Construction and Building Materials 154 (2017) 44–50

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Finite element modeling of hydration heat in a concrete slab-on-grade floor with limestone blended cement

Mohammad Tahersima [a,*], Paul Tikalsky [b]

[a] 315 Advanced Technology Research Center, Stillwater, OK, USA
[b] 201 Advanced Technology Research Center, Stillwater, OK, USA

HIGHLIGHTS

- Finite element model of hydration heat in mass concrete with limestone blended cement.
- Comparison of FE modeling results with site data and commercial software results.
- Better agreement of FE modeling with the site measurements.
- Importance of ambient temperature and calorimetry results in heat predication.
- Higher hydration heat of Limestone blended cement than cement Type I-II.

ARTICLE INFO

Article history:
Received 11 May 2017
Received in revised form 21 July 2017
Accepted 24 July 2017
Available online 1 August 2017

Keywords:
Hydration heat
Limestone blended cement
Finite element model
Mass concrete

ABSTRACT

Delayed ettringite formation and thermal cracks are two main concerns of temperature rise in mass concrete structures. The mass concrete containing limestone blended cement and fly ash has different hydration heat that was not well predicted by commercially available software. The purpose of this study is to provide such data for designers or software developers. In this study, results of thermocouple measurement at the construction site are compared with a widely used commercial finite element model (FEM) and a widely used concrete design software package. Verification of the FEM with experimental data has been completed with cement ASTM C595 Type I limestone blended cement (IL) with a 25% replacement by mass of ASTM C618 Type C fly ash (FC). In this study, the same mixture design of construction site was used in modeling of hydration heat of full scale building. The heat of hydration for cement Type I-II and 25% of FC and cement Type IL are predicted to compare the results of hydration heat generated by different mix proportions. The FEM result has a much better compatibility with the construction site data with respect to the commercial concrete software results. The prediction accuracy of finite element results is about 15% more for the maximum temperature rise and 30% more for the peak time. Cement Type IL has greater hydration heat than cement Type I-II. Applying measured ambient temperature and calorimetry results are two main factors in precise prediction of hydration heat.

1. Introduction

Cement hydration is the main cause in heat generation in concrete placing. The amount of cement is the main parameter in estimating the heat generated and resulting temperatures in mass concrete casts. Large volume of mass concrete elements and low thermal conductivity of concrete would lead to temperature accumulation at the interior section during concrete hardening. Compared to other materials used in the floor system like wood, concrete has high volumetric heat capacity and low thermal conductivity properties. These thermal properties allow the concrete slab to store the hydration heat during first hours of casting. The heat from exothermic reaction of cement hydration may cause early age strain accumulation within concrete contributing to cracks or displacements [1,2]. Controlling the early age thermal differential strains in concrete and utilizing the other thermal properties of concrete present a potential to utilize concrete as a more sustainable building material. The temperature difference between interior and cooled surface of the mass concrete elements, causes thermal stress formation [3]. The maximum temperature rise due to cement hydration should be controlled to prevent early age thermal cracking of the concrete [4,5]. It is important for large scale concrete casting to minimize or avoid cracks [6].

Limestone blended cement can reduce carbon dioxide footprint. In addition, the synergistic properties of limestone flour with

* Corresponding author at: 21 N University Pl, Apt. 8, Stillwater 74075, OK, USA.
E-mail address: mohammad.tahersima@okstate.edu (M. Tahersima).

http://dx.doi.org/10.1016/j.conbuildmat.2017.07.176
0950-0618/

portland cement are the justifications for its usage. Synergistic properties are related to how (relatively) inert limestone particles interact with cement hydration. Lower w/c concretes, energy saving, and reduction in CO_2 emission are the main parameters to substitute limestone powder in the cement production [7]. In addition, replacing the part of cement ingredient with secondary cementitious materials (SCMs) such as fly ash or slag in concrete production, improves the durability and permeability properties. SCMs can reduce the hydration heat, leads to the thermal stress and greenhouse gas reduction [8]. While limestone blended cement is widely available around the world, this kind of cement is not modeled in most temperature prediction commercial software [9]. Researcher have been studied the heat of hydration of limestone blended cement with calorimetry. The earlier researches have been shown that limestone seems more likely crystallization of monocarbonate rather than monosulfate [10,11]. Some studies have been completed about replacing the calcium sulfate up to 25% calcium carbonate will not change properties of the system [12]. The carbonate ion of limestone particles stabilizes the ettringite and increases the hydration products [13]. Limestone blended cement and low-calcium fly ash combination can enhance the durability of concrete mixture. However, hydration heat depends on the limestone particle size. Thongsanitgarn et al. showed that finer particle size of limestone (5 μm) increased the early hydration rate while there was no significant effect when 20 μm limestone particle was used [14]. Furthermore, the same process of the cement production is an important factor to compare the hydration heat of different cement types.

Heat of cement hydration needs to be predicted by engineers before casting the mass concrete. The temperature rise in the mass concrete with respect to subsequent effects have been studied [15]. The prediction of heat generated by blended limestone cement hydration is applied to a mass concrete to obtain the maximum internal temperature, time of peak temperature occurrence, and the temperature gradient. However, limestone blended cement is not a default input parameter for most temperature prediction models. Also, to solve more complicated structures such as dams, finite element software is used to attain more accurate results [16]. If the peak temperature rise exceeds the maximum allowable temperature of the concrete structures, some further consideration should be regarded including pre or post cooling of concrete section. The purpose of this article is to demonstrates the importance of heat rise by cement hydration and the differences between limestone blended cement with and without fly ash versus Type I-II cement. The heat of hydration is modeled with finite element using calorimetry results and measured weather data at the construction site.

2. Experiments

2.1. Site instrumentation

The experiment was conducted in the construction process of full scale building. The mass concrete floor was cast in dimension of $36 \times 14 \times 1.22\ m^3$. Concrete mixture proportion is shown in Table 1. The main parameter in heat generation of the concrete casting is the paste.

It can be found that construction site paste has cement, 25% Fly Ash Type C plus water. The water to cementitious material ratio (w/cm) of 0.49 should be considered for heat transfer modeling purposes. The aggregate is composed of natural sand as fine aggregate and limestone coarse aggregate. The Pozzolith 80 is used as water reducer. This water reducer is a liquid admixture to make uniform and predictable quality concrete. No calcium chloride or chloride based ingredient is used in the manufacture of Pozzolith 80. Average 7 days strength of concrete sample is 38 MPa.

Table 1
Mixture design of the construction site.

Material Type	Unit weight value (kg/m^3) lb/cy	Specific Gravity
Limstone Blended Cement	246 (414)	3.15
Type C Fly Ash	61 (103)	2.65
Water	151 (254)	1.00
Coarse Aggregate #57	1028 (1730)	2.80
Coarse Aggregate #2	247 (415)	2.80
Fine Aggregate	733 (1234)	2.63
Water Reducer	0.6 (1.01)	1.00

Temperature sensors were installed across the height of the mass floor to monitor the temperature profile inside of the concrete as T-type thermocouples. Thermocouple wires were attached to a column of concrete to read the temperature at different elevations of slab height before casting. All thermocouple wires were connected to a data logger for measuring the temperature every 5 min. The thermocouples' position in the 1.22 m floor is shown in Fig. 1 by triangular dots. The thermocouples are located at 0.05 m, 0.15 m, 0.3 m, 0.52 m, 0.82 m, and 1.22 m below the surface of the mass concrete. One thermocouple is located under the mud slab to measure the soil temperature. One thermocouple is located under the mud slab to measure the soil temperature.

To compare the hydration heat of different cements, it is necessary to look at the chemical composition of both cements from Holcim company which are shown at Table 2. Based on ASTM D448, aggregate #57 ranges from 1 to 0.19 inch (No. 4 sieve—25.0 to 4.75 mm) and aggregate #2 ranges from 2.5 to 1.5 inch (No. 4 sieve—63.0 to 37.5 mm) [17].

2.2. Calorimetry

Cement hydration behavior can be estimated from an isothermal calorimetry test. In order to obtain the kinetics of cement hydration, isothermal calorimetry was used to describe the generated heat. Because isothermal calorimetry is more precise than semi-adiabatic calorimetry for forecasting the heat of hydration, it was used as internal generation heat input for modeling [18]. An isothermal calorimeter is an instrument used to monitor the long-term behavior of heat of hydration [19]. Three of the same samples of blended limestone cement (cement Type IL) with 25% fly ash were exposed to water content in a calorimeter machine to gain the heat of hydration curves. Paste mix proportions are presented in Table 3. An average of three samples was used for modeling the hydration heat in the concrete slab. Furthermore, cement Type IL hydration with the same w/cm ratio (0.49) was used to compare fly ash usage in decreasing the heat of hydration.

The samples were prepared with 3 min mixing of the sample with a 1000 rpm vibrator machine. Because the calorimetry results are sensitive to prior mixing, the tests should be consistent and all sample preparations have the same condition. The mixing procedure includes pouring weighted cement into a calorimetry vial, adding SCMs, adding water, stiring the mixture with a wooden stick 10 times clockwise and 10 times counter clockwise, putting the cap on the mixture vial, putting the vial on vibrator machine for 3 min of 1000 rpm, and placing the vial in the calorimetry machine. The w/cm ratio is 0.49 which is the same as the job site water to cementitious material ratio in order to better cement hydration simulation.

3. Heat transfer modeling

The Finite Element (FE) method is a powerful technique to model the behavior of the heat transfer in different media. A com-