Evaluation of the Combined Pozzolanic Activities of Fly Ash and Blast Furnace Slag by Thermal Analysis

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1- Introduction

Since the end of last century, a significant increase in the production of blended cements incorporating Portland cement and two (ternary) or even three (quaternary) supplementary cementing materials (SCMs) has occurred. The advantages of these types of cements compared to the respective binary systems motivated considerable research in this field. The principal aim of all of these efforts was to produce resource-efficient cement and concrete with tailor-made properties, based on the unique features of the third component in the mix, which in most cases compensated for the shortcomings of the pozzolan initially used. Therefore, several types of blended cements with various combinations of fly ash-silica fume, fly ash-slag, or slag-silica fume were rapidly developed and nowadays are commonly used in several countries (Bagel, 1998). However, there are still a number of shortcomings, associated with several SCMs that actually prevent ternary blended cements from being applied universally. These include their higher cost relative to Portland cement, higher water requirement, generation of greater amounts of heat (during hydration) leading to undesirable temperature rises in concrete, and rare in compatible combinations of SCMs.

The work presented here, is part of a research programme dealing with the evaluation of ternary blended cements made with fly ash and ground granulated blast furnace slag. These materials are the paramount industrial by-product being generated in power plants and steel industries. This paper discusses the results of thermal analysis carried out to study their combined pozzolanic activity.

2- Experimental Program

Four different types of paste were prepared as follows: (a) Control without any mineral admixture (CTR), (b) Paste containing 25% fly ash (FC), (c) Paste of ternary blending of 25% fly ash and 25% ground granulated blast furnace slag (FSC), (d) Paste of 50% ground granulated blast furnace slag (SC). The tests were performed at the age of 3 days and 91 days to assess the pozzolanic reactively. For thermal analysis at given day, fractures of paste were chosen carefully and immersed in acetone to stop the hydration procedure and then dried up. After that, some of the fractures were ground into fine powder. Powder samples of pastes sieved through No.200 (75-μm) were used. Thermo-gravimetric tests were performed on Rigaku-TG810 ID Thermo flex TAS200, gradually raising temperature from 20^{o}C to 1000^{o}C at a rate of 6^{o}C/minute. Differential thermal analysis (DTA) locates the ranges corresponding to different phases in paste, while simultaneous weight loss due to decomposition is estimated with TGA.

3- Results and Discussion

Thermal analysis has been defined by the International Confederation of Thermal Analysis (ICTA) as a general term which covers a variety of techniques that record the physicochemical changes occurring in a substance as function of temperature. This term, therefore, encompasses many classical techniques such as differential thermal analysis (DTA), thermogravimetry (TG) etc. Differential thermal analysis is a method that monitors the temperature difference existing between a sample and a reference material as function of temperature assuming both sample and reference are subjected to the same environment. The differential temperature usually presented in term of electric potential (μ Volt). Thermogravimetry (TG) measures the loss of mass of a material as a function of temperature.

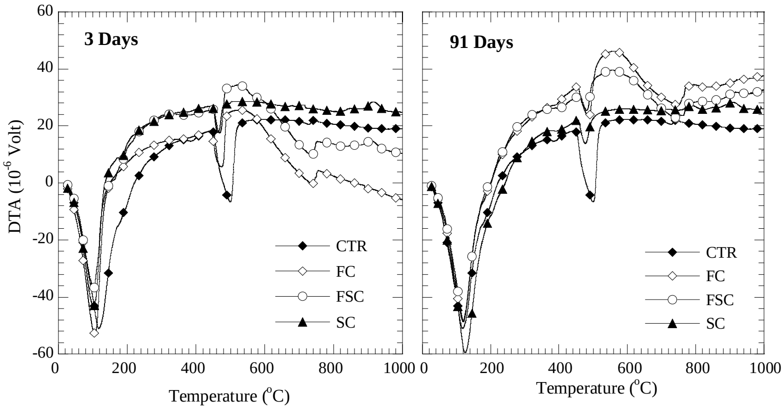

Fig 1 DTA of specimens at the age of 3 and 91 days

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DTA locates the ranges corresponding to thermal decompositions of different phases in paste, while TGA simultaneously measure the weight loss due to the decompositions. DTA thermograms for CTR, FC, FSC and SC specimens at curing age 3 and 91 days are shown in **Fig. 1**. The calcium silicate hydrates (C-S-H) trough (endothermal) can be identified at temperature range 115-225°C, ettringite at 120-130°C, calcium hydroxide (CH) in the range of 430-550°C, and calcium carbonate ($CaCO_3$) at 750-850°C (Ramachandan, 2003). The addition of mineral admixtures in cement results in formation of decreased amount of CH in the hydration product. This is attributed to the dilution effect and to the consumption of CH by pozzolanic reaction. At 3 days, both C-S-H and CH trough of all mineral substituted specimens were lowered than CTR indicating no pozzolanic action at this stage. While at 91 days, C-S-H trough of all mineral substituted specimens was higher than CTR and their CH trough was comparative lower than that at 3 days, denoting increased in C-S-H at the cost of CH due to pozzolanicity. The paste samples with fly ash substitutions (FC and FSC) had the peak range 550-680°C showing presence of crystalline silica.

The TG analysis is shown in **Fig. 2**. TGA of mature pastes indicated a loss at 420-550ºC primarily due to CH decomposition and the loss at 550ºC was partly caused by CO_2 and partly due to the final stage of dehydration of C-S-H and hydrated aluminates. Moreover, at about 750ºC, the thermo-analytic curves showed the endothermic phenomenon of decarbonation due to presence carbonates (Taylor, 1997). By comparing the decomposition CH and C-S-H, the hydration and pozzolanic reaction can be compared. An abrupt weight loss occurred between 0-150ºC attributed to moisture loss in the specimen. At the age of 91 days the higher loss of C-S-H and C-A-S-H was observed in mineral substituted specimen than in CTR, attributed to an extra amount of hydration product. Loss in CH weight of all pozzolan additives paste showed reduced values than CTR. These reduced values were calculated in term of percentage loss with respect to loss in CTR. The reduction in CH amount in FC, FSC and SC was 47, 70 and 56%, respectively. This could be attributed both to the dilution factor and the CH consumption by pozzolanic reaction. At 3 days, paste sample FSC paste showed less loss of C-S-H and CH as compare to other samples. However, the weight decomposition of hydration products was significant at 91 days. It was shown that the early hydration of FSC was very low but it accelerated at later stage.

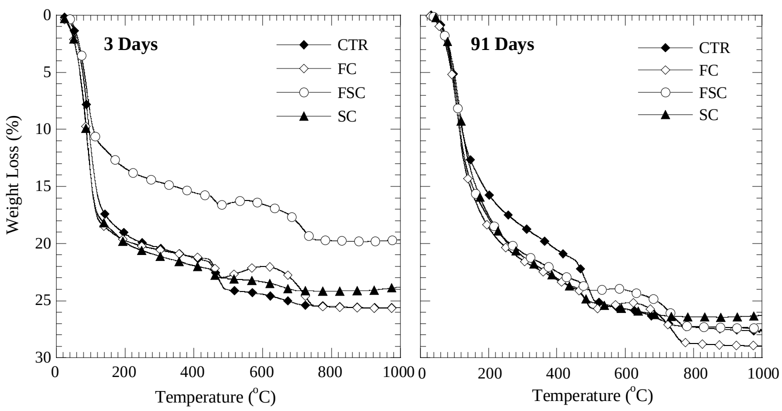

Fig 2 TGA of specimens at the age of 3 and 91 days

4- Conclusions

- The reacted CH determined by DTA/TG analysis, in paste of additives systems could be an indicative factor for pozzolanic reactivity evaluation.
- DTA/TG investigation has revealed different reaction kinetics of paste samples and could be ascribed to their physical and chemical characteristics.
- Lower trough of CH in DTA and reduced CH consumption in TG of mineral substituted samples could be attributed to the dilution effect and to the consumption of CH by pozzolanic reaction.
- FSC has shown remarkable result along with other mineral additives specimens.

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