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To Evaluate the Finite Element Analysis of R Beams

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Abstract: *This project is intended to study the elastic properties of reinforced concrete beam using combination of GFRP (Glass Fibre Reinforced Polymer), CFRP (Carbon Fibre Reinforced Polymer) and MMC (Metal Matrix Composites). The composite beams consisted of U shape profile and L shape profile with longitudinal and mid-section encasing using GFRP/CFRP/MMC materials. Reference design will be taken as one ordinarily RC beam from base paper. The variables included: (1) different arrangements of GFRP/CFRP/MMC layer in a U and L shape FRP profile, (2) conventional steel rebar. Group 1 encompasses bottom configuration consisting of MMC, GFRP and CFRP respectively. Group 2 encompasses U shape hybrid profile consisting of combinations of MMC with GFRP, MMC with CFRP. Group 3 encompasses L shaped hybrid beam consisting of 1 bottom plate and side plate comprising of MMC with GFRP, MMC with CFRP. Load deflection responses will be studied along with energy absorption capacity. Non-linear Finite Element Method will be conducted for analysis and software used for analysis is ANSYS 18.1*

Keywords: GFRP (Glass Fibre Reinforced Polymer), CFRP (Carbon Fibre Reinforced Polymer) and MMC (Metal Matrix Composites).

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1. Introduction

This chapter gives introduction of composite materials and concept of reinforcement, application of reinforcement, polymer matrix composites, and glass fibre reinforced polymer GFRP, carbon fibre reinforced polymer CFRP. The usage of Finite Element Method as a tool to solve engineering problem is also discussed here which includes general steps carried out in FEA simulation using ANSYS software and types of analysis available.

1.1 Concept of Reinforcement

Due to excessive loading, construction errors and improper maintenance strengthening of concrete structures becomes imperative. This brings improvement in load bearing capacity, improved ductility and reduces damages due to deterioration. Conventional strengthening by the use of steel plate, concrete jacketing has proved to be viable to increase strength and ductility of structural elements. The researchers are seeking new and innovative ways of strengthening of slabs and beams as conventional methods of reinforcement encountered certain limitations which are required to overcome. The corrosion resistance of steel plates are low therefore demands coating, painting which increases maintenance costs. In addition, steel plates have a heavy weight by comparison, which increases the dead load of the strengthened or retrofitted structural element. Section enlargement or reinforced concrete jacketing, where additional concrete and reinforcing steel are placed on an existing structural member, is often un favorable because it reduces the headroom and therefore reduces the usable living area. Moreover, section enlargement is not the best possible strengthening solution in active environments, such as hospitals and schools, because the enlargement process requires site preparation (shuttering, formwork) and produces a lot of noise. Likewise, external post-tensioning is limited to sections with large depth and has a high cost associated with its installation process and tensioning devices.

1.2 Application of Composite Materials

Composite materials encompass more than two materials with resultant property better than constituent material properties. The constituent materials of composites retain its properties like chemical property, mechanical property and physical property. Composite materials offer advantages with respect to higher strength, stiffness with low density and thus increases weight reduction is possible. The fibres are continuous type and discontinuous type. The discontinuous fibres have short aspect ratios and random orientation while continuous fibres have preferred orientation. Continuous-fibre composites are often made into laminates by stacking single sheets of continuous fibres in different orientations to obtain the desired strength and stiffness properties with fibre volumes as high as 60% to 70%. Fibres which include glass, aramid and carbon contain fewer surface defects as compared to bulk.

1.3 Polymer-Matrix Composites (PMCs)

Fibres are used as reinforcement medium in polymer matrix composites. Resins are used in polymer matrix composites (PMC) which is stronger than conventional materials. FRP system consists of resins for bonding, applied coatings on concrete substrate to protect constituents. The acceptance of FRP sheets has increased manifold due to high strength/self-weight ratio, high corrosion resistance, resistance to ultra violet radiation and oxidation, durability, ease of installation, speed of construction and design flexibility. The thin profile of FRP sheets makes them desirable to improve aesthetics like shielding of pipe.

1.4 Glass Fibre-Reinforced Polymer (GFRP)

Fibre glass is simply a composite consisting of glass fibres, either continuous or discontinuous, contained within a polymer matrix; this type of composite is produced in the largest quantities. Fibre diameters normally range between 3 and 20 m. Glass is popular as a fibre reinforcement material for several reasons due to which it is easily drawn into high-strength fibre from the molten state. It is readily available and may be fabricated into a glass-reinforced plastic economically using a wide variety of composite-manufacturing techniques. As a fibre it is relatively strong, and when embedded in a plastic matrix, it produces a composite having a very high specific strength. When coupled with the various plastics, it possesses a chemical inertness that renders the composite useful in a variety of corrosive environments.

1.5 Carbon Fibre-Reinforced Polymer (CFRP) Composites

Carbon is a high-performance fibre material that is the most commonly used reinforcement in advanced (i.e., no fiberglass) polymer-matrix composites. Carbon fibres have the highest specific modulus and specific strength of all reinforcing fibre materials. They retain their high tensile modulus and high strength at elevated temperatures; high temperature oxidation, however, may be a problem. At room temperature, carbon fibres are not affected by moisture or a wide variety of solvents, acids, and bases. These fibres exhibit a diversity of physical and mechanical characteristics, allowing composites incorporating these fibres to have specific engineered properties. Fibre and composite manufacturing processes have been developed that are relatively inexpensive and cost effective.

1.6 Metal Matrix Composites (MMCs)

Metal matrix composites (MMCs) usually consist of a low-density metal, such as aluminium or magnesium, reinforced with particulate or fibres of a ceramic material, such as silicon carbide or graphite. Compared with unreinforced metals, MMCs offer higher specific strength and stiffness, higher operating temperature, and greater wear resistance, as well as the opportunity to tailor these properties for a particular application. MMCs also have some disadvantages compared with metals. Chief among these are the higher cost of fabrication for high-performance MMCs, and lower ductility and toughness. Presently, MMCs are of two extreme types. One consists of very high-performance composites reinforced with expensive continuous fibres and requiring expensive processing methods. The other consists of relatively low-cost and low-performance composites reinforced with relatively inexpensive particulate or fibres. Current markets for MMCs are primarily in military and aerospace applications. Experimental MMC components have been developed for use in aircraft, satellites, jet engines, missiles, and the National Aeronautics and Space Administration (NASA) space shuttle. The first production application of a particulate-reinforced MMC in the United States is a set of covers for a missile guidance system.

1.7 FEM and ANSYS

In 1943 by Mr R. Courant, this method (FEA) was first developed, he obtained approximate solutions of vibration systems with the help of minimization of variation calculus and Ritz method for numerical analysis. In finite element analysis, the design is discretize or subdivided into a series of elements that are connected by nodes. Material properties and element properties are specified to represent the physical properties of the model. Boundary conditions and applied loads are then defined to represent the operating environment for which the design is to be subjected and its simulation tool that enables engineers to simulate the behaviour of an entire structure.

1.8 General steps in finite element method and its interpretation

There are two general approaches associated with the finite element method. One approach is called as the force, or flexibility, method, uses internal force as the unknowns of the problem. To obtain the governing equations, first the equilibrium equations are used. Then necessary additional equations are found by introducing compatibility equations. The result is a set of algebraic equations for determining the redundant or unknown forces. The second approaches, called the displacement, or stiffness, method, assumes the displacement of the nodes as the unknowns of the problem. For instance, compatibility conditions requiring that elements connected at a common node, along a common edge, or on a common surface before loading remain connected at that node, edge or surface after deformation takes place are initially satisfied.

Step: 1 Discretize and select the element types.

Discretise is to divide the whole body/part into small finite elements and choosing the most appropriate element type to get the closer result as compared to the actual physical behaviour.

Step: 2 Select a displacement function.

It involves choosing a displacement function within each element. By using the nodal values of the element defined the function. Cubic polynomials linear and quadratic are frequently used functions because they are simpler to work with in finite element formulation. High level polynomial can also be used as per requirement.

Step: 3 Define the strain and stress relationship or displacement and strain relationship.

Strain/displacement and stress/strain Relationship are necessary for deriving the equation for each finite element. In case of one dimensional we have strain E_x in the x direction for small strain, also here material defined is assumed as elastic which follows hooks law.

$$\varepsilon_x = \frac{du}{dx}$$

Step: 4 Make the element stiffness matrix and Equations.

Step: 5 To obtain the global or total equations assemble the element equations and explain boundary conditions.

Step: 6 Solve for the unknown Degree of freedom

Step: 7 Solve for the Element strain and stresses

Step: 8 Interpret the results

1.9 Application of FE analysis

(A) Automotive application

In the automobiles the road loads are transferred to the vehicles and hence the stresses and strain in the body panel are of interest. Hence the FEA tool is used to perform modal analysis, static analysis, torsional analysis, and service load analysis. In addition to this crash analysis is emerging as an important tool in finite element analysis. At the same time FEA is used to determine the temperature distribution through the engine.

(B) Electrical and Electronics engineering applications

FEA can be used for reliability enhancement and optimization of insulation design in high voltage equipment by finding accurately the voltage stress and corresponding withstands. For complex configuration of electrodes and dielectric insulating materials, analytical formulation are inaccurate and extreme difficult, if not impossible. The FEA Can used in such cases. An analysis of eddy currents in structural conducting parts and minimization of stray losses in electrical machines is possible also Using FEM.

(C) Aerospace application

In typical aerospace application, finite element analysis is used for several purposes, viz. structural analysis for natural frequencies, mode shapes, response analysis, aero-servo elastic studies, and aerodynamics.

(D) Manufacturing process simulation

The FEA is used as emerging tool in the field of manufacturing simulation. The FEA analysis is used to study the solidification, thermal field and evolution of stress and factors causing failure. This information is further used to change the processing conditions so as to eliminate these high tensile stresses. As may be evident from the above examples of real life application of finite element analysis, present day engineering design based on CAE tools involves extensive use of finite elements in wide variety of fields. Hence the knowledge of finite element analysis is crucial in significant way to aid intelligent use of commercial software in solving day-to-day problems.

2. Literature Review

This paper gives a review of researches carried out in the previous 10 years by the researchers. This review comprises of literature on strengthened beams under two classes of composite materials ie Polymer Matrix composites and Metal Matrix Composites. This chapter is divided into two sections, first section is about Polymer Matrix composites and second section gives review of Metal Matrix Composites. The technique for strengthening of beam wrapped with the composite material have been demanding increasingly. Various previous researches were conducted by wrapping of beam with the polymers but related to Metal matrix composite is very rare case. This chapter shows a review of work in the field of composite materials.

N. Atari, (2011) studied the numerical behaviour of controlled RC beam strengthened with GFRP, CFRP and hybrid FRP sheets. One control beam and 6 RC strengthened beams were made and tested through four point bending. Different strengthening combinations were carried outby the use of single layer, double layer and triple layer of CFRP, GFRP and hybrid FRP sheets in U shape. Results for ductility factor, strength, stiffness and mode failure were discussed for every strengthening schemes. It was noted that single layered hybrid composite or glass fibre alone improves ductility as compared to other strengthening schemes.

Jiangfeng Dong, (2013) they presentedabout RC beams strengthened with FRP laminates to investigate the flexural and flexural-shear performance. The FRP laminates includes GFRP and CFRP in U shape and L shape arrangement strips applied to the sides and bottom of the RC beam. In case of flexural strengthening one reference beam and others 6 beams were casted with one and two layers of CFRP. In flexural-shear strengthening 2 beams were casted with one layer of GFRP sheet in U shape arrangement and the other 4 beams casted with two layers of CFRP sheet in L shape. Parameters measured were load deflection behaviour, failure modes and cracking behaviour. The experimental research output shows that flexural strengthening arrangement was less effective as compared to the flexural-shear strength.

K. Vijay, (2013) carried the comparison between experimental and analytical investigation on the behaviour of RC beams laminated with CFRP. The nonlinear analysis was carried in ANSYS software. The 4 beam specimens were prepared including two beams were control beam of different sizes and the other remaining two beams were strengthened with CFRP at bottom side of the beam or in U shape pattern. Examined parameters were load vs. deflection relationship and cracks. The load carrying capacity of the beam laminated with GFRP in U shape was found to be high as compared to beam laminated with GFRP only at zottom side.

Rami A. Hawileh, (2014) introduced to strengthened the RC beam with Hybrid FFP system. This paper deals with hybrid GFRP and CFRP sheets bonded externally to the RC beam specimen. The results were obtained through experimental and analytical investigations also comparison made between them. One ordinary reference RC beam and 4 RC beams using different arrangements of CFRP, GFRP and hybrid FRP sheets were made. The data such as load deflection curves, modes of failure, and load vs. strain relationship were examined. It was noted that beams laminated with single CFRP sheet have less ductility at failure loads as compared to the GFRP/Hybrid FRP sheet. The conclusion was made that for achieving the strength in structural element and to improved ductility choose the most favourable combination of hybrid sheets.

Shweta S. Shetty, (2015) had performed the analytical analysis on RC beam laminated with GFRP. 3D beam was modelled in ANSYS under two point loading. One reference beam and 3 RC beams with GFRP laminate were modelled and analysed by ANSYS software. The analysis based on varying parameters such as different thickness of the laminates and varying width of the beam. Stress intensity variation and load vs. deflection relationships were examined. It was concluded that with the increase in width of the beam, deflection of the beam was reduced also the RC beams laminated with GFRP improves load carrying capacity of the beam.

Yuvraj Singh, (2015) he carried out the numerical analysis on nonlinear behaviour of RC beams with externally bonded FRP laminates using ANSYS. Total of 9 beams were modelled out of which one is control beam, and other eight beams were laminated with GFRP and CFRP laminates. In the first stage of research, four beams were modelled with GFRP in varying configurations and compared with to that of the experimental work and results found to be satisfied. In next stage of research, rest of five beams were carried out of which three beams were modelled with CFRP and two were hybrid beams in U shape wrap, side and bottom wrap. Examined parameters were load deflection curves and crack patterns. It was found that U shape CFRP wrapped beam was having maximum load carrying capacity among all nine models. Flexural cracks were greatly reduced by laminating the bottom face of the beam and shear cracks were reduced by laminating the side faces of the beam.

Mariamol Kuriakose, (2016) studied about nonlinear analysis of different types of FRP-RC beams. Finite Element Approach was used to study the Fiber reinforced beams using ANSYS. In this paper, RC beam specimen wrapped with different types of fibre sheets such as GFRP, CFRP and AFRP. To determine the best strengthening scheme, different geometric configurations were made by using the combination of these three fibre with different thickness and in layers which were wrapped around the beam. Different FRP's were wrapped along one side, both sides and bottom side of the beam specimen. Deformation shape and the crack patterns were obtained. It was observed that FRP-RC has more load carrying capacity as compared to the ordinary beam. There is 10 % increase in load carrying capacity when beam is wrapped around CFRP, 5 % with GFRP, 3.15% with AFRP and 13% with combination of GFRP/CFRP/AFRP. It was concluded that strength of the RC beam is increased by using fibre.

2.1 Metal Matrix Composites

A number of research studies have been conducted on strengthening of RC wrapped beams using Polymers (GFRP and CFRP), there is no previous research on the behaviour of strengthened MMC wrapped beams. The literature view shown below describes about the different MMC's, mechanical properties for different types of MMC's, their applications in different mechanical field components carried out by using Finite element Method.

S Santosh Kumar, (2009) studied the variations in behaviour of elastic properties of Aluminium Alloy Metal matrix composite with different volume fractions of Silicon carbide. The elastic properties of Aluminium MMC with different volume fractions of silicon carbide were determined from ultrasonic velocities such as longitudinal velocity and shear velocity. Examined elastic properties included elastic modulus, poison's ratio shear modulus and bulk modulus. The results indicated that with the increase in volume fraction of silicon carbide, to determined elastic moduli were found to be increase in a nonlinear manner. Also, the elastic moduli were determined on the basis of some predicted theories.

C.K. Tan, (2012) performed the theoretical and experimental investigation on mechanical properties of Aluminium alloy reinforced with two different types of reinforcement such as aluminium oxide and silicon carbide. Different weight fractions for both silicon carbide and aluminium oxide were mixed with aluminium alloy to form composite material. The test specimens of both materials aluminium alloy reinforced with aluminium oxide and aluminium alloy reinforced with silicon carbide were prepared and tested to determine the physical and mechanical properties of both materials. On the other hand theoretical calculations using equations were made to determine the mechanical properties of composites. The observed parameters were strength to density ratio, density, tensile strength, hardness and wear rate. It was found that the comparison for both composite material shown that aluminium alloy reinforced with silicon carbide have higher tensile strength and hardness as compared to the aluminium alloy reinforced with aluminium oxide. Graphical plots shown the good agreement between the predicted and experimental results.

K. L. Meena, (2013) presented the experimental investigation on mechanical behaviour of aluminium MMC’s reinforced with particles of silicon carbide material. To determine the mechanical properties of Aluminium MMC, MMC bars and plates were prepared. The composition was made up of aluminium and different mix percentages of Silicon carbide ranging from 5%, 10 %, 15% and 20 % respectively. Three different particle sizes of mesh 220, 300 and 400 were adopted. The observing parameters were examined such as hardness, impact strength, density, ultimate tensile strength, elongation, breaking strength, and area reduction, upper and lower yield tensile strength. The graphical plots of parameters shown that with higher the mesh size and weight fraction of particles, more will be gain in tensile and breaking strength and also there will be minimizing percentage area reduction as well as percentage in elongation. Hardness and density was also increased due to the increase in weight fraction and mesh size of particles.

P. Chandrasekhar, (2013) conducted the experimental investigation and numerical analysis by finite element simulation using DEFORM software. This paper deals with the deformation characteristics on solid disc made up of aluminium MMC reinforced with different percentages of Silicon carbide material. The material properties such as poison’s ratio, ultimate tensile strength and hardness for AMC reinforced with silicon carbide of 5% wt. and 13%wt were included. The results were obtained on the basis of stress and strain plots for both percentages of silicon carbide content.

Kumar K.S, (2015) had performed the finite element analysis of Aluminium Silicon Carbide MMC using ANSYS. Two dimensional element was adopted for the nonlinear analysis considering the fibre volume fraction of Silicon Carbide. Stress Strain behaviour for varying fibre volume fractions were observed. It was noted that stress strain curves becomes almost linear when volume fraction of silicon carbide is above 40 percent.

Dr. Sumathy Muniamuthu, (2016) carried the investigation over mechanical properties of Aluminium MMC reinforced Alumina Oxide**.** This paper deals with the use of MMC and to improve their mechanical properties. The properties that were analysed such as impact strength, tensile strength and hardness. Alumina oxide were taken in different weight proportions at 2%, 4%, 6% and 8%.in base Aluminium MMC. It was found that ultimate tensile strength, hardness and impact strength tends to be increased with the increase in alumina oxide particles, but elongations tends to be reduced.

D M Nuruzzaman, (2016) had taken the investigation on properties of aluminium Silicon Carbide Metal Matrix Composites. Specimens of ASC consisting of three different composition 10%, 20% and 30% of silicon carbide were prepared and tested under compaction load. Matrix material was aluminium powdered and reinforcement material was silicon carbide particulates with different volume fractions. The parameters analysed were density and hardness. It was noted that with higher percentage of silicon carbides increase the hardness as well as density of the composite.

Akhil R (2018) had studiedabout the trending applications of Metal Matrix Composites. This paper deals with their mechanical behaviour along with different usages of MMC material in automotive field. Comparison of MMC with PMC’s were also discussed in terms of mechanical properties. The chemical composition of MMC with physical and mechanical properties such as density, compressive strength and elastic modulus were also included. The research output shows that MMC demands have been widely increasing due to their advance development and improved mechanical, thermal properties in the aerospace industry

3. Experimental Methodology

This chapter gives a detailed methodology of conducting non-linear finite element analysis using ANSYS software. The details of base design i.e. control beam from base paper and FEA validation is also discussed along with various geometric configurations and material configurations of analysis. The load vs displacement curve along with energy absorption characteristics is also described and comparative analysis is made on the basis of load deformation curve and energy absorption characteristics.

3.1 Experimental setup for 4-point bending tests

Table 1: Material properties of reinforcement

Type	Density (g/cm^3)	Poisson's Ratio	Elastic Modulus (GPa)
Al–SiC MMCs	3198	.16	419.4

The schematic of testing to be used for FEA analysis in our research is shown in figure 4.1 below. It has clear span of the beam specimens was 1600mm and the span between the two loading points was 600mm. Steel bars with diameter of 8mm (A8) and 12mm (C12) were used as longitudinal reinforcement while the stirrups were made with 8mm diameter deformed bars.

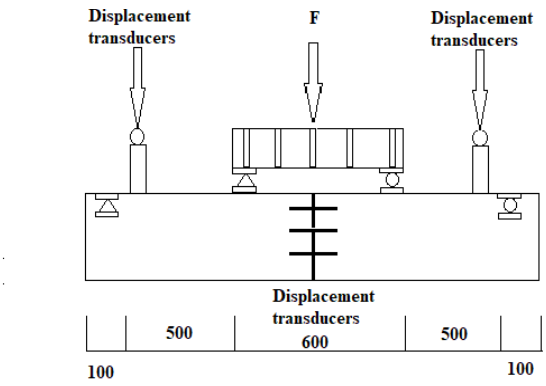


Figure 1.: Schematic of Experimental setup for 4-point bending tests.

3.2 Properties of Different Materials

(a) Reinforcement

Table 2: Material properties of different fibre fabrics

Type	Grade	Elastic Modulus (GPa)	Yield Strength (MPa)	Ultimate Strength (MPa)
A8	HPB300	210	306.2	402.1
C12	HRB400	210	422.8	511.6

Table 3 Material properties of MMC

Type	Tensile Strength (MPa)	Elastic Modulus (GPa)
Carbon Fibre	3198	221.7
Glass Fibre	645.5	79.7

(b) Fibre fabrics

(c) MMC

(d) Different Arrangements of GFRP, CFRP and MMC

Table 4: Groups of Analysis

Group 1	Bottom Configuration
	A Bottom Configuration MMC
	B Bottom Configuration GFRP
	C Bottom Configuration CFRP
Group 2	U shape hybrid beam
	H. CFRP + Mid-Section MMC
	I. GFRP + Mid-Section MMC
	J. GFRP (Bottom) + MMC (sides)
	K. CFRP (Bottom) + MMC (sides)
	L.MMC (Bottom) + GFRP (sides)
	M. MMC (Bottom) + CFRP (sides)
Group 3	L shape hybrid beam
	N. CFRP (sides) + MMC (bottom)
	O. CFRP (bottom) + MMC (sides)
	P.MMC (bottom) + GFRP (sides)
	Q. GFRP (bottom) + MMC (sides)

4. Experimental Modelling

4.1 Cad Modelling of Beam Using Creo 2.0

The CAD of test specimen CB (control beam) is modelled using Creo parametric software which is sketch based, parametric 3d modelling software developed by PTC. The Creo software is having bi-directional associativity and parent child relationship. The CAD model is then imported in ANSYS design modeller and checked for geometric errors, hard edges, tolerances.

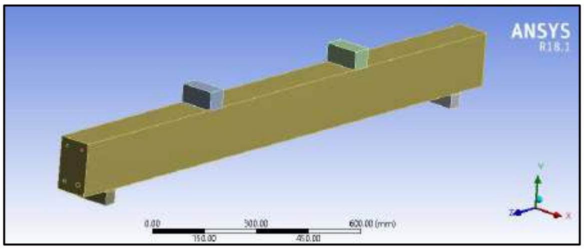


Figure 2.: CAD model of control beam (without encasing)

The wireframe model as shown below shows longitudinal reinforcement bars along with stirrups. Along with these 2-support geometries are provided at bottom and 2 features for load application is provided on top face as shown in figure 5.2 below.

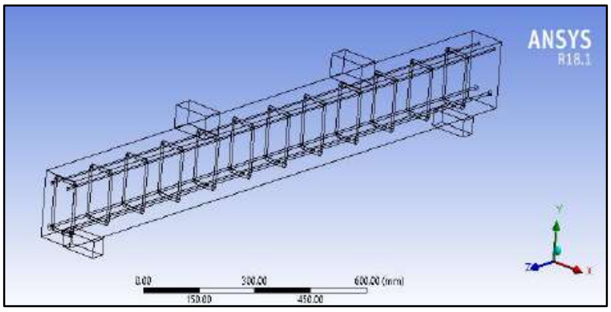


Figure 3.: Wireframe model of control beam

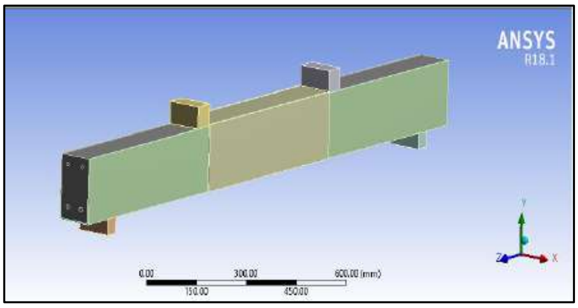


Figure 4.: Mid span encasing (GFRP/CFRP +MMC encasing)

The CAD model shown in figure 5.3 above shows encasing in mid span between the load application geometry. The longitudinal encasing is assigned with GFRP or CFRP material.

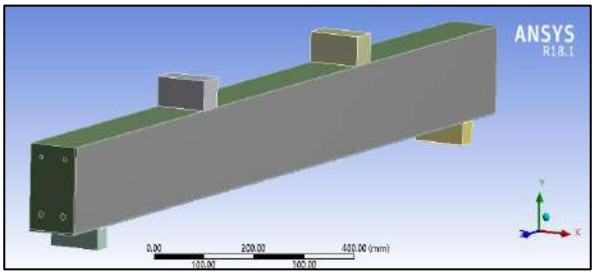


Figure 5.: Shaped geometry

The L shaped geometry consists of 2 flat faces of 3mm thickness at both right face and bottom face. The both faces are assigned with materials CFRP and MMC variably and vice versa.

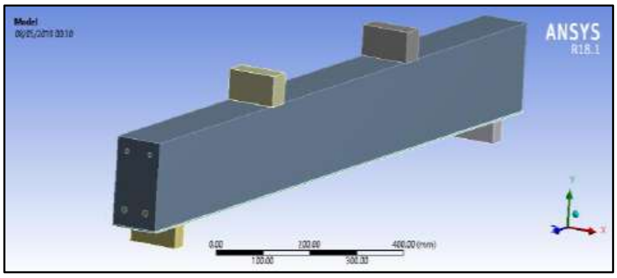


Figure 6.: Bottom face geometry

The CAD model of beam with bottom face with 3mm feature is individually analysed for MMC, CFRP and GFRP respectively.

4.1 Meshing

The imported model is meshed using hexahedral elements Figure 5.6 Imported CAD model in ANSYS using appropriate element size which is set to fine sizing. Inflation normal, growth rate normal, transition fast. Number of nodes formed is 280319 and number of elements formed is 121240.

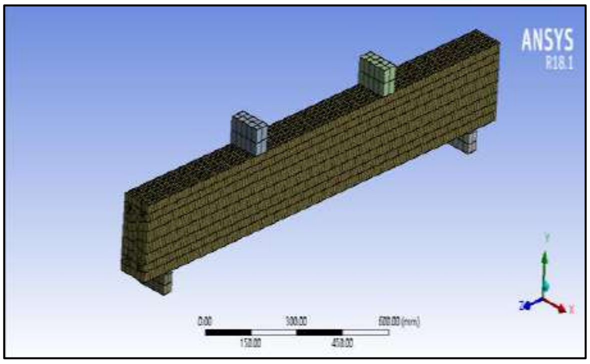


Figure 7.: Meshed model in ANSYS

4.2 Loads and Boundary Condition

Further stage involves applying loads and boundary conditions as shown in figure 5.7 below. Fixed support is applied at point A and displacement support restricted in y direction is applied on point B. Loading is applied in steps for total of 6 load steps.

Table 5.: Applied loads at different load steps

Load Steps	Applied Load (N)
1	2500
2	5000
3	10000
4	15000
5	20000
6	25000

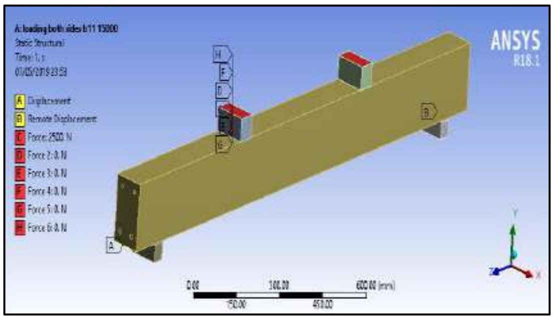
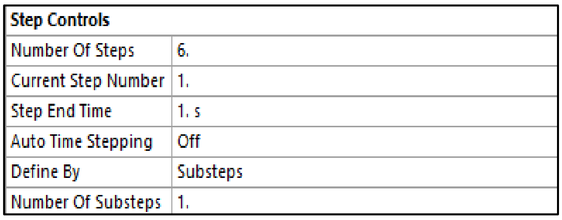


Figure 8.: Loads and Boundary Condition in ANSYS

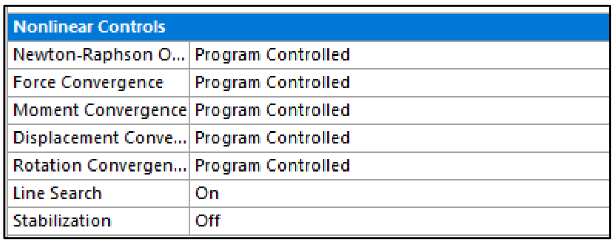
In nonlinear solution, the total load applied to a finite element model is divided into a series of load increment called load steps. The ANSYS program uses Newton-Raphson equilibrium iterations for updating the model stiffness. In this study, for the reinforced concrete solid elements, convergence criteria is based on force and displacement, and the convergence tolerance limits is initially selected by the ANSYS program. It is found that convergence of solutions for the models is difficult to achieve due to the nonlinear behaviour of reinforced concrete. Therefore, the convergence tolerance limits is increased to a maximum of 5 times the default tolerance limits (0.5 % for force checking and 5% for displacement checking) in order to obtain convergence of the solutions.



Step Controls	
Number Of Steps	6.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Off
Define By	Substeps
Number Of Substeps	1.

Figure 9 Time step settings

For the nonlinear analysis, automatic time stepping in the ANSYS program predicts and controls load step sizes. Based on the previous solution history and the physics of the models, if the convergence behaviour is smooth, automatic time stepping will increase the load increment up to a selected maximum load step size.



Nonlinear Controls	
Newton-Raphson O...	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Conve...	Program Controlled
Rotation Convergen...	Program Controlled
Line Search	On
Stabilization	Off

Figure 10.: Line search is ON for Newton Raphson Algorithm

If the convergence behaviour is abrupt, automatic time stepping bisect the load increment until it is equal to a selected minimum load step size. The maximum and minimum load step sizes are required for the automatic time stepping.

4.3 Solution Stage

Solution of finite element model. In this stage software carries out matrix formulations, inversions and multiplication. Element stiffness matrices are formulated and assemblage of global stiffness matrices takes at this stage.

4.4 Post Processing Stage

This stage involves viewing of results like deformations contours for displacement, etc., using visualization tools. After viewing the results necessary suggestions and geometric or material optimization are made.

5. Results and Discussion

5.1 Control Beam

The first case of analysis was RCC beams without composite materials. The deformation and equivalent stress obtained are shown in figure 6.1 and figure 6.2 below

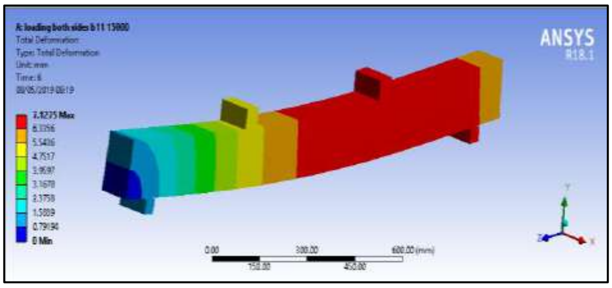


Figure 11 Deformation in RCC beam without composites

The maximum deformation obtained using RCC beam without using composites is observed at mid span with magnitude of 7.12mm for force of 50000N as shown in figure 6.1 and maximum equivalent stress obtained is 381.21MPa as shown in figure 6.2 below.

Table 6 Results with RCC beam without composites

Group1	Bottom Configuration
	A. Bottom Configuration MMC
	B. Bottom Configuration GFRP
	C. Bottom Configuration CFRP

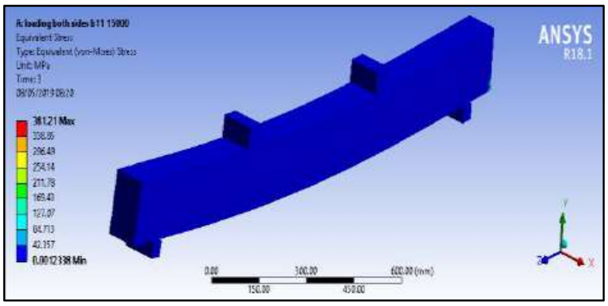


Figure 12 Equivalent stress in RCC beam without composites

Table 7: Group 1 Results

Load (N)	Deformation (Mm)	Equivalent Stress (MPa)
5000	0.71	95.73
10000	1.43	191.2
20000	2.87	381.2
30000	4.29	569.7
40000	5.71	756.6
50000	7.12	941.6

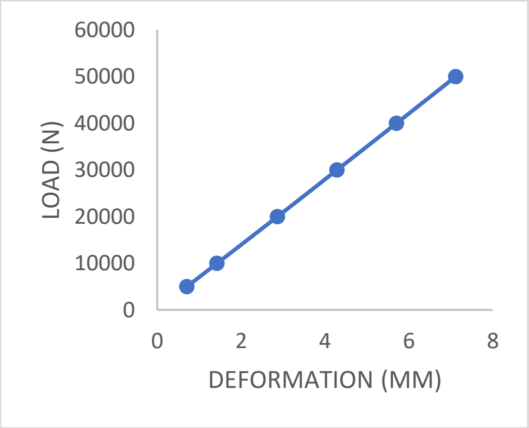


Figure 13.: Load vs. Deformation for control beam

Group A (Bottom Configuration MMC)

The analysis was RCC beams with single plate at bottom (MMC).The deformation and equivalent stress obtained are shown in figure 6.4 and figure 6.5 below

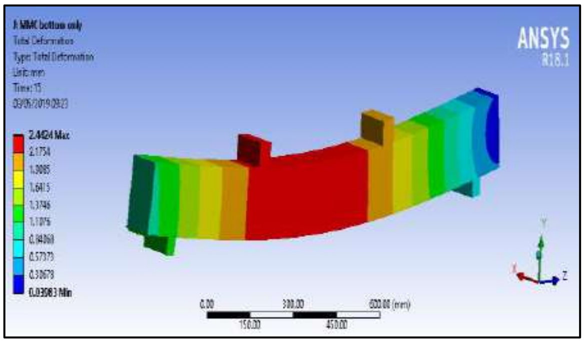


Figure 14 Deformation in RCC beam with single plate at bottom (MMC)

The maximum deformation obtained using RCC beam with single plate at bottom (MMC) is observed at mid span with magnitude of 2.42 mm for force of 50000N as shown in figure 6.4 and maximum equivalent stress obtained is 3415 MPa as shown in figure 6.5 below.

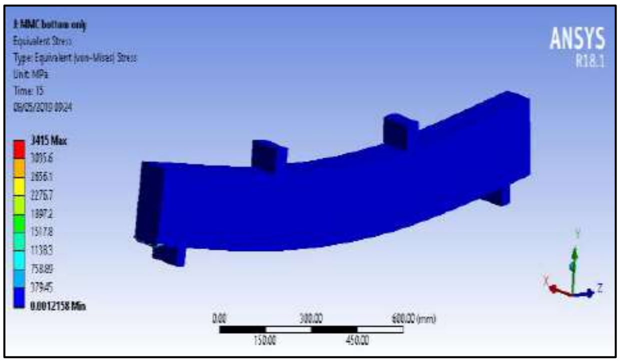


Figure 15.: Equivalent stresses in RCC beam with single plate at bottom (MMC)

Table 8: Results with single plate at bottom (MMC)

LOAD (N)	DEFORMATION (mm)	EQUIVALENT STRESS (MPa)
5000	0.24348	339.04
10000	.48	678.8
20000	.97	1360.5
30000	1.37	3225.2
40000	1.95	2727.4
50000	2.44	3415

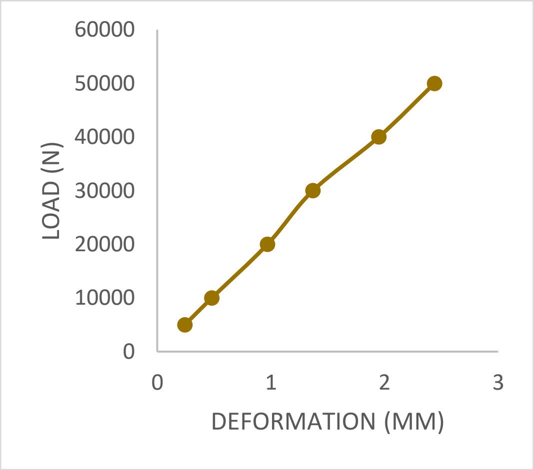


Figure 16.: Group A (Bottom Configuration MMC)

Group B (Bottom Configuration GFRP)

The analysis was RCC beams with single plate at bottom (GFRP).The deformation and equivalent stress obtained are shown in figure 6.7 and figure 6.8 below

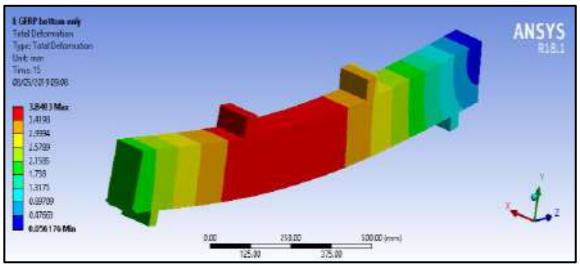


Figure 17 Deformation in RCC beam with single plate at bottom (GFRP)

The maximum deformation obtained using RCC beam with single plate at bottom (GFRP) is observed at mid span with magnitude of 3.84 mm for force of 50000N as shown in figure 6.7 and maximum equivalent stress obtained is 2951 MPa as shown in figure 6.8 below.

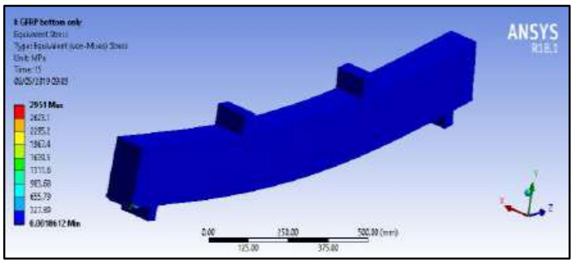


Figure 18.: Equivalent stress in RCC beam with single plate at bottom (GFRP)

Table 9: Results with single plate at bottom (GFRP)

Load (N)	Deformation (Mm)	Equivalent Stress (Mpa)
5000	0.3811	290.34
10000	0.76	582.28
20000	1.52	1170.4
30000	2.27	2786.3
40000	3.06	2353.3
50000	3.84	2951

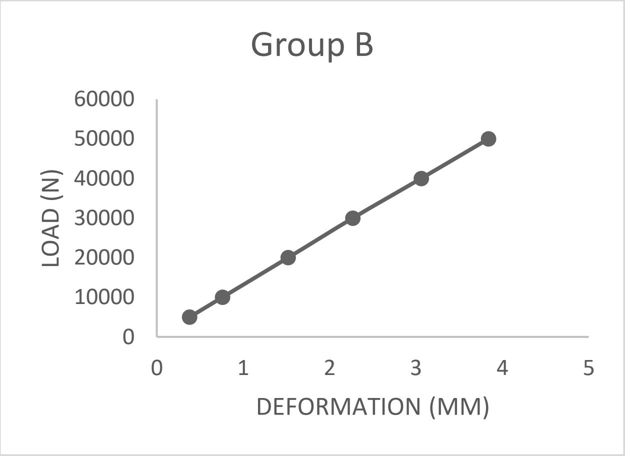


Figure 19.: Group B (Bottom Configuration GFRP)

Group C (Bottom Configuration CFRP)

The analysis was RCC beams with single plate at bottom (CFRP).The deformation and equivalent stress obtained are shown in figure 6.10 and figure 6.11 below

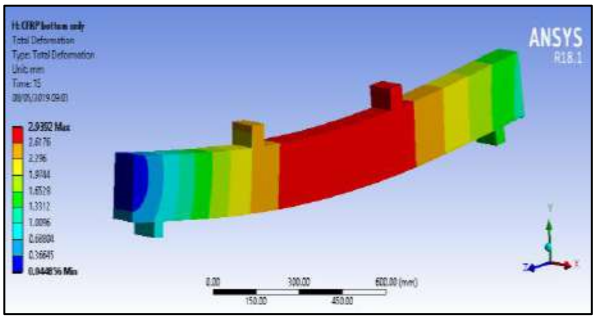


Figure 20.: Deformation in RCC beam with single plate at bottom (CFRP)

The maximum deformation obtained using RCC beam with single plate at bottom (CFRP) is observed at mid span with magnitude of 2.93 mm for force of 50000N as shown in figure

6.10 and maximum equivalent stress obtained is 3250 MPa as shown in figure 6.11 below.

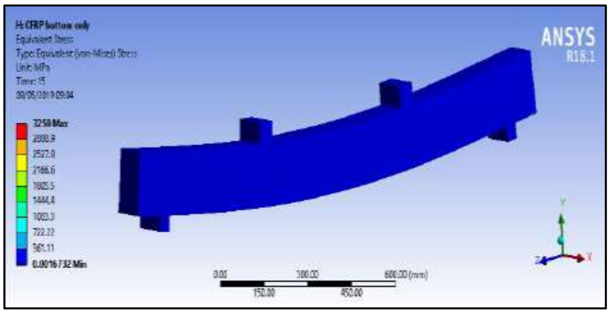


Figure 21.: Equivalent stress in RCC beam with single plate at bottom (CFRP)

Table 10 Results with single plate at bottom (CFRP)

Load (N)	Deformation (Mm)	Equivalent Stress (Mpa)
5000	0.29266	321.75
10000	0.58	644.53
20000	1.17	1293.1
30000	1.65	3069.2
40000	2.34	2594
50000	2.93	3250

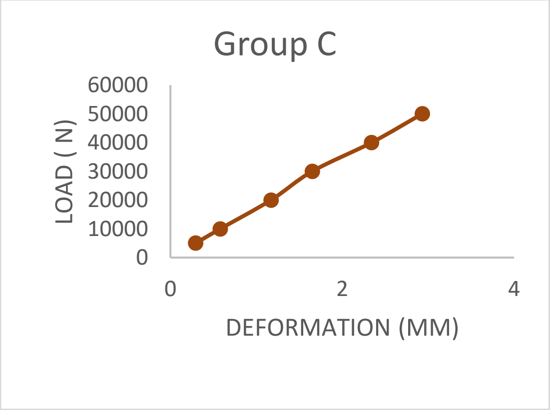


Figure 22.: Group C (Bottom Configuration CFRP)

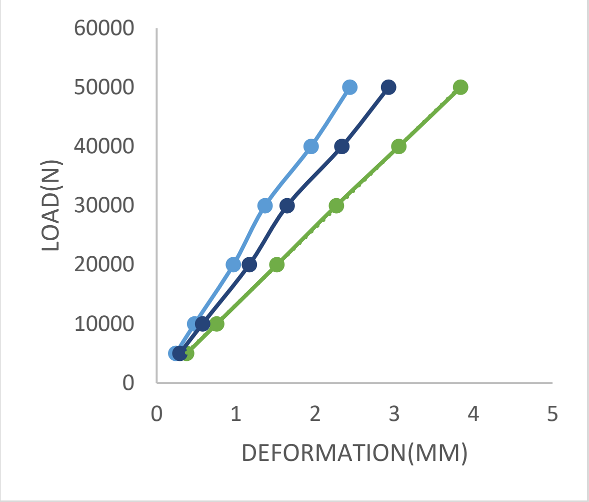


Figure 23.: Complete analysis for GROUP A, B, C

6. Conclusion

Finite Element Analysis of beam under various reinforcement profile is performed using ANSYS 18.1 software. The analysis type is contact non-linear and shear behaviour is analysed under various loads. Application of composite materials (MMC/CFRP/GFRP) has reduced deformation as compared to control beam without any composites. The maximum deformation is observed using control beam with magnitude of 7.12mm and minimum deformation is observed using u shape hybrid beam with CFRP + Mid-Section MMC. Using longitudinal encasing under U shape hybrid beam design along with mid-section encasing has strengthened the beam and deformation was lower using (CFRP + Mid-Section MMC) as compared to (GFRP + Mid-Section MMC).

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