Pergamon

Cement and Concrete Research 29 (1999) 255–259

CEMENT AND CONCRETE RESEARCH

The effects of sulphonated phenolic resins on the properties of concrete

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Manuscript received 10 December 1997; accepted manuscript 14 April 1998

Abstract

A water-soluble sulphonated phenolic resin (SPF) was synthesized from phenol, formaldehyde and sodium bisulfite through a four-step reaction. The synthesized SPF could reduce the water content, improve the workability and compressive strength of concrete. The best results were obtained for concrete containing 2 wt% SPF, which are comparable with commercial superplasticizers. Thus, SPF has the potential to be used as a superplasticizer.

Keywords: Chemical admixture; Sulphonated phenolic resin; Workability; Compressive strength; Concrete

High performance concrete (HPC) is a novel construction material, which exhibits higher workability, greater mechanical properties, and better durability than the conventional concrete. Currently, this new material has been applied in the construction such as tall buildings, bridges and off-shore structures [1]. One key for successful preparation of HPC is the addition of superplasticizers of proper mix design and mixed sufficiently. Sulphonated melamine formaldehyde condensates (SMF) and sulphonated naphthalene formaldehyde condensates (SNF) are two well-established commercial superplasticizers. It is reported that these admixtures exhibit very good dispersing effects on concrete, and can reduce water demand of concrete by up to 30% while still maintaining the flow characteristics of concrete. This has led to the development of very low water/cement (W/C) ratio HPC which exhibits very high compressive strength [2,3].

Because chemical admixtures have industrial importance in concrete technology, it is essential to evaluate and to learn how to apply them in concrete. Besides, the development of a new one is also very worthwhile. In our laboratory, a water-soluble sulphonated phenolic resin (SPF) has been synthesized [4]. This water-soluble polymer was found to act as a dispersion agent and allows the hydration reaction within material be carried out more uniformly. It could also have some interactions with the hydrated products [5]. Consequently, an improvement in workability and compressive strength of concrete was expected and will be described in the following.

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1. Experimental

1.1. Materials

Type I portland cement, river sand, and river gravel (from midwest Taiwan) were used. Properties of cement and aggregates are given in Tables 1 and 2, respectively. SPF samples were synthesized from phenol, formaldehyde, and sodium bisulfite in a proper ratio via addition, sulphonation, condensation, and rearrangement reactions, using preparation procedure described elsewhere [4]. In addition, two commercial superplasticizers, i.e., SNF and SMF were also used for comparison. The properties of these admixtures and the chemical structure of SPF are shown in Table 3 and Fig. 1, respectively.

1.2. Preparations of concrete

Concrete mixes containing chemical admixture (0–2%) were prepared at three different W/C ratios (i.e., 0.30, 0.36, and 0.42). The mix proportions of concrete are listed in Table 4.

1.3. Workability test

The workability of concrete was indicated by the slump value of the material measured in a slump test according to ASTM C143.

1.4. Compressive strength test

Concrete specimens of 10ϕ × 20 cm were prepared, cured, and tested at the ages of 3, 7, and 28 days according to ASTM C39.

PII: S0008-8846(98)00098-2

Table 1
Properties of cement

Component	wt%
SiO_2	20.49
Al_2O_3	6.57
Fe_2O_3	3.27
CaO	62.40
MgO	1.91
SO_3	2.20
f-CaO	1.03
Ignition loss	1.57
Specific surface area	3013 cm^2/g
Specific gravity	3.14 g/cm^3

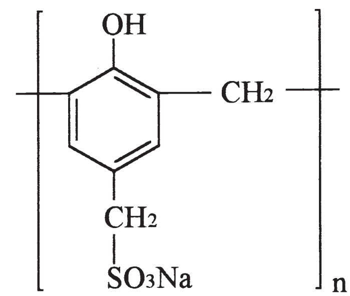

Fig. 1. The chemical structure of SPF resin.

Table 2
Properties of aggregates

Property	Coarse aggregate	Fine aggregate
Specific gravity, g/cm^3	2.63	2.63
Unit weight, kg/m^3	1573	—
Fineness modulus	6.47	3.07
Absorption capacity, %	0.95	2.13
Maximum size, mm	19.1	5.6

1.5. Gel Permeation Chromatography (GPC) measurements

The molecular weight of resin was determined from GPC measurements which were carried out with a Jasco liquid chromatography equipped with two coupled columns Shodex OHpak KB802.5 and KB804, a pump (Jasco PU-980) and a UV detector (Jasco UV-970) at a wavelength of 254 nm. The samples were analyzed using an 0.1 M KCl/methanol (80/20) aqueous solution as an eluant, at a flow rate of 1 ml/min. Monodispersed polystyrene sulphonates of different molecular weights were used as calibration standards.

2. Results and discussion

2.1. Water reduction in concrete

The chemicals to be used as water-reducing admixtures should allow a reduction in the water/cement (W/C) ratio at a given workability without significantly affecting the setting characteristics of the concrete [2]. The requirements of the water reduction percentage of different types of chemical admixtures are specified in ASTM C494. Table 5 gives the water reduction percentage of SPF and other two commercial superplasticizers (SNF and SMF) at two different W/C ratios. The weight-average molecular weights (Mw) of SPF, SNF, and SMF under study, unless specified otherwise, are 13000, 2000, and 40000, respectively. Apparently, the percentage value increases with the W/C ratio. Higher SPF dosage results in greater water reduction. Concrete with 2% SPF has 29% water reduction which is more than the value specified for either type F (superplasticizers) or type G (retarding superplasticizers) according to ASTM C494. Furthermore, this value is lower than that of SNF, but greater than that of SMF.

Table 3
Properties of chemical admixtures

	Chemical admixture		
Property	SPF	SNF	SMF
Appearance	Brown liquid	Dark brown liquid	Clear liquid
Solid content, %	35	46	33
Viscosity, cp*	2.1	2.5	5.9
Specific gravity, g/cm^3	1.18	1.21	1.14

* Viscosity of 20% Resin Solution, which was measured by a Brookfield DV-II viscometer.

Table 4
Mix proportions of concrete

Water/cement	0.30		0.36		0.42
Water, kg*	1.65		1.99		2.32
Cement, kg	5.51		5.51		5.51
Fine aggregate, kg	7.52		7.52		7.52
Coarse aggregate, kg	6.23		6.23		6.23
Admixture/Cement, wt %	0.0	0.5	1.0	2.0	3.0
Admixture, g†	0.0	27.5	55.0	110	165

*Including admixtures.
† Based on 100% solid content.

Table 5
Water reduction percentage by chemical admixtures

Admixture	SPF	SNF	SMF
Admixture/cement (w/c = 0.36)			
0.5%	2.1	8.4	11.1
1.0%	7.9	23.3	15.5
2.0%	20.8	22.6	19.0
Admixture/cement (w/c = 0.42)			
0.5%	6.4	15.0	20.0
1.0%	15.0	33.0	23.0
2.0%	29.0	32.0	26.5

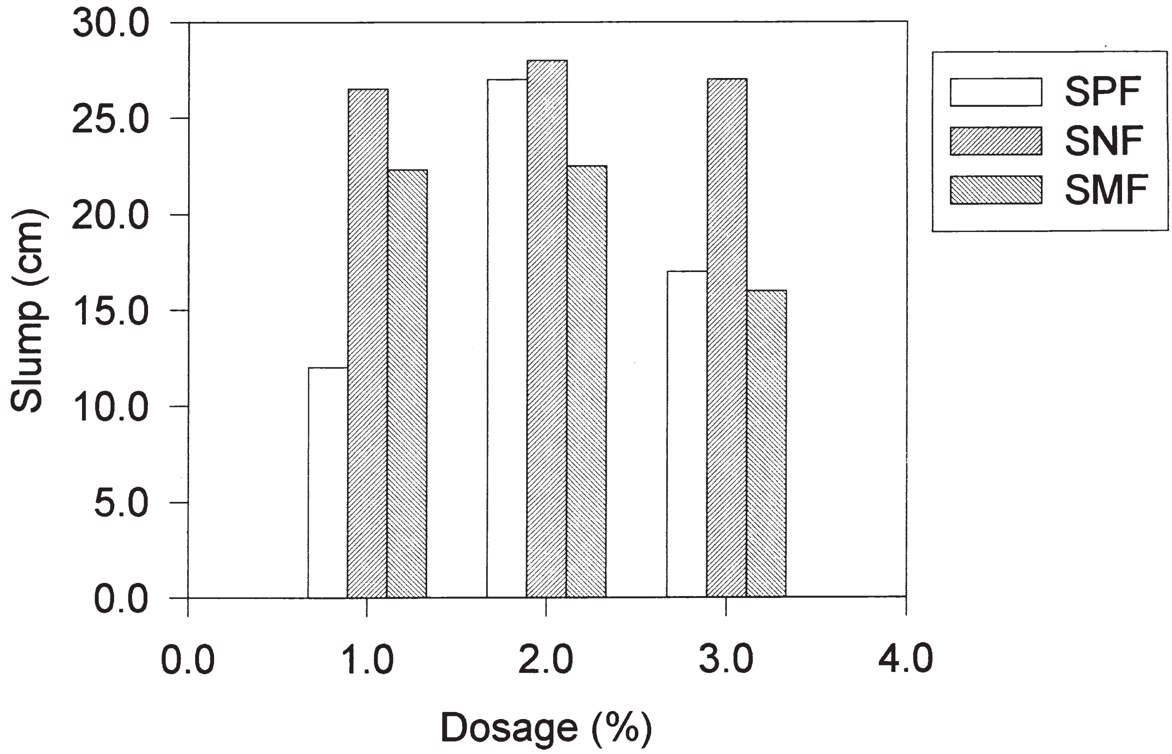

Fig. 2. Effect of chemical structures on the slump of concrete (W/C = 0.3).

2.2. Workability of concrete

Increasing the workability of concrete with low W/C ratio is one major function of chemical admixtures. Usually, the workability of concrete is indicated from the measured slump of the material. Figs. 2–4 give the test results of the effect of dosage of different chemical admixtures on the slump of concrete. There is almost no slump for concrete without admixtures at such low water:cement ratio (W/C = 0.3). Fig. 2 shows that the slump value of concrete increases with the dosage of admixtures up to 2%, and then decreases subsequently. It was reported that the performance of chemical admixtures would depend on their molecular weights [6,7]. The slump value of SPF-containing concrete was also found to be molecular weight-dependent, as is shown in Fig. 3. SPF with Mw about 3×10^4 appeared to be most effective in enhancing the workability of concrete. Furthermore, at 2% dosage, except for low molecular weight polymer, the slump values of all concrete are greater than 25 cm, which is one of the criteria of HPC defined in Taiwan [8]. Finally, SPF presents similar dispersing effect to the commercial

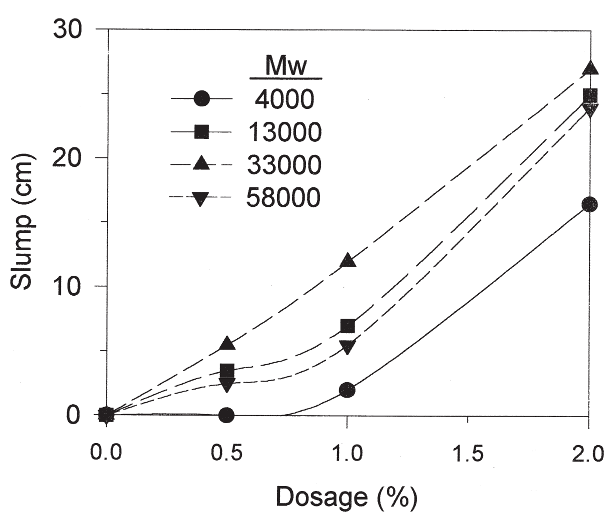

Fig. 3. Effect of SPF dosage on the slump of concrete (W/C = 0.3).

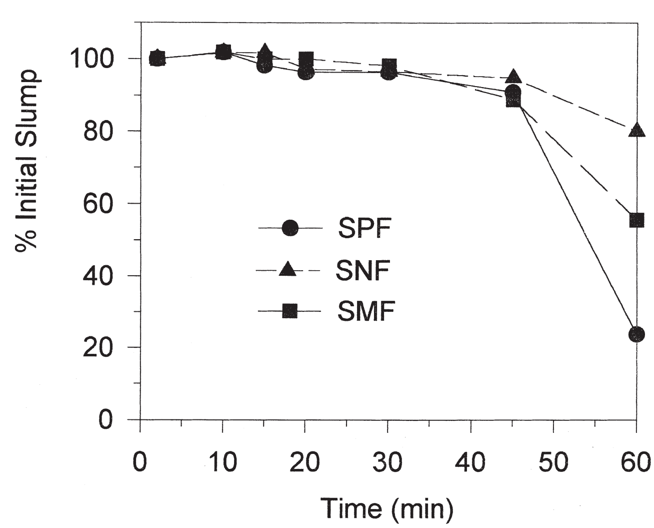

Fig. 4. Effect of chemical structures on the slump loss of concrete (W/C = 0.36).

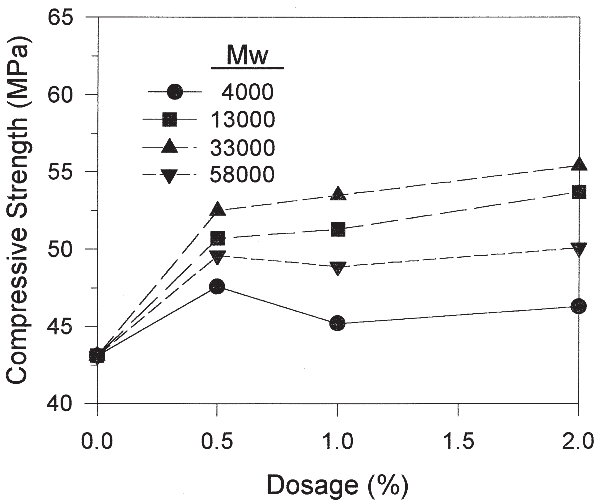

Fig. 5. Effect of SPF dosage on the compressive strength of concrete (W/C = 0.3).

SNF or SMF (see Fig. 2). Apparently, SPF seems to be more dosage-sensitive. This might be related with different chemical structures of admixtures.

The evaluation of slump loss is important for field applications [2]. A lower degree of slump loss will prolong the time available for transporting, handling and placing of concrete. Fig. 4 compared the slump loss of concrete (W/C = 0.36) with different admixtures at 2% dosage. The initial slump of all admixture-containing concrete is about 27–29 cm. Generally, each admixture-containing concrete exhibits similar behavior: the slump of concrete first slightly increases with time, maintains more than 90% of the initial slump values for about 45 minutes, and then decreases very quickly. However, the slump loss rates are different. Again, this is probably due to be different chemical structures of admixtures.

2.3. Compressive strength of concrete

Fig. 5 is the effect of SPF dosage on the compressive strength of concrete (W/C = 0.3) cured for 28 days. Apparently, the trend in this figure is similar to that in Fig. 3. The compressive strength of concrete without admixtures present is about 43 MPa. The strengh value will increase when chemical admixtures were added and it increases with the dosage. As molecular weight increases, the compressive strength of concrete increases first, reaches a maximum value, and then decreases afterwards. The maximum value also occurs at Mw about 3×10^4. The difference is that the effect of dosage on slump is more significant than that on compressive strength. The improvement in the properties such as slump and compressive strength can be attributed to the dispersion effect of SPF in concrete. Besides, this dispersion effect is more influential on the workability than the mechanical property of concrete. Finally, the slump and compressive strength of concrete with SPF were compared with those of concrete with either SNF or SMF present, as is shown in Fig. 6. It is clear that SPF exhibits similar performance in concrete to the other two.

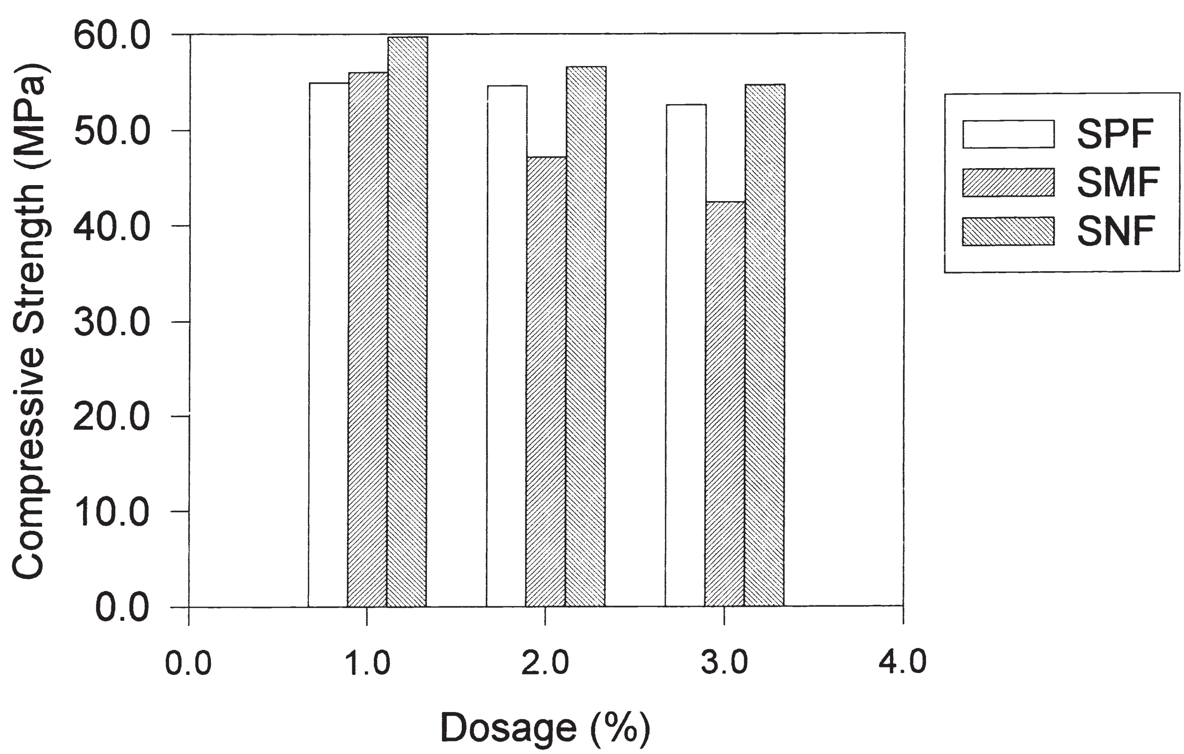

Fig. 6. Effect of chemical structures on the compressive strength of concrete (W/C = 0.3).

3. Conclusions

A water-soluble phenolic resin was synthesized and evaluated for its performance in concrete. It was found that SPF could reduce the water content, promote the workability and increase the compressive strength of concrete. Concrete containing 2 wt% SPF exhibits the best results, which are as effective as those of commercial superplasticizers such as SNF and SMF. Therefore, SPF has the potential to be developed as a superplasticizer.

Acknowledgment

The authors are grateful for the support of this work by the National Science Council of The Republic of China (Contract # NSC-86-2211-E-003-001).

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