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The influence of high-calcium fly ash on the properties of fresh and hardened self-compacting concrete and high performance self-compacting concrete

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ABSTRACT

This research presents findings on the influence of high-calcium fly ash (HCFA) on selected properties of fresh and hardened self-compacting concrete and high performance self-compacting concrete. HCFA was used as an additive for concrete (up to 30%) or as a main constituent in cement. Studies have confirmed the possibility of HCFA use in self-compacting concrete, while maintaining the assumed workability of fresh concrete and compressive strength of hardened concrete. HCFA should be processed by grinding, and its amount in the mixture should not be higher than 30% of the cement's mass. Cements that contain HCFA as the main component can be used in both normal and high performance self-compacting concrete. Studies have also confirmed the possibility of the use of high-ash, multi-component cements containing HCFA (CEM X – "CEM V/A (S-W)") for the new generation of concrete.

1. Introduction

The use of mineral additives in concrete or cement is one of the main trends in the development of concrete technology; at the same time it is an important element of a sustainable development strategy. It enables the properties of the concrete to be improved, especially in the aspect of resistance to the aggressive influence of the environment, as well as to obtain significant economic benefits. The main effects of the use of mineral additives have been already extensively presented in numerous other studies (Aïtcin, 1998; Neville, 2012; Ramachandran, 1995). Use of such additions makes waste management more efficient, reduces energy consumption during cement production and lowers CO_2 emissions. These properties will cause an increased demand for alternative cementitious materials, because in order to fulfil their future responsibilities cement and concrete producers need to have a high degree of flexibility in the selection and use of mineral admixtures.

Another important trend in the development of modern concrete technology is the use of self-compacting concrete (SCC). The mixture of this concrete has specific rheological properties that enable it to gravitationally fill tightly and completely the forms or formworks of any shape, even with thick reinforcement, without any need to use mechanical compacting or segregation. The three main reasons for creating SCC were: (1) the aspiration to obtain a better concrete quality by minimizing the influence of the human factor on the process of fresh concrete compacting; (2) the improvement in work conditions, which means eliminating the threat of vibration and noise; and (3) lowering the labour and energy consumption of concrete works. The advantages and possible benefits of using SCC are confirmed by the high number of its uses (De Schutter et al., 2008).

The necessity of fulfilling the workability requirements determines the composition of the SCC mixture (Szwabowski and Gołaszewski, 2010). One of the most significant features is the low water-cement (w/c) ratio, which ensures the mixture's resistance to segregation and sedimentation. The high fluidity of the mix is obtained by using a large amount of new generation of superplasticizers. Mineral additives are very important constituents of SCC. They are used in order to raise the amount of cement paste without increasing the amount of cement in the mix above a necessary minimum. Their presence leads to the better development of workability and increases the immunity of the mix to segregation and sedimentation. Choosing the appropriate type and amount of the mineral additives gives the possibility of forming the technical properties of concrete. Usually, for self-compacting mixes ground limestone powder is used, which is an additive with weak binding properties. In order to obtain a concrete of a higher class

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and better resistance to the influence of the environment, ground blast-furnace slag, fly ashes or, less often, silica fume should be used.

Just in Poland, as a result of burning brown coal in conventional furnaces, about 4 million mg of high-calcium fly ash (HCFA) is produced. This type of fly ash is distinguished by two significant features. One is its hydraulic–pozzolanic activity and the other one is its more complex and more changeable chemical and mineral composition than siliceous fly ash, which is a result of burning hard coal (Giergiczny, 2006). The analysis of existing standards and guidelines executed in Garbacik et al. (2011) shows that this kind of fly ash could be the main constituent of cement (PN-EN 197-1:2002) or the Type II addition to concrete composition (ASTM C618, CAN/CSA-A23.5-98). However, HCFA is used in concrete and cement production technology to a very limited extent.

There are several causes of this state that should be listed here. One of the reasons is the high and variable content of free calcium and sulfur compounds in the HCFA, which may negatively influence the concrete's properties. Another one is the high fineness (retained on 45 μm sieve) of the HCFA, which contributes to its high demand for water and has a negative impact on the workability of fresh concrete. What is more, HCFA shows a significant changeability of its physical properties and chemical and mineral composition over time (Baran et al., 2010).

Previous studies have examined the possibility of using waste materials as natural aggregate replacements in concrete: recycled demolition aggregate (Richardson et al., 2011), tyre aggregate (Bravo and de Brito, 2012), recycled concrete aggregates (Marie and Quiasrawi, 2012) and recycled cathode ray tube funnel glass sand (Zhao et al., 2013). Using blends of limestone powder and mineral admixtures such as fly ash, rice husk ash, blast furnace slag, or natural pozzolans improves the overall performance of SCC (De Weerdt et al., 2011; Makhloufi et al., 2012; Rizwan and Bier, 2012; Sua-iam and Makul, 2013). There is a lack of research that comprehensively presents the effects of using HCFA in concrete or cement. According to the previous but scarce studies that have been conducted, it may be stated that the addition of HCFA worsens the mixture's workability (Grzeszczyk and Lipowski, 2002; Yamei et al., 1997) and it may lower the effectiveness of water reducing and high-range water reducing admixtures (Tsimas and Moutsatsou-Tsima, 2005; Wei et al., 2003). The results of these studies also show that introducing a proportion of merely 10% of HCFA into the mix could significantly worsen the workability of the mix, especially in the aspect of loss of workability over time. In view of this research, the use of the HCFA in concrete technology is not simple, and it has hardly been considered for SCC technology. In fact, only a little information about the possibility of using HCFA in SCC can be found in the source literature (Yazici, 2008; Ponikiewski and Gołaszewski, 2012). However, it must be noted that in previous research no unequivocally negative influence of HCFA has been observed, although it should be stated that the extent of the durability tests were conducted was limited.

The latest tests to be conducted have shown that the negative influence of HCFA on the workability of fresh cement mixtures may be reduced by processing it by grinding or by separation of coarse fractions (Giergiczny et al., 2013). In this way an HCFA of the needed fineness and significantly lowered water-demand may be obtained. Moreover, the negative influence of processed HCFA on the rheological properties of fresh mixtures and the effectiveness of chemical admixtures, albeit still present, is significantly lower (Gołaszewski et al., 2011a). Another, even more promising way of using the HCFA is using it as a main constituent of cement, especially of multi-component cements (Giergiczny, 2006). In this case, by using an adequately composed cement it is possible to almost entirely eliminate the negative influence of HCFA on the rheological properties of the fresh cement mixtures (Gołaszewski et al., 2011b, 2013a). The effectiveness of water reducing and high-range water reducing admixtures on those cements does not diverge from commonly used cements without high-calcium fly ash (Gołaszewski et al., 2013b).

The main reason for conducting the research presented here was to prove the possibility of obtaining self-compacting concrete while using HCFA as an additive to concrete or as a main component of cement, including multi-component cements. The additional aim of the research was to determine the qualitative and quantitative influence of HCFA and cements with its addition on the properties of the fresh and hardened self-compacting concrete and high performance self-compacting concrete (HPSCC). The high-calcium fly ash multi-component cement, the so-called CEM X, was also encompassed in this research. This kind of cement consists of ground granulated blast furnace slag (GGBFS) and HCFA. Multi-component cements (CEM X) perfectly meet the requirements of a sustainable development strategy. They are currently subject to intensive researches and their introduction into industrial use may be expected soon (Hardtl and Koc, 2012).

2. Experimental

2.1. Research plan

The research was divided into two parts as follows:

1. The influence of HCFA on the properties of fresh and hardened self-compacting concrete (SCC) and high performance self-compacting concrete (HPSCC).
2. The influence of cement type (cements with the addition of HCFA) on the properties of fresh and hardened self-compacting concrete (SCC) and high performance self-compacting concrete (HPSCC).

The research examined the influence of the following factors on the properties of SCC and HPSCC:

- The presence and content of HCFA (10, 20, 30% as a replacement for a part of the cement by mass).
- The processing of HCFA (unprocessed HCFA, HCFA processed by grinding).
- The cement types:
  - SCC – CEM II 42.5/B-W, CEM IV 32.5/B-W, CEM II/B-M (LL-W) 42.5
  - HPSCC – CEM II 42.5/A-W, CEM II 42.5/A-M (V-W), CEM V 32.5/A (S-W)
- The consistency classes of self-compacting concrete mixtures according to EN 12350-8 (controlled by superplasticizer addition, for research on the influence of cements with the addition of HCFA only).

During the experiments the following rheological properties of HCFA content will be measured: D_{max}' – maximum spread value, and T_{500}' – the time taken to reach a spread of 500 mm. D_{max} corresponds with yield value and T_{500} corresponds with plastic viscosity.

The scope of the investigation in each part of research included the following: the rheological properties of fresh concrete, their compressive and flexural strength, and the water absorption and water permeability of hardened concrete. The properties of concretes with the addition of HCFA and cements with the same addition were compared to the properties of analogous concretes based on reference cement CEM I.