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Influence of superplasticizers on rheological behaviour of fresh cement mortars

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Abstract

To assure required workability of high performance concrete (HPC), various superplasticizers are used. Only by using superplasticizers can rheological properties of HPC mix be adequately adjusted to the methods and conditions of concrete processing. Thus, the key element in efficient workability shaping is the complex knowledge how superplasticizers influence the rheological properties of fresh concrete in different technological circumstances.

In the paper, the methodology and test results of an investigation into the influence of chemically different superplasticizers on the rheological properties of standard mortars are presented and discussed. The rheological parameters of mortars yield value *g*, and plastic viscosity *h* were determined using VISCOMAT PC rotational rheometer. In the research, the influence of the performance of superplasticizers was investigated taking into account following factors: chemical origin of superplasticizers (SNF/naphthalene sulfonic acid/, AP/polycarboxylate acid, PC/policarboxylate ester/), superplasticizer dosage, *W*/*C* ratio, cement type (CEM I, CEM II and CEM III), cement physical and chemical properties and temperature.

The results presented in the paper show that by testing rheological parameters of mortars with rotational viscometer, it is possible to complex and precisely determine the performance of superplasticizers. On the ground of obtained results, it is possible to optimise the composition of mortars and concretes from workability point of view.

Keywords: Workability; High-range water reducers; Rheology; Mortar; High performance concrete

1. Introduction

High performance concrete (HPC) is widely used in civil engineering as structural material assuring high strength, durability and reliability of concrete structures [1]. Although from a materials point of view, HPC is nothing more than an ordinary concrete with a very low porosity, its production as a result of conflict in between requires low water to cement (or water to binder) ratio, and high workability causes technological problems [2,3].

The definition of workability in concrete technology should be considered in terms of the state of the system (i.e., the composition of the concrete mix and the method of processing). This state is determined by the relationship between two factors: the rheological properties of the given mix and the forces acting on it during processing [4]. The rheological properties are determined by composition of the mix only. They characterise its strain–stress behaviour. Therefore, concrete mix workability is determined by the reaction of the mix to the forces acting on it during transport and mechanical processing as the resistance of its structure to these forces. Required workability can be achieved in two ways: to the given method and conditions of concrete processing, rheological properties of concrete mix are adjusted; or to the given rheological properties of concrete mix, method and conditions of concrete processing are adjusted. In practice, the first method is usually used.

To assure required high workability of HPC, various superplasticizers are used. Only by using superplasticizers can rheological properties of HPC mix be adequately adjusted to the method and conditions of concrete processing. Thus, the key element in efficient workability shaping is the complex knowledge how addition of superplasticizer influences the rheological properties of fresh concrete. Unfortunately, the quantity of experimental data on this topic is limited [5–8].

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The objective of this paper is to present how popular superplasticizers influence rheological properties of concrete mix in various technological circumstances. The performance of superplasticizers was investigated using standard mortars (PN EN 196) that can be considered to be model HPC concrete [9,10]. The rheological properties of superplasticized mortars are described by Bingham's model parameters—the yield stress g and the plastic viscosity h—and the effects of superplasticizer on these parameters are similar to those observed with concrete [4,9–12]. This suggests that tests on mortars are useful in predicting the behaviour of fresh concrete. The test results and relationships presented in this paper are selected from several research projects carried out by the authors, and shows typical effects of the superplasticizers on mortar and concrete rheological properties.

2. Experimental

2.1. Rheological model of fresh concrete

It is well documented that fresh mortar, like fresh concrete, behaves as Bingham body, whose properties can be expressed by the two fundamental rheological parameters: the yield stress and the viscosity according the formula:

$$\tau = \tau_0 + \eta\dot{\gamma} \qquad (1)$$

where τ (Pa) is the shear stress at shear rate $\dot{\gamma}$ (1/s), and τ_0 (Pa) and η (Pa s) are the yield value and plastic viscosity, respectively [9–12]. The physical interpretation of yield value is that of the stress needed to be applied to a material in order to start flowing. When the shear stress is higher then the yield value, the mix flows and its flow resistance depend on plastic viscosity. Detailed rheological properties of fresh mortars and concretes are presented and discussed in Refs. [2,10,13,14].

Fig. 1. Viskomat PC and its measuring element.

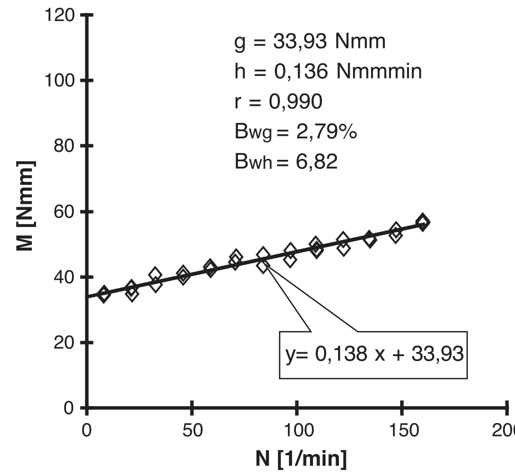


Fig. 2. Relationship between torque T and speed N—measurement realised using Viskomat PC rheometer for superplasticized mortar. Measurement according Procedure no. 1 after Table 6.

2.2. Measurements of rheological parameters of fresh mortars

Rheological parameters of fresh concrete or mortar can be measured by applying a given shear rate and the measuring of the resulting shear stress. Because of non-linear character of rheological behaviour of mortar and concrete mix, the measurements should be taken at no less than two considerably different shear rates. In this work, rheological parameters were measured using Viskomat PC rheometer (Fig. 1). With this instrument, a rotation rate N is applied to a paddle, and the torque T of sample shear resistance is measured. The rheological parameters are determined by regression analysis according to the relation:

$$T = g + Nh \qquad (2)$$

where g (N mm) and h (N mm min) are constants corresponding to yield value τ_0 and plastic viscosity η, respectively (Fig. 2). By suitable calibration of rheometer, it is possible, if necessary, to express g and h in fundamental units. In the present investigation where the object was to determine the relative changes in rheological parameters of mixes in relation to superplasticizer type, content, dosage procedure and cement type, calibration was considered unnecessary. The two-point test and its principles are in details presented in Refs. [12,13].

2.3. Materials and mixes

Different commercial cements and admixtures were used for the investigations. Their main properties are presented and discussed in the corresponding parts of paper (see Tables 1–4). The sand used was PN-EN 196-1 CEN model

Table 1
Chemical and phase compositions of cement (used in Sections 3 and 4)

Cement	Chemical composition (%)											Specific surface (cm^2/g)
	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Na_2O_{eq}	SO_3	C_3S	C_2S	C_3A	C_4AF	
CEM I 32,5	19.50	63.54	5.79	2.82	1.37	0.83	2.77	57.59	11.28	10.58	8.57	3289

Table 2
Chemical and phase compositions of cements (used in Sections 5 and 6)

Cement	Chemical composition (%)											Spec. surface (cm^2/g)
	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Na_2O_{eq}	SO_3	C_3S	C_2S	C_3A	C_4AF	
CEM I 32,5	19.5	62.2	6.3	2.5	1.9	0.74	1.9	53.63	15.74	12.47	7.6	3285
CEM II/B-S 32,5	24.7	56.7	6.3	2.3	2.9	0.70	3.2					3259
CEM III/A 32,5	29.3	50.5	6.6	1.7	4.0	0.83	3.3					3761

Table 3
The chemical and phase compositions of cements CEM I 42,5 (used in Section 5)

Cement	Ingredients (%)											Specific surface (cm^2/g)
	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Na_2O_{eq}	SO_3	C_3S	C_2S	C_3A	C_4AF	
A	19.29	64.06	5.69	2.82	1.37	0.83	2.77	64.07	6.96	10.31	8.57	3617
B	20.38	64.06	4.77	2.50	2.14	1.10	2.52	63.14	10.79	8.42	7.60	3790
C	22.55	64.30	4.39	2.98	1.02	0.65	2.52	49.49	27.31	6.60	9.06	3559

sand (2 mm maximum). The particle size distribution of this sand is given in Table 5. The mix proportions of all tested mortars were based on standard mortar proportioning according to PN EN 196:1994 (3:1 sand/cement, by weight). Water/cement ratio and superplasticizer type and dosage varied in the wide range as a part of the programme; this variations is given in the results below.

2.4. Mortar mixing and testing procedures

The PN EN 196:1994 mortar mixer was used. The mixing procedure was according to PN EN 196:1994. Superplasticizers were added with water or delayed 30 or 60 s depending on its type and test programme. After mixing, the sample of mortars were transferred to Viskomat PC and tested according procedures presented in Table 6 and in Figs. 3 and 4. When the Procedure no. 1 was used, in order to determine changes of rheological parameters in time, the measurements were performed at 10, 20, 30, 40 and 50 min. Procedure no. 2 roughly simulates process of transport in truck concrete mixer. Because measurement at the constant velocity of the impeller rotation for the Viskomat PC makes possible the investigation of only shear resistance, which at a given speed consists of yield value and plastic viscosity, at 10 and 60 min, the speed was changed from 120 to 20 l/min to define the rheological parameters from flow curves.

The correlation coefficients calculated from the flow curves used to determine rheological parameters of the mixes were generally in range of 0.95–0.99, with only less then 5% falling below 0.90. In the research range, segregation effects were not observed.

2.5. Testing programme

A literature survey [5–8] points out that the rheology of superplasticized fresh concretes (and mortars) can be affected by many factors, connected mainly with type,

Table 4
Properties of tested superplasticizers

Admixture	Chemical base	Density (g/cm^3)	Concentration (%)
AP	polycarboxylate acid	1.06	40
PC1	polycarboxylate ester	1.09	17
PC2	polycarboxylate ester	1.05	36
SNF1	naphthalene sulphonate acid	1.09	26
SNF2	naphthalene sulphonate acid	1.11	30
SNF3	naphthalene sulphonate acid	1.20	26

Table 5
Particle size distribution of CEN model sand

Sieve size (mm)	Total residue on sieve (%)
2.00	0
1.60	7 ± 5
1.00	33 ± 5
0.50	67 ± 5
0.08	99 ± 1

Table 6
Measuring procedures used in tests

Procedure no. 1[a]	Procedure no. 2
Start of measurement—speed 160 rev/min	Start of measurement—speed 120 rev/min
Speed held constant for 90 s at 160 rev/min	Speed held constant for 10 min at 120 rev/min
Measurement of torque at decreasing speed, 160–150–140–130–120–100–90–80–70–60–50–40–30–20 rev/min	Measurement of torque at decreasing speed, 120–100–80–60–40–30–20 rev/min. Total test cycle time—70 s
End of measurement. Total test cycle time—200 s	Speed held constant for 39 min at 60 rev/min
	Increase of speed to 120 rev/min. Speed held constant for 10 min
	Measurement of torque at decreasing speed, 120–100–80–60–40–30–20 rev/min. Total test cycle time—70 s
	End of measurement. Total test cycle time—3620 s

[a] In procedure no. 1 measurements are performed at specified time from end of mixing. Between measurements mortar is kept in mixer. Directly before measurement mortar is mixed for 30 s.

chemical and phase compositions and fineness of cement, chemical nature of the superplasticizer, its dosage and addition method, proportioning of concrete (especially water/cement ratio) and temperature. Therefore, the following factors were taken into consideration and changed in the research works:

- superplasticizer type (see Table 4),
- *W*/*C* ratio and superplasticizer dosage,
- method of superplasticizer addition (with water or delayed),
- type of cement (CEM I, CEM II, and CEM III according PN-EN 197-1, see Table 2),
- chemical and phase compositions of cement (effect of C_3A and alkalis content, see Table 3),
- mix temperature (ranges from 10 to 30 °C).

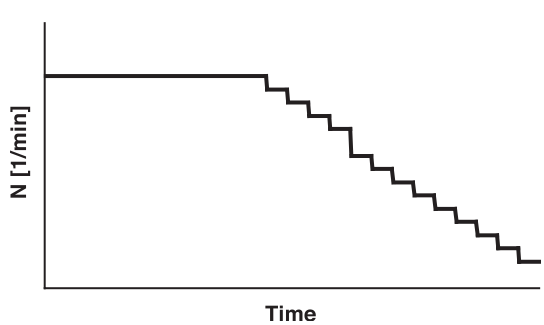


Fig. 3. Measuring Procedure no. 1 used in Sections 3, 4 and 5.

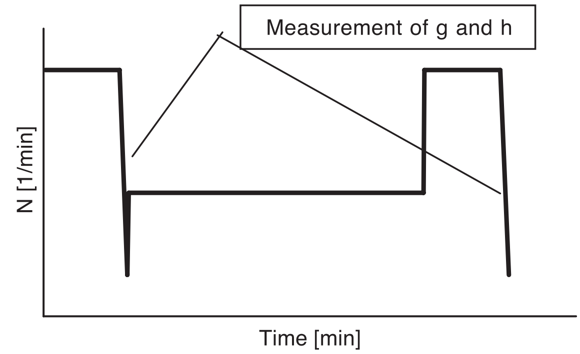


Fig. 4. Measuring Procedure no. 2 used in Sections 5 and 6.

The range of changes of factors and factors kept as constant are given below, in adequate parts of test results presentation.

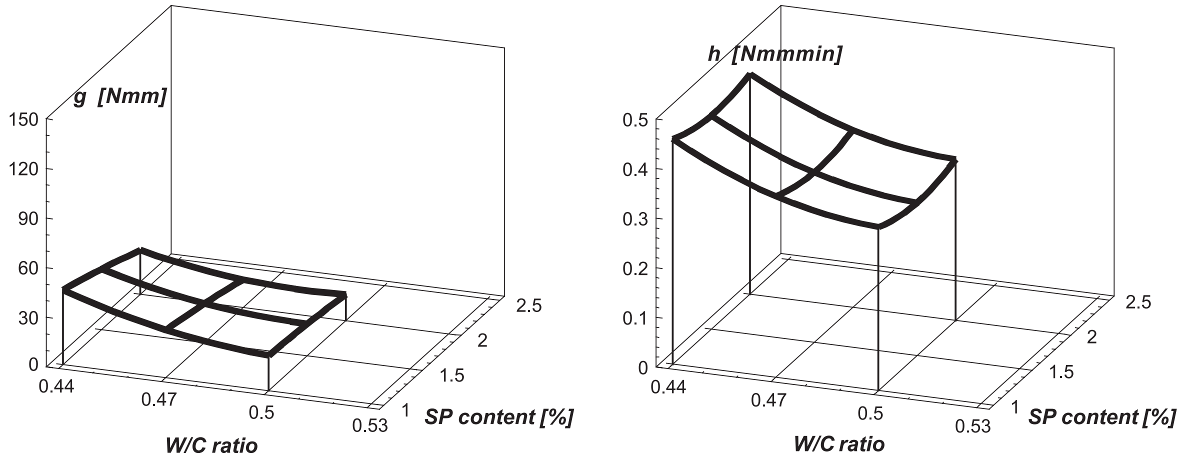
3. Influence of superplasticizer dosage and type and *W/C* ratio on the rheological properties of mortars

For this part of the investigation, commercial cement CEM I 32,5 was used (see Table 1). The investigation was carried out for the AP and the SNF1 superplasticizers (see Table 4). The results of the investigation are presented in Figs. 5–8, in the form of response surface accepting quadratic polynomial with second row interactions as the response function.

As can be seen in Figs. 5 and 6, the effect of both superplasticizers tested on *g* after 10 min is qualitatively much the same. However, to obtain a specific value of *g*, it is necessary to use approximately twice the dosage of SNF1 superplasticizer than the AP superplasticizer, especially for low *W*/*C* mortars. On the other hand, value of *h* of mortars made with AP superplasticizer is up to three times higher than that of mortars with SNF1 superplasticizer.

The range of change of *g* with time is clearly lower for mortars with AP superplasticizer than for SNF1 superplasticizer (Figs. 5–8). Generally, *g* of mortars with AP superplasticizer increases with time only for low *W*/*C* ratio and low superplasticizer dosage mortars. At the same time, *g* of SNF1 superplasticizer mortars increases considerably, which significantly decreases workability. The values of *h* of tested mortars generally decrease with time. This effect is especially pronounced for low *W*/*C* ratio mortars with the AP superplasticizer; a high drop in *h* in a relatively short time can be of importance for the stability of fresh concrete.

Both SNF1 and AP superplasticizers show similar effectiveness in high *W*/*C* ratios. The high effectiveness of the AP superplasticizer is fully revealed only at low *W*/*C* ratios. Thus, the AP type superplasticizers (and also PC type superplasticizers) are particularly suitable for production of concretes with low *W*/*C* as HPC or self-compacting concretes (SCC) (high plastic viscosity



$g = 1415.21-1415.21A-104.84B-26.15C+213.75AB+52.58AC+2.35BC+3864.07A^2-2.88B^2-5.02C^2$; $r = 0.988$

$h = 8.007-29.90A-0.270B+0.195C+0.075AB-0.292AC+0.008BC+29.674A^2+0.075B^2-0.059C^2$; $r = 0.970$

where A – W/C ratio; B – superplasticizer dosage [% of cement by weight]; C – superplasticizer addition method [min of delay]

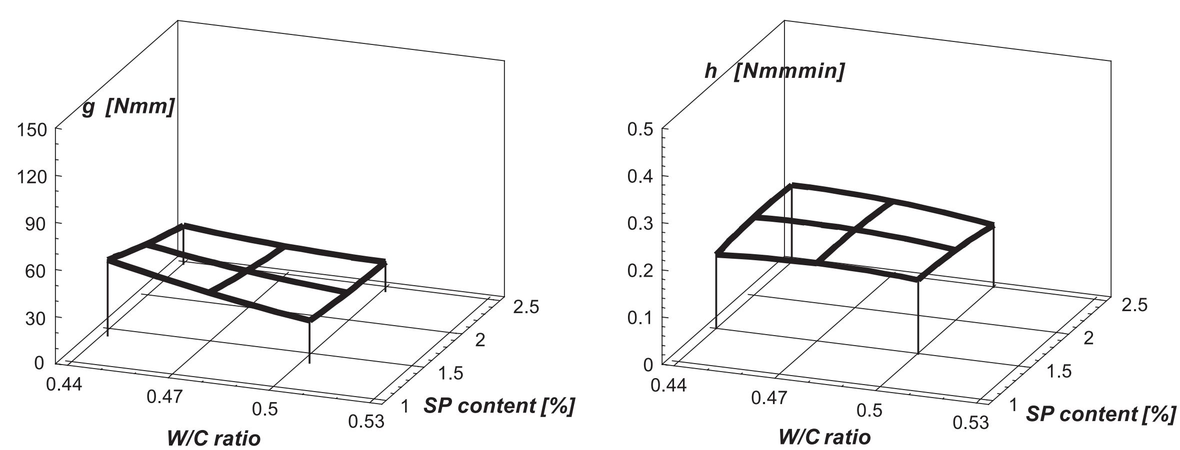
Fig. 5. Influence of *W/C* ratio and AP type superplasticizer dosage on rheological properties of mortars 10 min after end of mixing (CEM I 32,5 R; temperature at 20 °C).

due to superplasticizer addition is in this case very advantageous). For plain concrete, for economical reasons, the SNF superplasticizer should be used (AP superplasticizers are usually twice as expensive as SNF superplasticizers).

4. Influence of the superplasticizer addition method on the rheological properties of different *W/C* ratios fresh mortars

For this part of the investigation, commercial cement CEM I 32,5 was used (see Table 1). The investigation was carried out for AP and SNF1 superplasticizers (see Table 4).

The addition method of traditional superplasticizers is usually specified as one of the important factors determining workability. To obtain the high workability, the addition of SNF type superplasticizer (and also plasticizers and SMF type superplasticizers) should be delayed, and the optimum addition time corresponds to the beginning of the dormant period [15]. Plots in Fig. 9 confirm the strong influence of the superplasticizer addition method on the workability of SNF mortars. The addition of SNF1 superplasticizer with water (procedure A) produces fresh mortar with clearly a higher *g* than mortars with delayed superplasticizer addition (procedures B and C). Also, the increase of *g* with time is distinctly higher when the superplasticizer is added with water. On the other hand, value of *h* is slightly reduced due

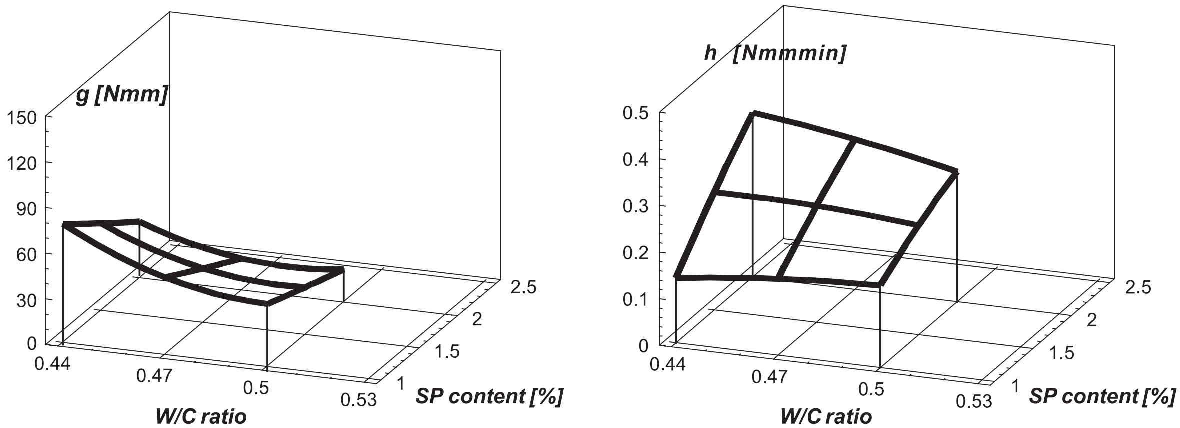


$g = 780.45-2280.15A-145.45B-35.49C+241.16AB+32.83AC+4.75BC+1670.5A^2+3.71B^2+7.37C^2$; $r = 0.985$

$h = -2.449+9.998A+0.340B+0.437C-0.517AB-0.7AC-0.036BC-8.927A^2-0.002B^2-0.002C^2$; $r = 0.903$

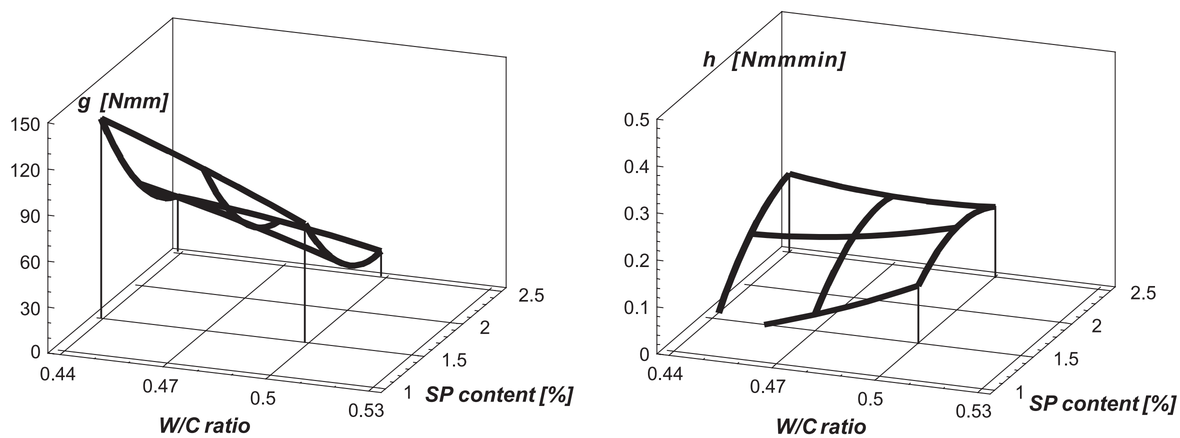
where A – W/C ratio; B – superplasticizer dosage [% of cement by weight]; C – superplasticizer addition method [min of delay]

Fig. 6. Influence of *W/C* ratio and SNF1 type superplasticizer dosage on rheological properties of mortars 10 min after end of mixing (CEM I 32,5 R; temperature at 20 °C).



g = 2508.07-9382.87A-188.10B-61.08C+326AB+133.33AC+1.26BC+8983.91A²+1.122B²-6.078C²; r = 0.979
h = 2.662+8.903A+1.074B-0.1499C+1.841AB+0.141AC+0.061BC-6.934A²-0.027B²+0.011C²; r = 0.979
where A – W/C ratio; B – superplasticizer dosage [% of cement by weight]; C – superplasticizer addition method [min of delay]

Fig. 7. Influence of *W*/*C* ratio and AP type superplasticizer dosage on rheological properties of mortars 50 min after the end of mixing (CEM I 32,5 R; temperature at 20 °C).



g = 943.50-76.51A-607.95B-205.33C+537.61AB+266.94AC+20.77BC-1829.11A²+67.28B²+19.85C² r = 0.994
h = -0.994-6.148A+2.123B+0.238C-2.804AB+0.012AC-0.086BC+13.585A²-0.162B²+0.003C² r = 0.984
where A – W/C ratio; B – superplasticizer dosage [% of cement by weight]; C – superplasticizer addition method [min of delay]

Fig. 8. Influence of *W*/*C* ratio and SNF1 type superplasticizer dosage on rheological properties of mortars 50 min after the end of mixing (CEM I 32,5 R; temperature at 20 °C).

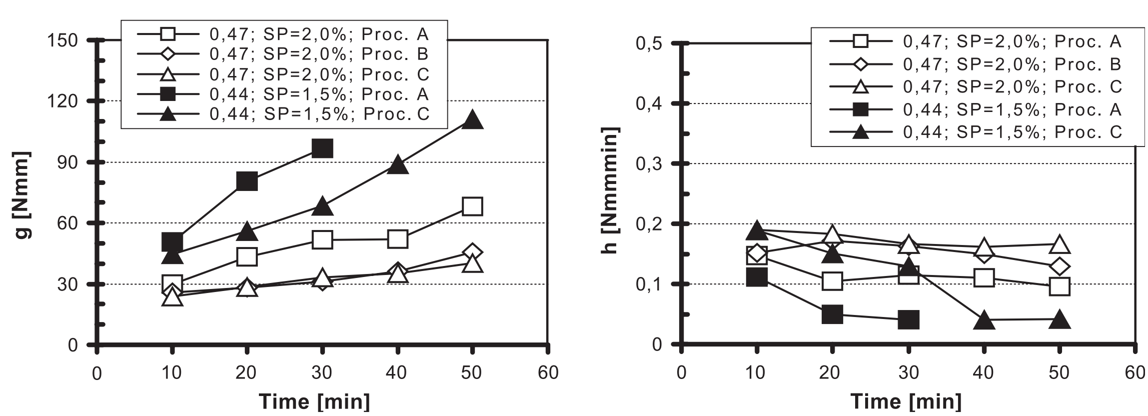


Fig. 9. Influence of superplasticizer addition method on rheological parameters of mortars with SNF1 type superplasticizer. Procedure A—addition of SP with water, Procedure B—addition of SP delayed at 30 s, Procedure C—addition of SP delayed at 60 s (CEM I 32,5 R; temperature at 20 °C).

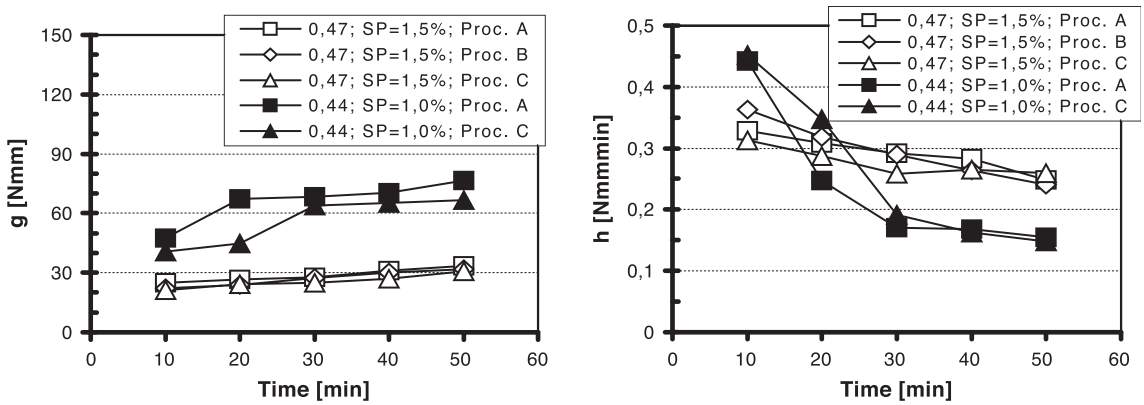


Fig. 10. Influence of superplasticizer addition method on rheological parameters of mortars with AP type superplasticizer. Procedure A—addition of SP with water, Procedure B—addition of SP delayed at 30 s, Procedure C—addition of SP delayed at 60 s (CEM I 32,5 R; temperature at 20 °C).

to the addition of superplasticizer with water, but under the effect of a high rate of change in g, this effect is insignificant from a workability point of view. The addition method of the SNF1 superplasticizer does not seem to affect the change of h with time.

In the case of the AP superplasticizer, the method of its addition influences the rheological parameters to a much lesser extent. With delayed dosage of superplasticizer for mortars with low W/C ratio, a slightly reduced g value was obtained (Fig. 10). For mortars with a higher W/C ratio, the addition time of superplasticizer does not influence the rheological parameters and its changes with time. The obtained results are generally in accordance with results presented by Uchikawa [16], which shows that the adsorption of acrylic polymer does not depend on the method of addition.

5. Influence of type, chemical and phase compositions of cement on the rheological properties of different W/C ratios fresh mortars

The influence of cement type on the performance of PC1 superplasticizer (see Table 4) was studied using commercial cements CEM I, CEM II/B-S and CEM III/A for mortars of different W/C ratios (= 0.50 and 0.40) and different superplasticizer dosages. The chemical and phase compositions of these cements, as well as their fineness, are presented in Table 2.

The results of the investigation for different W/C ratios and superplasticizer dosages are presented in Figs. 11–13. The following plots show the influence of cement type on g and h of mortars containing PC1 superplasticizer measured 10 and 60 min after the end of mixing and development of shear resistance with time.

Comparing the development of shear resistance with time for all cements, it can be seen that shear resistance is always highest for CEM I mortars, independent of W/C ratio and superplasticizer dosage. Mortars with cement CEM II and CEM III show a generally similar effect on shear resistance development over the first 40 min. For CEM II type, shear resistance starts to increase to a higher degree. The rate of change of shear resistance depends on W/C ratio and superplasticizer dosage.

For W/C = 0.50 and superplasticizer dosage of 1%, shear resistance continuously increases with time for all tested mortars, but clearly, the highest increase appears for mortar with cement CEM I. The increase of shear resistance for

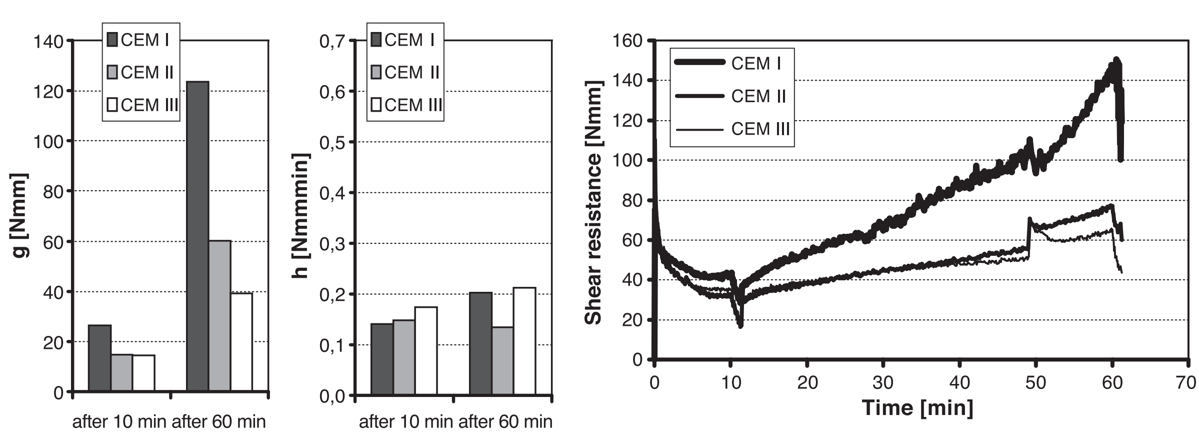


Fig. 11. Influence of cement type on rheological properties of mortars containing PC1 type superplasticizer (W/C = 0.50; SP = 1%; temperature at 20 °C).

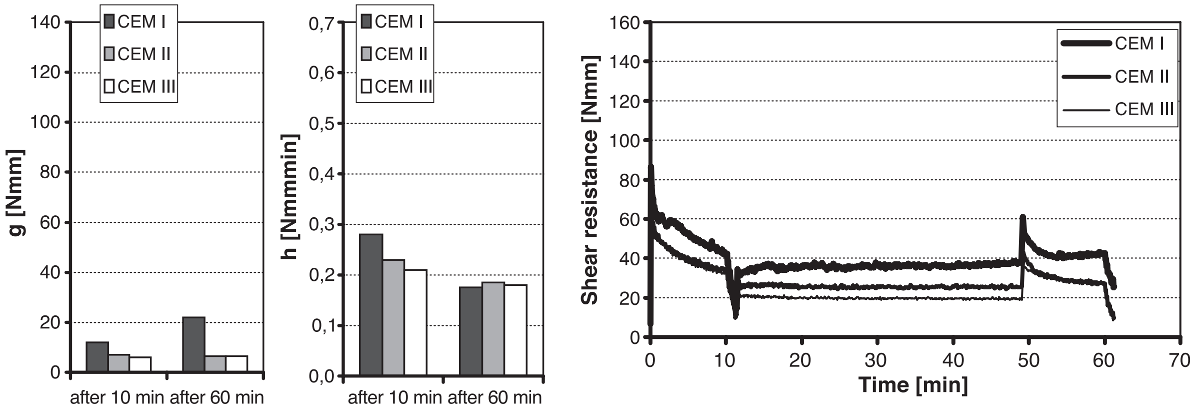


Fig. 12. Influence of cement type on rheological properties of mortars containing PC1 type superplasticizer ($W/C=0.50$; SP = 2%; temperature at 20 °C).

CEM II and CEM III mortars was considerably lower and remained the same for 40 min; then the CEM II mortar shear resistance showed more rapid growth.

The addition of a higher superplasticizer dosage (while W/C remains constant) results in the shear resistance generally not showing any changes during the test period; only for the CEM I mortar, shear resistance slightly increases with time. Moreover, mortar with cement CEM I shows clearly higher shear resistance than mortars with other tested cements.

The shear resistance of mortars with $W/C=0.40$ and superplasticizer dosage of 2.5% shows changes in a different way than for higher W/C ratio mortars. The shear resistance is nearly the same at 25 min for all the tested cement, and then slightly decreases. Then, the shear resistance for CEM I mortar starts to increase, especially rapid growth can be observed after 50 min. At the same time, shear resistance of mortars with CEM II and CEM III constantly decreased, for CEM III mortar, until end of test period, for CEM II mortar, until 50 min, and then slight increase of shear resistance takes place.

Changes of shear resistance with time when the mortar shows Bingham body behaviour are a consequence of g and h value changes. It is very important from a technological point of view to know how changes of these parameters contribute to shear resistance changes. For $W/C=0,50$ and 1% superplasticizer dosage, the increase of shear resistance is mainly due to the effect of increasing g value. Clearly, the highest g values after 10 and 60 min were obtained for the CEM I mortar. Mortars with CEM II and CEM III cements show the same g value in the beginning, but the g value of CEM II mortars increases more rapid with time than the CEM III. Value of h is highest for the CEM III mortar, but generally, differences in h value between the cements tested are low, and also the rate of change of h value is small. Increasing the dosage of superplasticizer causes a decrease of g value and increase in h value. Value of g increases with time only for CEM I, but remains at the same level for CEM II and CEM III. The value of h in the course of time slightly decreases. For $W/C=0.40$ changes of rheological parameters are generally of the same nature. It was observed for CEM II and CEM III mortars that a low increase or even decrease of g value, and considerable drop of high initial h value, causes a decrease of shear resistance. The increase of shear resistance for CEM I mortar is caused by the rapid increase of g value (at the same time, h value decreases). It is also worth noting that the high shear resistance of $W/C=0,40$ mortars is to a high degree caused by increased

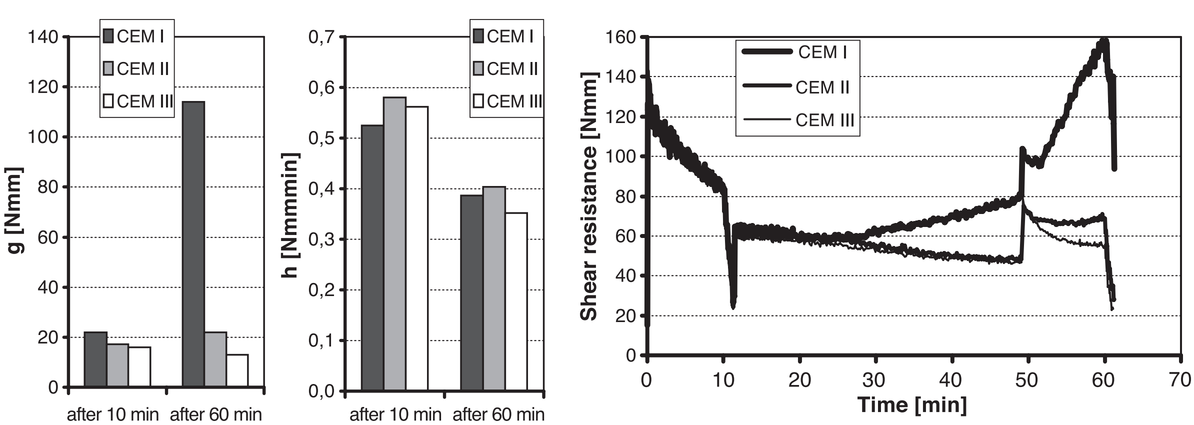


Fig. 13. Influence of cement type on rheological properties of mortars containing PC1 type superplasticizer ($W/C=0.40$; SP = 2.5%; temperature at 20 °C).

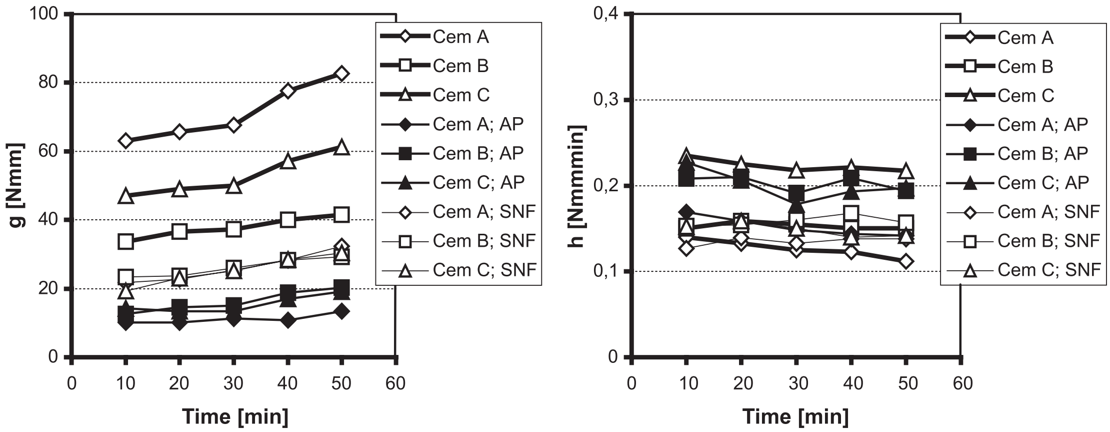


Fig. 14. Influence of cement composition on rheological properties of mortars containing SNF2 and AP superplasticizers ($W/C = 0.53$; SP = 0.2%/dry mass; temperature at 20 °C).

h value; the *g* value remains the same for mortars with $W/C = 0.5$ and 1% superplasticizer dosage.

The cement, chemical and phase compositions are considered as a factor determining the performance of the superplasticizer. It is generally believed that cement/superplasticizer interaction is mainly due to the effect of C_3A, gypsum (sulphate) and alkali content [5–8]. To investigate the effect of these ingredients on rheological properties of mortars, CEM I 42,5 commercial cements (see Table 3) and AP and SNF2 superplasticizers (see Table 4) were used.

The data presented in Fig. 14 indicates that mortars the with tested cements have different rheological properties (but the same compressive strength). Clearly, the lowest *g* value was obtained for cement B, with high alkali content. The highest *g* value (twice higher than for cement B) was obtained for cement A mortars; the highest *h* value was for cement C mortars.

Even a low addition of superplasticizer to the mortars with $W/C = 0.53$ caused the rheological properties of mortars to become very similar. The effect of cement/superplasticizer interaction is generally not visible for both the SNF2 and AP mortars. Only for mortars made with cement A, slightly lower *h* value was observed for both superplasticizers used and a lower *g* value for AP superplasticizer.

However, when mortars with $W/C = 0.47$ were investigated, the effect of cement type became very distinct. Figs. 15 and 16 shows that the type of cement has a critical influence on the performance of the superplasticizer. For a lower dosage of AP superplasticizer, the best results were obtained for cements A and C; at the same time, SNF2 superplasticizer performed well only with cement C (Fig. 15). For a higher dosage of AP superplasticizer, the effect of cement composition on the rheological properties of mortars disappeared. For mortars with SNF2 superplasticizer, although the initial properties of mortars are similar, a higher increase of *g* value can be observed for cements B and A (Fig. 16).

There is too limited data to draw a general conclusion about the influence of cement composition on superplasticizer performance, but it is important to notice that performance of tested admixtures is clearly better with low C_3A, C_3S and alkali content cement. Cement B is characterised by

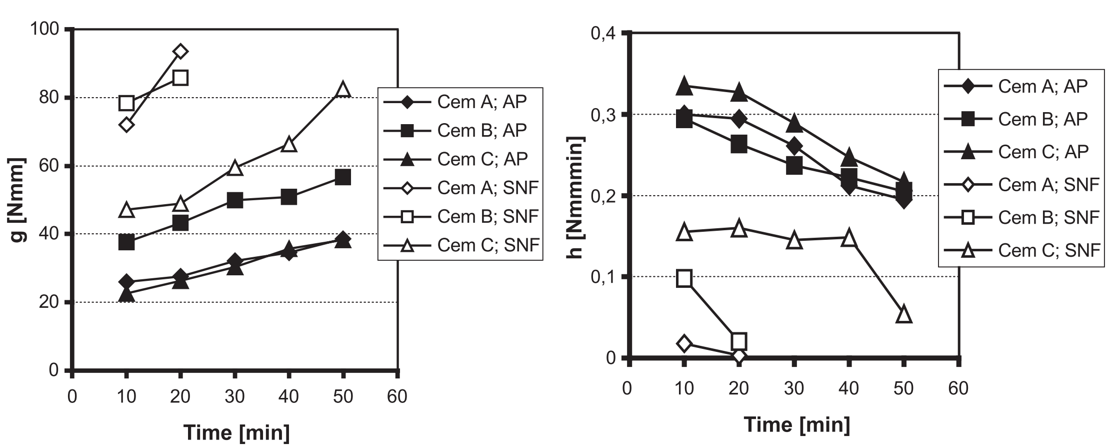


Fig. 15. Influence of cement composition on rheological properties of mortars containing SNF2 and AP superplasticizers ($W/C = 0.47$; SP = 0.2% (dry mass); temperature at 20 °C).

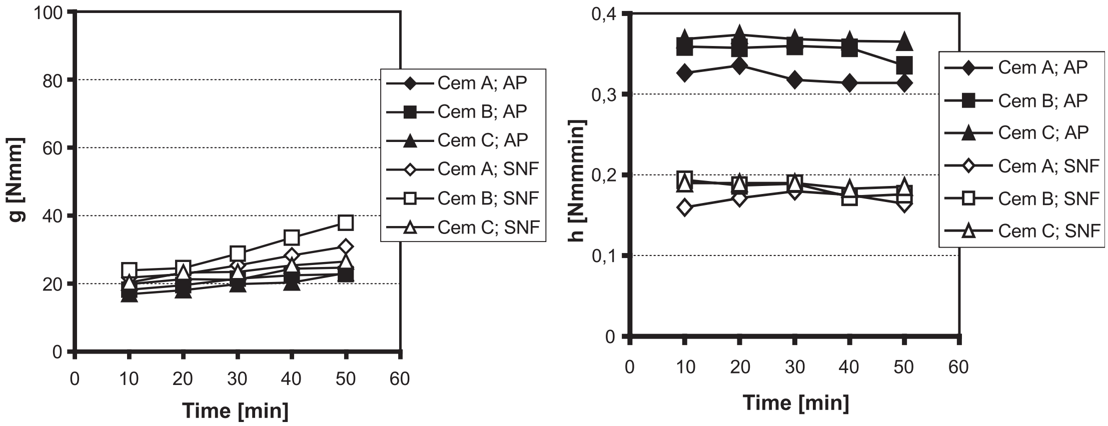


Fig. 16. Influence of cement composition on rheological properties of mortars containing SNF2 and AP superplasticizers ($W/C = 0.47$; SP = 0.4% (dry mass); temperature at 20 °C).

the highest alkali content, which seems to be an advantage for plain mortars but a disadvantage for superplasticized mortars.

6. Influence of temperature on rheological properties of different *W/C* ratios fresh mortars

The influence of temperature on the rheological properties of superplasticized mortars or concretes is a very important technological problem. The type of admixture used with a particular cement often gives different results depending on the concrete temperature during the use of concrete. The effect of temperature was studied using the cements shown in Table 2 and superplasticizers SNF3, and PC1 types (see Table 4), for mortars with different W/C ratio and superplasticizer dosage. To measure the rheological properties of mortars and the changes with time, Procedure no. 2 according Table 6 was used.

As can be seen from Figs. 17–19, the rheological properties of CEM I mortars containing SNF3 type superplasticizer are very strongly influenced by temperature. Generally, an increase of temperature increases *g* value, and at the same time, decreases *h* value. For mortars with $W/C = 0.5$ and superplasticizer dosage of 1% (Fig. 17), as well as for mortars with $W/C = 0.40$ and superplasticizer dosage of 2.5% (Fig. 19), an increase of shear resistance with increasing temperature can be observed, and also, the rate of shear resistance increase rises with increasing temperature. This phenomenon occurs mainly due to a high increase of *g* value and higher rate of *g* value increase with time at higher temperatures. In all temperatures tested, $W/C = 0.40$ mortars show tendency to stiffening (see fluctuation of shear resistance in Fig. 19), *g* value quickly increased with time while *h* value decreased. Increasing the dosage of SNF3 superplasticizer or increasing W/C ratio causes of course a drop of *g* value, *h* value and shear resistance (Fig. 18). In that case, rheological parameters of mortars become to a large degree independent of temperature.

Comparing the effect of temperature on the rheological properties of mortars with PC1 superplasticizer to mortars with SNF3 superplasticizer reveals general qualitative similarity, but significant quantitative differences (Figs. 20–22).

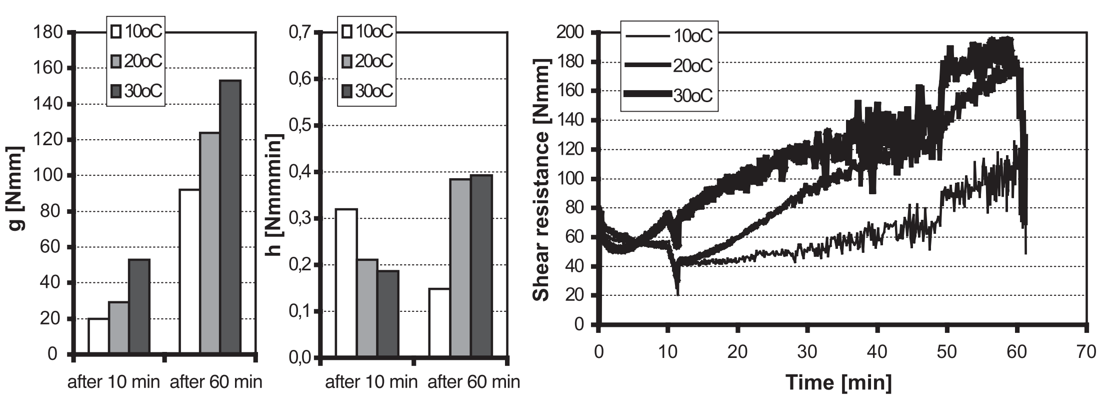


Fig. 17. Influence of temperature on rheological properties of mortars with SNF3 type superplasticizer (cement type CEM I 32,5; $W/C = 0.50$; SP = 1%).

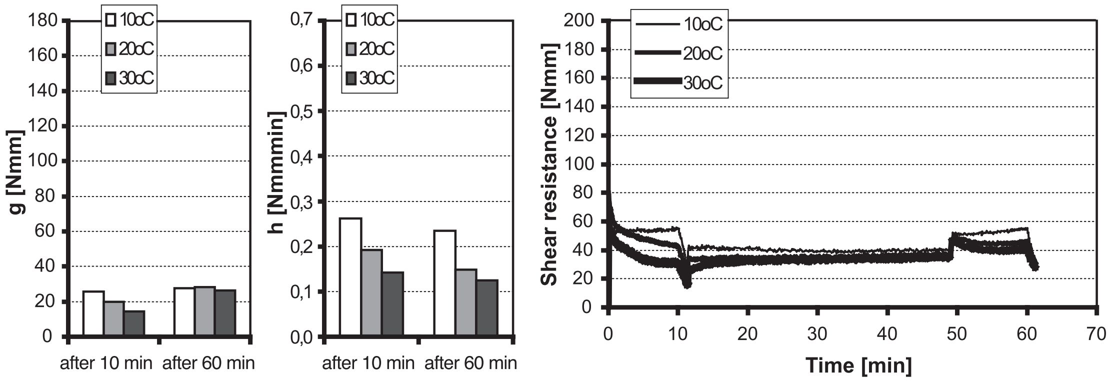


Fig. 18. Influence of temperature on rheological properties of mortars with SNF3 type superplasticizer (cement type CEM I 32,5; $W/C = 0.50$; SP = 2%).

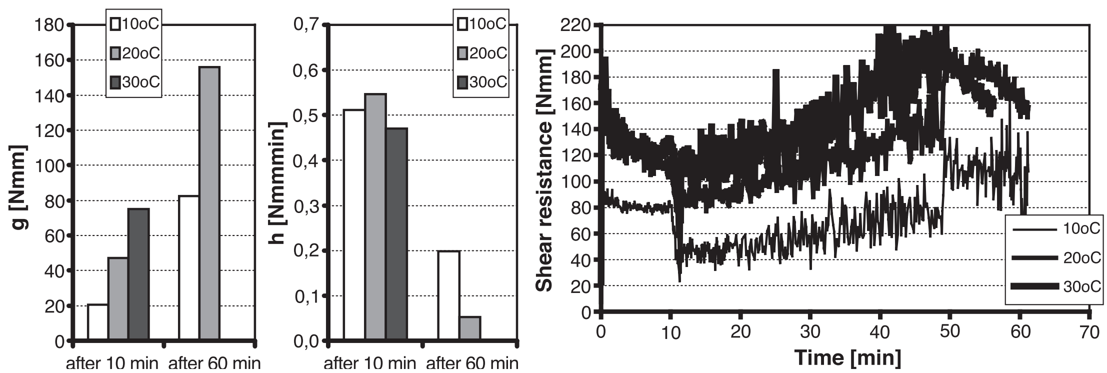


Fig. 19. Influence of temperature on rheological properties of mortars with SNF3 type superplasticizer (cement type CEM I 32,5; $W/C = 0.40$; SP = 2.5%).

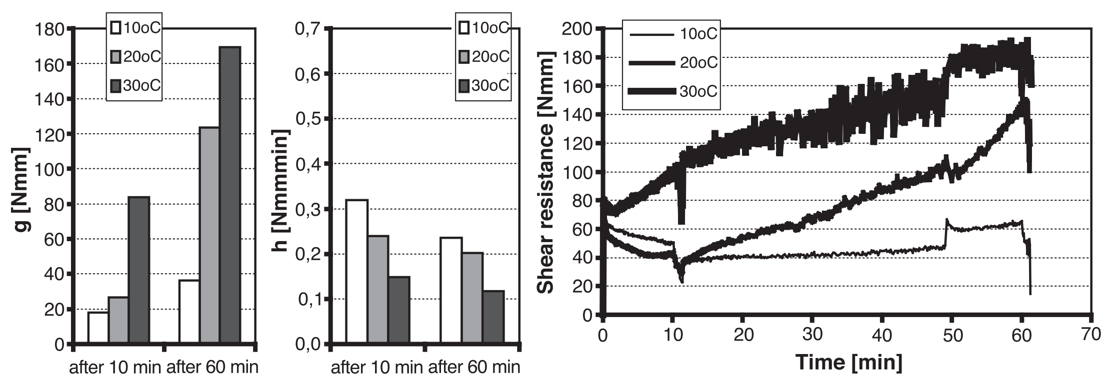


Fig. 20. Influence of temperature on rheological properties of mortars with PC1 type superplasticizer (cement type CEM I 32,5; $W/C = 0.50$; SP = 1%).

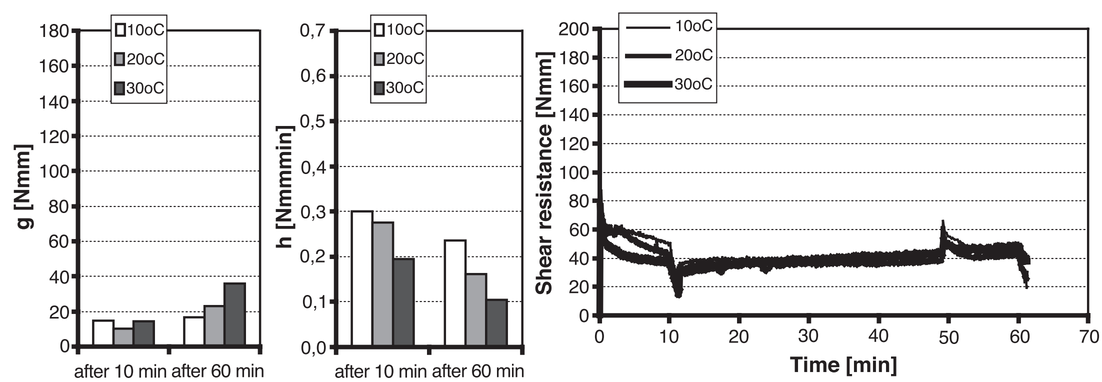


Fig. 21. Influence of temperature on rheological properties of mortars with PC1 type superplasticizer (cement type CEM I 32,5; $W/C = 0.50$; SP = 2%).

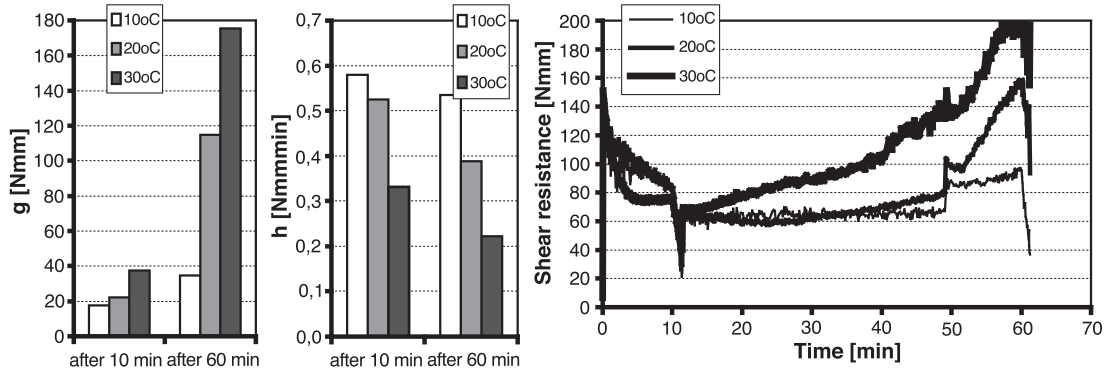


Fig. 22. Influence of temperature on rheological properties of mortars with PC1 type superplasticizer (cement type CEM I 32,5; $W/C = 0.40$; SP = 2.5%).

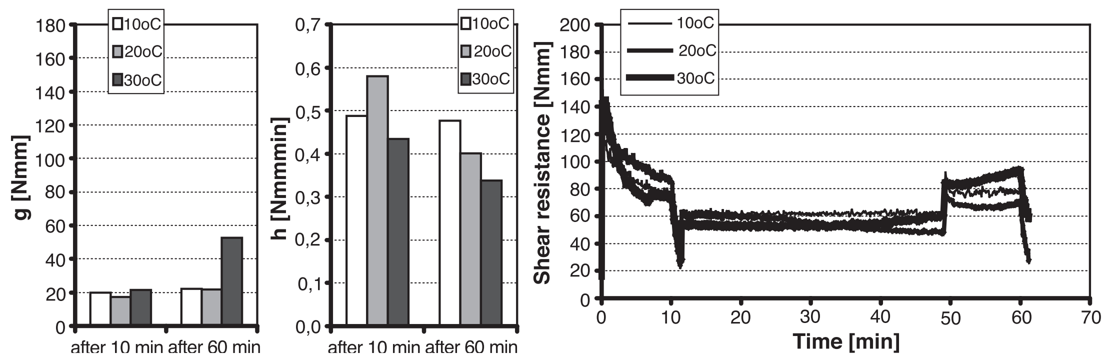


Fig. 23. Influence of temperature on rheological properties of mortars with PC1 type superplasticizer (cement type CEM II/B-S 32,5; $W/C = 0.40$; SP = 2.5%).

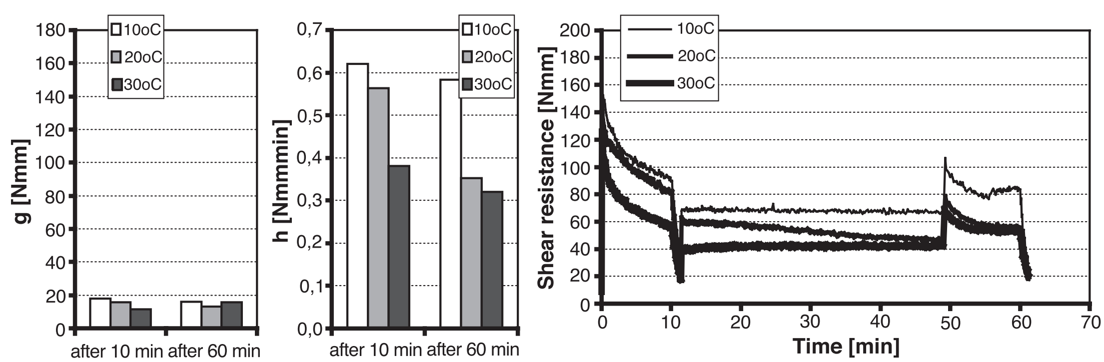


Fig. 24. Influence of temperature on rheological properties mortars with PC1 type superplasticizer (cement type CEM III/A 32,5; $W/C = 0.40$; SP = 2.5%).

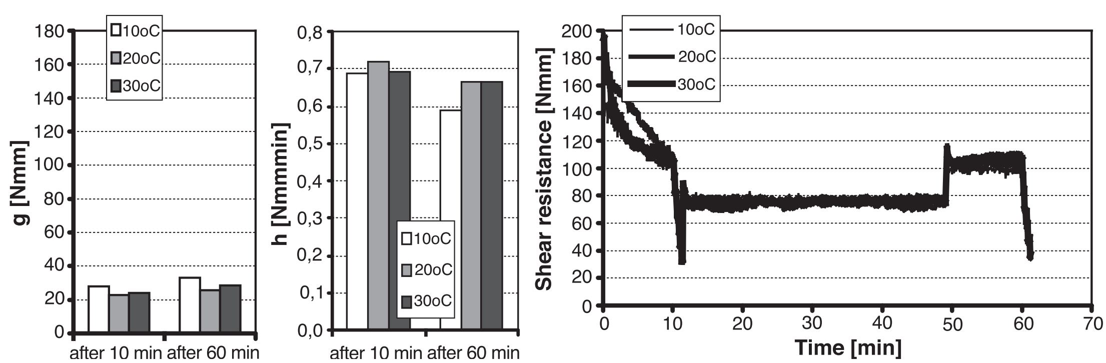


Fig. 25. Influence of temperature on rheological properties of mortars with AP type superplasticizer (cement type CEM II/B-S 32,5; $W/C = 0,40$; SP = 2.5%).

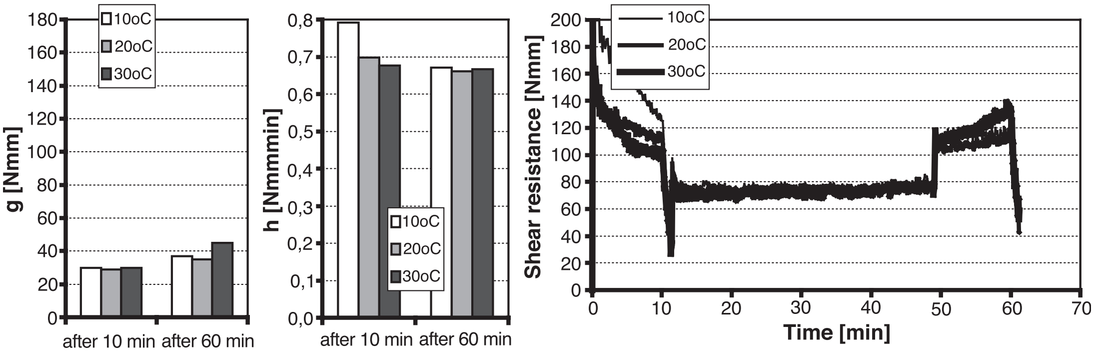


Fig. 26. Influence of temperature on rheological properties of mortars with PC2 type superplasticizer (cement type CEM III/A 32,5; $W/C = 0.40$; SP = 2.5%).

The shear resistance of mortars with PC1 superplasticizer is generally lower for mortars of given W/C ratio and of given SNF superplasticizer dosage at a given temperature. An increase of shear resistance with time at a temperature of 10 °C is, as a rule, very low and appears usually at the end of the testing period. At 20 and 30 °C temperatures, shear resistance of mortars with PC1 superplasticizer increases with time, but clearly to a lower degree than SNF3 mortars. The development of shear resistance also definitely starts later (Fig. 22).

Figs. 20, 23 and 24 show that the influence of temperature is particularly distinct, mainly for mortars with cement type CEM I. For mortars with CEM II and CEM III cements, the influence of temperature on shear resistance changes with time is clearly lower (Figs. 23 and 24). For mortars with CEM II, a significant constant increase in shear resistance can be observed only at a temperature of 30 °C. At temperatures of 20 and 10 °C, shear resistance remains constant until 40 and 50 min, respectively. For mortars with CEM III, g value is low and generally similar for all temperatures and does not change with time. Simultaneously, the h value of these mortars is relatively high, it strongly depends on temperature (the highest h value is at 10 °C, the lowest is at 30 °C) and decreases with time. Thus, the shear resistance of CEM III mortars tends to decrease with time. The low h value of mortars at 30 °C can cause the shear resistance of CEM III mortars to be lower at elevated temperatures, which is generally in opposition to CEM I and CEM II mortars.

Figs. 22, 25 and 26 show how other superplasticizers of AP and PC2 type perform in various temperatures. The performance is generally qualitatively similar, which is illustrated in the figures; the differences are of a quantitative nature.

7. Summary

Through the investigation with rotational rheometer, it is possible to precisely determine the influence of superplasticizers on the rheological properties of mortars. On the ground of this, it is possible to choose compatible cement–superplasticizer system and optimise the composition of mortar and concrete from workability point of view.

The results clearly show that the AP and PC type superplasticizers are more effective than SNF superplasticizers. Used in the same dosage, these superplasticizers make it possible to obtain mortars with considerably reduced g value and low workability loss. The characteristic of mortars with AP and PC superplasticizers is high h value, which is an advantage from the segregation point of view (e.g., the stability of SSC depends on high h value), but can cause some practical problems (e.g., with slip forming or equipment cleaning).

Using PC and AP superplasticizers, especially good results can be expected for low W/C ratio mortars or concretes. For plain concrete, with normal or high W/C ratio, the effectiveness of these superplasticizer is similar to SNF superplasticizers, and thus for economic reasons, their application is not beneficial.

The effectiveness of AP (and also PC) superplasticizers does not depend on the addition procedure. Thus, delayed addition to the mix is not necessary, which clearly eases the mixing process.

The type, chemical and phase compositions of the cement are the important factors for the performance of superplasticizers. Mortars of given superplasticizer type and dosage with different cements show clear differences in rheological properties. Relating these differences to physical and chemical properties of the cements and superplasticizers is the subject of ongoing studies.

Temperature influences the properties of mortars with superplasticizers. A drop of temperature usually decreases the g value but substantially increases h value; an increase in temperature causes these properties to move in opposite directions. The range of change of g and h values due to temperature also depends on W/C ratio and SP dosage; thus, the change in shear resistance of mortars can be qualitatively different for different W/C ratios and SP dosages.

Testing properties of mortars with rotational rheometer, it is also possible to recognise how other admixtures and additives, as air-entraining agents, accelerators, retarders, silica fume, fly ashes and slags, affect rheological properties of fresh concretes. The influence of these admixtures and additives is the subject of ongoing studies.

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