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SHAPING THE STRUCTURE OF LOW WATER-BINDER RATIO CEMENT PASTES

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Abstract: *Cement and aggregate composites constitute one of the basic structural and material solutions applied in civil engineering. A wide application range results mainly from the possibility of relatively flexible adjustment of required parameters, including the leading mechanical property which is the compression strength. As is known from the basic source literature, there exists an approximate proportional relation between the strength of a hardened paste and analogous characteristics of a cement paste and concrete, while the differences result from aggregate feeding. Considering the above, this paper describes selected issues and problems related to the design of cement composites of the assumed strength. Particular attention is paid to the problem of shaping low water-binder ratio cement dispersion.*

Keywords: Concrete, Cement paste, Water demand, Superplasticizer.

1. Introduction

Concrete is a composite which obtains its technical properties as a result of cement paste bonding and hardening. It is well known that the strength of concrete depends on the water-binder ratio (ω), thus on the rated content of a liquid phase in a fresh paste. Moreover, according to Neville (Neville, 2010), there exists an approximate proportional relation between the strength of a hardened paste and analogous characteristics of a cement paste and concrete, while the differences result from the feeding of fine aggregate and coarse aggregate, respectively. Therefore, a cement paste plays a particular role in shaping properties of modern cement composites. It follows that a paste of proper parameters is necessary to receive concrete of assumed properties. The problem of shaping the paste and cement stone structure has been widely studied, and the large number of research approaches resulting from actual needs and scientific objectives indicates the complexity of the analyzed problem.

2. Parameters of the fresh paste structure

One of the most popular methods of shaping the structure is an approach involving particle packing method (Chan, 2014, Dewar, 1999, Fennis, 2012, Jones, 2002, Li, 2014). It is a commonly used method, e.g. in material engineering, powder technology and processing industry. It can be applied to describe relations between particles of bulk solid. There is a range of interactions (Fig. 1) to include: filling effect, occupying effect, loosening effect, wall effect or wedging effect (Chan, 2014). These refer to a dry grain arrangement. A cement paste, however, is a suspension, the packing tightness of which depends on the relative water content (Li, 2014). It is important that the minimum water quantity is obtained at an aggregate composition provided for a mixture of dry grains of the highest tightness (Fennis, 2012, Li, 2014). This determines the suitability of the particle packing method for a selection of aggregate graining. Generally, it refers to a centre consisting of aggregate, binder and additives. However, there are significant limits when shaping the structure of pastes alone, resulting from the insufficient adequacy for centres of such a high degree of fineness (Chan, 2014).

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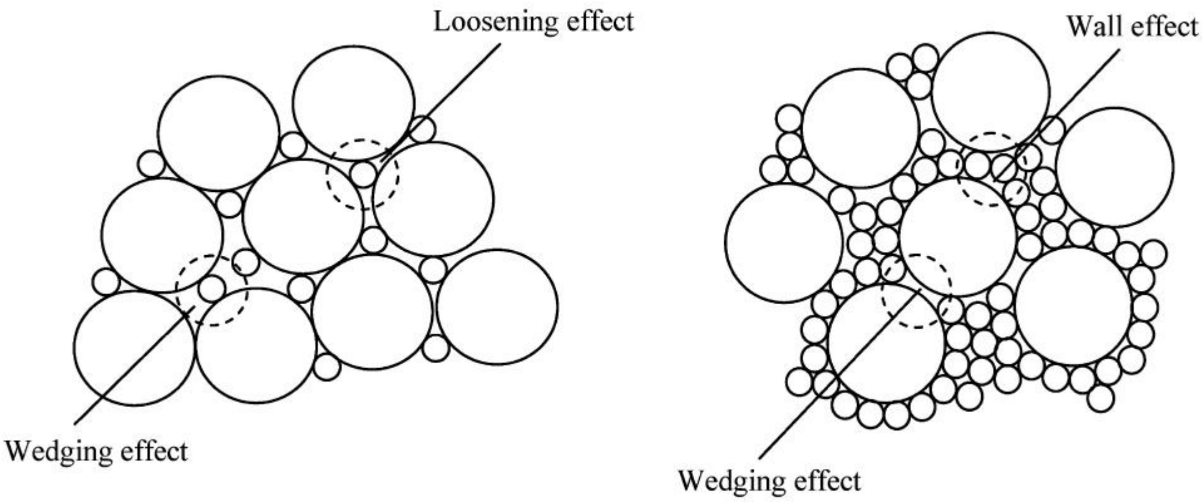

Fig. 1: Interactions in particle packing method (Chan, 2014).

Another approach methods are applying analytical and empirical relations between structure parameters and properties of the centre, e.g. a model presented in the study (Bleszczik, 1977) and its application for description of rheological properties of the paste (Świtoński, 2004).

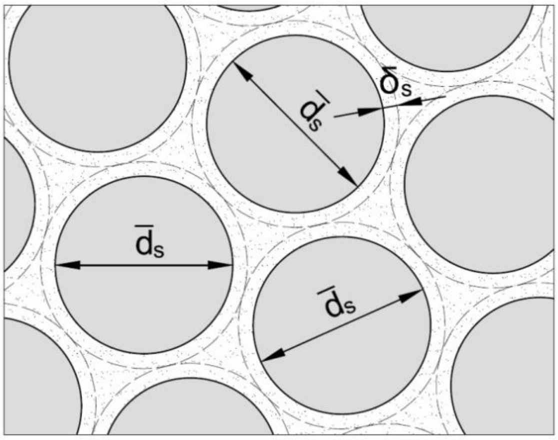

Fig. 2: Model of structure of fresh cement paste based on (Świtoński, 2004).

Similar assumptions were made in the paper (Świtoński, 2004) to design a three-level model of the structure of a concrete mixture, a cement paste (Fig. 2) and a micro-filler suspension. A geometrical model of a suspension of grains of an average size of $\overline{d}_s$ has been applied. The distance between them is equal to the double thickness of the layer of its surrounding liquid δ_s, whereas tightness of the binder grain arrangement s_{sz} is expressed as a ratio of the volume of grains with a water film to the total volume. A mathematic description was defined in the monograph (Świtoński, 2004) which can be used to develop a relation connecting structure parameters with the quantitative composition. Furthermore, it was proved that the highest tightness of the binder grain arrangement is at a quantity of the liquid phase corresponding to the normative water demand of cement ω_n (i.e. a standard paste). It was established in the paper (Sebok, 1986) that there is a minimum quantity of the liquid phase resulting from the surface forces, constituting 45 % of the total volume of liquid in the paste. According to (Świtoński, 2004), an assumption can be made that such liquid phase fractions will be maintained in a paste of $\omega \geq \omega_n$.

3. Influence of a superplasticizer

A standard paste consists of binder grains surrounded by a liquid layer and liquid in intergranular spaces. Extreme reduction of the water-binder ratio (below ω_n) is effective only when a suplerplasticizer is applied. If there is no admixture, it will not be possible to discharge air from the intergranular spaces or to condense the material.

Due to the complexity of this problem, experimental tests should be relied upon. Considerations in respect of the above were taken in the paper (Mrozik, 2012) where results of paste bulk density tests were included. The selected results concerning vibrating pastes with CEM II/A-M (S-LL) 52.5 cement are shown in Tab. 1 and Fig. 3.

Tab. 1: Comparison of structure parameters (Mrozik, 2012).

Item	Water-binder ratio ω [-]	Bulk density [kg/dm^3]		Air content p [%]	Binder volume fraction V_c/V_z [-]
		Actual ($\rho_{act.}$)	Theoretical ($\rho_{theor.}$)		
1	0.200	1.480	2.296	35.55	0.398
2	0.250	1.805	2.183	17.32	0.466
3	0.280 = ω_n	2.120	2.124	0.20	0.534
4	0.310	2.060	2.071	0.53	0.507
5	0.350	1.992	2.007	0.76	0.476
6	0.400	1.932	1.938	0.28	0.445
7	0.500	1.820	1.824	0.19	0.391
8	0.600	1.731	1.734	0.19	0.349
9	0.700	1.661	1.662	0.09	0.315
10	0.800	1.598	1.603	0.34	0.286

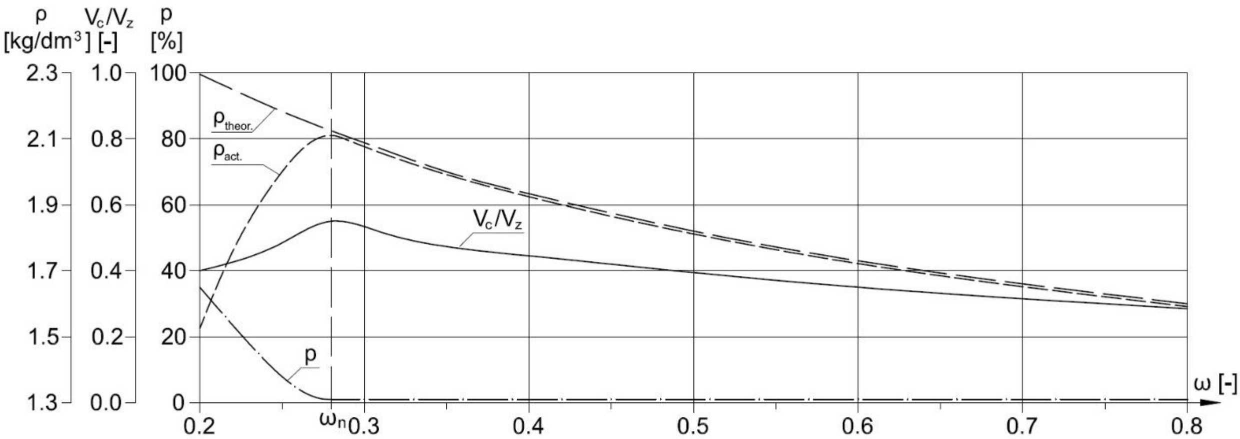

Fig. 3: Bulk density, air content and particle volume (Mrozik, 2012).

Presented results confirm that there is a specific liquid phase fraction at which the maximum bulk density is acquired. For pastes without admixtures, this fraction is determined by the standard water demand of the binder (Świtoński, 2004). It was also proved that at $\omega = \omega_n$ the volume fraction of binder grains is also the highest, and this is a limit level below which the air content is $p > 0$. Superplasticizers can be used to significantly reduce this level, as this was the author's subject of research. Below (Fig. 4), there is a sample set of so-called efficiency curves for a selected binder-admixture set (CEM II/A-M (S-LL) 52.5 + an admixture based on polycarboxylate ether in limit quantities recommended by the manufacturer).

The research shows that the similar density line is obtained after adding a suplerplasticizer. However, the ω level corresponding to the maximum value is reduced. Therefore, for each binder-additive set, the superplasticizer efficiency can be characterized by stating a minimum value of the water-binder ratio at which the density is equal to the value of $\rho_{theor.}$. Considering the widely known relation between the ω indicator and the strength, the determined limit level corresponds to the maximum strength value. Efficiency curves may then become a useful tool, e.g. when selecting a binder-additive set for high performance concrete of the assumed strength.

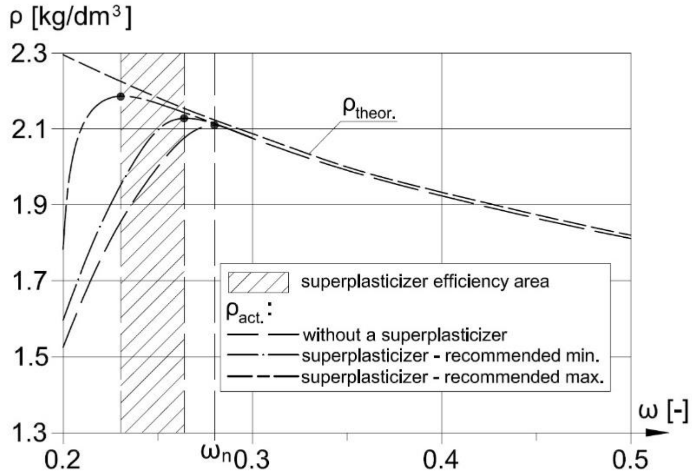

Fig. 4: Bulk density of cement pastes with superplasticizer.

4. Conclusions

- Selection of cement paste parameters is required to obtain concrete of specified properties.
- In order to design a paste composition of specified parameters, its structure has to be properly shaped.
- Plasticizers and superplasticizers have a significant influence on the binder grain arrangement, in particular at low water-binder ratios.
- Analytical and empirical efficiency curves for binder-additive sets can be used as a tool for designing modern cement composites.

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