ABSTRACT: This paper focuses on the water absorption of superabsorbent polymers in a cementitious environment. The paper discusses different techniques to measure the water absorption capacity, and in particular it describes a technique which enables a simple and quick estimation of the water absorption capacity in a cementitious environment. The challenges met in defining the concept of water absorption capacity are treated, and the appropriateness of different types of superabsorbent polymers is also briefly dealt with. The concept “water absorption capacity” and its measurement seem straightforwardly simple, but a closer examination of the topic discloses many, significant difficulties. However, given proper cautiousness it is possible both to quickly estimate the water absorption capacity through a simple measurement as well as to examine how it will be influenced by different factors.

1 INTRODUCTION

The most fundamental property of superabsorbent polymers (SAPs) is their ability to take up enormous amounts of specific substances from the surroundings and retain it within their structure; this property is reflected in the name of this class of materials. Far the majority of SAPs are designed for water take-up, though they can also be designed for absorption of other liquids or they can act as efficient absorbents for capturing specific, dissolved substances. When nothing further is mentioned, the absorbency can be assumed to refer to water absorption. Here and in the following, “water” refers to an unspecific aqueous solution, not chemically pure water. The aqueous solution may be e.g. tap water, saturated calcium hydroxide solution or it may be the pore fluid in a concrete: When dry SAP is exposed to these types of liquids it will take up both chemically pure water as well as some of the dissolved substances present in the aqueous solution and potentially even accumulate them.

Specific types of SAPs may be able to take up water amounting to 1500 times the weight of the dry material. Even though the absorption capacity observed in e.g. a cementitious environment is much lower - for example 20 times its own weight - this value is still much higher than the absorption capacity of other relevant water storage materials for use in cementitious systems, Jensen and Lura (2006).

The amount of water absorbed by a SAP depends on properties of the SAP, and its exposure environment. SAP geometry influences the rate of water exchange with the surroundings, whereas SAP chemistry influences both the rate of water exchange as
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well as the absorption capacity. Parameters in the exposure environment influencing the SAP water absorption include the temperature, the pressure, the water activity and the specific, ionic composition of the exposure liquid.

Figure 1: Scanning electron micrographs of different types of SAP. Optical microscopy may be less suited for study of SAP morphology due to visual artifacts created by light reflections on the SAP surface. Top left: Solution polymerized SAP, crushed to a particle size of approx. 500 μm. Top right: Suspension polymerized SAP in its simplest form - individual, spherical particles. Bottom left: Suspension polymerized SAP, intentionally agglomerated to reduce packing of particles and to enhance flowability of the powder. Bottom right: Suspension polymerized SAP with a highly convoluted, “broccoli”-shaped surface to avoid clogging during its ultra fast water-uptake.

2 BASIC TYPES OF SUPERABSORBENT POLYMERS

SAPs exist in a variety of different types. With regards to chemistry, i.e. the molecular composition of the SAP, it is useful to distinguish between two opposite extremes: ionic and nonionic polymers. Whereas the nonionic SAPs function mainly based on hydrophilic groups along the polymer chain, the ionic SAPs normally have a much higher absorption capacity due to strong dipole-ion interaction between water and
ions fixed to the polymer chain. However, in high-ionic solutions ionic SAPs perform less well due to shielding of the ionic charges along the polymer chain. Commercial SAPs are predominantly based on ionic polymers due to their usually higher absorption capacity. The common type of ionic SAP is poly(acrylic acid); a common type of nonionic polymer for SAPs is polyacrylamide. In addition to the opposite, pure extremes of ionic and nonionic polymers also co-polymerized mixtures of these types exist.

Crosslinks between the polymer chains is a vital part of SAPs as it prevents the SAP from dissolving - without crosslinks it would not be a SAP. Crosslinks can be based on covalent, ionic or hydrogen bonds. Covalent crosslinks may be preferred as they are stable and strong. The crosslink density of the polymer network is controlled during the production of SAPs. It is an important characteristic of SAPs as there is a fundamental relationship between crosslink density and absorption capacity as well as shear modulus of the SAP. An increased crosslink density may lead to a proportional increase in shear modulus and a monotonous lowering in the absorption capacity.

Another important grouping of SAPs refers to the production method which basically may be either solution polymerization or suspension polymerization. In principle, there is only a minor difference between the two: In the case of suspension polymerization the solution where the polymerization takes place is separated into a dispersed phase by means of agitation and by addition of a suspension aid. However, from a morphologic point of view the SAP particles produced with the two different techniques are very different. In the basic form the solution polymerized SAP consists of crushed particles, whereas suspension polymerized SAP consists of spherical particles. Many variations over these two production methods exist and they enable a considerable control over the appearance and physical properties of the SAP. Figure 1 shows examples of some SAP morphologies.

Buchholz and Graham (1998) have written a recommendable book on SAP technology from which the above overview is partly based.

3 THE DRY STATE OF SAP

Before discussing the water absorption of SAP it is useful to consider the “dry” state of SAP since water absorption, or moisture content, \( u \) (g/g), is calculated relative to this condition though the following equation:

\[
u = \frac{m_{\text{actual}} - m_{\text{dry}}}{m_{\text{dry}}}
\]

Where \( m_{\text{actual}} \) (g) is the mass of the SAP including its actual moisture content and \( m_{\text{dry}} \) (g) is the mass of the SAP in its dry state.
Within construction materials the usual definition of the dry state refers to drying at 105°C till a constant mass is achieved. This temperature will despite a minor measuring inaccuracy and despite dissolved species in the water normally ensure that water contained in the sample quickly boils away. Furthermore, the moisture contained in laboratory air will be insignificant in relation to a material sample equilibrated at 105°C. For SAPs the usual definition is also valid, however, it should be observed that the removal of water from SAP at 105°C is relatively slow. Raising the temperature speeds up the process, but the temperature should be kept below approx. 180-200°C to avoid deterioration of the SAP. Figure 2 shows an example of the mass loss from SAP as it is heated at increasing temperatures.

![Mass loss from SAP at increasing temperatures](image)

Figure 2: SAP dried at step-wise increasing temperatures. A truly stable equilibrium is not reached at any temperature within the given exposure times. During exposure to the highest temperature, 180°C, the color of the SAP darkened as an indication of deterioration of the SAP.

As seen from Figure 2 lack of true equilibrium during determination of the dry mass will only lead to a minor error, e.g. approx. 1%. Contrary to this, a major error may arise if for example the SAP has been exposed to a humid environment during storage. After commercial production SAPs typically contain 0.01-0.05 g water per g of dry SAP (Buchholz and Graham (1998)), whereas it during exposure to e.g. 50% RH may take up 0.25 g water per g of dry SAP (Jensen and Hansen (2002)).

If such a water up-take has occurred it certainly needs to be corrected for in the proportioning of concrete with SAP addition and in the measurement of SAP absorption capacity: 1 g of “apparently dry” SAP at 50% RH may contain only 0.8 g dry SAP. The moisture content of SAPs, therefore, should be controlled before use.

4 THE WATER ABSORPTION OF SAP AND ITS SENSITIVITY TO VARIOUS PHYSICAL AND CHEMICAL FACTORS

When a dry SAP particle is exposed to water it will swell, and after a certain time
reach a point of apparent equilibrium. This may be referred to as “the water absorption capacity of the SAP” in this specific environment. The equilibrium, however, is not stable. If, for example, the ionic composition of the exposure liquid changes, the SAP will exchange water with the surroundings until a new apparent equilibrium is established. Furthermore, even if the exposure environment is kept constant the amount of water held by the SAP may change. Depending on the type of SAP and the ions present in the water this phenomenon can be quite significant, though it will typically be a slow process compared with the initial water absorption.

The most common type of SAP, the acrylic acid polymer has particular difficulties with multivalent cations. In cementitious systems Ca\(^{2+}\) and Al\(^{4+}\) will diffuse into the SAP particle and slowly establish cross-links between the acrylic acid polymer chains and lead to a considerable water release from this type of SAP.

![Figure 3: Water absorption kinetics of solution polymerized SAP particles in different liquids at approx. 20°C. The approximate size of the initial, dry SAP particles are given. The synthetic pore fluid has the following composition (mmol/l): [Na\(^+\)]\(=\)400, [K\(^+\)]\(=\)400, [Ca\(^{2+}\)]\(=\)1, [SO\(_4^{2-}\)]\(=\)40, [OH\(^-\)]\(=\)722 (Page and Vennesland (1983)). The tap water is “very hard”, 21°dH, with a Ca\(^{2+}\)-equivalent of about 16% of the one found in saturated Ca(OH)\(_2\). The technique to measure the water absorption is described further on in the paper.

Figure 3 illustrates a number of features in relation to water absorption of SAP - it is a complex phenomenon. As shown, the water absorption capacity of SAP may be reduced considerably by even a very small amount of dissolved substances in the
exposure liquid. For this specific SAP a water absorption capacity around 300 g/g is observed in demineralized water. However, even the very small amount of ions present in tap water reduces the water absorption capacity to approximately 50 g/g. In saturated Ca(OH)₂-solution this value is reduced further to about 10 g/g. The Ca²⁺ in saturated Ca(OH)₂-solution as well as the Ca²⁺ in tap water is the main reason for both the lower absorption capacity and for the observed non-monotonous swelling; though the SAP has been exposed to a liquid with constant composition, the SAP exhibits initial swelling followed by deswelling. The ionic strength of the synthetic pore fluid is more than 10 times higher than the ionic strength of the saturated Ca(OH)₂-solution ([Ca²⁺]=23 mmol/l, [OH⁻]=46 mmol/l). Despite this, the absorption capacity in synthetic pore fluid, about 20 g/l, is twice the value found in saturated Ca(OH)₂-solution, and furthermore, no long time deswelling is observed. The reason for this is that [Ca²⁺] is strongly depressed in synthetic pore fluid due to a high [OH⁻] from NaOH and KOH.

Figure 3 additionally illustrates the influence of SAP particle size on its rate of water exchange. The particle size has a strong influence because diffusional processes are involved in the absorption and release of water from the SAP particles. From Figure 3 the mm-sized SAP particles are seen to equilibrate in a matter of about half a day. The relevant SAP particle size for use in concrete may be 100 μm or less (Jensen and Hansen (2002)). For this size range equilibrium swelling will be reached in a matter of seconds or a minute, i.e. usually before concrete mixing is finished.

Figure 4: Water absorption kinetics of different SAP types at approx. 20°C. Type 1 is a crosslinked sodium polyacrylate with a particle size of approx. 500 μm. Type 2 is a crosslinked potassium polyacrylate/polyacrylamide copolymer in a 30%/70% ratio with a particle size of approx. 1 mm. A few hours after exposure to the synthetic pore solution deterioration of SAP Type 1 starts; It turns into slime and dissolves. After a week it has completely disappeared. The technique to measure the water absorption is described further on in the paper.

Figure 4 shows the differences in sensitivity to aqueous solutions of two SAP types.
In demineralized water the acrylic acid polymer has more than twice the water absorption capacity than the acrylamide-based polymer, 420 g/g vs. 180 g/g. On the other hand the acrylic acid polymer performs in an unstable manner in the ionic environment of the synthetic pore fluid. This is in contrast to the stable performance of the acrylamide-based polymer. With regard to cementitious systems acrylamide-based polymers is preferred to the common acrylic acid polymer because of the better performance in a high ionic strength, multivalent-cation rich environment.

5 TECHNIQUES FOR MEASUREMENT OF WATER ABSORPTION OF SAP WITH REFERENCE TO CEMENTITIOUS ENVIRONMENTS

The water absorption of SAP can be measured in several different ways. Buchholz and Graham (1998) and Qi et al (2008) discuss a number of different methods. Several methods are based on direct observations of mass or volume changes whereas other methods are based on measurements of quantities that very indirectly allow determination of the SAP water absorption. An example of this is a method based on changes in concentration of an exposure liquid component which is not absorbed by the SAP.

At a first thought, the measurement of SAP water absorption seems simple, however, as shown further on there are many delicate points that need to be observed to avoid considerable measuring errors. It is important to take into consideration both the type of SAP and the context it will be used in. A measuring technique which is useful for a certain type of SAP in a specific exposure environment may be useless in other situations. Within the focus of this paper - cementitious systems there are common requirements for the measurement technique. In many cases the SAP used in cementitious systems should preferably have a narrow particle size distribution of 100 µm or less, the exposure liquid will be highly alkaline, etc.

On the other hand, even within the limits of cementitious systems there may also be requirements for the measuring technique depending on the more specific use of the SAP: When SAP is used for water-entrainment (Jensen and Hansen (2001, 2002)), in principle, the relevant quantity is the amount of water the SAP is able to release to the cementitious system from the point of setting. For SAP used in shotcreting (Jensen (2008)) the important factor may be the rheology change created by the SAP, i.e. the SAP water absorption within a few seconds. If the SAP is used for engineered air-entrainment (Laustsen et al (2008) and Laustsen (2011)) the quantity sought for is the volume of cavities created by the SAP in the hardened material.

5.1 Measurements on single particle

The measurements shown in Figure 3 have been carried out by submerging a single SAP particle into 0.5 ℓ of the indicated liquid. At the times marked in the graphs the
particle is removed from the liquid, the particle surface is blot dried with absorbent paper, the particle is weighed, and the particle is brought back into the liquid. This gravimetric technique is extremely simple, but to enable handling of the particle, to allow for measurement of a few points during the swelling and to ensure proper removal of the water attached to the SAP particle surface it requires that the particle surface is not convoluted and it requires large particles, i.e. in the dry state at least mm-size. This SAP particle size range, however, is typically not relevant for the use in cementitious systems.

Measurement of absorption capacity of a single, small SAP particles can be done with optical microscopy if the SAP particle has a regular geometry. As an example a single, dry, suspension polymerized, acrylamide/acrylic acid co-polymer SAP particle with a diameter of 390 µm was observed in an optical microscope. Synthetic pore fluid was added with a pipette and the diameter of the swollen particle was measured both after 0.75 h and after 3 days to approx. 1070 µm. This equals a water absorption of 22 g/g.

This method, however, is delicate and laborious, there may be a problem with representativity, and diameter change is a very uncertain way to measure the absorption capacity, since measurement uncertainty is scaled to the third power. Additionally, evaporation of the exposure liquid during the measurement may be a challenge, and light reflections in the convex particle surface and concave water surface makes it difficult to accurately identify the edge of the SAP particle.

5.2 The tea bag method

The dominating use of SAP is for urine absorption in baby diapers. The traditional techniques to measure absorption capacity of SAPs are focused on this use. A popular measuring technique is the so-called “tea bag method”. The method consists in filling dry SAP particles into a small, permeable bag - a “tea bag” which is subsequently submerged into a liquid which in principle could be urine. Additionally, the submerged, SAP-filled tea bag may be subjected to a light pressure to mimic the influence from a sitting baby. The absorption capacity is calculated based on the mass of initial, dry SAP in relation to the mass gain of the filled tea bag after it is removed from the exposure liquid and the sample is drained from excess liquid by means of gravity.

The tea bag method is not useful to measure absorption capacity in relation to cementitious systems. A part of the mass gain by the tea bag method is due to liquid held by capillary forces in between the SAP particles; interparticle, unabsorbed liquid. Contrary to cementitious systems it may be relevant to include this liquid in the case of diaper products the measured mass gain may in this case be referred to as the “retention capacity” rather than the “absorption capacity”.

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For mm-size, strong SAP particles it is possible to remove the interparticle liquid by centrifugation. The experimental results shown in Figure 4 is an example of this. Each sample in the figure consists of 0.1 to 0.5 g SAP i.e. between approx. 100 and 1,000,000 particles. The particles for one sample were contained in a small, permeable bag of polyamide fabric (made from lady stockings) with a mesh opening of approx. 200 µm. The swelling was measured by submerging the sample into 0.5 of the indicated liquid. At the times marked in the graphs the sample is removed from the liquid, the sample is centrifuged at 50 G to remove interparticle liquid, the sample is weighed, and the sample is brought back into the liquid.

For SAP particles sizes of relevance for cementitious systems, e.g. 100 µm or less in the state, this method is not useful. Experiments at up to 1400 G centrifugation show that centrifugal forces involved disintegrate the SAP and break the polyamide bags, whereas centrifugal forces are not strong enough to overcome the capillary forces and remove interparticle liquid.

5.3 Measurements on hardened cementitious materials

Direct measurement of the cavities formed in hardened cementitious materials obviously have some considerable advantages: In this case the SAP is accurately subjected to the relevant environment and, therefore, any complex aspect of e.g. changes in ionic composition of the pore fluid before setting is taken perfectly into consideration. For this reason the cavities directly represent the property of interest in the case of water entrainment or engineered air-entrainment.

Figure 5 shows an example of such a measurement which has been carried out similar to a traditional air-void analysis. Based on digital image analysis of the cross-section the absorption capacity of the SAP in this environment is calculated as approx. 13 g/g. With this kind of analysis it is possible to also investigate other very relevant phenomena in relation to the use of SAP in concrete such as the integrity of the individual SAP particles and the spatial distribution of the SAP within the cementitious matrix. A purpose of the experiment shown in Figure 5 was to examine if the SAP had segregated due to gravity. According to the analysis this is not the case. Had it been a concrete and had spherical SAP particles been used it would furthermore be possible to see if crushing of SAP particles had taken place due to the grinding action of the aggregate particles during mixing.

From investigations of SAP cavities in cross-sections of cementitious materials we have examined to what extent the cement type influences the water absorption of a specific acrylamide-based SAP. The cementitious systems were made of opposite extremes of Danish cements with regards to alkali content (Aalborg Portland White, Na₂O equivalent ~ 0.15%; Aalborg Portland Rapid, Na₂O equivalent ~ 0.55%). The cavity sizes in the hardened materials did not show a measurable difference, and thus
the water absorption of the SAP seemed stable in cementitious systems as regards to
cement type.

Figure 5: Picture captured by flat bed scanning of a vertical cross-section of cement
paste with SAP (SAP/c=0.3%, total w/c=0.35, 20% silica fume addition). As indicated
from the angular shape of the cavities the SAP is solution polymerized. Its largest,
particle size in the dry state is 250 µm. To observe the cavities created by the SAP
particles, the sample has been prepared like a traditional sample for air-void analysis:
The cement paste is plane polished with SiC #1200, colored with black ink and puttied
with white Zinc-paste. Further contrast is achieved by sprinkling the sample with
gypsum powder, and the sample surface is finally scraped with a cutter blade.

Due to advances in X-ray computed tomography during the last few years an even
more detailed investigation than the one based on cross-sectional analysis can be done
in 3D. As a further advantage computed tomography involves no particular sample
preparation contrary to the 2D method shown in Figure 5. Laustsen et al (2010) have
successfully used computed tomography to analyze SAP cavities in cementitious sys-
tems, though there still clearly is a potential for further development of this technique,
both concerning instrument measuring accuracy and concerning data analysis.

5.4 A simple method to estimate the water absorption capacity of SAP in
cementitious environments

X-ray computed tomography will undoubtedly develop into a very useful and accu-
rate technique for measurement of SAP water absorption capacity in cementitious
systems due to its realistic measurement it may become the technique of choice for this purpose. However, it requires access to very expensive instrumentation and the subsequent data analysis is not simple.

![Image of graduated cylinders demonstrating the determination of water absorption capacity of SAP](image)

Figure 6: Determination of water absorption capacity of SAP by means of graduated cylinders. 1: The relation between volume and mass of loosely packed, dry SAP particles is measured. 2a: A certain, small amount of dry SAP is filled into a graduated cylinder. 2b: The graduated cylinder is filled with synthetic pore fluid or another fluid of interest. The volume taken up by the swollen SAP particles is read after settlement.

In any case a quick and simple method to estimate the water absorption capacity of SAP in cementitious environments is needed for several purposes. These include quality control, survey of the water absorption by different SAP types and how it is influenced by different exposure parameters as it may not be possible or convenient via mixing of SAP concretes. Additionally an estimate of the SAP water absorption capacity may be needed before concrete mixing.

We are using a simple method to routinely estimate the water absorption capacity of SAP. The method consists in measuring the volume change of a certain mass of loosely packed SAP as it absorbs water. Primarily, the water absorption capacity at
equilibrium is measured, however, for a SAP with slow water absorption it is possible to measure a few points of the time development. The measuring principle and the measured quantities are indicated in Figure 6.

Initially the relation between volume and mass of the dry SAP powder is determined. This is done e.g. by filling a graduated cylinder to its maximum reading with dry SAP and determining the mass of the SAP (Figure 6 “1”). The volume will refer to the outer volume of loosely packed SAP particles. Subsequently, a small amount of SAP, with known mass, is filled into the cylinder (Figure 6 “2a”). Based on the initially established relation between volume and mass the outer volume of this powder can be calculated to a much higher accuracy than what can be read on the graduated cylinder.

Then the synthetic pore fluid is poured into the cylinder. During the water absorption the mixture is stirred to allow the SAP to swell freely. A measurement of the water absorption is done by terminating the stirring and waiting for the SAP particles to settle by means of gravity. The time for this will depend on the density of the swollen SAP particles and their size - it may be a few seconds or 1 hour. When the swollen SAP particles have settled in the synthetic pore fluid their volume is read (Figure 6 “2b”). As shown by Equation (2) the water absorption can subsequently be calculated based on measured volumes \( V_1, V_2 \) and masses \( m_1, m_2 \) of SAP, its dry, solid density \( \rho_{\text{SAP}} \), and the density of water \( \rho_{\text{water}} \). The usual unit for water absorption is \( \text{ml/g} \) or \( \text{g/g} \); in Equation (2) it is given in \( \text{g/g} \).

\[
K = \frac{\rho_{\text{water}}}{\rho_{\text{SAP}}} \left[ \frac{V_2}{V_1} \cdot \frac{m_1}{m_2} - 1 \right] \tag{2}
\]

The method involves a number of assumptions. As with other volumetric techniques it is assumed that the volume of the swollen SAP is the sum of the volume of the initial, dry SAP and the volume of water before absorption by the SAP. Usually chemical reactions involving condensed phases are associated with a decrease in the total volume, but it is normally a very small effect, and in the present case it seems reasonable to neglect it. As mentioned previously in this paper the absorbed water is not chemically pure, but will contain dissolved substances. For this reason its density will not be 1000 kg/m\(^3\), however, considering other uncertainties in the method it will be a good approximation to assume this value.

Another assumption, which is more dubious, is that the particle packing of SAP after settlement in the liquid is similar to the particle packing of the dry SAP particles. Two phenomena are expected to shift the particle packing by settlement in liquid to be looser than dry packing:

1. As the SAP particles absorb a significant amount of water their density approaches the density of the surrounding liquid. The SAP particles will be almost buoyant
in water and may pack less dense for this reason. The measuring technique will, therefore, not be useful e.g. for acrylic acid SAP in demineralized water.

2 The settlement in water will act like a sieve separating different sized SAP particles from each other. Small particles will have a relatively higher viscous drag than large particles. If the particle size distribution of the SAP is broad this may lead to a looser particle packing during settlement compared with dry packing.

Despite the mentioned, debatable assumptions it appears that the water absorption capacity measured with the graduated cylinder method is in reasonable accordance with the value measured directly on cavities in hardened cementitious materials. As an example for the experiment shown in Figure 6 the following data apply: Exposure liquid is given in the caption of Figure 3, \( V_1 = 100 \text{ m}^3 \), \( V_2 = 46 \text{ m}^3 \), \( m_1 = 71.5 \text{ g} \), \( m_2 = 1.00 \text{ g} \), \( \rho_{\text{SAP}} = 1500 \text{ kg/m}^3 \) (Buchholz and Graham (1998)), and \( \rho_{\text{water}} = 1000 \text{ kg/m}^3 \). This gives \( K = 21 \text{ g/g} \). The swelling capacity determined on the same SAP by means of CT scanning suggests a value in the range 20-25 g/g (Laustsen (2011)). According to our present experience the value obtained by the graduated cylinder method may deviate up to approx. 20% from the value measured on hardened cementitious materials, however, a more thorough investigation is needed to identify the exact accuracy of the technique.

6 FINAL REMARKS

The water absorption of SAP and its sensitivity to various parameters is certainly significant and complex. However, given proper care and attention it should not cause difficulties e.g. for the use of SAP as an agent for water-entrainment or controlled pore formation in cementitious systems. SAPs exist in a variety of different morphologies, particle sizes and chemical forms and within these it seems possible to select a type where the technological difficulties are insignificant. Proper attention is also needed for the measurement of water absorption of SAP in relation to cementitious systems. Special techniques are required as the usual techniques may be unsuitable.

The data and experiments reported in this paper are from 1999 and 2000. They have not been published previously but were part of the research leading to the publications by Jensen and Hansen (2001, 2002). The observations described in the present paper enabled the identification and further development of a well-working SAP type for the use in cementitious systems. The papers Jensen and Hansen (2001, 2002) and the identification of a useful SAP type seem to have been the initiator of SAP related research within cementitious systems during the following decade. Hopefully the additional information in the present paper will help to promote the research further.

Within the limits of the present paper it has not been possible to deal with all the relevant elements related to the use of SAP in cementitious systems which were observed more than 10 years ago. This may be the subject of a later publication.
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