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Influence of Type of Cement on The SCC Formwork Pressure During and After Casting

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Abstract. Formworks for SCC are usually designed under the assumption of full hydrostatic pressure. Nevertheless, current research is attempting to explain the mechanism of this phenomenon as observed pressure usually is at the lower lever than expected. This causes formworks for SCC are usually overdesigned. It was noticed the rheological properties of fresh concrete might be a key to predict the SCC formwork pressure. Therefore, knowing the influence of fresh concrete properties on formwork pressure will enable to design formworks more efficiently. This paper presents the influence of type of cement on formwork pressure caused by SCC. Mixes were design under the assumption of equal dispersion ratio. Three types of cement were investigated: portland, blast furnace and composite cement with a different w/c ratio (0.30, 0.40) and in presence of carboxyl ethers superplasticizer. Formwork pressure was determined on the element imitating a column with dimensions of 0.20x0.20m and a height of 1.20 m with casting speed of 7 m/h. Results show the formwork pressure was registered at the lower than hydrostatic level. Rheological properties had an influence on formwork pressure. It was noticed the different cement types had an influence on rheological properties. Lateral pressure reduction over time was observed with the intensity depending on the cement.

1. Introduction

Mixtures of self-compacting concrete are mixtures with appropriate rheological properties that ensure the ability to fill the mould, cover the reinforcement and remove the air from its volume without the influence of external loads. The compaction process takes place only under the influence of its own weight, hence the necessity of proper mixing of the mixture. The necessity to ensure appropriate fluidity and viscosity that ensures the resistance to segregation of mixture components causes many problems in the construction practice. This is one of the reasons why the participation of self-compacting concrete mixtures in the global production of concrete mixtures is difficult to consider as large. The second reason for this is the lack of generally accepted methods for forecasting the pressure of the mix of self-compacting concrete on the formwork. Most often, formwork for the construction of self-compacting concrete is designed with the condition of hydrostatic pressure. However, measured lateral formwork pressure during the casting showed results quite opposite to what was presupposed. The pressure was far from hydrostatic [1]. Nevertheless, limited knowledge the influence of SCC on formwork pressure has the designers use hydrostatic pressure as the safest method to predict lateral pressure [1-7]. Nevertheless, research shows the assumed pressure could be reduced to a range

between 18 and 99% of hydrostatic [1, 4, 7, 11, 12,13]. Changes under load are rheological, well described in detail in [1, 8, 9, 14]. Studies [1, 8, 9, 10, 15] show and it is commonly accepted, the rheological behaviour of fresh concrete may be sufficiently described by the Bingham model's rheological parameters: yield stress and plastic viscosity. The rheological properties of concrete mixes are highly dependent on the cement type, superplasticizer and w/c ratio. By properly choosing the component of the mixture, we can shape workability and its changes over time. That gives a chance to shape the load applied on the mix on the formworks. Besides Bingham's parameters the SCC formwork pressure depends on static yield stress and thixotropic behaviour (A_t index) [16]. Intensity of those decides about stiffening which leads to pressure reduction. The stiffness clearly depends on the binder type which is expressed by the rheological properties [16]. Therefore, depends on concrete composition. This paper presents an influence of cement type and w/c on formwork pressure determined on the element imitating a column with dimensions of 0.20x0.20m and a height of 1.20 m. SCC were in the presence of carboxyl ethers superplasticizer. Portland, blastfurnace and composite cement was used. W/c coefficient was on level of 0.3 and 0.4. Column casting speed was 7 m/h.

2. Experimental details

2.1. Materials and concrete composition
Research was conducted with different w/c ratio (0.30, 0.40), commonly produced cement (CEM I 42.5 R, CEM III/A 42.5N-HSR/NA, CEM V (S-V) 32.5R-LH), and carboxyl ethers superplasticizer. Tests were carried out at constant temperature of 20ºC. The compositions of fresh concretes are shown in Table 1. All mixes have the same cement paste volume. A natural sand 0-2 mm and gravel was used as 2-8 mm aggregate. The amount of superplasticizer was selected in such a way that the mixes characterized with similar flow diameters after mixing the components.

Table 1. Concrete mix composition.

Concrete	w/c ratio	Cement	Cement, kg/m^3	SP, %C	Sand content, kg/m^3	Aggregates, kg/m^3	Sand ratio %
SCC1		CEM I	580	2.00			
SCC2	0.3	CEM III	579	1.00			
SCC3		CEM V	559	2.00	884	780	53.2
SCC6		CEM I	510	0.75			
SCC7	0.4	CEM III	504	0.50			
SCC8		CEM V	493	0.75			

2.2. Testing procedures
The rheological parameters were determined using rotational rheometer Viskomat XL by regression analysis according to the relation (1) corresponding to a Bingham model:

$$T = g + h \cdot N \tag{1}$$

where *g* [Nmm] and *h* [Nmms] are rheological constants corresponding to Bingham yield stress and plastic viscosity respectively After determining the measurement constants of the rheometers the values *g* and *h* may be represent in physical units. For purpose of this work both *g* and *h* are named as respectively yield stress and plastic viscosity. The rotational speed for Viskomat XL and the time of measure is shown in Figure 2 (left). The proposed procedure allows to measure: the 1st and 2nd static yield stress (g_{stat}), the nature of the hysteresis loop, the dynamic yield stress (*g*) and plastic viscosity (*h*) during one measure (Figure 2 right).
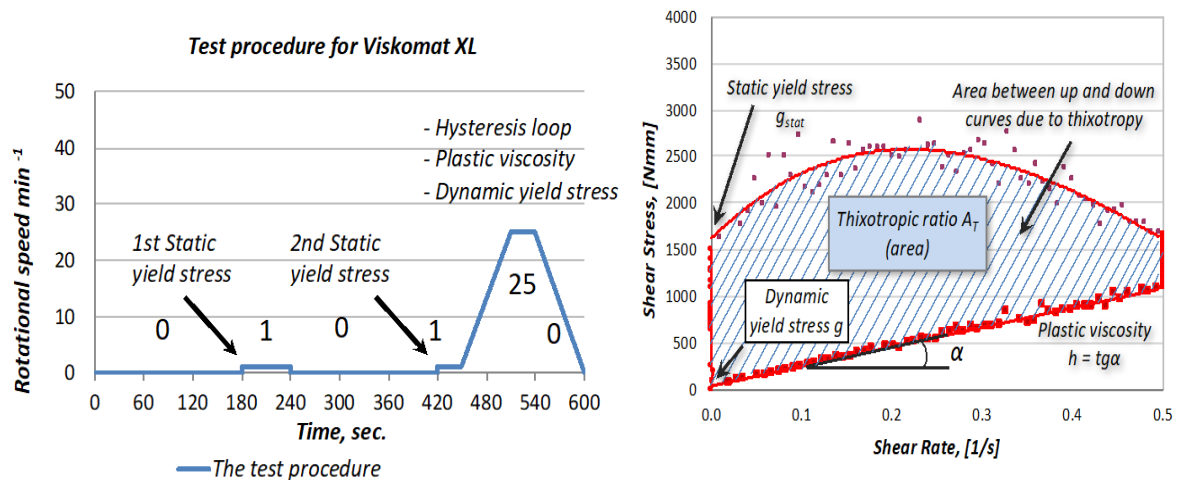
Figure 1. The rheological test procedure for Viskomat XL (left) and graphical determination of hysteresis loop, initial static and dynamic yield stress, and plastic viscosity - measurement between 420-600 sec. (right).

In parallel to the rheometric tests, were performed technical tests, according to EN 12350-2, EN 12350-8 for fresh concrete using the Abrams cone (slump-flow test). It was determined the diameter of concrete slump flow and propagation time T_{500} to a diameter of 500mm with an accuracy of 0.1s. Spreading was carried out using a device for vertical lifting of the cone at a constant speed. Tests were determined after mixing (0'), after 20, 40 minutes of resting (20', 40'), in the 80 minute, after one-minute re-mixing (80') and after 20 min of resting (100'). Measurement of SCC formwork pressure were determined on the element imitating a column with dimensions of 0.20x0.20m and a height of 1.20 m. Casting speeds was constant at the level of 7 m/h. Formwork pressure were measured by pressure sensors with diameter of 87 mm. The pressure sensors were at the bottom of the column, at the heights of 0.135 m, 0.375 m and 0.75 m (from the bottom of the formwork). Presented results illustrate the lowest sensor measurement (0.135 m from the bottom).

3. Research results and discussion

The rheological parameters of tested concrete mixtures in time varies within a wide range depending on the cement type used (Table 3, and Figures 1, 2). This confirms the decisive importance of the appropriate selection of cement when shaping the rheological properties of mixtures. The yield stress measured immediately after mixing are close to each other for w/c = 0.4. This is a consequence of the adopted method of superplasticizer selection. Its quantity was supposed to provide similar flow diameters of mixtures. This also resulted in the fact that mixtures after completion of concreting the column with a height of 1.2 m exerted similar pressure on the formwork (figure. pressure).

The yield stress of mixtures with w/c = 0.3 increases relatively slowly within 40 minutes from the end of mixing. It is similar in 80 and 100 minute except for the mixture with portland cement which yield stress is clearly increasing. The changes of the yield stress with the passage of time for mixtures with w/c = 0.4 are more distinct. This is particularly noticeable in case of mixtures with multi-component cement. Faster worsening of workability expressed by the increase of the yield stress is in case of mixtures with higher w/c, caused by a smaller amount of superplasticizer in these mixtures. Hydration products that cover adsorbed admixture chains, which makes it less effective. After 80 minutes, the g yield stress is fast, and this applies especially to mixtures with CEM I and CEM V. The plastic viscosity of mixtures increases with time, this tendency is more distinct in case of mixtures with lower w/c. For mixtures with w/c = 0.3, there is also a strong dependence of viscosity

on the cement type – the highest viscosity has a mixture with blast furnace cement, and the smallest with portland cement. The w/c ratio clearly affects the plastic viscosity, which is clearly lower for mixtures with w/c = 0.4. The static yield stress of concrete mixes is always greater than g yield stress and usually increases in time faster than it. For mixtures with w/c=0.3 the yield stress of mixtures with blast furnace cement and Portland cement is clearly higher than that of multi-component cement.

The static yield stress of mixtures with w/c = 0.4 increases at a similar pace for all cements, but with the highest tendency to stiffening when left at rest in case of mixtures with CEM V, then CEM I and CEM III.

Table 2. Properties of concrete mixtures with w/c=0.3 and 0.4

| Mixture	w/c	Time [min]	g [Nmm]	h [Nmms]	At [Nmm/s]	g_{stat} [Nmm]	Slump flow [cm]	Flow time T_{500} [s]
SCC1		0	65	2847	260	876	72	6
		20'	91	2915	498	1940	-	-
		40'	89	3505	607	2509	59	45
		80'	102	3864	261	364	68	9
		100'	381	3976	269	728	-	-
SCC2	0.3	0	29	4445	164	263	75	9
		20'	43	4483	436	1491	-	-
		40'	54	4563	457	1918	55	19
		80'	71	4720	232	408	72	10
		100'	80	5589	392	1114	-	-
SCC3		0	59	3689	257	232	71	8
		20'	81	3841	270	473	-	-
		40'	91	4174	463	494	69	24
		80'	104	4386	200	211	70	9
		100'	124	4539	335	823	-	-
SCC4		0	61	1193	113	1255	72	2
		20'	104	1226	165	2420	-	-
		40'	177	1356	127	3061	59	7
		80'	280	992	80	543	54	3
		100'	331	1218	91	1399	-	
SCC5	0.4	0	69	1068	40	144	72	2
		20'	183	1226	168	1690	-	
		40'	214	1281	66	3967	56	9
		80'	264	929	39	405	53	4
		100'	603	1360	51	1383	-	-
SCC6		0	77	1359	84	1215	72	3
		20'	84	1555	211	2593	-	-
		40'	383	1967	141	4568	46	-
		80'	518	1315	55	840	39	-
		100'	645	1395	110	1388	-	-
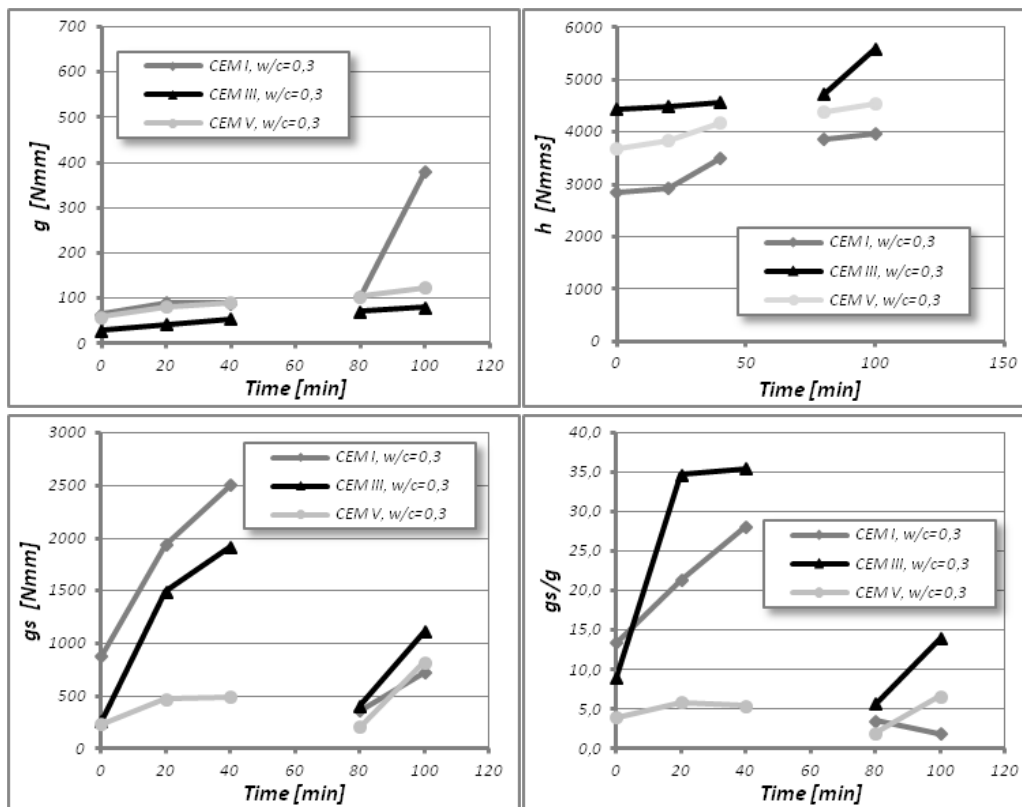
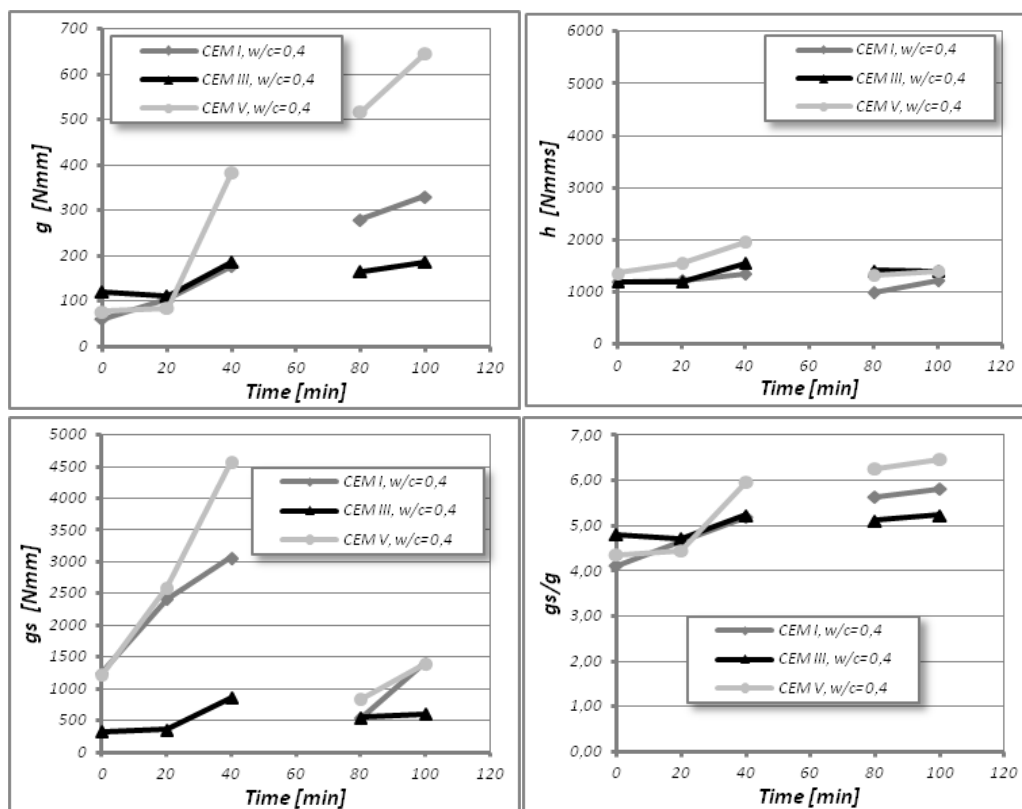**Figure 2.** Rheological properties of mixtures with w/c=0.3

Figure 3. Rheological properties of mixtures with w/c=0.4

Figure 3 presents the formwork pressure registered at the lowest located sensor:
1. when casting is finished (20 minutes after mixing the components),
2. in the end of 20-minute rest (40 minutes after mixing the components), then the reduction of the formwork load is observed,
3. in the end of the mixture loading in the formwork with the mass equivalent of the concrete mix column with a height of 1.2m (60 minutes after mixing the components), then the increase in pressure is observed.
4. in the end of an hour period of leaving the mixture at rest (120 minutes after mixing the components.

The visible pressure changes in the figures are a consequence of changes in the size of the indicators showed in Table 5. Their usefulness in this respect has been demonstrated on a much larger population of trials at work. The pressure of concrete mixes registered at the lowest position of the sensor at the time then the column had a height of 1.2 m is of similar size due to close yield points and slump flow of mixtures. The difference between the static yield stress (g_s) and dynamic yield stress g, correlates well with the reduction of the pressure applied (Figure 4, 5).

Table 3. Properties defining the ability to stiffening of the mixtures determined after 40 minutes of rest, and after re-mixing after 80 minutes

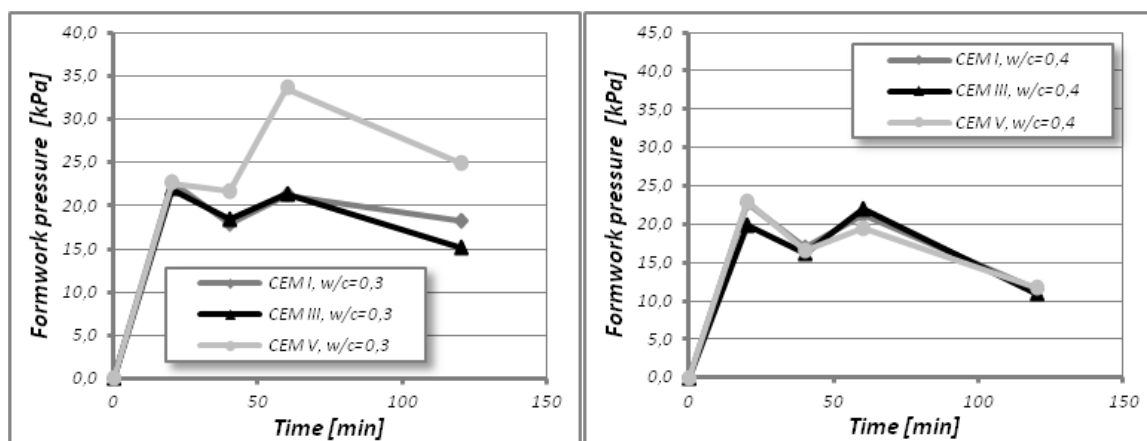| w/c		After 40 minutes				After 80 minutes			
		g_s [Nmm]	g_s-g [Nmm]	g_s/g	A_t [Nmm/s]	g_s [Nmm]	g_s-g [Nmm]	g_s/g	A_t [Nmm/s]
	CEM I	2509	2420	28	607	364	262	28	269
0,3	CEM III	1918	1864	36	457	408	337	6	232
	CEM V	494	403	5	463	211	107	2,0	200
	CEM I	3061	2884	17	127	543	263	1,9	80
0,4	CEM III	1424	1237	8	55	552	386	3,3	35
	CEM V	4568	4185	12	141	840	322	1,6	55

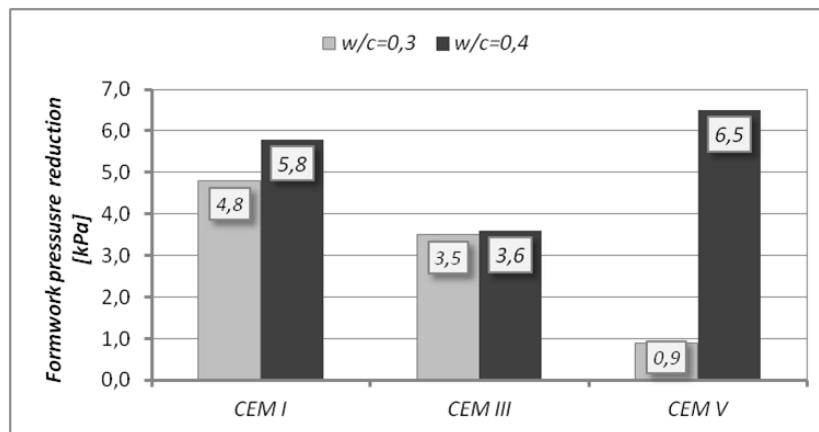**Figure 4.** Formwork pressure of fresh concrete and its change over time

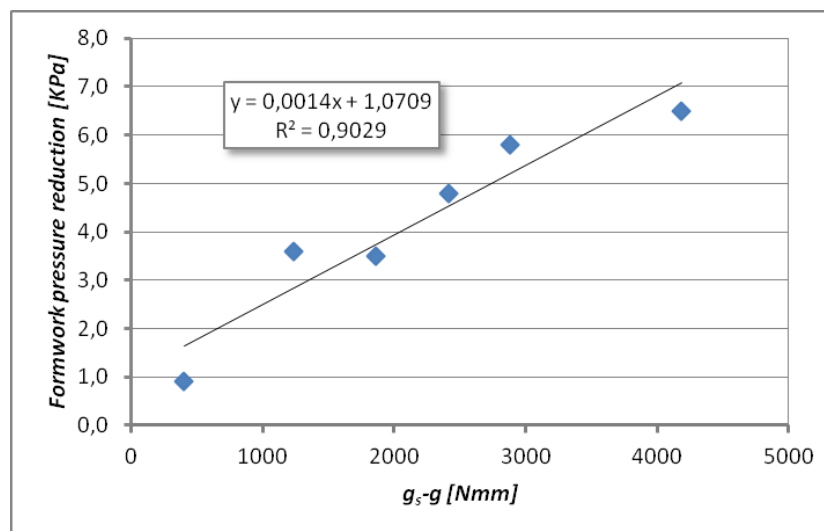**Figure 5.** Reduction of pressure on the formwork after 20 minutes of rest from the end on casting

Figure 6. Correlation of the pressure and g_s-g difference, after 20 minutes of rest

On the basis of g_s-g change the reduction in pressure, the reduction in pressure can be anticipated. Figure 6 shows that in case of w/c=0.3, the most beneficial effect is in case of portland and blast furnace cement, while the mixture with multi-component cement does not show such effect practically at all. Mixture with the same cement but with a higher w/c has already the desired property from the technological point of view. In case of mixtures with Portland and multi-component cement, the decrease in w/c reduces the tendency to limit the applied pressure. For mixtures with blast furnace cement, the influence of w/c in this aspect is absent.

Stability of obtained pressure reduction is important due to further stages of concreting. In case of mixtures with w/c=0.3, there is a clear effect of cement on the increase in pressure observed after simulating by loading of further concreting (Figure6).

The influence of cement on the stability of the obtained pressure reduction is dependent on w/c ratio. For w/c=0.3, the mix with multi-component cement clearly reacts to the additional load, which results in an almost 12 kPa increase in pressure. This mix did not tend to stiffen (the smallest g_s-g), besides A_t index is also not great, which together with small g_s static point results in such a large increase. In case of mixtures with w/c=0.4, the most sensitive to the increase of pressure is the mix with blast furnace cement, its tendency to build a stable structure (expressed as g_s-g), and its resistance

to load increase (A_t index) are the smallest. Mixes with portland and multi-component cement increase the applied pressure of similar sizes.
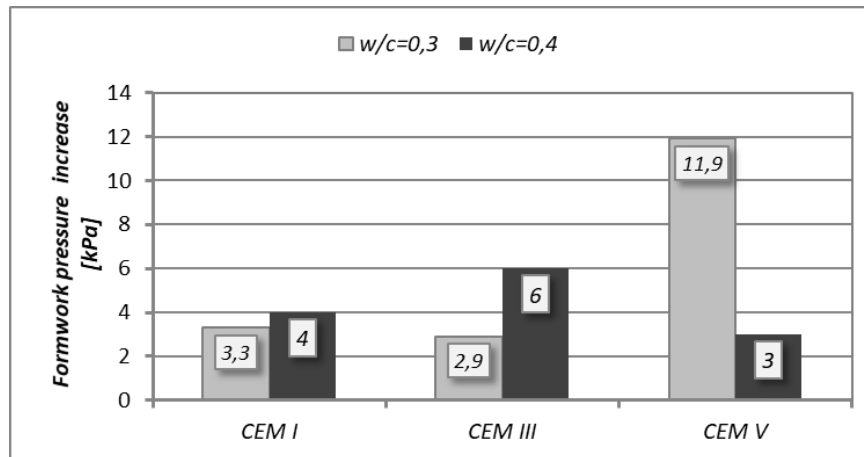

Figure 7. Increase of pressure on the formwork after loading the mixture in the formwork

4. Conclusions

Presented results of rheological tests give the characteristics of mixes based on which one can infer about the pressure of the mixture on the formwork of its changes in time. The g parameter simply treated as the yield point determines the size of the pressure, the greater the g parameter the smaller the pressure is. The g_s-g difference allows to assess whether the mixture laid in the formwork will have a tendency to stiffen, which may lead to a reduction in the load of the formwork. The assessment of the stability of pressure reduction can be made by comparing the changes in At index. Generally, the greater the A_t index, the mix will have a lower tendency to increase the pressure with concreting progress. This is the right conclusion when quasi-thixotropic effects are responsible for the reduction of pressure changes in the load of the formwork with the mixture depend on the type of cement, but it is difficult to generalize this effect on the basis of the tests carried out. It depends on w/c ratio and the type of superplasticizer, this factor is not considered in this paper. Research carried out by the authors confirm the strong influence of fluxing admixtures in the formation of the stiffening effect of self-compacting concretes.

Acknowledgements

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