Available online at www.sciencedirect.com
SCIENCE DIRECT®
Cement & Concrete Composites 27 (2005) 217–222
Cement & Concrete Composites
www.elsevier.com/locate/cemconcomp

Influence of superplasticizer type and mix design parameters on the performance of them in concrete mixtures

I. Papayianni *, G. Tsohos, N. Oikonomou, P. Mavria

Department of Civil Engineering, Aristotle University of Thessaloniki, 54 124 Thessaloniki, Greece

Abstract

The use of superplasticizers in concrete manufacture was a milestone in the history of concrete, and this played a central role in the development of high strength and performance concrete. Superplasticizers are admixtures, which are added to concrete mixture in very small dosages. Their addition results in significant increase of the workability of the mixture, in reduction of water/cement ratio or even of cement quantity. Their performance depends on the type of the superplasticizer, the composition of the concrete mixture, the time of addition and the temperature conditions during mixing and concreting.

Measurements of workability, slump loss, air content, as well as of strength development have been made to reach a conclusion about superplasticizers performance with the use of two kinds of aggregate: one natural (river) and one crushed limestone. Apart from this, it seems that the quantity of fines in a mixture influences the performance of superplasticizers.

Keywords: Superplasticizers; Performance; Concrete mixture; Proportions

1. Introduction

The use of superplasticizers in concrete began in the 1960s and was a milestone in concrete technology and the field of construction [1]. In this way the production of concrete of high performance and durability was achieved, because adding, superplasticizers high workability remained at a very low ratio of w/c. The superplasticizers are poly-electrolytes of organic origin, which function like the dispersing chemical media in heterogeneous systems.

The naphthalene—formaldehyde sulphonate is the most well known superplasticizer. It is generally acceptable that lignosulfonic superplasticizers in high dosages result delaying the curing of concrete. Another group of reactive superplasticizers are based in sulfonated products of synthetic polymers (e.g. SNF, naphthalene or SMF, melamine). These materials result in a higher decrease of required water and so higher strengths are achieved. The family of superplasticizers which are based in polycarboxylic products are more recent (1980s). These materials are of higher reactivity, they do not contain the sulfonic group and they are totally ionized in alkaline environment. The superplasticizers of high reactivity, which in high dosages do not have the side-effect of delaying the curing of concrete, made the production of concrete with a big volume of fly ash or slag possible [2].

As it is known the superplasticizers increase the workability of a mixture very much. However, this increase is not retained for more than 30–60 min. There are various ways (addition of admixtures during the placement or in doses) in which workability can be retained for longer time. The type of the admixture also seems to affect the loss of slump [3,4].

Although the superplasticizers do not react by a chemical action on hydrated products, they affect the microstructure of cement gel and concrete. The porosity and the bleeding decrease significantly and, on a second level, the drying shrinkage and creep deformations. Thus, beyond the increase of strength, there is also an increase of the durability of concrete with the use of superplasticizers [5,6].

2. Experimental part

Three types of modern superplasticizers were checked in mixtures of concrete with local materials. The first

* Corresponding author. Tel./fax: +30-310-995699.
E-mail address: papayian@civil.auth.gr (I. Papayianni).

0958-9465/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconcomp.2004.02.010

type (code S1) is based on water diluted sulfonated polymers of high relative density and alkalinity, and it is recommended for mixtures of low ratio of water/binder. The second type (code S2) is based on synthetic polymers, it is of low relative density and alkalinity (pH 6–8), and it is recommended for cases where retaining workability for a long time is required. The third type (code S3) is based on modified polycarboxylic ether, it is of low relative density and it is recommended for high decrease of required water and retaining workability for a long time. All types comply with the relative specifications ASTM C494 and ASTM C1017. The most important characteristics of the admixtures appear in Table 1.

Among the parameters which affect the performance of the admixtures, the following ones were studied:

Dosage of admixture. Three dosages (1%, 1.5%, 2% per weight of cement) were checked for every type of superplasticizers.

Type and gradation of aggregates. Each dosage for the admixtures mentioned above was used in mixtures of concrete with natural river aggregates of two gradations (a) 0–8 mm and (b) 0–31.5 mm. In both gradations the choice of the participating fragment of aggregates (0–4, 8–16 and 16–31.5 mm) was made according to the criterion that the gradation curve of the final aggregate mix should be in the limits of the gradation curves which are proposed by Greek "Standards of Concrete Technology". In two gradations, (c) 0–8 mm and (d) 0–31.5 mm, crushed aggregates from the quarry of Drimos, Thessaloniki were also used for all dosages. The gradations of the participated fragments of aggregates and their ratio in the final mixtures appear in Tables 2 and 3. It is also noticed that the used aggregates were cleared off the fine material <0.25 mm.

Cement of type I42, 5N was used in two percentages and its composition is given in Table 4. Cement was added to the mixture with 0–8 mm aggregates (river or limestone ones) at an amount of 420 kg/m^3, which corresponds to the category of high performance concrete.

Cement was added to the mixture with 0–31.5 mm aggregates at an amount of 320 kg/m^3, which corresponds to the category of medium strength concrete, which is widely used in common structures.

Volume density, voids percentage and workability (measured by slump test) were checked in the mixtures, in order to clarify the influence of the type of superplasticizer as well as its dosage on loss of workability through time. The compressive strength of concrete in hardened condition was checked at 3, 7 and 25 days in cylindrical specimens of 15×30 cm. The characteristics

Table 2
Granulometric gradation of natural aggregates (Axios river)

Sieve (mm)	% Passing			
	0–4 mm	4–8 mm	8–16 mm	16–31.5 mm
31.5	100	100	100	100
16	100	100	100	33.42
8	100	100	67.08	0.27
4	97.38	33.04	0.77	0
2	77.32	1.28	0.12	0
1	55.11	0.75	0	0
0.5	23.11	0.65	0	0
0.25	1.02	0.24	0	0
0	0	0	0	0

Table 3
Granulometric gradation of natural crushed limestone aggregates (Drimos quarry)

Sieve (mm)	% Passing			
	0–4 mm	4–8 mm	4–16 mm	16–31.5 mm
31.5	100	100	100	100
16	100	100	100	30.39
8	100	100	24.13	0.19
4	99.92	36.56	0.56	0.18
2	53.62	12.49	0.38	0.17
1	24.42	9.15	0.36	0.15
0.5	9.01	7.4	0.3	0.13
0.25	0	5.97	0.24	0.1
0	0	0	0	0

Table 4
Chemical composition of Cement I42, 5N

Compound	In weight (%)
SiO_2	22.0
Al_2O_3	5.5
Fe_2O_3	2.4
CaO	62.5
MgO	2.9
SO_3	3.0
Cl	<0.01

Table 1
Characteristics of superplasticizers

Code no	Colour	Specific gravity (gr/m^3)	pH	Viscosity (cps)	Chlorides (%)
S1	Brown	1.23–1.25	7–9	–	0.0%
S2	Light Brown	1.02–1.08	6–8	100–200	<0.01%
S3	Brown	1.06	7	39 ± 5	0.0%

Table 5
Characteristics of mixtures with superplasticizers

Mixture	Percentage of SP on cement (%)	W/C	Loss of water (%)	Specific gravity (gr/cm^3)	Voids percentage (%)
Cement I42, 5N 420 kg/m^3	0	0.675		2.369	2.5
River aggregates	1	0.665	1.48	2.319	4.8
0–8 mm	1.5	0.576	14.67	2.231	3.5
Superplasticizer S1	2	0.365	45.93	2.219	3.6
Cement I42, 5N 420 kg/m^3	0	0.693		2.344	0.6
River aggregates	1	0.547	21.07	2.456	1.1
0–8 mm	1.5	0.519	26.12	2.481	1.0
Superplasticizer S1	2	0.468	32.47	2.519	0.28
Cement I42, 5N 320 kg/m^3	0	0.571		2.494	3.4
Crushed limestone aggregates	1	0.570	0.18	2.419	3.2
0–8 mm	1.5	0.527	7.71	2.394	2.5
Superplasticizer S1	2	0.492	13.84	2.356	2.4
Cement I42, 5N 320 kg/m^3	0	0.842		2.444	1.7
Crushed limestone aggregates	1	0.640	23.99	2.519	2.6
0–31.5 mm	1.5	0.578	31.35	2.544	2.2
Superplasticizer S1	2	0.515	38.84	2.544	2.1
Cement I42, 5N 420 kg/m^3	0	0.675		2.369	2.5
River aggregates	1	0.516	23.56	2.244	1.7
0–8 mm	1.5	0.432	36	2.294	1.0
Superplasticizer S2	2	0.316	53.19	2.231	0.15
Cement I42, 5N 420 kg/m^3	0	0.693		2.344	0.6
River aggregates	1	0.571	17.6	2.506	0.9
0–8 mm	1.5	0.529	23.67	2.494	0.8
Superplasticizer S2	2	0.523	24.42	3.081	0.5
Cement I42, 5N 320 kg/m^3	0	0.571		2.494	3.4
Crushed limestone aggregates	1	0.533	6.65	2.494	3.4
0–8 mm	1.5	0.505	11.56	2.394	3.2
Superplasticizer S2	2	0.481	15.76	2.356	3.0
Cement I42, 5N 320 kg/m^3	0	0.842		2.444	1.7
Crushed limestone aggregates	1	0.609	27.67	2.506	1.9
0–31.5 mm	1.5	0.538	36.1	2.556	1.75
Superplasticizer S2	2	0.515	38.84	2.594	1.65
Cement I42, 5N 420 kg/m^3	0	0.675		2.369	2.5
River aggregates	1	0.500	25.93	2.344	3.7
0–8 mm	1.5	0.427	36.74	2.306	3.4
Superplasticizer S3	2	0.409	39.41	2.191	3.2
Cement I42, 5N 420 kg/m^3	0	0.693		2.344	0.6
River aggregates	1	0.691	0.29	2.319	1.7
0–8 mm	1.5	0.576	16.88	2.344	0.6
Superplasticizer S3	2	0.458	33.91	2.519	0.4

(*continued on next page*)

Table 5 (*continued*)

Mixture	Percentage of SP on cement (%)	W/C	Loss of water (%)	Specific gravity (gr/cm^3)	Voids percentage (%)
Cement I42, 5N 320 kg/m^3	0	0.571		2.494	3.4
Crushed limestone aggregates	1	0.477	16.46	2.494	3.2
0–8 mm 0-31.5	1.5	0.471	17.51	2.494	3.0
Superplasticizer S3	2	0.457	19.96	2.506	2.9
Cement I42, 5N 320 kg/m^3	0	0.842		2.444	1.7
Crushed limestone aggregates	1	0.609	26.67	2.506	3.1
0–31.5 mm	1..5	0.531	36.94	2.594	2.8
Superplasticizer S3	2	0.503	40.26	2.596	2.2
Cement I42, 5N 420 kg/m^3	0	0.675		2.369	2.5
River aggregates	1	0.500	25.93	2.344	3.7
0–8 mm	1.5	0.427	36.74	2.306	3.4
Superplasticizer S3	2	0.409	39.41	2.191	3.2
Cement I42, 5N 420 g/m^3	0	0.693		2.344	0.6
River aggregates	1	0.691	0.29	2.319	1.7
0–8 mm	1.5	0.576	16.88	2.344	0.6
Superplasticizer S3	2	0.458	33.91	2.519	0.4
Cement I42, 5N 320 kg/m^3	0	0.571		2.494	3.4
Crushed limestone aggregates	1	0.477	16.46	2.494	3.2
0–8 mm 0–31.5	1.5	0.471	17.51	2.494	3.0
Superplasticizer S3	2	0.457	19.96	2.506	2.9
Cement I42, 5N 320 kg/m^3	0	0.842		2.444	1.7
Crushed limestone aggregates	1	0.609	26.67	2.506	3.1
0–31.5 mm	1.5	0.531	36.94	2.594	2.8
Superplasticizer S3	2	0.503	40.26	2.596	2.2

of the checked concrete syntheses and the decrease of required water which was achieved for stable original workability of 15 ± 1 cm are given in Table 5. The development of compressive strength at various dosages of superplasticizers are given in Figs. 1–6. The loss of workability of these mixtures with 1.5% of superplasticizers S1, S2, S3 and 420 kg/m^3 of cement are indicatively given in Figs. 7 and 8 and the loss of workability for dosages 1% of S1, S2, S3 and 320 kg/m^3 of cement are given in Figs. 9 and 10.

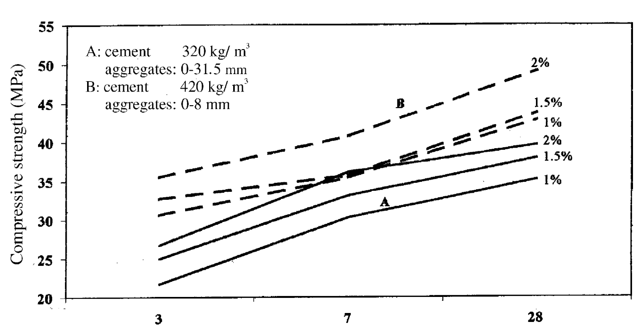

Fig. 1. Increase of compressive strength with S1 and natural (river) aggregates.

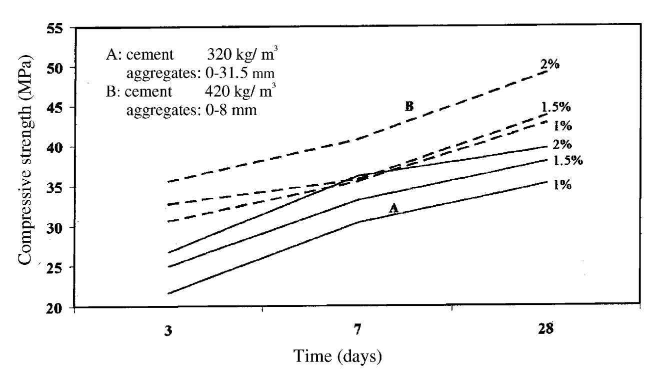

Fig. 2. Increase of compressive strength with S1 and crushed limestone aggregates.

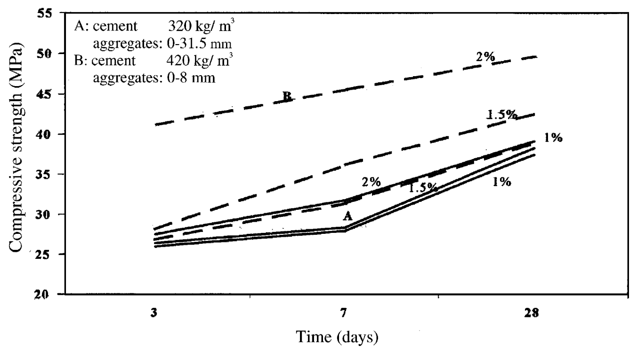

Fig. 3. Increase of compressive strength with S2 and natural (river) aggregates.

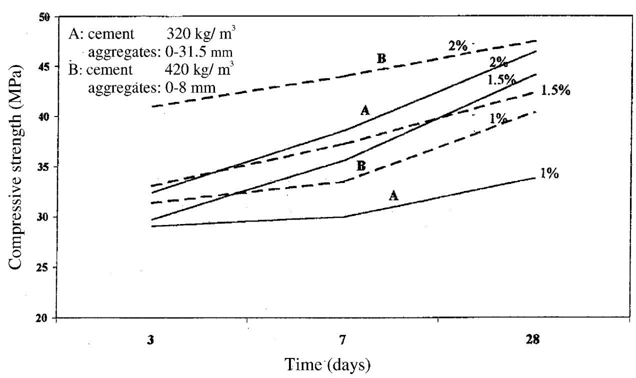

Fig. 4. Increase of compressive strength with S2 and natural crushed limestone aggregates.

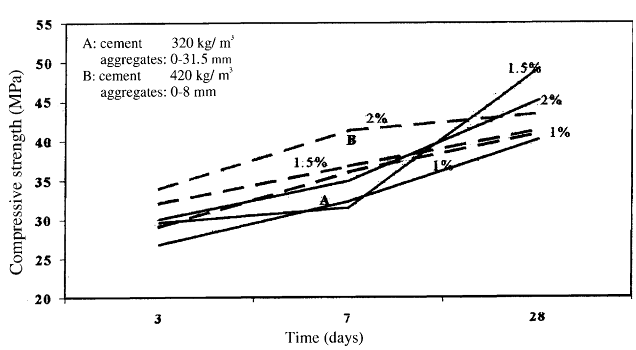

Fig. 5. Increase of compressive strength with S3 and natural (river) aggregates.

3. Conclusions

From the comparison of the superplasticizers the conclusion drawn is that the type S3 of carboxylic base is of higher performance than types S1, S2. It gives a higher decrease of the w/c ratio which is up to 40% in mixtures with crushed aggregates. The loss of workability through time is normal and in the case of concrete with coarse aggregates it is of the same level compared with that of the reference mixture without

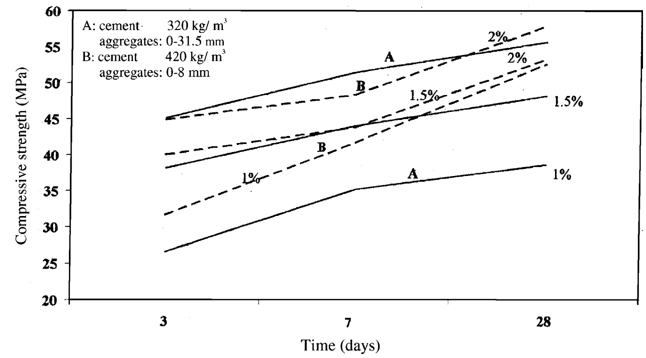

Fig. 6. Increase of compressive strength with S3 and natural crushed limestone aggregates.

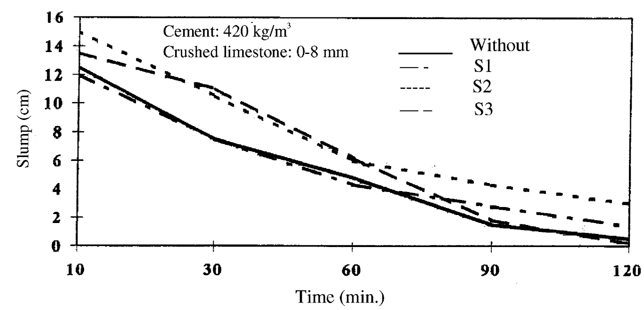

Fig. 7. Loss of slump because of superplasticizers addition (1.5%) Aggregates: natural (river), 0–8 mm.

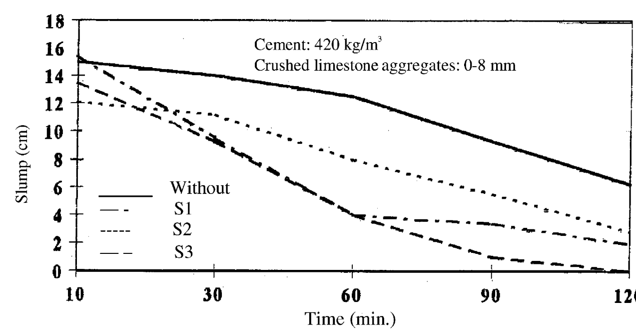

Fig. 8. Loss of slump because of superplasticizers addition (1.5%) Aggregates: crushed limestone, 0–8 mm.

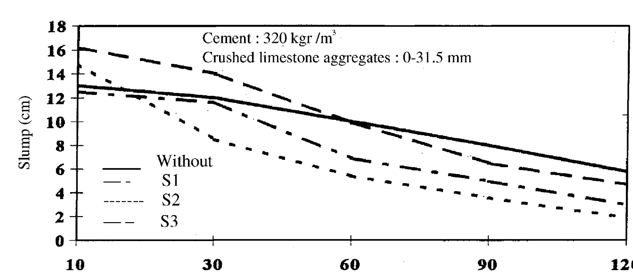

Fig. 9. Loss of slump because of superplasticizers addition (1%) Aggregates: natural (river), 0–31.5 mm.

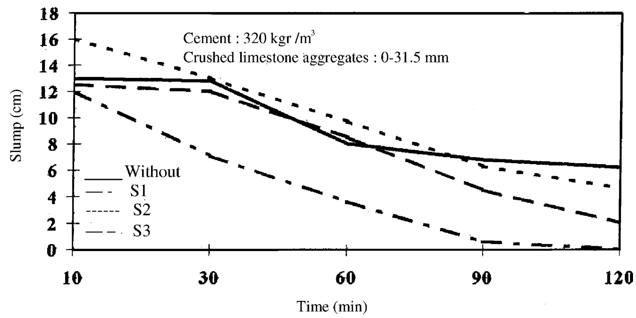

Fig. 10. Loss of slump because of superplasticizers addition (1%) Aggregates: crushed limestone, 0–31.5 mm.

superplasticizers. The performance depends, of course, on the dosage. A compressive strength of 58 MPa (an increase of 50% compared with reference strength) is developed in 28 days in mixtures with 2% of S3 by weight of cement. Higher loss of workability is given by superplasticizers of type S1, which are based on sulfonated polymers. This type in dosage of 2% gives a compressive strength in 28 days of approximately 50 MPa (an increase of 25% compared with reference strength). The type S2 which is based on synthetic polymers behaves in a similar way to type S1 but the loss of workability through time is relatively smaller and more normal. The maximum strength, which is achieved with 2% dosage, is 47 MPa (increase of 18% compared with the reference strength). Comparing the corresponding pairs of mixtures, in which superplasticizers of the same type and in the same dosage were added and which also differ only in the type of aggregates (river/crushed), it can be said that the performance of all superplasticizers with natural river aggregates is lower. Water decrease and the achieved strength is of a lower level. This can be explained by the higher amount of fine materials (0.25–1.0) mm which exist in river aggregates (see grading). In most of the mixes the inclusion of a superplasticizer produced an increase in the voids content of the concrete.

In general terms, concreting with superplasticizers results in a decrease of workability from 15 cm slump to 7–8 cm after 1 h—although the method of testing workability is not direct and accurate.

Acknowledgements

The authors would like to thank MAC BETON HELLAS SA company of the SKW—MBT Master Builders Technologies team for the cooperation and supply of the admixtures for conducting this research.

References

[1] Malhotra VM. Innovative applications of superplasticizers in concrete—A review. In: Mehta PK, editor. Proceedings of Mario Collepardi Symposium on Advances in Concrete Science and Technology 5th CANMET/ACI International Conference on Superplasticizers and Other Chemical Admixtures Rome, 7–10 October 1997. p. 271–314.
[2] Langley WS, Carette GG, Malhotra VM. Structure concrete incorporating high volume of ASTM class F fly ash. ACI Mater J 1989;86:507–14.
[3] Mailvaganam NP. Slump loss in flowing concrete, ACI SF62. In: Malhotra VM, editor. 1979, pp. 389–404.
[4] Collepardi M, Corradi M, Valente M. Low-slump loss superplasticized concrete. Transportation Research Record 720. Washington, DC, 1979.
[5] Whiting D, Schmitt J. Durability of in place concrete containing high-range water-reducing admixtures. NCHRP Report No. 296. Trans Res Board, Washington, 1987.
[6] Mehtra PK. High performance concrete durability affected by many factors. Concrete Constr 1992;37(5):367–70.