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Analytical Study on Thermal Behaviour of RC Beam Retrofitted with Rubberised Concrete and GFRP using Ansys Workbench

Manju P[1], Saritha Sasindran[2]
[1]PG Student, Department of Civil Engineering, Sree Narayana Guru College of Engineering & Technology, Payyanur, Kerala, India-670307
[2]Assistant Professor, Department of Civil Engineering, Sree Narayana Guru College of Engineering & Technology, Payyanur, Kerala, India-670307
Email address: [1]manjup778@gmail.com, [2]sasindransaritha@gmail.com

Abstract— *Strengthening of existing damaged structures is one of the ongoing studies in civil engineering. The purpose of retrofitting is to structurally study the member with an aim to restore the structure to its original strength. The focus of this study is the retrofitting of a partially damaged RC beam. The damage may be due to physical damage, chemical attack, structural movement and material degradation on exposure to severe environment conditions. In this study RC beam of M25 grade concrete and Fe 415 grade steel is retrofitted with rubberized concrete and GFRP (Glass Fiber Reinforced Polymer) sheet. ANSYS Workbench software is used for this study. A fire damaged reinforced concrete beam will lose its strength and may not satisfy the load bearing capacity and serviceability conditions. Also it is necessary to study the effect of high temperature on concrete structure to understand its behaviour and reduce the losses due to fire hazards. In this study, structural and thermal analysis is conducted for the retrofitted beam. The retrofitting materials selected for the study are rubberized concrete and the GFRP. These materials have good strength and thermal resistance. The analysis is carried out in ANSYS Workbench software.*

Keywords— *Retrofitting, Rubberised concrete, GFRP, ANSYS Workbench.*

I. INTRODUCTION

Failure of a civil structure refers to the loss of structural integrity due to loss of the load-carrying capacity. In a well-designed system, a localized failure should not cause immediate or even progressive collapse of the entire structure for any kind of loading. Various factors affect the deterioration of a structural member. Apart from structural deterioration due to ageing, errors made during design, construction phase and increased load, all contribute to the deficient behavior of structures. In recent years, lot of research was focused on strengthening of under-designed and deficient RC structures. The useful application of waste materials such as scrap tires within the construction industry allow for their use as a resource material thus solving disposal problems. Many studies have been conducted on rubberised concrete containing crumb rubber as a replacement of fine aggregate at different percentages. The findings of these studies indicated that although the compressive and flexural strength of the rubberized concrete decreased as the percentage of fine aggregate replacement increased.

Conventional materials for strengthening include Fiber Reinforced Polymer, Ferrocement, High Strength Fiber Reinforced Concrete, Steel plate bonding etc. Apart from low maintenance cost and improvement in the service life of buildings, Fibre Reinforced polymer (FRP) wrapping has several benefits like high strength, light weight, resistance to corrosion, low cost, and versatility. Also the interaction between concrete and fiber will increase the concrete strength and ultimate strain. FRP are composite materials made up of fibers and polymer matrix. FRP are of different types such as GFRP, CFRP, and AFRP. FRP materials are widely used in construction of bridges and aerospace industries.

Although reinforced concrete structures are extensively used due to their thermal resistance, deterioration after exposure to fire include a loss in strength and elastic modulus, cracking, and spalling of the concrete. The performance of structures during a fire has been studied by researchers using material experiments, structural tests and finite element (FE) analyses. The material properties, such as specific heat, conductivity, density and thermal expansion of concrete have been studied under high temperatures. The rubberised concrete and the GFRP have the thermal insulating property.

Rubberisd concrete is a type of concrete in which fine aggregate or coarse aggregate is replaced with tyre rubber particles. Chipped rubber is used for replacing coarse aggregate and crumb rubber is used for fine aggregate. In this study, the rubberised concrete with 10% of crumb rubber is used for the retrofitting of the beam.

Fiber Reinforced Polymer is a composite material made up of a polymer matrix reinforced with fibers. The usually used fibers are glass, carbon, aramid, or basalt. Rarely, other fibers like paper, wood, or asbestos have been used. The polymers usually used are epoxy, vinylester or polyester thermosetting plastic, though phenol formaldehyde resins are still in use. In this study glass fiber reinforced polymer is used for the retrofitting of beam.

II. SCOPE AND OBJECTIVES OF THE STUDY

The rubberised concrete and the GFRP have the thermal insulating property. Retrofitting of RC beam using rubberised concrete and GFRP sheets. Strengthening and fire resistance

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of the damaged beam retrofitted with rubberised concrete and GFRP sheet. The rubberised concrete with 10% of crumb rubber by replacing fine aggregate is used for the retrofitting of the beam. M25 grade of concrete and Fe 415 grade steel is used. The size of beam is 150 x 200 x 1800 mm. ANSYS Workbench software is used for the modeling and analysis. The main objectives of this study are follows.

- Retrofitting of RC beam by using rubberised concrete and GFRP sheet.
- Study of Finite element (FE) models of retrofitted RC beams.
- Analysis of thermal resistance and structural performance of conventional concrete beam and retrofitted RC beams.

III. Finite Element Modelling

A. Geometry

Three-dimensional models were developed in ANSYS Workbench to demonstrate the behaviour properly. The dimensions and material properties considered in this thesis are fixed with reference to Indian Standards. First RC beam model is a conventional beam, next four models included rubberised concrete and last five RC models included rubberised concrete and GFRP sheet. The size of beam is 150 x 200 x 1800 mm. In this study, 25mm, 50mm, 75mm and 100mm thick rubberised concrete were provided at the bottom of the beam. Thickness of GFRP sheet provided is 1.17mm (1mm epoxy and 0.17mm GFRP laminate).

B. Material Properties

In this study, M25 grade of concrete and Fe 415 grade steel is used. Compressive strength, thermal conductivity and specific heat of concrete provided are 25MPa, 1.25W/mK and 970J/kgK respectively. Yield strength of reinforcing steel provided is 415MPa. Poisson's ratio of steel is 0.3 and Poisson's ratio of concrete is 0.15. Compressive strength, thermal conductivity and specific heat of the rubberised concrete provided are 25MPa, 0.7W/mK and 1380J/kgK respectively.

C. Modelling and Analysis

The RC beams are modelled using ANSYS Workbench. The material properties were assigned, support (simply supported) and loading conditions were provided. There are two analysis in this study. They are thermal analysis and structural analysis. First five models are analysed thermally and structurally. Last five models are analysed structurally only. The beams are thermally analysed by exposing two sides and bottom to the standard temperature curve specified in ISO 834 standard fire. Based on ISO 834 standard fire curve, 1100°C temperature is applied on the beam with time. There are ten models in this study. They are as shown in table I.

The models that analysed in this study are shown in fig.1. Every model was meshed using a 20 noded Hexahedron element [Solid 188] to achieve better accuracy in nonlinear analysis as shown in fig.2. In GFRP diagonal wrapping, the width of GFRP strip is 50mm, the distance between two strips is 50mm and the angle of inclination of diagonal wrap is 45°.

TABLE I. RC beam models

Model 1	RUB 0	Conventional concrete beam –M25
Model 2	RUB 25	25mm thick rubberised concrete is provided at the bottom of the beam
Model 3	RUB 50	50mm thick rubberised concrete is provided at the bottom of the beam
Model 4	RUB 75	75mm thick rubberised concrete is provided at the bottom of the beam
Model 5	RUB 100	100mm thick rubberised concrete is provided at the bottom of the beam
Model 6	RUB 100 + Gb	RUB 100 model provided with 1.17mm thick GFRP sheet at Bottom side of the beam
Model 7	RUB 100 + GU50	RUB 100 model provided with 1.17mm thick GFRP sheet U wrap at 50mm depth from the bottom of the beam
Model 8	RUB 100 + GU100	RUB 100 model provided with 1.17mm thick GFRP sheet U wrap at 100mm depth from the bottom of the beam
Model 9	RUB 100 + GU200	RUB 100 model provided with 1.17mm thick GFRP sheet U wrap at 200mm depth of the beam
Model 10	RUB 100 + GD200	RUB 100 model provided with 1.17mm thick GFRP sheet Diagonal wrap at 200mm depth of the beam

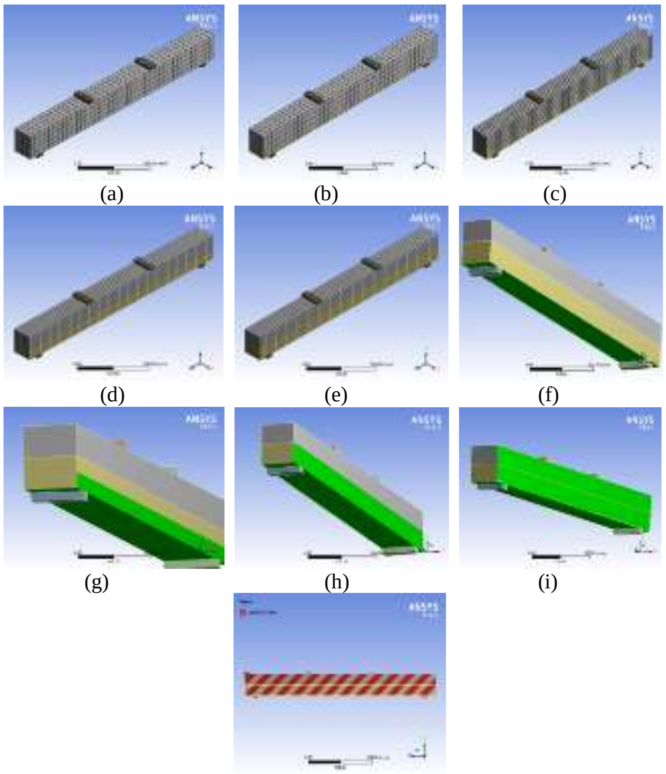

Fig. 1. Model figure of RC beam RUB 0(a), RUB 25(b), RUB50(c), RUB 75(d), RUB 100(e), RUB 100 + Gb(f), RUB100 + GU50(g), RUB 100+ GU100(h), RUB 100 + GU200(i), RUB 100 + GD200(j)

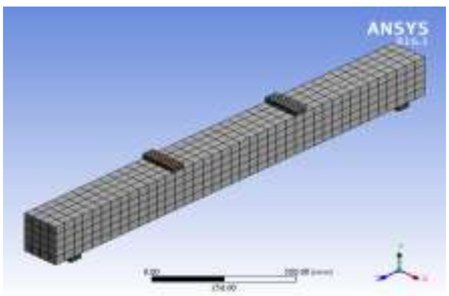

Fig. 2. Mesh of RC beam model

D. Results and Discussions

In thermal analysis the first five models are analysed. The models that are analysed are RUB 0, RUB 25, RUB 50, RUB 75 and RUB 100. The temperature of the beam at 0.5hr, 1hr and 1.5 hr are shown in table II and the combined time-temperature graph of these models are shown in figure 4.

- The maximum temperature in conventional reinforced concrete beam (RUB0) at 0.5hr, 1hr and 1.5hr are 150.2°C, 302.91°C and 460°C respectively.
- After that maximum temperature on beams RUB 25, RUB 50, RUB75 and RUB 100 are gradually decreasing. So, the maximum temperature on beam RUB 100 at 0.5hr, 1hr and 1.5hr are 50.68°C, 119.98°C and 206.06°C.
- When comparing the maximum temperature of beam RUB 0 (conventional RC beam) at 1.5hr to the maximum temperature of beam RUB 100 in 1.5hr, the percentage increase in thermal resistance of beam RUB 100 is 55% as shown in table III.
- From this, we can say that the beams with rubberised concrete have low thermal conductivity (ie, higher thermal resistance).

The load carrying capacity of the conventional reinforced concrete beam (RUB 0) is 78.989KN. The load carrying capacities of the retrofitted beams RUB 25, RUB 50, RUB 75, and RUB 100 are decreasing. Finally the load carrying capacity of beam RUB 100 is 63.004 KN. The retrofitted beams using rubberised concrete have less load carrying capacity than conventional beam. So, to improve the load carrying capacity of the retrofitted beam RUB100, GFRP sheet is provided. RUB 100+Gb, RUB 100+GU50, RUB 100+GU100, RUB 100+GU200 and RUB 100+GD200 are the beams that are with GFRP sheet.

- The beam with GFRP U-wrap at 200mm depth (RUB 100+GU200) and the beam with GFRP diagonal wrap at 200mm depth (RUB 100+GD200) have more load carrying capacities than other beams as shown in table IV.
- Also, the beam with GFRP diagonal wrapping (RUB 100+GD200) have better load carrying capacity than the beam with GFRP U-wrap (RUB 100+GU200) as shown in figure 5.

Deflections of all the beam models are shown in table V. Deflection of conventional beam (RUB0) is 18.236mm. When beam is retrofitted with both rubberised concrete and GFRP sheet, the deflection increased, as shown in table 5.4. Deflections of all models are calculated as shown in fig. 3. Comparison of the deflections of the beam is shown in figure 6.

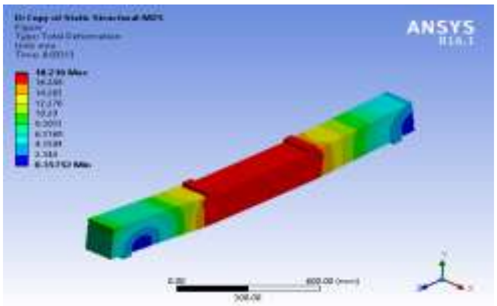

Fig. 3. Total deformation.

- The beam with GFRP U-wrap (RUB 100+GU200) and beam with GFRP diagonal wrap (RUB 100+GD200) have deflections 45.455mm and 51.204mm respectively. So GFRP sheet increase the ductility of the beam.

TABLE II. Comparison of temperatures on beams

Model	Temperature at(°C)		
	1800 sec (0.5 hr)	3600 sec (1 hr)	5400 sec (1.5 hr)
RUB 0	150.2	302.91	460
RUB 25	64.572	143.35	233.45
RUB 50	61.511	135.46	220.69
RUB 75	57.151	127.96	212.58
RUB 100	50.68	119.98	206.06

TABLE III. Percentage increase of thermal resistance

Maximum temperature of beam RUB 0 in 1.5 hr	Maximum temperature of beam RUB 100 in 1.5 hr	Percentage increase of thermal resistance
460°C	206.06°C	55%

TABLE IV. Load carrying capacities of beams

MODEL	LOAD (KN)
RUB 0	78.989
RUB 25	70.762
RUB 50	64.835
RUB 75	63.607
RUB 100	63.004
RUB 100 + Gb	64.928
RUB 100 + GU50	66.159
RUB 100 + GU100	67.606
RUB 100 + GU200	105.34
RUB 100 + GD200	116.45

TABLE V. Deflection of beams

MODEL	DEFLECTION (mm)
RUB 0	18.236
RUB 25	17.845
RUB 50	10.118
RUB 75	12.511
RUB 100	12.58
RUB 100 + Gb	13.279
RUB 100 + GU50	11.177
RUB 100 + GU100	12.805
RUB 100 + GU200	45.455
RUB 100 + GD200	51.204

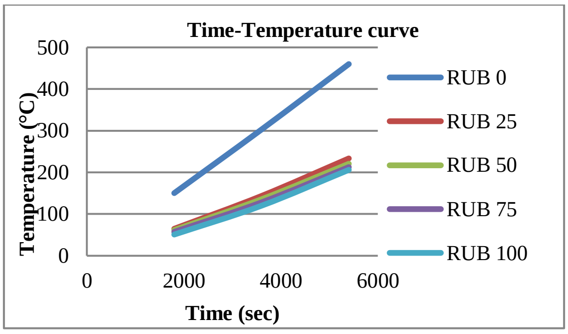

Fig. 4. Time-temperature curve of beams.

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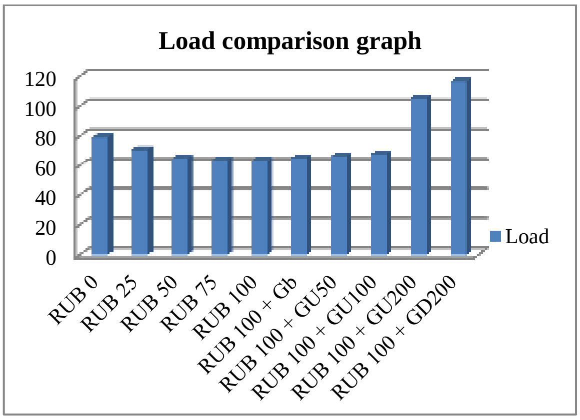

Fig. 5. Comparison of load carrying capacities of beams

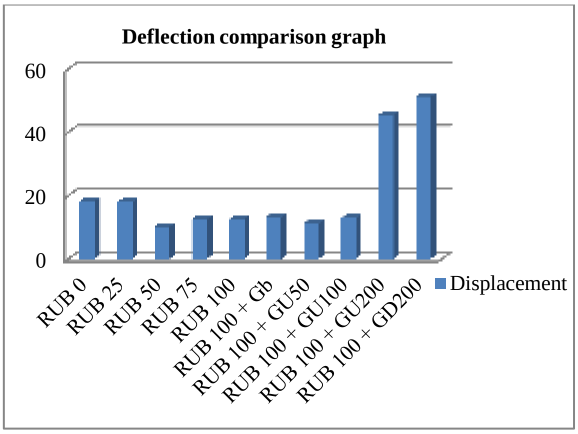

Fig. 6. Comparison of deflection of beams

IV. Conclusions

The following conclusions can be drawn from the present investigations on conventional RC beam and retrofitted RC beam using rubberised concrete and GFRP sheet.

- Rubberised concrete is a good thermal resistant material.
- When comparing the maximum temperature in beam RUB 0 (conventional RC beam) at 1.5hr with maximum temperature in beam RUB 100 at 1.5hr, the percentage increase in thermal resistance of beam RUB 100 is 55%.
- The RC beam retrofitted with rubberised concrete can improve the thermal resistance of the beam.
- But the load carrying capacity of the retrofitted beam with rubberised concrete is lower than the conventional beam.
- The load carrying capacity of the beam with GFRP U-wrap at 200mm depth (RUB 100+GU200) is 105.34KN which is 25% higher than the conventional beam.
- The load carrying capacity of the beam with GFRP diagonal wrap at 200mm depth (RUB 100+GD200) is 116.45KN which is 32.2% higher than the conventional beam.
- By providing the GFRP sheet (U wrap or diagonal wrap) to the retrofitted beam, one can increase the load carrying capacity of the beam.
- In this study, beam with GFRP diagonal wrapping have more load carrying capacity than beam with GFRP U-wrap.
- So, rubberised concrete and GFRP sheets can be used as retrofitting materials for the RC beams.

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