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Influence of the physicochemical properties of Portland cement on the strength of reactive powder concrete

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Abstract

The paper presents an analysis of mechanical properties and microstructure of reactive powder concretes RPC manufactured with the use of three different industrial Portland cements diversified in terms of the strength class (42.5 and 52.5), chemical and mineral composition as well as specific surface area. All developed materials were subjected to three different hydrothermal curing conditions. The test results confirm that the factors most influencing the consistency of the concrete mixture are the chemical and mineralogical composition of the binder. However, it appears that when it comes to mechanical properties, the factor which plays the crucial role is the specific surface area of cement. For one of the analysed cements, due to its favourable chemical and mineralogical composition, it was possible to limit the value of W/B ratio up to 0.17, without adversely affecting the properties of the concrete mixture. Nevertheless, it has not contributed to any spectacular increase in strength as compared to materials based on the cement with the largest surface area, where the minimum realizable W/B ratio was 0.20.

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1. Introduction

Reactive powder concretes, characterized by ultra high mechanical properties, are multi-component cementitious composites, in which the role of the binder is mainly played by cement and silica fume. The average

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volume fraction of this part of composite, also including mixing water and superplasticizer, comprises about 60% of the whole material [1]–[5]. The amount of cement in 1 m^3 of concrete mixture ranges from 700 to 950 kg [6]–[8]. Therefore, proper selection of the binder type, i.e. its class, mineralogical and chemical composition and, finally, its specific surface area is very important since it is a factor influencing properties of the concrete mixture and, consequently, of the matured composite. The average values of the water-binder ratio in RPCs are in the range of 0.18 - 0.25 [3], [4], [9]–[11], which in some cases allows obtaining the value of compressive strength exceeding 200 MPa. A parameter associated with consistency of the mixture (in the case of RPC usually expressed in cm as a flow measured on table for mortars [12]), according to [13], should be within very narrow limits of 25 – 30 cm. This is due to two phenomena that may take place during preparation of reactive powder concrete mixtures. The first one is related to the problem of sedimentation of frequently used steel fibres when the flow is greater than 30 cm. The second one is the amount of air entrapped during mixing, reaching even more than 3 – 4 vol.% if the consistency is too thick.

The best results so far, in terms of technological parameters and the subsequent mechanical properties of the matured material, have been achieved with the use of Portland cement CEM I, characterized by strength classes 42.5 and 52.5 [6], [7], [14]. Very few studies are described in [3], [15], [16], in which experimental mixtures were made with the use of cements type CEM II and CEM III. Extensive research on the impact of phase and chemical composition of different cements on the properties of hardened RPC were undertaken by [14]. Three Portland cements of strength class 42.5 and 52.5 were analyzed. They were different in terms of the content of C_3A phase and alkalis as well as the specific surface area. The composites were manufactured preserving constant mass proportions of ingredients, and two different curing regimes were applied during setting (natural conditions at temperature 20^{o}C and steam curing at 90^{o}C). For the cement characterized by strength class 42.5, the best results were obtained using cement CEM I 42.5 LA in both curing conditions ($f_{c,28(20oC)}$=188MPa and $f_{c,28(90oC)}$=258MPa), whereas the worst when CEM I 42.5 R was applied ($f_{c,28(20oC)}$=155MPa and $f_{c,28(90oC)}$=231MPa). The reasons for obtaining lower compressive strength in the second case were ascribed by authors [14] to the cement chemical and phase composition, which was characterized by the highest content of C_3A and alkalis as well as surface area. These three parameters were the reason why in order to get sufficiently good rheological properties of the concrete mixture, the amount of mixing water had to be increased from predetermined W/C = 0.23 to 0.25. In the case of cements of strength class 52.5, the compressive strength of all composites after 28 days of setting remained on the same level and varied from 177 to 183 MPa, regardless of the curing conditions or the cement type. However, as in the case of class 42.5, the concrete mixture containing cement CEM I 52.5 R showed the worst workability, although this cement had a smaller surface area than CEM I 52.5 R LA. Thus, [14] concluded that the rheological properties of RPC mixtures are primarily determined by the presence of the C_3A phase and alkaline ions.

In addition to the negative impact of C_3A on rheological properties of concrete mixtures, confirmed several times, consisting in adsorption of superplasticizer molecules on the surface of this phase, [17] gives a number of other reasons for lack of compatibility between cement and superplasticizer. The following factors are mentioned: the form of sulphate ions (i.e. K_2SO_4, Na_2SO_4, anhydrite, hemihydrate, and gypsum) and free calcium oxide. According to the information given in [17], the presence of alkaline ions does not necessarily play a negative role in the process of concrete mixture manufacture. Indeed, the presence of appropriate amounts of Na^+ and K^+ supplied in the form of sulphates increases the concentration of SO_4^{2-} in the solution, which leads to more rapid formation of ettringite on the surface of C_3A, and thereby increases the effectiveness of superplasticizer in the mixture. One way or the other, as to the general requirements for selection of proper cement for reactive powder concrete production, authors [8] and [14] agree that it should be characterized by:

- the lowest possible content of C_3A phase,
- reduced amount of alkaline ions,
- relatively low development of specific surface area, so that it would not cause excessive increase in water demand,
- high silica modulus, which provides both excellent rheological and mechanical properties of the matured material.