Estimation of Rheo-Technological Effectiveness of Polycarboxylate Superplasticizer in Filled Cement Systems in the Development of Self-compacting Concrete for High-Density Reinforced Building Constructions

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Abstract. Analysis of rheo-technological effectiveness of the polycarboxylate superplasticizer Melflux 5581 F in the microcalcite-filled cement systems was performed. Optimal quantities of polycarboxylate superplasticizer and carbonate filler were determined, which allow obtaining highly mobile cement-mineral suspensions at reduced water content, which is an important step in the development of self-compacting concrete mixtures.

Keywords: Cement-mineral suspension · Rheology · Efficiency · Superplasticizer · Microcalcite · Self-compacting concrete

1 Introduction

Currently, there is an active growth in the area of concrete development, which the world technological community clearly classifies as cement composites of the new generation with high strength, workability, volume stability and durability (Collepari 2006; Nawy 2001; Nizina and Balykov 2016; Nizina et al. 2017; Sivakumar et al. 2014; Tran and Kim 2017). A special place among the concretes of the new generation is occupied by Self-Compacting Concrete (SCC) – Selbstverdichtender Concrete (SVB, German), Betonautoplasant (BAP, French), which are currently fairly widespread abroad. This term, proposed in 1986 by the Japanese professor H. Okamura (Okamura and Ouchi 2003), combines concrete mixtures with high workability characteristics (standard cone flow over 55–60 cm at water-to-cement ratio reduced to 0.35–0.4 or less), which are due to the high deformability of the suspension matrix, along with its high resistance to segregation or separation during movement.

A number of papers experimentally proved that one of the basic principles for producing self-compacting concrete mixtures is the presence of a significant amount of dispersed micro-particles of cement or mineral fillers (mainly 1–100 microns in size) in their formulation, which, together with Portland cement, increase the volume of a dispersion-water suspension. At the same time, not all dispersed fillers are capable of providing a higher flowability in suspension with a superplasticizer (SP) as compared

with cement suspensions. The research (Kalashnikov et al. 2014) shows that carbonate rocks (limestone, marble, dolomite), which include particles with a significant proportion of positively charged active centers, are the most compatible with anionic superplasticizers.

Thus, the generate of self-compacting concrete mixtures must begin with the development of rheological active formulation of the filled cement binders, which allow, when mixing together with the superplasticizer, to form aggregate resistant suspensions, which have a high concentration of the solid phase, low values of the shear stress limit and plastic viscosity at high gravitational fluidity under its own weight. At the same time, the efficiency of plasticizers in such systems will depend on many factors – addition procedure and optimal quantity of the plasticizer, rheological activity of the fillers used, etc.

The purpose of the study is to determine the optimal quantity of polycarboxylate superplasticizer and carbonate filler in cement-mineral suspensions when developing self-compacting concrete mixtures.

2 Methods and Approaches

To prepare suspensions, Portland cement CEM I 32.5R (C) by Mordovtsement PJSC (GOST 31108) was used. The mineral part included a carbonate filler from KM100 microcalcite (MKM) by Polipark LLC with the dosage of 0÷300% of Portland cement weight (0÷75% of solid phase weight) with the variability pitch of 100%. Melflux 5581 F (SP) polycarboxylate superplasticizer by BASF Construction Solutions (Trostberg, Germany) was used as a plasticizer.

The study was carried out with the fixed water-solid ratio $W/S = 0.15$ with the varying factors being:

- ratio MKM/C, $x_1 = 0 \div 3.0$ relative units;
- ratio SP/(C + MKM), $x_2 = 0 \div 1.5\%$.

3 Results and Discussion

The study results were used to develop an experimentally statistical (ES) model describing the changes in the flow diameter of cement-carbonate suspensions (Portland cement + microcalcite) $[D_f^{\text{HC}}, \text{mm}]$ from the Heggermann cone from the content of the varying factors x_1 and x_2 :

$$D_f^{\text{HC}} = 288.9 + 52.9 \cdot x_1 + 64.8 \cdot x_2 + 19.8 \cdot x_1 \cdot x_2 - 51.33 \cdot x_1^2 - 89.3 \cdot x_2^2 + 37.97 \cdot x_1^3 + 32.34 \cdot x_2^3 - 59.06 \cdot x_1 \cdot x_2^2 - 15.19 \cdot x_1^2 \cdot x_2 + 31.64 \cdot x_1^2 \cdot x_2^2. \quad (1)$$

Using the polynomial (1), isolines have been built, which reflect the changes in the flow diameter of cement-carbonate suspensions from the Heggermann cone depending on the content of microcalcite and Melflux 5581 F superplasticizer (Fig. 1). It has been

found that for the constant water/solid ratio of $W/S = 0.15$ relative units, an increase in the dosage of the superplasticizer and the mineral filler (microcalcite) causes a significant increase in the flow diameter of the cement-mineral suspension.

Fig. 1. Changes in the flow diameter of cement-carbonate suspensions from the Heggermann cone depending on the superplasticizer dosage and microcalcite filling degree

Analysis on Fig. 1 shows that cement suspensions without microcalcite at the specified water content $W/S = 0.15$ begin to flow under the action of gravity and the value of the Heggermann cone flow diameter $D_f^{HC} = 100 \div 135$ mm with superplasticizer quantities exceeding $0.1 \div 0.5\%$ the mass of the solid phase. However, even an increase in the superplasticizer content to $1.0 \div 1.5\%$ does not allow achieving self-compacting of suspensions ($D_f^{HC} = 160 \div 210 < 280$ mm).

It was determined (Fig. 1) that the level of rheo-technological indices specified for self-compacting suspensions ($D_f^{HC} \geq 280$ mm) is achieved at the microcalcite content $x_1 = 0.82 \div 3.0$ relative units ($82 \div 300\%$ of the Portland cement mass or $45 \div 75\%$ of the solid phase mass ($C + MKM$)) and the quantity of Melflux 5581 F superplasticizer $x_2 = 0.45 \div 1.5\%$ of the solid phase mass, wherein when decreasing the indicator x_1 , an increase in the indicator x_2 in the specified ranges ($(x_1 = 3.0$ relative units; $x_2 = 0.45\%) \rightarrow (x_1 = 0.82$ relative units; $x_2 = 1.5\%)$) is required.

4 Conclusions

The analysis of research results found the optimal levels of the varying factors that allow reaching the self-compacting of suspensions for the flow diameter from the Heggermann cone above 280 mm and the water/solid ratio of 0.15 relative units: the dosage of Melflux 5581 F superplasticizer is $0.5 \div 1.0\%$ of the solid phase weight; the filling degree of suspension with microcalcite is at least 105% of the Portland cement weight.

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