Numerical Modeling on Behavior of Concrete under Elevated Temperatures

Aravindhan. C, Vasudevan M, Arun M

Abstract--- ***Thermal behavior of structural members has become a topical interest with in field of civil engineering due to the major fire accidents in buildings. The thermal behavior of the structural members subjected to thermal conductivity will give an overview about how they react with temperature. Concrete elements exposed to fire, as a result it undergoes spalling and exposing steel reinforcement. The experimental study on the behavior of structural members is hazard, costly and time consuming. In this work finite element modeling was carried out for Normal and Self Compacting concrete beams under elevated temperatures. Finite element modeling of the beams was done using ANSYS 11 software. These beams were heated as per IS-3809 Time- Temperature curve. This study is extended for different grades of concrete such as M25, M30, M35, M40 and different nominal cover as per IS 456-2000. Reduced strength and increased deflection was observed on temperature loads, the changes in behavior of Normal and SCC beams on temperature loads. It was observed from the analysis that when the grade of concrete increases the reduction in strength also increases.***

Keywords: ***Self compacting concrete, Normal compacting concrete, Elevated temperature, Finite element Analysis, Time-Temperature Curve, Ultimate compressive strength.***

1. INTRODUCTION

The impact of fire on building members has a vital job in the development. The thermal conduct of the members exposed to temperature loads will give a overview about how they react with temperature. The field nature of fire assurance materials is currently getting merited consideration. It is a positive pattern that engineers work with fire engineers to secure the structures, and the duty regarding fire-resistant design is assigned to the structural designers. Due to the expanded occurrences of significant fire in structures; assessment, repairs and rehabilitation of fire harmed structures has turned into a topical intrigue. This is a particular field includes mastery in numerous zones like concrete technology, material science and testing, structural engineering, repair materials and systems and so forth. Research and formative endeavors are being completed here and other related disciplines. The reinforced concrete is the a standout amongst the most generally utilizing construction material, and the fire will influence the members gravely through spalling, exposing of reinforcement and so on. The structural property of concrete that has been generally broadly considered as an element of temperature exposure is compressive strength. Generally few studies about have been attempted on flexural strength of reinforced cement concrete (RCC) beams and their repair. Accordingly, this investigation was completed to produce analytical data on load defection behavior of heated NC and SCC beams.

The finite element modeling for the purpose of this study is mainly based on the limitations. ANSYS program based on finite element method has been developed in such a way that it could be finds itself a bigger practice field since 1971. For simple storey structures, the behavior if there should be an occurrence of fire is important just for the security of the fire fighters. The protection of tenants and products involves fire spread, smoke engendering, dynamic putting out fires measures and clearing offices. Fragile disappointment, dynamic fall and partial failure of components outwards may imperil the fire contenders and have to be avoided. So as to manage such a target, the simulation softwares projects needs to cover the 3D structural behavior including membrane and limited impacts as well as the failure mode so that post-local failure stage can be analyzed.

The decision of Finite component demonstrating with the end goal of this examination is mostly.

2. REVIEW OF LITERATURE

Zhaohui Huang[2] developed a non-linear model to characteristic between concrete and reinforcing steel for reinforced concrete structures subjected to fire load. The model was demonstrated by the analysis of one pull-out test and one beam test at ambient temperature. Four beams were modelled and tested in two different thermal conditions. The model was created that reinforced concrete members and structures in a fire with suitable accuracy. It was reported that the bond between the concrete and reinforcement has an important impact on the fire resistance of RC structures, specifically when the temperature of the reinforcing steel bar is very high.

Ilker Bekir Topcu et al[3] investigated the mortar specimen where reinforcement is placed between 3cm and 5cm covers. The changes after high temperatures in mechanical properties of the reinforcement steels. In order to ensure 3 and 5 cm covers 76 × 76 × 310 and 116 × 116 × 350 mm sized reinforced mortar specimen were prepared. These reinforced mortar specimens were exposed to temperatures and after that on the steels taken out of these mortar specimen tensile strength, tests were applied in order to determine the mechanical properties. With the tensile strength tests performed stress–strain curves of the steel bars

---

Revised Manuscript Received on December 22, 2018.

Aravindhan. C, Assistant Professor, Department of Civil Engineering, Bannari Amman Institute of Technology, Coimbatore, Tamilnadu, India (Email: aravindhanc@bitsathy.ac.in)

Vasudevan M, Assistant Professor (Sl. Grade), Department of Civil Engineering, Bannari Amman Institute of Technology, Coimbatore, Tamilnadu, India (Email: vasudevan@bitsathy.ac.in)

Arun M, Assistant Professor (Sl. Grade), Department of Civil Engineering, PSG Institute of Technology and Applied Research Coimbatore, Tamilnadu, India

exposed to several temperatures were drawn. Besides, the yield and ultimate strengths of the steel bars were determined. The consequences of the study have shown that the larger the covers, the better the steel bars are protected against high temperatures.

Anand. N et al[4] investigated the correct us nderstanding of the effects of raised temperatures on the properties of SCC is important to ensure the safety of buildings made with SCC during fire. During the present examination, an endeavor has been made to think about the pressure strain conduct of Normal Compacting Concrete and Self Compacting Concrete at a temperature of 900°C. A critical decrease in the Extreme compressive quality of SCC was observed during this study. The decrease was observed to be more for SCC contrasted with Normal compacting concrete. The decrease in the compressive quality of SCC was observed to be 81.5 % for M40 solid when uncovered to 900°C.

Experimental Investigation

Experimental setup in software requires a lot of pre-analysis data to be collected so that the modeling can be created as closer to the actual experimental model as possible in order to reduce the limitations in FEM analysis. Experiments were conducted to find the material properties such as stress-strain relation of concrete, rate of heating, rate of cooling, coefficient of thermal expansion and density of reference and heated specimens as mentioned in Anand N et al[4].

Table. 1 Ultimate Compressive Strength of Normal Concrete

Grade of Concrete	Compressive Strength (N/mm2)			
	Reference Specimen	300°C	600°C	900°C
M25	21.12	15.91	12.56	9.26
M30	26.19	18.43	15.01	11.35
M35	30.86	21.25	16.98	13.12
M40	34.25	23.12	18.56	13.68

Table.2 Ultimate Compressive Strength of Self Compacting Concrete

Grade of Concrete	Compressive Strength (N/mm2)			
	Reference Specimen	300°C	600°C	900°C
M25	23.61	21.36	14.05	5.82
M30	27.03	24.46	16.41	6.05
M35	31.21	28.24	18.62	6.41
M40	34.86	31.54	20.75	6.88

3. MODELLING OF BEAMS

The finite element modelling [1] of NC and SCC beams for various Nominal cover as mentioned in IS-3809 Time-Temperature curve. Normal Concrete (NC) and Self-Compacting Concrete (SCC) beams were modeled by using Ansys 11.0. These beams were investigated by using coupled thermal – structural method of analysis. The modeled beams were heated as per IS 3809 Time-Temperature curve [5] for various elevated temperatures and duration of heating. Then the same beams were cooled by using method of convection by Ansys. The following are the type of cooling adopted to cool the specimens.

i) Air cooling (From Specified heated temperature to room temperature)
ii) Spraying water (From Specified heated temperature to room temperature)

After the cooling process the beam specimens were applied for structural loading up to failure. The load deflection data were extracted from the analysis for reference and heated beams. The Nonlinear coupled thermal – structural analysis was carried out with the support of many input parameters. The time temperature relation used to heat and cool the specimen in Ansys.

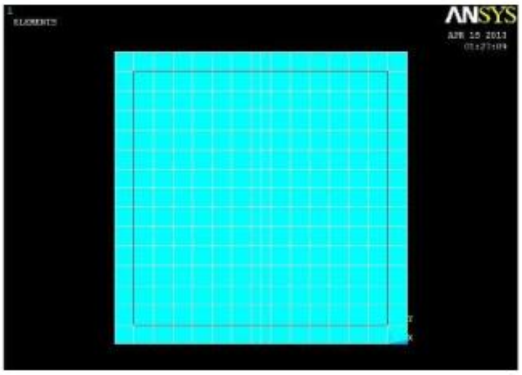

Fig. 1 20mm Nominal Cover cross section[6]

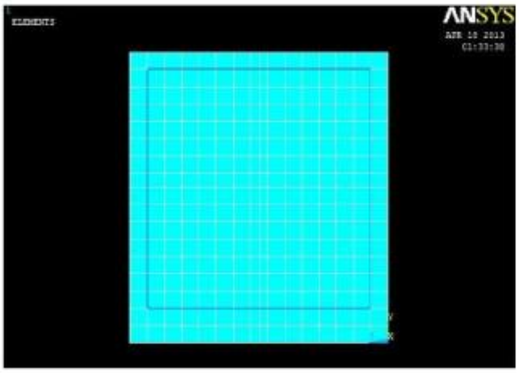

Fig.2 40mm Nominal Cover Cross Section[6]

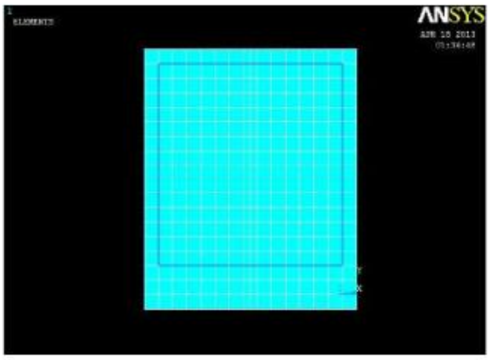

Fig. 3 60mm Nominal Cover cross section[6]

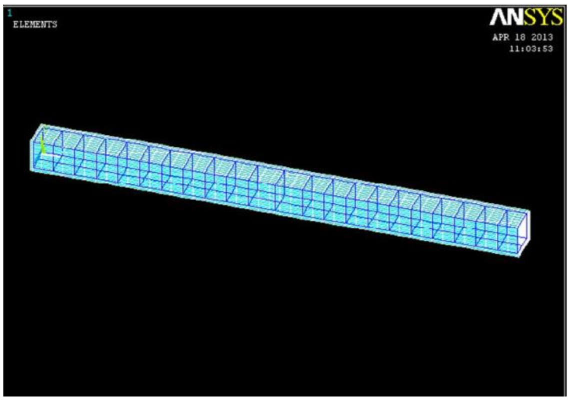

Fig. 5 Modelling of Beam

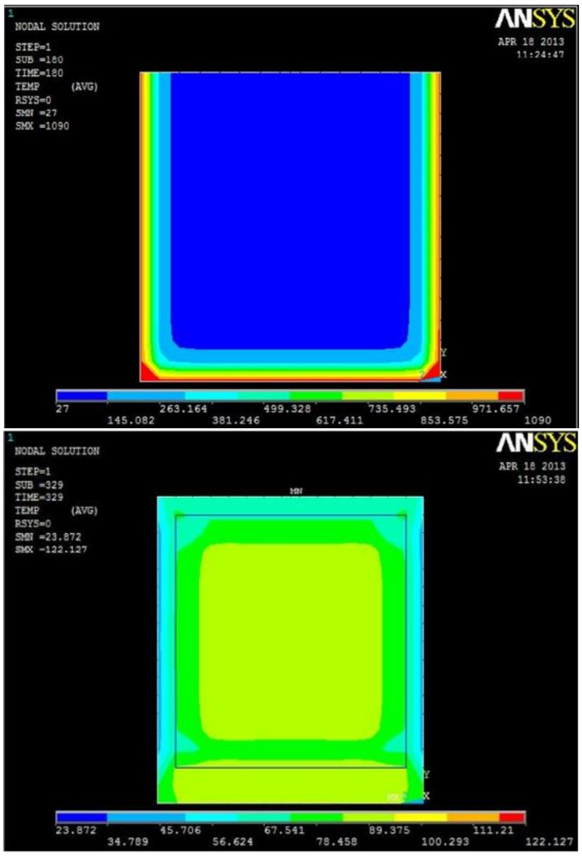

Fig. 5 Effect of Heating and cooling in modelling as per IS 3809 - 1979 Time Temperature Curve [7]

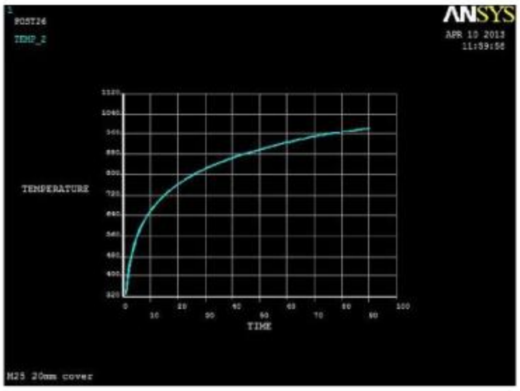

Fig.6 Heating and Cooling of Beam as per IS 3809 - 1979 Time-Temperature Curve [7]

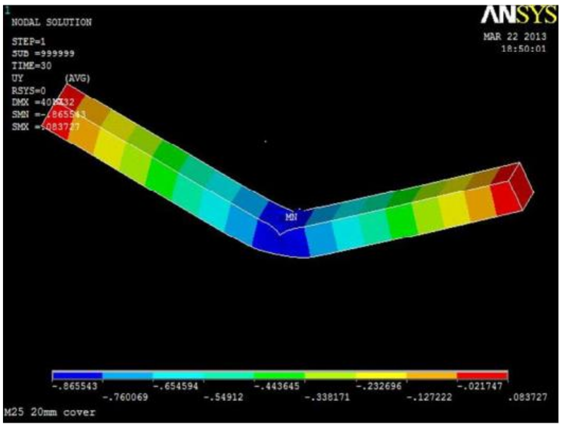

Fig. 7 Deflected Beam

Table.3 Load-Deflection Behavior of Reference Beams for Various Nominal Cover

Cover (mm)	Normal Concrete				Self-Compacting Concrete			
	Reference Specimens							
	Grade of Concrete				Grade of Concrete			
	M25	M30	M35	M40	M25	M30	M35	M40
20	43.5	51	58.5	66	42.5	49	56	64
40	44	52	58.5	66	42.5	49	56	64
60	43.5	51.5	59	66	42	49	56.5	64
70	43.5	51	58.5	67	42.5	49	56	63.5

Table.4 Load-Deflection Behavior of Air Cooling Beams for Various Nominal Cover

Cover (mm)	Normal Concrete				Self-Compacting Concrete			
	Air Cooling Specimens							
	Grade of Concrete				Grade of Concrete			
	M25	M30	M35	M40	M25	M30	M35	M40
20	36	39.5	43	45	37	40	42.5	45
40	33	36	38	40	35	37.5	39	41
60	31.5	34.5	35	36.5	32.5	35	37.5	39
70	29.5	32	33	34.5	30	32.5	35	37

Table.5 Load-Deflection Behavior of Water Cooling Beams for Various Nominal Cover

Cover (mm)	Normal Concrete				Self-Compacting Concrete			
	Water Cooling Specimens							
	Grade of Concrete				Grade of Concrete			
	M25	M30	M35	M40	M25	M30	M35	M40
20	24	25.5	26.5	27	27	28	29.5	31
40	21	22	22.5	23	25.5	26.5	28	29
60	18	19	19.5	20	23.5	25	26	27
70	15	15.5	16	16.5	21	22.5	24	25

4. DISCUSSION OF RESULTS

The decrease in ultimate load was found to be more for beams were heated and cooled by water compared to beams were heated and cooled by air. Imperviousness to fire of the aggregates is commonly high. Nonetheless, having non-

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

uniform high temperature impact of aggregate or cooling the warmed total utilizing water splash may cause interior weight in the aggregates. This pressure may make the aggregates to spall. A portion of the distortion in the concrete is because of the extension of cement in its composition. Hydrated Portland cement contains a lot of free calcium hydroxide and will break down into calcium oxide because of loss of water at 400– 450°C. On the off chance that this calcium oxide is wetted in the wake of being cooled or is kept in a soggy domain, it changes into calcium hydroxide once more. The concrete may disintegrate because of such changes in volume. The loss of strength related with increment in temperature

It was demonstrated that thin covers and delayed exposures essentially influence the qualities of concrete and reinforcement. In the present examination the nominal cover of the bar was expanded by 20mm, 40mm, 60mm and 70mm respectively without influencing the effective depth of the beam. Impacts of nominal/effective cover at different elevated temperatures were considered. At the point when the nominal cover increases the ultimate load carrying capacity decreases, it is because of the expanding temperature and heating duration for expanding nominal of the beams. It was discovered that the M25 review SCC beams with nominal cover 70mm heated by 1133°C for the length of 4 hours and cooled by water give the lesser ultimate load of 15kN contrasted with different cases. It was discovered that reduction in load carrying capacity increases when the grade of concrete increases for SCC as compared to NC. A higher compressive strength is normally observed with more packing and less porosity, which may prompt higher pore weights and spalling. When compared with temperature of self-compacting cements (SCC) and Normal Concrete (NC), SCC are more vulnerable than the Normal Vibrated Concrete (NC). SCC was found to spall more contrasted with NCC because of lower penetrability and higher dampness content. SCC were normally arranged with higher bond and filler content joined with lower water to cover proportions when contrasted with customary cements. When compared to normal concrete, the SCC where found to spall due to lower absorbency and higher dampness content, SCCs were usually prepared with higher cement and filler content combined with lower water to binder ratios as compared to traditional concretes.

5. CONCLUSION

1. While increasing the grade of concrete, the percentage of decrease in ultimate load also increases; for M25 grade the reduction was 65.52% and for M40 grade, the reduction was 75.37% for SCC beams of 70mm nominal cover and cooled by water.
2. While increasing the grade of concrete, the percentage of decrease in ultimate load also increases; for M25 grade the reduction was 50.59% and for M40 grade, the reduction was 60.63% for NC beams of 70mm nominal cover and cooled by water.
3. The ultimate load carrying capacity of M40 grade SCC beams of 70mm nominal cover decreases 38.89% as compared to SCC beams of 20mm Nominal cover.
4. The ultimate load carrying capacity of M40 grade NC beams of 70mm nominal cover decreases 19.35% as compared to NC beams of 20mm Nominal cover.
5. The ultimate load carrying capacity of SCC heated beams decreases as compared to Reference SCC beams in the case of water cooling.
6. The ultimate load carrying capacity of SCC heated beams decreases 48.51%as compared to Reference SCC beams in the case of Air cooling.
7. The ultimate load carrying capacity ofM40 grade SCC beams of 70mm Nominal cover decreases about 75.37%, but in the case of M40 grade NC beams of 70mm nominal cover, the reduction was 60.63%in the case of water cooling.

REFERENCES

1. R.A. Hawileh, M. Naser, W. Zaidan and H.A. Rasheed, “Modeling of insulated CFRP-strengthened reinforced concrete T-beam exposed to fire”, Engineering Structures 31 (2009) 3072-3079.
2. Zhaohui Huang, “Modelling the bond between concrete and reinforcing steel in a fire”, Engineering Structures 32 (2010) 3660–3669.
3. Ilker Bekir Topcu, Ahmet Raif Boga, Abdullah Demir, “Influence of cover thickness on the mechanical properties of steel bar in mortar exposed to high temperatures”, Fire and Materials, Volume 35, Issue 2, pages 93–103, March 2011
4. Anand N and Prince Arulraj G, “Experimental Investigation on Mechanical properties of Self Compacting Concrete under elevated Temperatures”, International Journal of Advances in Mechanica and Civil Engineering, Feb 2015, pp 15-19
5. IS 3809-1979, “Fire Resistance Test of Structures”.
6. IS 456-2000, “Plain and Reinforced Concrete-Code of Practice”