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USE OF ADMIXTURE EFFECTIVENESS CURVES FOR PREDICTION OF THE COMPRESSIVE STRENGTH OF CONCRETE

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Abstract

This paper presents the results of individual laboratory tests conducted in the Research and Experiment Facility of the University of Science and Technology in Bydgoszcz, in particular of tests conducted on pastes of low water-binder ratios (from 0.2 to standard water demand (MROZIK 2012)). The purpose of this document is to examine the effect of the applied admixtures (plasticizer or superplasticizer) and its amount on the bulk density of a cement paste, thus on the compressive strength of concrete (as shown in the paper (NEVILLE 2012), properties of concrete can be estimated on the basis of pastes). Conclusions concerning the suitability of specific amounts of plasticisers and superplasticizers were formulated and effectiveness curves were established on the basis thereof.

Introduction

High performance concrete provides many more opportunities as compared with ordinary concrete. However, their production requires the use of high class cement, aggregate of appropriate quality and quantity, chemical admixtures and special methods of compacting (AÏTCIN 2014, BENTZ, CONTWAY 2001, CZARNECKI, JUSTNES, 2012, MROZIK 2012, NEVILLE 2012. It is also important to obtain a low water-binder ratio which ensures that concrete is less porous, its absorption properties are reduced, while frost resistance improves. In particular, its

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compressive strength increases (which is one of the components of high performance concrete properties). A low value of the water-binder ratio causes problems with concrete mixture workability, therefore it is necessary to use plasticizers or superplasticizers (BENTZ, CONTWAY 2001, CHEN et al. 2013, ŁUKOWSKI 1998). As is known, the bulk density of a paste, which is the weight-to-volume ratio, together with binder (cement) air void has a direct impact on the compressive strength of a finished cement composite (BHANJA, SENGUPTAB 2003, MROZIK 2012, NEVILLE 2012). This was a basis for considerations of this subject matter. The purpose of this paper is to present the results of tests of the influence of selected admixtures (plasticizers or superplasticizers) and their amounts on the bulk density of a cement paste. Effectiveness curves of the additives were developed to determine their effective share in the mixture. Conclusions concerning the strength of high performance concrete produced with low water-binder ratio pastes were formulated on the basis thereof.

Material and methods

Laboratory tests of cement pastes were conducted with the following admixtures:

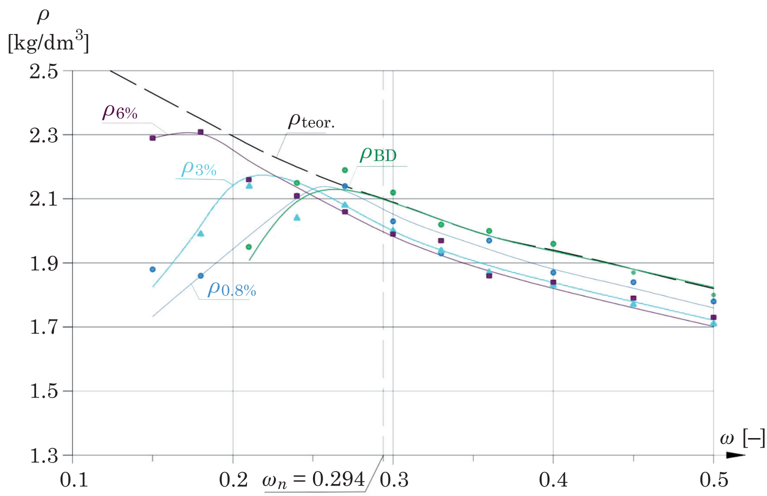
– plasticizer no. 1 (a chemical admixtures of the new generation produced on the basis of modified lignosulphonates; owing to a greasing effect, it reduces the amount of batched water at consistent texture and improves the fluidity and cohesion of a concrete mixture at a constant value of the water-cement ratio);

– superplasticizer no. 2(a chemical admixtures of the new generation produced on the basis of modified polycarboxylates; it reduces the amount of batched water through a greasing and steric effect and causes disaggregation of binder grains, which ensures production of concrete of a very low water-cement ratio).

Cements of the following classes were applied: CEM I 42.5 R (Portland, rapid hardening), CEM IV/B(V) 32.5 R – LH/NA (pozzolanic, rapid hardening with siliceous fly ash (up to 10%), low-alkaline of low hydration heat), CEM II/A-M (S-LL) 52.5 N (mixed Portland, normal hardening, containing furnace slag and limestone – the amount of the above-mentioned additives should fall within the range of 36–55% and the content of silica fume must not exceed 10%). 42.5 R cement is a basis, the composition of which is not modified by mineral additives. Results may be reproducible due to their lower distribution in comparison with the results obtained with different batches of multi-component cement. Portland cements are characterised by a very high hydration heat, rapid strength growth and slightly longer curing time. The basic difference between Pozzolanic cement properties, in particular between the analysed CEM IV/B and Portland cements, is that they are characterised by a slower hardening rate resulting from a low pozzolanic reaction rate, extended setting time and higher resistance to chemically aggressive factors. The above multi-component cement was taken for tests due to significant differences between respective binder water demands. Tests of cement pastes were carried out, since concrete properties can be estimated on the basis of pastes, as shown in the paper (Neville, 2012). The tests were conducted on the following pastes: without admixtures, with admixture no. 2 in the amount of 0.8%, 3% and 6% (for CEM I) and with admixture no. 1 in the amount of 0.5%. Samples were made with water-binder ratios from 0.15-0.50 and weighed after compacting on a vibration table. 102 samples (for each type of cement) were made in total. They had different components and a water-binder ratio which for pastes without admixtures and including admixture no. 1 was: 0.21, 0.24, 0.27, 0.30, 0.33, 0.36, 0.40, 0.45 and 0.50, whereas for pastes with admixture no. 2, additional samples of 0.15 and 0.18 ratio were prepared. The samples were made in cylindrical moulds of a known volume of 208 cm^3, repeating the test three times for each water-binder ratio.

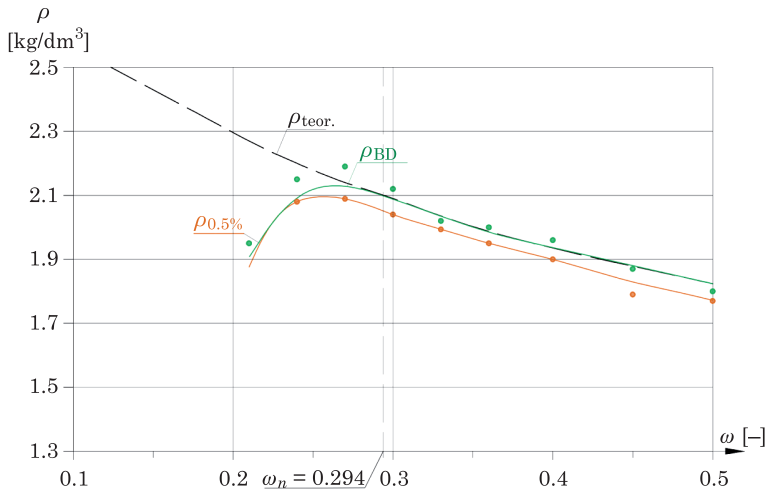
Results and discussion

The obtained results of the density of pastes without admixtures and including admixture no. 2 in the following quantities: 0.8%, 3% (for CEM II and CEM IV) and 0.8%, 3% and 6% (for CEM I) were compared and shown in Figures 1, 3 and 6. A similar list was made for a paste without admixtures and including admixture no. 1 in the amount of 0.5% and shown in Figures 2, 4 and 6.

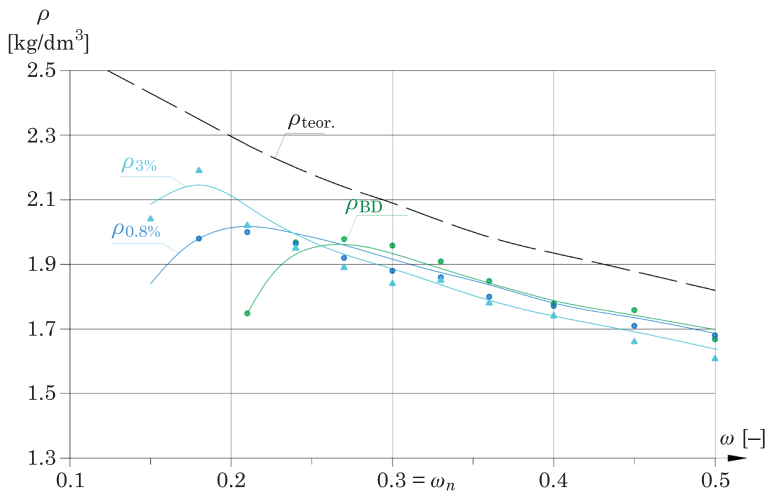


$\rho_{teor.}$ – theoretical bulk density, ρ_{BD} – cement without admixtures, $\rho_{0.8\%}$ – admixture no. 2 in the amount of 0.8%, $\rho_{3\%}$ – admixture no. 2 in the amount of 3%, $\rho_{6\%}$ – admixture no. 2 in the amount of 6%

Fig. 1. Bulk density of pastes with superplasticizer no. 2 for CEM I

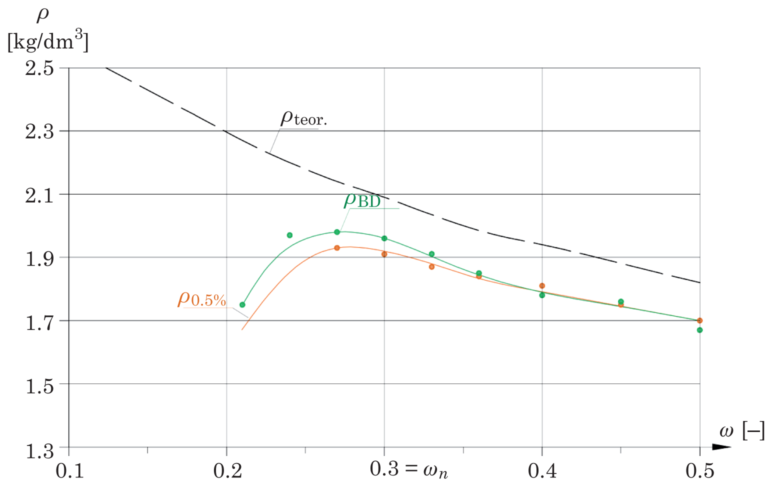


$\rho_{teor.}$ – theoretical bulk density, ρ_{BD} – cement without admixtures,
$\rho_{0.5\%}$ – admixture no. 1 in the amount of 0.5%
Fig. 2. Bulk density of pastes with plasticizer no. 1 for CEM I

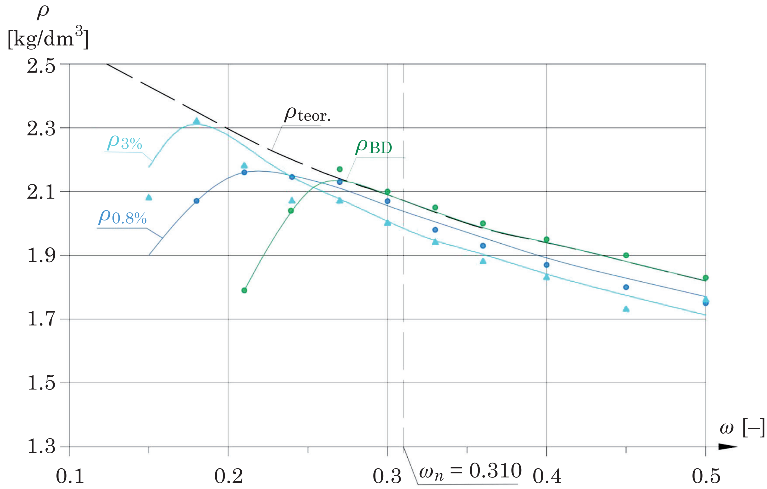


$\rho_{teor.}$ – theoretical bulk density, ρ_{BD} – cement without admixtures,
$\rho_{0.8\%}$ – admixture no. 2 in the amount of 0.8%, $\rho_{3\%}$ – admixture no. 2 in the amount of 3%
Fig. 3. Bulk density of pastes with superplasticizer no. 2 for CEM IV

It should be emphasized that new generation additives no. 2 have a particularly strong influence on the bulk density due to their electrostatic and steric effect, whereas additive no. 1 has little influence. Moreover, the relations shows an obvious impact of the quantity of the applied admixture on the analysed properties. The above vertical translation of the charts with regard to



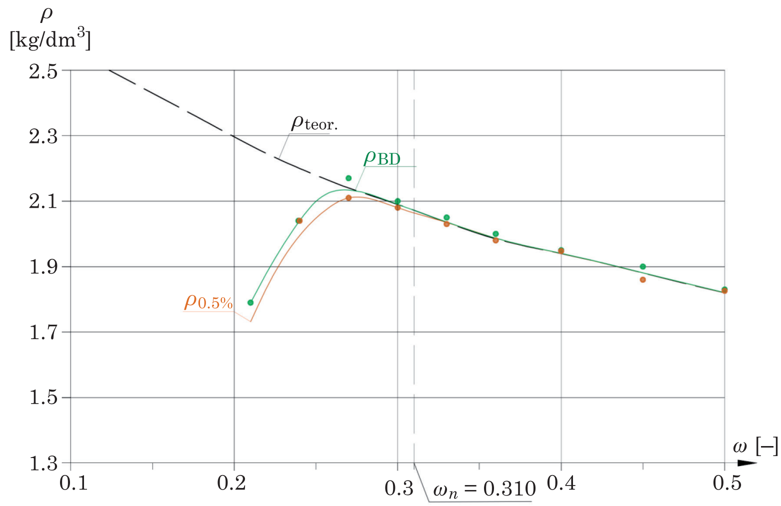
$\rho_{teor.}$ – theoretical bulk density, ρ_{BD} – cement without admixtures,
$\rho_{0.5\%}$ – admixture no. 1 in the amount of 0.5%
Fig. 4. Bulk density of pastes with plasticizer no. 1 for CEM IV



$\rho_{teor.}$ – theoretical bulk density, ρ_{BD} – cement without admixtures,
$\rho_{3\%}$ – admixture no. 2 in the amount of 3%, $\rho_{0.8\%}$ – admixture no. 2 in the amount of 0.8%
Fig. 5. Bulk density of pastes with superplasticizer no. 2 for CEM II

the theoretical density calculated on the basis of a water-binder ratio for the amounts of water greater than that resulting from the standard water demand indicates air-entraining properties of admixtures.

Empirical relations between the quantitative and qualitative shares of an admixture which reduces the amount of batched water and the bulk density



$\rho_{teor.}$ – theoretical bulk density, ρ_{BD} – cement without admixtures
$\rho_{0.5\%}$ – admixture no. 1 in the amount of 0.5%
Fig. 6. Bulk density of pastes with plasticizer no. 1 for CEM II

of a paste provide a practical opportunity to design concrete of extremely low water-binder ratios. It is commonly known that the most favourable structure of a cement stone is obtained at extremely reduced share of batched water. It is not enough though, since at low values of the water-binder ratio the necessity to maintain proper workability constitutes a problem. Insufficient workability makes compacting of a paste or concrete mixture much harder, which results in the presence of scattered mesopores and macropores decreasing the strength and impairing other essential properties (absorption, frost resistance, etc.). Taking this into consideration, the compressive strength prediction cannot be based on the water-binder ratio and the quantitative and qualitative share of composites. The paper (MROZIK 2012) shows that there is a minimum amount of water for each paste at which it is possible to obtain the highest bulk density of the paste. At the same time, the greatest volume fraction of binder grains is obtained with this share. For a paste without admixtures, this quantity is similar to that resulting from the standard water demand of the binder, while for plasticizer and superplasticizer modified pastes it results from the quantitative and qualitative share of the admixture. Therefore, designing concrete of extremely low water-binder ratios should be based on experimental tests.

A simplified equation of the high performance concrete strength was applied in the paper (MROZIK 2012):

$$f_{cm} = \alpha_g \cdot R_c \cdot \frac{\sqrt[3]{1 + 0{,}5 \cdot \frac{\rho_c}{\rho_w}} - 1}{\sqrt[3]{1 + \omega \cdot \frac{\rho_c}{\rho_w}} - 1},$$

where:

ω – a water-binder ratio [-],

ρ_w – density of water [kg/m^3],

ρ_c – density of cement [kg/m^3] (it can be taken as equal to 3,100 kg/m^3),

a_g – a ratio including the effect of coarse aggregate on the concrete strength [–], for crushed-stone aggregatea_g= 1.3–1.4,

R_c – cement strength class [MPa].

On the basis of the above relation, a theoretical maximum strength of high performance concrete was estimated with the following assumptions:

– no addition of micro-fillers,

– vibration compacting,

– no thermal and pressure treatment,

– use of coarse aggregate of good quality (a_g=1.4),

The value of the water-binder ratio ω_{opt} was used for the above formula, at which the highest apparent density of a paste with identical components was obtained. The results are shown in the Table 1.

Table 1

Maximum theoretical strength of high performance concrete

No.	Paste	$\omega_{opt\ [-]}$	f_{cm} [MPa]
1	CEM I 42.5 R without admixtures	0.265	98.5
2	CEM I 42.5 + admixture no. 2 in the amount of 0.8%	0.258	100.7
3	CEM I 42.5 + admixture no. 2 in the amount of 3%	0.220	115.1
4	CEM I 42.5 + admixture no. 2 in the amount of 6%	0.180	136.8
5	CEM I 42.5 + admixture no. 1 in the amount of 0.5%	0.253	102.3
6	CEM IV 32.5 R without admixtures	0.265	75.3
7	CEM IV 32.5 R + admixture no. 2 in the amount of 0.8%	0.208	92.3
8	CEM IV 32.5 R + admixture no. 2 in the amount of 3%	0.180	104.6
9	CEM IV 32.5 R + admixture no. 1 in the amount of 0.5%	0.265	75.3
10	CEM II 52.5 N without admixtures	0.265	121.6
11	CEM II 52.5 N + admixture no. 2 in the amount of 0.8%	0.215	145.0
12	CEM II 52.5 N + admixture no. 2 in the amount of 3%	0.178	170.6
13	CEM II 52.5 N + admixture no. 1 in the amount of 0.5%	0.270	119.8

Conclusions

Production of concrete of low water-binder ratios requires chemical admixtures which reduce the amount of batched water (ŁUKOWSKI 1998). However, it is difficult to select admixtures (PN-EN 934-1:2009) for concrete of assumed strength parameters in proper quantities and quality. This refers in particular to the analysed group of composites of a low relative water content in the mixture. There are no universal criteria for assessing the effectiveness of binder-admixture sets with regard to the improvement of workability of mixtures made of water in the amount lower than that resulting from the standard water demand of the binder. The proposition of the authors of this paper is to use the above effectiveness curves. They can be used to estimate a minimum value of a water-binder ratio at which effective compacting at a specific amount of an admixture is possible. This value corresponds to the maximum possible compressive strength which can be calculated on the basis of commonly known relations which are deemed precise. Thus, effectiveness curves can be used by technologists to resolve problems such as selection of an effective admixture for high performance concrete of a specific water-binder ratio.

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