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Rheological properties and the air content in fresh concrete for self compacting high performance concrete

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HIGHLIGHTS

- Rheological parameters of fresh HPSCC may be use for predicting air content in mixture by the statistical model.
- The air content of fresh HPSCC depends on universal components of the mixture.
- HPSCC with a high viscosity and slump flow below 65 cm have low ability to self-venting.

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ABSTRACT

The results of the influence of rheological properties and universal components of a fresh High Performance Self-compacting Concrete (HPSCC) on the content of entrapped air in the concrete mix are presented in the paper. The nature of changes the air content in fresh HPSCC depends on rheological parameters. When yield value g and plastic viscosity h decrease thereby diameter of slump flow increase and time of slump flow decrease then air content in mixture also decrease. The results of tests show that we can predict the influence of rheological properties (yield stress, plastic viscosity or diameter and propagation time) on air content in fresh HPSCC by statistical model presented in the text of the paper. Obtaining the air content of less than 2% of the fresh concrete is possible if the diameter of slump flow is greater than 65 cm – according to the slump-flow test (yield stress limit is less than 250 N mm – according to tests performed rheometer BT) and the time of slump flow is less than 16 s (plastic viscosity h less than 14,000 N mm s – measured by rheometer BT2).

1. Introduction

High Performance Self-compacting Concrete (HPSCC) is a composite designed due to a compressive strength equal or greater than 60 MPa and which composition and components are also chosen because of the specific properties of the fresh concrete.

These characteristics should provide the ability of the mixture to fill the space between the reinforcement and the space inside the formwork under its own weight without the need for mechanical compaction [1–11].

These characteristics allow the fresh concrete to fulfill three conditions of self-compacting: flowability, segregation resistance and self-venting [12,13].

Condition of flowability with the ability to flow through the reinforcement [12] is dependent on the rheological properties of the mixture but also on the corresponding density of reinforcement and the adoption of the size of the aggregate. Condition will be met if yield stress and plastic viscosity of the mixtures are as small as possible. The smaller is the yield stress the better will be leveled in formwork. The lower the yield stress and plastic viscosity of the mixture are, the greater the speed of propagation of fresh concrete and less time of filling forms.

Condition of segregation resistance [12] will be fulfilled when segregation of components in the mixture and separation of the paste do not occur. Segregation occurs when yield stress of the mixture is much smaller than the shear stress caused by the weight of the aggregate.

The way to prevent settling of the aggregate in the mixture is to increase the plastic viscosity of the mixture.

Self-venting will be met with low values of yield stress and plastic viscosity of the mixture, determining the appropriate density of the mixture. The lower the yield stress and viscosity, the smaller are the air bubbles, automatically eliminated from the mixture due to buoyancy force.

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Each condition should be checked by measuring the rheological parameters by technical methods and/or by rheometric methods. There is a very good correlation of rheological parameters: yield stress and plastic viscosity of the values measured in technical tests which will be discussed later in this paper.

In practice, the study of self compacting compound takes place mainly in order to check the condition of flowability, more rarely the condition of stability. In most cases, the stability is assessed subjectively during the production of fresh concrete and/or based on sampling of hardened concrete. The condition of self-venting is rarely controlled.

The ability of the self-venting of the mix is not directly tested, as it is often assumed that the relevant properties allowing for appropriate fluidy and the lack of segregation also provide adequate self-venting of the mixture [7–10].

Confirmation of this statement is published in [14] which Domon over 11 years had been analyzing the cases of self-compacting concrete and air content in the fresh mixture is not specified.

The authors of the paper performed their analysis to HPSCC cases. The authors have carried out the analysis on the basis of 76 cases of HPSCC [15–40]. Analysis the authors of summary of statistics for the air content in concrete mixture for HPSCC and a typical composition for HPSCC used in practice-analysis of 76 cases was show in Table 1. Results showed that in all 76 analyzed cases of HPSCC only in 35% cases air content is specified. This shows problem of marginalization of air content in HPSCC.

Only in literary sources [16,20,30,32] there are few information about the air content. In the literature on HPSCC there is also lack of information about the determinants of the value of air. If assumed that the fresh concrete, which is characterized by adequate fluidity and maintains the stability, at the same time is also characterized by an appropriate degree of self-compaction. That means the appropriate rheological properties influence the air content. Are the material factors (related to the ingredients and their proportions in the mixture), which substantially impact the yield stress and plastic viscosity [6,7–10,14,18,42–45,47,48] also affect the air content?

According to the analysis of the literature data parameter of median air content is equal to 3.6% (Table 1). Taking into account the reported [41,42], where it was found that in the case of compacted concrete mix by mechanically compacted deemed to be one which have no more than 1.5 ÷ 2% of the air consequently the value of 3.6% seems to be high.

The problem seems to be important considering the fact that increasing the air content of the fresh concrete by 1% causes a decrease in compressive strength by 5 MPa [13]. In the case of HPSCC the ensuring of fresh concrete's the maximum venting is a necessary condition to obtain them.

Table 1
Summary of statistics for the air content in HPSCC concrete mixture and a typical composition of HPSCC (analysis of 76 cases made by authors) [15–40].

Indication	Median	Intervals commonly used and other informations
Air content (%)	3.6	Percentile 25% – 1.6 Percentile 75% – 4.8 Average – 3.5 Standard deviation – 1.6
w/b ratio	0.31	0.25 ÷ 0.40
Content of silica fume	9.5% b.m.	5 ÷ 10% b. m.
Content of cement	400 kg/m^3	350 ÷ 500 kg/m^3 (in some cases 500 ÷ 600 kg/m^3)
Content of fraction particulate	560 kg/m^3	500 ÷ 650 kg/m^3
The size of the aggregate	16 mm	<20 mm
Sand point	45%	⩾40%

Therefore, the condition of self-venting appears to be necessary checked for HPSCC also because it entails to achieve adequate compressive strength.

The available literature on HPSCC does not provide the information about the influence time on the air content that has a significant impact on the rheological properties. Therefore, should check whether and how the passage of time changes the air content in the mixture of HPSCC.

Taking into account the limited reports on a study of air content in the HPSCC mix and the lack of systematic research on the numerical relationship between the air content and rheological properties the purpose of the research was to develop the mathematical relationship between the rheological properties and the air content in the fresh concretes in the form of a statistical model.

Considering also the fact that in the literature there is lack of systematic data concerning a hierarchy of composition's factors and time influence on the air content [6,43–45,47,48] present the analysis of the significance of composition's factors and time influence on the air content.

These studies reveal new information in order to explain the influence the rheological properties on the content of entrapped air in the mixture.

2. Experiment details

2.1. Variables and research plan

The authors analysis of 76 cases of HPSCC (Table 1) showed that the factors influencing the self-compacting fresh concrete are: physicochemical properties of the mixture, ingredients and their content, the proportions in the mixture and the time elapsed since the mixing the components and the temperature of the mixture. The most important properties of the ingredients include [2,6,44-46]:

- aggregate characteristics (type, density, bulk density, shape) and particle size (amount of sand, the tightness of the pile clastic);
- properties of cement paste resulting from the nature and physicochemical properties of cement; the type, content and characteristics of mineral additives; the presence and properties of chemical additives and the w/c ratio;
- the filling's ratio of the aggregate's crumb pile with paste (the content of paste in the mix) (1 and 2).

The proportions of the apparent volume fraction of the aggregate volume of the paste are presented using known technology indicators such as: the filling's ratio of the aggregate's crumb pile with paste – φ. The aggregate thickness of the concrete cover leaven $d/2$, or swell index m – increasing the original volume of the aggregate grains under the influence of cover aggregate leaven of paste. The filling's ratio of the aggregate's crumb pile with paste – φ is defined as follows:

$$\varphi = \frac{D_m}{D_s} \tag{1}$$

where, φ – the filling's ratio of the aggregate's crumb pile with paste – φ; D_m – the rate of dispersion of the mixture, D_s – the rate of dispersion of clastic pile.

D_m indicator is the average static surface wrapping detrital grains stack cement paste or cement.

Using transformation formulas one can get the following equation:

$$\varphi = \frac{V}{A \cdot P} \tag{2}$$

where, V – absolute volume of paste in the mix [m^3], A – weight of aggregates [kg], P – specific porosity of the poured loosely stack available for water [m^3/kg].

The definition of the filling's ratio of the aggregate's crumb pile with paste – φ is been presented in detail in [47].

On the basis of this information, extensive studies were conducted on a broad-based preliminary on a number of variable factors, selected on the basis of literature [2,6,15–40,44–46]: w/b ratio, the filling's ratio of the aggregate's crumb pile with paste-index φ, content of condensed silica fume, sand point and content of superplasticizer. The study allowed the selection of appropriate composition with a suitable rheological properties and compressive strength.

The levels of factors were selected based on the analysis of literature data. The authors have carried out on the basis of 76 cases of configurations HPSCC (Table 1) and preliminary tests so as to correspond to the compositions of the test compounds within the scope of its typical configurations HPSCC variation in practice (Table 2).