Influence of Superabsorbent Polymers on the Mechanical Properties and Shrinkage of Pavement Concrete

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Abstract: This paper examines the effect of superabsorbent polymers (SAPs) with varied particle sizes and contents on the mechanical strength and shrinkage of cement concretes. SEM measurements were performed to identify the mechanisms of internal curing. It was shown that the incorporation of SAPs generally increased the compressive strength and shrinkage resistance capability of specimens, especially the relatively small particle sizes. A large number of hydration products were generated and grouped around the remained pores of SAP, which could enhance the hydration degree and improve the compactness of cement concretes, as well as the performance growth.

1 INTRODUCTION

Nowadays, High-performance concrete (HPC) has been increasingly promoted for use in road egngineering because of its potential durability benefits, which normally has a low water-to-cement (w/c) ratio of 0.20–0.38 [1]. However, water is insufficient to promote complete hydration of cement under compact conditions in concretes with a w/c ratio below 0.42 [2]. The above problem will result in an early-age autogenous shrinkage and a strength difference between interior and surface of cement concrete, probably reducing the long-term properties of cement concrete.

Superabsorbent polymers are cross-linked polymer networks able to swell in solution. These reservoirs can absorb significant amount of water either during mixture and release water gradually during concrete hardening [3]. The released water contributes in restoring part of the water that has been lost through autogenous or drying shrinkage, achieving the curing effect. In addition, water released from SAPs could also contribute to the hydration of unhydrated cement particles, thereby improving the microstructure and, as a result, the durability of the materials [4].

The effect of SAPs on the shrinkage behavior and mechanical properties of cement concretes have been investigated by several researchers [5]. The results have indicated the effectiveness of SAPs in reducing the autogenous shrinkage. For the mechanical properties, some researchers discover that the strength of cement concretes with SAPs would be reduced, while the other researchers find it increased. These phenomena indicate that the swelling capacity of SAPs has not been accurately assessed till now, because the swelling capacity is influenced by several factors, including the SAP variety, partical size and content, especially the ionic concentration of different cement grout[6–7].

As a thin plate with large area exposed in the envirnment, concrete pavements could be more easily to crack than concrete structures. However, the applications of SAPs are mainly on structural concretes, except the pavement concretes. Thus the influence of SAPs on the mechanical properties of pavement concrete has not been explored presently .

The goal of this article is to elucidate the effect of a variation in the particle sizes and content of the SAPs on the strength and shrinkage resistance capability of pavement concretes modified with SAPs. Swelling capacity of SAPs in the cement grout was meansured by the tea bag method. Cement concretes with additions of various SAPs were prepared for testing. Mechanical strength and shrinkage strain were investigated using flexural strength test and displacement sensor, respectively. Ultimately, the mechanisms of internal curing on pavement concrete were explored using Scanning Electron Microscope (SEM).

2 EXPERIMENTAL METHODS

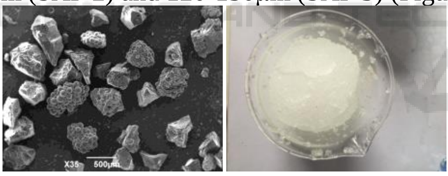
2.1 Materials

Ordinary Portland cement (PO. 42.5) was employed with a Blaine fineness of 365 m^2 /kg and the following chemical composition in wt.% (SiO_2: 22.06, Al_2O_3: 5.13, Fe_2O_3: 5.25, CaO: 64.37, MgO: 1.06, and SO_3: 2.03). Its physical and mechanical properties are shown in Table 1. The coarse aggregate (limestone) was divided into 4.75~9.5 mm and 9.5~19.00 mm and the mixing ratio was 1:4. The fine aggregate was river sand with a fineness modulus of 2.6 and an apparent density of 2.65 g/cm^3.

Table 1: Physical and mechanical properties of cement.

Blaine specific surface /(m^2 /kg)	Setting time /min		Compressive strength /Mpa		Flexural Strength /Mpa	
336	Initial set	Final set	3d	28d	3d	28d
	210	270	27.4	54.8	6.1	8.7

A polycarboxylic acid type high performance water-reducing admixture with 26% water-reducing rate was used. Polyacrylicacid-based SAP were used with a dry particle size of 380-830 μm (SAP 1), 180-380 μm (SAP 2) and 120-150μm (SAP 3) (Figure 1).



(a) (b)

Figure 1: (a)SEM image of SAPs, (b) SAP after swelling.

2.2 Mixture Proportions

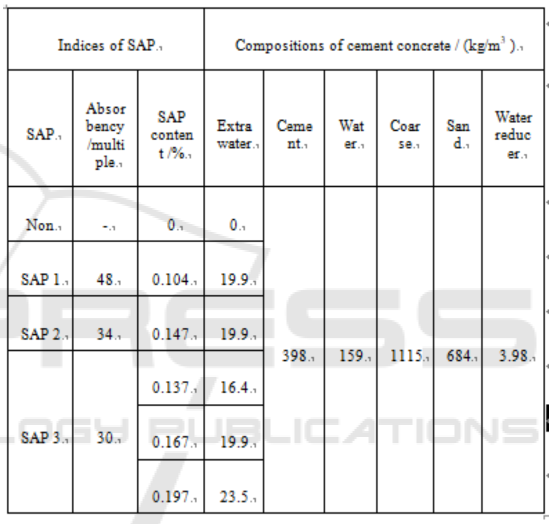
Cement concrete with 0.31 w/c was used in the study. The contents (the proportion of cement) of SAP and the extra water absorbed by SAPs could be determined by its swelling capacity in cement grout (The measuring procedure is shown in Figure 2) and the Powers formula (Eq.1), the results are presented inTable 2. Dry SAP powders were mixed with cement before the wet-mixing procedure of cement concrete. And the extra water was added together with the common water and the water reducer.

Figure 2: The meansuring procedure of swelling capacity of SAPs by the tea bag method.

The Powers formula is shown in Eq.1:

$$w/c \le 0.36，(w/c)_e = 0.18(w/c) \tag{1}$$

Table 2: Compositions of cement concrete.



Indices of SAP				Compositions of cement concrete / (kg/m^3)				
SAP	Absorbency /multiple	SAP content /%	Extra water	Cement	Water	Coarse	Sand	Water reducer
Non	-	0	0	398	159	1115	684	3.98
SAP 1	48	0.104	19.9					
SAP 2	34	0.147	19.9					
SAP 3	30	0.137	16.4					
		0.167	19.9					
		0.197	23.5					

2.3 Experimental Testing

The flexural strength test was conducted using concrete beams (100mm×100mm×400mm) experienced 3 days' and 7 days' curing with three-point loading according to ASTM C78. A material testing machine was utilized to perform the flexural strength test and the average results of three specimens were obtained and reported.

The shrinkage test was performed by a high precision displacement sensor system at a standard environment (20±2 °C, 80% RH) continuously from 1 day to 7 day, which is the most crucial period to the concrete cracking, as shown in Figure 3.

Figure 3: The displacement sensor system.

The microstructure of the concretes cured by SAPs was measured using the SEM.

3 RESULTS AND DISSCUSSION

3.1 Flexural Strength

The flexural strengths of the control concrete without SAP and the internal curing concretes with different paticle sizes and contents of SAP are presented in Figure 4. The results correspond to flexural strengths at 3days and 7 days of curing, .

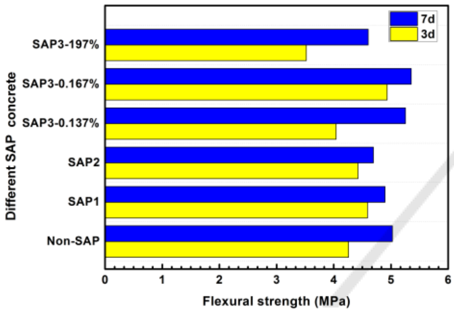


Figure 4: Flexural strength of different internal curing concrete.

It can be concluded from Figure 4 that the addition of SAPs studied here is not always accompanied with a decrease in the strength of concretes as the references mentioned before. For 3 days' concretes, the flexural strength of SAP 1, SAP 2 and SAP 3-0.167% (with the same extra water) are overall higher than that of the concrete with no SAP. It means that an appropriate extra water for internal curing plays a critical role in the mechanical property of concrete. On the contrary, inadequately extra water would decrease the curing effect while excessively extra water may increase the effective w/c (0.31), reducing the concrete strength, such as SAP 3-0.137% and SAP 3-0.197%, respectively.

Interestingly, although the flexural strength of SAP 3-0.137% is 5.09% lower than that of the Non-SAP on the 3rd day , it surpasses the latter for about 5% in the 7th day. It can be explained by the internal curing effect played by SAPs during the days from 3-7, meanwhile this effect could promote the hydration process of the cement, which can also enhancing the degree of compaction and making up for shortage of the SAP pore that occured in early stage.

It is worth noting that the flexural strength of SAP 1 and SAP 2 is 7.78% and 3.89% higher than the concrete with no SAP on the third day , however, they are 2.54% and 6.60% lower than the latter on the seventh day. Due to the relatively large particle size and quick water-release speed of SAP 1 (380-830 μm) and SAP 2 (180-380μm), the internal curing effect of these two SAP are excellent, which can restrain the shrinkage cracks that would probably generated in the first three days, thus the flexural strength could also be improved during the same period.

Unfortunately, the water-release speeds of SAP 1 and SAP 2 make them release water prematurely in the first three days, thus there is no enough time for SAPs to cure the concrete gradually and adequently. In addition, the remained pores generated from SAP could not be filled with hydration products from day 3 to day 7 due to the useless water release of SAPs in the first three days, which is not good for the pore structure of concrete. Consequently, the flexural strength of SAP 1 and SAP 2 are all lower than that of Non-SAP.

3.2 Shrinkage Strain

Figure 5 exhibits the shrinkage of the concretes with and without SAPs from the first day to the seventh day continuously.

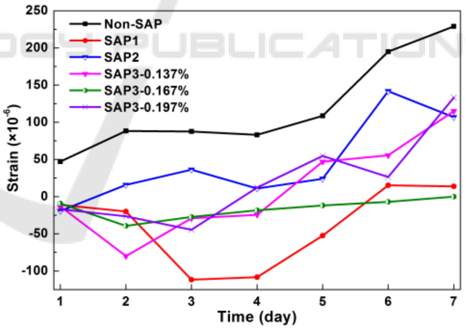


Figure 5: Shrinkage strain of different internal curing concrete.

It is seen that the addition of SAPs can significantly reduce the shrinkage strain in the early days, which can minigate the risk of cracking for concrete. In the first three days and with the same amount of extra water, SAP 3-0.167% achieves the best shrinkage property, then the SAP 2, SAP 1. It can be indicated that the number of particles and distribution of SAP 3 gel in the concrete is more uniformly than SAP 2 and SAP 1 (with the same amount of extra water), thus the range for internal curing of SAP 3 is wider than the rest, which can reduce the capillary force of concrete effectively.

Accoring to the datas at the seventh day, it can be found that SAP 3-0.167% obtains the best shrinkage property again, immediately followed by the SAP 1, SAP 2, SAP 3-0.137% and SAP 3-0.197%. These results can be explained that inadequately extra water (SAP 3-0.137%) could not reduce the capillary force and shrinkage strain, and excessively extra water is unnecessary for the curing process, which always accompanied with a side effect.

3.3 Microcosmic Mechanism

SEM measurements were performed to identify the microcosmic mechanism of the concretes cured by SAPs. As exhibited in Figure 6, the hydration products are highly crystalline into the remained pore of SAP, together with the shrivelled SAP. Furthermore, the shape of the pore is sphere, which can also plays a air entraining role and optimizes the pore strctucture on the cement concrete.

Next, the release of extra water adsord by SAP can accelerate the hydration process of cement concrete, enhancing the degree of compactness and flexural strength.

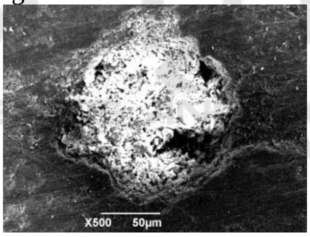


Figure 6: Microstructure of the concrete cured by SAP.

4 CONCLUSIONS

The mechanical strength and shrinkage strain of cement concretes with and without SAP were investigated using flexural strength test and displacement sensor, respectively. On this basis, reinforcement mechanisms of SAP were revealed by using SEM.

Based on the results presented in this paper, the following concluding remarks can be drawn:

(1) SAP 3 with appropriate amount of extra water obtained an excellent flexural strength and shrinkage property in 7 days.

(2) Inadequately extra water would decrease the curing effect while excessively extra water may increase the effective w/c, reducing the concrete strength.

(3) An appropriate water-release speeds of SAP for at least 7 days was imperative.

(4) A large number of hydration products were generated and grouped around the remained pores of SAP, which could enhance the hydration degree and improve the compactness of cement concretes.

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