# INFLUENCE OF MORTAR VOLUME ON THE RHEOLOGICAL PROPERTIES OF FRESH HIGH PERFORMANCE CONCRETE

Jacek Gołaszewski

**Abstract**
The methodology and the results of the investigation into the influence of mortar volume in concrete on the fresh concrete rheological parameters and its changes with time are presented and discussed in the paper. Rheology results have been evaluated according to the Bingham model, which describes the rheology with the parameters: yield value and plastic viscosity. Rheological parameters were measured using Two-Point Workability Test. On the ground of obtained results and its statistical analysis it was shown that rheological parameters of fresh concrete and direction and range of its changes with time significantly depend on volume of mortar in fresh concrete, w/c ratio, superplasticizer content and interaction of these factors. Increasing volume of mortar and w/c ratio causes decrease in yield value *g* and plastic viscosity *h*. Yield value *g* of concrete mixtures increases with time. The nature of changes with time in plastic viscosity *h* of fresh concrete depends on mortar volume in concrete and w/c ratio. When mortar volume in concrete and w/c ratio are high plastic viscosity *h* increases with time. Together with decreasing mortar volume in concrete and w/c ratio plastic viscosity *h* shows tendency to decreasing with time. The range of changes of rheological parameters with time decreases, while superplasticizer content increases. It is also proved that results obtained with mortars may be used for predicting rheological behavior of fresh concrete. Designing and optimizing workability of fresh self-compacting concrete may be performed basing on measurements of rheological parameters of the fresh mortar.

**Keywords:** rheology, fresh concrete, high-performance concrete, self-compacting concrete

## 1 Introduction

From the point of view of workability forecasting and control, identification of fresh high-performance concrete rheological parameters and its changes with time in respect to material (properties of concrete ingredients, concrete proportioning) and technological (temperature) factors have essential significance [1-4]. In a recent years, a considerable number of studies concerning the rheological properties of cement based mixtures were done. It was stated, that the rheological parameters of fresh cement mixture and nature and range its changes with time depend mostly on cement and superplasticizer physicochemical properties, superplasticizer content, time of superplasticizer addition, w/c ratio and temperature. Detailed information on influence of these factors on changes of rheological properties of fresh concrete is presented in existing literature [1 - 7]. Simultaneously analysis of so far executed studies indicates, that the nature and range of changes of rheological properties of fresh concrete in time may also be related to the cement paste volume (or mortar volume) content in this material [8].

The methodology and the results of the investigation into the influence of mortar volume in concrete on the fresh concrete rheological parameters and its changes with time are presented and discussed in the paper.Additionally the possibility of prediction of changes in rheological properties of fresh concrete in time basing on testing of mortars properties was proved.

## 2 Experimental

### 2.1. Measurements of rheological parameters of fresh mortar and concrete

So far executed laboratory studies show that rheological behaviour of fresh concrete mixtures may be sufficiently enough described by the Bingham model according to equation:

$$\tau = \tau_o + \dot{\gamma}\, \eta_{pl} \tag{1}$$

where: $\tau$ (Pa) is the shear stress at shear rate $\dot{\gamma}$ (1/s) and $\tau_o$ (Pa) and $\eta_{pl}$ (Pas) are the yield value and plastic viscosity respectively [6, 9, 10]. Yield value $\tau_o$ determines the value of load necessary for producing mixture flow. When the shear stress $\tau$ surpass yield value $\tau_o$ the flow of mixture occurs, and the resistance of the flow depends on plastic viscosity $\eta_{pl}$; the bigger the plastic viscosity $\eta_{pl}$ of the mixture, the smaller the speed of its flow.

The rheological parameters of fresh concrete or mortar can be measured by applying no less than two considerably different shear rates *N* and the measuring the resulting shear stresses *M*. The rheological parameters are determined by regression analysis according to the relation:

$$\mathrm{M} = g + h\,\mathrm{N} \tag{2}$$

where $g$ (N.m) and $h$ (N.m.s) are rheological constants corresponding to yield value $\tau_o$ and plastic viscosity $\eta_{pl}$ respectively. After determining measurement constants of rheometer one may, if necessary, represent the values $g$ and $h$ in physical units. The method of determining measurement constants of rheometer are presented in [9]. Theoretical basis and rules for rheological measurements are discussed widely in monographic studies [6, 9, 10].

### 2.2. Testing program

In the research the influence of mortar volume in concrete and superplasticizer content on rheological parameters of fresh concrete different in w/c ratio was investigated. Four degrees of filling the voids of coarse aggregate with mortar were adopted, corresponding with mortar to concrete volume proportion: $Z_V$ = 1.00, 0.66, 0.61, 0.56 and two levels of w/c ratio: w/c = 0.30, 0.35 (Table 1). Superplasticizer content was changed in range from 1 to 3% of cement by mass (w/c = 0.30) or in range from 1,5% do 3% by mass (w/c = 0.35). Factors taken into consideration and their levels are shown in Table 1. Additionally influence of superplasticizer content on rheological parameters of fresh concrete of w/c = 0.40 and Zv = 0.64 was investigated. Levels of factor were chosen according to proportioning recommendation for high performance and self-compacting concretes [4, 5, 11].

### 2.3. Materials features and compositions of mixtures

Properties of cement CEM II/B-S 32,5 R and superplasticizer used in tests are given in Table 3 and 4 respectively. The mortars have been designed with sand to cement ratio P/C = 1.5, and they have been prepared from sand of grading index $U_k$ = 3.43. Coarse aggregate 2 ÷ 8 mm of graining index of $U_k$ = 6.40 were used to concrete. Sieve grading for sand and aggregate are given in Fig. 1. Compositions of mixes are presented in Table 2.

Table 1 Research program

| $Z_V$ | w/c | Superplasticizer content |
|---|---|---|

| | | |
|---|---|---|
| 0,68 | 0,30 | 1,5; 2,0; 2;5; 3,0 |
| | 0,35 | 1,0; 1,5; 2,0; 2;5; 3,0 |
| 0,64 | 0,30 | 1,5; 2,0; 2;5; 3,0; 3,5 |
| | 0,35 | 1,0; 1,5; 2,0; 2;5; 3,0 |
| | 0,40 | 0,5; 1,0; 1,5; 2,0; 2; |
| 0,58 | 0,30 | 2,0; 2;5; 3,0; 3,5 |
| | 0,35 | 1,0; 1,5; 2,0; 2;5; 3,0 |

Table 2 Proportioning of mortars and concretes

| Mortar to concrete volume proportion $Z_V$ | Ingredients, kg/m$^3$ | w/c ratio 0,30 | 0,35 | 0,40 |
|---|---|---|---|---|
| | Mortars | | | |
| $Z_V = 1$ | C | 841 | 807 | 776 |
| | P | 1262 | 1211 | 1164 |
| | W | 252 | 282 | 310 |
| | Fresh concretes | | | |
| $Z_V = 0,68$ | C | 570 | 554 | |
| | P | 855 | 831 | |
| | K | 855 | 831 | |
| | W | 171 | 194 | |
| | $\varphi_{m/a}$ | 1,06 | 1,10 | |
| $Z_V = 0,64$ | C | 532 | 518 | 505 |
| | P | 797 | 777 | 757 |
| | K | 975 | 949 | 926 |
| | W | 159 | 181 | 202 |
| | $\varphi_{m/a}$ | 0,86 | 0,90 | 0,94 |
| $Z_V = 0,58$ | C | 491 | 479 | |
| | P | 736 | 718 | |
| | K | 1104 | 1077 | |
| | W | 147 | 168 | |
| | $\varphi_{m/a}$ | 0,70 | 0,73 | |

C - cement; W - water, P - sand 0 - 2 mm; K - aggregate 2 - 8 mm;
$\varphi_{m/a}$ - , degree of filling the aggregate with mortar

Table 3 Properties of cement CEM II/B-S 32,5 R

| Ingredients, [%] $SiO_2$ | $CaO$ | $Al_2O_3$ | $Fe_2O_3$ | $MgO$ | $Na_2Oe$ | $SO_3$ | Specific surface, [m$^2$/kg] |
|---|---|---|---|---|---|---|---|
| 24,7 | 56,7 | 6,3 | 2,3 | 2,9 | 0,70 | 3,2 | 325 |

Table 4 Properties of superplasticizers

| Major constituent | Density, [g/cm$^3$] | Concentration, [%] |
|---|---|---|
| polyeter | 1,09 | 34 |

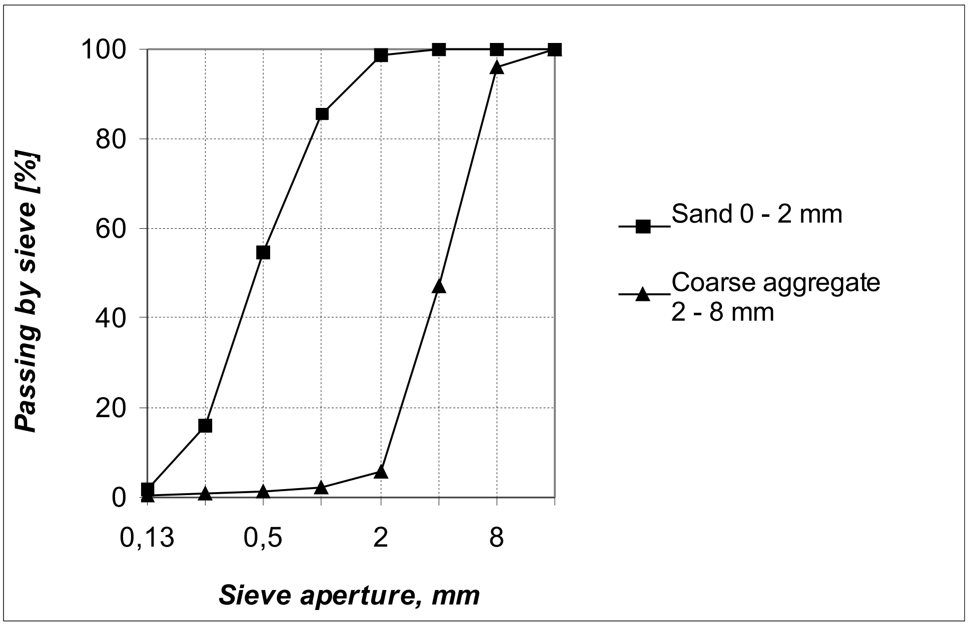


Figure 1: Aggregate grading

**2.4. Testing method**

The mixtures have been prepared in pan mixer of 50 $dm^3$of volume. Measurement of rheological parameters has been performed using BT2 rheometer for flowing fresh concretes (of slump at least 200 mm). BT rheometer is presented in Fig. 2. To execute the measurement, a sample of testing material is placed in a sample container, the BT2 rheometer is placed in the middle of measurement container, and subsequently one full turn is performed. During this turn the moment is measured on two probes, as well as angular velocity. On this basis values of rheological parameters of the mix are calculated. Rules and method of rheological parameters measuring using BT2 are discussed with details in [12]. In the tests a fixed time of measurement (of complete turn) was adopted, equal to 15±2 s. As measurement constants have not been yet determined for BT2 rheometer, measured rheological parameters are presented in conventional units. For each tested mixture at least four measurements of rheological parameters have been carried out after 5 and 60 min after end of mixing.

Figure 2: BT 2 rheometer

# 3 Results and discussion

Rheological parameters of mortars analogical to mortars filling the voids of aggregate of tested fresh concretes decrease with increasing quantity of addend superplasticizer and increase with decreasing w/c ratio (Fig. 3). Yield value g of mortars shows weak tendency to increase with time, more visible for mortars of lower w/c ratio and lower superplasticizer content. Plastic viscosity h of mortars generally does not change with time. Only when w/c ratio and superplasticizer addition are low, weak tendency to plastic viscosity h decrease with time. It should be noted that rheological parameters yield value *g* and plastic viscosity *h* of fresh concretes are on the average respectively 40 and 20 times higher then of fresh mortars.

As comparison between relationships obtained for mortars (Fig. 3) and for fresh concretes (Fig 5 - 7) indicate, the nature of changes in yield value *g* and in plastic viscosity *h* of fresh concrete and mortars analogous to the mortars is generally analogical. However, in the case of mixtures of low w/c ratio and superplasticizer addition and when volume of mortar in concrete is low, nature of plastic viscosity *h* changes in mortar and concrete may be different. In the Fig. 4 linear relations are given, enabling converting the values of mortar rheological parameters obtained during measurements (of proportion P/C = 1.5 with superplasticizer) into rheological features of concrete mixture with coarse aggregate of maximum size of 8 mm and of different volume of the analogous mortar ($Z_v$ ratio). In general these relations confirms relations presented in [13], at the same time showing that in case of concrete mixtures of low volume of mortar predicting of plastic viscosity *h* may be incorrect. One should also pay attention to a certain difficulty. Small range of changes in yield value *g* for mortar is accompanied by very big range of changes in yield value g for concrete mixtures. This forces the necessity of the very precise determination of yield value *g* for mortar.

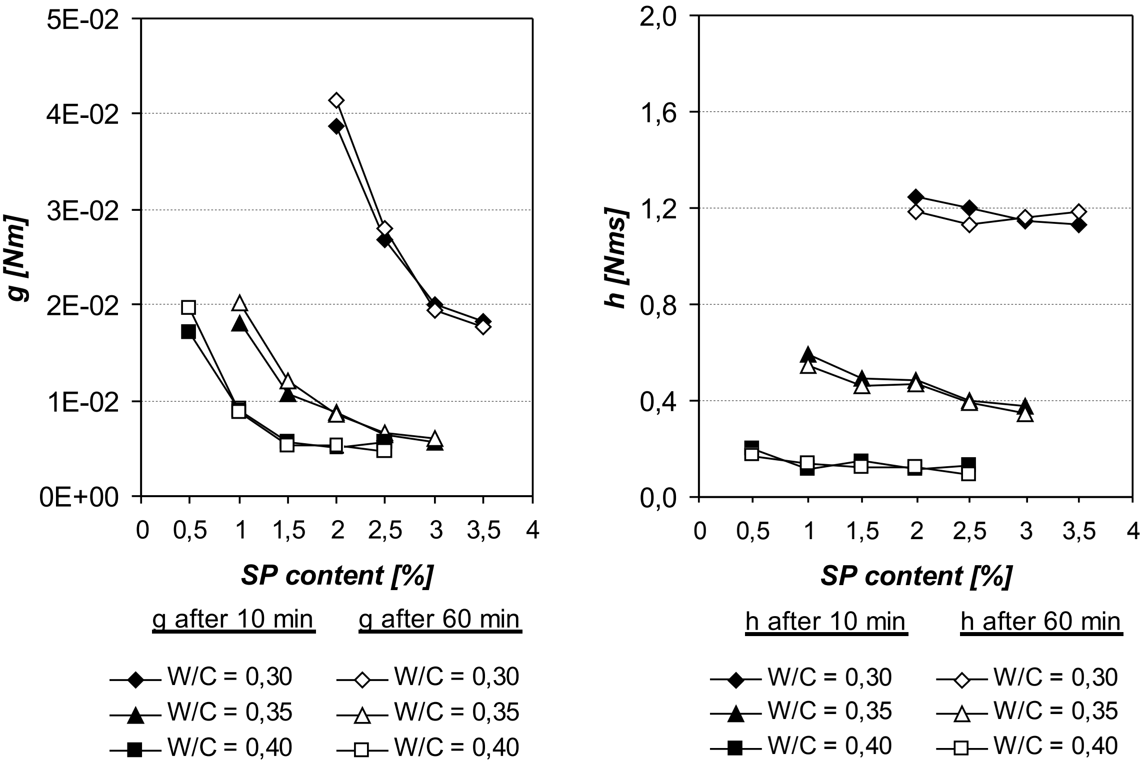


Figure 3: Influence of superplasticizer cotent on rheological properties of mortars used in investigation.

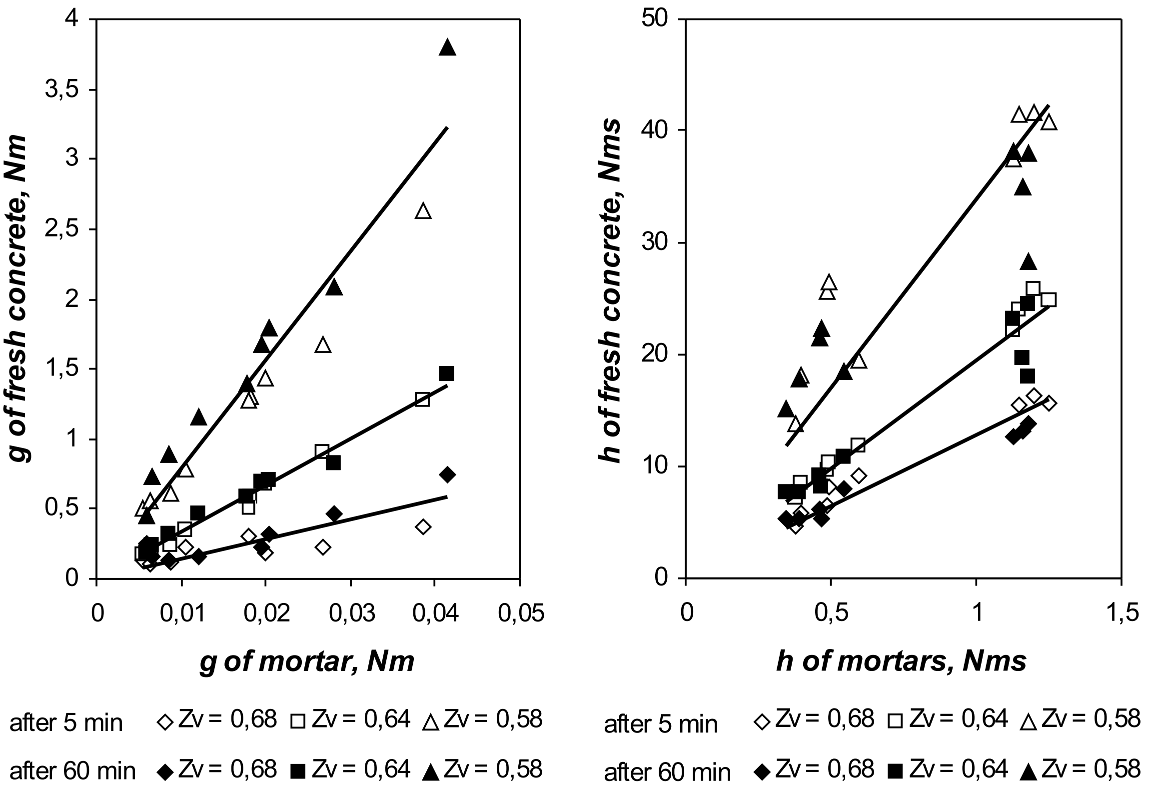


Figure 4: Rheological parameters of mortars and rheological parameters of fresh concrete of fresh concrete after 5 and 60 min after the end of mixing.

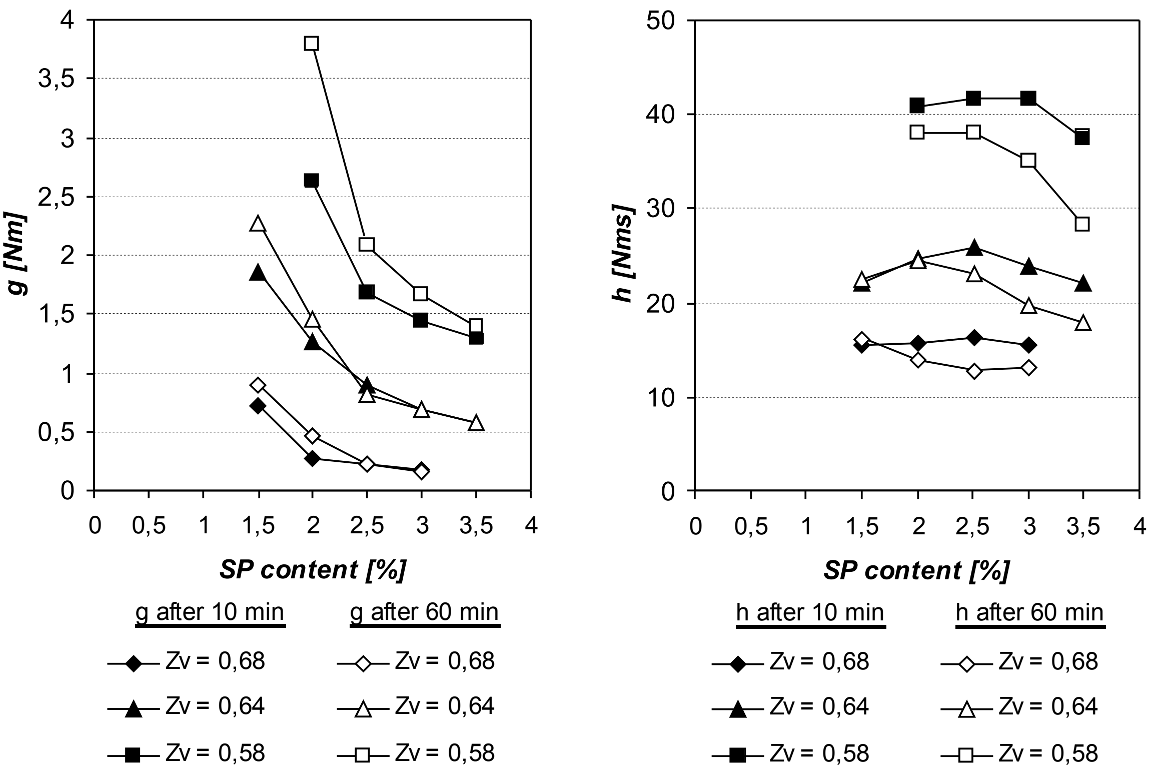


Figure 5: Influence of mortar volume in concrete and superplasticizer content on rheological properties of w/c = 0.30 fresh concrete.

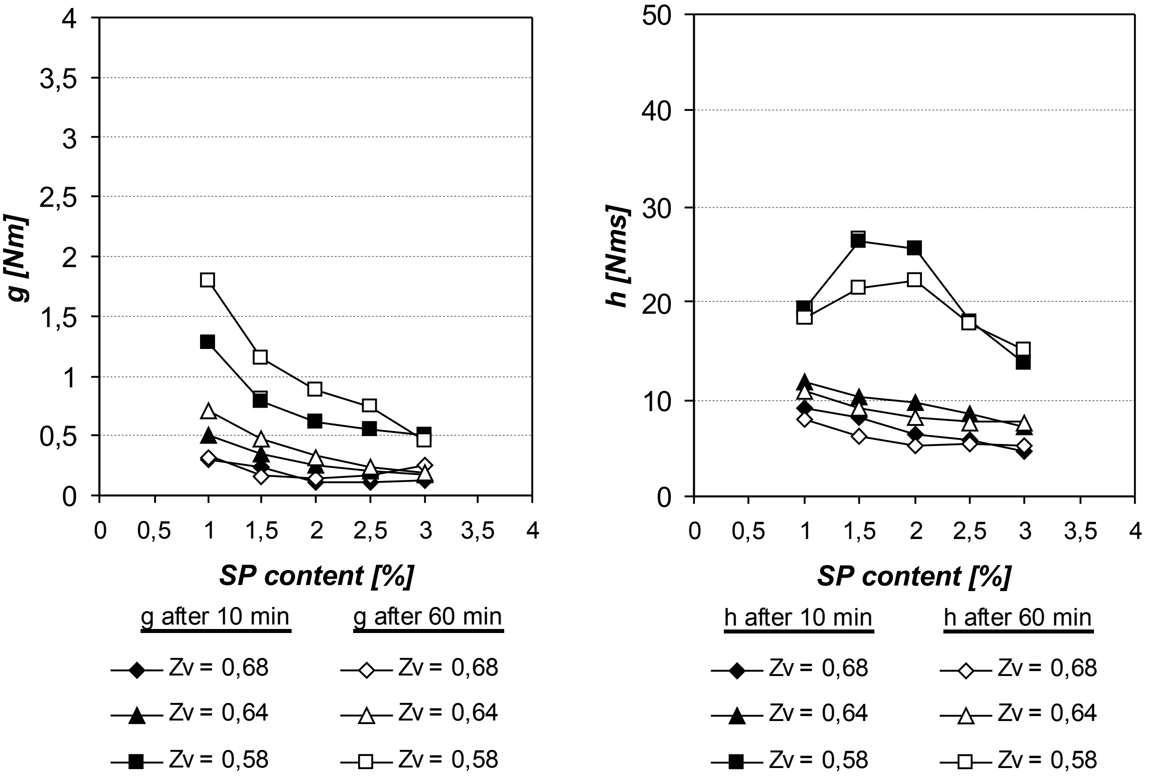


Figure 6: Influence of mortar volume in concrete and superplasticizer content on rheological properties of w/c = 0.35 fresh concrete.

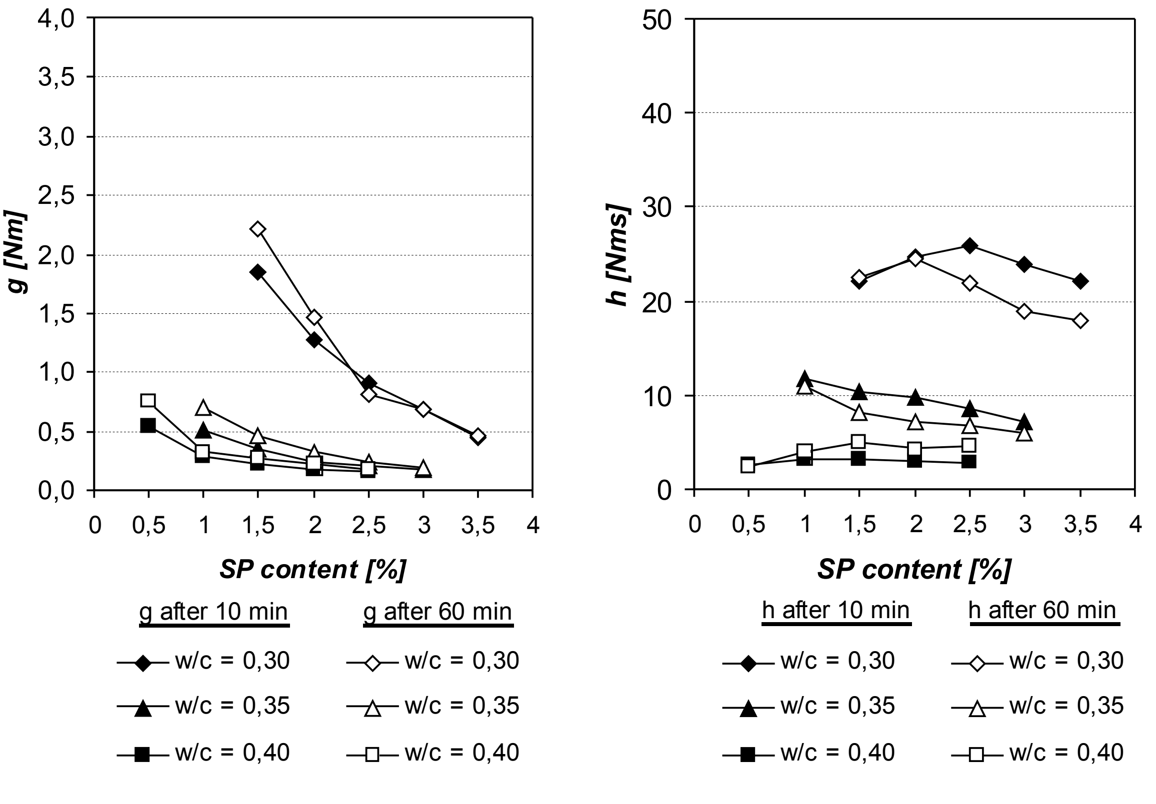


Figure 7: Influence of w/c ratio and superplasticizer content on rheological properties of fresh concrete of $Z_V = 0{,}64$

Table 5 Analysis of variance ANOVA of influence of time w/c ratio, mortar volume and superplasticizer content on yield value *g* and plastic viscosity *h* of fresh concrete in 10 and 60 min after end of mixing

| Source of variation | Yield value *g* | | Plastic viscosity *h* | |
|---|---|---|---|---|
| | F-ratio | α | F-ratio | α |
| A: Time | 24,208 | 0,000 | 15,898 | 0,000 |
| B: w/c ratio | 558,767 | 0,000 | 1780,920 | 0,000 |
| C: Mortar volume | 356,452 | 0,000 | 1175,613 | 0,000 |
| D: SP content | 92,139 | 0,000 | 11,918 | 0,000 |
| AB | 8,406 | 0,004 | 7,472 | 0,007 |
| AC | 12,453 | 0,000 | 2,065 | 0,131 |
| BC | 143,799 | 0,000 | 61,491 | 0,000 |
| AD | 4,841 | 0,003 | 0,092 | 0,964 |
| BD | 55,685 | 0,000 | 11,622 | 0,000 |
| CD | 21,119 | 0,000 | 3,155 | 0,007 |

Obtained relations of mortar volume influence in concrete and superplasticizer content on rheological parameters of fresh concrete are presented in Fig. 3, 5, 6 and 7. The analysis of variance ANOVA of time influence, w/c ratio, mortar volume in concrete and superplasticizer content on rheological parameters of fresh concrete are presented in Tables 5.

Increasing w/c ratio, increasing mortar volume in concrete and increasing superplasticizer content causes decrease in yield value *g* of fresh concrete (Fig. 5 - 7). Influence of increasing w/c ratio on decrease in yield value *g* is the greater the more mortar is in concrete mixture. Increasing volume of mortars causes considerable decrease in yield value *g* of w/c = 0.30 concrete mixtures. Similar tendency occurs in w/c = 0.35 concrete mixtures, but in that case decrease in field value *g* due to increase mortar volume in concrete is clearly weaker. Independently on mortar volume in concrete and on w/c ratio increasing addition of superplasticizer causes initially fast decrease of yield value *g* of fresh concrete until a certain minimum. Further increasing of superplasticizer content only insignificantly changes the yield value *g*. As may be seen from obtained results, for concretes with small mortar volume and/or low w/c ratio changes of yield value *g* when superplasticizers quantity increases are great and reduce as mortar volume in concrete and/or w/c ratio increase. Simultaneously, the lesser is mortar volume in concrete and/or w/c ratio, the higher superplasticizer addition is necessary to obtain fresh concrete of given yield value *g*. It is also worth to notice, that if mortar volume in concrete mixture is small, obtainment of fresh concrete of similar yield value *g* as for fresh concrete with high volume of mortar is difficult, even if quantity of added superplasticizer is very large.

Yield value *g* of all tested fresh concretes, independently on mortar volume, w/c ratio and superplasticizer content, increases with time. The range of increase of yield value *g* with time is lesser when w/c ratio, superplasticizer content and/or cement paste volume in mortar (factor $\varphi_{m/p}$) are larger. It is worth to mention, that obtaining fresh concrete of insignificant changes of yield value *g* with time demands a considerably higher quantity of added superplasticizer then obtaining minimum yield value *g* directly after the end of mixing.

Plastic viscosity *h* of fresh concrete decreases with increasing w/c ratio and/or mortar volume in concrete. Influence of mortar volume in concrete on plastic viscosity *h* decreases with increasing w/c ratio. The influence nature of superplasticizer content on plastic viscosity *h* of fresh concrete, in opposition to nature of influence on yield value *g*, depends on mortars volume in concrete and w/c ratio.

In case of concrete mixtures of w/c = 0.30 increase of superplasticizer content initially increases plastic viscosity *h* and then, after reaching some maximum value, plastic viscosity *h* decreases. Range of such changes decreases as mortar volume in concrete increases, but generally is not too great and only in limited extent influences rheological properties of mortars. In case of mortars of w/c = 0,.35 and 0.40 superplasticizer content usually causes decrease in plastic viscosity *h*. Such effect is the lesser the higher volume of mortar in concrete is. Only for fresh concrete of w/c = 0.35 and low mortar volume ($Z_V$ = 0.58) increasing superplasticizer content initially causes increase in plastic viscosity *h*.

The nature of changes in plastic viscosity *h* with time of fresh concrete depends mainly on w/c ratio. In case of concrete mixtures of w/c = 0.30, plastic viscosity *h* decreases with time. Range of these changes is the higher the lower mortar volume in concrete is, and the higher superplasticizer content is. When the mortar volume is high and superplasticizer addition is low, the changes in plastic viscosity *h* with time may be insignificant. In case of concrete mixtures of w/c = 0.35, direction of changes in plastic viscosity with time depends on mortar volume in concrete. For concrete mixtures of $Z_V$ = 0.58 and 0.64 plastic viscosity *h* decreases with time, and for concrete mixtures of $Z_V$ = 0.68 increases with time. The range of these changes decreases with increasing superplasticizer content. In case of concrete mixtures of w/c = 0.40, plastic viscosity *h* increases with time.

## 4 Conclusions

Increasing volume of mortars causes decrease in yield value *g* and plastic viscosity *h*. Yield value *g* of concrete mixtures increases with time. The range of these changes increases with decreasing mortar volume in concrete, decreasing w/c ratio, and decreasing superplasticizer content. The nature of changes with time in plastic viscosity *h* of fresh concrete depends on mortar volume in concrete and w/c ratio. When mortar volume in concrete and w/c ratio are high plastic viscosity *h* increases with time. Together with decreasing mortar volume in concrete and w/c ratio plastic viscosity *h* shows tendency to decreasing with time. Generally, the range of changes of rheological parameters decreases with time, while superplasticizer content increases. Only in case of w/c = 0.30 mixtures the tendency to increase in range of plastic viscosity *h* with time due to increasing superplasticizer content can be observed.

The results obtained with mortars generally may be used for predicting trends of changes in rheological behavior of fresh concrete with time. Thus, designing, optimizing, controlling and correcting workability of fresh concrete may be performed on the basis of measurements of the mortar's rheological parameters. However, presented research was performed in relatively narrow range. Thus further tests are necessary, comprising mortars and mixtures of different proportions of constituents, different rheological characteristics, as well as aggregates of different type and grading.

## References


[1] Punkki J., Gołaszewski J., Gjørv O.E. 1996: Workability loss of High-Strength Concrete. *ACI Materials Journal, V.93, No. 5*: 427 - 432

[2] Aitcin, P-C. 1998: *High Performance Concrete,* London: EF&N SPON

[3] Neville, A M. 2000: *Properties of concrete,* Kraków: Polski Cement (in polish)

[4] Giergiczny Z., Małolepszy J., Szwabowski J., Śliwiński J. 2002: *Cements with mineral additives in technology of new generation concretes,* Opole: Wydawnictwo Instytut Śląski sp. z o.o. w Opolu (in polish)

[5] Collepardi M. A. 2006: *The New Concrete,* Treviso: Grafiche Tintoretto

[6] Szwabowski, J. 1999: *Rheology of cement binders based mixtures,* Gliwice: Wydawnictwo Politechniki Śląskiej (in polish)

[7] Gołaszewski, J. 2006: *Influence of superplasticizers on rheological properties of cement binder mixtures in the system of variable technological factors*, Gliwice: Wydawnictwo Politechniki Śląskiej (in polish)

[8] Gołaszewski J. 2006: The influence of cement paste volume in mortar on the rheological effects of the addition of superplasticizer, *Proceeding of 8th International Conference Brittle Matrix Composites, Ed. A.M. Brandt, Warszawa, Poland*: 441 - 449

[9] Ferraris Ch. F. 1999: Measurement of the Rheological Properties of High Performance Concrete: State of Art Report. *Journal of Research of the National Institute of Standards and Technology, Vol. 104, No. 5:* 461 - 478.

[10]Tattarsall, G H, Banfill, P F G. 1983: *The Rheology of Fresh Concrete*, Boston: Pitman Books Limited

[11]2005: *The European Guidelines for Self-Compacting Concrete Specification, Production and Use,* EFNARC Report

[12]Greim M. 1997: Rheological Measurement on Building Materials, a Comprehensive Research Program, *Annual Transactions of the Nordic Rheology Society, Vol. 5*: 13 - 26.

[13]Gołaszewski J. 2006: Rheology of fresh mortars and fresh concretes, *Cement Wapno Beton, Nr 1*: 17-28.



***Jacek Gołaszewski, D.Sc., Ph.D.****, Department of Building Processes in the Faculty of Civil Engineering at the Silesian University of Technology, Akademicka 5, 44-100 Gliwice, Poland*
*Tel: +48 32 237 22 94, fax: +48 32 237 27 37, e-mail: jacek.golaszewski@polsl.pl*