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Influence of palm oil fuel ash in reducing heat of hydration of concrete

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Abstract

The utilisation of pozzolanic materials in concrete construction has become increasingly widespread in recent years, and this trend is expected to continue in the years ahead because of technological, economical and ecological advantages of the materials. This paper highlights test results on the performance behaviour of a relatively new variety of pozzolan called palm oil fuel ash (POFA) in reducing the heat of hydration of concrete. Two concrete mixes namely concrete with 100% OPC, as control and concrete with 70% OPC and 30% POFA were prepared, and the temperature rise due to heat of hydration in both the mixes was recorded. It has been found that palm oil fuel ash not only reduced the total temperature rise but also delayed the time at which the peak temperature occurred.

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1. Introduction

The hydration of cement compounds is exothermic i.e. heat is generated within the concrete matrix during hydration. In other words, when cement is hydrated the compounds react with water to acquire stable low-energy states, and the process is accompanied by the release of energy in the form of heat. The quantity of heat evolved upon complete hydration of a certain amount of unhydrated cement at a given temperature is defined as heat of hydration (Neville 1995). The significance of heat of hydration in concrete technology is manifold. The total amount of heat liberated and the rates of heat liberation from hydration of the individual compounds can be used as indices of their reactivity. Furthermore it characterizes the setting and hardening behaviour of cement and predicts the temperature rise as well.

The temperature of concrete due to hydration is largely controlled by materials and mix properties and by environmental factors. In fact, the heat of hydration depends on the chemical behaviour of the compounds, and nearly equal to the sum of the heats of hydration of the individual pure compounds when their respective proportions by mass are hydrated separately. Again the major constituent of Portland cement is calcium; therefore the development of total heat will surely be affected by the quantity of cement in the mix. High cement contents may be beneficial to obtain higher initial strengths in concrete, but the greater heat developed due to the chemical reactions produces undesirable cracks and shrinkage in the concrete (Orchard 1973, Ramachandran 1981).

As heat released by the cement is a result of cement hydration, admixture e.g. water reducers, set-retarders, set-accelerators etc. used to control the rate of hydration will obviously influence the rate of heat release. Water reducers, for example, causes binder particles to disperse more fully thereby increasing the surface area exposed. This increased surface contact with water will speed up the hydration and consequently the heat of evolution. Retarders in concrete, however, affect the hydration process in different ways. Initially, some totally stems the hydration for a period after which hydration continues at a normal rate. Others slow the hydration rate and may reduce the peak temperature rise slightly. Accelerator, on the other hand, increases the rate of heat release and hence the rise in temperature (Chen et al. 1995).

Like that of chemical admixture the use of pozzolanic materials in reducing heat of hydration in concrete is well established. Unlike OPC, pozzolan starts reacting somewhat belatedly with the calcium hydroxide produced by clinker hydration and therefore, at least initially, it behaves like an inert diluting agent towards the Portland cement with which it has been mixed. These phenomena result in a reduced rate of heat evolution i.e. rise in temperature and reduce ultimate heat of hydration. Perhaps the first field trials with the use of fly ash were made in 1950 at the Otto Holden Dam on the Ottawa River near Mattwa, Ontario (Sturrup et al. 1983). It has been found that fly ash concrete containing 30% ash lowered the maximum temperature rise by 30 percent. Other pozzolanic materials like slag, silica fume, rice husk ash etc. have been shown to influence the concrete by lowering the adiabatic heat in concrete mass (Mehta and Pirtz 1978, Lessard et al. 1983, Sturrup et al. 1983, Swamy 1993, Chusilp et al. 2009).

With the advances in concrete technology the number of pozzolanic materials has also been increased. Perhaps the latest addition to the ash family is palm oil fuel ash (POFA), a waste material obtained on burning of palm oil husk and palm kernel shell as fuel in palm oil mill boilers that has been identified as a good pozzolanic material (Salihuddin 1993, Hussin and Awal 1996). It has been estimated that the total solid waste generated by this industry in Malaysia alone has amounted to about ten million tons a year. In view of the utilization of POFA as a supplementary cementing material, extensive research works have been carried out in the Faculty of Civil Engineering, Universiti Teknologi Malaysia in examining various aspects of fresh and hardened state properties of concrete. This paper presents some experimental results on the effect of palm oil fuel ash in reducing heat of hydration of concrete.

2. Materials and test methods

2.1 Manufacture and properties of POFA

Palm oil fuel ash (POFA), as mentioned earlier is a waste product obtained in the form of ash on burning palm oil husk or fibre and palm kernel shell as fuel in palm oil mill boiler. In the present study, POFA was obtained from the Golden Hope Palm Oil Mill at Bukit Lawang of Johor, southern state of Malaysia. The collection of ash was done at the foot of the flue tower where all the fine ashes are trapped while escaping from the burning chambers of the boiler. After collection all the ashes were sieved through a 300um sieve in order to remove bigger size ash particles and foreign materials, if any. The ashes were then ground in a modified Los Angeles abrasion test machine having 20 stainless steel bars (12 mm diameter and 800 mm long) instead of steel balls inside. A typical flow-chart for the preparation of POFA is given in Fig.1.

In bulk, POFA is grayish in colour that becomes darker with increasing proportions of unburned carbon. However, it is much finer than OPC and its specific gravity is 2.22. The particles have a wide range of sizes but they are relatively spherical, a typical electron micrograph of POFA is shown in Fig. 2. The chemical analysis, illustrated in Table 1, reveals that POFA satisfies the requirements to be classified in between Class C and Class F according to the standard specified in ASTM C 618-01 (2001). Further details regarding the properties and performance of the ash in mortar and concrete have been shown elsewhere (Hussin and Awal 1998, Awal and Hussin 1999).

2.2 Cement

Ordinary Portland cement (OPC) from a single source was used in this study. The physical properties and chemical composition of OPC are also shown in Table 1.

2.3 Aggregate

Dry mining sand with fineness modulus of 2.4 and crushed granite of 10 mm size were used as fine and coarse aggregate respectively. The specific gravity and water absorption of fine aggregates were 2.5 and 1.34% respectively, while the same for coarse aggregates were 2.61 and 0.76%.

2.4 Concrete mixes

In the present investigation two concrete mixes were made: one with OPC alone and the other with OPC replaced by weight of 30% POFA. This replacement level of 30% was considered because of the fact that the highest strength gain was attained at this level of replacement for the particular concrete mixes (Fig. 3), the detail of the mix proportions of both types of concrete being shown in Table 2.

2.5 Measurement of heat of hydration

Heat of hydration is basically the property of cement concrete in its hardening state. However, the temperature rise due to heat of hydration eventually turns into concern of durability, particularly in mass concrete. The rise in temperature due to heat of hydration of cement, when no heat is lost or gained from the surrounding environment is termed as adiabatic temperature rise of the concrete. One of the means of attaining this condition is by perfectly insulating the concrete, even though this is rarely achieved in practical cases.

In the present investigation, cubical plywood of sides 500mm was internally pact with 76 mm thick expanded polystyrene acting as the insulator. Each concrete mix (one with 100% OPC and the other with OPC replaced by weight of 30% POFA) was cast into another plywood cubical with internal dimension of 300mm. Prior to casting, a thermocouple (Type K) was inserted into the centre of each box through the drilled hole of the polystyrene foam lid and was connected to a computer driven data acquisition system (Schlumberger SI 3531D). A general view of the plywood boxes and the test arrangement is shown in Fig. 4.

When concrete was poured into the box, heat was liberated by the hydration process that subsequently increased the temperature of the concrete mass. This increase in temperature and subsequent drop was monitored with close intervals during the first 24 hours and with lesser frequents afterwards until the temperature dropped close to the initial reading. In this study recording of temperature was continued up to 5 days for both the mixes.

3. Results and discussion

The development of temperature due to heat liberation by the hydration process in both the mixes was determined, and the recorded data measured at the mid-depth of concrete blocks are graphically presented in Fig. 5. The time-temperature history along with the mix proportions have been shown in Table 2. Fig. 4 reveals that during the initial period, the temperature rise for both OPC and POFA concrete was almost equal. With time, a two-fold effect of the partial replacement of OPC by POFA can be detected. Firstly, concrete with POFA reduced the total temperature rise and secondly, it delayed the time at which the peak temperature occurred. The data presented in Table 2 depict that although the initial mixing temperature of both the mixes was approximately the same, considerably more heat was evolved from OPC concrete during the first day i.e. within 24 hours after casting. The peak temperature of 36.7°C, as obtained for OPC concrete, was recorded at 20 hours. On the other hand, the highest temperature of 35.4°C was monitored in concrete with 30% POFA at 28 hours of casting. Both the concretes eventually showed a gradual drop in temperature until a relatively steady state was attained during the later period of the investigation.

It is generally known that fineness of cement influences the rate of heat development to some extent. In spite of the higher surface area of POFA, no adverse effect had been detected during the period of study. Neither the peak temperature obtained for POFA concrete was recorded to be higher nor was the time to reach the highest peak early as compared to OPC concrete. In both ways POFA concrete performed better than the control. A similar trend has been reported by Sata et al. (2004) who observed a lower temperature rise in concrete having ground palm oil fuel ash with polymer based superplasticiser.

While no further tests were conducted to evaluate the fineness of the ash on heat of hydration, the lower cement content in the mix and the pozzolanic behaviour of the ash would be responsible for the reduction of heat of hydration in POFA concrete. A close observation, though with slag concrete, has been noted by Swamy (1993) who concluded that the slag fineness not only ensured high strength but also high early strength without enhancing the heat of hydration.

4. Conclusion

Palm oil fuel ash is relatively a new pozzolanic material and has been characterised to be a unique supplementary cementing material in concrete. The results obtained and the observation made in this study clearly demonstrate that the partial replacement of cement by palm oil fuel ash is advantageous, particularly for mass concrete where thermal cracking due to excessive heat rise is of great concern. The present investigation has been carried out incorporating a single replacement of 30% ash obtained on the basis of the highest strength gain. Along with the subsequent effect on strength and deformation characteristics, the time-temperature behaviour in concrete having various levels of ash content has been considered worthwhile for future investigation.

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