Research upon self-sealing of fibre reinforced mortar with integral crystalline waterproofing admixtures

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Abstract. The paper presents results of an experimental research made upon the self-sealing of a fibre reinforced mortar with an integral crystalline waterproofing admixture in a dosage rate of 1-3 % of the cement mass. Samples were pre-loaded in three point bending up to 90 % of the ultimate capacity and conditioned in wet-dry cycles. Micro-cracks width was measured with a microscope after pre-loading, and up to 20 days. The results show that the 3 % admixture content presents the superior self-sealing performance both in the terms of the self-sealing degree and self-sealing rate. According to the results, lower contents of crystal-line admixture cannot predict a desirable self-sealing target, despite the fact that the self-sealing potential/ability is indisputable and may take longer periods.

1 Introduction

Cementitious composites prove a historic autogenous self-healing ability [1], credited for many decades to the ongoing hydration reaction. Thus, its contribution to the self-sealing of early age cracks was studied since the late XIX century [2]. Self-sealing impacts the life expectancy of concrete structures, and much research was done on the topic within the latter 40 years. Thus, today we know that the natural ability to fill micro-cracks is made mainly through continued hydration of unhydrated cement and calcium carbonate precipitation. Expansion/swelling of calcium-silicate hydrate gel and deposition of impurities, even if of secondary importance, contribute as well to the self-healing potential [3-5].

Integral crystalline waterproofing (ICW) admixtures have crystalline chemicals that react in the presence of water and produce tinny crystals that fill pores, capillaries and micro-cracks [6]. The process continues as long as moisture is present. Once the cementitious composite is dried, the crystalline chemicals become dormant till water returns, when crystallization starts again [7-8].

Next, the paper provides experimental information about the self-sealing potential of mortars with ICW admixtures. An ICW content of 1-3 % of the mass of the Portland Cement was studied [9].

2 Mixes content

Table 1 shows the reference mortar mix T0, with settled self-healing potential [10]. The ingredients are:

• Portland cement CEM I 42.5R (PC), as the main binder material;

Table 1. Reference mix (T0) content – kg [1].

PC	FA	S	MS	HRWRA	W	PVA
580	650	476	141	12.75	327	26

• Type C fly ash (FA), as a green supplementary binder;
• Standard quartz sand (S) with the maximum grain size of 2 mm, with quartz crystals (i.e., SiO2) content more than 96 % (see Figure 1 for the particle size distribution);

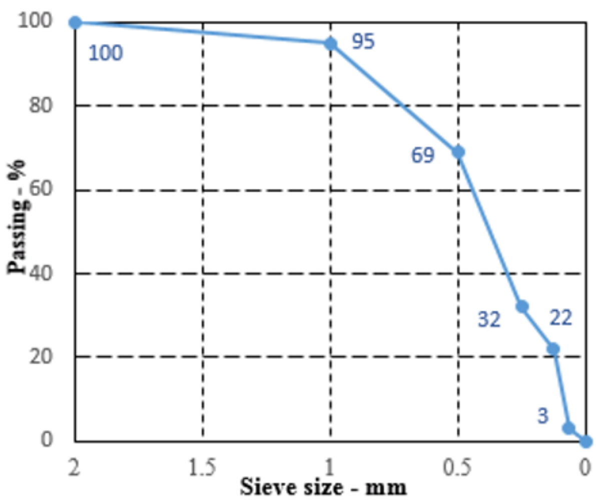

Fig. 1. Particle size distribution of the sand.

• Marble slurry (MS), an important by-product of the marble production, was considered as a fine aggregate ranging from 0.075-4.75 mm;
• A polycarboxylate based high range water reducing admixture (HRWRA);
• Synthetic polyvinyl alcohol fibres (PVA) to endorse precipitation of crystallization products on the cracks surface [45], 8 mm in length and 39 μm in diameter,

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with the tensile strength of 1.2 GPa and 1.2 % mineral oil coating to reduce the interfacial chemical bond with the matrix.

Mixes proportions are shown in Table 2 in the terms of the relative mass.

Table 2. Relative mix proportions.

Mix	T0	T1	T2	T3
C	1			
FA	1.12	1.11	1.10	1.09
S	0.82			
MS	0.24			
HRWRA	G 0.02			
W	0.56			
PVA	0.04			
ICW	0.00	0.01	0.02	0.03

3 Preliminary processing

Specimens of 40×40×160 mm were shielded in plastic foil and stored in the environmental enclosure at 20±2 °C and 90 % relative humidity (RH). After 24 h, the specimens were cured in water for 28 days at room 20±2 °C and RH=50 %. Further, three specimens of each mixture were fully tested in three-point bending, while other three specimens were partially loaded and cracked up to 90 % of the mean modulus of rupture previously determined, shown in Table 3. Finally, daily wet-dry cycles were applied for 20 days. Each day, after 16 hours of water immersion followed 8 hours of drying at 20±2 °C and RH=50 %.

Table 3. Mean modulus of rupture.

Mix	Mean Bending Strength [MPa]
T0	16.7
T1	15.7
T2	18.9
T3	20.2

4 Criteria and evaluation

Micro-crack widths were measured with a Leica DMC2900 microscope at 0, 1, 4, 8, 14 and 20 days after preloading during the wet-dry exposure. The following time dependent self-sealing parameters are introduced and discusse further:

• The mean self-sealing degree (SD_m - %), considering the relative decrease of the average crack width (w_{av}) at time t, related to the initial moment of conditioning

$$SD_m(t) = \frac{w_{av}(0)-w_{av}(t)}{w_{av}(0)} \times 100 \quad (1)$$

• The maximum crack self-sealing degree (SD_M - %),, considering the relative decrease of the initial maximum crack width (w_{max}) at time t related to the moment initial moment of conditioning, after preloading

$$SD_M(t) = \frac{w_{max}(0)-w_{max}(t)}{w_{max}(0)} \times 100 \quad (2)$$

• The mean self-sealing rate (TSR_m - µm/h), considering the decrease of the average crack width corresponding to a mixture at time t compared to time (t-1) of conditioning, related to the corresponding interval

$$TSR_m(t-1,t) = \frac{w_{av}(t-1)-w_{av}(t)}{(t)-(t-1)} \quad (3)$$

• The maximum self-sealing rate (TSR_M - µm/h), considering the decrease of the maximum crack width corresponding to a mixture at time t compared to time (t-1) of conditioning, related to the corresponding interval

$$TSR_M(t-1,t) = \frac{w_{max}(t-1)-w_{max}(t)}{(t)-(t-1)} \quad (4)$$

Cracking regression in the terms of the mean and maximum cracks width is summarized in Tables 4 and 5.

The cracking evolution is reflected by the time dependent self-sealing degrees in Figures 2 and 3. Mixture T3, with a 3 % content of ICW, fills entirely both the mean and the maximum crack widths at 14 days (i.e., SD_m=100 % and SD_M=100 % after 14 days). Lower ICW content gives poor results even in relation with reference mix T0, T1 and T2 presenting similar trends. However, it has to be mentioned that an ICW content of 1 % seems to be slightly superior to a content of 2 %.

Table 4. Average crack widths in mixtures.

t - days	w_{av} - µm			
	T0	**T1**	**T2**	**T3**
0	67.5	46.3	60.3	39.0
1	62.6	42.6	59.3	32.3
4	38.8	37.8	51.9	13.3
8	25.8	29.2	39.7	1.3
14	12.8	23.0	33.7	0.0
20	9.3	13.4	29.1	0.0

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Table 5. Maximum crack widths in mixtures.

t - days	w_{max} - μm			
	T0	**T1**	**T2**	**T3**
0	114.0	78.0	140.0	60.0
1	92.0	75.0	140.0	60.0
4	69.0	59.0	140.0	27.0
8	47.0	51.0	92.0	21.0
14	30.0	49.0	89.0	0.0
20	30.0	30.0	84.0	0.0

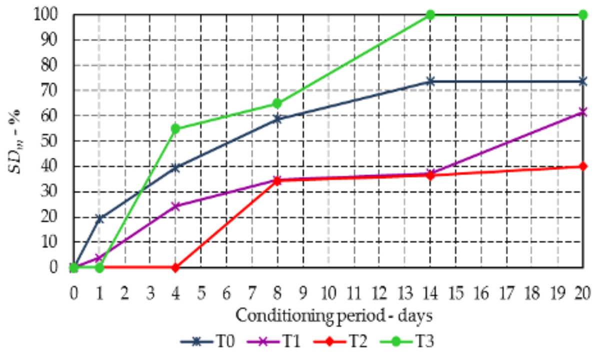

Fig. 2. Time dependent mean crack self-sealing degree.

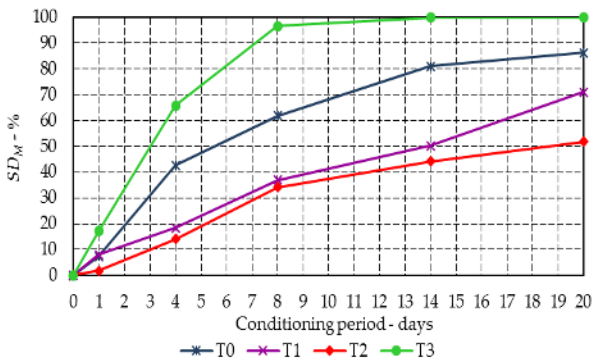

Fig. 3. Time dependent maximum crack self-sealing degree.

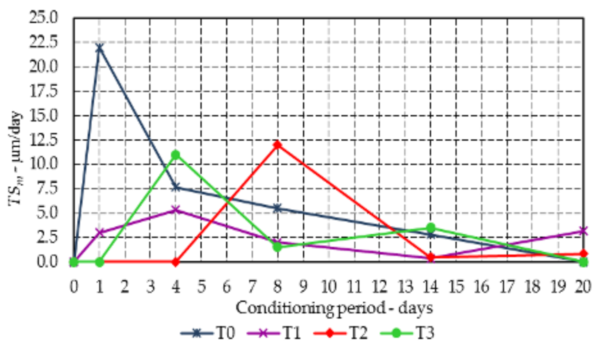

Fig. 4. Mean crack self-sealing rate in time.

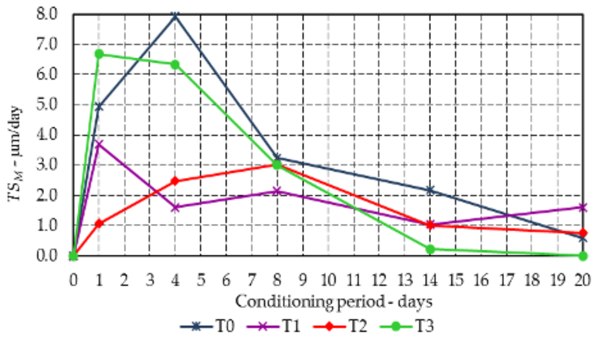

Fig. 5. Maximum crack self-sealing rate in time.

The self-sealing rates emphasize similar superior pattern of the performance of mixture T3 (see Figures 4 and 5) related to T1 and T2. In the early stages T3 shows rates of 11.0 μm/day in the terms of the average crack width and 6.7 μm/day with regard to the maximum crack width. Mixtures T1 and T2 have lower early rate during the first day but seems to stabilize at rates of 1.0-2.5 after 14 days. However, the lack of ICW in the mixture presents the higher initial rates (see T0 trends in Figures 4 and 5), that shows that a low ICW content presents a latency in the early stages.

5 Conclusions

The main conclusions result naturally from the trends of the considered self-sealing parameters. The evidence clearly shows that an ICW content of 3 % of the cement quantity brings superior self-sealing performance. A lower content of ICW admixture cannot ensure/predict a given/desirable self-sealing performance. Results are inconclusive yet, but self-sealing may extend over longer periods.

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