Thermal Analysis of Early Age Mass Concrete Structure by using FEM

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Abstract— This study is about a Thermal analysis of early age mass concrete structure by using FEM. This paper discussed to predict the distribution of temperatures within a hydrating massive concrete by the development of a finite element model with different levels of replacements of fly ash. In this analysis, the replacement levels of fly ash such as 0%, 30%, 40%, and 50% are used to predict the temperature distribution of hydration of mass concrete with FEM model by using transient thermal analysis with software called ANSYS WORKBENCH 15.0. It is observed that by increasing the % replacements of cements with fly ash, the heat of hydration reduced significantly.

Key words: Mass Concrete, Heat of Hydration, Adiabatic Rise, Temperature Distribution, Replacement of Cement with Fly Ash, FEM

I. INTRODUCTION

Concrete is the most widely used construction material in the world and ordinary Portland cement (OPC) is the major ingredient used in concrete. (Saroka 1979) states that cement as an adhesive material, which is having the ability of bonding particles of solid matter into any compact whole[1]. (Bye 1999) stated that a cement is a composite material which binds together solid bodies or aggregates, by hardening from a plastic state[2]. Mass concrete is an origin concrete which is formed by binding of fine and coarse aggregates, water and Portland cement together. Strength is the main characteristic of mass concrete structures. Generally, mass concrete members consist of larger aggregate size and smaller content of cement**.** Neville and brooks, (1987) have been investigated about the heat evolution and temperature rise. In massive concrete sections, because of more self-insulation in total heat evolution the temperature is more dependent where as in smaller concrete sections, the rate of heat evolution is more dependent[3]. Malhotra and Mehta (1996) has been presented about the replacement of Portland cement by mineral admixtures(except silica fume and high calcium fly ash) that may be resulted in reduction of temperature rise of both fresh and hardened concrete[4]. Mehta, (1983) discussed about the addition of mineral admixtures to Portland cement, i.e addition of fly ash and ggbfs to Portland cement leads to the pore refinement or transformation of large pores into fine pores, which determines the permeability of hardened cement paste [5].(hardjito et.al 2005)The spherical shape of fly ash often helps to improve the workability of fresh concrete , and to produce dense and durable concrete, it small particle size plays as filler of voids in concrete[6]. (Joshi and Lohita,1997) states that by increases the percentages of fly ash in cement, the rate of heat generation released is slows down, and resulting in a lower maximum temperature in the mass concrete, where as compared with concrete having no fly ash percentage[7] . (Bamforth,1984) reported that For low level of replacement(15%), there is not any significant changes in the rise of temperature in ordinary portland cement concrete, but the higher replacement levels such as (30 to 50 %) , the rise of temperature reduces considerably[8].(Folliard et al., 2008) The temperature in inner region of the massive concrete at early age experiences high but uniform temperatures while the temperature in the outer region decreases as we move closer to the surface. Moreover, durability, workability and also economy must be considered too [9]. Mass concrete structures are widely used in case of large volume of concrete pours, therefore the need of economy is magnified in the use of concrete. According to de Borst and van den Boogaard (1994), Ishikawa (1991)[10], Jaafar (2007) [11], Lawrence et al. (2012)[12], Noorzaei, Bayagoob, Thanoon, and Jaafar (2006)[13], and Tang, Millard, and Beattie (2015)[14], Finite Element Method (FEM) which is a numerical modelling method is seen as the best predictor of thermal cracks in concrete. It offers a step-by-step approach in solving the problem though it has its own limitations of been costly and impossibly used at site to quickly determine the maximum heat of hydration of concrete.

II. MATERIALS AND METHODS

Our objective was to determine the temperature distribution at different % of replacements of cements with fly ash in mass concrete placed on soil foundation of fem model by performing transient thermal analysis in ANSYS Workbench 15.0. To perform this analysis, input parameters are initial temperature, convection, internal heat generation and thermal properties of concrete and soil.

A. *Basic Theories*

1) *Heat Balance Equation*

The basis for thermal analysis is the heat balance equation or governing heat transfer equation, which is based on the principle of energy conservation. The governing heat transfer equation is generally the rate of heat of hydration. The equation for rate of heat of hydration is as the follows.

$$\Delta Q/\Delta T = T_{max}\,(rse^{(-r(t-t_0)^{\wedge}s)})\rho C(T-T_0)^{1-s}$$

Where $\Delta Q/\Delta T$ = rate of heat of hydration

ρ = density (kg/m^3), C = specific heat

T = temperature, t = time

This equation is used to calculate the different rates of heat of hydration of cements for various replacements.

Adiabatic Temperature Rise: General expression for the adiabatic temperature rise due to heat of hydration was computed as

$$T = T_{max}\,(1-e^{(-r(t-t_0)^{s})})$$

Where

- T = adiabatic temperature rise,
- T_{max} = ultimate temperature rise,
- r = constant,
- s = constant,
- t_0 = temperature difference

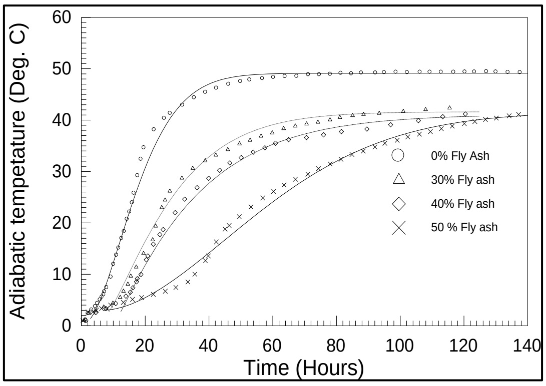

Fig. 1: Adiabatic temperature rise in the fly ash concretes (Galeota 1995).

% Replacement	Max Temperature	S	R	T_0
0	49.1	1.58	0.01	2
30	41.5	1.245	0.02	8
40	41	1.07	0.03	12
50	41.6	1.77	0.0007	7

Table 1: constant in the adiabatic condition

B. Convection

Convection refers to the energy transported as a result of macroscopic motion. In other words, the transfer of heat from the surface of a material to the fluid that is moving over it. The analysis of convection heat transfer from a surface from which equation is derived.

$$q_c = h\, A_s(T_s - T_f)$$

Where q_c =rate of heat transfer (w/m^{2}-^{0}C) T_s = temperature of the surface (^{0}C), h= mean coefficient of heat transfer.

T_f = fluid temperature (^{0}C), A_s = surface area (m)^2

The above equations are used to generate the rate of heat generation and temperature values which are input parameters of mass concrete for transient thermal analysis.

III. MODELLING

A. Transient Thermal Analysis

Almost all heat transfer processes are transient in nature. This kind of analysis is used to determine temperature and other thermal quantities in the body due to different thermal loads. Thermal loads applied to the structure are time dependent. For practical problems, transient thermal analysis can be a difficult task especially when dealing with complicated shapes and long periods. Among different methods of analysis, the finite element method is a very acceptable and commonly used method for such kind of problems.

B. Execution Parameters

In this study Execution parameters are taken as type of analysis and type of element used for finite element analysis. Analysis type is Thermal Analysis. This type of analysis calculates thermal quantities of the model. The most common thermal quantities of interest are temperature field and rate of heat generation. When we are performing with thermal analysis the element type must have thermal properties. Analysis is three dimensional and element type is also three dimensional, isoparametric, eight noded and four-noded quadrilateral thermal solid element. These are called PLANE70 - 3D Thermal Solid in ANSYS.

C. Material Properties

In this analysis, material properties will be assigned in engineering data. These properties either we take from saved library itself otherwise we make specified properties according to our study. For thermal analysis of mass concrete we need to obtain Thermal properties of concrete and soil are thermal conductivity, specific heat, density , and convective heat transfer coefficients. The range of these properties are different at various situations are shown in table taken from literature [15].

Parameters	Units	Concrete	Soil
Thermal conductivity	W/m ^{0}C	2.2	0.3
Specific heat	J/kg ^{0}C	840	800
Density	Kg/m^3	2300	1600
Coefficient of thermal expansion	^{0}C	1.4e-005	-
Convection	W/m^2 ^{0}C	11	11
Placement temperature	^{0}C	20	20
Ambient temperature	^{0}C	20	20
Analysis time	Hr	510	510

Table 2: execution parameters used for thermal analysis

D. Model Geometry

The structure model was drawn in AutoCAD software and saved in .dxf file, with the dimensions of 94m*94m for foundation and diameter of 90m for mass concrete. The depth of both foundation and mass concrete was taken as 4.5m. That file was imported to ANSYS workbench 15.0. Figures are shown below for the modelled structure and imported structure.

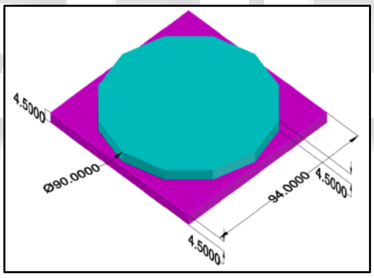

Fig. 2: Modelled structure in auto cad

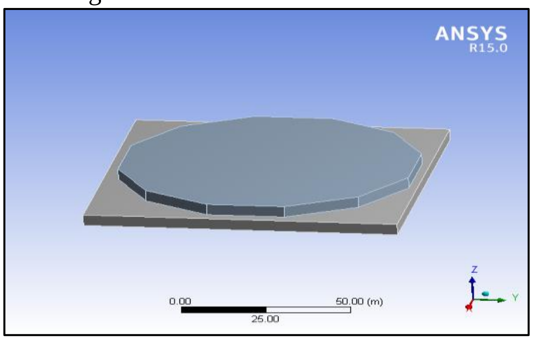

Fig. 3: Structural model in ANSYS Workbench 15.0

E. Properties of Frame Work

The model consists of two parts one is foundation and another is structure. The material adopted for foundation is soil, and for structure is concrete.

1) Meshing

After the implementation of frame work, meshing will be done in this analysis. A discretization of 4.5 of minimum edge length and 2 m of element size is chosen to obtain reliable estimates of the temperature distribution.

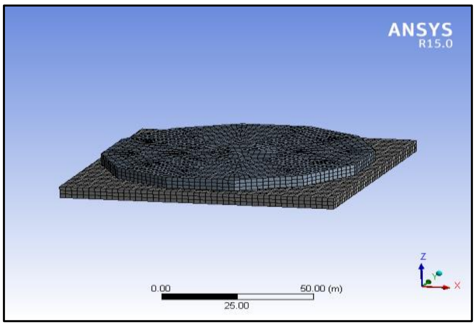

Fig. 4: Mesh model

2) Boundary Conditions

In transient thermal analysis Boundary conditions are thermal boundary conditions, and in this model, it is taken as Convection, Ambient temperature and initial temperature. Initial temperature is nothing but placing temperature, adopted 20^{0}C for this analysis. Convection which is taken on all the surfaces of the model except the bottom face of mass concrete. In this analysis convection value is adopted as 11 W/m$^{2.}$ ^{0}C. The model is exposed to the ambient conditions, which means that heat convection occurs between model and air. Ambient temperature for the whole model is adopted as 20^{0}C only. Internal heat generation rates are taken as load factors in transient thermal analysis. In this study, for various percentages of fly ashes like 0%, 30%,40% and 50% , the heat rates are varies. Heat of hydration of mass concrete precisely depends on the composition of cement. Rate of heat of hydration in only cement was high whereas compared with replacements of cement. It also depends on time on placing temperature of concrete. In this analysis internal heat is only applied to the mass concrete. Various values of internal heat generation rates for different percentages of fly ashes are taken. These are the common type of boundary conditions for this type of thermal analysis.

3) Solution Phase

In solution process, the data for all the parameters and boundary conditions and load factors are solved for model execution and report form. In addition, temperature distribution at selection nodal point during time integration can be observed. Al1 those results are explained below.

IV. Results and Discussion

In this section, we are discussing about the results. By the performing the transient thermal analysis for mass concrete fem model, the temperature rise for the replacements of cements by fly ash at various percentages are reduced when compared to the no replacements of fly ash. The replacement levels that are adopted in this analysis are 0%,30%,40% and 50%.

A. Analysis Results

Various types of results can be generated by using ANSYS software. In this analysis the temperature distribution of the model and various selections of nodes are generated, Such as core section with node number 36369, surface corner 15708 for different percentage levels of fly ashes. Such as 0%, 30%, 40%, and 50%.

1) 0% replacement of cements with Fly Ash:

The temperature rise distribution for the no replacement i.e 0% Fly ash at various sections like vertical cut section, top view cut section and whole model for better understanding is shown in below figures.

In the below figures it shows the maximum temperature rise of 62.738 ^{0}C and minimum temperature rise of 11.365^{0}C, at maximum time of 91800 seconds for no (0%) replacement. The inner surface of the concrete shows the maximum temperature and as we move for the boundaries, the outer surface of the concrete reduces the temperature gradually.

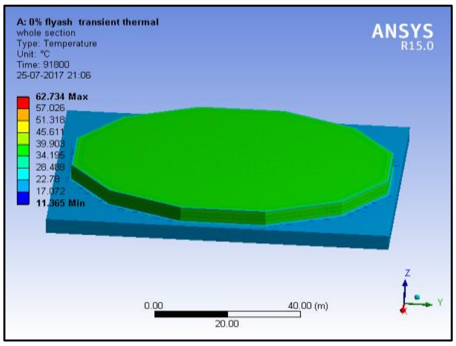

Fig. 5: Transient Thermal>Temperature>whole section

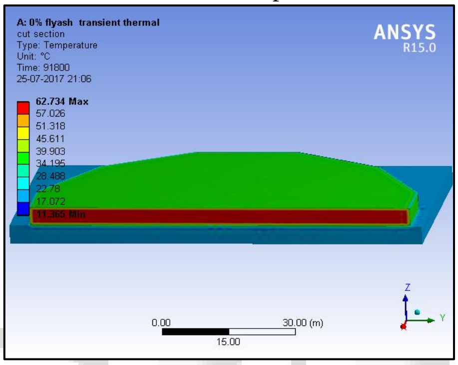

Fig. 6: Transient Thermal>Temperature>cut section

Below tables of temperature and node selection gives the temperature distribution according to the time. Individual location of nodes gives the different levels of heat.

0% fly ash			
Time [hr]	Time [s]	Temperature max [°C]	Temperature min [°C]
5.1	18360	28.625	18.215
10.2	36720	40.896	15.613
25.5	91800	62.734	11.365
71.4	257000	61.012	14.325
122.4	441000	59.812	15.696
173.4	624000	58.022	16.491
224.4	808000	55.84	17.031
275.4	991000	53.494	17.413
326.4	1180000	51.135	17.702
377.4	1360000	48.848	17.933
428.4	1540000	46.675	18.126
479.4	1730000	44.636	18.293
510	1840000	43.462	18.386

Table 3. : Temperature rise for 0% Fly Ash

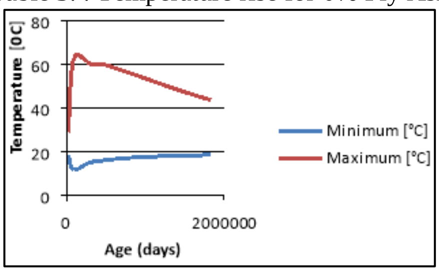

Fig. 7: Temperature rise for 0% fly ash

The 30%, 40%, and 50% replacements of cements with fly ash can be done by the above same procedure, then comparison graphs are generated below.

B. Temperature for all % replacements of cement with fly ash

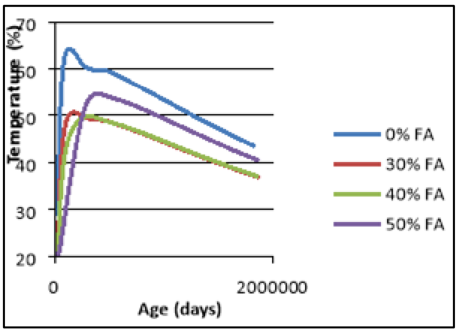

Fig. 8: Temperature rise for all % fly ash

From the above results, it is observed that by increasing the % of replacements of cements with fly ash, maximum temperature also reduced.

C. Nodal Results for 0% Fly Ash

1) Case 1: Middle section at node 36369

Below figure shows the nodal result for 0% fly ash with middle section node number36369. The maximum temperature obtained is 61.401^{0}C at time of 91800 seconds. Because of inner surface of concrete, it attains maximum temperature rise of 61.401^{0}C.

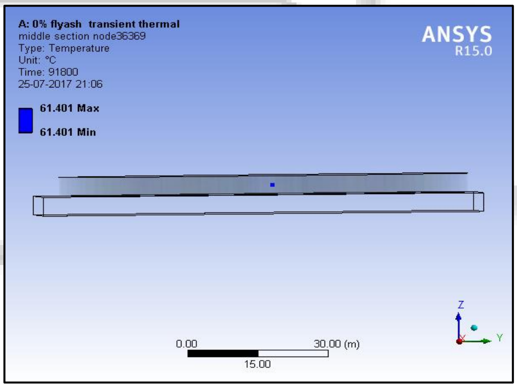

Fig. 9: Transient Thermal>middle section node36369

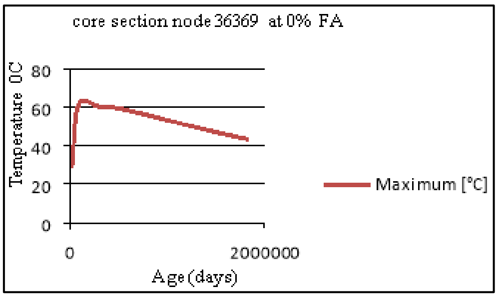

Fig. 10: Temperature at node36369 for 0% fly ash.

node36369 at 0% fly ash		
Time [hr]	Time [s]	Temperature[^{0}C]
5.1	18360	27.985
10.2	36720	39.456
25.5	91800	61.401
71.4	257000	60.853
122.4	441000	59.695
173.4	624000	57.889
224.4	808000	55.684
275.4	991000	53.318
326.3889	1180000	50.944
377.3889	1360000	48.646
428.3889	1540000	46.467
479.3889	1730000	44.425
510	1840000	43.25

Table 4: Temperature at node36369 for 0% fly ash.

2) Case 2: Surface corner at node 15708:

Below figure shows the nodal result for 0% fly ash with surface corner node number15708. The maximum temperature obtained is 27.338^{0}C at time of 36720 seconds. As earlier said that inner surface of concrete gives maximum temperature whereas outer surface of concrete is of reduction in temperature. Because of that reason maximum temperature of surface corner node is about to 27.338^{0}C.

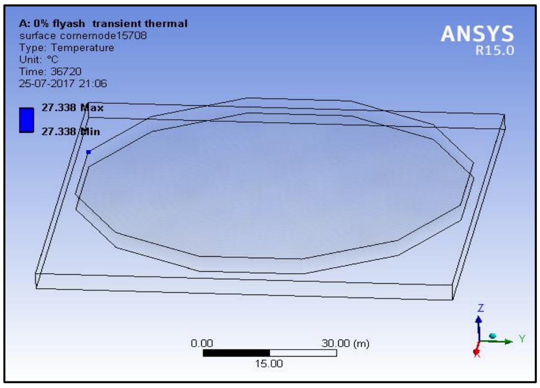

Fig. 11: Transient Thermal > surface corner node15708

node15708 at 0% fly ash		
Time [hr]	Time [s]	Temperature[^{0}C]
5.1	18360	23.841
10.2	36720	27.338
25.5	91800	26.541
71.4	257000	20.511
122.4	441000	20.295
173.4	624000	20.366
224.4	808000	20.362
275.4	991000	20.325
326.4	1180000	20.284
377.4	1360000	20.247
428.4	1540000	20.214
479.4	1730000	20.187
510.0	1840000	20.172

Table 5: temperature at node15708 for 0% fly ash.

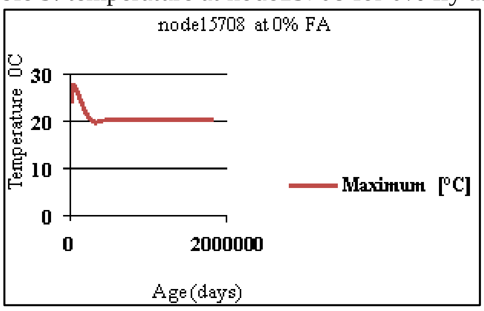

Fig. 12: temperature at node15708 for 0% fly ash.

The 30%, 40%, and 50% replacements of cements with fly ash can be done by the above same procedure, then comparison graphs are generated below. Temperature at middle section of node36369 for all % replacements of cement with fly ash:

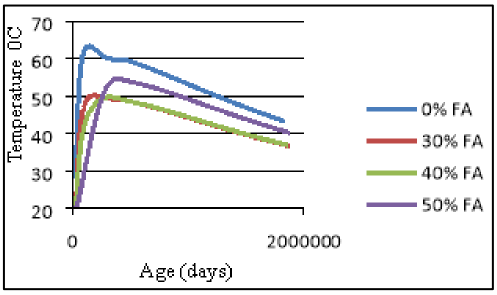

Fig. 13: temperature at node36369 for all % fly ash.

Temperature at middle section of node15708 for all % replacements of cement with fly ash:

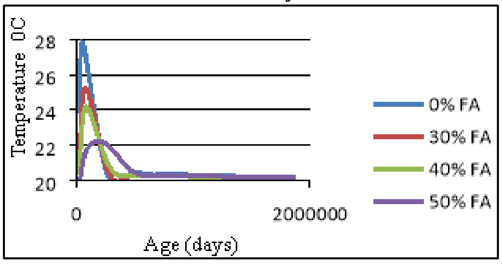

Fig. 14: temperature at node 15708 for all % fly ash.

As it can be seen from above results, it is observed that the maximum temperature at core (middle) section is higher than the maximum temperature at surface section.

D. *Maximum Temperature Rise*

From the figures, it can be noticed that the model with no replacements of cements with fly ash has shown higher temperature distribution in core section than the models with 30%, 40%, and 50% replacements of cements with fly ash and also the temperature distribution at selection nodes varies with the percentage levels of fly ashes.

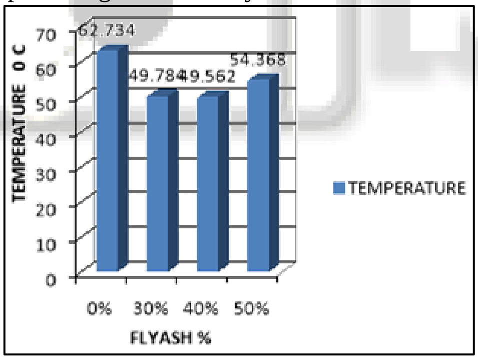

Fig. 15: Maximum temperature in core.

E. *Maximum Temperature Differences*

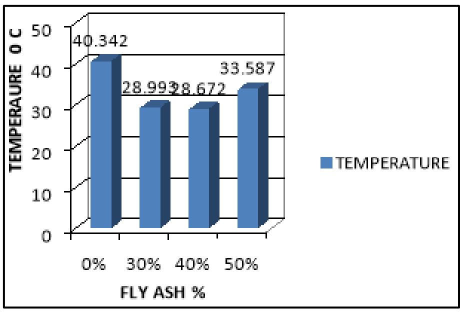

Fig. 16: temperature difference between core & surface.

V. CONCLUSIONS

The temperature distribution for the thermal analysis is varies with the percentages of replacements of cements with fly ash.

The maximum temperature attained in core section for 0% replacement of fly ash is 62.734^{0}C, for 30% replacement of fly ash is 49.784^{0}C, for 40% replacement of fly ash is 49.582^{0}C, for 50% replacement of fly ash is 54.368^{0}C. The temperature difference between core and surface is resulted as for 0% replacement of fly ash is 40.342^{0}C, 30% replacement of fly ash is 28.993^{0}C, 40% replacement of fly ash is 28.672^{0}C, 50% replacement of fly ash is 33.587 ^{0}C respectively.

By that, it is observed that by increasing the % replacements of cements with fly ash, the heat of hydration reduces, by that the cracks also avoided in mass concrete.

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