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EFFECT OF SUPERABSORBENT POLYMERS ON PLASTIC SHRINKAGE CRACKING AND PROPERTIES OF FRESH STATE MORTARS REINFORCED BY POLYMERIC FIBRES

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Abstract

Superabsorbent polymers (SAPs) in cementitious materials can be successfully used as internal curing agents by providing continuous supply of water for hydration processes. The kinetics of absorption and desorption of water play a critical role in formation of dense and uniform microstructure and hence significantly influence long term durability and sustainability of mortars. However, the effect of SAPs on shrinkage cracking in early age fibre reinforced mortars (FRM) still remains unclear and deficient. The current study aims to address this issue by evaluating the effect of SAPs on plastic shrinkage cracking in cementitious mortars reinforced by polymeric fibre and made with three types of cement (CEM I–PC, CEM II –FA and CEM III–GGBS). The plastic shrinkage cracking was analysed by the optical microscopy according to ASTM C1579-13 standard. Fresh state properties were characterised by flow table, air content and setting time tests. The results showed that SAPs significantly reduce development of plastic shrinkage cracking and enhance its serviceability. It was also found that the fresh state properties of fibre reinforced mortars with different type of cements are strongly affected by different SAPs as governed by their particles size and absorption/desorption kinetics.

Keywords: Superabsorbent polymers, Fibre Reinforced Mortars, Plastic Shrinkage, Fresh state Properties

1. INTRODUCTION

Supplementary cementitious materials (SCMs) are commonly used to improve sustainability of Portland cement-based materials and reduce its environmental impact. The use of SCMs, leads to a significant reduction in carbon dioxide emissions from cement industry [1]. However, early age shrinkage of cementitious systems is still a major concern due to the complex hydration reactions. This often leads to early cracking induced by self-desiccation processes [2]. Even within the first hours after casting before final set, plastic shrinkage can take place, leading to crack formation in concrete and to compromising its serviceability. Addition of Superabsorbent Polymers (SAPs) may mitigate Autogenous [3] and plastic shrinkage [4]. SAP is a natural or synthetic water-insoluble three-dimensional network of polymeric chains, with the ability to absorb aqueous fluids from the environment dispersed throughout the structure. Although there are some studies on SAP application in terms of plastic shrinkage mitigation [4, 5], its influence on shrinkage cracking at early age in fibre reinforced mortars (FRM) still remain unclear. Therefore, the main purpose of this study is to assess the effect of different SAPs on plastic shrinkage and properties of FRM in fresh state. Three types of SAPs with SAP with different particles size and different water absorption capacities and three types of cement (CEM I– Portland cement (PC), CEM II– fly ash (FA) and CEM III– Ground Granulated Blastfurnace Slag (GGBS)) were analysed.

2. MATERIALS AND METHODS

Three types of cement have been used, including CEM I 52.5N (PC), CEM II/B-V 42.5N (FA), and CEM III/A 42.5N (GGBS). CEM I, II and III have been supplied by Hanson Cements (UK), Lafarge (UK) and Ecocem (Ireland) respectively. Chemical and physical characteristics of cements provided by manufacturers are presented in Table 1.

Table 1: Chemical and physical analysis of CEM I, II and III

Compound (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Cl	MnO	TiO_2	ZnO	Mn_3O_4	Loss on ignition
CEM I	20.76	4.99	2.57	64.30	2.19	0.27	0.06	0.00	0.00	0.00	0.00	2.39
CEM II	32.69	13.13	3.29	43.48	1.33	1.26	0.00	0.07	0.56	0.02	0.00	0.00
CEM III	24.50	8.99	1.76	57.13	5.33	0.00	0.04	5.33	0.58	0.00	0.16	1.19

The micro polypropylene fibres used in this study were provided by ADFIL Construction Fibres (UK). The length of fibre is 6-mm, diameter 18µm and density 0.91 kg/m^3.
Three different types of SAPs (BASF) have been considered: SAP A, SAP C and SAP E with water absorption capacities (WAC) in cement paste solution of 20 g/g, 25-30 g/g and 30 g/g respectively. SAPs were characterized by SEM analysis (Fig. 1). The chemistry of SAP C and E are the same, but different particle sizes (Fig. 2a). Figures 2(a) and (b) show results of particle size distribution tests of SAPs by the Laser Diffractometry and the fine sand (Fife Silica Sands, UK) determined by sieving test (BS EN13139:2013[6]).

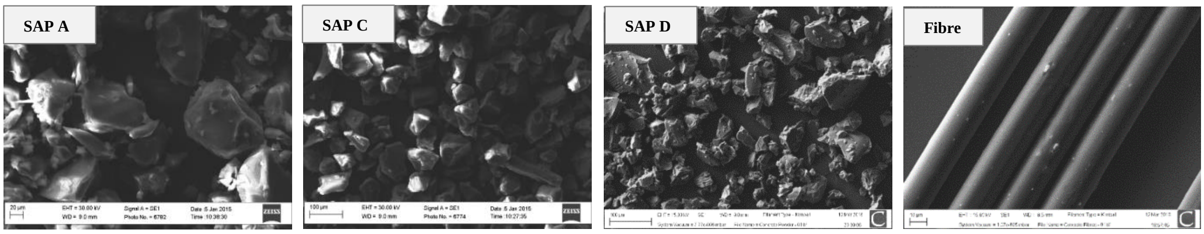

Figure 1: The SEM micrographs of SAP A, C, E and Fibre

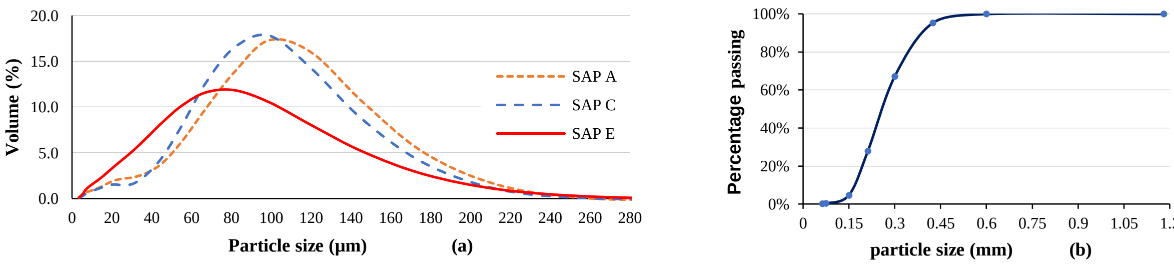

Figure 2: (a) Particle size distribution of SAPs and (b) Sand

All studied mortars had cement to fine sand ratio of 1:2 (by weight). In order to obtain similar consistencies of plastic mortars total water/binder ratios have been adjusted to achieve flow values in a range of 140 - 200 mm according to EN 1015-6:1999 [7]. The theoretical calculation of the amount of water/binder ratio (0.47) was based on the adopted concepts of water bound by cement hydration [8]. The additional water-to-binder ratio $(w/b)_{add}$ is the amount of water absorption by the SAP [9]. Three types of SAPs were added to mixtures in equal amounts of 0.25 % by mass of cement as previously adopted in studies by [3, 8]. The amount of fibre used was constant 0.50 % by mass of cement. The chosen dosage of PP fibres was based on the previously published reports [10, 11]. Table 2 shows the mix proportions of materials used in this study together with effective water/binder ratio $(w/b)_{eff}$, additional water/binder ratio $(w/b)_{add}$ and the total water/binder ratio $(w/b)_{tot}$ and flow values (EN 1015-3:1999 [12]).

Table 2: Mix proportions of materials, water/binder ratios and flow values

cement	Sample name	SAP type	SAP content	Fibre type	Fibre content	Binder : Sand	$(W/b)_{eff}$	$(W/b)_{add}$	$(W/b)_{tot}$	Flow of $(W/b)_{tot}$
CEM I	I	-	-	-	-	1 : 2	0.47	0.01	0.48	141
	I1	-	-	1	0.50%	1 : 2	0.47	0.05	0.52	141
	IA1	A	0.25%	1	0.50%	1 : 2	0.47	0.11	0.58	142
	IC1	C	0.25%	1	0.50%	1 : 2	0.47	0.11	0.58	141
	IE1	E	0.25%	1	0.50%	1 : 2	0.47	0.11	0.58	140
CEM II	II	-	-	-	-	1 : 2	0.47	-0.02	0.45	140
	II1	-	-	1	0.50%	1 : 2	0.47	0.03	0.5	140
	IIA1	A	0.25%	1	0.50%	1 : 2	0.47	0.09	0.56	142
	IIC1	C	0.25%	1	0.50%	1 : 2	0.47	0.09	0.56	141
	IIE1	E	0.25%	1	0.50%	1 : 2	0.47	0.1	0.57	139
CEM III	III	-	-	-	-	1 : 2	0.47	0.01	0.48	142
	III1	-	-	1	-	1 : 2	0.47	0.05	0.52	142
	IIIA1	A	0.25%	1	0.50%	1 : 2	0.47	0.11	0.58	142
	IIIC1	C	0.25%	1	0.50%	1 : 2	0.47	0.11	0.58	141
	IIIE1	E	0.25%	1	0.50%	1 : 2	0.47	0.11	0.58	140

Fresh state mortars were characterised with respect to their consistency (flow table method, EN 1015- 3:1999[12]), air content (pressure method, EN 1015-7:1999[13]), and initial and final setting times (Vicat apparatus, EN 460- 3:2006[14]) in laboratory environment (temperature 21 ± 2°C and RH 40 ± 5%).

The effect of SAPs on plastic shrinkage cracking in cementitious mortars reinforced by PP fibres and made with three types of cement (CEM I-PC, CEM II –FA and CEM III- GGBS) were determined and compared. The plastic shrinkage was analysed by the optical microscope according to ASTM C1579-13 [15] standard. According to ASTM C1579-13[15], the temperature during the first 24 hours of experiment was maintained at 36 ± 3 °C, and the relative humidity at 30 ± 10 %. Free shrinkage measurements were done on mortar specimens of 160 × 140 × 40 mm. For the restraint conditions, three 140 × 20 × 0.2 mm aluminium plates were placed equally and symmetrically on each steel threaded bar (Φ 8 mm) (Fig. 4).

The moulds were filled with mortar in two layers and compacted for 10 seconds (using vibrating table).

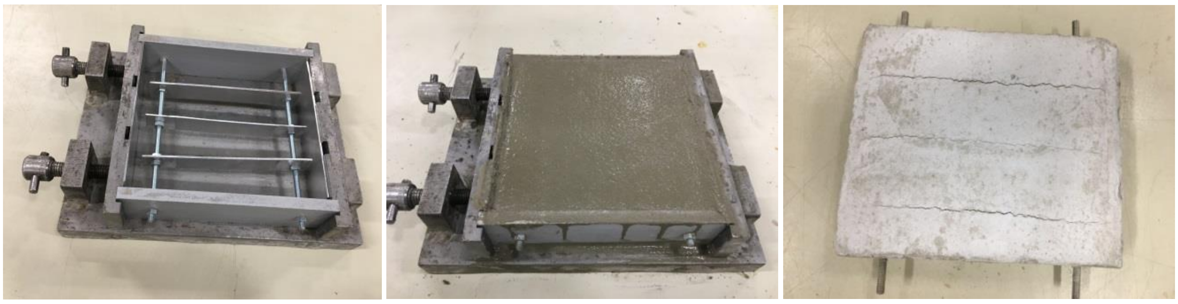

Figure 4: Moulds used for plastic shrinkage tests

The water evaporation was recorded after 30 min, 60 min and afterwards every hour after mixing. An optical microscope system was used to measure the crack widths on the free surface.

3. RESULTS AND DISCUSSION

As shown in Table 2, in order to achieve the similar flow values different amounts of water had to be added and hence different total w/b ratios have been used. It is clear that both SAPs and PP fibres decrease workability, however, the effect of SAPs is more pronounced in all three sets of samples (cement types). Mortars with CEM III (GGBS) had only slightly reduced consistencies in comparison with CEM I mortars. However, as anticipated the biggest adjustments were required for mortars containing CEM II (FA).

Physical properties of fly ash particles, their spherical shape, glassy surfaces and usually finer particles than PC and GGBS result in lower water demand [16]. As it can be seen, the addition of PP fibres required additional water to keep the same consistency of mortars. This effect is directly linked to the characteristics of fibre, including fibre type, geometry, content, distribution and its orientation as well as matrix properties [17]. The addition of SAPs to FRM leads to decreased workability of mortars due to its high water absorption capacity. By comparing the additional w/b values used for SAP mortars, it can be concluded that SAP A has the highest effect on consistency for all three types of cement. SAP E had lower consistency. This can be explained by the lowest (WAC) of SAP A and finer particles of SAP E.

The corresponding air content of mortars is shown in Figure 4. The presence of PP fibres lead to the increase of air content. Addition of SAPs only slightly decreased air content for CEM I and III. The strongest effect was recorded for CEM II, where air content dropped by approximately 2.6%. This could be attributed to reduce total water/binder ratios in CEM II mortars and lower additional water in SAPs with CEM II mortars. Higher air content values have been recorded for FRM containing CEM I and III in comparison to their reference samples. Addition of SAPs to CEM I and III had very limited effect on air content; however, SAP E had the lowest air content. Likely reasons for this wide variety of results can be associated, on one hand, with the effect of different WAC of SAPs (SAP C has higher WAC) and on the other hand with different particles size (SAP E has smaller particles).

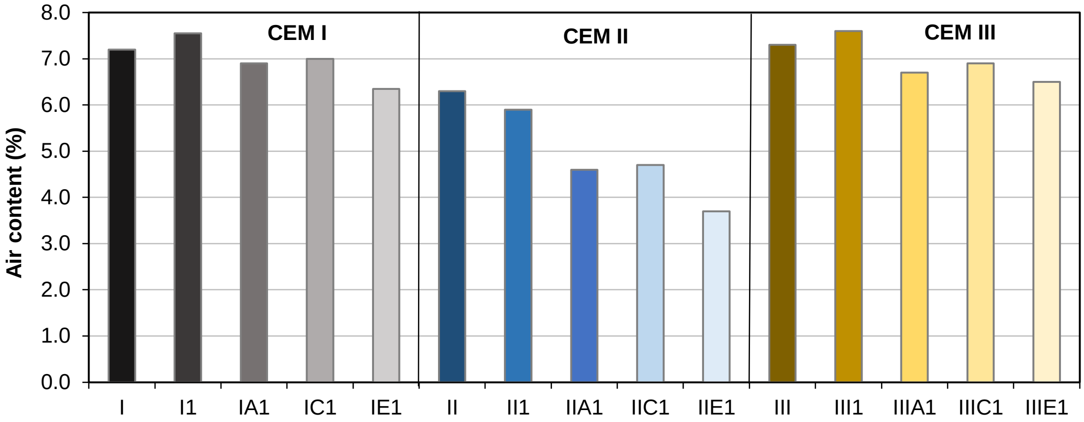

Figure 5: Air content of fresh state mortars

In addition, it can be concluded that the addition of SAP leads to slightly reduced air content for most of FRM. However, SAPs in CEM II mortars can have a noticeable effect on air content of mortars, probably due to finer cement particles [16].

The results of initial and final setting times of mortars are shown in figure 6. Initial setting times for mortars with fibres occur slightly earlier then for the reference samples. However, the time of initial setting is increased for all SAP samples regardless the type of cement.

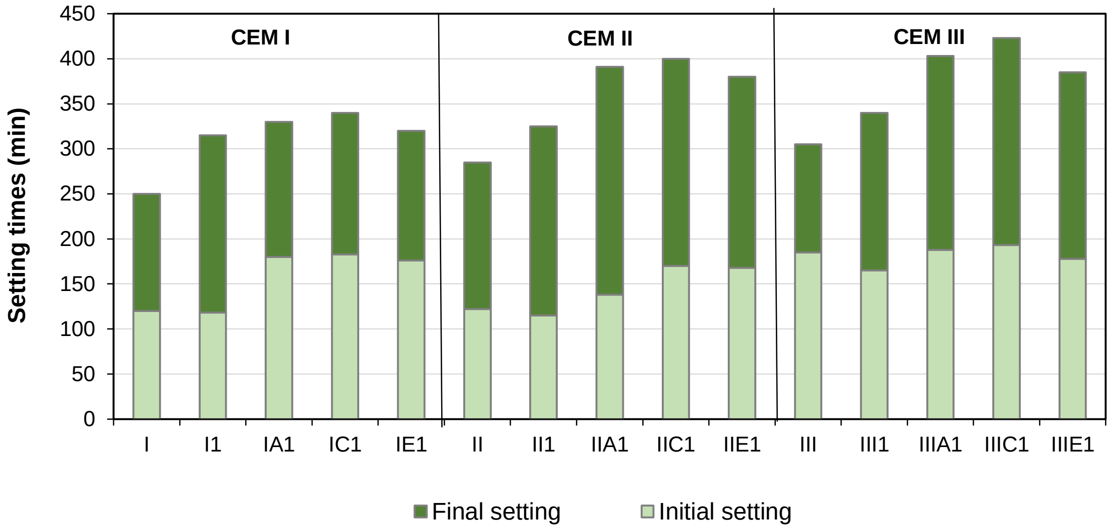

Figure 6: Setting times of mortars

The similar trends have been also observed for the final set times, although it was more pronounced for blended cements. Samples with CEM III (GGBS) had longer setting times than with CEM I and CEM II (FA). These times were further prolonged by addition of fibres and SAPs, as previously reported in [18]. When analysing samples within three different sets (cement types) the common feature was identified: all SAP C mortars had the longest final setting times, followed by SAP A and SAP E mortars. The bigger differences were observed between mortars with SAP C and SAP E (of the same chemistry) leading to the conclusion that the particle sizes are more important than the total water absorption capacities.

The shrinkage due to capillary pressure is the main reason of plastic shrinkage cracking [3]. The visible cracks displayed on all reference samples were measured according to the ASTM C1579-13 standard [15] (Fig.7). Cracks below 0.05 mm are very fine and difficult to be identified. Furthermore, the minimum visible cracks that can be identified by the naked eyes are around 0.1 mm width [19]. The optical microscope was used for measurements of cracks 0.05 mm wide. Therefore, in this study the maximum of large cracks (above 0.1 mm) and minimum of fine cracks (below 0.05 mm) were considered for determining total average for all mortars. Figure 7 shows representative micrographs of the average largest crack found on the surfaces of each mortar after 24 hours under severe environmental conditions. The crack distributions on the surfaces of mortars for different type of cement with PP fibre and different types of SAPs are presented.

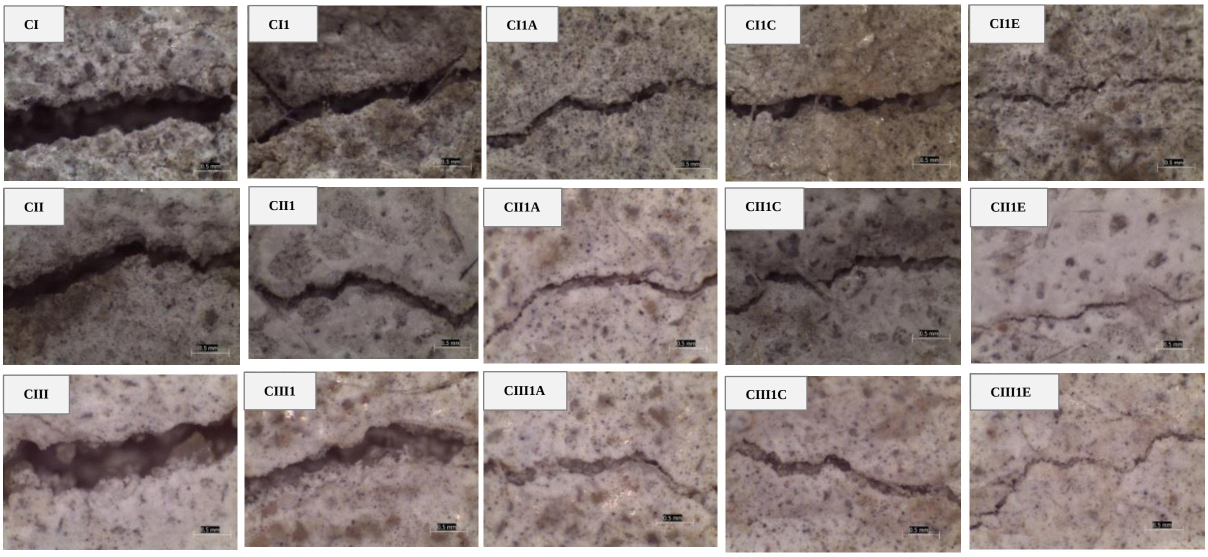

Figure 7: Comparison of the largest cracks formed in different mortars (35x magnification)

Overall, SAPs significantly reduced the development of plastic shrinkage cracking in all samples. By comparing (Figs. 7 and 8), it can be concluded that CEM II mortars had the smallest crack width and CEM III mortars had the widest cracks. Also CEM I mortars showed smaller crack width when compared to CEM III. It can be attributed to the fineness of cement [16]. As it has been reported by [4] the increased cement fineness reduces the maximum crack width. Moreover, the cements with SAP E, which had smaller particle sizes, lead to the finest crack width than those with other SAPs. One the other hand, SAP C mortars showed the largest crack formation than SAP A and E, probably due to the lager particle sizes of SAP C. It can be concluded that the smaller SAP is more suitable for reduction of plastic shrinkage.

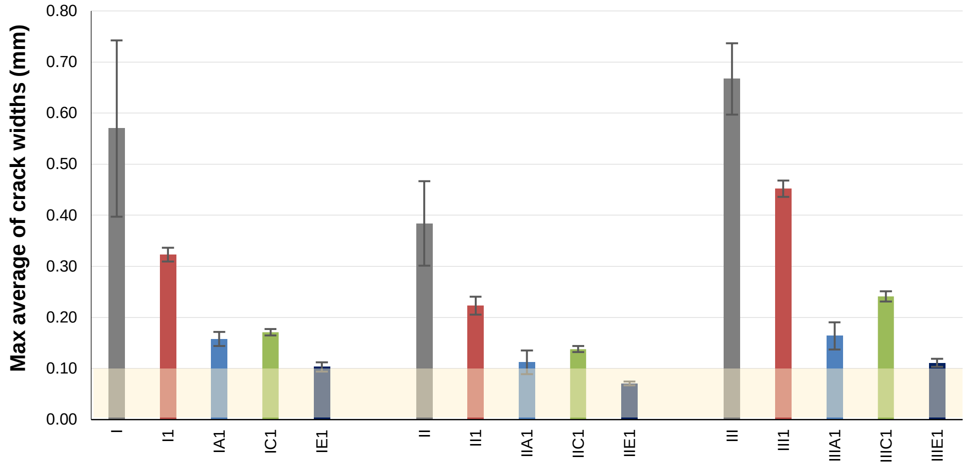

Figure 8: Maximum averages of crack widths (mm)

Figure 9 shows the evaporation rates of all mortars over time at 24h. For clarity purpose, the Figure only shows the results of references samples, SAP E and CEM III were presented. However, other samples had similar pattern. These evaporation rates are shown around 5-6%, which confirm effectiveness of designed system used in this study according to the ASTM C1579-13 standard [15].

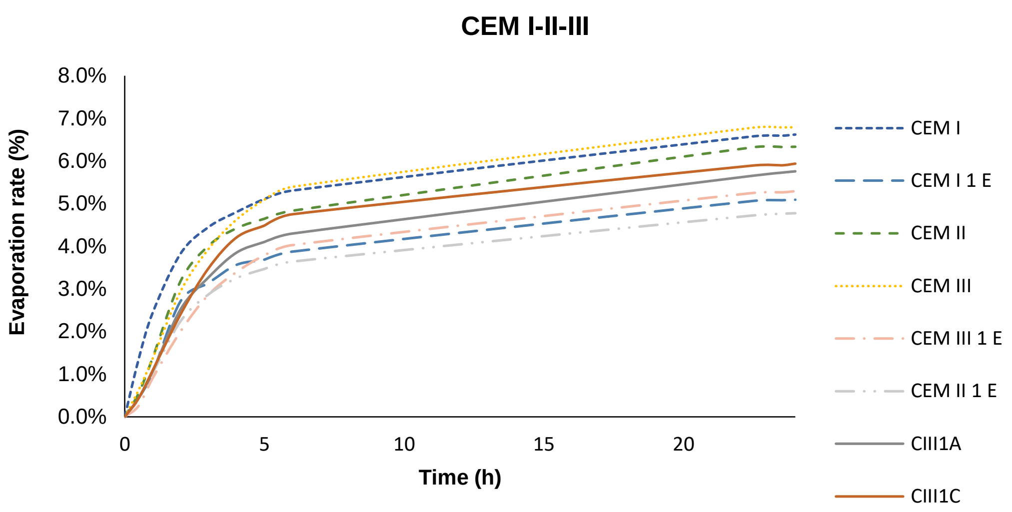

Figure 9: Water evaporation rates during plastic shrinkage tests

As shown in Figure 9, the highest water evaporation rates were recorded for the reference mortars. This in turn resulted in formation of larger cracks. The samples with SAPs had the lowest evaporation rates when compared to the reference. Furthermore, SAP E in mortars with CEM II had the lowest evaporation rate due to smaller particle sizes. Consequently, smaller SAP had significant effects on reduction of plastic shrinkage and is more suitable for mitigation of plastic shrinkage.

4. CONCLUSION

The reinforced mortars made with three types of cement (CEM I–PC, CEM II–FA and CEM III–GGBS) and three types of SAP with different particles size and different water absorption capacities have been analysed. It was found that the addition of SAPs have major influence on the fresh state properties of FRM and different SAPs (particle sizes and absorption/desorption kinetics) behave differently in blended cements with SCM. From the obtained experimental results, the following can be concluded:

- The addition of SAP to FRM leads to decreased workability of mortars due to its high WAC. The highest workability was recorded for samples with SAP A (lowest WAC) and the lowest workability was displayed by samples containing SAP E (with finest SAP particles);
- SAPs slightly reduce air content for most of FRM, but the strongest effect was recorded for CEM II with SAP E, where air content dropped by approximately 2.6%. Furthermore, SAP C had the highest air content (higher WAC) and SAP E had the lowest air content (smaller particles);
- Addition of SAP retards both initial and final set times of FRM. SAP C mortars had the longest final setting times, followed by SAP A and SAP E mortars. The bigger differences were observed between mortars with SAP C and SAP E (of the same chemistry) leading to the conclusion that the particle sizes are more important than the total water absorption capacities;

SAPs significantly reduce the development of plastic shrinkage cracking in all mortars. Evaporation rates for all SAP samples were lower than for the reference ones, hence the cracks widths were smaller. The biggest effect on crack reduction can be achieved by application of fine SAPs (SAP E). The effect of different water absorption capacities (SAP A and C) is of less importance.

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