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Hydration Characteristics of Pozzolanic Substitutes in Cementitious Binder

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Abstract: The role of alternative substitute for cementitious binder is of great concern owing to additional hydration products leading to enhanced strength properties of composite. However the choice of selecting the right supplementary material depends on the reactivity index and its relative performance levels at 28 days of testing. The main focus of this study is to evaluate the degree of hydration in terms of rate of hardening of supplementary cementitious materials (SCM) such as Silica fume, GGBS, Rice husk Ash, Fly ash, Bentonite and Fly ash activator for different curing periods and also to determine the reaction potential of these supplementary cementitious materials with cement. Rate of hardening for the different supplementary cementitious materials are systematically evaluated so as to find the optimum dosage of SCM with cement.

Key words: Compressive strength · Degree of hydration · Rate of hardening · Silica fume · Furnace slag · Rice husk ash · Bentonite · Flyash

INTRODUCTION

The role of new sustainable allternate construction materials in cement concrete is of great conceren owing to huge cost saving and improved concrete performance. Fly ash has been widely tested and applied on the field as a result of beneficiation of large scale release of industrial waste products. In addition to this, slag and silica fume had been another widely used industrial waste in cement concrete for improving the mechanical properties of cementitious systems. There necessates a wide analysis of all these supplementary cementitious system are beneficial used in concrete [1]. During normal concrete construction, the heat is dissipated into the soil or the air and resulting temperature changes within the structure are not significant. However, in some situations, particularly in massive structures, such as dams, mat foundations, or any element more than about a meter or yard thick, the heat cannot be readily released [2]. The mass concrete may then attain high internal temperatures, especially during hot weather construction, or if high cement contents are used. Today supplementary cementitious materials (SCMs) are widely used in concrete either in blended cements or added separately in the concrete mixer. The use of SCMs such as blast-furnace slag, a byproduct from pig iron production, or fly ash from coal combustion, represents a viable solution to partially substitute Portland cement (PC). The use of such materials, where no additional clinkering process is involved, leads to a significant reduction in CO2 emissions per ton of cementitious materials (grinding, mixing and transport of concrete use very little energy compared to the clinkering process) and is also a means to utilize by-products of industrial manufacturing processes [3]. Most of the available studies on the properties of blended systems focus on mechanical or durability aspects of a specific fly ash or slag [4]. The main processes taking place in the hydration of Portland cements (PC) are such that the clinker phases hydrate formed at various rates resulting mainly in the formation of C-S-H, portlandite, ettringite and AFm phases [5]. The blending of SCMs with Portland cement leads to a more complicated system where the hydration of the Portland cement and hydraulic reaction of the SCM occur simultaneously and may also influence the reactivity of each other [6-8]. The hydration kinetics of SCM reaction depends on the chemical composition, the fineness and on the amount of reactive phases such as glass or zeolites of the SCM used as well as on the composition of the interacting solution. Comparatively little is known about

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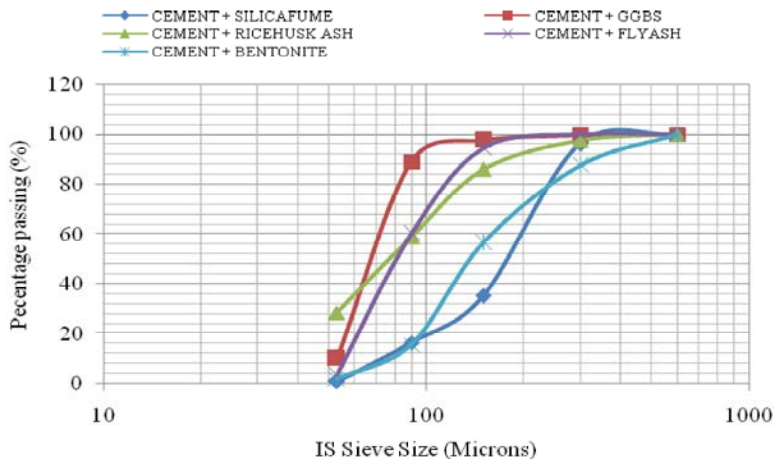

Fig. 1: Sieve analysis for various binders

Fig. 2: Snapshot of cement mortar cubes casted for compression testing

Fig. 3: Compression Testing of Mortar Cubes

the detailed effect of these parameters due to the difficulty to measure the reaction of SCMs quantitatively in blended systems. In this present study a systematic approach has been made to identify the effects of replacement levels of various SCMs in cement.

Experimental Methodology: The experimental study was carried out with the evaluation of following parameters:

- Evaluation of the basic properties of different raw materials used for the study.
- Pozzolanic properties of the various percentage replacement of SCM in cement for different w/b ratio and the effects of curing in hot air oven and water curing.
- Rate of hardening of SCM for different replacement levels

Cement and Pozzolanic materials A 53 grade of ordinary Portland cement (OPC) was used in this study with specific gravity of 3.12 and fineness of 315 m^2/kg and the specific gravity of various pozzolanic materials were found to be; furnace slag-2.91, silicafume-1.60, rice husk ash-1.83, bentonite-2.70, fly ash-2.82. A river sand of specific gravity 2.65 was used for preparing the mortar mixtures and the sieve analysis report for the different binder combinations is shown in Figure 1.

Compressive strength of Mortar The rate of hardening and pozzolanic activity of different SCM with cement was tested for different curing periods. Mortar cubes of 50cm^2 (as shown in Figure 2)were casted for testing in compression (Figure 3) and the binder to sand ratio of 1:3 was used in the study with the percentage replacements of supplementary cementitious materials were taken as 10%, 20%, 30% and 40%. The cement mortars were kept for water curing and the compressive strength of these mortar cubes were tested for different curing periods such as 3^{rd}, 7^{th} and 28^{th} day using compression testing machine.

RESULTS AND DISCUSSIONS

The experimental test results on the compressive properties of various pozzolanic mixtures are presented in Figures 4 to 8. It is observed that the compressive test results of cement mortar cubes with different SCM and cement at different curing days (3rd day, 7th day and 28th day) and for different percentage of replacements (10%, 20%, 30% and 40%). It is seen from the results of different percentage of replacements that the use of fly ash, shown in Figure 4; 20% replacement showed greater compressive strength (24.075N/mm^2 at 28 day) whereas it showed a decrease with increase in percentage of replacement (40% showing a compressive strength of 21.067N/mm^2 at 28 day). In the case of flyash-GGBS (shown in Figure 5), there is decrease in compressive strength with increase in percentage of replacement; with 20% giving the maximum compressive strength of 26.28 N/mm^2 and 40 % giving minimum of 20.665N/mm^2 for 28th day tests. For silica fume, as it can be seen in Figure 6, 10% replacement giving a compressive strength of 24.08 N/mm^2 at 28th day and showing a decrease in strength with 40% giving a minimum of 9.43 N/mm^2. For cement and Bentonite (Figure 7), 19.66 N/mm^2 was obtained as the maximum compressive strength with 10% replacement at 28th day compared with other percentage of replacement giving minimum of 6.42 N/mm^2 at 28th day for 40% replacement

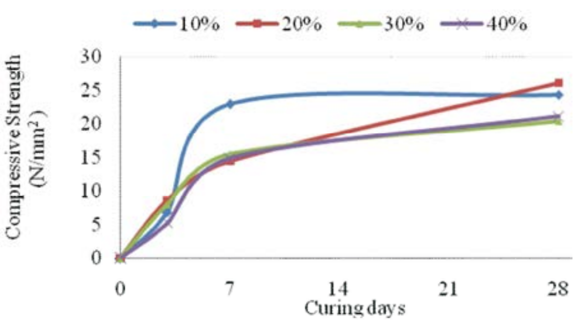

Fig. 4: Compressive strength of cement with fly ash mortar specimens

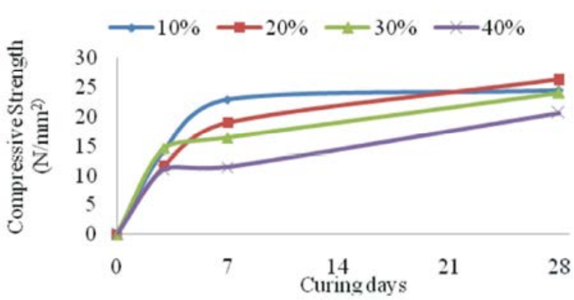

Fig. 5: Compressive strength of cement with slag mortar specimens

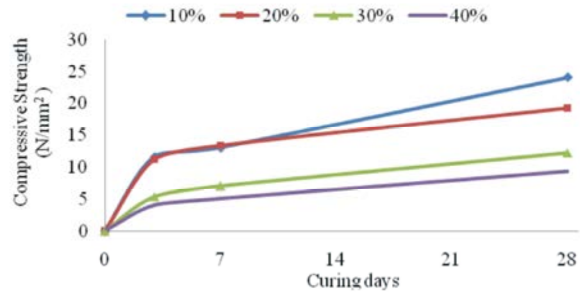

Fig. 6: Compressive strength of cement with silicafume mortar specimens

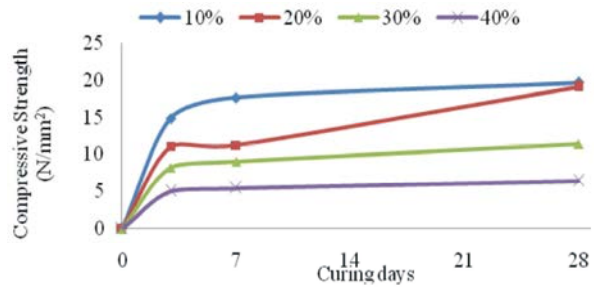

Fig. 7: Compressive strength of cement with bentonite mortar specimens

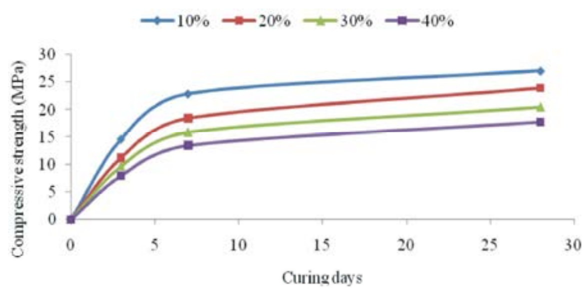

Fig. 8: Compressive strength of cement with fly ash with activator mortar specimens

with the binder. The use of fly ash and rice husk ash with cement showed typical strength variation in which there was a decrease in compressive strength for all percentage of replacements from 3rd day to 7th day and then finally showing an increase at the 28th day tests (Figure 8). The maximum strength was obtained for 10% replacement giving 27.03 N/mm^2 and a minimum of 17.72 N/mm^2 for 40% replacement at 28th day. For rice husk ash, the compressive strength decreases with increase in percentage of replacements having 23.07 N/mm^2 for 10% replacement and minimum of 7.82 N/mm^2 for 40% replacement at 28th day testing. The rate of hardening of all the supplementary cementitious materials at different percentage replacements with cement and at different curing days compared with 28th day strength were assessed as shown in Figures 9 and 10.

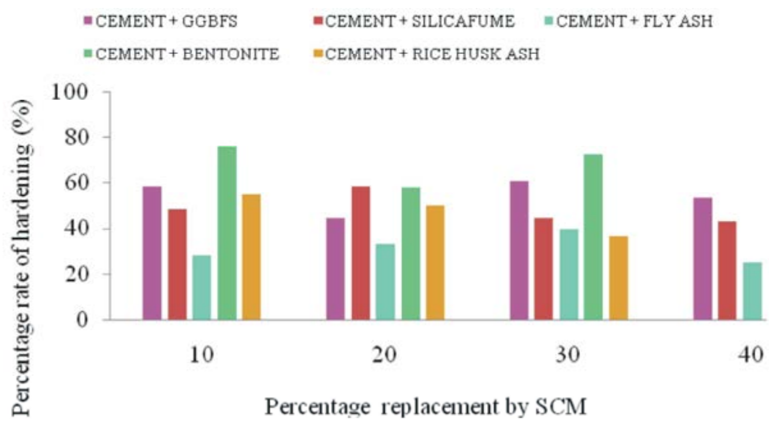

Fig. 9: Rate of hardening for various SCM at 3 days curing

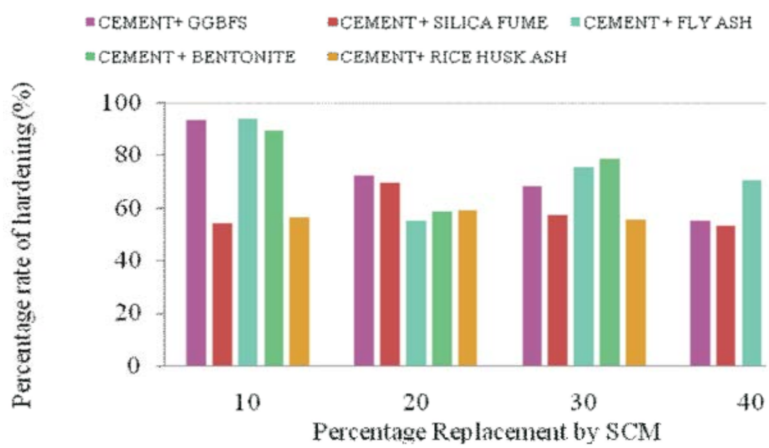

Fig. 10: Rate of hardening for various SCM at 7 days curing

CONCLUSIONS

The salient conclusions from the study are drawn as follows:

- Addition of supplementary cementitious material in concrete provided adequate strength gain due to later age pozzolanic reaction.
- Rate of strength gain in concrete was found to be higher at 28day for different percentage of replacement by SCM compared to initial curing days. The pozzolanic activity of fly ash with cement showed showed a considerable increase with increase in the percentage of replacements upto 30%.
- In the case of silica fume substitution the reactivity of silicate was found to be higher at 10% and beyond this there was a gradual reduction; this was essentially due to the increased specific surface of silia fume and subsequently led to increased water demand and a loss in consistency further lead to poor packing.
- The reaction efficiency of bentonite mixed cement concrete was found to be higher at 20% replacement and the 3rd day compressive strength of bentonite was showing comparatively higher percentage of strength gain; while the addition of GGBS showed greater strength gain after 7th day of intial curing.
- In the case of bentonite addition the maximum dosage is restricted upto 20% and for rice husk ash the maximum replacement level is limited upto 10% by weight of cement.
- The theoretical and experimental analysis conducted in this study provides a useful information on the right selection of pozzolanic substitutes in cement concrete. Also, the careful proportion with cement can lead to higher cementing efficiency at later curing days. However, effect of accelerated curing can be an ideal choice to improve the hardening characteristics at much earlier curing period.

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