Practical application of superabsorbent polymers as a water-regulating agent in concrete and other building materials. Chapter 10

Cusson, D.

Publisher's version / Version de l'éditeur:

State-of-the-Art Report on Application of Super-Absorbent Polymers in Concrete Construction RILEM Committee TC-225, 2012-01-01

Practical application of superabsorbent polymers as a water-regulating agent in concrete and other building materials. Chapter 10

Cusson, D.

NRCC-53941

A version of this document is published in: State-of-the-Art Report on Application of Super-Absorbent Polymers in Concrete Construction RILEM Committee TC-225, January-01-12

CHAPTER 10 – Practical applications of superabsorbent polymers as a water-regulating agent in concrete and other building materials

Daniel Cusson[1] (Coordinator), Viktor Mechtcherine[2], Ole M. Jensen[3], Pietro Lura[4]

[1] Institute for Research in Construction, National Research Council Canada, Canada

[2] Institute of Construction Materials, TU Dresden, Germany

[3] Department of Civil Engineering, Technical University of Denmark, Lyngby, Denmark

[4] Empa, Materials Science and Technology, Switzerland

Abstract: Superabsorbent polymers (SAP) possess a number of features that make them attractive for use in many different applications. The aim of this chapter is to present existing and foreseen opportunities for the use SAP in many different functions to improve the performance and durability of the built environment. Two case studies are also presented in this chapter: one on a thin-wall architectural structure in Germany, and another on shotcreting of wall panels in Denmark.

10.1. INTRODUCTION

The use of SAP in building materials is relatively recent, with most studies being conducted in the laboratory and very few known field applications. This chapter includes three major sections, which will discuss the improvement of concrete properties due to the use of SAP (section 10.2), potential applications for SAP in the construction sector (section 10.3), and case studies using SAP-modified concrete in the field (section 10.4).

10.2. IMPROVEMENT OF PROPERTIES

10.2.1 Shrinkage reduction

Controlling early-age cracking due to volume changes in concrete structures is essential to obtain long-term durability. Today, many concrete structures experience early-age shrinkage cracking. This is more common when high cement contents and low water-cement ratios are used to make the concrete, leading to autogenous shrinkage induced by self-desiccation. As presented in Chapter 7, SAP can be effectively used as a water-entraining agent in high-performance concrete to provide internal curing water that is needed to maximize cement hydration and minimize self-desiccation, with negligible adverse effects on other engineering properties.

10.2.2 Frost resistance

The production of concrete that is resistant to freezing and thawing requires special attention to some specific material parameters, including the air-void system, of which effectiveness is controlled by the volumetric air content, spacing and size of the air voids. To this effect, SAP particles can be engineered to provide an adequate pore system, since SAP particles can de-swell during cement hydration and leave gas-filled voids, according to Jensen [1]. In fact, this concept has been recently demonstrated in the lab by Reinhardt et al. [2] and Laustsen et al. [3], where mixtures containing specific types of SAP were found to provide increased resistance to freezing and thawing in the presence of de-icing chemicals. It was hypothesized in [2] that SAP may have interacted with the superplasticizer to increase the air content, or very small air bubbles adhered to the SAP particles during mixing. In [3], the authors demonstrated the advantages of SAP-based technology over traditional chemical air entrainment, which are: stability of the air void system and improved control of both the amount of added air and the air void size. Their results clearly showed that the amount of scaled material depended solely on the amount of air voids in the concrete created by SAP, whereas the spacing factor was found to have only a minor influence.

As reported in [3], air entrainment with conventional air-entraining admixtures often encounters technical difficulties such as coalescence of air bubbles in fresh concrete, loss of air during consolidation or pumping, and chemical incompatibility with superplasticizers. Again, the use of SAP as an air-entraining agent could solve some of these difficulties in practice, since this technology is uninfluenced by the pumping and placing procedures [1].

More information on the effect of SAP addition on the frost resistance of concrete can be found in Chapter 9.

10.2.3 Rheology modification

The addition of SAP during concrete mixing can produce a considerable change in rheology, as observed by Jensen and Hansen [4]. SAP addition can allow a decrease in the free water-cement ratio, which can lead to an increase in both the yield stress and plastic viscosity, as mentioned in Chapter 5.

10.2.4 Controlled release

SAP may also be used to control the release of substances other than water that are dissolved in the SAP particles. Substances that are initially at a higher activity in the polymer will diffuse out of the particles into the surroundings, according to Buchholz and Graham [5]. Compared to other absorbent polymers, superabsorbent polymers have a special feature: their swelling depends on the pH of the swelling medium [5], which is a feature that may be used as switches for controlled release. Current commercial uses of SAP in this field are for pesticides, fertilizers and pharmaceuticals. As suggested in [1], a possible use of SAP as a controlled release agent in concrete could be for particular plasticizing admixtures that are more effective if they are first released shortly after initial contact between water and cement, at which time the pH of fresh concrete is relatively high.

10.2.5 Waterproofing

The volume increase of the gel of water-saturated swollen SAP can be used to form a barrier to water flow [5]. Sealing composites made by blending modified SAP into rubber (Tsubakimoto et al. [6]), or a thermoplastic elastomer [7] have been developed for sealing around the joints of various building materials. The composite may be used like mortar in joints and, if any gaps were left during construction or created after construction due to settlement, the SAP swells when in contact with leaking water and seals the joints, as suggested by Shimomura and Namba [8]. According to [5], such a composite was used in the construction of the Channel Tunnel between France and England.

10.2.6 Crack healing

Tsuji et al. [9, 10, 11] used SAP for blocking cracks in concrete. A special type of SAP that can hardly absorb alkaline water in fresh and hardened concrete was used to absorb neutral or acidic water infiltrating through cracks. In this case, SAP particles remain dormant (unswollen) within the concrete until a crack exposes them to the surface and water flowing through the crack causes them to swell. The effectiveness of the SAP was confirmed by the reduced permeability measured in the healed concrete.

A similar concept was proposed by Song et al. [12], in which a precursor solution of acrylic acid-co-acrylamide was injected into the concrete cracks together with an initiator and a cross-linker. The precursor was then activated with infrared radiation to initiate copolymerization. Preliminary tests on concrete cracks filled with large SAP particles (0.63-1.25 mm) showed reduced permeability of the repaired concrete. The swelling ratios of SAP in water, acidic, saline and basic solutions were also measured before and after accelerated ageing by ultraviolet radiation. In another study, Song et al. [13] used in-situ polymerization of SAP as a concrete surface treatment to improve sulphate resistance.

10.2.7 Surface curing

Poor surface curing conditions can reduce the durability of concrete surfaces due to high evaporation rates of water leading to plastic shrinkage cracking and slower development of surface strength. This could be prevented by applying a water-laden gel sheet to the concrete surface during the curing period, which would provide water to the surface, as required [5]. The gel layer is strengthened and protected from evaporation by applying a latex rubber coating on top of the gel [14].

Harrison [15] illustrated the use of a type of controlled-permeability formwork made of conventional formwork lined with SAP sheeting, which is impermeable to air and could absorb up to 200 times its weight of water. The SAP sheets are simply cut to length, folded over the form edge, and stapled to the form. During the compaction of concrete, some of the mix water escapes through the SAP form leaving the concrete in the cover zone with a reduced water-cement ratio. As a result, controlled-permeability formwork can achieve significant increase in concrete durability in the critical cover zone, improved surface appearance, and a substantial reduction in formwork pressures.

10.2.8 Fire protection

Jin et al. [16] used a SAP gel pre-soaked in an aqueous solution of calcium chloride to provide fire protection to building materials. This aqueous solution of calcium chloride has the ability to absorb water vapour or release it to the atmosphere until it reaches equilibrium with its surrounding. This approach was developed further by Asako et al. [17] who used SAP pre-saturated with a calcium chloride solution, mixed with cement, perlite, and water to obtain a fire-resistant mortar.

10.2.9 Removal of concrete contaminants

In [18], a technique was described by which radioactive isotopes present in the pore solution of concrete and other porous materials can be removed. A wetting agent and a SAP gel with engineered nanoparticles are applied onto the contaminated surface from a remote location. The wetting agent causes the radioactive material to re-suspend in the pore water. The SAP gel then draws the radioactiveladen water out of the pores, while the engineered nanoparticles irreversibly capture the radioactive molecules. The dried gel is then vacuumed and recycled, leaving only a small amount of radioactive waste. It was claimed that a single application of gel can remove up to 90% of the radioactive elements.

10.3. POTENTIAL APPLICATIONS

This section presents expected applications, in which SAP could be effectively used to improve the construction process, performance, and durability of the built environment. It is noted that some of the following applications have already been introduced in previous sections and chapters; however, it was decided to present an overview of these applications for the sake of completeness.

10.3.1 Shotcreting

The use of SAP to increase viscosity and decrease rebound of shotcrete was the subject of a 1991 patent application from Snashall [19], in which it is proposed to premix SAP with the aggregate and 10% to 15% of aggregate weight of water, followed by a 10-minute stand in the mixer, and finally add the cement and the rest of the mix water. Water absorption by SAP is expected to happen in only 10 minutes. According to a later patent application from Jensen and Hansen [20], SAP can be added (i) dry in the nozzle to reduce the viscosity of a wet mix, or (ii) pre-swollen or partially pre-swollen for internal curing purposes. In the first case, a very rapid absorption of the SAP is desired to obtain a reduced viscosity before the shotcrete hits the wall. The second case has no such special requirement.

10.3.2 Backfilling

A water-blocking construction filler that is composed of cement, SAP, and an asphalt emulsion has been developed by Moriyoshi et al. [21]. The components may be mixed on site to form a gelled solid serving as a backfill material. For example, it could be used in tunnel construction to fill the gap between the tunnel liner and the walls of the boring [5]. A main advantage of this SAP-modified backfill material is its high deformability [21] compared to conventional backfill materials (e.g. gravel or sand) that often fracture during ground movement.

10.3.3 Soil stabilization

SAP may be blended with cement and other materials to form a composite soil stabilizer [22]. The composite may be added directly to the wet soil to absorb and gel any water present and, at the same time, form a rigid surface upon which the foundation footings of a building can be placed, as suggested in [5].

10.3.4 Smart paints

The swelling character of SAP could be used for water-blocking in designed waterproofed paints, as suggested in [1]. The deposited SAP particles of a carefully selected size range would inhibit quick ingress of water in wood, for example, without influencing evaporation of water from saturated wood.

10.3.5 Sensors

The swelling ability of SAP gels, their mechanical modulus, and sensitivity to changes in water content, pH and ionic strength make SAP suitable for the development of sensors [5], which could be used for the structural health monitoring of smart infrastructure and buildings. A pressure-sensitive switch based on a polyelectrolyte hydrogel has been developed by Sawahata et al. [23], and works on the principle that an electrical potential can be induced in a soft hydrogel by (i) applying mechanical stress in one part of the gel, or (ii) a change in the pH of the gel caused by deformation. By attaching wires to the gel, the potential difference generates a signal, of which intensity depends on the magnitude of the mechanical deformation. Water-sensing devices that use the high conductivity of swollen polyelectrolyte gels as the detection switch have also been developed [24], based on the fact that dry polymers do not conduct electricity and swollen polymers do conduct electricity and complete the circuit. The magnitude of the gel conductivity indicates the degree of water absorption.

With regard to concrete applications, it may be thought that such SAP-based sensors could be eventually developed to monitor pH or salt concentration in concrete structures, which are key parameters influencing chloride-induced or carbonation-induced corrosion of the steel reinforcement in concrete structures.

10.3.6 Other applications in concrete construction

The following applications, summarized from [25], are grouped in this section as they relate to a given commercial SAP composed of methyl cellulose, which is a well known viscosity modifier.

Adhesives and grouts – Methocellulose ethers have the ability to thicken adhesives and grouts, while making them easier to mix and apply. They provide water retention properties, which can help improving the workability, open times, adhesion, and sliding resistance of various cement-based adhesives.

Jointing compounds and mortars – They can be used in jointing compounds, due to their ability to provide improved bonding strength and workability.

Plasters and fillers – They can be used in plasters and fillers that are cement-based, gypsum-based, or dispersion-based. They help make plasters and fillers easier to mix & apply, while improving their bond strength, workability and water retention.

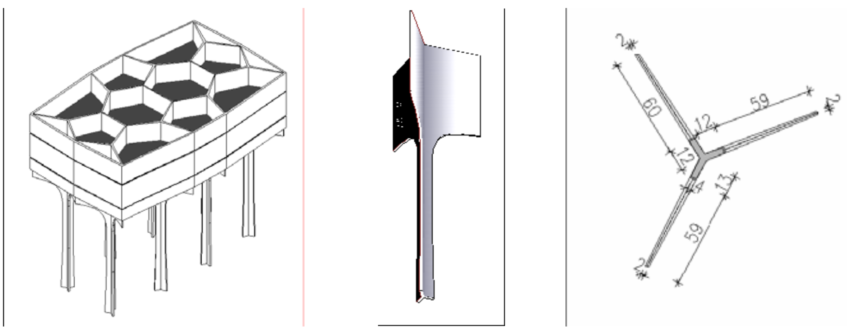
Self-leveling floor compounds – They can improve adhesion strength of self-leveling compounds used for covering poured surfaces before flooring installation.

Extruded cement panels – They can control water retention during the extrusion process to enhance the strength of extruded panels, allowing for durable materials.

10.4. CASE STUDIES

10.4.1 Fifa World Cup Pavilion, Germany

This pavilion was built for the 2006 FIFA World Cup in Kaiserslautern, which was one of the host cities. As reported by Mechtcherine et al. [26], it was designed as a filigree, thin-walled structure with very slender columns (minimum wall thickness of 20 mm) and no conventional reinforcement (Figs. 10.1 and 10.2).



(a) (b) (c)

Fig. 10.1. FIFA World Cup Pavilion, City of Kaiserslautern, Germany [26] – (a) Schematic view of pavilion; (b) & (c) geometry of a column (dimensions in cm).

Fig. 10.2. Photograph of built pavilion [28].

In order to meet the rigorous design requirements (including reduced autogenous shrinkage, high durability, enhanced ductility, self-compaction, and high-quality surface), self-compacting fibre-reinforced high-performance concrete with internal curing was developed by Dudziak and Mechtcherine [27]. SAP made of covalently cross-linked acrylamide/acrylic acid copolymers were used for internal curing, and a polycarboxylate superplasticizer was used to ensure adequate self-compaction of the concrete.

Table 10.1. Compositions of UHPC with and without addition of SAP, adapted from [27]

Component	Pav	Pav-SAP
Cement, CEM I 42.5 R HS (kg/m³)	800	800
Silica fume (kg/m³)	120	120
Water, total (kg/m³)	179	203
SAP (% mass cement)	-	0.4
$(w/c)_{total}$ (incl. IC water)	0.25	0.28
$(w/c)_{effective}$ + $(w/c)_{internal\ curing}$	0.25+0	0.25+0.03
Quartz powder (kg/m³)	206	195
Fine sand 0.125/0.5 mm (kg/m³)	229	217
Crushed basalt sand 0/2 mm (kg/m³)	184	173
Basalt split 2/5 mm (kg/m³)	522	493
Steel fibres 6 x 0.015 mm (kg/m³)	144	144
Superplasticiser (% mass cement)	4.3	4.3
Pigment Fe_2O_3 (kg/m³)	12	12

The concrete had a free water-cement ratio of 0.24 and included CEM I 42.5 R HS cement and micro silica as binders, a blend of quartz powders and basalt sands, 6-mm steel fibers, and SAP with an average particle size of 200 μm. The content of SAP was adjusted to provide up to 45 kg/m^3 of internal curing water in the concrete. A number of different compositions were developed, optimized and compared in the laboratory for this project. Table 10.1 above gives the compositions of the UHPC used for the construction of the pavilion (referred to as Pav-SAP) and of the corresponding reference mix made without addition of SAP and extra water (referred to as Pav).

The laboratory tests conducted on the concrete revealed that the rheological properties of the fresh concrete (slump flow diameter of approximately 80 cm) were not adversely affected by the use of SAP and IC water when compared to a reference mixture made without SAP. The early-age autogenous shrinkage was greatly reduced by internal curing (from -605 με to -72 με at 7 days); however, total shrinkage (incl. drying shrinkage) was only found to decrease slightly at older age (from -1050 με to -950 με at 28 days). This finding indicates that the quantity of internal curing water was sufficient to prevent self-desiccation. Table 10.2 presents test results on the mechanical properties of the SAP-cured concretes.

Table 10.2. Average mechanical properties of investigated concretes (standard deviations are given in parentheses), adapted from [27].

	Compressive strength [MPa] (tested on cubes)			Flexural strength [MPa] (tested on prisms)		
Mixture	Sealed 2d	Sealed 28d	Unsealed 28d	Sealed 2d	Sealed 28d	Unsealed 28d
Pav	96 (-)	139 (-)	140 (3)	13 (0.6)	15 (1.1)	21 (2.4)
Pav-SAP	85 (-)	131 (-)	140 (6)	15 (-)	19 (1.2)	16 (-)

(-) only two specimens tested

10.4.2 Shotcreting of Wall Panels, Lyngby, Denmark

According to Jensen [1], the thickening effect caused by the presence of SAP in concrete can be used advantageously in some practical situations such as pumping. Successful wet-mix shotcreting requires overcoming several technical challenges [1]. For instance, high slumps are usually required to achieve adequate pumpability, however, low slumps allow better thickness build-up and minimize rebound. Set-accelerating admixtures are often required but their use may lead to marked reductions in long-term compressive strengths, as found by Jolin & Beaupré [28]. Another difficulty is related to the control of air-entrainment in placed shotcrete.

It was tentatively shown in [1] that these difficulties can potentially be avoided by the dry addition of SAP in the nozzle during shotcreting (Fig. 10.3). The concrete had an initial w/c of 0.4 and contained 0.4% SAP with a water absorption near 15g of water per gram of dry SAP. It was observed that the uptake of water by SAP created a change in viscosity during placing and allowed the build-up of thick layers without the use of a set-accelerating admixture. In this case, SAP was added to shotcrete as a rheology modifier, however, other benefits may be found, such as internal water curing and mitigation of autogenous shrinkage (as explained in previous chapters).

Fig. 10.3. Shotcreting of wall panels with SAP-modified concrete, Lyngby, Denmark [1].

10.5. SUMMARY AND FINAL REMARKS

As shown in this chapter, superabsorbent polymers possess a large number of features that make them attractive for use in many different applications. Current applications using SAP in concrete structures have been reported and include: shrinkage reduction, frost protection, rheology modification, waterproofing, and fire protection, to name a few. Expected applications in the near future have also been identified, such as: shotcreting and backfilling, as well as potential uses in the development of innovative sensors.

It was shown through a case study that SAP-modified ultra-high strength concrete could be made in the field to build a thin-wall architectural structure that could meet the following rigorous design requirements: self-compaction, low autogenous shrinkage, enhanced ductility and high durability. A second case study provided evidence that challenges normally encountered in typical shotcreting applications could be overcome by the dry addition of SAP in the nozzle during the shotcreting operation.

There are clearly many opportunities to use SAP in many different functions to improve the performance and durability of the built environment. It is expected that future applications will increasingly move towards the use of SAP in the construction sector, as this new technology becomes better known through good practice and evidence of good performance records.

10.6. REFERENCES

[1] Jensen OM (2008) Use of superabsorbent polymers in construction materials, 1st International Conference on Microstructure Related Durability of Cementitious Composites, Nanjing, China, 757-764.

[2] Reinhardt HW, Assmann A, Mönnig S (2008) Superabsorbent polymers (SAP) – an admixture to increase the durability of concrete, 1st International Conference on Microstructure Related Durability of Cementitious Composites, Nanjing, China, 313-322.

[3] Laustsen S, Hasholt MT, Jensen OM (2008) A new technology for air entrainment of concrete, 1st International Conference on Microstructure Related Durability of Cementitious Composites, Nanjing, China, 1223-1230.

[4] Jensen OM, Hansen PF (2002) Water-entrained cement-based materials – II. Experimental observations, Cement and Concrete Research, 32(6):973-978.

[5] Buchholz FL, Graham AT (1998) Modern Superabsorbent Polymer Technology, WILEY-VCH, New-York, 279 p.

[6] Tsubakimoto T, Shimomura T, Kobayashi H, Japan, Kokai Tokkyo Koho, 62-149, 335, 1987.

[7] Suetsugu, Japan, Kokai Tokkyo Koho, 06-157, 839, 1994.

[8] Shimomura T, Namba T (1994) Superabosorbent Polymers, Science and Technology, Symposium Series 573, F.L. Buchholz, N.A. Peppas (eds), American Chemical Society, Washington DC, 112-115.

[9] Tsuji M, Okuyama A, Enoki K, Suksawang S (1998) Development of new concrete admixture preventing from leakage of water through cracks, JCA Proc. of Cement & Concrete (Japan Cement Association) 52:418-423.

[10] Tsuji M, Shitama K, Isobe D (1999) Basic Studies on Simplified Curing Technique, and Prevention of Initial Cracking and Leakage of Water through Cracks of Concrete by Applying Superabsorbent Polymers as New Concrete Admixture, Journal of the Society of Materials Science, Japan, 48(11):1308-1315.

[11] Tsuji M, Koyano H, Okuyama A, Isobe D (1999) Study on method of test for leakage through cracks of hardened concrete, JCA Proc. of Cement & Concrete (Japan Cement Association) 53:462-468.

[12] Song XF, Wei JF, He TSH (2009) A method to repair concrete leakage through cracks by synthesizing super-absorbent resin in situ, Construction and Building Materials 23(1):386-391.

[13] Song XF, Wei JF, He TSH (2008) A novel method to improve sulfate resistance of concrete by surface treatment with super-absorbent resin synthesised in situ, Magazine of Concrete Research 60(1):49-55.

[14] Onoda Cement Company Ltd, Japan, Kokai Tokkyo Koho, 62-56, 382, 1987.

[15] Harrison T (1991) Introducing controlled permeability formwork. Increase concrete durability in the cover zone, Publication # C910198 Aberdeen's Concrete Construction 36(2):198-200.
[16] Jin ZF, Asako Y, Yamaguchi Y, Yoshida H (2000) Thermal and water storage characteristics of super-absorbent polymer gel which absorbed aqueous, International Journal of Heat and Mass Transfer, 43(18):3407-3415.
[17] Asako Y, Otaka T, Yamaguchi Y (2004) Fire resistance characteristics of materials with polymer gels which absorb aqueous solution of calcium chloride, Numerical Heat Transfer, Part A, 45:49-66.
[18] Gel cleans radioactive concrete, Chemical Processing 67(9):9-11, 2004.
[19] Snashall HT (1991) Cementitious mixes, South African Patent Application ZA9100876 A 19911224.
[20] Jensen OM, Hansen PF (2001) Water-entrained cement-based materials, PCT Patent Application WO01/02317A1.
[21] Moriyoshi A, Fukai I, Takeguchi M (1990) Nature, 344:230-232.
[22] Nippon Synthetic Materials Ltd., Japan, Kokai Tokkyo Koho, 06-287, 556, 1994.
[23] Sawahata K, Gong JP, Osada Y (1995) Macromol., Rapid Commun., 16:713-716.
[24] Nippondenso Co. Ltd., Japan, Kokai Tokkyo Koho, 06-300, 724, 1994.
[25] The Dow Chemical Co., Dow Wolff Cellulosics, Market and Applications - Construction Materials, http://www.dow.com/dowwolff/en/markets_apps/consmaterials.htm (accessed May 25, 2010).
[26] Mechtcherine V, Dudziak L, Schulze J, Staehr H (2006) Internal curing by super absorbent polymers (SAP) – Effects on material properties of self-compacting fibre-reinforced high performance concrete, *International RILEM Conference on Volume Changes of Hardening Concrete: Testing and Mitigation*, Lyngby, Denmark, 87-96.
[27] Dudziak L, Mechtcherine V (2008) Mitigation of volume changes of Ultra-High Performance Concrete (UHPC) by using Super Absorbent Polymers, Second International Symposium on Ultra High Performance Concrete, E. Fehling et al. (eds.), Kassel University Press GmbH, 425-432.
[28] Jolin M, Beaupré D (2003) Understanding wet-mix shotcrete: mix design, specification, and placement, Shotcrete, 6-12.