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Synthesis and the effects of water-soluble sulfonated acetone–formaldehyde resin on the properties of concrete

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Abstract

Water-soluble sulfonated acetone–formaldehyde (SAF) resins were synthesized by the reaction among acetone, formaldehyde, and sodium bisulfite. The surface activity of SAF resins and their performance in concrete were evaluated. The effect of molecular weight (MW) of synthesized SAF resins on the performance of the superplasticized concrete was determined. The results showed that the SAF resin has the potential to be developed as a superplasticizer used in concrete.

Keywords: SAF; Superplasticizer; High-performance concrete; Adsorption; Slump

1. Introduction

Water-soluble polymer used in the construction industry is known as a superplasticizer. Only a small amount of superplasticizer can significantly improve the workability, mechanical strength, and other properties of concrete. The roles of this water-soluble polymer are to (1) improve the rheological properties of fresh concrete without segregation or bleeding; (2) act as a lubricant or a dispersing agent so that solid particles become more uniformly dispersed; (3) interact with cement or hydrated products to modify the morphology of materials; and (4) make hardened concrete stronger or more durable [1–3].

Sulfonated melamine formaldehyde condensate (SMF) and sulfonated naphthalene formaldehyde condensate (SNF) are two typical superplasticizers used commercially [4]. It has been reported that these admixtures exhibit very good dispersing effects on concrete, and can reduce water demand of concrete by up to 25% while still maintaining the flow characteristics of concrete.

Due to the high cost of SMF, the relatively low cost SNF is the main kind of superplasticizer being used in China. The application of SNF is limited in preparing pumping concrete and high-performance concrete due to its higher content of sodium sulfonate, which induces alkali–aggregate reaction, large slump loss with time elapsed, and complicated synthetic process [5]. In order to find a suitable superplasticizer used in preparing pumping concrete and high-performance concrete, we previously synthesized a water-soluble sodium sulfanilate–phenol–formaldehyde condensate (SSPF), which exhibits excellent capability of low slump loss with time elapsed [6]. It is found in practice that the synthesized SSPF has a disadvantage of relatively higher bleeding ratio.

Because of the industrial importance of superplasticizers in concrete technology, research and development focused on them have attracted great attention recently [7–13]. In this article, we have prepared a new, water-soluble sulfonated acetone–formaldehyde (SAF) resin as a superplasticizer, and the surface activity and performance effects on concrete of SAF resins were systematically investigated.

2. Experimental

2.1. Synthesis of SAF resin

Sodium bisulfite was dissolved in water in a jacketed reactor flask equipped with a baffle stirrer and a reflex condenser at 50 °C. The temperature of the solution was maintained at 50 °C before the solution is clear. As soon as the solution became clear, the temperature was decreased to

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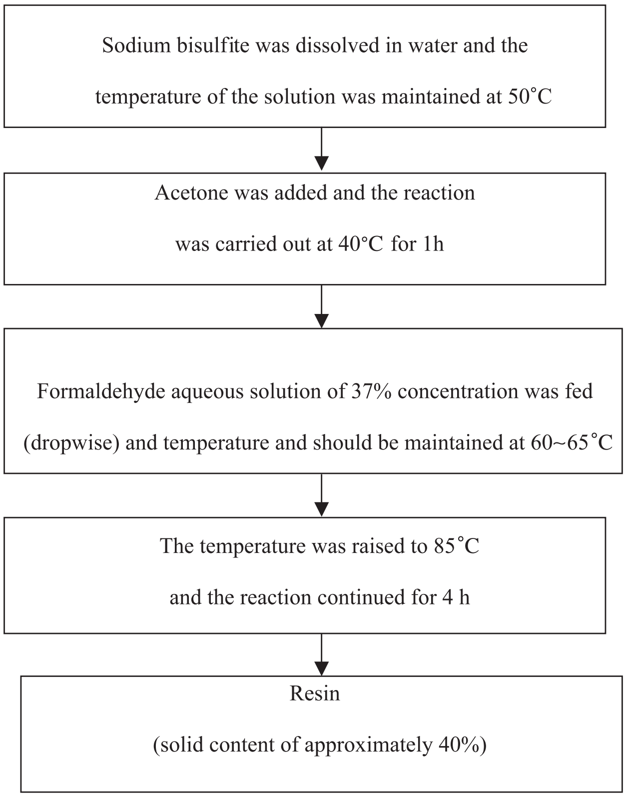

Fig. 1. Synthetic process of SAF resin.

40 °C and acetone was added. Then the reaction was carried out at 40 °C for 1 h. Formaldehyde aqueous solution of 37% concentration was fed into the reactor through a dropping funnel. During the feeding process, the temperature of the reaction automatically increased and had to be maintained at 60–65 °C. The reaction continued at 60–65 °C for another 1 h when the feeding of formaldehyde finished. The temperature was raised to 85 °C and the reaction continued for 4 h. After cooling, the resin prepared according to the above procedure has a solid content of approximately 40% and the final pH of the red-brown solution is above 12. The synthetic process is shown in Fig. 1.

2.2. Adsorption property

Adsorption amount was measured by determining the adsorption ratio of dispersants on $CaCO_3$ particles with the amount of dispersant added at a constant contact time (30 min) in $CaCO_3$–H_2O system ($W/CaCO_3 = 2.0$) [5]. In this test, the adsorption rate and amount of dispersant were measured using ultraviolet spectrophotometry and determined by Eq. (1):

$$\text{Adsorption concentration } (C_A) = \text{initial concentration } (C_I) - \text{residual concentration } (C_R) \quad (1)$$

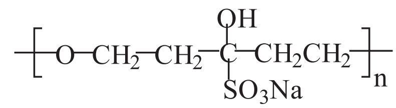

Fig. 2. The molecular structure of SAF resin.

2.3. Materials

The cement used is normal 525# Portland cement, fine aggregate siliceous sand with a fineness modulus of 2.70 and specified grading, and coarse aggregate crushed stone (MS = 20 mm) with specified grading. The chemical structure of SAF resin is shown in Fig. 2.

2.4. Mix proportion of concrete

Mix proportion of concrete is given as follows: cement:sand:gravel = 1:2.16:3.54, cement = 330 kg/m^3, slump = 8 ± 1 cm, air content < 4.5%.

2.5. Preparation and test of concrete

Preparation and test of concrete were performed according to GB8076-1997.

2.6. Gel permeation chromatography (GPC) measurements

The molecular weight (MW) of resin was determined with GPC measurements. The samples were analyzed using a 0.1 M KCl/methanol aqueous solution as an eluant, at a flow rate of 1 ml/min. Monodispersed polystyrene sulfonate of different MWs were used as calibration standards.

3. Results and discussion

3.1. Adsorption property

Fig. 3 shows the adsorption amounts of various weight-average MW SAF resins on the surface of $CaCO_3$ particles

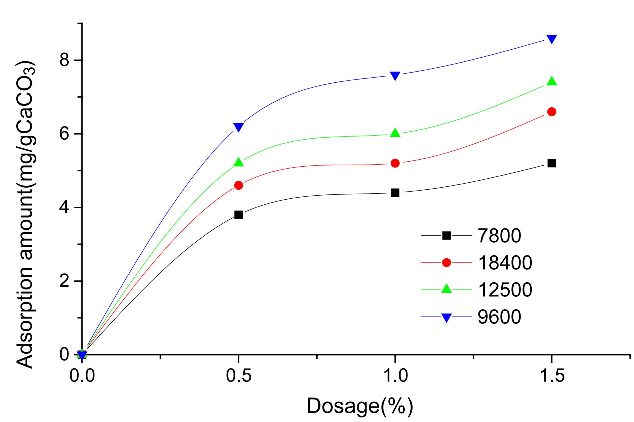

Fig. 3. Adsorption amount changes of various weight-average MW resins with the increase of resin in $CaCO_3$ suspension ($W/CaCO_3 = 2.0$; contact time = 30 min).

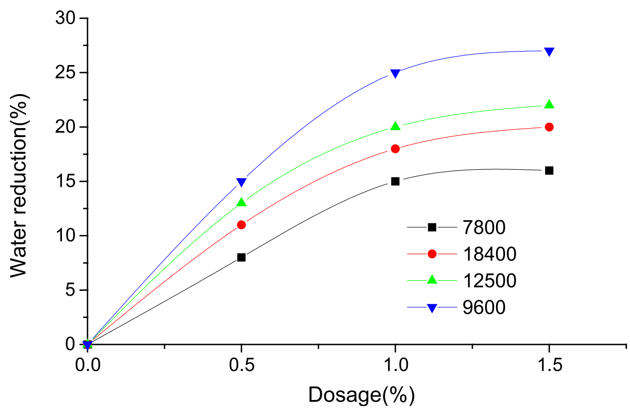

Fig. 4. Water reduction of various weight-average MW resins with the increase of resin.

when the amount of dispersants added increases from 0.5 to 1.5 wt.%, respectively. The adsorption amount of the dispersant onto cement particles is generally determined by the functional groups in its molecule and its MW. Generally, the adsorption amount increases with the increase of MW in an adequate time. Fig. 3 shows that the resin with 9600 weight-average MW has higher adsorption amount than those with over 9600 weight-average MW. This is because bigger molecules have lower moving speed and it is difficult for them to attain equilibrium in a short time.

3.2. Water reduction in concrete

Fig. 4 shows the effect of MW of the SAF resins on their water reduction. As expected, the water reduction increases with increasing MW of the synthesized polymer. Apparently, the trend in the figure is similar to that in Fig. 3. The observed higher water reduction for the higher degree of polymerization is attributed to greater negative charges on the cement surface and, therefore, stronger electrostatic repulsions generated among solid particles [14]. The optimum MW for the superplasticizer in achieving the best plasticizing effects is about 9600. For SAF resin with MW above the optimum value, the water reduction begins to decrease because of the occurrence of flocculent interactions [15]. At a 1.5% dosage, except for low-MW polymer, the water reduction ratios of all polymers are higher than 18%, which is one of the criteria of superplasticizer defined in China.

3.3. Slump loss of the superplasticized concretes

The evaluation of slump loss is important for field application. A lower degree of slump loss will prolong the time available for transporting, handling, and placing of concrete. Table 1 shows the slump loss of SAF superplasticized concrete with synthesized superplaticizer (MW = 9600) at 1.0% dosage. Generally, the slump of superplasticized concrete first slightly decreases with time, and then decreases a bit quickly. The SAF superplasticized concrete maintains more than 70% of the initial slump values for about 120 min, so the SAF resin has excellent capability of slump loss control and is more suitable for preparation of pumping concrete.

Table 1
The slump loss of the SAF superplasticized concrete with the time elapsed

Time (min)	0	30	60	90	120
Slump (cm)	22.3	21.5	20.3	18.4	15.8

Table 2
The compressive strength of plain concrete and SAF superplasticized concrete at 3, 7 and 28 days

	W/C	Slump (mm)	3-Day compressive strength (MPa)	7-Day compressive strength (MPa)	28-Day compressive strength (MPa)
Plain	0.65	83	19.2	34.0	41.8
SAF-7800	0.56	80	23.8	37.4	44.6
SAF-9600	0.49	81	27.8	42.6	49.2
SAF-12500	0.53	82	26.6	40.2	47.0
SAF-18400	0.54	82	25.2	38.6	45.2

Cement:sand:gravel = 1:2.16:3.54.

3.4. Compressive strength of concrete

Table 2 shows the effect of MW of the SAF resins on the compressive strength of concrete cured for 3, 7, and 28 days. The compressive strength also rises with increasing concentration or MW of SAF resin. The maximum value also occurs at an MW of about 9600. It is apparent that the compressive strength of concretes treated with the synthesized superplasticizers with different MW is higher than that of untreated concrete due to the plasticizing effect of synthesized SAF resins.

4. Conclusions

Water-soluble SAF resins were synthesized by the reaction among acetone, formaldehyde, and sodium bisulfite. The synthesized SAF resins could reduce the water content, improve the workability and compressive strength of concrete, and maintain more than 70% of initial slump after 120 min. The results indicate that the MW of SAF resins is a key factor to the plasticizing efficiency: resin with MW of about 9600 is more effective in promoting concrete properties in terms of workability, slump loss control, and compressive strength. Thus, SAF resin has the potential to be used as a superplasticizer in concrete.

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