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Analytical Investigations on Flexural Behavior of FRP Reinforced Beams under Elevated Temperatures

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Abstract—*Concrete structures when exposed to elevated temperatures undergo changes that can lead to damage of structures by reduction in strength and spalling. In this research, an attempt has been made to determine the performance of concrete members reinforced with Fiber Reinforced Polymer (FRP) bars, subjected to elevated temperatures. The analytical investigations have been carried out to study the flexural behavior of concrete beams reinforced with FRP bars, using the finite element package ANSYS 11. The beam specimen were modeled using different FRP bars such as Carbon (CFRP), Basalt (BFRP), Aramid (AFRP) and Glass (GFRP), with concrete of M20 grade. The RCC beams were heated from 27^{0}C to 1029^{0}C as per rate of heating given in IS 3809:1979.The specimens were cooled by air or water using coupled thermal analysis. The load deflection behavior of reference and heated beams were compared. A reduction in ultimate load and an increase in deflection were found for the heated beams with that of reference beams. The ultimate load was found to be more for the beams reinforced with CFRP followed by AFRP, BFRP and GFRP. The deflection was found to be more for the beams reinforced with GFRP followed by BFRP, AFRP, and CFRP.*

Keywords*: Elevated temperature, FRP reinforced beam, CFRP, AFRP, BFRP, GFRP, ANSYS*

1. INTRODUCTION

FRP's used to reinforce and strengthen structures, has the following advantages such as high strength and lightweight, corrosion resistance, low thermal conductivity, impact resistance, non-conductivity, electromagnetically transparency, and low lifecycle costs than typical reinforcing steel. Glass fiber, carbon fiber, basalt fiber and aramid fiber are used as predominant FRP reinforcements. Although it was found that the behavior of FRP reinforced concrete structures at ambient temperatures is satisfactory, information regarding the behavior of FRP reinforced concrete members at high temperatures is still lacking. The behavior of FRP reinforced concrete under fire exposure is quite different from conventional steel reinforced concrete. When FRP bars embedded in concrete, the lack of oxygen will inhibit the burning of FRP reinforcement, but the resin will soften. The critical time will occur when the resin on the surface of the FRP bar reaches its glass transition temperature leading to bond failure and hence increased crack width and deflections. The fire resistance of concrete reinforced with FRP rebar depends on the change in mechanical properties of FRP and concrete due to fire exposure. Therefore it is necessary to carry out extensive research, so that fire resistance performance of FRP reinforced members can be better understood and FRP materials can be used in civil engineering applications more efficiently and more effectively.

2. REVIEW OF LITERATURES

Mohamed Saafi (2002) conducted studies on the performance of FRP reinforced concrete beams subjected to high temperatures and examined the effect of fire on the flexural and shear capacities of concrete beam reinforced with one layer of GFRP, AFRP, CFRP and steel rebar's. Due to rapid deterioration of FRP reinforcement, these concrete beams exhibited significant degradation in shear and flexural resistance than steel reinforced concrete. **Amnon Katz et al (2000)** studied the effect of high temperature on the bond between FRP rebar's and concrete. Pullout tests of glass fiber reinforced polymers (GFRP) at high temperature were conducted. The bond strength exhibited a severe reduction of 80-90% at relatively low temperature (up to 200°C). **Abdolkarim Abbasi et al (2005)** considered the effects of water and alkaline environments on the bond strength between the concrete and rebar, also the strength and stiffness of the GFRP rebar's at a range of different temperatures (20–120 ^{0}C). The glass fiber strength and modulus is reduced by exposure to alkali and by testing at elevated temperatures. **Saleh Alsayed et al (2012)** investigated the residual tensile properties of glass fiber reinforced polymer (GFRP) bars subjected to elevated temperatures for different periods. The results showed that increasing the temperature level affected the resin matrix surrounding the glass fibers and consequently affected the bond between the fibers and the matrix. **Valter Carvelli et al (2013)** carried out an experimental investigation on the behavior of concrete beams reinforced with GFRP rebar's exposed to elevated temperatures. The heating temperature generated damage in concrete and partial evaporation of the matrix in the GFRP rebar's without causing the collapse of the element.

In this research, an attempt has been made to carry out an analytical investigation with the objective to study the load deflection behavior of FRP reinforced beams, at elevated temperatures.

3. ANALYTICAL INVESTIGATIONS

Finite element method (FEM) is a numerical technique for getting approximate solutions to boundary value problems. ANSYS is a popular finite element analysis package that can be used to simulate the response of a physical system subjected to structural and thermal loading. In case of analytical modeling, it is easy to vary the parameters such as grade of concrete, type of fiber, intensity of temperature, duration of heating and rate of cooling etc. Specimens for reference, air cooling and water cooling were created and analyzed using ANSYS to study the behavior of FRP reinforced beams under elevated temperatures for M20 grade of concrete. The material properties are to be given as input data to carry out analysis of beams using the ANSYS software, which are given in Table1.

Beams of dimension 4.5m*0.3m*0.3m, is heated according to IS: 3809:1975 Time Temperature Curve and cooled by both Air and Water cooling using ANSYS, by coupled thermal analysis. The cooled specimen were applied two point loading. The analysis steps involved like, first heating of the specimen to the required temperature, then cooling of the specimen by convection and then loading of the heated and cooled specimen.

The functions for heating should be created and saved for controlling the rate of heating. IS 3809:1979 standard specifies standard heating and pressure conditions. The temperature-rise shall be controlled so as to vary with time within the limits specified according to the following relationship as $T - T_o = 345 \log_{10} (8t + 1)$.For this research, heating of specimens carried out for a period of 120 minutes to attain 1029^0C.

4. ANALYSIS OF RESULTS

The load deflection curves are plotted, obtained after loading of modeled beams in ANSYS subjected to heating and cooling by air and water. The results are discussed. Fig. 1 shows the Load Deflection graph for reference beams reinforced with FRP bars.

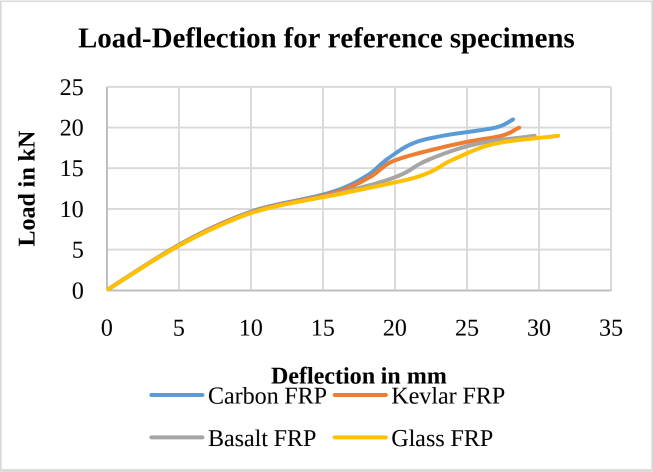

Fig. 1. Load Deflection graph for reference beams reinforced with FRP bars

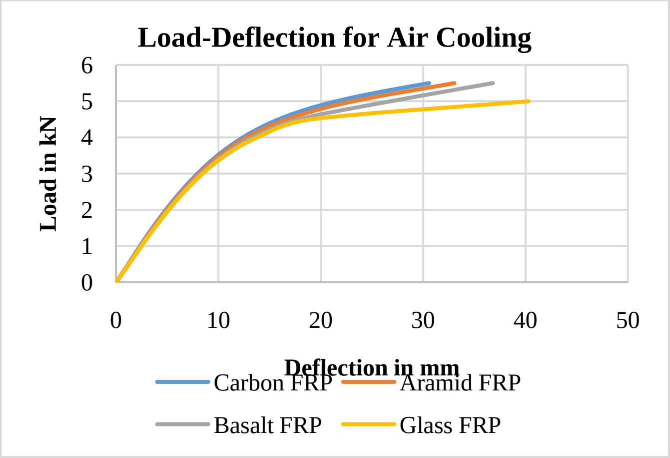

Fig. 2: Load Deflection graph for beams reinforced with FRP subjected to air cooling

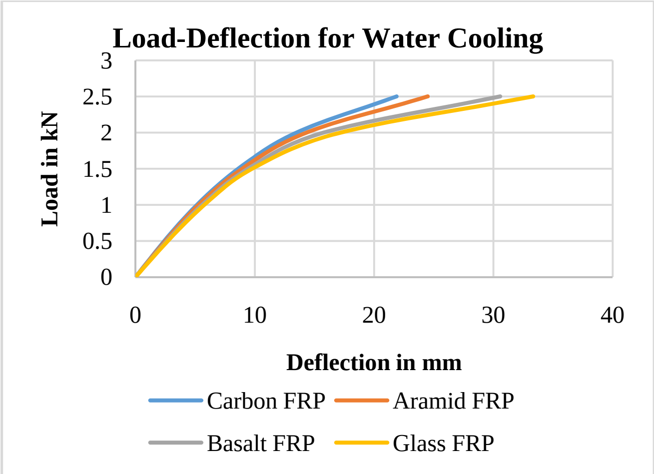

Fig. 3: Load Deflection graph for beams reinforced with FRP subjected to water cooling.

Fig. 2 shows the Load Deflection graph for air cooled beams reinforced with FRP bars.

Fig. 3 shows the Load Deflection graph for water cooled beams reinforced with FRP bars.

The values of the ultimate load of reference, air cooled and water cooled RCC beams reinforced with different FRP bars are shown in Table 2.

The values of the deflection corresponding to a load of 2.5kN for reference, air cooled and water cooled RCC beams reinforced with different FRP bars are shown in Table 3.

The values of the stiffness corresponding to a load of 2.5kN for reference, air cooled and water cooled RCC beams reinforced with different FRP bars are shown in Table 4.

5. DISCUSSION OF RESULTS.

Analytical investigations have been carried out to study the load deflection behavior of beams reinforced with FRP bars under elevated temperature. The beams were reinforced with CFRP, AFRP, BFRP & GFRP bars. Coupled thermal structural analysis is used to solve the problem by using FEM package ANSYS.

The ultimate load of beams reinforced with CFRP, AFRP, BFRP & GFRP are 21kN, 20kN, 19kN & 19kN respectively in the case of reference specimens. The ultimate load of beams reinforced with CFRP, AFRP, BFRP & GFRP are 5.5kN, 5.5kN, 5.5kN & 5kN respectively in the case of heated and air cooled specimens. The ultimate load of beams reinforced with CFRP, AFRP, BFRP & GFRP are 2.5kN, 2.5kN, 2.5kN & 2.5kN respectively in the case of heated and water cooled specimens. It was observed from the results that, the ultimate load of beams reinforced with CFRP, AFRP, BFRP & GFRP, were almost the same. The Young’s modulus and tensile strength of CFRP is higher, whereas the thermal conductivity is also high when compared to other FRP bars. But in the case of AFRP, BFRP & GFRP, the Young’s modulus and tensile strength is lower, whereas has low thermal conductivity compared to CFRP bars.

Table 1: Material Property of FRP bars.

Material	Young’s Modulus GPa	Poisson’s Ratio	Tensile strength MPa	Density g/cm3
CFRP	100	0.45	1750	1.65
BFRP	60	0.295	1700	2.70
AFRP	83	0.38	1450	1.44
GFRP	45	0.22	1240	2.60

Table 2: Ultimate load of RCC beams reinforced with different FRP bars.

Ultimate Load (kN)					
Type of FRP	Reference	Air cooled	Water cooled	% Decrease w.r.t Reference Beam	
				Air cooled	Water cooled
CFRP	21	5.5	2.5	73.80	88
AFRP	20	5.5	2.5	72.50	87.50
BFRP	19	5.5	2.5	71.05	86.84
GFRP	19	5.0	2.5	73.68	86.80

Table 3: Deflection at load of 2.5kN for RCC beams reinforced with different FRP bars.

Deflection at 2.5kN (mm)					
Type of FRP	Reference	Air cooled	Water cooled	% increase w.r.t Reference Beam	
				Air cooled	Water cooled
CFRP	2.18	6.13	21.89	181.2	904
AFRP	2.19	6.41	24.50	192.7	1018.7
BFRP	2.21	6.57	30.57	197.3	1283.2
GFRP	2.23	6.67	33.33	199	1394.6

Table 4: Stiffness at load of 2.5kN for RCC beams reinforced with different FRP bars.

Stiffness at 2.5kN (N/mm)					
Type of FRP	Reference	Air cooled	Water cooled	% Decrease w.r.t Reference Beam	
				Air cooled	Water cooled
CFRP	1.15x103	0.40 x103	0.11 x103	65.20	90.43
AFRP	1.14 x103	0.39 x103	0.10 x103	65.70	91.22
BFRP	1.13 x103	0.38 x103	0.08 x103	66.37	92.90
GFRP	1.12 x103	0.37 x103	0.07 x103	66.96	93.75

The deflection corresponding to a load of 2.5kN for beams reinforced with CFRP, AFRP, BFRP & GFRP are 2.18mm, 2.19mm, 2.21mm & 2.23mm respectively in the case of reference specimens. The deflection corresponding to a load of 2.5kN for beams reinforced with CFRP, AFRP, BFRP & GFRP are 6.13mm, 6.41mm, 6.57mm & 6.67mm respectively in the case of heated and air cooled specimens. The deflection corresponding to a load of 2.5kN for beams reinforced with CFRP, AFRP, BFRP & GFRP are 21.89mm, 24.5mm, 30.57mm & 33.33mm respectively in the case of heated and water cooled specimens. It may be due to that the Young’s modulus and tensile strength of CFRP being the highest, whereas GFRP has the lowest.

The ultimate load of beams reinforced with CFRP, AFRP, BFRP & GFRP decreased by 73.8%, 72.5%, 71.05% & 73.68% respectively for heated and air cooled beams when compared to reference specimen. The ultimate load of beams reinforced with CFRP, AFRP, BFRP & GFRP decreased by 88%, 87.50%, 86.84% & 86.8% respectively for heated and water cooled beams when compared to reference specimen.

The deflection corresponding to a load of 2.5kN for beams reinforced with CFRP, AFRP, BFRP & GFRP increased by 181%, 192.7%, 197.3% & 199% respectively for heated and air cooled beams when compared to reference specimen. The deflection corresponding to a load of 2.5kN for beams reinforced with CFRP, AFRP, BFRP & GFRP increased by 904%, 1018.7%, 1283.2%, 1394.6% respectively for heated and water cooled beams when compared to reference specimen.

The stiffness corresponding to a load of 2.5kN for beams reinforced with CFRP, AFRP, BFRP & GFRP decreased by 65.20%, 65.7%, 63.37% & 66.96% respectively for heated and air cooled beams when compared to reference specimen. The stiffness corresponding to a load of 2.5kN for beams reinforced with CFRP, AFRP, BFRP & GFRP decreased by 90.43%, 91.22%, 92.9%, 93.75% respectively for heated and water cooled beams when compared to reference specimen.

6. CONCLUSIONS

1. The analytical study reported in this research has shown that the fire exposure has a significant effect on the behavior of FRP reinforced concrete beams.
2. Due to rapid heating and cooling of FRP reinforced concrete beams, a significant degradation in flexural strength is observed.
3. It was observed from the results that, the ultimate load of the beams heated and cooled by air or water, is less than that of the reference specimens.
4. The deflection of the beams heated and cooled by air or water, is more than that of the reference specimens.
5. The beams reinforced with CFRP bars shows better performance than AFRP, BFRP, & GFRP in terms of load carrying capacity and deflections measured, while beams reinforced with GFRP bars showed the poor performance in case of reference and heated specimens.

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