

Numerical Study of FRP Reinforced Concrete under Fire Exposure

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ABSTRACT: Investigation on the fire resistance of fibre-reinforced polymer (FRP) reinforced concrete (RC) is essential for increased application of FRP bars in the construction industry. Experimental tests for determining the fire resistance of RC elements tend to be expensive and time-consuming. The factors which make FRP attractive includes: its high strength to weight ratio, reduction in overall construction cost, excellent corrosion resistance etc., but there is only limited knowledge about the performance of FRP under elevated temperature. The behaviour of FRP reinforced beam is analysed using ANSYS software. With constant beam size the numerical study is continued with change in cover, variation in diameter of bar and FRP material. Analysis is done for beams reinforced with steel (control beam), GFRP and CFRP reinforcing bars and for commercially available bar diameters. The analysis is done to obtain minimum cover required by FRP reinforcing bars to resist fire up to fire endurance limit as well as with controlled deflection.

KEYWORDS: Analytical study, FRP, Fire endurance limit, Deflection

I. INTRODUCTION

Over last five decades steel reinforcing bars are the most commonly used reinforcing material. From the previous observations, especially structures susceptible to chloride ions (e.g.: offshore structures, bridges meeting with de-icing chlorides, etc.) the failure of structure is mainly due to corrosion of steel reinforcing bars. Hence studies become necessary to provide a substitute to steel where corrosion becomes the reason for structural deterioration. The basic necessity of the substituting material is, it should possess high tensile strength and anti-corrosion properties. Fibre Reinforced Polymers (FRP) are the most commonly used substituting material due to its high tensile strength, corrosion resistant nature, resistivity towards electric and magnetic fields, high strength to weight ratio, durability and lesser maintenance cost. To obtain the tensile properties the amount of fibres used in FRP rebar should be more than that of resin content. Nowadays, most of the countries use FRP reinforcing bars in construction of bridges, marine and offshore structures etc. Apart from its brittle nature and low resistance towards temperature, FRP reinforcing bars are used due to its pre-dominant importance.

The behaviour of FRP rebar are satisfactory under the ambient temperature. But, under higher temperature, the behaviour of FRP bars is quite different from that of steel reinforcing bars. During fire, the FRP reinforcing bars which are embedded in concrete will fails due to softening of resin content in the rebar even without oxygen. When it reaches the transition temperature the bond between rebar and concrete breaks and cracks are developed which leads to increased deflection. In the absence of codal provisions, obtaining the material properties of FRP rebar's under elevated temperature was difficult. The commonly used FRP's are, Carbon fibres, Glass fibres, Basalt fibres and Aramid fibres. Fig. 1.1 and 1.2 shows the GFRP and CFRP reinforcing bars respectively. Before using the FRP reinforcing bars in multi storey buildings, parking garages etc., its stability should be checked. The fire resistance of FRP RC should be done because of its developing importance. The investigation can be done in two ways, either experimental or analytical. The experimental study of reinforced concrete elements are expensive as well as time consuming. Due to the unavailability of FRP reinforcing bars in India, the analytical method was carried out. With the advancement in modern computing technology, the analysis can be done more precisely. Therefore, study on FRP reinforced concrete is done by using the Finite Element Modelling (FEM) software ANSYS workbench.

This study deals with cover required by GFRP and CFRP reinforcing bars to pass the fire endurance limit as per BS 476: part 20. The fire performance of the material can be obtained from the maximum fire escape time the structure

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provides during fire. For steel reinforced concrete beam as per IS 456:2000, the nominal cover required is 40mm for 2hours of fire endurance. Initially, the analysis is done for beam reinforced with steel bars with 40mm cover as control beam. Thereafter, FRP reinforced beam with 40mm, 50mm and 60mm cover is analysed. Also from the previous studies, it was observed that beams reinforced with FRP reinforcing bars deflects more than that of steel reinforced beam with same load. Hence, in this study the deflection criteria is also taken into consideration and proposing minimum cover required by FRP (GFRP and CFRP) reinforced concrete beam to pass fire endurance limit as well as deflection criteria.

II. RELATED WORK – FRP BARS

The verification of analytical study is done based on an experimental study done by A. Abbasi and P.J. Hogg^[1] in “Fire testing of concrete beams with fibre reinforced plastic Rebar”. In this study, researchers are mainly concentrated to study the effect of temperature in flexural capacity of the beam. Two full scale beam of size 4400mm×400mm×350mm is used for the experiment and the effective depth of beam is taken as 325 mm. The beam is designed based as per Euro code 2 and ACI-440. A cover of 50mm provided on the sides and top of beam. GFRP reinforcing bars are provided as main bar for both beams. The shear reinforcement provided for beam 1 is made of GFRP and for beam 2 is made of steel reinforcing bars. 7numbers of 12mm dia. bars are provided on the tension side and 2 numbers of 12mm dia. bars are provided on compression side. Shear reinforcements are provided at 160mm c/c. The beams are loaded with a static load of 40kN applied in four points with 1m interval, and the temperature is applied on sides and soffit of the beam as per BS 476: part 20 or ISO 834 fire curve. Thermocouples are also provided to measure the temperature on surface of beam as well as the rebar. During Experimental analysis, it was decided that the test should be terminated when the specimen attained a larger deflection, or when it was judged as incapable of sustaining applied load or showed signs of instability, whichever occur earlier. Even though, the study is done to calculate the flexural behaviour of beam with increase in temperature. Hence the analysis is continued till the beam shows any of the above decided changes. Larger deflections are observed as a result of experimental study. In this study Beam 1 is taken for comparison with analytical model, modelled using ANSYS Workbench. After the experimental study beam1 is split into two, which cannot be afforded in practical situation. Therefore, the experimental study is limited up to the time at which beams shows larger cracks. Because, FRP bars are less resist to temperature, when the applied temperature reaches the rebar through cracks, its strength starts reducing. Therefore, from the experimental study at 100th minute, a large crack is visible on the beam. The corresponding temperature is calculated from the time depended temperature graph of the rebar, and is obtained as 345°C and for beam 2 failure time of 94minute is obtained with a failure temperature of 377°C.

In "Thermal-stress analysis of RC beams reinforced with GFRP bars" by R.A. Hawileh and M. Z. Naser^[2], the analysis done in ANSYS Mechanical provided with different cover and with different fire exposure curve. The size of beam analysed is 4400mmx 400mm x350mm. By considering the advantage of symmetry only quarter portion of the beam is analysed. The material data for concrete is adopted from Euro-code 2, the properties varying with temperature is considered from code. But, the material properties of GFRP reinforcing bars with temperature is not available. Hence, the properties at ambient temperature is adopted for study. The analysis is continued with the assumption that, the beam will fail due to the material failure of FRP. The failure is considered when temperature in rebar reaches 462°C, the value obtained from experimental study. A parametric study is done for varying cover (65mm, 60mm and 45mm) and different fire curves. The time dependent temperature and deflection is plotted as a result. The main conclusion of this study is, non-linear analysis using ANSYS provides good agreement with the experimental study, hence it can be used as the method of analysis for beams reinforced with FRP reinforced concrete beam.

Ali Nadjai, Didier Talamona, Faris Ali^[3] studied about the fire performance of concrete beams reinforced with FRP bars. The behaviour of beam reinforced with hybrid FRP and steel reinforcing bars under elevated temperature is done. The method of study is done based on slice method. In this method the cross section of the beam is divided up to a maximum of 100 slices, reinforcements are not sliced the reduction in area of concrete due to rebar are ignored. The application of this method is limited to beams with width between 100 to 300 and overall height to width within the range of 1 to 3. The objective of study is to evaluate the plastic moment capacity of cross section at each time step so that flexural strength history duration of fire event may be plotted. The beam is analysed for 25mm cover and 50mm cover and the hybrid reinforcement provided in one layer and in two layers. It is concluded that even for a small failure loads beams will have large deflection *i.e.*, at fire time equal to 10 minutes the failure loads for AFRP, CFRP and GFRP are respectively: 17kN, 38kN and 13kN. But once, the cover is increased to 50mm the loads increases to 65kN,

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80kN and 39kN for AFRP, CFRP and GFRP respectively. It can be seen that a small addition of cover makes an increase of failure load almost 50 % compared to a cover used of 25 mm. The hybrid steel reinforcement beam with CFRP bars exhibits better performances than AFRP, GFRP; example at 30 minutes the failure load for beam reinforced with CFRP is equal to 71kN compared to AFRP and GFRP which are 50kN and 31kN as given in the order. It is also concluded that the minimum cover provided for hybrid FRP steel reinforced concrete is 50mm.

The Maher A. Adam, Mohamed Said, Ahmed A. Mahmoud, Ali S. Shanour^[4] "Analytical and experimental flexural behaviour of concrete beams reinforced with glass fibre reinforced polymers bars", an experimental, numerical and analytical study of the flexural behaviour of concrete beams reinforced with locally produced glass fibre reinforced polymers (GFRP) bars is done in this journal. A total of ten beams, measuring 120 mm wide x 300 mm deep x 2800 mm long, were cast and tested up to failure. The main parameters used for study are reinforcement material type, concrete compressive strength and reinforcement ratio. The mid-span deflection, crack width and GFRP reinforcement strains of the tested beams were recorded and compared. The test results revealed that the crack widths and mid-span deflection were significantly decreased by increasing the reinforcement ratio. The ultimate load increased by 47% and 97% as the reinforcement ratio increased.

Mathieu Robert and Brahim Benmokrane^[5] on 'Behaviour of GFRP Reinforcing Bars Subjected to Extreme Temperatures', an experimental study is done to evaluate the variation of mechanical properties of sand-coated GFRP reinforcing bars subjected to low temperatures (ranging from 0 to -100°C) and elevated temperatures (ranging from 23 to 315°C). The experiment is initiated by conditioning of GFRP samples by immersing the specimens in water in accordance with procedure 7.4 of ASTM D570 standard except that a water temperature of 50°C was used. From the study, it is concluded that for unconditioned samples with reduction in temperature the mechanical properties (tensile, shear and flexural strengths) and flexural elastic modulus of GFRP bars increased, but for conditioned specimens the tensile strength is reduced but shear and flexural strengths are unaffected. For temperature ranging from -40° to 50°C, GFRP bars are not or little effected. For higher temperature the strength is reduced, at 120°C there is a drop of strength is observed.

Some of the studies are done to obtain the fire performance of GFRP reinforcing bars. Saleh Al Sayed et.al^[6] in "Performance of glass fibre reinforced polymer bar under elevated temperature" an experimental study is done with 12mm diameter bars, in the test half of the specimen is protected with a concrete cover of 40mm and rest without a cover. The tensile strength of the specimen is tested as per American standard test method and American Concrete Institute Guide. A controlled temperature of 100, 200 and 300°C at three different period of 1,2 and 3hours. From the results it is evaluated that by providing a proper concrete cover the tensile strength of the reinforcement can be maintained. From analysis it is obtained that with lowest temperature level and shortest time period is more effective for this concrete cover. By using SEM technique it is observed that, with increase in temperature the bond between the fibres and the matrix is consequently affected.

Muhammad Masood Rafi and Ali Nadjai^[7] studied the behaviour of CFRP and hybrid (CFRP- steel) bar RC under elevated temperature. A numerical modelling is done by using finite element modelling and compared with the fire test done on University of Ulster. It is concluded that the brittle behaviour can be improved by combining steel and FRP bars. As well as the fire resistance is depend on the concrete cover provided and a highly nonlinear rebar stress evolution with time was found for both the steel and the CFRP bars is observed.

V. K. R. Kodur, and L. A. Bisby^[8] done parametric studies to investigate the effect of a range of parameters on the fire performance of FRP-reinforced concrete slabs. The concrete cover thickness, type of reinforcement, and the type of aggregate in the concrete are the main factors used for analysis. The concrete cover provided will influence the fire resistance of FRP having higher resistance with larger cover and the thickness of slab does not influence the fire resistance. Aggregate type has a moderate influence on the fire resistance of FRP-RC slabs. Concrete slabs with carbonate aggregate display about 10% greater fire resistance as compared with siliceous aggregate concrete slabs.

III. METHODOLOGY

1. Modelling and analysis of experimental study done by Abbasi and Hogg in "Fire testing of concrete beams with fibre reinforced plastic rebar" using ANSYS Workbench.
2. For the area of steel reinforcement, designed as per IS 456-2000, area of FRP bar is calculated by equating with tensile strength.

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4. Analysis is done to obtain minimum cover required to resist fire up to 90minutes for beams reinforced with GFRP and CFRP reinforcing bars. The cover provided is 40mm, 50mm and 60mm. The temperature is applied as per ISO 834 fire curve.
5. From the obtained minimum cover for both GFRP and CFRP reinforcing bar, analysis is done with different diameter of bars. The effect of diameter of bars in failure temperature is studied.
6. For beams with minimum cover required, deflection check is done and compared with maximum permissible limit.
7. The one with lower deflection and fire resistance is taken.

IV. FAILURE CRITERIA

In a finite element model, the failure of the beam is obtained from the adopted failure criteria. From the failure criteria, the member which first fails either concrete or FRP rebar can be predicted.

Assumptions

1. Concrete fails when strain in compression side exceeds 0.003.
2. FRP fails when stress on rebar reaches a value of rupture stress as per ACI Committee report ^[11].
3. Steel ruptures, if the strain exceeds 0.05 or 5%.
4. Deflection of beam limited to $l/350 = 12.5\text{mm}$ as per IS 456-2000.

V. FINITE ELEMENT MODEL DEVELOPMENT

The dimensions of the numerical model is adopted from the beam of tested by Abbasi and Hogg [1]. The cross section of the beam is 4400mm x 400mm x 350mm. The study is done to obtain the minimum cover required by GFRP and CFRP reinforced concrete beam. Hence, initially the control beam is designed as per IS 456-2000 with this dimension with steel reinforcing bars. From the area of steel reinforcement obtained, equivalent area of FRP reinforcement is calculated. From the area of reinforcement number of bars for different cover is calculated. As per IS 456- 2000, the nominal cover provided to meet the 2hours of fire resistance for simply supported beam is obtained as 40mm, hence the minimum cover required is 40mm. Though FRP bars are less resistant to temperature, the cover adopted are 40mm, 50mm and 60mm. The data's used for design are,

Depth, $D = 400\text{mm}$

Breadth, $b = 350\text{mm}$

Cover = 40mm

Effective depth, $d = 400 - 40 - 10 - 12.5 = 337.5\text{mm}$

(25mm diameter main bars and 10mm diameter stirrups, 40mm cover)

$f_{ck} = 40\text{N/mm}^2$

$f_y = 415\text{N/mm}^2$

Due to the higher strength of FRP bars, M40 grade concrete is used. The tensile strength of FRP reinforcing bars are adopted from the manufacturer results.

From the results obtained the beams studying are tabulated below.

The first beam analysed is a control beam with nominal cover of 40mm. The beams are named, for e.g. B1G/Cb, in that B represents beam, number represents increase in cover, alphabets G and C represents the material used for reinforcement i.e., GFRP and CFRP respectively. The variation with diameter of bars are numbered with alphabets in small letters with increase in diameter of bars.

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Table 1: Calculated number of bars

Beam	Reinforcing bar	Cover (mm)	Diameter of bar (mm)	No. of bars
Control beam	Steel	40	25	5
B1Gb	GFRP	40	25	4
B2Gb	GFRP	50	25	4
B3Gb	GFRP	60	25	4
B3Ga	GFRP	60	16	7
B3Gb	GFRP	60	25	4
B3Gc	GFRP	60	32	3
B1Ca	CFRP	40	10	5
B1Cb	CFRP	40	13	3

The bars calculated is provided on the tension side, 10mm diameter FRP stirrups are provided at 200mm c/c spacing. To hold the stirrups 2#10mm diameter FRP bars are provided on the compression side.

VI. PROPERTIES OF BEAM

From the previous studies done in steel reinforced concrete structures it is evident that with increase in temperature the mechanical properties shows degradation. Hence for FE modelling it requires the temperature dependent mechanical and thermal mechanical properties as input. The temperature depended mechanical properties of only steel and concrete is known. But experimental thermal material properties of FRP reinforcing bars are not available. Hence material properties at room temperature taken for analysis.

The thermal material properties for density, specific heat and thermal conductivity of concrete as a function of temperature were taken from Euro code 2.

The coefficient of thermal expansion as a function of increasing temperature for concrete is,

$$\alpha_{c,T} = (0.008T_c + 6) \times 10^{-6} \quad (1)$$

Unlike steel reinforcing bars, FRP reinforcing bars will behave elastically till failure. Also, it should be noted that they are less resistant to temperature.

Table 2 shows the material properties of concrete and FRP bars at room temperature

Properties	Concrete	GFRP	CFRP
Young's modulus (GPa)	30.5	40.8	150
Poisson's ratio	0.2	0.28	0.3
Thermal conductivity (W/mm K)	2.7×10^{-3}	4.0×10^{-5}	4.0×10^{-8}
Specific heat (J/kg.K)	722.8	1310	1310
Thermal conductivity (longitudinal)	6.08×10^{-6}	6.58×10^{-6}	-0.9×10^{-6}
Thermal conductivity (transverse)	-	33.7×10^{-6}	4×10^{-8}
Density (kg/mm3)	2.32×10^{-6}	1.6×10^{-6}	1.4×10^{-6}

Fig. 1 shows the graphical representation of temperature dependent material property of concrete obtained from Euro code 2^[12].

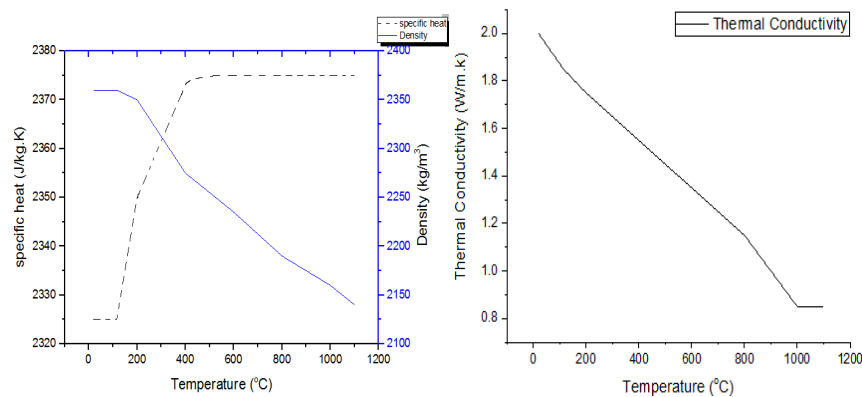


Fig. 1: Temperature Dependent Material Property of Concrete

VII. LOADING AND BOUNDARY CONDITIONS

- i. Loading of Static load of 40kN at 1m interval
- ii. Temperature as per ISO 834 fire curve.

The developed model undergone through two stages, transient thermal and static structural analysis. Four point loads of 40kN is applied at 1m interval, and the temperature is applied on the soffit and side walls of beam. The beam was modelled as simply supported. For analysis fine meshing is done with 50mm mesh size. For this mesh sizing the convergence of the analysis can be obtained. For composite structures the nodes should be merged to avoid more than one node at a point. The tolerance value provided for node merge group is 10mm. It is assumed that, the failure of beam will be considered either concrete failure due to larger cracks observed on the concrete surface or else due to the failure of FRP bars due to temperature. The temperature is applied as per ISO 834 fire curve. The static load applied on the beam is shown in fig. 2.

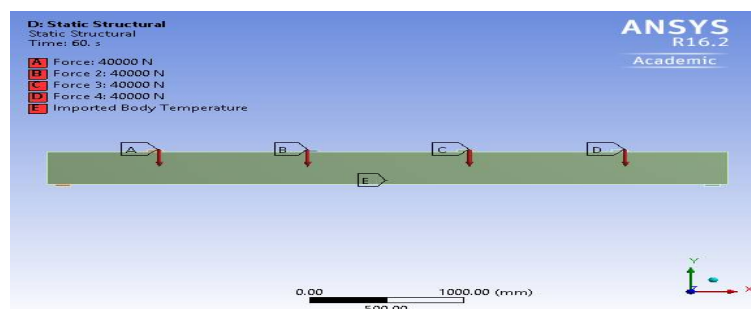


Fig. 2: Static Load applied on Beam

VIII. RESULTS AND DISCUSSIONS

The study was carried out to investigate the influence of cover and diameter of bar for CFRP and GFRP reinforcing bars. The obtained results are compared with control beam reinforced with steel reinforcing bars.

(a) Minimum concrete cover required

The minimum cover required to pass the fire endurance limit of 90 minutes as per BS 476: part 20 is taken as the limiting criteria. The analysis is done initially with control beam having 25mm diameter steel reinforcing bars. The cover provided is 40mm as per IS 456-2000 for a fire endurance of 2hours. Then the analysis is continued for GFRP reinforced concrete beam for 40mm, 50mm and 60mm cover for 25mm diameter GFRP reinforcing bars. For 60mm

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cover pass the minimum fire endurance limit of 90minutes. And for CFRP reinforcing bars the minimum cover of 40mm is required to pass the fire endurance limit. The results obtained are tabulated in table 3.

Table 3: Minimum cover required

Beam	Reinforcement material	Cover	Dia. of bar	Temperature of Rebar at the time of Failure	Failure Time	Deflection observed at the time of failure	Reason to fail (limit reaches)
		mm	mm	°C	min.	mm	
C B*	Steel	40	25	526.24	126	8.6989	Stress in Concrete
B1Gb	GFRP	40	25	335.21	63	52.992	Strain in Rebar
B2Gb	GFRP	50	25	344.54	74	41.232	Strain in Rebar
B3Gb	GFRP	60	25	346.83	90	28.946	Stress in Concrete
B1Ca	CFRP	40	10	650.83	91	26.166	Strain in Rebar

*C - Control Beam

It can be conclude that the minimum cover required by GFRP reinforcing bars to provide a fire endurance limit of 90minutes is 60mm and for CFRP reinforcing bars 40mm cover is required. The deflection observed is more than the permissible value as per IS 456-2000. Also noted that, with increase in cover the deflection decreases. The time dependent temperature variation of GFRP rebar for varying cover is shown in fig. 3.

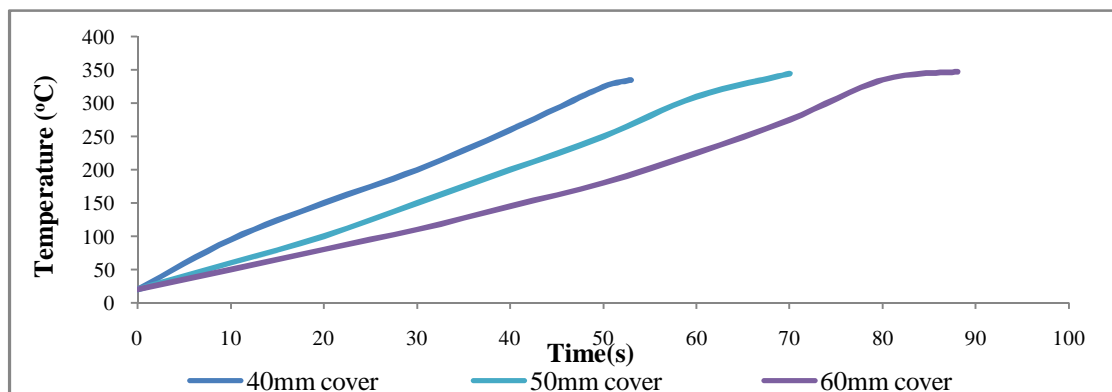


Fig. 3: Time dependent temperature variation of GFRP rebar for varying cover

(b) Effect of Diameter of bar

The study is conducted to understand the effect of diameter variation in temperature resistance and deflection of beam. For analysis, the commercially available FRP are used. i.e., for GFRP reinforcing bars, 16mm, 25mm and 32mm diameter bars are taken for study and CFRP reinforcing bars, 10mm and 13mm diameter bars are considered. The analysis is conducted for 60mm cover and 40mm cover for GFRP and CFRP reinforcing bars respectively. The results obtained are tabulated in Table 4.

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Table 4: Comparison of beams reinforced with GFRP reinforcing bars

Beam	Reinforcement material	Cover	Dia. of bar	Temperature of Rebar at the time of Failure	Failure Time	Deflection observed at the time of failure	Reason to fail (limit reaches)
		mm	mm	°C	min.	mm	
B3Ga	GFRP	60	16	348.02	92	25.057	Stress in Concrete
B3Gb	GFRP	60	25	346.83	90	28.946	Stress in Concrete
B3Gc	GFRP	60	32	343.15	87	32.848	Stress in Concrete
B1Ca	CFRP	40	10	650.83	91	26.166	Stress in Rebar
B1Cb	CFRP	40	13	625.76	89	28.39	Stress in Rebar

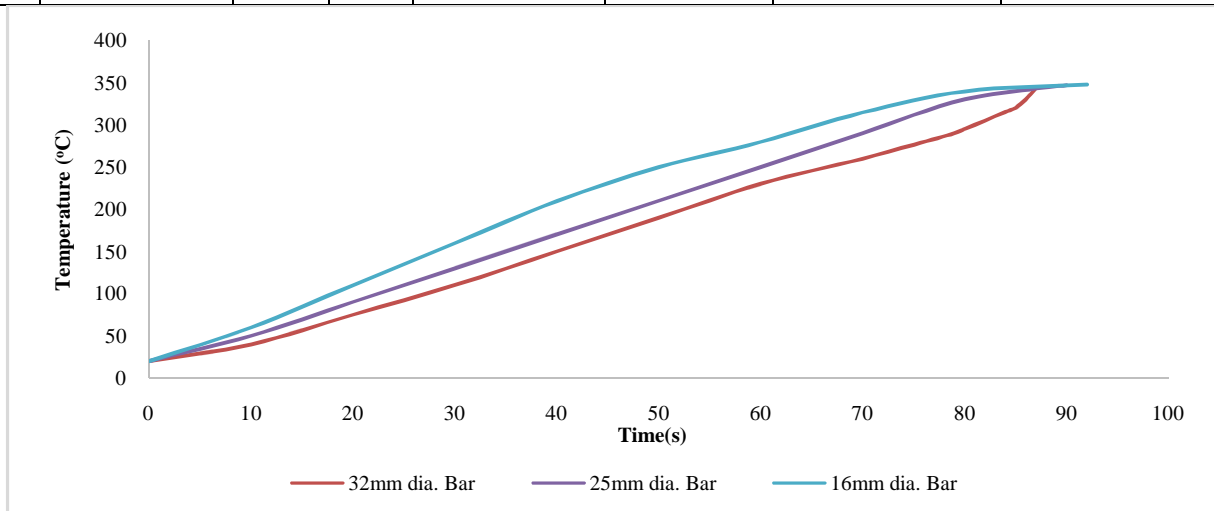


Fig. 4: Time dependent temperature variation of GFRP rebar (60mm cover)

From the obtained results it can be conclude that, with increase in diameter of bar, the strength to resist temperature decreases. It may be due to the increase in the resin content with increase in diameter of FRP reinforcing bars. The resin content in the FRP rebar control the fire resistance. Therefore, beam reinforced with GFRP reinforcing bars need a minimum cover of 60mm and for CFRP reinforcing bars with 40mm cover and smaller diameter bars will provide good results during fire. Fig. 4 and 5 shows the graphical representation of results obtained for GFRP and CFRP reinforcing bars under varying diameter.

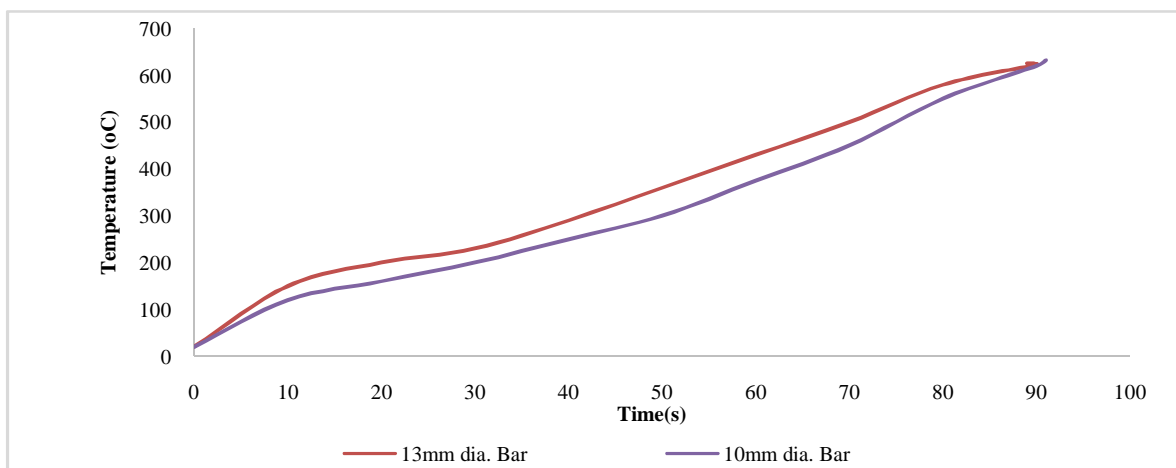


Fig. 5: Time dependent temperature variation of CFRP rebar (40mm cover)

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(c) Check for Deflection

From Table 3 and 4, it can be inference that, deflection of beam is more than the limit. Hence, to satisfy the deflection check, the cover should be increased. The maximum value of deflection is limited to 12.5mm as per IS 456-2000.

(i) GFRP reinforcing bars

The cover is increased to 80mm to check the deflection requirement. From the study with varying diameter of bar, it was observed that lower the diameter of bar, better fire performance. Hence the analysis is done with 5#16mm diameter bar. The cross section of the beam is kept constant as that of control beam. The beam is failed due to the failure of concrete. The cover provided is more than the cover required to resist temperature. Fig. 6 shows the deflection diagram of the beam at the time of failure. The deflection of beam reinforced with GFRP reinforcing bars with 80mm cover is obtained as 10.193mm, which is within the permissible limit.

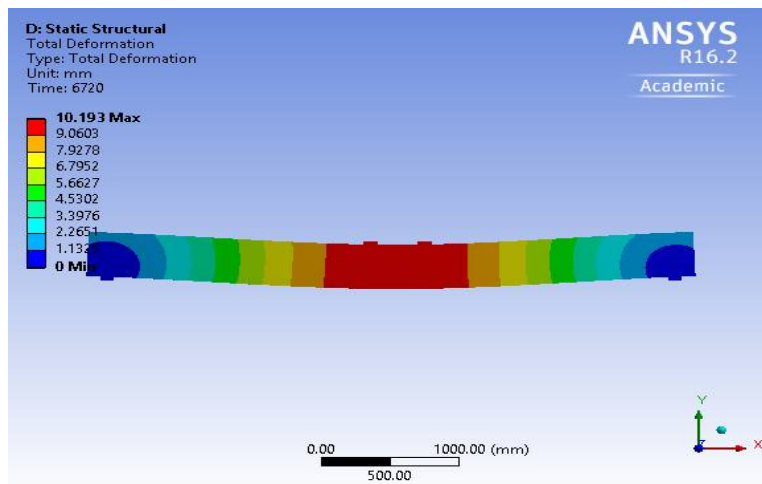


Fig. 6: Deflection Diagram of GFRP reinforced beam (80mm cover)

(ii) CFRP reinforcing bars

5# of 10mm diameter CFRP reinforcing bars are provided, the dimensions of the beam is kept same as control beam. A cover of 60mm is provided to understand deflection. The failure of beam is observed due to the failure of concrete. The deflection at failure time is shown in fig. 7.

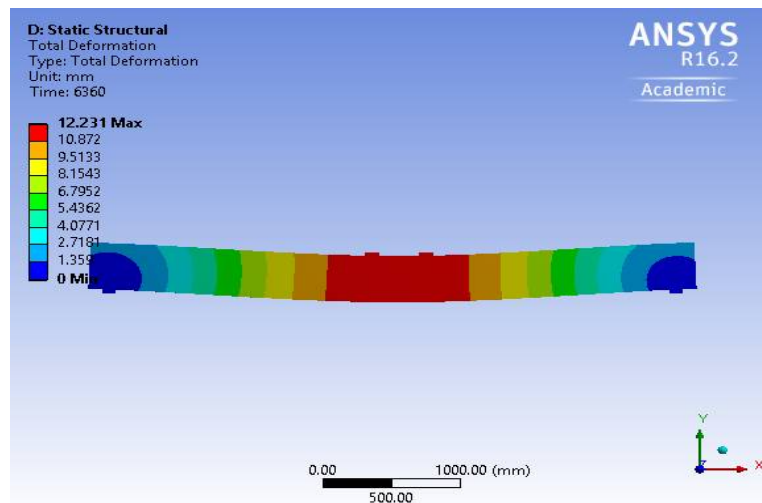


Fig. 7: Deflection Diagram of CFRP reinforced beam (60mm cover)

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IX. CONCLUSION

The numerical study were conducted carefully and successfully to determine the concrete cover required to pass the minimum fire endurance value of 90 minutes and maximum deflection of 12.5mm as per BS 432: part 20 and IS 456-2000 respectively. The results obtained from analytical model is checked with experimental study done by Abbasi. A. & Hogg. P. J. The variation of experimental and analytical results is 6.95%.

The main conclusion is that with increase in cover the beam fails by the failure of concrete and with decrease in cover the failure of beam is noted due to failure of reinforcing bar. The temperature is applied as per ISO 834 fire curve and a static loading of 40kN is also applied. The critical temperature obtained for GFRP reinforcing bar is in between 330-350°C and for CFRP reinforcing bar the critical temperature is obtained in between 600-650°C. The results can be infer that,

1. For GFRP reinforcing bars minimum cover required to resist fire is 60mm, and for CFRP reinforcing bar minimum cover required is 40mm.
2. Lower diameter bars are showing higher strength than higher diameter bars. It may be due to higher resin content in higher diameter bars, at higher temperature resins get damaged first.
3. With increase in cover deflection of beam is decreasing.
4. To satisfy deflection check, minimum cover required by GFRP and CFRP reinforcing bars are obtained as 80mm and 60mm respectively.

The minimum cover required by the GFRP reinforcing bars to pass Fire endurance limit and deflection criteria is 80mm and for CFRP reinforcing bar the minimum cover of 60mm is required.

FUTURE SCOPE

1. Validating the numerical study with experimental study for using in practical purposes.
2. Analysis of FRP reinforced slabs, which are having practical applications in bridge decks, offshore structures etc.
3. Comparison of beams reinforced with hybrid FRP and steel reinforcing bars and beams reinforced with FRP reinforcing bars under elevated temperature using FE analysis.
4. Considering the effect of alignment of reinforcing bars under elevated temperature.

REFERENCES

- [1] Abbasi, A. & Hogg, PJ. "Fire testing of concrete beams with fibre reinforced plastic rebar." *ELSEVIER Composites: part A*, Vol.37, pp. 1142-1150, 2006.
- [2] Ali Nadjai, Didier Talamon, FarisAli, "Fire Performance of Concrete Beams Reinforced With FRP Bars", *Proceedings of the International Symposium on Bond Behaviour of FRP in Structures*, pp. 401-410,2005
- [3] Hawileh, R., Naser, M., "Thermal-stress analysis of RC beams reinforced with GFRP bars"*ELSEVIER Construction and Building Materials*, Vol. 43, pp. 2135-2145, July 2012.
- [4] Maher A. Adam, Mohamed Said, Ahmed A. Mahmoud, Ali S. Shanour, "Analytical and experimental flexural behavior of concrete beams reinforced with glass fiber reinforced polymers bars", *ELSEVIER Construction and Building Materials*, Vol. 84, pp. 354-366, March 2015
- [5] Mathieu Robert and BrahimBenmokrane, "Behaviour of GFRP Reinforcing Bars Subjected to Extreme Temperatures", *ASCE Journal of Composites for Construction*, pp. 353- 360, July/August 2010,
- [6] Saleh Alsayed, Yousef Al-salloum, Tarek Al-nusallam, Sherif EI Gamal, Mohamed Aqel, "Performace of glass fiber reinforced polymer bars under elevated temperature", *ELSEVIER Construction and Building Materials*, Vol. 43, pp.2265-2271, 2012.
- [7] Muhammad Masood Rafi and Ali Nadjai, "Numerical modelling of carbon fibre-reinforced polymer and hybrid reinforced concrete beams in fire," *Fire and Materials Wiley Online Library*, pp. 0-16, 2012
- [8] V. K. R. Kodur, and L. A. Bisby, "Evaluation of Fire Endurance of Concrete Slabs Reinforced with Fibre-Reinforced Polymer Bars," *ASCE Journal of Structural Engineering*, pp. 34- 43, January 2005.
- [9] IS. 456: 2000, *Indian Standard Plain and Reinforced Concrete - Code of Practice*, Bureau of Indian Standards, New Delhi.
- [10] SP 16 (1980): *Design Aids for Reinforced Concrete to IS: 456-1978*, Bureau of Indian Standards, New Delhi.
- [11] ACI Committee, "Guide for the Design and Construction of Concrete Reinforced with FRP Bars" Reported by ACI Committee 440, January 5, 2001.
- [12] CEN, Eurocode 2: *Design of concrete structures, part 1-2: general rules structural fire design, ENV 1992-1-2*, European Committee of standardization, Brussels
- [13] ISO 834, *Fire Resistance Tests, Elements of building construction*, International Standard Organization, Geneva,1970.
- [14] *Glass Fiber Reinforced Polymer (GFRP) Rebar - Aslan™ 100 series*, Hughes Brothers, 2011.
- [15] *Carbon Fiber Reinforced Polymer (CFRP) Bar - Aslan™ 200 series*, Hughes Brothers, 2011.