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A Proof of Concept

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Innovative Application of Self-healing Technology to Masonry: A Proof of Concept

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Abstract. Cracks are one of the most common expressions of damage in masonry structures. Aside from aesthetic issues, they can compromise the overall behaviour of the structure; therefore, they are undesirable and need to be repaired. The repointing technique is traditionally implemented in this context, especially in historical masonry. Nevertheless, future damage is not prevented and may arise again, thus requiring renewed repointing interventions.

The paper describes a preliminary study conducted at Delft University of Technology to investigate the applicability of the innovative self-healing technology to enable an automatic repair of masonry cracks. A bacteria-based self-healing mortar, developed to repair existing concrete structures, was implemented to explore the capacity of couplets to recover their original strength and aesthetic aspect after multiple damaging events. Specimens built with calcium-silicate and clay bricks were subjected to subsequent cracking cycles using a crack-mouth-opening-displacement controlled bond-wrench test.

Experimental results showed that self-repair, in terms of strength restoration and aesthetic filling of cracks, occurs even after multiple cracking cycles when the self-healing mortar is used with both types of bricks, optimizing the autogenous healing of cement-based mortars. In this context, the healing effectiveness tended to decrease as the crack width and the number of cycles increased. The effectiveness varied also according to the types of brick and healing environment used, e.g. under humid conditions (RH ~ 95%), 50% vs 80% of the original capacity was regained in fully separated couplets made respectively with clay and calcium-silicate bricks. This outcome provides the ground to delineate the remaining testing campaign.

Keywords: Masonry · Heritage · Repair · Cracks · Self-healing

1 Introduction

In view of a safe, cost-effective, and sustainable future, growing attention worldwide is being placed on preserving the existing building and infrastructure stock by implementing effective repair techniques. This awareness mainly includes unreinforced masonry (URM), which, besides representing the highest percentage of contemporary and historic structures worldwide, is often vulnerable to display damage during its service life. The damage commonly starts at the wall surface with cracks at the brick-to-mortar

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interface, along the mortar and/or bricks themselves. Regardless of the cracks' location, the building's performance drops due to aesthetic issues in the best-case scenario. In the worst-case scenario, also structural problems arise, which might compromise the structure's stability leading to the partial or total collapse of the building. In fact, cracks reflect a loss of strength, not being able to carry tensile stresses and having a much-reduced shear capacity. In addition, the component's watertightness or impermeability is compromised, allowing the ingress of water which might further weaken the masonry through salt crystallisation decay, freeze-thaw damage, and/or leaching. In this light, cracks in structures are undesirable and should be prevented or at least repaired.

The repointing technique is commonly used to repair cracks, at the brick-to-mortar interface or within the mortar joint, due to its limited invasiveness and the ability to preserve the original aesthetics of the structure [1]. This makes the strategy perfect for interventions in historical structures where aesthetics should be conserved. In addition, the repair is relatively straightforward; it consists of removing the deteriorated mortar from the outer parts of joints and replacing it with a new compatible mortar. However, even if repointing restores the strength, watertightness and aesthetic condition of the masonry, future damage is not prevented and might reappear. In fact, if differential settlement, vibration or whatever other action or process, which caused the crack in the first place, has not been resolved or is expected to occur again, the crack may reappear, either in the same or in a neighbouring joint; and then, the repair needs to be carried out again. Besides requiring additional maintenances costs, the latter case does not follow the main objective of the restoration which foresees minimum intervention.

In this context, a novel research on the use of a bacteria-based self-healing mortar as repointing mortar for masonry is presented in this paper. Developed for the repair of concrete structures [2][3][4] and already commercialized in the Netherlands (Basilisk, Delft, The Netherlands), this innovative mortar can repair itself by recovering its original set of properties (watertightness, strength, aspect) after degradation or damage has occurred. The automatic repair is given by so-called "limestone-producing bacteria" incorporated in the mortar paste through a self-healing agent, also containing their nutrients. When the mortar cracks, dormant bacterial spores activate when in contact with water and metabolically convert nutrients resulting in limestone precipitation. The limestone produced through bacterial healing optimizes the so-called autogenous healing, i.e. the innate ability of cement-based materials to self-heal cracks up to 0.1 mm in width. As a result, larger cracks can be bacterially self-repaired and thus, further interventions can be avoided with a significant reduction in maintenance costs. Despite the benefits that could be obtained by implementing this technology in masonry structures, this mortar type has been developed for use in concrete and hence, its effective application in masonry structures needs to be validated.

To this purpose, a pilot investigation was conducted at Delft University of Technology to explore the feasibility of the mortar to repair masonry couplets, the impact of the healing environment on the healing process and the effectiveness of bacterial healing against autogenous healing. In this context, two different types of brick (calcium-silicate and clay) were used due to their different absorption properties and three different healing conditions were considered, i.e. humid conditions (RH ~ 95%), wet-dry cycles and dryer conditions (RH ~ 70%). The effectiveness of the technology was assessed in terms of

(i) peak force recovery, testing the specimens periodically by means of a computer-controlled bond wrench test set-up, and (ii) filling of the cracks (aesthetic property), by taking photographs before and after each healing period This paper presents the materials and methods implemented, the results obtained, and the main conclusions drawn from this experimental study.

2 Materials and Methods

The pilot program's goal was to investigate the applicability of the self-healing technology to masonry. First, the feasibility of the mortar to repair masonry specimens was explored; subsequently, the influence of the healing environment and the effectiveness of bacterial healing compared to autogenous healing was investigated. To this purpose, couplets were built and subjected to multiple cracking-healing cycles; their capacity to recover the original strength and aesthetic aspect was accordingly explored. The materials used and experiments conducted for this purpose are detailed in this section.

Calcium-silicate bricks (f_{bc} 13.26 MPa [5]) and clay bricks (f_{bc} 28.31 MPa [6]), having nominal dimensions (length x height x thickness in mm^3) respectively of 210 x 70 x 100 and 210 x 50 x 100, were used to cast the masonry specimens. Since the healing environment plays a crucial role in the effectiveness of the proposed technique, the types of brick were selected due to their different absorption properties, herein quantified through the initial rate of absorption (IRA) [7] and the rate's evolution over time experimentally determined by Gaggero et al. in [8] (Fig. 1). In fact, due to the pore's dimensions, the process of absorption of clay bricks is significantly faster than the calcium-silicate one, which, however, reaches a higher absorption level in the long term. Please note that the bricks used in the present research and in the one by Gaggero et al. [8] were manufactured in the same production batch and stored in closed space at room temperature.

In combination with the two types of bricks, a currently marketed self-healing mortar (Basilisk, Delft, the Netherlands) was employed to cast the self-healing masonry specimens. The composition of the cement-based mortar containing the patented Basilisk's healing agent [2] is confidential, but preliminary mix designs investigated in experimental studies performed before the marketing phase are available in literature, e.g. [3]. As declared by the producer, the R3-type mortar has a compressive and flexural strength at 28 days of 37.7 MPa and 7 MPa, respectively. In addition to the self-healing mortar, a control mortar having identical composition as the self-healing one but without the healing agent was used to cast control specimens. The latter set was employed to discriminate between the healing contribution of the self-healing agent and the so-called autogenous healing, verifying the agent's benefits (Sect. 5.2).

Specimens consisted of two bricks bonded together by a 10 mm thick mortar joint (Fig. 2-a) and were built in controlled laboratory conditions. Specimens were entirely cast either with the self-healing mortar or the control mortar, hereafter referred to as self-healing couplets or control couplets respectively; no repointed couplets were considered within the present study. To have all the specimens built identically, simple plastic jigs were used to align the bricks properly and to ensure a 10 mm mortar joint in between. Due to the different absorption properties of the two types of bricks used, different mix fluidities were implemented, i.e. 0.45 and 0.72 water-to-cement ratios for calcium-silicate and clay couplets, respectively. Accordingly, different failure mechanisms resulted: at the brick-to-mortar interface and within the mortar joint for calcium-silicate and clay couplets, respectively. The implemented ratios were experimentally chosen to obtain the best masonry bond properties (the reader is referred to [9] for further details). Regardless of the specimens' type, bed joints were painted white to better observe induced cracks in photographs taken before and after the healing period (aesthetic restoration). A water-based acrylic paint has been used because of its water-permeability. In addition, a 15 mm diameter circle was drawn on each specimen's face by using an indelible marker to provide a reference scale in the photographs.

Bond wrench tests have been systematically performed to crack the specimens and evaluate their healing capacity. A crack-mouth-opening-displacement (CMOD), computer-controlled, bond-wrench test set-up (Fig. 2-b), designed in previous studies at Delft University of Technology [10], was used due to its simplicity and suitability in controlling the induced cracking phenomenon. The test consisted of applying an eccentric vertical load to the masonry couplet while the specimen is rigidly restrained from its bottom. The load was applied by a 100 kN hydraulic jack, operated in deformation control using the relative vertical displacement between the two clamps fixing the specimen as control variable. Two LVDTs were glued on both sides of the specimens to measure the width of the induced bending crack. This allowed to pre-crack specimens at specific intensities (e.g. 0.2 mm, 1 mm) before being allowed to heal. In particular, some of the specimens were opened to a CMOD of 0.2 mm (hereafter referred to as partially cracked couplets, i.e. there is still partial load transfer) while some others were tested until failure occurred (hereafter referred to as fully cracked couplets, i.e. no partial load transfer as completely broken). The latter case enabled observation of the fracture area, determination of the location of failure (brick-mortar interface or within the mortar joint), and examination of the presence of limestone precipitation.

Between subsequent tests, the specimens were left to heal for 65 days in specific healing environments that aimed to provide the water and oxygen needed for the healing process to occur successfully. Depending on the specimen's set considered, a different healing environment may have been implemented, i.e. humid conditions (RH ~ 95%), wet-dry cycles and dryer conditions (RH ~ 70%). Humid conditions were created in a fog room at about 95% relative humidity, while dryer conditions were in a conditioning room at about 70% relative humidity. Instead, wet-dry cycles were performed by wetting the specimens in a plastic box once a week; the box collected the water, which was then absorbed by the lower bricks or evaporated.

3 Experimental Results

The results obtained of the multiple cracking cycles are listed by the set's goal in Table 1. According to the set's goal, the specimen's type (mortar and brick type), cracking specifics (hardening time at which pre-cracking was carried out, CMOD cracking intensity, i.e. partially or fully separated, and the number of specimens tested) and healing environment used is specified. The peak force F_i obtained with the bond wrench test is reported specifying the number of the relative cracking cycle by the subscript "i". Since the width of the crack induced in each specimen was always the same for subsequent

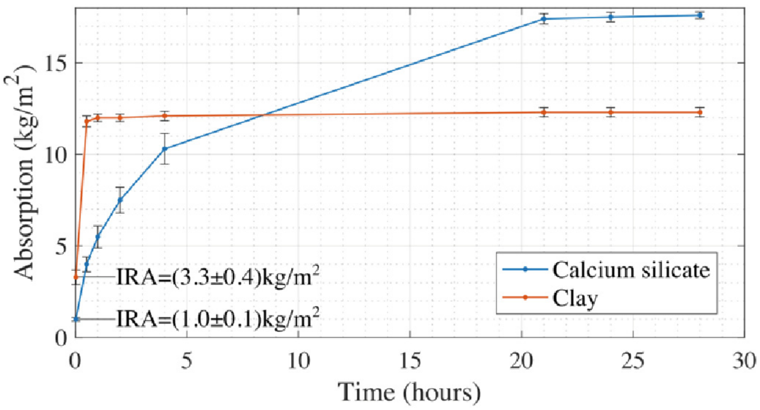

Fig. 1. Cumulative water absorption rate of both types of bricks determined by Gaggero et al. in [8].

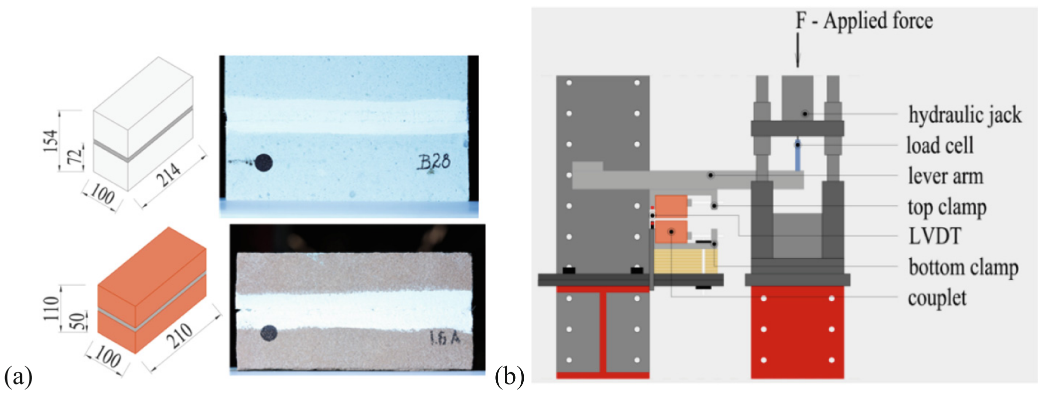

Fig. 2. (a) Masonry specimens and (b) computer-controlled bond wrench test set-up used for testing [9].

cycles, only the width for the first cracking cycle was reported (CMOD). The type of specimen, the implemented healing environment, and the number of tests performed are also included.

4 Feasibility of the Self-healing Technology in Self-repairing Masonry Couplets

The self-healing mortar's capability to enable the automatic repair of masonry cracks is explored in this section. The exploratory analysis is conducted by considering the peak force recovery (Fig. 3) and crack's closure (Fig. 4) of calcium-silicate (CS) and clay brick masonry specimens entirely built with the self-healing mortar, hereafter referred to as self-healing couplets, after multiple cracking-healing cycles performed with the bond wrench test (Table 2). As a product of the different mortar's mix fluidity used in combination with the two types of bricks, the location of the cracks to be repaired was different for both types of specimens, i.e. at the brick-to-mortar interface in the case of

Table 1. Experimental results obtained per set-goal: width of the induced crack (CMOD) and peak force (F_i) of the bond-wrench test for cracking-healing cycle i, with relative coefficient of variation specified in brackets. The specimen's type (mortar and brick type) tested, cracking specifics (hardening time at which pre-cracking was carried out, CMOD cracking intensity, i.e. partially or fully separated, and the number of specimens tested) and healing environment used are indicated for each set.

Set goal	Mortar type	Brick type	Hardening time at pre-cracking (days)	Partially / Fully separated	(No. Tests)	Healing environment	CMOD (mm)		F_1 (N)		F_2 (N)		F_3 (N)		F_4 (N)	
Applicability of the self-healing mortar	Self-healing	CS	7	Partially	(11)	RH ~ 95%	0.04	(46)	98	(25)	229	(26)	82	(37)	60	(81)
				Fully	(2)		0.2	(35)	83	(28)	60	(25)	0	(-)	0	(-)
		Clay		Fully	(3)		0.1	(21)	261	(54)	82	(11)	0	(-)	0	(-)
Influence of **healing environments**	Self-healing	CS	28	Partially	(5)	RH ~ 95%	0.2	(32)	245	(30)	107	(102)	-		-	
					(5)	Wet-dry cycles	0.2	(14)	298	(18)	67	(53)	-		-	
					(5)	RH ~ 70%	0.2	(23)	277	(41)	62	(56)	-		-	
		Clay		Partially	(5)	RH ~ 95%	0.3	(19)	453	(12)	214	(50)	-		-	
					(5)	Wet-dry cycles	0.3	(17)	414	(34)	230	(36)	-		-	
					(5)	RH ~ 70%	0.3	(27)	404	(32)	198	(45)	-		-	
Bacterial vs autogenous healing	Self-healing	CS	28	Partially	(5)	RH ~ 95%	0.1	(57)	52	(45)	182	(30)	50	(66)	-	
				Fully	(5)		0.3	(35)	61	(41)	45	(120)	2	(224)	-	
			93	Partially	(5)		0.1	(40)	321	(28)	61	(24)	-		-	
				Fully	(5)		0.5	(36)	299	(70)	5	(140)	-		-	
			158	Fully	(10)		-		329	(40)	-		-		-	
	Control		28	Partially	(5)		0.1	(16)	48	(20)	146	(80)	17	(60)	-	
				Fully	(5)		0.2	(19)	37	(30)	12	(60)	0.0	(-)	-	
			93	Partially	(5)		0.1	(13)	164	(40)	16	(10)	-		-	
				Fully	(5)		0.7	(54)	129	(30)	0	(-)	-		-	
			158	Fully	(5)		-		113	(52)	-		-		-	

CS couplets and within the mortar joint in the case of clay couplets. This facilitated the examination of two scenarios that could have varied effectiveness in terms of repair. In fact, although cracks at the brick-to-mortar interface are the most common situation in masonry structures, this case might be expected to be slower, with calcium carbonate production possible on only one side of the crack. In both cases, the mechanical recovery was analysed by comparing the original capacity of the specimen (peak force obtained from the first cycle) to the healed peak force obtained in subsequent cracking cycles. To quantify the recovery against the original capacity, a healing ratio (F_i/F_1 in %, "i" indicating the cracking cycle's number) was computed. Figure 3-a shows the peak force and the corresponding healing ratio, where applicable, against the cracking cycle's number, while Fig. 3-b displays the healing ratio computed in the second cycle against the width of the repaired cracked. The latter parameter was computed at the first cracking cycle, as the average of the measurements of the two LVDTs monitoring the induced crack on both sides of the specimen once the load was removed. A trend line is included in Fig. 3-b to highlight the tendency. Besides the mechanical recovery, the crack's closure was also examined to verify the recovery in terms of aesthetic property. To this purpose, Fig. 4 shows the photographs taken before and after each cracking-healing cycle.

The results obtained show that self-repair in terms of peak force restoration (Fig. 3) and aesthetic filling of cracks (Fig. 4) does occur, regardless of the type of brick, when the self-healing mortar is used with masonry. Despite a substantial difference between the two types of masonry considered, pre-cracked self-healing couplets showed their capacity to (fully or partially) repair induced cracks of up to 0.2 mm width. The resulting process efficiency, however, was strongly influenced by the type of masonry (mix fluidity and water absorption properties of bricks), the number of cycles performed (Fig. 3-a) and the crack width (Fig. 3-b). These aspects are discussed in detail next.

The multiple cracking-healing cycles performed on CS couplets showed that the self-healing properties of the mortar are effective, even for multiple damaging events, when cracks are not opened more than 0.1 mm. In fact, specimens gained 240% of the original strength on average after the first healing cycle, while after the second and third cycles, they regained 90% and 60%, respectively. Nonetheless, the healing process was less effective in fully cracked couplets, capable of regaining up to 80% of the original capacity only after the first healing cycle. The latter case, however, was only considered to observe the failure mechanism and does not represent cracks in real structures. In fact, although the couplets were put back together as best as possible, the specimens were unintentionally misaligned and not exactly pressed back together, leaving relatively large open cracks and discontinuous contact areas.

Although cracks occurred within the mortar, the healing process of clay specimens resulted to be less efficient in comparison with the healing process of CS specimens, probably due to the healing environment and/or the duration of the healing period. At the end of the healing period in the fog room, specimens were found completely soaked, which may have partially hindered the healing process. The capacity of clay bricks to absorb water faster and reach saturation earlier than CS bricks (Fig. 1), negatively affected the healing process of clay specimens cured under humid conditions (RH $>$ 95%). Even if the presence of water is essential for the self-healing process to take place, an excess of water can be harmful to its development. A fog room with lower relative humidity or wet-dry cycles may have yielded better results. Hence, the optimal healing conditions are dependent on the masonry type considered and are thus fundamental to assess the maximum efficiency that the self-healing technology can achieve.

An inverse relationship was observed between the healing ratio and the number of healing cycles (Fig. 3-a) and between the healing ratio and crack width (Fig. 3-b). Nonetheless, this research has considered a constant duration of 65 days regardless of crack width and the number of healing cycles performed. A longer healing duration is reasonably needed for specimens with larger crack amplitudes and also for second or third cracking cycles.

The photographs taken before and after the multiple cracking-healing cycles show that cracks can be filled with calcium-carbonate deposition, fully or partially recovering the original aesthetics of the specimens (Fig. 4). As pointed out for the mechanical recovery, the aesthetics' recovery diminished as the number of the cracking cycle and width of the induced crack increase.

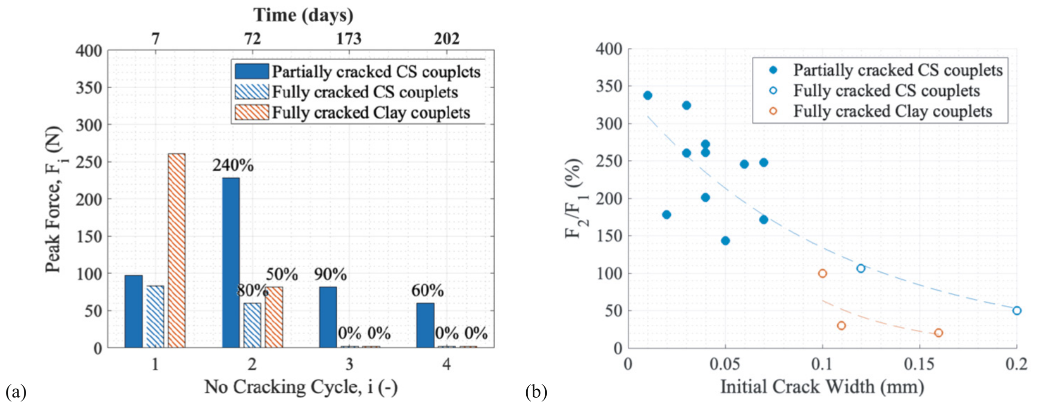

Fig. 3. Feasibility of the self-healing technology with bricks: (a) peak force after multiple cracking-healing cycles with the relative healing ratio (F_i/F_1) computed against the original capacity obtained at first cracking cycle; (b) healing ratio (F_2/F_1) against the initial crack width, evaluated at the end of the first cracking cycle.

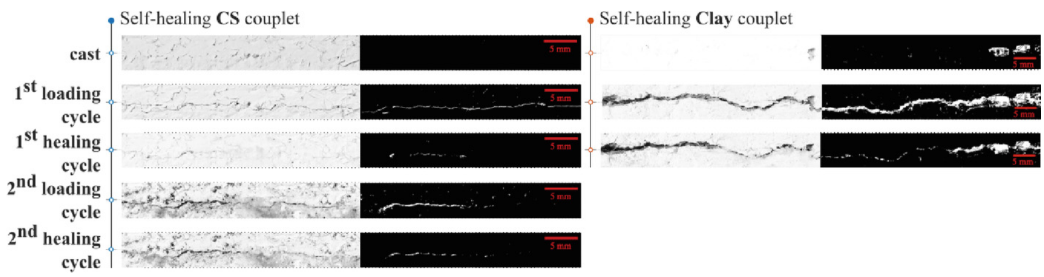

Fig. 4. Fully cracked self-healing couplets before and after multiple cracking-healing cycles.

5 Sensitiveness and Effectiveness of the Self-Healing Process

5.1 Comparison Against Multiple Healing Environments

The influence of different healing environments on the effectiveness of self-healing couplets is investigated in this section. Given the significantly different performance of CS and clay self-healing specimens under humid conditions (RH ~ 95%), a curing room with lower relative humidity (RH ~ 70%) was considered in addition to wet-dry cycles performed by wetting the specimens once per week. Figure 5 shows the results obtained in terms of the healing ratio, computed by dividing the healed peak force obtained in the second cracking cycle (F_2) by the original capacity of the specimen (peak force obtained from the first cycle, F_1).

The cracking-healing cycle performed on both types of specimens confirms that the healing environment can strongly influence the performance of self-healing couplets and that the optimal conditions depend on the type of brick used, especially on the brick's absorption properties. By comparing the results obtained with the selected environments (Fig. 5), humid conditions and wet-dry cycles led to better CS and clay couplets performance, respectively. The slow water absorption process of CS bricks requires a humid environment (RH ~ 95%) to constantly provide the water demand required for a successful healing process; accordingly, the water absorbed during wet-dry cycles was probably insufficient. In fact, the latter environment periodically provided a high water supply followed by the possibility to dry, which was optimal for clay bricks that can absorb water faster and reach saturation earlier than CS bricks. Yet, a humid ambient (RH ~ 95%) provided an excess of water that was harmful to the self-healing process for clay bricks. Hence, a surplus or a deficiency of water, such as the one given regardless of the brick type with the curing room with lower relative humidity (RH ~ 70%), might be detrimental. A preliminary suitability study is needed before the use in practice to evaluate the optimal healing conditions according to the brick type considered and the environmental conditions available on site. For instance, the climate in the Netherlands should favour this technology when combined with clay brick masonry, having about 80% average annual humidity and frequent rainfall occurring throughout the year, which means that wet-dry cycles are possible.

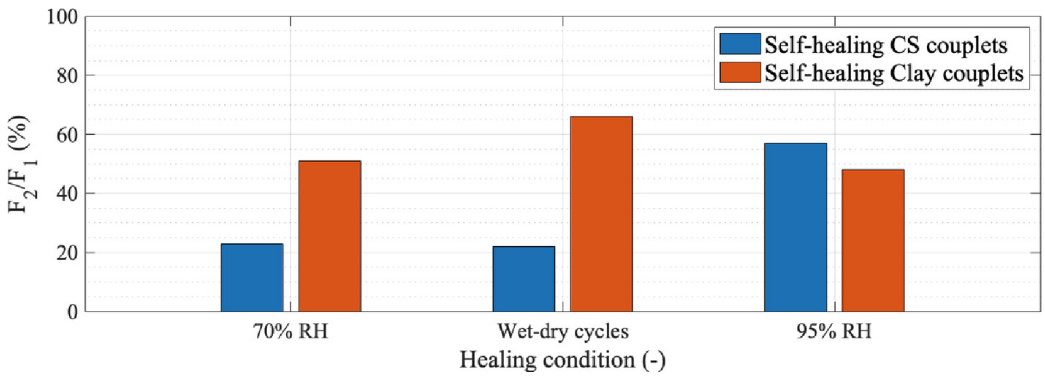

Fig. 5. Effectiveness of self-healing couplets according to different healing environments. Based on the mean values of five specimens.

5.2 Comparison Against Control Mortar

To assess the effectiveness of self-healing couplets, this section quantifies and contrasts the healing contribution from the self-healing agent and the so-called autogenous healing. A clear distinction between the two is necessary to verify the agent's implementation, autogenous healing being the innate ability of cement-based materials to repair cracks up to 0.1mm in width. Among the mechanism contributing to the latter phenomenon, rehydration of the cement paste is the most significant one. To evaluate the latter's influence, two sets of couplets were tested: one constructed entirely with self-healing mortar (self-healing couplets) and the other with control mortar (control couplets) which has the same composition as the self-healing mortar but lacks the healing agent. Regardless of the specimen's type, tested couplets underwent the same curing history, i.e. air-cured for the first 28 days and then placed in a fog room at about 95% relative humidity. Specimens were tested at 28, 93 and 158 days to evaluate the influence of hardening time in both types of specimens. The specimens tested at 28 and 96 days were then subjected to multiple healing-cracking cycles to validate the agent's effectiveness.

The peak force of both types of specimens tested at different hardening times shown in Fig. 6 indicates that the hydration of the cement paste can be considered complete after 93 days under the assumed curing conditions. The latter assumption is based on the behaviour of control specimens and can be extended to self-healing couplets since the same mortar composition was used. The additional force gain observed in self-healing couplets can be attributed to the introduced healing agent. In fact, although specimens were intact, brick porosity allowed the ingress of carbon dioxide and water needed for the calcium carbonate production inside small gaps probably present at the interface increasing the bond.

The multiple cracking-healing cycles performed on masonry couplets first cracked at 28 days confirm that the self-healing agent optimises the mechanical restoration (Fig. 7) and aesthetic filling of cracks (Fig. 8) obtained due to autogenous healing, primarily due to delayed hydration of un-hydrated cement grains in the cement paste. In particular, by comparing the healed peak force resulting from multiple cracking-healing cycles (Fig. 7-a), the ability of self-healing specimens to recover their original strength was greater than that of control specimens. For instance, fully separated couplets cast with the self-healing mortar recovered 64% of the original peak force in average after the first healing cycle, while control specimens recovered only 37%. Furthermore, when cracks were restricted to 0.1 mm, the self-healing mortar could regain almost the original peak force capacity (90%) after two subsequent crack-healing cycles, whilst the control mortar recovered less than half (40%). Besides the better performance as the number of cycles increases, self-healing couplets also showed a higher healing capability than control ones as the crack width increases (Fig. 7-b). Anyhow, an inverse relationship was observed between the healing ratio and the number of healing cycles (Fig. 7-a) and between the healing ratio and crack width (Fig. 7-b), as exposed in Sect. 4. A trend line was included in Fig. 7-b to highlight the latter behaviour. Results on self-healing couplets are, in fact, in line with those discussed in the previous section, since no significant difference has been obtained in terms of bond capacity and healing percentage.

A less effective healing process is observed for specimens first cracked at later ages, where up to the 10% of the original peak force in average was recovered (Fig. 9-a). As previously explained, autogenous healing in control specimens mainly due to delayed hydration of the cement paste can be considered concluded after 93 days. This explains the incapacity of control specimens pre-cracked at 93 days to heal induced cracks. Different from this, in self-healing specimens the partial failure within the brick (delamination of the brick surface at the brick-to-mortar interface) made the self-healing properties of the mortar ineffective (Fig. 9-b).

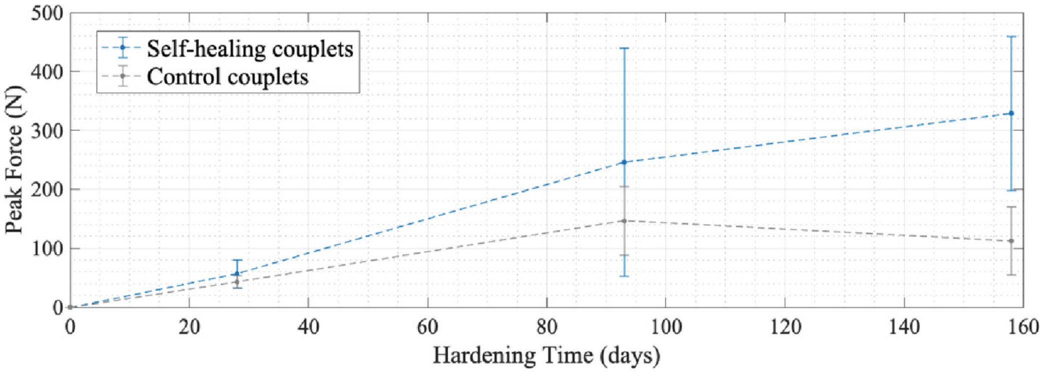

Fig. 6. Peak force versus hardening time for control and self-healing couplets. Each data point is based on mean values of ten specimens.

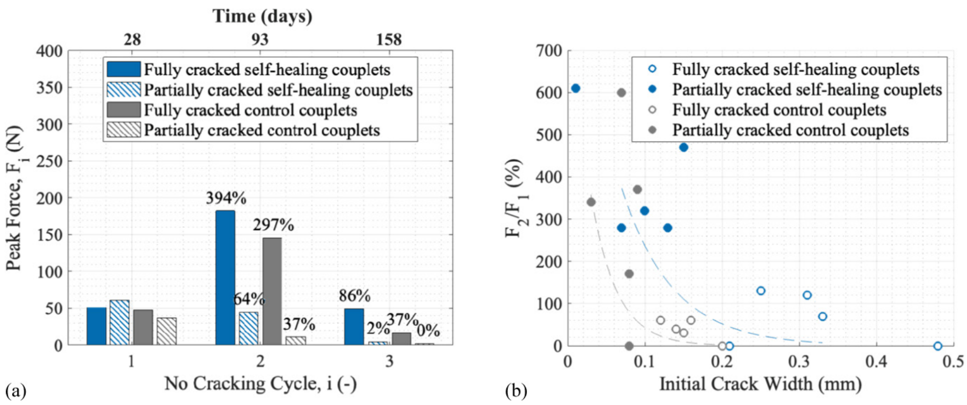

Fig. 7. Effectiveness of self-healing specimens compared to control specimens pre-cracked at 28 days: (a) peak force after multiple cracking-healing cycles with the relative healing ratio (F_i/F_1) computed against the original capacity obtained at first cracking cycle; (b) ratio (F_2/F_1) against the initial crack width, evaluated at the end of the first cracking cycle.

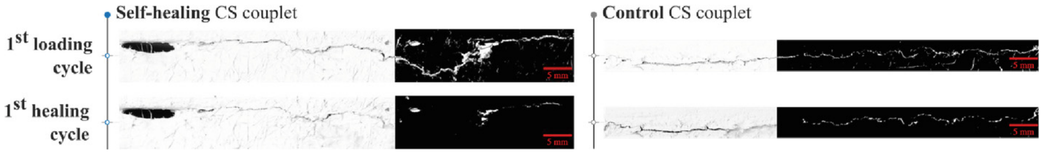

Fig. 8. Self-healing and control couplets before and after the first healing cycle.

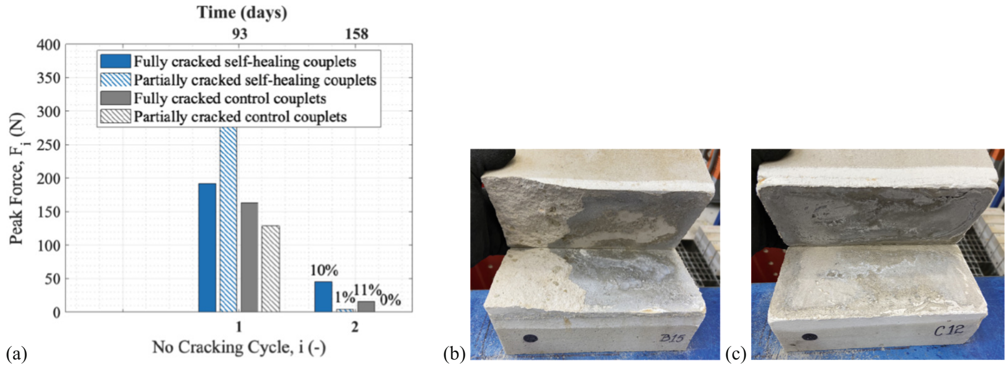

Fig. 9. Effectiveness of self-healing specimens compared to control specimens pre-cracked at 93 days: (a) peak force after multiple cracking-healing cycles with the relative healing ratio (F_i/F_1) computed against the original capacity obtained at first cracking cycle; failure mode obtained in (b) self-healing and (c) control couplets at 158 days.

6 Conclusions

The repointing technique is often used to repair masonry cracks, especially in historical buildings, due to its limited invasiveness and the ability to restore the original strength, watertightness and original aesthetic condition of the structure. Nevertheless, if the cause initially generating the damage is not or cannot be resolved, damage might reappear, leading to future cracks and requiring additional repointing interventions. In this context, the applicability of a self-healing mortar could enable the automatic repair of forthcoming cracks and reduce maintenance costs accordingly. This innovative technology has been deeply investigated and is already used to repair concrete structures. Still, its practical application in masonry structures has not been explored nor validated yet. To this purpose, a pilot program was performed at Delft University of Technology implementing a self-healing mortar currently marketed to repair existing concrete structures. The feasibility study consisted of subjecting some variations of masonry couplets to multiple cracking-healing cycles and exploring their capacity to recover their original strength and aesthetic aspect. A crack-mouth-opening-displacement (CMOD), computer-controlled, bond wrench test set-up was used to crack the couplets to different intensities and evaluate the strength restoration, while photographs taken before and after each healing period were used to observe the filling of the cracks (aesthetic property). The following conclusions can be drawn.

The proposed self-healing mortar successfully enabled the self-repair of masonry couplets built with calcium-silicate (CS) and clay bricks. For both types of specimens, pre-cracked couplets entirely made with the self-healing mortar showed their capacity to partially or totally self-repair and fill induced cracks up to 0.2 mm width. The two bricks considered have different absorption properties and surface roughness and allowed generalizing the technology's application to different types of bricks. In fact, the efficiency of the self-healing process varied according to the type of brick considered, mainly due to the healing environment used in combination. The importance of compatibility between brick's absorption characteristics and healing conditions was hereby highlighted.

The performance of self-healing couplets made with CS bricks was satisfactory under humid conditions, with cracks up to 0.1 mm at the brick-to-mortar interface self-healed even after multiple damaging events. For these partially cracked specimens, healing ratios of 240%, 90% and 60% have been reached respectively for the first, second and third healing cycle. On the other hand, about 80% of the original peak force was recovered in fully cracked couplets after the first cracking cycle. An inverse relationship is thereby observed between the number of healing cycles and healing ratio, and between the initial crack width and healing ratio.

Conversely, a significantly lower efficiency was observed on self-healing couplets built with clay bricks left to heal under humid conditions. Even if cracks occurred within the mortar, a healing ratio of only about 50% after the first healing cycle was reached. Although the maximum efficiency of the mortar would be expected in the latter case since calcium carbonate production would be possible on both sides of the crack instead of one, the excess of water provided to the specimens during the healing period (due to the ability of clay bricks to quickly reach saturation) negatively affected the healing process.

The influence of the healing environment on the efficiency of self-healing couplets was, in fact, confirmed in the second part of the study. Humid conditions (RH ~ 95%) and wet-dry cycles led to a better performance of CS (+40%) and clay (+20%) couplets, respectively. On the other hand, dryer conditions (RH ~ 70%) did not provide sufficient water for the healing process to succeed correctly, regardless of the type of brick considered.

Eventually, the potential of the self-healing technology was further verified with comparisons between self-healing and control couplets, the latter cast without the self-healing agent. The innate capacity of cement-based materials to repair cracks up to 0.1 mm, through the so-called "autogenous healing", was confirmed but appeared dwarfed by the efficacy of the self-healing mortar at this task.

The presented study provides a first insight into the potential of applying the self-healing technology to masonry. Further research is required to determine the feasibility of the proposed repair measure as it is based on a limited number of tests and was conducted on a commercially available cement-based mortar, which is not commonly used for the repointing of masonry due to compatibility issues.

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