International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 03, March-2018

Effect of High Temperatures on Concrete/ RCC: A Review

Chirag R. Ajmera
PG Student,
Civil Department,
PRMITR, Badnera,
Amravati-444701, India,

Dr. Ashok R. Mundhada
Professor,
Civil Department,
PRMIT&R, Badnera,
Amravati-444701, India,

***Abstract*—Fire & fire incidents can damage a structure to extent that it can collapse, no structure however well build, is immune to from fire & hence design considerations for fire has become very important part of structural engineering. Spacing of stirrups plays an important role in design of structure. It is intended to study if closely spaced stirrups heat the core sooner. This paper reviews the previous work done on fire performance of concrete & what are the effect of stirrups spacing on R.C.C members at high temperatures.**

Keywords-- Confinement, Cover Blocks, Flexural Strength, R.C.C beams, Spalling, Temperature.

I. INTRODUCTION

With the increased incidents of major fires and fire accidents in buildings; assessment, repair and rehabilitation of fire damaged structures has become a topic of interest. This field involves specialized expertise in many areas like concrete technology, material science and testing, structural engineering, repair techniques & materials etc. To make a structure functionally viable after the damage due to fire has become a challenge for the engineering community. It is vitally important that we create buildings and structures that protect both people and property as effectively as possible.

Most studies on concrete under high temperatures have not considered the effect of stirrup spacing. The aim of this review is to increase the awareness of the structural engineers to the concepts behind structural design for fire safety & to assess if simplified design tools that predict the fire performance of structural elements have been developed.

II. LITERATURE REVIEW

Gabriel A. Khoury, Patrick J.E. Sullivan [1]:

In this paper, authors discussed their research work on effect of elevated temperatures on concrete. Authors found that,

- Basic creep studies at constant temperatures indicated a marked increase in creep above 550–600°C for cement paste and lightweight concrete. From this they suggested that the structural, though not necessarily the refractory, usefulness of Portland cement-based concretes in general would be limited to temperatures below 550–600°C.
- Initial studies of the effect of heating on the strength of concrete show certain trends which may differ from those expected from current knowledge.
- This suggests that it may be possible to design concretes in the future which retain a larger proportion of their initial strength after heating than is achieved at present.

Mohammed Mansour Kadhum et.al [2]:

In this paper, the authors discussed a study in which some mechanical properties and deflection behavior of rectangular reinforced concrete beams under the effect of fire flame exposure is presented. The properties investigated were compressive strength and load-deflection behavior of rectangular reinforced concrete beams under the effect of fire flame exposure. The concrete specimens and beams were subjected to fire flame temperatures ranging from (25-800) °C at different ages of 30, 60 and 90 days, three temperature levels of 400, 600 and 800 °C where chosen for exposure duration of 2.0 hours. Authors found that,

- The residual compressive strength ranged between (62 – 72 %) at 400 °C, (52 – 62%) at 600 °C and (38 – 49 %) at 800 °C.
- Large proportion of drop in compressive strength occurs at the first 1.0-hour period of exposure
- Based on the results obtained, it was found that the shrinkage values increase with temperature increase.
- The temperature distribution through the thickness of beam that was found in this investigation is similar for all the beams which have the same thickness and exposed period to fire flame.
- After the beams were subjected to fire flame, two types of cracks developed. The first was thermal cracks, which appeared in honey comb fashion all over the surface. The second cracks originated at mid-span region due to bending from the applied load and called flexural cracks.
- It was noticed that the load deflection relations to specimens exposed to fire flame are flat, representing softer load-deflection behavior that of the control beams. This can be attributed to the early cracks and lower modulus of elasticity.
- At temperature of (400°C), both burning and subsequent cooling did not affect the mechanical properties of steel reinforcement; the effect was observed at 600 and 800°C. The residual yield tensile stress and residual ultimate stress was (90.6%, 78.8% and 89.8%, 81.4%) respectively.
- Modulus of elasticity of concrete is the most affected by fire flame temperature rather than compressive strength.

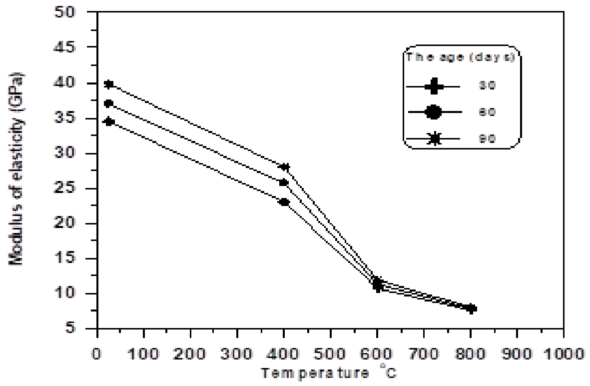

Fig.1 Drop in elastic modulus with temperature

S. C. Chakrabarti, K. N. Sharma et al. [3]:

The authors conducted an extensive test program for assessing the residual strength of concrete after fire. The conclusions of the test were,

- The authors concluded that the concrete actually gained some strength between 100 to 300°C in the presence of siliceous & carbonaceous aggregates.
- Some other researchers too have reported this phenomenon, but they faced criticism then support.
- As per the authors, concrete didn't lose much of its strength up to 500°C & in fact regained 90% of lost strength up to this temperature after about a year.
- Concrete cubes heated beyond 800°C for 4 hours started crumbling after 2-3 days.

The theory of fire affected concrete regaining some of its strength with time is not an established one & lacks supporting evidence.

R. Sri Ravindrarajah, R. Lopez et al. [4]:

In this paper, authors discussed about the degradation of the strengths and stiffness of high-strength concrete in relation to the binder material type. As per the authors high strength concrete mixtures generally have low water to cement ratio and high binder material content. They used high-water reducing admixture (super plasticiser) to achieve workable concrete at low water cement ratio which resulted in producing concrete having its 28-day compressive strength well over 100MPa. For testing they used four types of mixes having varying binder materials. Mixes 1 and 2 consisted of 565 kg/m3 of general purpose cement, general blended cement having 62% blast furnace slag content. In Mix 3, 20% of the Type GP cement was replaced with low-calcium fly ash (115 kg/m3). Mix 4 contained 565 kg/m3 of general purpose cement and 40 kg/m3 of condensed silica fume. For all four mixes, the water to binder ratio was kept at 0.30. Concrete test specimens were heated at temperatures of 200oC, 400oC, 600oC, 800oC, and 1000oC. The results were,

- High-strength concrete, independent of the binder material type used, experienced weight loss and the relationship between the weight loss and maximum temperature was non-linear.
- Compressive and tensile strengths showed noticeable losses (above 15%) even at the temperature of 200ºC, however the elastic modulus dropped marginally by about 5%.
- Concrete with silica fume suffered the most under increased exposure temperature below 800ºC.
- High-strength concrete showed 90% drop in its strengths once exposed to 1000ºC irrespective of the type of binder materials used.
- Modulus of elasticity of high-strength concrete was less sensitive to the maximum temperature than either compressive or tensile strength.
- Ultrasonic pulse velocity measurement could be used to estimate the temperature-related damage in concrete.

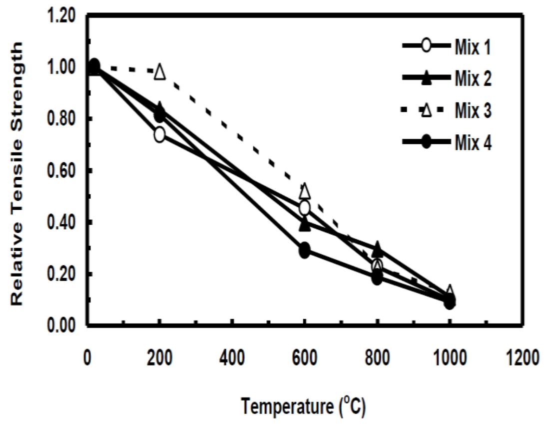

Fig.2 Residual tensile strength of concrete after high-temperature exposure

Dattatreya, B. Balakrishna Bharath [5]:

In this paper author did a research work on studying the impact of fire on reinforcement provided in R.C.C structures of various types of buildings which are under blast or fire. The Behavior of Steel Reinforcement at various elevated temperatures from 100° C to 1000°C was studied. The specimens for testing were TMT bar of 12mm diameter. 20 bars were cut to 30 cm size. Then the specimens were tested for the mechanical properties using UTM before heating at normal room temperature and the properties were tabulated. 10specimens each were heated in the electric furnace at 100°, 300°, 600°, 900°C and 1000°C for an hour without any interference. After heating, out of 10 specimens for each temperature 5 samples were quenched in cold water for rapid cooling and the other 5 were kept aside for normal cooling at atmospheric temperature. These specimens later were tested for mechanical properties with UTM. The authors concluded that,

- Ductility of quickly cooled reinforced bars after heating to high temperature of 1000°C decreased which could be dangerous for a structure.
- Significant change in ductility was observed at high temperatures & near ultimate load.
- A major problem caused by high temperatures was spalling of concrete i.e. separation of concrete mass from concrete element which resulted in the exposure of steel reinforcement directly to high temperatures.
- If the duration and the intensity of fire are higher, the load bearing decreased to the extent of the applied load resulting in collapse of structure.

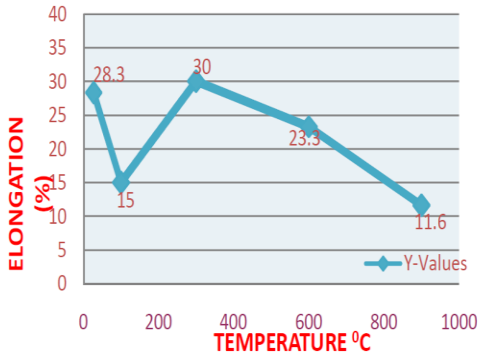

Fig.3 Elongation with rising temperatures

A. R. Mundhada et.al [6]:

The authors performed an experiment on effect of confinement on fire performance. 108 R.C.C beams (36 each for concrete grades M 30, M 25 & M 20) of size 100*100*450 were cast. The beams were reinforced with 2 no's 8Y bars at top & bottom. Half the beams had closely spaced stirrups whereas the remaining had sparsely spaced 5mm Ø stirrups. After the beams were cured for 28 days, they were heated at 30°C, 200°C, 350°C, 500°C, 650°C, and 800°C. After heating, specimens were air-cooled at room temperature for 24 hours. After cooling, various non-destructive tests like Thermo-gravimetric analysis, Schmidt Hammer Test & UV Pulse Velocity Test were carried out. Finally, all the specimens were broken in UTM by applying two-point loads to find out the flexural strength.

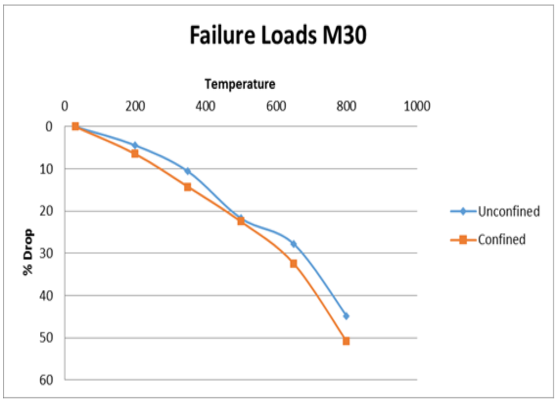

Fig. 4 Graph between temperature and % drop

The conclusions of the test conducted were,

- Up to 350°C, concrete remained unaffected quality wise and strength wise. Strength lost was @10% or less.
- At 500°C, quality of concrete decreased, but remained fair & strength came down by 20-25%. Structure/members remained serviceable but factor of safety decreased. Affected member would require minor repairs to become serviceable again.
- At 650°C, strength decrease was noticeable and come down by a third.
- At 800°C, concrete lost most of its strength & affected portion would require replacement.
- Strength of the confined (closely spaced stirrups) beam was almost always higher in absolute terms, as compared to the unconfined (less stirrups) beam. At the same time, the percentage drop in strength & quality in case of a confined section was always higher vis-à-vis its unconfined alter ego.
- Judicious stirrup spacing would be required for resisting forces like earthquake, but too closely spaced stirrups were not desirable from fire point of view.

Rahul P. Chadha, Ashok R. Mundhada [7]:

In this experiment, the authors studied effect of fire on flexural strength of reinforced concrete beams. 42 beams of c/s 150*150*700mm were cast. Six specimens were tested for the Flexural strength using UTM before heating at normal temperature and twelve specimens (6 specimen of 25mm clear cover & 6 specimen of 30mm clear cover) each were heated in the electrical furnace at 550°C for 1 hour and 2 hour respectively without any disturbance & same procedure was repeated for 12 specimens each for 750°C and 950°C. 3 specimens were cooled at normal temperatures, 3 but were quenched with water & rapidly cooled. Thermogravimetric tests were carried out & finally the beams were tested for strength under UTM. The conclusion was,

- Up to 550°C, the weight loss for RCC was negligible & the flexural strength reduced by 1/3rd. No cracking, spalling or scaling was observed up to this stage. The fire affected structure up to this point would only require rapid cooling & repairs.
- At @ 750°C, there was a further drop in weight & flexural strength, cracks did appear but there was hardly any spalling or scaling. The fire affected structure at this point would require rapid cooling & retrofitting. Factor of safety would come down, but the structure would remain serviceable.
- Beyond this stage, all the parameters dropped drastically. Weight loss at 950°C exceeded 10%, flexural strength came down by 2/3rd, major cracking, spalling & scaling was observed.
- The fire affected portion at this stage would require replacement.
- Greater cover & faster cooling would provide relief.

Ashok R. Mundhada, Arun D. Pophale [8]:

In this paper author studied effect of high temperatures on compressive strength of concrete. 90 concrete cubes of 150 mm size, divided equally over three different grades of design mix concrete viz. M 30, M 25 & M 20 were cast. After 28 days' curing & 24 hours' air drying, the cubes were subjected to different temperatures in the range of 200°C to 800°C, for two different exposure times viz. 1 hour & 2 hours in an electric furnace. The heated cubes were cooled at room temperature for 24 hours & then subjected to cube compressive strength test. Mix design was carried out using the Ambuja method of design. The conclusions of the test were,

- Up to 350°C, concrete remained almost unaffected in appearance & strength.
- At 500°C, quality of concrete came down slightly & strength too came down. Affected members remained serviceable although the factor of safety would come down.
- At 650°C, the fall in concrete quality & strength became a cause for concern. Major retrofitting might be required.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 7 Issue 03, March-2018

- Beyond 650°C, concrete lost most of its strength and was not structurally stable & it might require replacement.
- Higher exposure time resulted in greater damage.
- Higher grade concrete performed better in absolute terms.

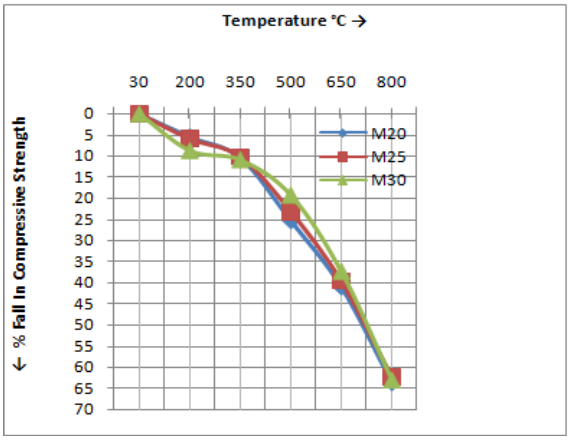

Fig. 5 % drop in compressive strength after 2 hrs

Poorna S, Reshma Prasad [9]:

In this study the thermal behaviour of reinforced concrete slab exposed to fire was studied. The paper mainly focused on the percentage deflection of RC slab when exposed to elevated temperature. The behaviour of one-way reinforced concrete slabs exposed to fire was investigated using ANSYS 14.5.11. Simply supported one way reinforced concrete slab models were considered with three different parameters namely: M 25, M 70 and M 100 grades of concrete, different covers of 30mm, 40mm and 50mm with grade of steel 415 N/mm2. The size of the slab panel was, 3300mm x 1200mm x 200mm. The temperature applied on the slab was based on the ISO 834 fire curve. A pressure of 0.1 N/mm2 was applied on the slab. The deflection was noted and studied.

Table 1 Interpretation of results based on cover

Sl.No	Grade of concrete	Cover (mm)	deflection (mm)	variation (%)	total variation (%)
1	M25	30	25.5893		17.08
2		40	23.141	9.56	
3		50	21.216	8.32	
4	M70	30	19.998		23.66
5		40	17.4992	12.49	
6		50	15.2675	12.75	
7	M100	30	16.4387		27.34
8		40	14.0705	14.4	
9		50	11.9439	15.11	

The conclusion of this study was,

- The normal strength concrete M 25 and high strength concrete M 70 and M 100 exhibited linear response.
- The deflection of slab decreased as the cover was increased. This was because concrete's enhanced capacity to resist fire.
- From the above analysis it was concluded that M 100 with a cover of 50 mm showed minimum deflection when exposed to high temperature and pressure.
- Maximum deflection was shown by M 25 grade with 30 mm cover at high temperature and pressure.

M. M. Hossain, N Apu et.al [10]:

This paper deals with the behaviour of reinforced concrete beams exposed to fire at three different temperature levels. For this purpose, eight RCC beam samples were cast with identical cross section. The materials used for the casting of the beams like rebar and concrete were tested. Two reference beam specimens were tested for flexural strength that were not subjected to fire. The other six specimens two in each group were subjected to fire of levels 400°C, 600°C and 800°C respectively for an exposure period of 2 hours which were then allowed to cool naturally up to room temperature. Then flexural strength of all the specimens was measured by an UTM and the results were compared with the two unburnt beams. The conclusion was,

- In general, majority of fire damaged RCC structures were repairable. But the observation of effect of elevated temperature at 800°C on the reinforced concrete beams showed that there was a significant reduction in flexural strength.
- The cracking load for flexure for beams exposed to fire at 400°C & 600°C for 2 hours declined by about 35.46% and 57.77% respectively with respect to unburnt beams.
- But for 800°C there was a significant decrease in flexural cracking load by about 75.44% which was alarming.
- The ultimate strength for beams exposed to fire at 400°C, 600°C & 800°C for 120 minutes were less than that for the reference beam by about 16.71%, 31.18% & 44.05% respectively.
- To minimize the effect of temperature of 400°C, immediate quenching and minor retrofitting was recommended.
- For 600°C temperature, immediate repairing was prescribed to help regain strength.
- For 800°C of fire effect, member replacement was suggested.

K. Thamaraiselvan, V. Jeevanantham et.al [11]:

Authors carried out an experimental program to assess the residual compressive strength of cube specimens. This study specifically addressed three types of concretes viz. normal, high strength and fly ash concrete. These specimens were tested in two separate condition states. The first representing air-cooled state involves heating the specimen to the required temperature for prescribed duration and air cooled to the room temperature. Phase two involves heating the specimen to the required temperature for the prescribed duration and immediately cooled to the room temperature by immersing it in the water (called water quenched). The strength and stiffness degradation of concretes for various grades has been studied and compared with the similar studies carried by other researchers. The conclusion of research work was,

- Weight reduction was marginal at 200°C.
- At higher temperatures, the reduction was observed to be higher. About 8% weight loss was observed in high strength concrete specimens at 1000°C.

- At 500°C sudden explosive spalling was observed in few high strength concrete specimens.
- For specimens exposed to 200 to 400° C, the average reduction of compressive strength was 20% and 25% respectively.
- The reduction was found to be more in high strength concrete specimens. At 600 and 800C the residual strength was observed to be around one fourth of its original capacity.
- Further the rate at which the strength reduced was comparatively more in high strength concrete specimens than other types.
- The performance of fly ash concrete exposed to high temperature was comparatively better than all the three types of concrete.

III. DISCUSSION

This paper presents a review of various research works carried out on effect of fire on concrete. It becomes clear, no matter how well is the structure designed, it is not safe from fire. Concrete and temperature are directly related to each other, higher the temperature, higher the damage.

The theory of fire affected concrete regaining some of its strength with time, as propounded by Chakrabarti & Sharma [3] is not an established one & lacks supporting evidence.

Concrete's performance under fire is robust & up to 500° C, it only requires minor repairs. Stirrups spacing is very important in designing the structure for earthquake. Closely spaced stirrups leading to better confinement are beneficial for structural members. However A. R. Mundhada et al. [6], suggest that during the event of fire, closely spaced stirrups may heat the core of structure sooner and hence may lead to faster degradation of concrete. Since their unique study was performed on leaner members, it needs further exploration with thicker beam specimens.

IV. CONCLUSION

Effect of stirrup spacing on performance of a structural member under fire is a least explored area & needs more investigation.

REFERENCES

[1] Gabriel A. Khoury, Patrick J.E Sulliva, "The effect of elevated temperatures on Concrete", Fire Safety Journal, Volume 13, Issue 1, 7 April 1988, pp 69-72.

[2] Mohammed Mansur Kadhum, "The fire endurance of reinforced concrete beams", Babylon University. www.uobabylon.edu.iq/publications/applied_edition7/paper_ed7_14.doc

[3] S. C. Chakrabarti, K. N. Sharma, Abha Mittal, "Residual strength in concrete after Exposure to elevated temperatures", The Indian Concrete Journal, December 1994, pp. 713-717.

[4] R. Sri Ravindrarajah, R. Lopez, H. Reslan "Effect of Elevated temperature on the properties of High strength concrete containing cement supplementary materials". 9th International Conference on Durability of Building Material & Components, 17-20th March 2002, Paper 81, 8 pages, Rotterdam, Netherlands.

[5] A. Dattatreya & B. Balakrishna Bharath, "Impact of Fire on Reinforcement Provided in R.C.C Structures of Buildings", IJIRSET Journal, Volume 6, Issue 2, Feb-2017, pp 4-9.

[6] Prof. A. R. Mundhada & U. G. Project batch, "Experimental studies on Effect of Confinement on reinforced concrete at elevated temperatures", Bachelor of Engineering project 2015-2016, Prof Ram Meghe Institute of Technology & Research (P.R.M.I.T&R), Badnera.

[7] Rahul P. Chadha, A R. Mundhada, "Effect of fire on flexural strength of reinforced concrete beam", International Journal of Engineering Research Technology (IJERT) Volume 1, Issue 3, May-2012, pp 1-6.

[8] Ashok R. Mundhada, Dr. Arun D. Pophale, "Effect of High Temperature on Compressive Strength of Concrete", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 12, Issue 1 Ver. II (Jan- Feb. 2015), pp 66-70.

[9] Poorna S, Reshma Prasad, "Effect of Fire on RC Slab", IJIRST – International Journal for Innovative Research in Science &Technology, Volume 3, Issue 04, Sep -2016, pp 179-183.

[10] M. M. Hossain, N Apu, U. H Sumaiya & Mahmood, "Testing of RCC Beams Exposed to Various Burning Temperatures", Proceedings of the 3rd International Conference on Civil Engineering for Sustainable Development (ICCES2016),12-14 Feb -2016, pp 703-706, Khulna, Bangladesh.

[11] K. Thamaraiselvan, V. Jeevanantham, A. Parthiban, "Experimental Study on Strength Reduction Factor in Concrete Specimen Subjected to High Temperature", IOSR Journal of Mechanical & Civil Engineering (IOSR-JMCE) Volume 14, Issue 3 Version 7 (May-June 2017), pp 60-64.