# NONLINEAR TRANSIENT THERMAL ANALYSIS OF NORMAL AND HIGH STRENGTH CONCRETE GRADE COLUMN UNDER FIRE EXPOSURE

**Mathane.T.S[1], Tande.S.N[2]**

[1]PG Student, Dept. of Civil Engineering, Walchand College of Engineering, Sangli, Maharashtra, India, 416415
[2]Professor, Walchand College of Engineering, Sangli, Maharashtra, India, 416415

---

**Abstract** - *Composite columns are currently being increasingly used and construction industry gives more preference to use of high strength concrete as compared to normal strength concrete. Even shape of composite column and type of concrete used has significant influence on strength and behaviour of composite columns. Also, fire performance of structural system is prime concern. The main objective of this research work is to carryout finite element simulation namely nonlinear transient thermal analysis on concrete column model having unit thickness under exposure to ISO834 standard fire curve for both normal and high strength concrete grade. The FE model was developed and exposed to elevating temperature for total 90 minutes to calculate temperature distribution and total heat flux for both normal strength and high strength concrete grade column. It was observed that temperature distribution and total heat flux generated in high strength concrete column was more as compared to normal strength concrete column. Also, the temperature induced at location of center, reinforcing steel and structural steel for high strength concrete column model was more as compared to normal strength concrete column model.*

***Key Words***: Composite column, finite element simulation, nonlinear transient thermal analysis, normal strength concrete, high strength concrete, structural steel, reinforcing steel, ISO834 fire, temperature distribution, heat flux, etc.

## 1. INTRODUCTION

Nowadays, composite columns are mostly used for construction due to their properties such as high strength, fire performance, favourable construction method etc. Fire performance of structural members should be considered while designing composite structures as matter of safety. The construction industry prefers high strength concrete over normal strength concrete because of its overall good structural behaviour. Some studies have stated that high strength concrete behaves differently as compared to normal strength concrete at high temperatures. Also, in some studies it is stated that HSC behaves less better as compared to NSC under fire because of its material properties.

In this research work, composite column consisting of structural steel I section at center and reinforcing steel is selected as shown in Fig-1. The purpose of this research work covers finite element method (FEM) simulation of concrete column model having unit thickness under exposure to ISO834 standard fire curve for both normal and high strength concrete grade. The FEM model was established as shown in Fig-2 to calculate temperature distribution and total heat flux for both normal and high strength concrete grade columns. Also, temperature induced at location of center, structural steel and reinforcing steel was obtained for both grade of concrete columns. The transient thermal analysis results of both normal and high strength concrete grade columns were compared.

## 2. SCOPE

Analytical approach specifically finite element simulation can be useful for investigation of fire behaviour of concrete column with different types of concrete grade. Finite element model can be developed using an relevant software to analyze effect of concrete grade and its properties on nonlinear behaviour of concrete column under standard fire exposure. Finite element simulation namely transient thermal analysis can be carried out to obtain induced temperature at location of structural steel and reinforcing steel. Steel temperature induced can be ultimately used to determine properties of both structural steel and reinforcing steel using standard equations stated in Eurocodes and by some famous authors.

## 3. OBJECTIVES

1. To develop an finite element model of concrete column having unit thickness.
2. To carryout transient thermal analysis on developed model in order to determine the behaviour of concrete column for both normal and high strength concrete grade under ISO834 standard fire exposure.
3. To obtain temperature distribution and total heat flux for both normal and high strength concrete grade column model.
4. To obtain temperature induced at location of center, structural steel and reinforcing steel for both grade of concrete columns.
5. Result Interpretation for both grade of concrete columns.

## 4. MODELLING & ANALYSIS OF COLUMN

The selected totally enchased square composite column is of dimension 350mm x 350mm. It consist of structural steel I section ISHB250 at the center of column and reinforcing steel as shown in Fig-1. Nonlinear transient thermal analysis of pure concrete column having unit thickness is carried out to determine temperature versus time curve at location 1,2 and 3 corresponding to center of column, structural steel and reinforcing steel position respectively as shown in Fig-4. When outer sides of concrete column of unit thickness is exposed to elevating temperature, certain temperature is induced at all three locations. The temperature field remains same along the height of column, so model with unit thickness is developed.

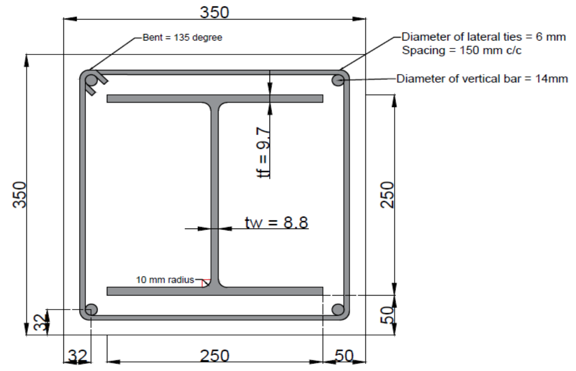


**Fig -1:** Cross section of selected composite column

### 4.1 Finite Element Model

Concrete column model of dimension 350mm x 350mm x 1mm is prepared to carry out transient thermal analysis. Finer meshing of concrete column model is done.

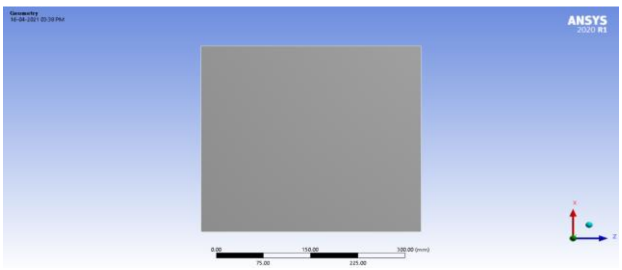


**Fig -2:** Geometry

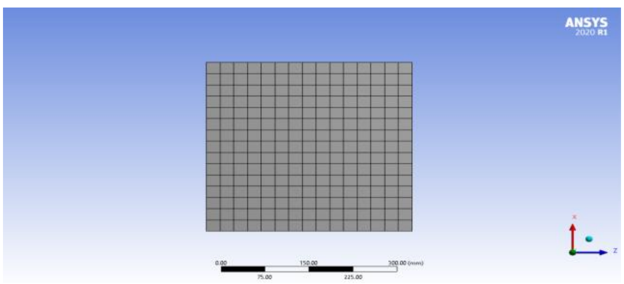


**Fig -3:** Meshing

- Node 1 indicates location of center of concrete column model.
- Node 2 indicates location of center of outer face of flange of structural steel I section which is at 50 mm from outer face of concrete column model.
- Node 3 indicates location of center of reinforcing steel which is at 32 mm from outer face of concrete column model.

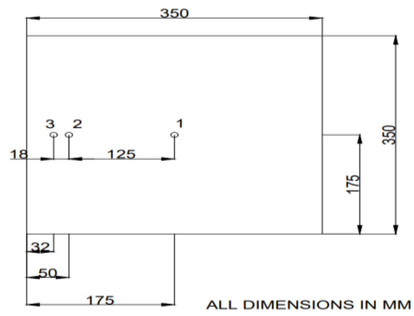


**Fig -4:** Location of thermocouples

### 4.2 Input Engineering Data

Nonlinear thermal properties of normal and high strength concrete grade are derived for total 90 minute fire exposure with time interval of 1 min. Those properties are obtained using standard equations as mentioned below –

(A) For normal strength concrete grade (M30) –

According to European norm EN 1992-1-2:2004 and Canadian Scholar Lie;

(i) Thermal conductivity ( $k_c$ ) in W/m.°C :

$$k_c = \begin{cases} 1.355 & 0°C \le T \le 293°C \\ 1.7162\text{-}0.001241T & T > 293°C \end{cases} \quad [W/(m \cdot °C)]$$

(ii) Specific heat ($c_c$) in J/kg.K :

$c_c = 900$; $20°C \le T \le 100°C$

$c_c = 900 + (T - 100)$; $100°C < T \le 200°C$

$c_c = 1000 + (T - 200)/2$; $200°C < T \le 400°C$

$c_c = 1100$; $400°C < T \le 1200°C$

(iii) Density ( $\rho_c$ ) in kg/m$^3$ :

$\rho_c = \rho(20°C)$; $20°C \le T \le 115°C$

$\rho_c = \rho(20°C).(1 - (T - 115)0.02 /85)$; $115°C < T \le 200°C$

$\rho_c = \rho(20°C).(0.98 - (T - 200)0.03/200)$; $200°C < T \le 400°C$

$\rho_c = \rho(20°C).(0.95 - (T - 400) 0.07/800)$;$400°C < T \le 1200°C$

(B) For high strength concrete grade (M80) –

According to author V.K.R Kodur : 2003;

(i) Mass loss :

$M/M_o = \rho/\rho_o = 1.000 - 0.00005T$ ; $0\,^oC \le T \le 1000^oC$

where, $\rho$ = Density at temperature (T); $\rho_o$ = Density at room temperature (20 °C)

(ii) Thermal conductivity ( $k_c$ ) in W/m. °C :

$k_c = 2.00 - 0.0011T$; $0^oC \le T \le 1000^oC$

(iii) Specific heat ($c_c$) in J/kg. °C :

$$c_c = \begin{cases} 1091.91 & 0°C \le T \le 400°C \\ 75.106T - 28950.64 & 400°C < T \le 410°C \\ -21.460T + 10641.15 & 410°C < T \le 445°C \\ 1091.91 & 445°C < T \le 500°C \\ 6.821T - 2318.64 & 500°C < T \le 635°C \\ 70.787T - 42937.13 & 636°C < T \le 715°C \\ -94.055T + 74924.86 & 715°C < T \le 785°C \\ 1091.914 & T > 785°C \end{cases} \quad [J/(kg \cdot °C)]$$

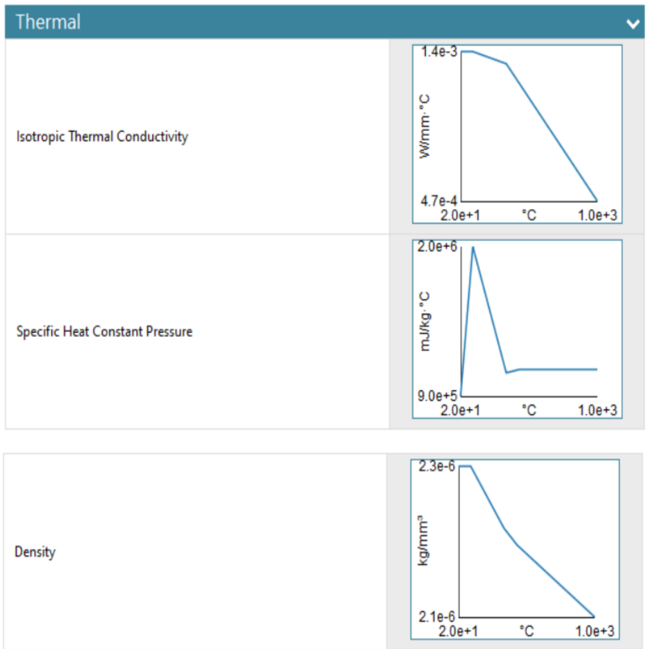


**Fig -5:** Graphical Depiction of nonlinear properties for normal strength concrete grade M30

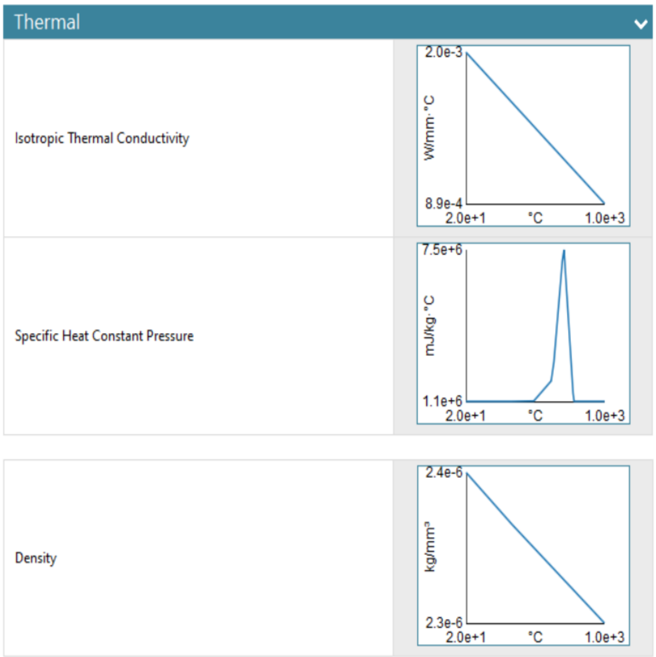


**Fig -6:** Graphical Depiction of nonlinear properties for high strength concrete grade M80

### 4.3 Fire Exposure

Concrete column model having unit thickness is subjected to elevating temperature at all 4 sides of column as shown in fig. Total fire exposure time is 90 minutes. This elevating temperature is obtained from standard fire equation given by ISO 834 stated below -

T= 20 + (345*log (8*t+1))

where, T = Temperature (T) in °C; t = Time (t) in min

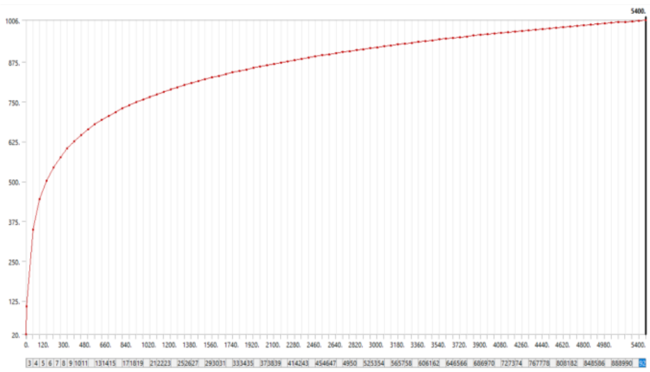

**Fig -7:** Elevating temperature exposure according to ISO834 standard fire curve

### 4.4 Results for Transient Thermal Analysis

The developed finite element model was exposed to elevating temperature for total 90 minutes and results for transient thermal analysis were obtained. Results of temperature distribution and total heat flux for both normal strength and high strength concrete grade column were obtained and compared. Also, the temperature induced at location of center, reinforcing steel and structural steel of selected concrete column for both concrete grade types were obtained and compared. Following results were observed -

(A) Temperature Distribution :

The average temperature induced after fire exposure for 90 minutes in normal strength concrete column model is 482 °C and in high strength concrete column model is 548.74 °C.

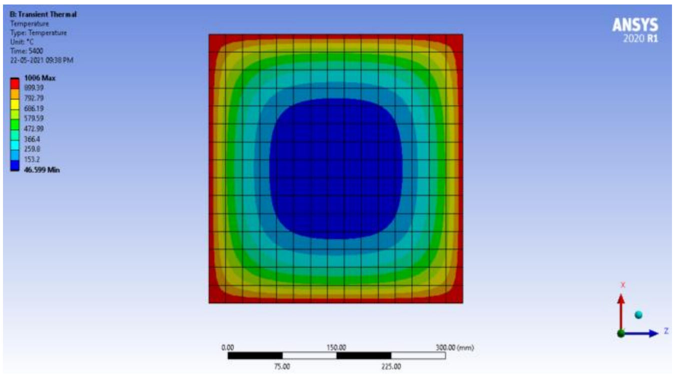


**Fig -8:** For normal strength concrete model

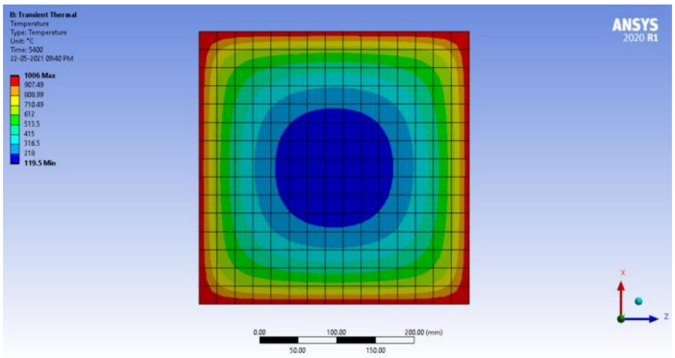


**Fig -9:** For high strength concrete model

- At center of column model (i.e Node 1) -

After fire exposure for 90 minutes, temperature induced at center of normal strength concrete column model is 45.713°C and at center of high strength concrete column model is 117.4 °C.

- At location of structural steel (i.e Node 2) -

After fire exposure for 90 minutes, temperature induced at location of structural steel for normal strength concrete column model is 341.4 °C and at location of structural steel for high strength concrete column model is 436.34°C.

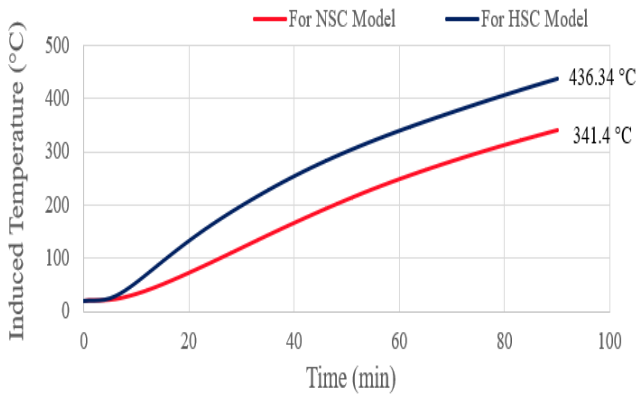


**Chart -1:** Induced temperature vs time at location of structural steel i.e. Node 2

**Table -1:** Induced temperature at location of structural steel i.e. Node 2 for NSC and HSC model

| Time (min) | Induced Temperature at location of structural steel i.e. Node 2 (°C) | |
|---|---|---|
| | For NSC column model | For HSC column model |
| 1 | 21.219 | 20.728 |
| 10 | 33.282 | 54.677 |
| 20 | 73.039 | 132.6 |
| 30 | 119.93 | 198.57 |
| 40 | 166.92 | 253.83 |
| 50 | 210.61 | 299.96 |
| 60 | 249.36 | 339.04 |
| 70 | 283.21 | 373.62 |
| 80 | 313.66 | 405.99 |
| 90 | 341.4 | 436.34 |

- At location of reinforcing steel (i.e Node 3) -

After fire exposure for 90 minutes, temperature induced at location of reinforcing steel for normal strength concrete column model is 503.55 °C and at location of reinforcing steel high strength concrete column model is 573.03°C.

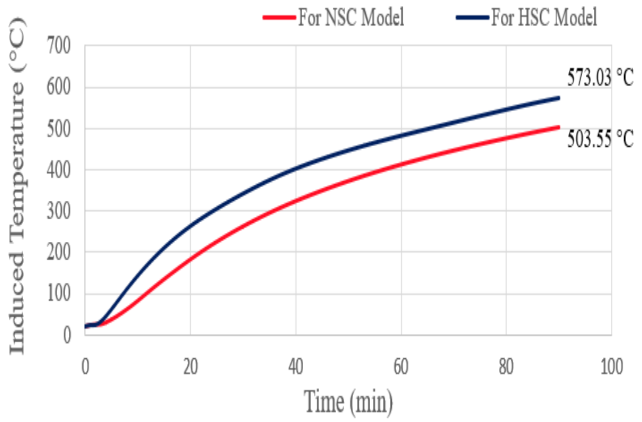


**Chart -2:** Induced temperature vs time at location of reinforcing steel i.e. Node 3

**Table -2:** Induced temperature at location of reinforcing steel i.e. Node 3 for NSC and HSC model

| Time (min) | Induced Temperature at location of reinforcing steel i.e. Node 3 (°C) | |
|---|---|---|
| | For NSC column model | For HSC column model |
| 1 | 23.301 | 23.256 |
| 10 | 81.886 | 142.43 |
| 20 | 182.47 | 262.61 |
| 30 | 262.84 | 341.3 |
| 40 | 324.34 | 401.83 |
| 50 | 372.94 | 446.21 |
| 60 | 413.11 | 481.71 |
| 70 | 447.2 | 513.69 |
| 80 | 477.03 | 545.01 |
| 90 | 503.55 | 573.03 |

(B) Total Heat Flux :

The average heat flux generated in normal strength concrete column model is 7.527 x $10^{-3}$ W/mm$^2$ and in high strength concrete column model is 9.294 x $10^{-3}$ W/mm$^2$.

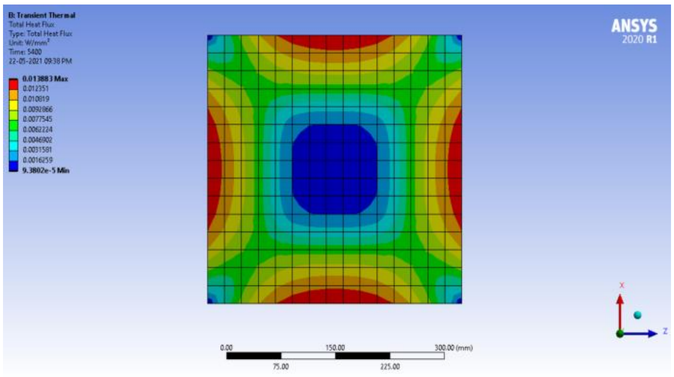


**Fig -10:** For normal strength concrete model

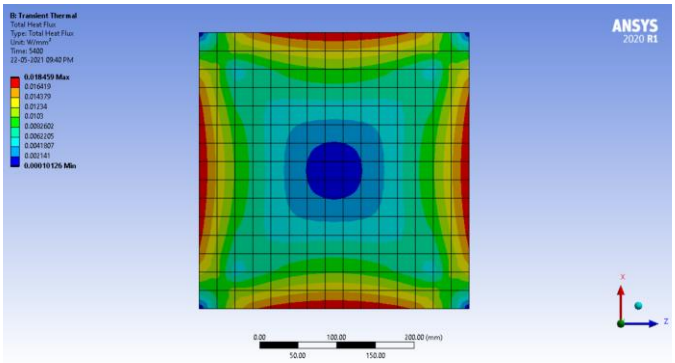


**Fig -11:** For high strength concrete model

## 5. CONCLUSIONS

1. Transient thermal analysis was carried out on concrete column model of unit thickness in order to obtain temperature induced at location of center, reinforcing steel and structural steel for both high and normal strength concrete grade.
2. After fire exposure for 90 minutes, the average temperature induced in normal strength concrete column model is 482°C and in high strength concrete column model is 548.74°C. Thus, 14% more temperature is induced in high strength concrete model as compared to that in normal strength concrete model.
3. After fire exposure for 90 minutes, temperature induced at center of normal strength concrete column model is 45.713°C and for high strength concrete column model is 117.4 °C. Difference is 54%.
4. After fire exposure for 90 minutes, temperature induced at location of structural steel for normal strength concrete column model is 341.4 °C and for high strength concrete column model is 436.34 °C. Difference is 28%.

5. After fire exposure for 90 minutes, temperature induced at location of reinforcing steel for normal strength concrete column model is 503.55 ºC and for high strength concrete column model is 573.03 ºC. Difference is 14%.
6. The average total heat flux for normal strength concrete column model is 7.527 x $10^{-3}$ W/mm$^2$ and for high strength concrete column model is 9.294 x $10^{-3}$ W/mm$^2$. Thus, 23% more heat flux is generated in high strength concrete model as compared to that in normal strength concrete model.
7. Overall, it was observed that temperature distribution and total heat flux generated in high strength concrete column was more as compared to that in normal strength concrete column.

## ACKNOWLEDGEMENT

We would like to appreciate environment and support provided to us by our institute Walchand College of Engineering, Sangli, Maharashtra.

## REFERENCES

[1] Ben Young and Ehab Ellobody, "Investigation of the concrete encased steel composite column at elevated temperature" ,Journal of thin walled structure (48) 597–608, 2010, 12 pages.

[2] CEN-EN 1992-1-2, "Eurocode 2: Design of concrete structures- Part 1-2: General rules structural fire design", European standards; Brussels, 2004.

[3] Gernay, T, "Fire performance of columns made of normal and high strength concrete: A comparative analysis", Key engineering materials, 711, 564–571, 2016, 8 pages.

[4] Kai Xiang, Guo-hui Wang, "Experimental study on temperature distribution of the concrete filled steel tube reinforced concrete square short columns", Procedia engineering 71 :16 – 21; 2014, 6 pages.

[5] Kodur V. K. R, Wang T. C. & Cheng F. P, "Predicting the fire resistance behaviour of high strength concrete columns", Journal of cement and concrete composite, 26(2), 141–153, 2004, 13 pages.

[6] Rodrigues, J. P. C, Correia, A. J. M. & Pires, T. A. C, "Behaviour of composite column made of totally encased steel sections in the fire", Journal of constructional steel research, 105, 97–106, 2015, 10 pages.

[7] Venkatesh Kodur, "Properties of concrete at elevated temperatures". Hindawi publishing corporation ISRN civil engineering, Article ID 468510, 2014, 15 pages. http://dx.doi.org/10.1155/2014/468510.

[8] V.K.R Kodur and Wasim Khaliq, "Effect of temperature on the thermal properties of different types of high strength concrete", Journal of materials in civil engineering , 23(6): 793-801, 2011, 9 pages.