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# Heat evolution during the hydration of Portland cement in the presence of fly ash, calcium hydroxide and super plasticizer

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ABSTRACT

Rate of heat evolution during the hydration of OPC, OPC-20 wt% FA, OPC-5 wt% CH and OPC-20 wt%FA-5 wt% CH in the presence of 0.2 and 0.5 wt% super plasticizer has been studied at 35 and 45 °C with the help of TAM Air isothermal calorimeter for 60 h. The results have shown that hydration retarded in the presence of super plasticizer. Higher the concentration of super plasticizer, higher is the retardation. However hydration accelerated with the increase of temperature. Mechanism of hydration is discussed in this manuscript.

## 1. Introduction

Portland cement is one of the most important binding materials that sets and develops strength by chemical reaction with water by formation of hydrates and is capable of doing so under water. This is the main glue for making concretes, the most utilized construction material (World production of concrete is more than 3.5 billion tones per year) [1]. Hydration of Portland cement is a complex and exothermic process. Heat up to 500 J/g of cement is liberated during the hydration [2]. Because the thermal conductivity of concrete is relatively low, it acts as an insulator, and in the interior of a large concrete mass, hydration can result in a large temperature rise. The exterior of the concrete loses heat so that a steep temperature gradient may be established, and during cooling of the concrete surface cracking may result. Therefore it is essential to know the thermal response of cement in the design and construction of high early strength concrete mixtures as well as mass concrete structures. Heat production results from the cement hydration reactions. Both the quantity of heat as well as the rate at which this heat is evolved depends on the mineralogical and morphological characteristics of the cement clinker and depends on number of factors [3–11] such as: water/cement or water/binder ratio, the fineness of the cement – particle size distribution and specific surface area, the temperature at which the hydration takes place, the presence of any chemical admixtures, the chemical and crystallographic composition of the cement, the presence of any cement extenders such as fly ash, blast furnace slag or silica fume, etc. At any given time, these factors influence the degree of hydration, the amount and rate of heat produced and the engineering properties of the material such as strength. Mineral admixtures not only affect the hydration but reduce $CO_2$ emissions and save energy. Recently we studied the hydration behaviour of OPC-FA-CH mixes in the presence of super plasticizer with a view to enhance the early compressive strength [12]. However in order to understand the process of hydration, study of detailed heat evolution behaviour is needed. In this paper hydration of OPC, OPC-FA, OPC-CH and OPC-FA-CH in presence of 0.2 and 0.5 wt% super plasticizer at 35 and 45 °C have been studied and results discussed.

## 2. Experimental

### 2.1. Materials

Portland cement commonly known as ordinary Portland cement (OPC) obtained from Vikram Cement, India and fly ash (FA) obtained from Dadri Thermal Power Plant, India were used for studies of heat of hydration. Calcium hydroxide (CH) and Polycarboxylate type super plasticizer, Glenium 51 (BASF chemicals construction

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**Table 1**
Chemical composition (wt%).

| Constituents | OPC | Fly ash |
|---|---|---|
| $SiO_2$ | 22.28 | 59.02 |
| CaO | 65.60 | 2.19 |
| $Al_2O_3$ | 3.78 | 31.98 |
| MgO | 0.82 | 0.28 |
| $Fe_2O_3$ | 1.35 | 4.79 |
| $Na_2O$ | 0.16 | 0.47 |
| $K_2O$ | 0.61 | 0.22 |
| $SO_3$ | 3.16 | – |

company, India) (SP) were used as admixtures. The chemical compositions of OPC and FA are given in Table 1.

### 2.2. Heat of hydration measurement

Heat evolution and the total heat evolved during the hydration of cements were determined with the help of a TAM-AIR isothermal calorimeter. TAM Air is an eight channel micro calorimeter designed for sensitive heat flow measurements. 2.0 g of OPC, OPCFA and OPCFACH were weighed in glass vials separately. The cements in each vial were mixed with 1.0 ml water or SP (0.2 and 0.5%) solutions by the use of a syringe to have a water/solid ratio of 0.5 and vibrated for 30 s in order to have homogeneous mixing. The vials were then immediately placed in the calorimeter chamber. Quartz powder was used as a reference. The experiments were performed at 35 and 45 °C. As a result of the hydration process, heat is formed and the rate of heat production is continuously monitored as a function of time (for 60 h).

## 3. Results and discussion

When Portland cement is mixed with water its constituents undergo a series of exothermic chemical reactions (Fig. 1). The rate of heat evolution curve is divided into five periods. These periods are called: the initial period (I), the induction period (II) the acceleration period (III), the deceleratory period (IV) and retardation period (V). During the initial period, a rapid heat evolution occurs due to wetting of cement, dissolution of different ions and hydration of hemihydrate and aluminate phases. Rate of heat evolution drops to a very low value within 5 min and becomes almost constant up to <2 h, the induction or the dormant period (period II). During the dormant period it appears that different ions present in the solution are arranged in a regular way forming nucleis, which in due course may disappear due to various type of disturbances in the system. The process of formation and disintegration of nucleis may continue till the critical size nucleis are formed. After this the hydration accelerates with time and the rate of heat evolution reaches to its maximum value at ≈6 h of hydration (period III). This is mainly due to hydration of alite phase in the cement. After this peak, deaceleratory period starts (period IV) and soon after a second maxima at ≈12 h of hydration appears. This second heat flow maximum has been described by Lerch [13] as “sulfate depletion peak” or due to renewed $C_3A$ dissolution and an accelerated ettringite precipitation [14,15]. After the second heat evolution

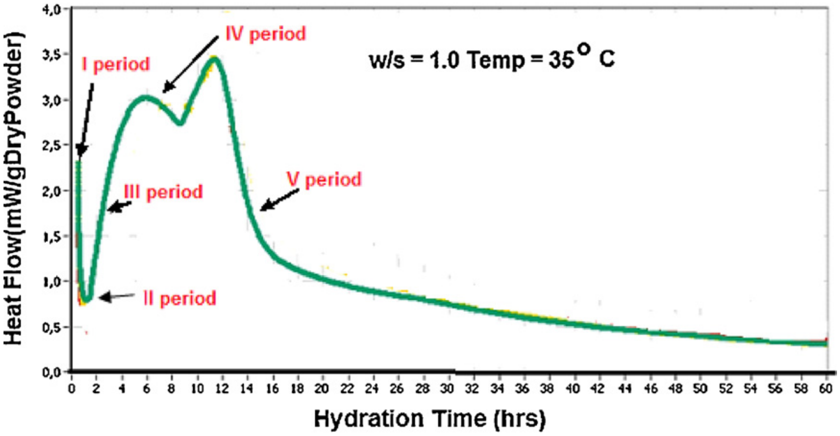

**Fig. 1.** Rate of heat evolution during the hydration of OPC as a function of time at 35 °C.

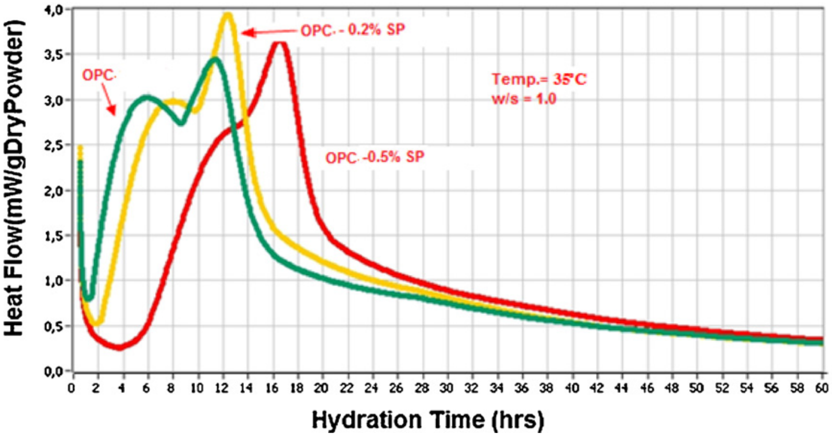

**Fig. 2.** Rate of heat evolution during the hydration of OPC in presence of super plasticizer (SP) as a function of time at 35 °C.