Scientific Journal Impact Factor (SJIF): 1.711
IJMTER
International Journal of Modern Trends in Engineering and Research
ISSN (ONLINE) : 2349 - 9745
ISSN (PRINT) : 2393 - 8161

Thermal Analysis of Concrete using Finite Element Approach

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Abstract- Present paper considers the temperature distribution in the concrete subjected to transient thermal loading on the concrete due to boiling water. Concrete when exposed to elevated temperatures during fire or in the spent fuel tanks, the heat causes changes in mechanical properties of concrete such as compressive and flexural strength. The study of temperature distribution in concrete subjected to thermal loading was done using finite element approach. The transient thermal analysis was done on the concrete and the results were matched with the experimental data available. The finite element software ABAQUS ver. 6.12 was used to study the transient thermal analysis of concrete. Thermal properties of concrete were adopted from Eurocode 2. The results of temperature distribution in the concrete obtained from the software coordinate with the experimental results available.

Keywords- Thermal Analysis, Concrete, Finite Element Analysis, Temperature distribution, Concrete subjected to Elevated Temperature

I. INTRODUCTION

Concrete when subjected to elevated temperature gets damaged and undergoes a various reactions, thereby causing disintegration of cement gel structure and loss in its load-bearing capacity, durability, and increased tendency of drying shrinkage, structural cracking. Assessment of the condition of concrete, the temperature distribution over the concrete and extent of damage after the heat is an important requirement for taking possible remedial measures for its restoration. Therefore, systematic parametric studies on simulated conditions of temperatures such as in the spent fuel tanks structures are of utmost importance.

II. THERMAL PROPERTIES OF CONCRETE

For the thermal analysis of concrete, the study of thermal properties of concrete was carried out. Properties such as thermal conductivity, specific heat and thermal expansion of concrete were studied. Eurocode 2 was referred to study the thermal properties of concrete.

2.1 Thermal conductivity

It is the property of the material to conduct heat. Heat transfer occurs at a lower rate across materials of low thermal conductivity than across materials of high thermal conductivity. It is evaluated primarily in terms of Fourier's Law for heat conduction. Thermal conductivity is measured in watts per meter kelvin (W/(m-K)). Thermal conductivity of concrete at 100^{o}C was adopted as 1.8 W/m-K for concrete with siliceous aggregate[11].

2.2 Specific heat

The specific heat is the amount of heat per unit mass required to raise the temperature by one degree Celsius. The specific heat of water is 1 calorie/gram °C = 4.186 joule/gram °C which is higher than any other common substance. As a result, water plays a very important role in temperature regulation. Specific heat of concrete adopted was 880 J/kg-K[11].

Volume 02, Issue 09, [September – 2015] ISSN (Online):2349–9745 ; ISSN (Print):2393-8161

2.3 Thermal Expansion co-efficient

Concrete exhibits thermal expansion when it is subjected to a temperature change. Cracking occurs when stresses develop in concrete structures due to non-uniform thermal expansion. Coefficient of thermal expansion of concrete was adopted was $12 \times 10^{-6}\ K^{-1}$[11].

III. THERMAL ANALYSIS OF CONCRETE

The thermal analysis of concrete in the software was carried out using calculation of heat flux. The heat flux was calculated by using Fourier's law of heat conduction and the temperature on one of the face of concrete was then calculated. The concrete was subjected to temperature from one of its face for a specific time. The heat in the concrete subjected to temperature increases to point and a steady state heat condition was obtained. The transient thermal analysis was done on the software and the results were compared to the experimental results available. The source of the heat subjected to the concrete was boiling water from the steel lined concrete tank.

Figure 1. Concrete block with RTD sensors

Figure 2. Steel lined concrete water tank

The temperature in the concrete was measured using RTD sensors placed at three different depths-135mm, 80mm and 40mm. These experimental readings of temperature distribution were compared to the analytical results from the software.

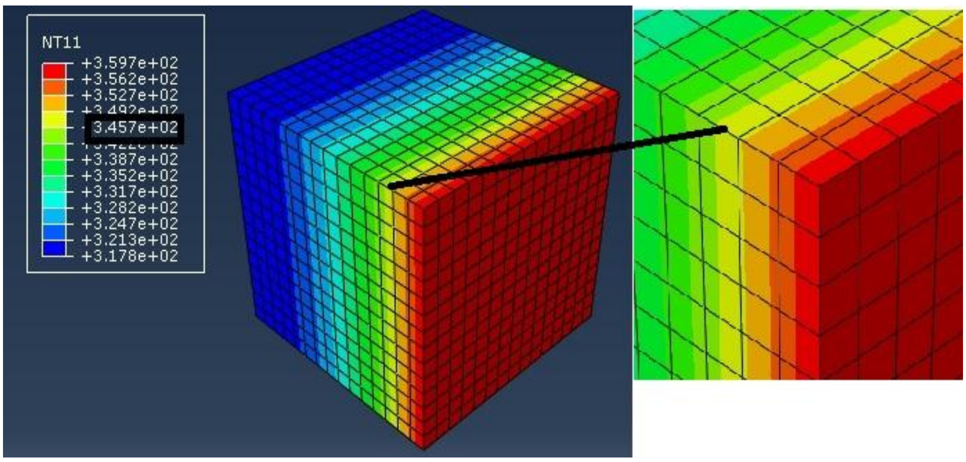

Figure 3. Temperature distribution in concrete

The temperature inside the concrete at the depth of 135mm using the software was analyzed and was found nearly equal to 344.8K. The temperature in the concrete at the same depth using RTD sensors was 347.5K.

Table 1. Comparison of results of thermal analysis

Depth	Temperature (software)	Temperature (experimental)	% error
135mm	344.8K	347.5K	0.8
80mm	332.4K	335.9K	1.04
40mm	323.3K	329.7K	1.7

The results conducted experimentally matches satisfactorily with the results generated in the software.

IV. CONCLUSION

1. The transient thermal analysis of concrete matches satisfactorily with the experimental results.
2. The results in the transient thermal analysis can be more accurate if the thermal conductivity of the concrete is experimentally calculated.
3. In thermal analysis of concrete study of boundary conditions is necessary and the results can be better if the conditions satisfy.
4. The study of combined thermal and mechanical behaviour of concrete can be done using finite element approach and can be compared with the experimental data available.

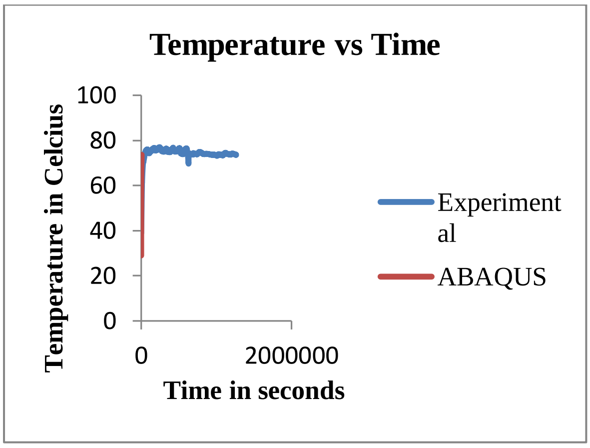

Figure 4. Variation of temperature with time (Depth 135mm)

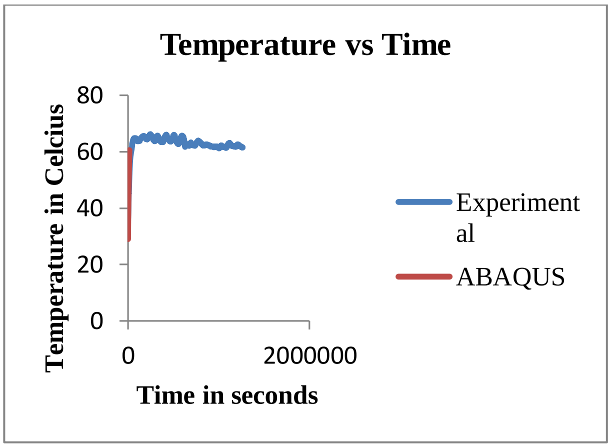

Figure 5. Variation of temperature with time (Depth 80mm)

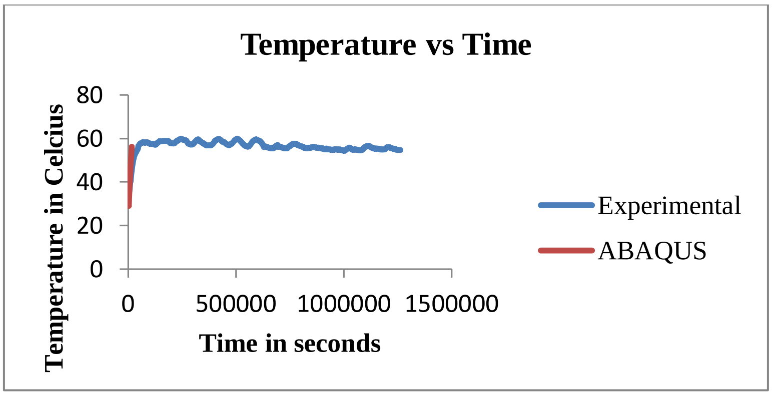

Figure 6. Variation of temperature with time (Depth 40mm)

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