

Janusz Szwabowski – Jacek Gołaszewski \*

# NÁVRH SPRACOVATEĽNOSTI VYSOKOHODNOTNÉHO BETÓNU PRI POUŽITÍ REOMETRICKÉHO TESTU

## DESIGNING WORKABILITY OF HIGH PERFORMANCE CONCRETE USING RHEOMETRICAL WORKABILITY TEST

*Článok uvádza a dáva na diskusiu výsledky skúmania vzájomnej kompatibility medzi cementom a superplastifikátorom za prítomnosti prevzdušňovacieho prostriedku a kremičitého úletu. Prešetrovanie sa urobilo na štandardných typoch mált pri použití reometrického testu spracovateľnosti (RTS). Výskum bol prvým krokom k návrhu vysokohodnotného betónu určeného pre použitie v mostnej konštrukcii. Výsledky plne potvrdili použiteľnosť reometrického testu spracovateľnosti (RTS) na odhad systému kompatibility medzi cementom a superplastifikátorom, ako aj pre skúšky vplyvu prímies na reologické vlastnosti čerstvého betónu.*

*In the paper the results of investigation on cement/superplasticizer compatibility in presence of air entraining agent and silica fume are presented and discussed. Investigation was carried out on standard mortars using rheometrical workability test (RWT). The research was a first step in designing HPC to be used in bridge construction. The research fully proves usefulness of RWT for estimation of compatibility of cement/SP systems and for testing of admixtures influence on rheological properties of fresh concrete.*

### 1. Introduction

High performance concrete (HPC) is widely used in civil engineering as a structural material assuring high strength, durability and reliability of concrete structures. [1] Although, from a material point of view, HPC is nothing more than ordinary concrete with a very low porosity, its production causes technological problems. Low W/C, high dosage of superplasticizer (SP) and implementation of supplementary cementitious materials (usually silica fume (CSF)) [1], characteristic of HPC, cause problems mainly concerning workability. Thus, crucial for fresh HPC properties is to select an efficient SP which shows good rheological compatibility with cement. [1, 2] Compatible SP and cement should be defined as the very first step in HPC designing, and carrying it out of the presence of other admixtures and additives and condition of concreting should be taken into account.

At the present time it is impossible to know by looking at data of a particular cement and particular SP what rheological behaviour of fresh concrete can be obtained. [1, 2, 3.] Thus, it is necessary to perform a number of check tests to see how SP and cement work together. As performing concrete trial batches is time and material consuming, other methods, involving smaller amount of material and easier to implement and repeat, have been developed. These methods generally base on studying the rheological behaviour of grouts. [1, 2, 3.] Because of essential differences between rheology of grouts and fresh concretes the usability of these methods for concrete designing is very limited. [1, 4, 5] More complex and reli-

able information on rheological properties of fresh concrete can be obtained by testing rheological properties of modified standard mortars according to PN-EN 196-1 using rheometrical workability test (RWT). [4, 5] Because of similar behaviour of fresh mortar and fresh concrete, this method makes possible to define not only cement/SP compatibility but also gives a number of significant data about influence of SP on rheological properties of fresh concrete in presence of other admixtures and in different technological conditions. Because of qualitative nature of this data, optimal SP dosage should be defined using fresh concrete in the next steps of designing.

In the paper the results of investigation on cement/SP compatibility in presence of air entraining agent (AE) and silica fume (CSF) using RWT and standard mortars are presented and discussed. The research was the first step in designing of HPC to be used in a bridge construction. Rheological compatibility of cement and SP was assessed taking into consideration reduction of shear resistance of fresh mortars and changes of rheological properties in time. Because SP and admixtures can reveal significant secondary effects, their influence on setting time and compressive strength was also tested.

### 2. Experimental

Rheological compatibility was tested for two different CEM I 42.5 R cements and two SPs – of PC and SNF type. (Tables 1 &

\* Prof. dr. hab. inż. Janusz Szwabowski, Dr. inż. Jacek Gołaszewski

Silesian University of Technology, Department of Building Processes, ul. Akademicka 5, 44-100 Gliwice, Poland,  
Tel.: ++48-32-2372294, Fax: ++48-32-2372737, E-mail jski@polsl.gliwice.pl, jgolasz@polsl.gliwice.pl

2) In spite of higher effectiveness of PC than SNF type SP [for ex. 6], SNF usage was considered due to economical reason. Due to durability reason, AE and CSF were applied, and thus effect of these admixtures on rheological properties of mortars was also investigated. Mortars proportioning is presented in Table 3. Mortars were prepared according to PN EN 480-1:1999, mixing sequence is presented in Table 4.

Rheometrical workability test was performed using Viskomat PC viscometer (Fig. 1). Principles and methodology of RWT and characteristics of Viskomat PC are presented in detail in [5]. The measuring procedure used in the research, roughly simulating process of transport in truck concrete mixer, is presented on Fig. 1. Both rheological parameters were determined using the following equation:

$$T = N * h + g \quad (1)$$

where  $T$  - torque registered by rheometer

$N$  - rotation speed

$h$  - value of parameter related to plastic viscosity

$g$  - value of parameter related to yield value

In rheology the yield value and plastic viscosity are normally expressed in the conventional units as  $g$  and  $h$  respectively. These parameters can be transferred into the proper yield value and plastic viscosity terms by multiplying with certain viscometer - dependent factors. In the present work the conventional units are used. The final results of each test consist of: the yield value  $g$  and plastic viscosity  $h$  results, the correlation coefficient  $R$ , representing the degree of linearity ( $R$  gives the best fit of the Bingham rheological model to the practical behaviour of material, any non typical behaviour during the test is usually apparent by an outstandingly low value of  $R$ ) and estimation of the experimental errors of the yield value  $g$  and plastic viscosity  $h$  from correlation coefficients and linear regression.

Rheological properties were tested at 30 °C, only cement A and PC type SP mortars were tested at 20 °C to point out influence

of the temperature. Setting times were defined on mortars according to PN EN - 480-3:1999 at the temperature of 20 and 30 °C. Compressive strength was tested according to PN EN 196-1:1996.

Properties of tested superplasticizers.

Table 2

Admixture	Chemical base	Density [g/cm <sup>3</sup> ]	Concentration [%]
PC	polycarboxylate ester	1.09	36 %
SNF	naphthalene sulphonate acid	1.20	26 %

Procedure of mixing (modified procedure according to PN EN 480-1:1999).

Table 4

Action	Mixing speed	Time [s]
<b>Addition of cement, CSF and sand</b>		
Mixing	low	30 ± 2
<b>Addition of water (90 %) and SP</b>		
Mixing	low	30 ± 2
Mixing	high	30 ± 2
Break		90 ± 5
<b>Addition of water (10 %) and AE</b>		
Mixing	high	60 ± 5

### 3. Test results and discussion

Rheological properties of cement A mortars with PC SP and AE and CSF at 20 °C and 30 °C are presented in Figs. 2 & 3. At the temperature of 30 °C the yield value and plastic viscosity of mortars, and thus shear resistance are clearly higher than at 20 °C. Mortars containing only addition of SP show the highest shear resistance - the yield value and plastic viscosity for these mortars are also highest. Mortars with CSF show the lower yield value and plastic viscosity - as an effect of a higher paste volume because

Chemical and mineralogical composition of tested cements.

Table 1

Cement	Ingredients [%]											Specific surface [cm <sup>2</sup> /g]
	SiO <sub>2</sub>	CaO	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	Na <sub>2</sub> O <sub>e</sub>	SO <sub>3</sub>	C <sub>3</sub> S	C <sub>2</sub> S	C <sub>3</sub> A	C <sub>4</sub> AF	
A	19.7	62.3	6.3	2.5	2.2	0.74	3.1	49.1	19.7	12.5	7.6	3600
B	19.3	64.1	5.7	2.8	1.4	0.83	2.8	64.1	7.0	10.3	8.6	3602

Mix compositions.

Table 3

Additives	W/(C+CSF)	Ingredients [g/batch]					
		Cement	Sand	SP PC	SP SNF	AE (0,5%) mC	CSF (10% mC)
SP	0.40	450	1350	10.13	18	—	—
SP + AE	0.40	450	1350	10.13	18	2.25	—
SP + CSF	0.40	450	1305	10.13	18	—	45
SP + CSF + AE	0.40	450	1305	10.13	18	2.25	45

CSF was used as replacement of part of sand. However, it is important to remember that addition of CSF as cement replacement increases the yield value and thus significantly decreases workability of mortars. [7] An addition of AE significantly decreases the yield value and plastic viscosity and, consequently, the shear resistance – this effect is independent on CSF. At 20 °C changes in time of mortars workability are insignificant – only plastic viscosity slightly increases in time.

An increase of temperature clearly increases workability changes in time of mortar without AE addition – the yield value distinctly increases, and shear resistance shows tendency to increase in spite

of the decrease of plastic viscosity. In the case of AE mortars, due to an additional fluidising effect of such admixtures, workability changes in time are negligible.

For mortars with cement A and SNF SP to obtain the same yield value as for mortars with PC SP, two times higher dosage of admixture is necessary. (Fig. 4) In the same time, the plastic viscosity of SNF mortars is three times lower and thus shear resistance of these mortars is, in the beginning, clearly lower. However, in opposite to PC SP mortars, mortars with SNF SP, show a high workability loss during 60 min. This time the yield value rapidly increases, while the plastic viscosity significantly decreases – such

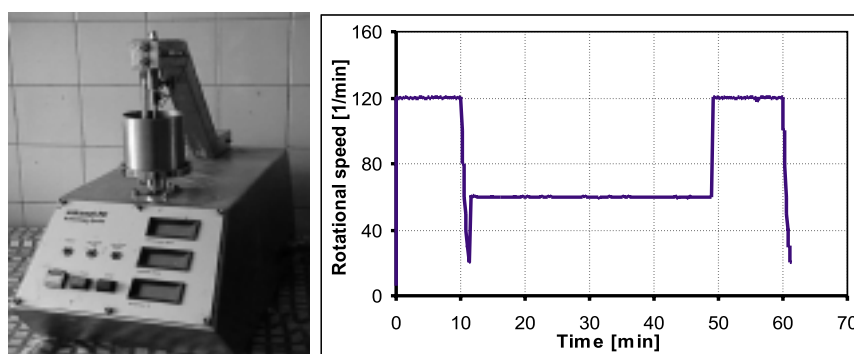


Fig. 1. Viskomat PC viscometer and measuring procedure used in tests

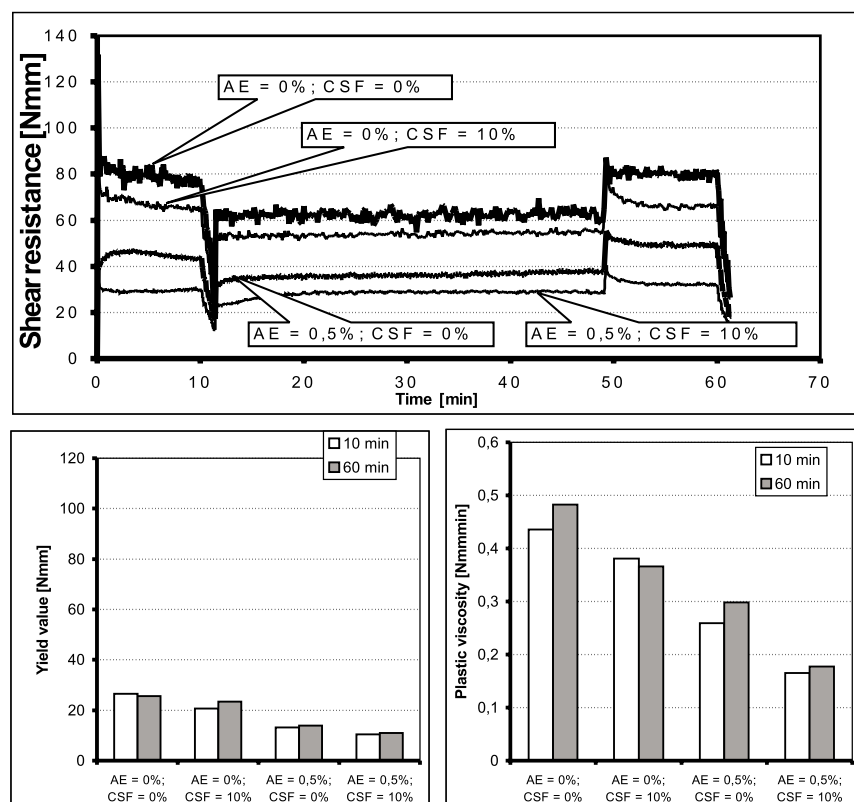


Fig. 2. Rheological properties of cement A mortars with PC SP (2.25 % C by weight), air entraining admixture (AE) and silica fume (CSF) at temperature of 20 °C; W/C = 0.40

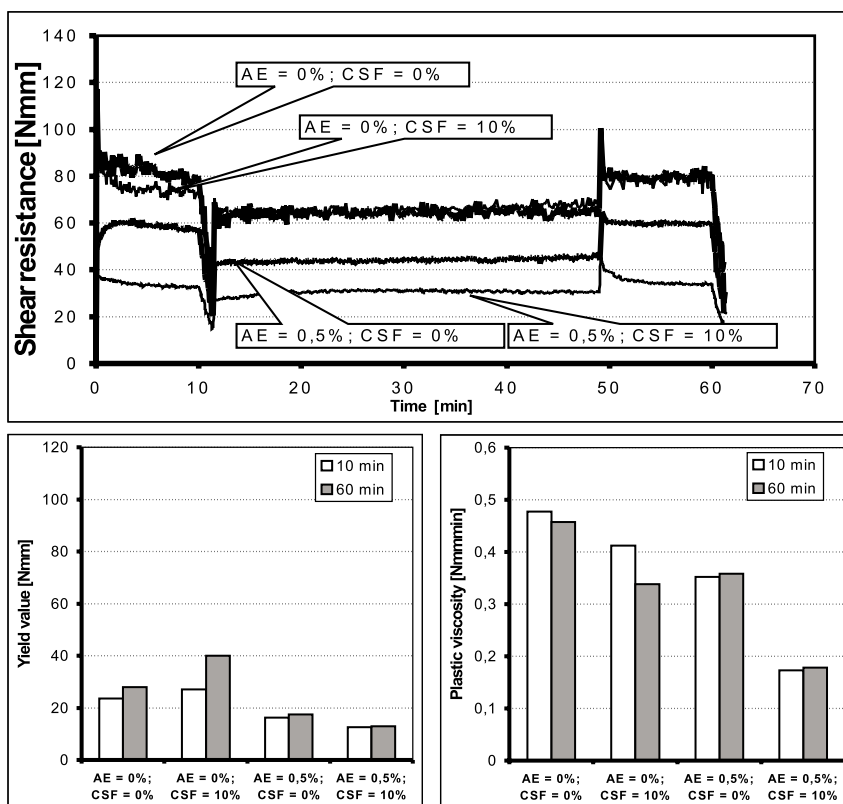


Fig. 3. Rheological properties of cement A mortars with PC SP (2.25 % C by weight), air entraining admixture (AE) and silica fume (CSF) at temperature of 30 °C; W/C = 0.40

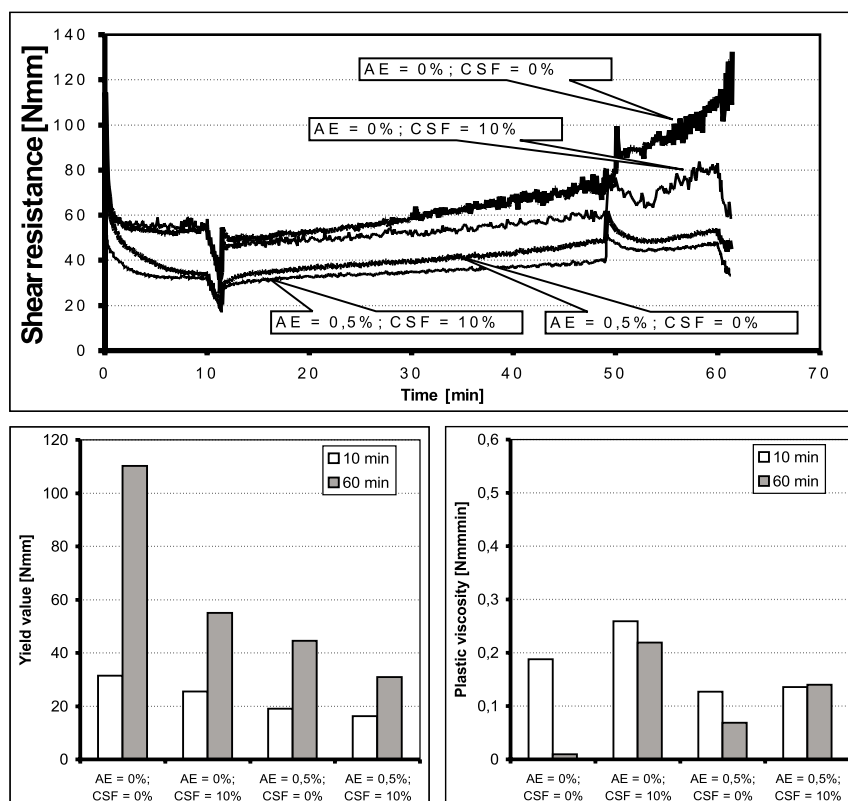


Fig. 4. Rheological properties of cement A mortars with SNF SP (4.0 % C by weight), air entraining admixture (AE) and silica fume (CSF) at temperature of 30 °C; W/C = 0.40

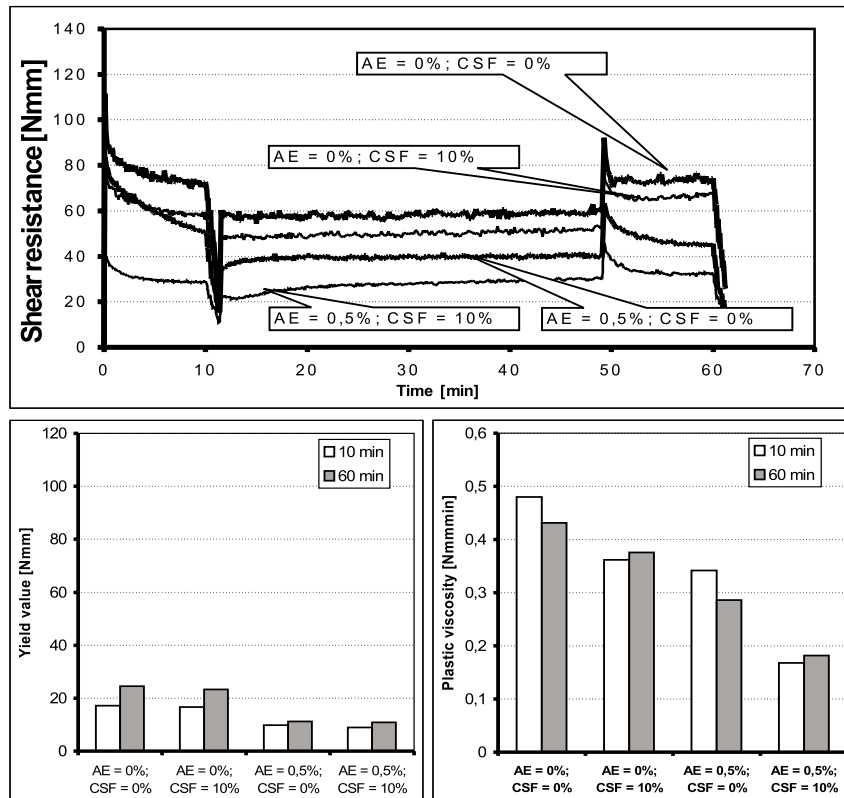


Fig. 5. Rheological properties of cement B mortars with PC SP (2.25 % C by weight), air entraining admixture (AE) and silica fume (CSF) at temperature of 30 °C; W/C = 0.40

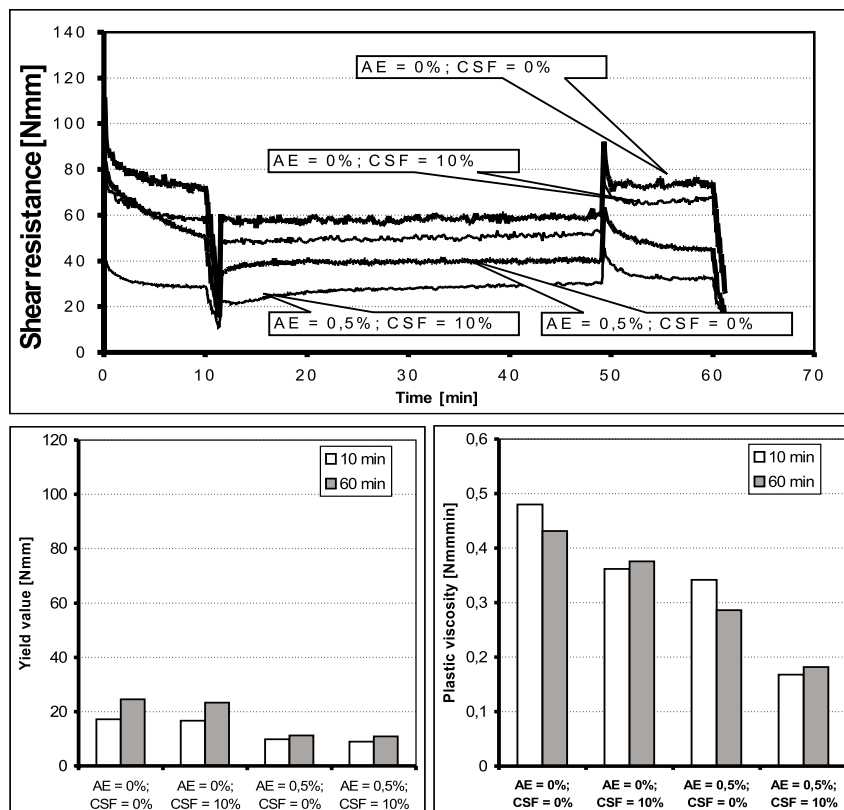


Fig. 6. Setting times of cement A & B mortars with PC SP (2.25 % of C by weight) and CSF (10 % of C by weight) and AE (0.5 % C by weight)

Compressive strength after 28 days of tested mortars [MPa].

Table 5

Cement	SP type	Temperature	SP	SP + AE	SP + CSF	SP + AE + CSF
A	PC	20 °C	51.7	30.5	68.1	34.5
A	PC	30 °C	52.9	34.3	70.0	40.6
A	SNF	30 °C	55.5	49.7	66.6	64.6
B	PC	30 °C	61.7	52.2	82.7	55.6

a meaningful changes in rheological properties of fresh concrete may be a result of technological problems during concreting and determine low usability of SNF SPs to HPC.

In Fig. 5 the effect of PC SP, AE and CSF on rheological properties of cement B mortars at the temperature of 30 °C is presented. These mortars show clearly a lower yield value and plastic viscosity than mortars with cement A at the same temperature (35 % and 10 % respectively). Mortars with cement B show also low changes of rheological properties in time – thus the workability is also very stable.

Effect of admixtures on cement A and B mortars setting at 20 and 30 °C is presented in Fig. 6. The increase of temperature significantly accelerates the setting of the mortars, but leaves enough time for safe concrete processing. Addition of SP retards the setting of mortars with cement A. In the case of cement B a disadvantageous effect of SP addition can be observed – an accelerated initial setting and, in the same time, a retarded end of the setting. Addition of AE and CSF retards the setting and covers a negative effect of SP on cement B mortars setting. At 30 °C the setting of cement B mortar with SP, AE and CSF is close to the control sample.

Compressive strengths of tested mortars are presented in Table 5. It is worth noticing that: mortars with cement B show clearly higher compressive strength than mortars with cement A. The addition of CSF causes a significant increase of compressive

strength but the addition of AE substantially decreases the compressive strength.

#### 4. Conclusions

The presented investigation makes possible to select cement B and PC SP as a rheologically compatible system suitable for designed HPC. Decisive for this choice are:

- a higher effectiveness of PC than SNF SP action – PC SP effectiveness can guarantee stable maintenance of high workability in time;
- a clearly better workability of cement B than cement A mortars at the same SP dosage – this make possible a higher reduction of water or reduction of SP dosage.
- satisfactory setting and strength properties of cement B mortars.

The obtained results also confirm that:

- the addition of AE improves workability of fresh concrete, which makes possible a reduction of SP dosage or W/C ratio;
- the temperature is an important factor influencing rheological properties of fresh concrete; effect of temperature is presented in detail and discussed in [7];
- a rheometrical workability test on modified standard mortars is a very effective method of the testing of cement/SP compatibility. RWT makes also possible a complex investigation of rheological properties of fresh HPC.

#### References

- [1] AITCIN, P. C.: *High Performance Concrete*. EF&N SPON 1998.
- [2] KUCHARSKA, L.: *Tradycyjne i współczesne domieszki do betonu zmniejszające ilość wody zarobowej*. Cement, Wapno, Beton. 2/2000
- [3] *Proceedings of the Sixth CANMET/ACI Internationale Conference „Superplasticizers and Other Admixtures”* Edited by V. M. Malhorta, Nice, France, 2000.
- [4] BANFILL, P. F. G: *The rheology of fresh mortar*. Mag. of Concrete Research, Vol. 43, 1991
- [5] SZWABOWSKI, J.: *Reologia mieszanek na spoiwach cementowych*. Wydawnictwo Politechniki Śląskiej, Gliwice, 1999
- [6] SZWABOWSKI, J., GOŁASZEWSKI, J.: *Metodyka badania efektywności działania domieszek uplastyczniających i upłynniających*. Kraków-Mogilany, III KNT MATBUD 2000
- [7] SZWABOWSKI, J., GOŁASZEWSKI, J.: *Wpływ superplastyfikatora i pyłu krzemionkowego na urabialność betonu wysokowartościowego*. Cement Wapno Beton. 6/1996