The Influence of Environmental Conditions on the Performance of Self-Healing Mortars for Masonry Repair

Maria B. Gaggero[1][0000-0003-0420-2817], Paul A. Korswagen[2][0000-0002-2587-7808], Rita Esposito[1][0000-0002-8519-5999] and Jan Rots.

[1] Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands
[2] Institut für Kontinuumsmechanik, Leibniz Universität Hannover
M.B.Gaggero@tudelft.nl

Abstract. The preservation of historic masonry structures requires durable repair techniques that minimize intervention while maintaining the original appearance. In this context, bio-based self-healing mortars present a promising solution, yet their application in masonry remains underexplored.

Previous research demonstrated the potential of a poly-lactic acid (PLA)-based agent to heal cracks in masonry with cement-based mortars, restoring both bond strength and aesthetics. However, when extended to more porous cement–lime mortars and clay bricks, new challenges emerged. Leaching, likely resulting from interactions between the mortar's porosity and the healing environment, underscored the need for further investigation.

To this purpose, the study investigates clay brick couplets built with two mortar compositions of increasing lime content, exposed to two different healing environments. Specifically, a PLA-based healing agent was incorporated into cement–lime mortars with lime/cement ratios of 1.0 and 3.33 by volume. Each mortar was used both plain and with 10% of the healing agent (by binder volume) to build the specimens. After pre-cracking through bond wrench testing, the couplets were left to heal for 60 days under either high humidity or wet–dry cycle conditions.

The results highlight the critical influence of the healing environment on overall performance. While wet–dry cycles proved ineffective in this case, humid conditions enabled partial recovery of flexural bond strength, with values reaching up to 15% in samples containing the healing agent and higher lime content. Visual inspection confirmed complete crack closure, supporting the aesthetic—and potentially watertightness—restoration. Additionally, reference samples with higher lime content also exhibited minor strength recovery, likely due to the migration of free lime and its reaction within the crack.

These advancements underscore the potential of bio-based self-healing mortars for masonry repair and establish a foundation for further research.

Keywords: heritage, lime, durability, masonry repair, self-healing, bacteria.

1 Research overview

The growing need for durable construction materials has brought increasing attention to self-healing mortars as a potential solution to extend the service life of constructions. While self-healing technologies have been extensively investigated for concrete, resulting in commercially available products, their application in masonry has only recently become an active research field. Current studies are investigating various approaches, including micro-vascular systems with nanolimes [1] and bacteria-based self-healing agents [2]. In the context of the latter, an experimental study ongoing at Delft University of Technology is evaluating the potential applicability of a polylactic acid (PLA) self-healing agent, originally developed for concrete [3]. Initial results showed that the agent effectively restored both bond strength and aesthetic appearance in calcium silicate brick couplets when used in the original commercial cement-based formulation [4]. However, further applications to more porous materials—such as cement–lime mortars and solid clay bricks—revealed performance limitations [5]. Recent efforts have focused on assessing the agent's compatibility with mortars featuring increasing lime/cement ratios [6], considering different healing environments to identify the most favourable conditions. This study has shown that the agent is effective in promoting healing in lime-rich mortars, with humid and wet–dry curing conditions identified as the most favourable. However, its use with clay bricks had not been explored further.

Therefore, this follow-up study aimed to investigate the agent's performance in clay brick couplets using two cement–lime mortar formulations and two distinct healing environments. To this purpose, masonry couplets were built with solid clay bricks, having nominal dimensions (length x height x thickness in mm^3) respectively of 210 x 50 x 100. Samples were built with 2 cement-lime mortar compositions featuring a lime/cement ratios by volume of 1 and 3.33, respectively. These ratios were selected as part of the ongoing study [6] exploring the agent's applicability across mortars with increasing lime content (lime/cement ratio from 0 to 1.33), ranging from pure cement to a formulation typical in Dutch masonry repair for historical buildings (C. Groot, personal communication, 2022). The binders used were Ordinary Portland Cement (CEM I 42.5 N) and commercial aerial lime (CL80S – EN 459-1) with an apparent density of 0.52 g/cm^3. Standard river sand, with a particle size distribution between 0.08 and 2 mm, was used in a volumetric proportion of 1:2.5 (binder: sand). Per mortar composition, 2 sets of 3 couplets were built: one with the added-in agent at a concentration of 10% of the total mortar's binder volume (*Bacteria-based* **[B]**) and the other with plain mortar as reference (*Reference* **[R]**). The employed agent consists of a poly-lactic acid (PLA) derivative matrix, Bacillus cohnii-related bacterial spores, and essential nutrients [3]. Samples were tested at 7 days with an in-situ bond wrench test set-up [7] and left to heal for a month under humid (20 ± 2 °C, 95 ± 5 % RH) and wet-dry cycle conditions. Subsequently, samples were tested using the same configuration for assessing the agent's performance in terms of strength recovery. Pictures taken before and after the healing were used to qualitatively assess the aesthetic restoration.

Experimental results show partial recovery of flexural bond strength under humid conditions, with enhanced performance in bacteria samples (containing the healing agent) (Fig. 1). Among the reference samples, only those with a higher lime content (lime/cement ratio of 1.33) exhibited any measurable recovery, reaching approximately 5% of the original strength. This limited recovery is likely due to the migration of free lime to the crack surfaces—promoted by early-age testing and the humid environment—rather than the typical formation of calcium carbonate associated with autogenous and bacterial healing. In contrast, bacteria samples consistently outperformed their reference counterparts, achieving up to 15% recovery in couplets with a 1.33 lime/cement ratio. Moreover, the healing agent was more effective in samples with higher lime content, likely because the increased availability of free lime facilitated carbonation in the presence of CO_2 produced by bacterial activity.

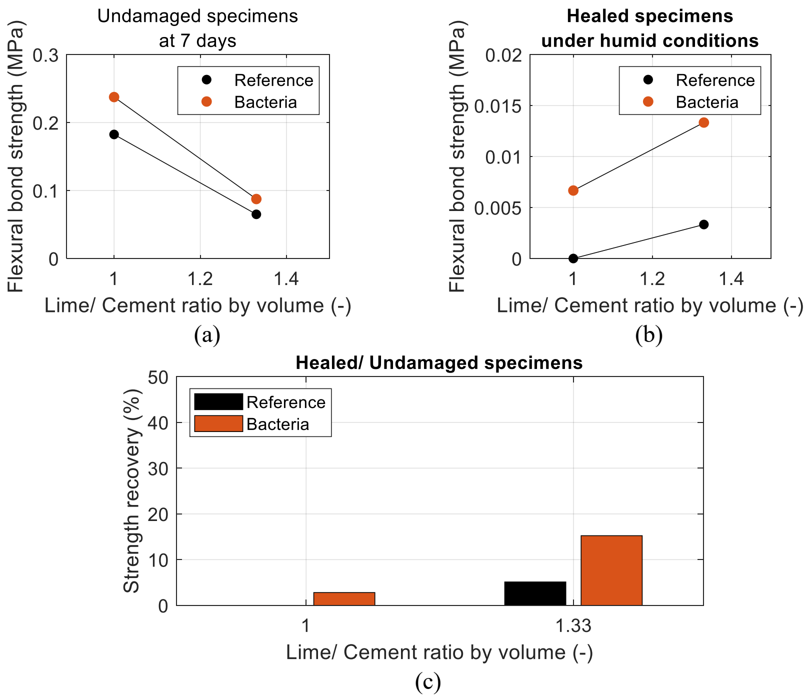

Fig. 1. Flexural bond strength of masonry couplets (a) before and (b) after healing, along with (c) the corresponding strength recovery. Results are shown for the two mortar mixes considered (lime/ cement ratio 1 and 3.33), both with and without the healing agent. Healed couplets refer to specimens cured under humid conditions (T =20, RH = 95%).

The mechanical recovery observed under humid conditions is further supported by visual observations of the cracks before and after healing (Fig. 2). No visible precipitation was observed in the reference samples with a lime/cement ratio of 1.0, which is consistent with their lack of strength recovery. Conversely, the other three series exhibited cracks that appeared fully resealed, confirming aesthetic recovery. The presence of calcium carbonate, presumably formed through bacterial activity, may contribute not only to visual sealing but also to the restoration of watertightness.

In contrast to couplets cured under humid conditions, specimens exposed to wet-dry cycles showed no signs of healing, regardless of mortar composition. All couplets remained completely unbonded at the time of re-testing, resulting in null flexural bond strength. In addition, no visible precipitation was detected in images taken before and after the healing period. Therefore, high humidity proved to be the most favorable environment for the masonry types considered in this study.

Beyond its healing capacity, experimental results also confirm the agent's impact on early-age flexural bond strength. An increase of approximately 33% was observed at 7 days, regardless of the lime-to-cement ratio. This finding aligns with previous studies [4][5]. This is likely related to the increased air content due to the presence of the agent [8][9]—a hypothesis that is currently under further investigation.
These findings confirm the potential applicability of the agent and highlight the importance of selecting suitable environmental conditions. Although recovery levels were modest, the short healing duration leaves open the possibility that longer periods may enhance performance. A more systematic experimental program is currently underway to assess the recovery of flexural bond strength and watertightness, along with the characterization of mineral formation and the agent's impact on the functional properties of masonry.

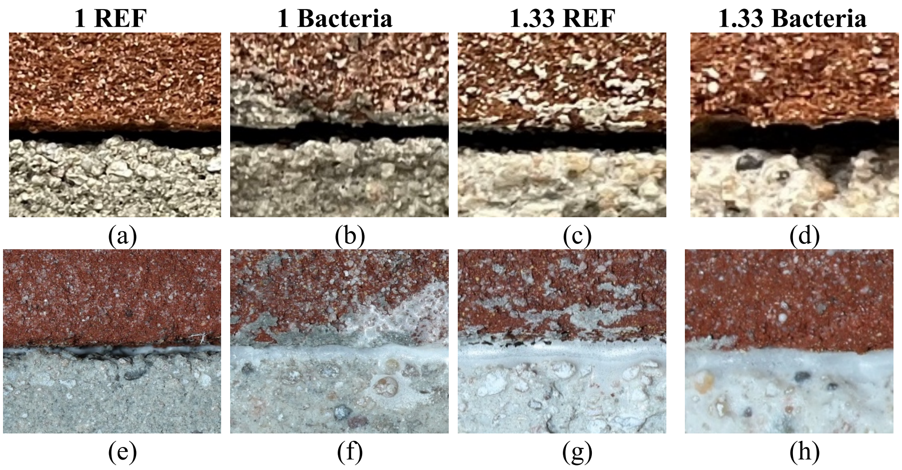

Fig. 2. Crack pictures in masonry couplets before ((a)–(d)) and after ((e)–(h)) healing under humid conditions. Images correspond to two mortar compositions—1and 1.33 lime/ cement ratio — with and without the healing agent.

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