Biomimicry in Built heritage: Mini Vascular Networks for Self-healing Lime-based Mortars

Cristina De Nardi[1*], *Diane* Gardner[1] *and Tony* Jefferson[1]

[1] Cardiff University, Queen's Building, Cardiff CF24 3AA, United Kingdom

Abstract. Heritage buildings face progressively severe and unprecedented risks due to climate change, at particular risk is the building facade. In response to this, it is vital to reconsider the approaches employed in the restoration of masonry, the predominant structural material used in historic facades. Inspired by self-healing concrete research, this study proposes using biomimetic mini-vascular networks (m-MVNs) to repair lime-based mortar cracks. m-MVNs consist of interconnected channels designed to store and release healing agents as needed. They seamlessly integrate into mortar joints of historical masonry walls, meeting conservation requirements. Initial findings indicate promising results with transparent PLA m-MVNs, as they effectively store healing agents without encountering issues such as leakage or premature curing.

Introduction

Recent changes in weather patterns have increasingly exposed historic structures to severe hazards, reducing their longevity. A variety of traditional intervention strategies, such as repointing and bed joint reinforcement, are available to address damage in masonry structures, although their success has not always been consistent [1].

Cardiff University has researched self-healing technologies for concrete, focusing on vascular and meso-vascular networks (MVNs) as alternatives to conventional continuous networks. The latter has the potential to cause delays in the concrete casting process. As depicted in Figure 1, 3D PLA-printed tetrahedral units, known as TETs, can be seamlessly integrated into wet concrete during the mixing phase. TETs are designed to bond strongly with concrete and can store either single (TETs) or dual-component (d-TETs) healing agents. Recent research conducted by De Nardi et al. [2], [3] has shown that both TETs and d-TETs in concrete can rupture and release sufficient healing agents when a specified crack width is reached, achieving strength and stiffness recoveries of up to 30% and 80% respectively using combinations of Sodium Silicate and Nanolime.

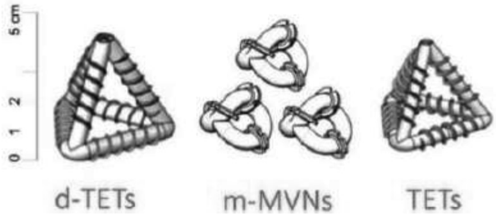

Figure 1 MVNs: single channel (TETs), dual-channel (d-TETs), mini-vascular networks (m-MVNs).

Recently, the MVN design has been revised and optimized, enabling the application of this technology to historical masonry walls. Traditionally, when significant portions of

* Corresponding author: denardic@cardiff.ac.uk

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masonry deteriorate to the point where mortar joints become non-functional, patching techniques are used to restore structural integrity while preserving the original blocks.

The dimensions and design of the previous MVNs have been completely overhauled, allowing mini-vascular networks (m-MVNs) to fit entirely within the thickness of mortar joints. Like MVNs, m-MVNs serve as reservoirs for healing agents, keeping them dormant until they are activated for release when damage exceeds a specific threshold. One of the main challenges is to ensure the watertightness of the m-MVN units, as this will govern the longevity and hence viability of the healing agent

Materials and methods

m-MVNs were printed from clear PLA, purchased from Verbatim®, using an Ultimaker2+® printer with a 0.25 mm nozzle. The initial phases aimed to refine the design and printing process to meet specific requirements for the proposed application, including ensuring 3D printability of units with reduced geometry and wall thickness as well as watertightness. To verify the latter, the weight variation of three m-MVNs, whether with or without a thin paraffin wax coating and filled with either aqueous ink or nanolime (CaOH2) dispersion - marked as Nanorestore by CSGI- was monitored at intervals of 1, 3 and 7 days. Weight measurements were conducted using a KERN scale (d=0.01g).

Results and Discussion

Initially, the precision of measurements was assessed by recording the weight of an empty m-MVN 50 times, resulting in a Coefficient of Variation (CoV) of 2%. Watertightness test results are outlined in Table 1. Leakage occurred in m-MVNs filled with aqueous ink or Nanorestore within the initial 24 hours, leading to weight decreases of approximately 36% and 45%, respectively in 7 days. However, a thin paraffin wax coating, weighing only 0.14 grams, effectively prevented leakage in both cases over time. This is of particular significance for m-MVNs containing Nanorestore, the results of which show no significant weight reduction overtime, despite the propensity of Nanorestore to evaporate due to the alcohol based dispersion used in the bland.

Table 1. Longevity test for m-MVNs exposed to laboratory environmental conditions

Agents	Average weight of m-MVNs (g)				Average weight of waxed m-MVNs (g)			
	Initial (CoV%)	1day (CoV%)	3 days (CoV%)	7 days (CoV%)	Initial (CoV%)	1day (CoV%)	3 days (CoV%)	7 days (CoV%)
Aqueous ink	2.00 (2)	1.61(25)	1.38 (38)	1.29(37)	2.14(1)	2.13(2)	2.13(2)	2.12(1)
Nanorestore	1.70(1)	1.13(23)	1.01(31)	0.94(34)	1.86(1)	1.86(1)	1.81(2)	1.77(2)

Conclusion

The newly designed-MVNs form the basis of a viable self-healing system for masonry joints, capable of effectively storing a nanolime dispersion for a significant period, ensuring its longevity and functionality.

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