PREDICTION OF TEMPERATURE RISE IN CONCRETE DUE TO HEAT OF HYDRATION OF CEMENT

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Thesis submitted in fulfillment of the requirements for the degree Master of Philosophy in Civil Engineering

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Declaration

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Abstract

Temperature rise due to heat of hydration in concrete depends on many factors such as geometry of the concrete element, chemical, physical and thermal properties of concrete materials, mix proportion, initial temperature during concrete batching, and thermal boundary conditions during concrete hardening etc. The multicomponent cement hydration model developed by Maekawa et al., predicts the heat generation due to cement hydration based on cement contents, water contents, reference heat generation rate of main mineral components in cement, i.e. alite (C_3S), belite (C_2S), aluminate (C_3A), ferrite (C_4AF), and gypsum (CS_2H), mineral of cement, fineness of cement, thermal activity and interdependences of mineral components, and effects of consumption of free water during the hydration process etc. This cement hydration model was incorporated in the transient heat conduction analysis. The transient heat conduction analysis was carried out with ANSYS, finite element analysis software using Advance Parametric Design Language (APDL) computer programming to predict the temperature ruse due to heat of hydration of cement in concrete element for a given thermal boundary conditions.

Since the heat of hydration of cement is highly temperature dependent, variation of thermal properties of concrete at early ages is essential to predict the temperature response due to heat of hydration of cement in concrete. Experimental investigations were carried out to develop a model to estimate the variation of thermal conductivity of concrete from fresh to hardened state. The specific heat capacity of concrete (c) was estimated based on the specific heat capacities of cement powder and hydration products using Dulong – Petit Rule (DPR), Neumann – Kopp Rule (NKR), and mixing theory. Thermal conductivity of concrete (λ) was determined by fitting temperature rise curve at center of cube with temperature rise curve predicted by transient heat conduction analysis. Estimated specific heat capacity of concrete was applied in transient heat conduction analysis program, to predict temperature rise curve from 1hrs to 1day for several mix proportions.

A mathematical model was developed to predict the variation of thermal conductivity based on experimentally investigated thermal conductivity data, mix proportions, thermal conductivity of concrete material found in literature, cement and water contents, formation, shapes, and saturation of gel and capillary pores of cement paste , degrees of hydration, surface saturation of aggregates by applying into general and effective medium theories used in estimation of effective thermal conductivity of a multicomponent material. The developed model was calibrated and verified with experimental data of concrete cube samples for several mix proportions. A computer program was developed using APDL coding of ANSYS software to predict the thermal properties of concrete once mix proportion, chemical, physical and thermal properties of concrete materials are known. This model was coupled with the multicomponent heat of hydration model to improve the program's ability to predict temperature rise with effects of variation of thermal properties with degree of hydration of cement.

The developed multicomponent heat of hydration model was calibrated and verified with temperature rise data detained from several field tests which were carried out in several construction projects in Sri Lanka. Measured and predicted temperature response are in good agreement, and therefore the proposed model can be used to predict temperature rise when chemical composition, mix proportions, and thermal boundary conditions are known.

Furthermore, the developed hydration model was used to obtain appropriate values for T1 (i.e. temperature drop between hydration peak and ambient temperature under local conditions which are required in design of water retaining structures.

Keywords: heat of hydration, thermal conductivity, specific heat capacity, early age concrete, transient heat conduction analysis.

This thesis is dedicated

To my Parents, Loving Wife and Son

Without whom none of my success would be possible

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List of Symbols

Latin Symbols

OPC	Ordinary Portland Cement
APDL	Advance Parametric Design Language
THW	Transient Hot Wire
TLS	Transient Line Source
THS	Transient Hot Strip
TPS	Transient Plane Source
C	Carbon
Mg	Magnesium
Al	Aluminum
Fe	Ferrous
Si	Silicon
Ca	Calcium
C_3S	$3CaO.SiO_2$ - Alite
C_2S	$2CaO.SiO_2$ - Belite
C_3A	$3CaO.Al_2O_3$ - Aluminate
C_4AF	$4CaO.Al_2O_3.Fe_2O_3$ - Ferrite
CSH	Calcium Silicate Hydrates
$C\dot{S}2H$	Gypsum
AEt & FEt	Ettringite
CH	Calcium Hydroxide
LH	Low Heat
SR	Sulfate Resistant
DPR	Dulong-Petit Rule
NKR	Neumann - Kopp Rule
HS	Hashin-Strikman Bound Theorem
MM	Maxwell Model
MEL	Maxwell – Eucken Limits
EMT	Effective Medium Theory
DoH	Degrees of Hydration
T_0	Temperature at 0 K
T_{100}	Temperature at 100 K
Q_R	Volumetric Heat Generation Rate
K	Thermal Conductivity
K_0	Thermal Conductivity of Concrete at 0 K
K_{100}	Thermal Conductivity of Concrete at 100 K
M	Fractional Mass
X	Molar Fraction

P	Pressure
V	Volume
W	Weight
A	Area
Q	Heat Flow
T_s	Surface Temperature
T_a	Ambient Temperature
NLS	Number of Time Intervals
H_c	Specific Heat Generation Rate for Cement Powder
p	Fractional Mass of Cement Minerals
Q_i	Accumulated Heat
R	Gas Constant
E/R	Thermal Activity
T	Temperature
s_i	Fineness of Cement Powder
S_i	Blaine Value of Cement Minerals
S_{io}	Reference Blaine Value of Cement Minerals
WC	Unite Weight of Cement
P3A	Weight Percentage of Aluminate
P3S	Weight Percentage of Alite
P4AF	Weight Percentage of Ferrite
P2S	Weight Percentage of Belite
PPCS2H	Weight Percentage of Gypsum
PPC	Weight Percentage of OPC
BLN	Blaine Value of OPC
PSG	Weight Percentage of Slab
BLNSG	Blaine Value of Slag
SGCS2H	Weight Percentage of Sulfate in Slag
PFA	Weight Percentage of Fly Ash
BLNFA	Blaine Value of Fly Ash
FACS2H	Weight Percentage of Sulfate in Fly Ash
PLS	Weight Percentage of Superplasticizer
BLNLS	Blaine Value of Superplasticizer
WP	Water to Powder Ratio
QSP	Constant for the Effects of Superplasticizer Dosage
QSPAD	Constant for the Effects of Superplasticizer Dosage
CHARSP	Constant for the Effects of Superplasticizer Dosage
QSGMX	Final Accumulated Heat Generated by Slag
RSGW1	Weight Percentage of Consumed Water of by Slab
RSGCA	Weight Percentage of Consumed Calcium

	Hydroxide when reacts with Slag
QFAMX	Final Accumulated Heat Generated by Fly Ash
RFAW1	Weight Percentage of Consumed Water by Fly Ash
RFACA	Weight Percentage of Consumed Calcium Hydroxide when reacts with Fly Ash
RH3AMN	Factor for Mono-sulfate Conversion
w	Velocity of Wind
h	Convection Coefficient
E_N	Solar Radiation on Horizontal Surface
E_V	Solar Radiation on Vertical Surface
L_a	Latitude
L_o	Longitude
LST	Local Standard Time
LSM	Local Standard Time Meridian
q	Heat Flux
T_{dp}	Dew Point

Greek Symbols

c	Specific Heat Capacity of Concrete
ρ	Density of Concrete
γ	Retarding effects of fly ash and admixture
β	Free water content
μ	Effects of weight percentage of clinker minerals
λ	Effects of calcium hydroxide production on reaction of fly and slag
ø	Porosity
δ	Solar Declination Angle
σ	Stefan – Boltzmann Constant
ε	Emissivity
α	Thermal Diffusivity

Subscript

i, j, k	Counters
t	Time
x, y, z	Directions