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Evaluation of heat of hydration of concrete containing high volume palm oil fuel ash

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H I G H L I G H T S

- ▶ Palm oil fuel ash (POFA) has been identified as a good pozzolanic material.
- ▶ High volume POFA will save environment and also cost-effective in construction.
- ▶ The effectiveness of POFA in controlling heat of hydration of concrete is highlighted.

A R T I C L E I N F O

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A B S T R A C T

Pozzolanic materials, either naturally occurring or artificially made, have long been in practice since the early civilization. In recent years, the utilisation of pozzolanic materials in concrete construction has become increasingly widespread, and this trend is expected to continue in the years ahead because of technological, economical and ecological advantages of the materials. One of the latest additions to the ash family is palm oil fuel ash, a waste material obtained on burning of palm oil husk and palm kernel shell as fuel in palm oil mill boilers, which has been identified as a good pozzolanic material. This paper highlights test results on the performance behaviour of high volume palm oil fuel ash (POFA) in reducing the heat of hydration in concrete. Four concrete mixes namely OPC concrete i.e. concrete with 100% OPC as control, and high volume concrete i.e. concrete with 50%, 60% and 70% POFA were prepared, and the temperature rise due to heat of hydration in all the mixes was recorded. It has been found that palm oil fuel ash significantly reduced the total temperature rise in concrete. The result obtained and the observation made clearly demonstrate that the high volume 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.

1. Introduction

The hydration of cement compound 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 state, 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 [1]. 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 characterises 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 heat 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 calcium in the mix. High cement content may be beneficial to obtain higher initial strengths in concrete, but the greater heat developed due to the chemical reactions produces undesirable durability problems like cracks and shrinkage in the concrete [2,3]. Regarding the durability of concrete structures modern concrete practices stipulate special measures to reduce peak and differential temperatures using materials with lower release of heat in order to minimise or prevent thermal cracking thereby avoiding the corrosion of embedded steel reinforcement [4,5]. In this regard, the use of fly ash either as a conventional replacement or in higher amount in reducing heat of hydration of concrete is well established.

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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 [6]. It has been found that fly ash concrete containing 30% ash lowered the maximum temperature rise by 30%. The inclusion of higher amount (over 50%) of fly ash in concrete has been shown to be beneficial in many aspects of durability including thermal cracking due to heat liberation [7]. 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 [6,8–10].

With the advances in concrete technology the number of pozzolanic materials has also been increased. One of the latest additions 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 [11–13]. This waste is commonly available in South-East Asia and African Sub-Sahara region were palm oil production plays an important role in the national economy. It has been estimated that the total solid waste generated by the industry in Malaysia alone has amounted to about ten million tons a year [14]. 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 experimental results on the effect of high volume palm oil fuel ash in reducing heat of hydration of concrete.

2. Materials and test methods

2.1. Collection and preparation of palm oil fuel ash

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 a factory in 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 chamber of the boiler. After collection the ashes were sieved through a 150 μm sieve to remove bigger size ash particle and foreign materials, if any. To increase fineness, the ashes were then ground in a modified Los Angeles abrasion test machine having 10 stainless steel bars (12 mm diameter and 800 mm long) instead of steel balls inside.

2.2. Concrete materials and mixes

Ordinary Portland cement (Type I) was used in the study. A saturated surface dry local river sand with fineness modulus of 2.9, passing through 4.75 mm sieve having specific gravity and water absorption of 2.6% and of 0.70% respectively was used as fine aggregate. The coarse aggregate was 10 mm crushed granite with specific gravity of 2.7, having 0.5% water absorption. Municipal water, supplied to the concrete laboratory was used throughout the research work. In this study, four concrete mixes were made: one with OPC alone and the others with OPC replaced by weights of 50%, 60% and 70% POFA. Superplasticizer (Rheobuild 1100) of 2% by weight of binder was added to concrete mix in order to achieve slump value of 80–160 mm. The relative mix proportions are shown in Table 1.

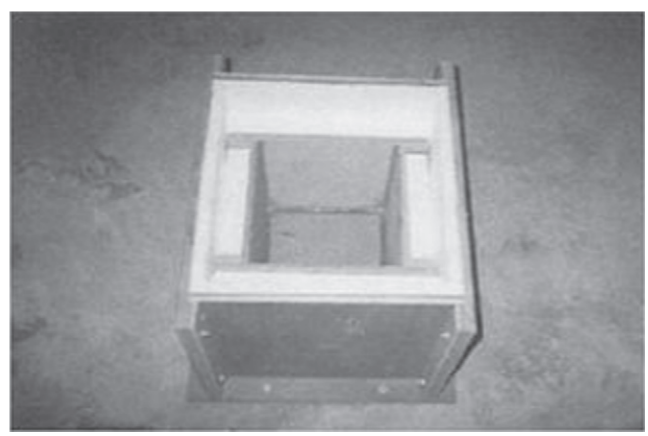
Table 1
Mix proportions of OPC and POFA concrete.

Materials	OPC concrete	50% POFA concrete	60% POFA concrete	70% POFA concrete
OPC (kg/m^3)	427	214	171	128
POFA (kg/m^3)	–	213	256	299
Coarse aggregate (kg/m^3)	961	961	961	961
Fine aggregate (kg/m^3)	787	787	787	787
Water (kg/m^3)	205	205	205	205
Slump (mm)	160	115	90	80

2.3. Measurement of heat of hydration

Heat of hydration is essentially the property of cement concrete in its hardening state. 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 gain from the surrounding environment is termed as adiabatic temperature rise of concrete. It involves perfect insulation of concrete, even though this is rarely achieved in real cases.

In the present investigation, cubical plywood of sides 500 mm was internally insulated pact with 76 mm thick expanded polystyrene acting as the insulator. Concrete mix with 100% OPC and those with OPC replaced by 50%, 60% and 70% by weight were cast into the cubical plywood. Prior to casting, a thermocouple was inserted into the centre of each box through the drilled hole of the polypropylene foam lid and was connected to a computer driven data acquisition system (Schlumberger SI 3531D). An insulated cubical box and the test arrangement are illustrated in Fig. 1.



An insulated plywood box

Testsetup

Fig. 1. Internal view of an insulated plywood box and test arrangement.