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Application of Superabsorbent Polymers in blended cement mortars reinforced by polymeric fibre

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ABSTRACT

Superabsorbent polymers (SAP) have been proved to be an effective internal curing agent which facilitate hydration process and control water supply of cement-based materials in the fresh, hardening, and hardened states. Although the use of SAP in concrete has been previously documented, however, its effect on prolonged hydration, microstructure alteration and mechanical characteristics of fibre reinforced mortars with supplementary cementitious materials (FRM-SCM) still remains unclear and deficient. This paper provides an overview of the effect of Superabsorbent polymers (SAPs) on short- and long-term performance of FRM-SCM. The experimental results confirmed that the addition of SAP to FRM leads to notable reduction of workability and it has a dominant influence on mitigation of shrinkage of FRM-SCM. SAPs facilitate SCM hydration by a prolonged supply of water, adhered to smaller pores and by provision of space for deposition of secondary hydration products. Finer SAP is more effective and more efficiently facilitate improvement of compressive strength.

1. INTRODUCTION

The wide popularity of blended cement is mainly justified by their improved performance when compared to plain Portland cement and by the lower environmental impact (Scrivener et al., 2015). In early ages, the contribution of SCMs to strength development is generally negligible due to slower reactions. Furthermore, concrete with SCMs can be more susceptible to early age cracking, induced by self-desiccation and shrinkage processes (Wyrzykowski and Lura 2016). Nevertheless, SCMs have the major effect on hydration kinetics and enhancement of the reaction of clinker components due to their physical presence, this is known as "filler effect". First, partial replacement of PC clinker by FA or GGBS, at the same w/b ratio, implies a dilution effect. The higher replacement the larger space is available for the formation of clinker hydrates at early ages. Therefore, the degree of reaction of clinker component in blends containing FA or GGBS is significantly higher than in PC cements. One the other hand, SCM surfaces may act as nucleation sites for the hydrates (Scrivener, Juilland and Monteiro 2015, Scrivener et al. 2015). However, this effect is fast for the species in the pore solution and the distribution of C-S-H is quite homogeneous. Moreover, it is relatively minor due to particle size of SCMs (FA and GGBS), which have similar sizes to PC (Berodier and Scrivener 2014). Polymeric fibres (PF) are commonly used in concrete as a strengthening material in order to enhance mechanical capacity. However, their efficiency is often limited, particularly in blended cements (Rostami et al. 2021a), and some form of internal curing may be required to decrease self-desiccation and promote cement hydration. As it has been previously reported SAP ability to provide water during hydration process, which can be used to further reduce these phenomena (Snoeck et al. 2015; Almeida, and Klemm, 2018; Rostami, and Klemm, 2019; Almeida, Rostami, and Klemm, 2019; Rostami, and Klemm, 2020). However, their effectiveness depends on a number of parameters, including their chemical composition, particle grading and ionic concentration in surrounding pore solution.
The main body of the paper is to present the current state-of-the-art and to provide an overview of SAP as a new admixture, highlighting its effects in FRM-SCM matrices.

2. SUPERABSORBENT POLYMERS

There has been significant interest on use of Superabsorbent Polymers (SAPs) in cement-based materials in the recent years. SAP is a natural or synthetic water-insoluble three-dimensional network of polymeric chains, with the ability to absorb aqueous fluids from the environment (Mechtcherine and Reinhardt, 2012; Mechtcherine et al., 2014; Rostami et al. 2021b). When the dry three-dimensional network with chemical cross-links of SAP get in contact with fluid, the water molecules diffuse into the void space inside the polymer network to hydrate polymer chains and swollen polymer gel is formed (Mechtcherine and Reinhardt, 2012). This process is reversible due to dilution of surface charges, reduction of osmotic pressure and removal of water, resulting in collapsing of SAP (Mechtcherine and Reinhardt, 2012). Figure 1 presents schematic diagram of absorbency and swelling of SAP.

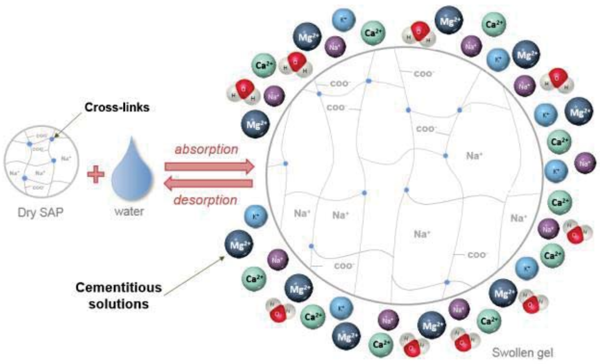

Figure 1. Schematic diagram of absorbency of SAP.

To demonstration the effect of SAPs on FRM-SCM systems, two different types of SAP were analysed (Table 1).

Table 1. Characterization of SAPs.

Properties	SAP A	SAP E
Type of polymer	copolymer of acrylamide and acrylic acid	modified polyacrylamide
Particles size (μm)	30-140	20-130
Modes values (μm)	102.51 ± 0.43	76.74 ± 0.22
WAC[1] $_{\text{deionized water}}$ (by tea-bag test)	340 g/g	340 g/g
WAC $_{\text{CEM II/B-V Solutions}}$ (by tea-bag test)	33 g/g	46 g/g
WAC $_{\text{CEM III/A Solutions}}$ (by tea-bag test)	25 g/g	40 g/g

[1] WAC: water absorption capacity

Two series of mortars (CEM II/B-V 32.5R and CEM III/A 42.5N) with micro polypropylene fibres (6 mm length) have been designed for the experimental tests (Table 2).

Table 1. Mortars samples composition

Cement	Sample Name	PF Content	SAP Content	$(w/b)_{eff}$ ratio	$(w/b)_{total}$ ratio
CEM II	II	-	-	0.47	0.45
	IIF	0.50%	-	0.47	0.50
	IIF-A	0.50%	0.25%	0.47	0.56
	IIF-E	0.50%	0.25%	0.47	0.57
CEM III	III	-	-	0.47	0.48
	IIIF	0.50%	-	0.47	0.52
	IIIF-A	0.50%	0.25%	0.47	0.58
	IIIF-E	0.50%	0.25%	0.47	0.58

Tests of workability, plastic shrinkage (at 24 h), autogenous shrinkage (up to 90 days) and mechanical properties were performed.

3. Effect of SAPs on workability

Figure 2 illustrates results of consistency measurements of mortars modified by SAPs. Due to the absorption of part of mixing water by SAPs all two sets of samples demonstrated a loss of workability.

A similar trend was observed with respect to the effect of SAP addition. The lowest flow values were obtained for mortars with SAP E due to the highest WAC. This could be attributed to smaller particle sizes of this SAP and consequently the higher relative access to mixing water. On the contrary, SAP A had the least effect on the consistence (more fluid) among all SAP samples. The lower slump flow values of SAP A mortars in comparison to those with SAP E results from different kinetics of absorption. With regard to the better workability of SAP E, additional explanations can be given.

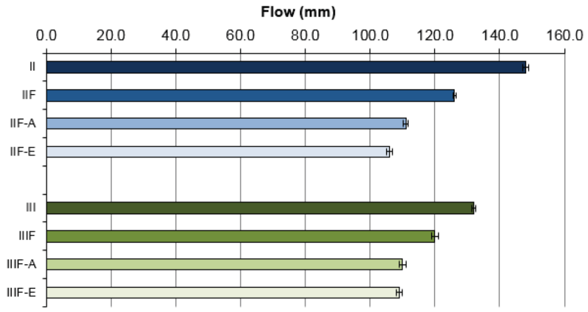

Figure 2. Schematic diagram of absorbency of SAP.

Furthermore, better workability of samples with SAP E is also related to a dilution effect of blended cements ions by the presence of solid particles (sand) in the mix. This may restrict the swelling behaviour of SAP. Other factors influencing workability of SAP include smaller particle sizes of SAP E; absorption of SAPs in blended cements solutions was not comparable to SAP absorption in mortars.

4. Effect of SAPs on mitigation of shrinkage

SAP leads to a significant additional reduction in plastic, and autogenous shrinkage (compared to a conventional fibre reinforced mortar with SCM). However, the level of efficiency depends on either particle sizes and/or water absorption capacity (WAC).

The greatest effect on crack propagation in plastic shrinkage, can be achieved by the application of fine SAP (Table 1) with high WAC (Figure 2).

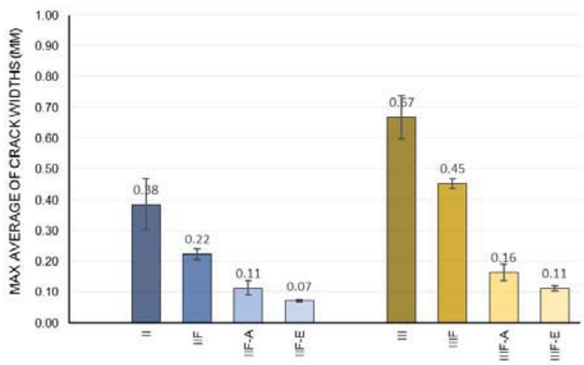

Figure 3. Maximum averages of crack widths (mm).

Overall, CEM II/B-V mortars had the narrowest cracks and CEM III/A mortars the widest cracks. This can be attributed to a decrease of total bleeding water and bleeding rate of fly ash cement.
Furthermore, it is related to the lower w/b of CEM II/B-V samples, and lower susceptibility to plastic shrinkage cracking. On the contrary, in CEM III/A samples, GGBS leads to prolonged setting times, resulting in higher bleeding rate. This, in turn, results in advanced tensile capillary pressure and the higher probability of plastic shrinkage cracking. Moreover, the addition of polymeric fibres reduces PS by providing bridging forces across the cracks.
Figure 4 shows development of autogenous shrinkage (AS) in the mortars during the first 90 days.

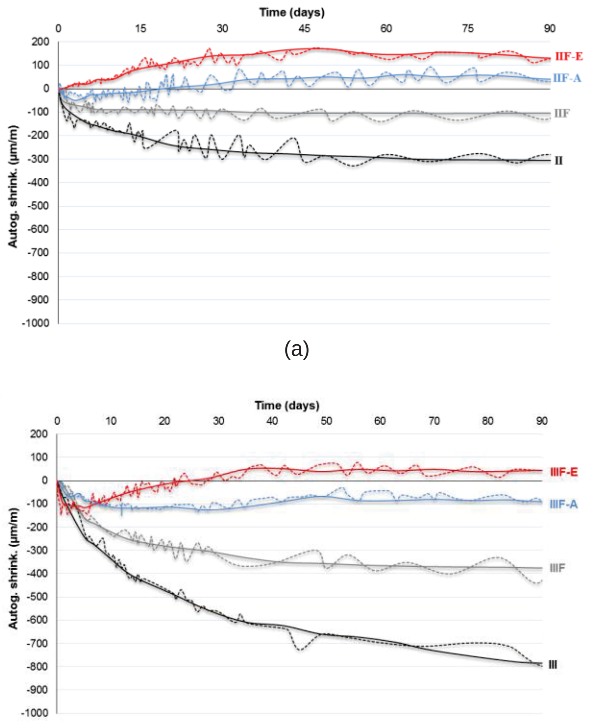

Figure 4. The autogenous shrinkage (AS) (a) CEM II and (b) CEM III.

All SAP samples experienced a noticeable volume expansion during the first 45 days, in particular mortars with SAP E. SAP E experienced higher expansion due to SAP fineness and faster absorption kinetics (Table 1).

SAPs promote precipitation of further C-S-H phases (later reactions of FA and GGBS) leading to an overall bulk expansion of hardened matrix.
This effect is more prominent for SAP E due to its very fine particles and greater water absorption capacity for all cementitious solutions (Table 2).

5. Effect of SAPs on microstructure alterations

Microstructural development in cementitious composites is strongly dependent on type of binder used and a lifespan exposure to environmental conditions. In particular, the use of SCM such as FA or GGBS, has an important impact on hydration kinetics and subsequent strength development (Vanderley et al. 2019; Almeida, and Klemm, 2018).
The presence of SCM and SAP has a significant influence on microstructure development of fibre reinforced mortars, in particular on their overall porosities and pore size distributions (Rostami and Klemm 2020). The presence of SAPs can alter microstructural features of concrete, due to formation of macro pores as a result of collapsing of polymer. In spite of the presence of these voids (i.e., less physical filling effect), the strength loss can be mitigated by the later intensified hydration by SAP, especially in blended cements with the longer lasting reactions.

6. Effect of SAPs on mechanical properties

Figure 5 show the results of compressive strength development for all samples. As anticipated all SAPs had a negative effect on strength development at early age because of the formation of “extra” pores after collapsing of SAP. Reduction of compressive strength during the first 14 days depends predominantly on particle sizes; the larger

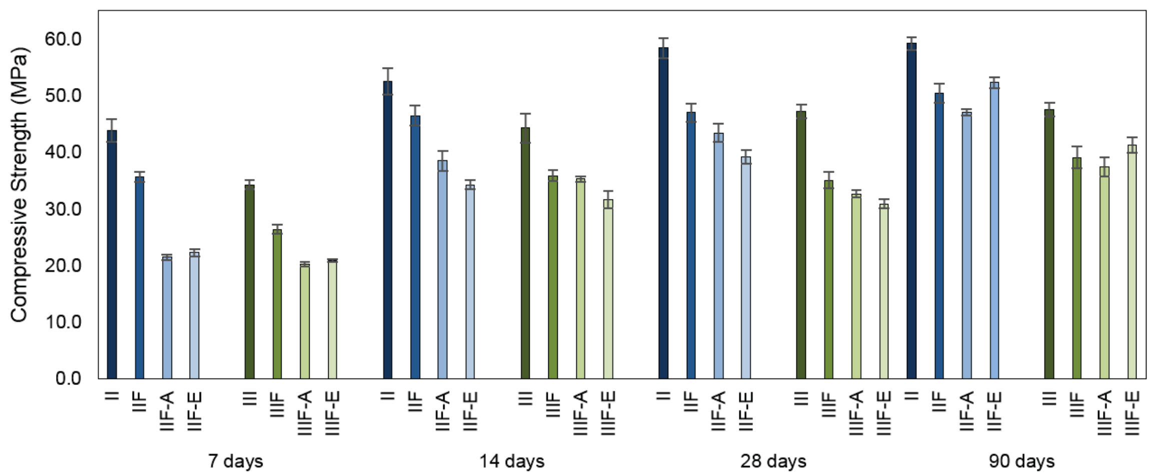

Figure 5. Compressive strength results of all mortars.

pores and hence the larger reduction of strength. Although all SAPs lowered the strength at early ages, this negative effect was significantly minimised at later age. SAP E with smaller particle sizes was more effective and by the age of 90 days its improved strength by nearly 45% (Figure 5).

4. CONCLUSION

The application of SAP has major influence on the fresh state properties of fibre reinforced mortars containing SCMs. The addition of SAP to FRM leads to notable reduction of workability and is closely related to total absorption capacity of SAP.
The highest reduction of workability was recorded for samples with SAP E due to the highest water absorption capacity (WAC) of this SAP.
SAP facilitate substantial additional reduction in plastic, and autogenous shrinkage in FRM-SCM. However, the level of efficiency depends on either particle sizes and/or water absorption capacity (WAC).
Particle sizes of SAPs have a very strong effect on microstructure development of fibre reinforced mortars, in particular on their overall porosities and pore size distributions.
SAPs had a negative effect on compressive strength development at early age because of the formation of "extra" pores after collapsing of SAP. Initial reduction of the compressive strength of SAP modified mortars can be later recovered. Finer SAP is more effective and more efficiently facilitate improvement of compressive strength.

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