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DESIGNING THE COMPOSITION OF CONCRETE MIXTURES BASED ON PROPERTIES OF MORTAR

PRZEWIDYWANIE WŁAŚCIWOŚCI MIESZANKI BETONOWEJ NA PODSTAWIE BADANIA ZAPRAW – METODA PROJEKTOWANIA ZAPRAW

Abstract

The paper presents proposed methods for designing the composition of mortars, which can be useful when designing concrete. To design a mortar, with properties which will correspond to the concrete, it is necessary to define the appropriate correction of the mortar composition. Research is the next step in proposing a method to determine the composition of the mortar, which in a possitive way will describe the properties of concrete, in particular self-compacting concrete.

Keywords: cement mortar, self compacting concrete, rheological properties

Streszczenie

W artykule przedstawiono propozycję prognozowania właściwości samozagęszczalnej mieszanki betonowej za pomocą właściwości zapraw. Do uzyskania jak najlepszej zgodności w odpowiedzi zaprawy i mieszanki betonowej, konieczne jest wprowadzenie odpowiedniej korekty składu zapraw. Badania są kolejnym etapem mającym na celu określenie fizycznie uzasadnionej metody korekty składu zaprawy, której właściwości w sposób wystarczająco dobry określałyby właściwości mieszanki betonowej.

Słowa kluczowe: BSZ, właściwości reologiczne zapraw, właściwości reologiczne BSZ

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1. Introduction

In studies of rheological properties of concrete, mortars are most often selected as the subject of research. This is not without reason. Tests performed on mortars are cheaper and less labor and material intensive.

However, the question is: Whether we can easily transpose designated properties characteristic of the mortars, into the properties of concrete?

A series of systematic studies, confirmed that the mortar approximately corresponds to the behavior of concrete in various process conditions, for example [3]. This is a significantly better approximation than in the case of a comparison cement paste and a concrete, where there often isn't even a qualitative compliance. We should be aware of certain limitations in designing mortars, mainly posed by not takeing coarse aggregate, water demand, capillary phenomena of aggregate grain stack and a friction between the aggregate grains into account. To describe the properties of concrete by using mortar, its composition should be adjusted accordingly, which comes down to a choice of the method.

Results from the verification correction methodsadopted for designed mortars are shown in [4].

The aim of this paper is to show the next step of research which will be helpful in developing an appropriate correction method, and consequently the method of concrete design.

2. Assumption of the adopted method

The adjustment is based on the assumption of equal values of the dispersion *D* for mortar and concrete determined according to the formula (1):

$$D = \frac{V_{fc}}{S_{fr}} \text{ [m]} \tag{1}$$

in which:

- V_{fc} – the volume of the continuous phase (scattering),
- S_{fr} – developed area of the dispersed phase (discontinuous), an interfacial area.

For the concrete dispersion index $D_{m\ is}$ determined by the formula (2):

$$D_m = \frac{V_{zb}}{S_{wsk} \cdot K} \text{ [m]} \tag{2}$$

in which:

- V_{zb} – the volume of cement paste in concrete,
- S_{wsk} – static surface area of the grains stack,
- K – the weight of the aggregate in the concrete.

For the mortars dispersion index D_{zc} is determined by the formula [m] (3):

$$D_{zc} = \frac{V_{zz}}{S_{wskp} \cdot K_p} \text{ [m]} \tag{3}$$

in which:

V_{zz} – the volume of cement paste in mortar,
S_{wsk} – static surface area of the grains stack,
K_p – the weight of the aggregate in the mortar.

The assumption of an equal dispersion ratio of the concrete D_m and ratio of the dispersion of cement mortar Dzc shows the amount of cement paste which should be in cement mortars, which is formed after the “removal” of coarse aggregate in concrete

$$V_{zz} = V_{zb} \cdot \frac{S_{wsk} \cdot K}{S_{wskp} \cdot K_p} \text{ [m}^3\text{]} \tag{4}$$

The rest of the calculations are based on the tightness condition of concrete and mortar. Due to the simplicity of this condition, it does not require explanation here. It is also very convenient is to use of a suitably programmed spreadsheet.

Using this methodology, we can make adjustments to the composition thus:

- To design the mortar, which is a template for the coarse aggregate, adding the right amount of cement paste;
- To design the concrete, subtracting cement paste after the removal of coarse aggregate. It gives us mortars by which we can study the impact of technological factors on its properties, and in consequently the properties of concrete.

3. Experimental investigation

The rheological parameters of mortars and concrete were determined by using a rheometer (Viskomat NT and Viskomat XL). Studies [3, 5, 6] show it’s commonly accepted, that the rheological behavior of fresh mortar and concrete may be sufficiently described by the Bingham model. In rheometry, the Bingham model is described in:

$$M = g + N\,h \tag{5}$$

where:

g (Nmm), h (Nmms) – parameters corresponding to the Bingham’s yield stress and plastic viscosity.

To determine the parameters g and h, a modified test procedure was used, which is described in detail in [1] and [2]. The rotational speed for Viskomat NT and XL and the time of measure are shown in.

Parallel to the rheometric tests, technical tests were performed, according to PN-EN 1015-3 for mortars and PN-EN 12350-2, PN-EN 12350-8 for fresh concrete.

Tests were determined after mixing (0’), after 40 minutes of resting (40’) and in the 80 minute, after re-mixing (80’). The temperature of the mortar and the concrete during the measurements were kept at a pre determined level.

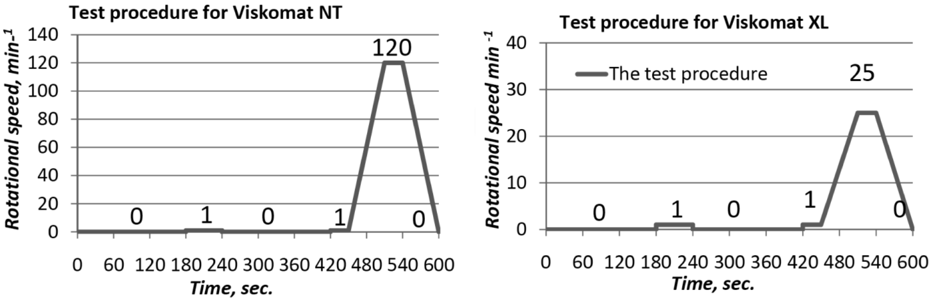

Fig. 1. The rheological test procedure for Viskomat NT and XL

4. Material properties and composition of mixtures

For investigation was used three types of cement CEM I 42,5 R, CEM III/A 42,5N-HSR/NA oraz CEM V/A (S-V) 32,5 R-LH, two kinds of superplasticizers based on polycarboxylate ether sand from Niedomice and gravel with maximum grain size of 8 mm from Sieciechowice. The composition of mortars and concrete are shown respectively in

Table 1

The composition of fresh mortar – components for 1 m^3 mortar

Symbol/ Mixture Component/ Składnik	[unit]	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12
CEM I 42.5 R	[kg]	775	688	785	691								
CEM III/A 42.5 N-HSR/ NA	[kg]					776	680	784	682				
CEM V/A (S-V) 32.5 R – LH	[kg]									751	662	757	668
Water	[kg]	232	275	236	276	233	272	235	273	225	265	227	267
w/c ratio	–	0.30	0.40	0.30	0.40	0,30	0.40	0.30	0.40	0.30	0.40	0.30	0.40
SP PE2 [% m.c]	[kg]			2.00	0.75			1.00	0.50			2,00	0.75
SP PE1 [% m.c]	[kg]	3.00	1.00			1,75	0.75			2.50	1.50		
Sand 0–2	[kg]	1315											

Table 2

The composition of concrete for 1 m³

Symbol/ Mixture Component/ Składnik	[unit]	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
CEM I 42.5 R	[kg]	572	508	580	510								
CEM III/A 42.5 N-HSR/ NA	[kg]					573	502	579	504				
CEM V/A (S-V) 32.5 R – LH	[kg]									555	489	559	493
Water/woda	[kg]	172	203	175	204	172	201	174	202	167	195	168	197
w/c ratio	–	0.30	0.40	0.30	0.40	0,30	0.40	0.30	0.40	0.30	0.40	0.30	0.40
SP PE2 [% m.c]	[kg]			2.00	0.75			1.00	0.50			2,00	0.75
SP PE1 [% m.c]	[kg]	3.00	1.00			1,75	0.75			2.50	1.50		
Sand 0–2	[kg]	884											
Coarse aggregates 2–8	[kg]	780											

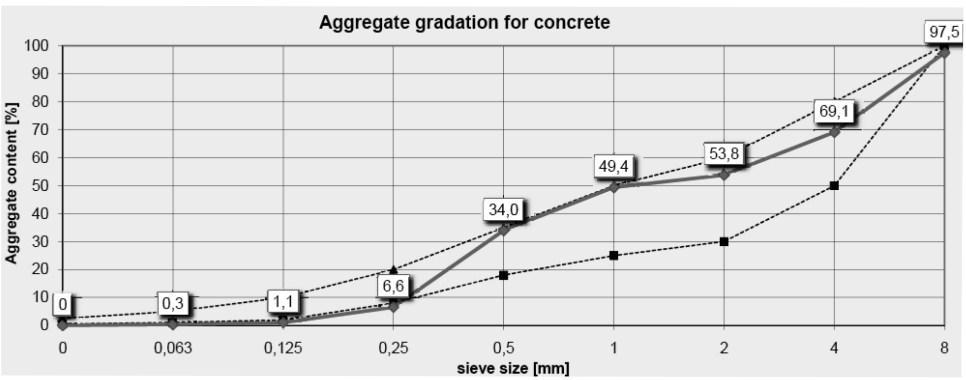

Fig. 2. Aggregate gradation for concrete

and Table 2. Aggregate gradation for concrete are showed in Fig. 2.

Mortars were prepared in accordance with PN-EN 196-1. Concrete was prepared in accordance with PE-EN 206-1. Chemical additives added with the mixing water.

5. Experimental results and discussion

Table 3

Properties of fresh concrete

Mortar / Properties		Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12
Mini slump flow [cm]	0’	19	23	28	26	29	28	31	28	24	22	26	24
	40’												
	80’	27	21	24	23	31	27	29	25	27	21	26	22
g [Nmm]	0’	31.6	9.7	19.7	6.9	15.6	11.9	19.9	7.9	23.0	16.8	20.0	10.6
	40’	33.8	10.1	27.7	9.0	15.8	16.0		10.2	30.0	18.2	25.9	13.2
	80’	26.0	29.2	36.0	16.7	15.2	24.0		15.0	31.0	32.5	27.5	35.0
h [Nmms]	0’	52.0	19.7	54.4	15.4	65.2	26.2	77.0	24.2	68.0	21.6	64.5	30.5
	40’	57.7	21.0	65.6	19.8	67.0	27.8	79.1	28.0	65.6	24.3	68.8	30.5
	80’	58.3	16.7	64.7	17.9	71.6	24.9	55.0	22.0	49.1	19.3	70.9	24.7

Adjustments to the composition of mortars which ensure the possibility of predicting the properties of concrete is the aim of this paper. Because cement mortar in concrete fills the spaces between distributed coarse aggregate, the composition of mortars should be properly designed. Fig. 4 shows a comparison of mortars and concrete slump flow (comparision with Table 3 and 4). The coefficient of determination $R^2 = 0.873$ can be described as good.

With a good approximation, we can determine the diameter of concrete slump flow knowing the diameter of mortar mini slump flow.

Rhelogical test of mortar and concrete showed that the proposed method is satisfactory for yield stress value (*g*) (comparison of Fig. 5 and Fig. 6). This occurs both in terms of the time (Fig. 5) and different ratio *w/c* (Fig. 6).

In terms of plastic viscosity (*h*), the adopted method of correction was not as good as in case of yield stress (*g*) (comparison of Fig. 7 and Fig. 8).

For concrete of ratio w/c respectively of 0.3 and 0.4, coefficients were not satisfactory.

In this case, it would be hard to predict the properties (plastic viscosity) of concrete by using the mortar.

Table 4

Properties of fresh mortars

Mixture / Properties		B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Slump flow [cm]	0’	62.0	67.5	74.5	72.0	79.5	77.0	79.5	74.5	74.0	68.0	74.5	69.5
	40’	55.5	62.0	63.0	61.5	70.8	46.5		64.3	70.0	74.0	72.0	46.0
	80’	69.0	62.0	69.5	53.0	78.2	46.5			72.3	73.5	72.0	39.0
Flow time T_{500} [s]	0’	5.7	1.6	5.9	2.2	3.5	1.6		1.7	6.9	2.5	6.8	3.0
	40’	29.2	5.8	46.9	7.2	20.4	6.5			5.1	2.4	10.3	6.0
	80’	6.4	2.0	9.8	3.0	5.8	6.6			5.1	2.4	10.3	6.0
g [Nmm]	0’	452	186	326	145	153	106	30	127	228	97	257	183
	40’	502	220	349	156	203	267		244	305	93	328	275
	80’	348	235	411	257	231	403		348	310	80	437	541
h [Nmms]	0’	2349	1316	2784	1191	3043	1176	3481	1153	2788	1337	3662	1476
	40’	3140	1363	3647	1433	4613	1180		1272	3245	1356	4746	1979
	80’	2545	961	3795	1041	3818	1127		1127	3365	1371	5200	1557

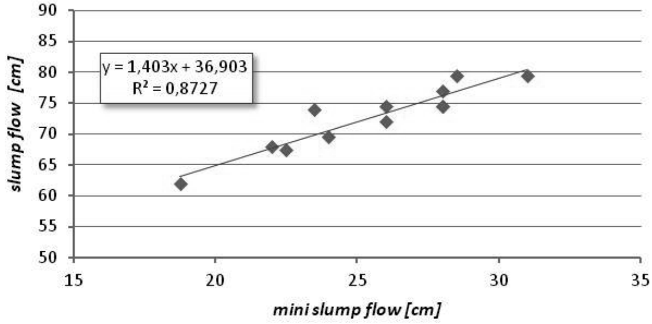

Fig. 3. Comparison of slump flow mortars and fresh concrete

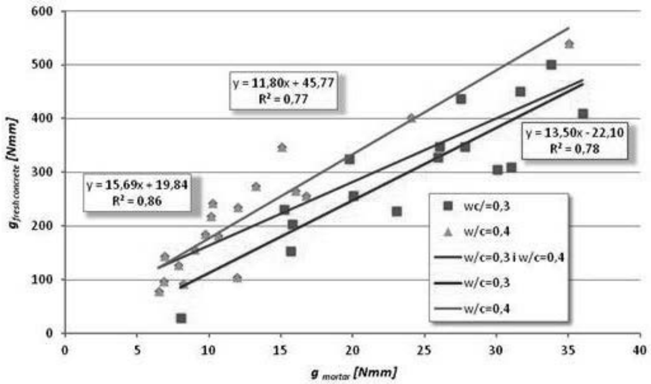

Fig. 4. Correlation between yield stress of mortars and fresh concrete with ratio *w/c* = 0.3 and 0.4

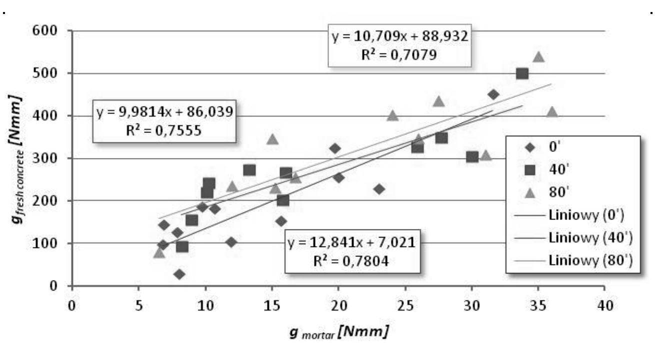

Fig. 5. Correlation between yield stress of mortars and fresh concrete with ratio *w/c* = 0.3 and 0.4 after mixing (0'), resting (40') and re-mixing (80')

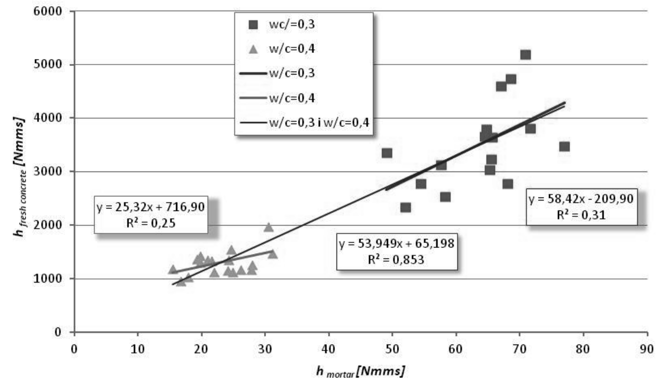

Fig. 6. Correlation between plastic viscosity of mortars and fresh concrete with ratio *w*/*c* = 0.3 and 0.4

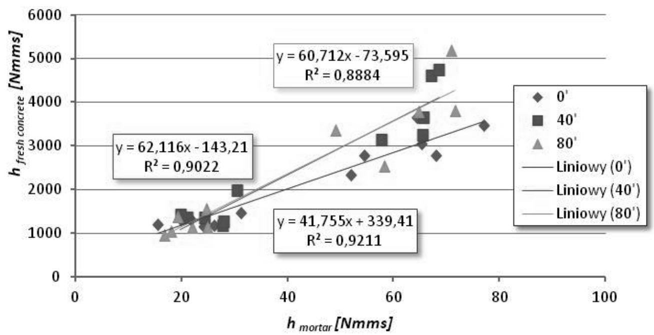

Fig. 7 Correlation between plastic viscosity of mortars and fresh concrete with ratio *w*/*c* = 0.3 and 0.4 after mixing (0'), resting (40') and re-mixing (80')

6. Conclusions

Cement mortar adjusted according to the adopted method shows a good fit when it comes to forecasting on the basis of the yield stress of the concrete.

In the case of plastic viscosity we can talk about unsatisfactory matches, but on the other hand, the proposed adjustment show that plastic viscosity of mixtures with ratio *w*/*c* = 0.3 and 0.4 are in two areas – a mixture with ratio *w*/*c* = 0.3 which is a blend of distinctly higher viscosity and a mixture with ratio *w*/*c* = 0.4 lower viscosity. Adjusted mortars accurately reflected the tendency to bleed as can be found with concrete. In situations where the mortar was not susceptible to this phenomenon, it was also observed on the surface of the concrete.

Loss of the workability of concrete, due to the time limitations, can also be a sufficiently accurate in determining by observations made regarding the behavior of mortars. These results are part of a larger research program involving the impact of technological factors (e.g. time, temperature) for predicting the properties of concrete by using mortars. Nevertheless, the results obtained can be considered to be satisfactory and clearly indicating the necessity of correcting the composition of the mortar used in the laboratory tests.

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References

[1] Billberg P., *Form Pressure Generated by Self-Compacting Concrete – Influence of Thixotrophy and Structural Behaviour at Rest*, Doctoral Thesis, Royal Institute of Technology, Stockholm, Sweden 2006.

[2] Gołaszewski J., Drewniok M., Cygan G., *Właściwości reologiczne mieszanki betonowej w aspekcie efektu tiksotropii – procedury badawcze*, Technika Transportu Szynowego, No. 9, 2012, 1953-1962.

[3] Gołaszewski J., *Wpływ superplastyfikatorów na właściwości reologiczne mieszanek na spoiwach cementowych w układzie zmiennych czynników technologicznych*, Zeszyty Naukowe Politechniki Śląskiej, Gliwice 2006.

[4] Gołaszewski J., Kostranowska A., and Cygan G., *Właściwości reologiczne mieszanki z zaprawy o różnych składach w układzie zmiennych temperatur*, Konferencja Dni Betonu, Wisła 2012, 759-768.

[5] Koehler E.P., *Use Rheology to specify, Design and manage self-consolidating concrete*, 9th ACI International Conference on Superplasticizers & 10th International Conference on Recent, Seville, Spain, Octobet 2009, 609-623.

[6] Szwabowski J., *Reologia mieszanek na spowach cementowych*, Wydawnictwo Politechniki Śląskiej, Gliwice 1999.