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Effect of Pozzolanic Additives on the Strength Development of High Performance Concrete

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Abstract

The aim of this research is to estimate the effect of pozzolanic substitutes on the temperature generated by the hydration and on the final strength of concrete. Differential thermal analyses (DTA) were conducted. Ternary cementitious systems with different ratios of Portland cement, silica fume and calcined illite clay were investigated. The results showed that the rates of pozzolanic reaction and portlandite consumption in the silica fume-blended cement pastes are higher than in the illite clay-blended cement pastes.

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Keywords: High performance concrete; pozzolanic additives; silica fume; ternary systems.

1. Introduction

Today, pozzolanic materials are enjoying a renaissance as supplementary cementing materials in Portland cements pastes and may replace part of the clinker in order to enhance the performance of the hydrated cement. When Portland cement clinker is produced there is a significant amount of CO_2 emitted from the calcination of the limestone. [1]. In order to reduce the emission of CO_2, reduction of the cement amount in concrete production and usage of pozzolans is an advantage [2].

Pozzolans are materials that consist predominantly of silica and alumina [3] and are able to combine with portlandite in the presence of water to produce new reaction products exhibiting a binding character [4,5]. The amount of portlandite produced during the cement hydration will be reduced relatively to the percentage of pozzolans used in

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the mixture, and it will vary depending on the type of cements. Amount of portlandite is also related to the ratio of cement hydration. It will depend upon the amount of C_3S and C_2S in the cement. Each of these compounds react with water to form C-S-H (calcium silicate hydrate) and portlandite – $Ca(OH)_2$. A small portion of portlandite enters into reactions with alumina and sulphates to form compounds such as ettringite. Therefore not all of the portlandite produced is available or free to react with pozzolans [6,7]. It has been noted in the research by Massazza, that approximately 22% of free portlandite is available in the system. [8] Moreover, it has been found that adding calcium to pozzolan, which has a low calcium /silica ratio, enhances the hydration reaction for the formation of calcium silicate hydrate (C-S-H) gels and improves the mechanical strength of high-performance concrete [9].

Materials that exhibit pozzolanic activity can decrease the hydration heat by means of cement substitution, which increases the heat generated during hydration due to the pozzolanic reaction [10].

Pozzolans are known to increase the durability [11], lower the hydration heat [12], increase the resistance to sulphate attack [13] and reduce the energy cost per cement unit [12].

In the scientific research work by other scientists [14-16] it has been proved that by addition of metakaolin with pozzolanic character to the PC (in the reaction with PC hydratation products calcium silicates appear in the structure), the binding time is accelerated in the early stage of hydration. Giergiczny has detected, that by replacing half of PC amount in the composition with metakaolin – the shrinkage and amount of cracks diminishes for the concrete samples [17].

Consequently, the present study focuses on modification of cement pastes with binary and ternary cement paste systems in order to determine changes of hydration heat. In addition, the hydration characteristics of the cement mortars prepared by blending cement with silica fume (SF) and calcined illite clay (CC) were examined at different curing ages.

2. Materials and methods

2.1. Test methods

Chemical composition of raw materials was determined according to LVS EN 196-2 with precision +/- 0.5%. Specific surface area has been detected by BET method. SEM was used for microstructural investigation of hardened specimens and for description of raw materials. To describe the hydration process of blended cement pastes, thermogravimetrical research was carried out by DTA. The temperatures of exothermic effects during the binding and hardening of concrete paste were registered according to the methodology devised by company Alcoa, (Calcium Aluminate Cement Test Methods. Exothermic Reaction (EXO). Alcoa Industrial Chemicals: 16 p.).

Properties of fresh mixes were determined according to LVS EN 1015-3:2000 with flow table for mortar. The initial cement setting time was determined according to LVS EN 196-3, the normal consistency was tested according to LVS EN 196-3. Compressive strength of specimens was determined according to standard LVS EN 1015-11 'Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar'.

2.2. Materials

All materials used in this study were commercially available raw materials - silica fume (SF) ("Elkem Microsilica® Grade 971-U"), calcined illite clay (CC) (brick factory "Lode"), Portland cement (CEM) ("Kunda®" CEM I 42,5 N) and superplasticizer (SP) admixtures ("Sikament® 56"). Chemical compositions of raw materials are given in the Table 1. The initial setting time of cement was 182 min and the final setting – 224 min, the normal consistency was 28.2%.

According to technical data sheet the density of granulated silica fume is 300 kg/m^3. Specific surface area of the material is 18-20 m^2/g (technical information obtained from the commercially available data sheet), 99.8% of silica fume particles are smaller than 45µm. 90% of silica fume particles had dimensions ranging from 20 nm to 0.5 µm. It is confirmed by SEM image (Figure 1).