars.

In summary, in diverse aspects, the existing knowledge about concrete and cementitious-based materials gave an important initial support, due to the near-absence of specific references for the subject of the present work.

Therefore, the research developed presented herein can be considered in several aspects seminal, due to the scarce of literature information about the study of aerial lime mortar.
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4 References


