

# EFFECT OF DIFFERENT TYPES OF SUPERPLASTICIZERS ON FRESH PROPERTIES AND STRENGTH OF SELF-CONSOLIDATING CONCRETE

Ali Mardani-Aghabaglou<sup>1\*</sup>, Murat Tuyan<sup>1</sup>, Gökhan Yılmaz<sup>2</sup>, Ömer Ariöz<sup>3</sup> and Kambiz Ramyar<sup>1</sup>

<sup>1</sup> Ege University, Department of Civil Engineering, Izmir, TURKEY.

<sup>2</sup> Draco Construction Chemicals Company, Izmir, TURKEY.

<sup>3</sup> Çim-Beton Ready Mixed Power Plant, Izmir, TURKEY.

\*: corresponding author. ali.mardani16@gmail.com

## ABSTRACT

*The effect of different types of superplasticizers on fresh properties and strength of self-consolidating concrete (SCC) was investigated. For this purpose, four mixtures containing different superplasticizer types were prepared. The admixtures had same main chain and same polymer structure but different molecular weight and different side chain density of carboxylic acid groups. The slump-flow, V-funnel, slump-flow loss and L-box tests of SCC mixture were determined. In addition, the compressive strength of SCC mixtures was determined at 1, 3, 7 and 28 day ages. Test results indicated that using the different types of superplasticizer affected the fresh properties of the SCC mixtures. It was observed that the compressive strength of SCC mixtures was also influenced slightly with the incorporation of different types of superplasticizers. The effect was more pronounced at early ages.*

**Keywords:** self-consolidating concrete; superplasticizer; side chain density; strength

## INTRODUCTION

Self-consolidating concrete (SCC) is a special type of highly flowable concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely fill formwork and achieve full compaction, even in the presence of congested reinforcement. SCC is a new variety of high performance concrete with superior deformability and segregation resistance. The mechanical properties and

durability of SCC are highly affected by its fresh properties, such as flowability, filling ability etc. [1-3]. The high flowability of SCC is commonly achieved by using superplasticizer, not by adding extra mixing water. Besides, superplasticizers used in SCC contribute many fresh and hardened properties of the mixture [4,5].

Nippon Shokubai and Nippon Master Builder Technology invented the polycarboxylate superplasticizer (PC) in the middle of the 1980's in Japan. PC is synthesized from petrochemical products and widely used in concrete in recent years, especially to produce SCC. It is composed of three essential parts: a backbone of polyethylene, grafted chains of polyoxyethylene (POE) and carboxylic groups as adsorbing functional groups. The dispersion mechanism of PC-based superplasticizers is more related to a steric hindrance effect (produced by the presence of neutral side long graft chains) rather than to the presence of negatively charged anionic groups ( $\text{COO}^-$ ), which are responsible for the adsorption of the polymers on the surface of cement particles [6]. The chemical structure modifications of PC-based superplasticizers include charge density differentiation, side chain length, main backbone length, degree of backbone polymerization and composition of functional groups [7-9].

In this study, the effects of four types of polycarboxylate ether-based superplasticizer admixtures having same main chain and same polymer structure but different molecular weight and different side chain density of carboxylic acid groups on the fresh properties as well as compressive strength of SCC were investigated.

## **EXPERIMENTAL PROGRAM**

In this study, a CEM II B-M (L/W) 42.5 R type cement conforming to EN 197-1 standard [10], crushed limestone aggregate with maximum size of 15 mm, limestone powder as filler and four different types of polycarboxylic ether-based superplasticizer admixtures (SP) were used. The admixture used in this study had same main chain and same polymer structure but different molecular weight and different side chain density of carboxylic acid groups. The chemical compositions, as well as some mechanical and physical properties of the cement and some properties of SP, obtained from their manufacturers are given in Table 1 and 2, respectively.

The specific gravity and water absorption capacity of the crushed aggregate limestone with two different particle sizes, e.g. 0-5 mm and 5-15 mm used in the experiments, were determined in accordance with EN 1097-6 standard [11]. The physical properties of aggregates are presented in Table 3. The gradation of the combined aggregate obtained by mixing 50% 0-5 mm and 50% 5-15 mm aggregate size fractions as well as standard gradation limits are shown in Figure 1.

Table 1. Chemical and physical properties of cement

Oxide	(%)	Physical properties		
SiO <sub>2</sub>	20.52	Specific gravity		2.97
Al <sub>2</sub> O <sub>3</sub>	6.46	Soundness (mm)		0.5
Fe <sub>2</sub> O <sub>3</sub>	3.31	Setting time (min)	Initial	180
CaO	57.45		Final	275
MgO	1.54	Fineness		
K <sub>2</sub> O	0.88	Blaine specific surface (cm <sup>2</sup> /g)		4590
Na <sub>2</sub> O	0.44	Residual on 0.090 mm sieve (%)		0.3
SO <sub>3</sub>	3.13	Residual on 0.032 mm sieve (%)		9.2
Cl-	0.01	Mechanical properties		
Free CaO	2.02	Compressive strength (MPa)	2 Day	32.1
LOI	3.8		7 Day	46.3
<b>Total</b>	<b>99.56</b>		28 Day	55.2

Table 2. Properties of polycarboxylate ether based superplasticizer admixtures

	A	B	C	D
Appearance	slightly yellowish liquid	slightly yellowish liquid	slightly yellowish liquid	slightly yellowish liquid
pH, 25 °C	6.2	6.03	6.0	6.86
Density, (g/cm <sup>3</sup> )	1.116	1.097	1.073	1.116
Mass average molecular weight (Mw)	50000	42000	48000	42000
Side chain density of carboxylic acid groups	1:5	1:3	1:4.5	1:6
viscosity cP, impeller rotational velocity (rpm)	896 cP, 20	265 cP, 100	256 cP, 100	940 cP, 30

Table 3. Physical properties of aggregates

Aggregate		Bulk SSD specific gravity	Absorption capacity (%)	Loose bulk density (kg/m <sup>3</sup> )
Type	Size (mm)			
Limestone	0-5	2.60	0.21	1740
	5-15	2.65	0.67	1505

Four SCC mixtures (incorporating four different types of superplasticizer admixtures) with water/cement ratio of 0.4 and slump flow of 730±10 mm were prepared. In all of the mixtures 450 kg/m<sup>3</sup> CEM II B-M (L/W) 42.5 R type cement was used. In order to achieve required slump flow the superplasticizer content of the mixtures was adjusted in the range of 5.5 to 7.5 kg/m<sup>3</sup>. During mixing the aggregates were placed in the laboratory paddle type mixer then the cement was added. The materials were

mixtures in the dry state for 1 min. A part of admixture was mixed with water and added to the mixture gradually while the mixer was rotating. In order to achieve the required slump flow value additional admixture (if any) was introduced in the mixer finally. The proportions of SCC used in this study are listed in Table 4.

Figure 1. Gradation curve of combined aggregate and TS 802 [12] standard limits

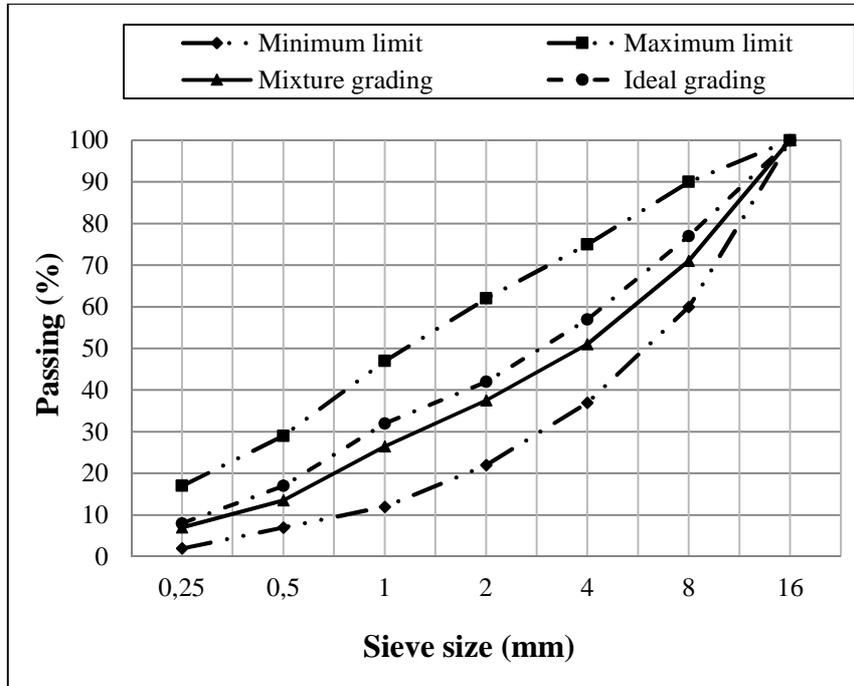


Table 4. Mix proportions of the SCC mixtures (kg/m<sup>3</sup>)

Mixture	Cement	Water	L.P**			SP***	Unit Weight	
			0-0.125 (mm)	0-5 (mm)	5-15 (mm)		Theoretical	Measured
A*	465	186	173	793	793	6.6	2338.4	2416.6
B*	459	183	171	783	783	6.1	2338.0	2385.1
C*	461	184	172	786	786	5.7	2337.6	2394.7
D*	442	177	165	754	754	7.4	2339.5	2299.4

\*Incorporating four different types of super plasticizer admixtures whose polymer chains and structures were modified, \*\*LP: Limestone powder as filler, \*\*\*SP: Superplasticizer admixture.

The fresh properties of SCC mixtures were determined by using the slump-flow, V-funnel and L-box tests in accordance with EFNARC [13] and slump-flow loss after 15 and 30 mins. The 1, 3, 7 and 28-day compressive strength of mixtures were determined on 150 mm cubic specimens which were demolded after 24 h and stored in a moist room under water at 23±2°C until the testing day.

## TEST RESULTS AND DISCUSSION

The fresh properties of all SCC mixtures are summarized in Table 5. The slump flow values were kept constant in the range of  $730 \pm 10$  mm by changing the dosage of the superplasticizer. It was found that, for a given slump flow value, Mix C and Mix D required the minimum and the maximum superplasticizer dosage, respectively. In all of the SCC mixtures, V-funnel flow times were determined in the range of 27-47 seconds. V-funnel flow time is related to viscosity and cohesiveness of the mixtures [13]. As expected, V-funnel flow times decreased with increasing superplasticizer dosage. This may be in part due to difference between side chain density of carboxylic acid groups of the admixtures and in part due to the admixture dosage. For example, Mix D containing the admixture with the highest side chain density and the highest dosage among the other mixtures showed the lowest V-funnel flow time. V-funnel flow time increased with decreasing side chain density of carboxylic acid groups. Houst et al. [14] stated that steric effect is influenced by the backbone chain length, the side chain length and spacing of side chains. The V-funnel flow times of Mix A, B and C, decreased with increasing molecular weight of the superplasticizer. Uchikawa et al [15] found similar results.

In the L-box test, H2/H1 ratios of Mix B and D were lower than 0.80 (lower limit of EFNARC standard) indicating their lower passing-ability compared to the other mixtures.

Table 5. Fresh properties of concrete mixtures

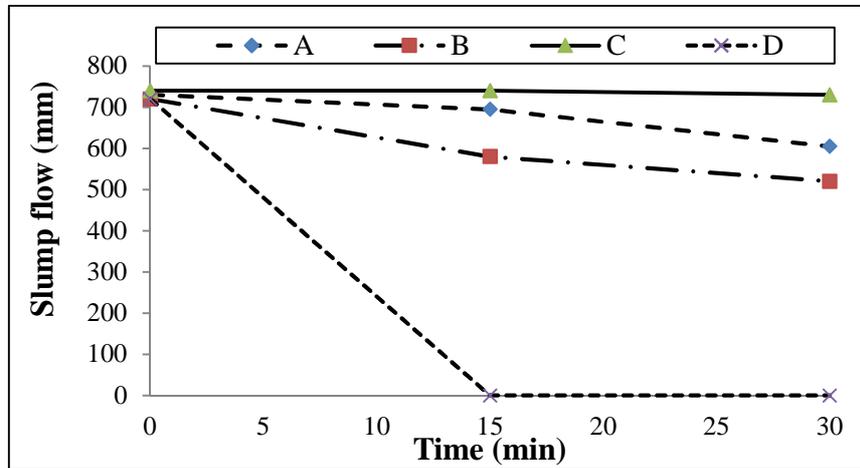
Mix	Slump flow (mm)	L-Box			V-Funnel (s)	SP (w% of cement)
		20 cm (s)	40 cm (s)	H2/H1		
A	730	2	5.5	0.95	40	1.42
B	720	2.5	6.5	0.76	47	1.33
C	740	1.5	5	0.90	44	1.24
D	720	1	3	0.58	27	1.67

As emphasized in the V-funnel flow time test results, as side chain density of carboxylic acid groups increased, causing an increase in steric hindrance, V-funnel time of the mixtures decreased. For example, the superplasticizer used in Mix B had minimum side chain density, thus, showed the greatest V-funnel time among the admixtures.

The slump values of the SCC mixtures at 0, 15 and 30 minutes are shown in Figure 2. When the slump loss values of Mix A, B and C are compared, it becomes obvious that Mix C showed roughly no slump loss within 30 minutes. This may be attributed to the lower side chain density of the superplasticizer. However, there was a slight reduction in slump flow of the Mix A and Mix B within this period. Mix D had no slump retention beyond 15 minutes. This indicates that the superplasticizer and cement used in this mixture are incompatible. The incompatibility may be arisen from the higher amount of side chains of the polymer which may in turn increase the risk of flocculation of

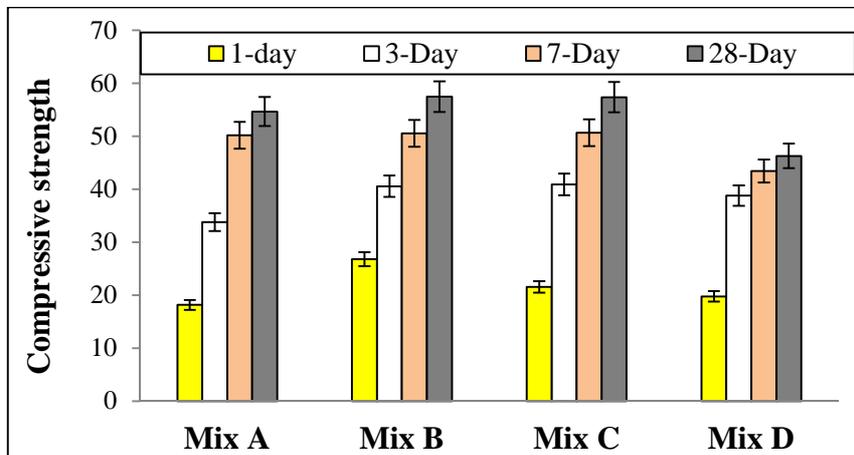
cement particles. Similar results are reported in the case of admixtures having extremely long side chains [16].

Figure 2. Slump flow values at different times



The compressive strengths of SCC mixtures at different ages are shown in Figure 3. Each value presented is the average of three measurements. As it can be seen from Fig. 3, as the slump loss of mixture increased, the rate of stiffening and consequently the rate of hardening of the mixtures seem to be increased. Thus, the early strength of the mixture increased. However, although Mix D has the highest slump loss among the mixtures, it showed the lowest compressive strength. This may be arisen from the fact that there was no enough time to consolidate the Mix D due to very rapid slump loss of the mixture. The same observation was made regarding the unit weights of the hardened mixtures. Mix D with  $2299 \text{ kg/m}^3$  showed the lowest unit weight value among the mixtures. However, except for Mix D, the effect of superplasticizer type on the compressive strength of SCC mixture diminished at the ages beyond 7 days.

Figure 3. Compressive strength of SCC at different ages



## CONCLUSIONS

In this experimental study, the effects of four type of polycarboxylate ether-based superplasticizer admixtures having same main chain and same polymer structure but different molecular weight and different side chain density of carboxylic acid groups on the fresh properties and compressive strength of SCC were investigated. The following conclusions were drawn:

1. V-funnel flow time of SCC mixtures decreased with increasing side chain density of carboxylic acid groups of superplasticizer admixture.
2. As the amount of side chains of the polymer increased, the slump retention of the cementitious system decreased. This may be due to the interlocking of the side chains.
3. When the admixture and the cement were compatible, the early strength was dependent on the type of admixture whereas at the ages beyond 7 days the strength became independent of the admixture type. The admixture causing the highest slump loss caused the highest concrete strength at early ages.

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