# Study of RC Wrapped Beam with Polymers and Metal Matrix Composites

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**Abstract -** *Due to excessive loading, construction errors and improper maintenance strengthening of concrete structures becomes critical. This brings improvement in load bearing capacity, improved ductility and reduce damages due to deterioration. The researchers are seeking new and innovative ways of strengthening of beams as conventional methods of reinforcement encountered certain limitations which are required to overcome. The technique of wrapping a Reinforced Concrete (RC) beam with composite material becomes popular and have been widely adopted in the structural applications due to their superior properties. In the present study an attempt has been made to compare the performance of Polymers such as Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP) and Metal Matrix Composites (MMC). Finite Element Analysis (FEA) is conducted using ANSYS 18.1 Workbench to investigate the elastic behavior of modelled beam wrapped with different configurations of composite materials (GFRP/CFRP and MMC).The performance of the above wrapped RC beams are then compared with the controlled specimen and results of load deflection curves along energy absorption characteristics are presented in the paper. The main aim is to investigate the MMC as a reinforcing material.*

***Key Words*: Reinforced Concrete Beam, GFRP, CFRP, MMC, FEA, ANSYS, Composite Material**

## 1. INTRODUCTION

Now days, strengthening is usually needed for various reasons to keep the structures at a certain performance level. Structures all around the world are susceptible to deterioration and damage. Even the most modern structures such as skyscrapers and bridges are susceptible to degradation. These structures are required to maintain a certain performance level, which includes load carrying capacity, durability, function and aesthetic appearance. Conventional strengthening of Reinforced Cement Concrete (RCC) beams by the use of steel plate, concrete jacketing have proved to be viable to increase strength and ductility of structural elements. But these conventional strengthening of RC beams encountered certain limitations such as steel plates have heavy weight and corrosion resistance of steel plate's demands coating which increases maintenance costs. To overcome these problems, wrapping of RC beam with Fiber Reinforced Polymer (FRP) composite sheets becomes popular due to their light weight property and found to be best suited in structural applications. Most of the previous experimental and numerical researches were carried out on the FRP and different Hybrid FRP for strengthening of different elements of structure (structural walls, columns, beams and slabs), bridge components (decks, girder and piers) to enhance the ductility as well as loading capacity, flexural and shear capacity.

## 1.1 Fiber Reinforced Polymer Composites and Metal Matrix Composites

Due to widely use of FRP system, Glass Fibers and Carbon Fibers are more commonly used composite materials for strengthening of RC beams. Other Fibers Basalt Fiber Reinforced Polymer (BFRP) and Aramid Fiber Reinforced Polymer (AFRP) gaining attention in structural applications. But very little attention has been given to recently developed another class of composite materials i.e. Metal Matrix Composites (MMC). The continuous research began in 1950's make the material more adaptable and showing rapid growth. MMC's are one of the fastest growing families among all other classes of composites. MMC's have gain wide attention in the aerospace industry, then slowly cover all aspects of engineering. MMC is generally a two phased material in which one is usually a metal and the other is reinforcement which both form the whole MMC. It is generally reinforced for improving strength, stiffness properties of the material. Metals involved such as aluminum, magnesium etc. bonded together with the dispersed ceramics such as silicon and boron carbide, alumina etc. The properties of MMC totally depend upon the selection of the matrix and the reinforcement material. The most active country involved in the production of MMC material are United States. So many companies and organizations of US and Canada were involved in the development of MMC's such that Ford Motor company, Advanced Composites Material Corporation. MMC's also have advantages over polymer matrix composites (GFRP/CFRP) such as more transverse strength and stiffness, better radiation resistance and conduciveness, no moisture absorption. The general key characteristics of MMC as compare to the uniaxial plastics are such that they are more efficient in plate buckling, combined loads of tension, compression or shear, also in transverse and off- axis loads. On the other hand (PMC's) Polymer Matrix Composites are highly anisotropic material in which strength and stiffness are highly parallel to the fibers but it is low perpendicular to the fibers. They have stress strain curves generally linear to failure. PMC's have higher tensile strength and stiffness. They are more adaptable to design changes and can be easily repaired also they are more advanced in the state of art.

In the light of above discussion, the tool for analyzing the structural member to stimulate their behavior in linear and nonlinear manner and also cost effective approach is Finite Element Method. Non Linear Simulation on ANSYS workbench gives powerful environment and interface for solving different problems.

This study focuses on finite element modelling of RC beam wrapped with FRP and MMC laminates with the intention to determine their elastic behavior.

### 1.2 Fiber Reinforced Polymer and Metal Matrix Composites Strengthening

FRP and MMC laminates can be externally bonded to RC members for strengthening in flexural, shear and confinement. Previous researches have shown the greater use of GFRP, CFRP as a reinforcing bars. Here are the different wrapping configurations for laminating the RC beam involve a)Bottom Configuration; b) U shape configuration such that laminates are applied to bottom and both side faces of the beam and c) L shape configuration such that laminates are applied to one side and tension face of the beam. FRP and MMC laminates can also be applied with different thickness of layers, strips to know the effect on behaviour of RC members

## 2. NUMERICAL MODELLING AND ANALYSIS

### 2.1 Geometry, Material Properties and Different Configurations

The Geometry of the RC beam as reported by L. Huang, et al. (2018) is used for this study. The four point bending testing to be used for FEA analysis in our research. It has clear span of the beam specimen is 1600mm and the span between the two loading points is 600mm. The width and depth of the beam is 100 x 160mm provided. 2 Steel bars with diameter of 8mm and 12mm are used as reinforcement on tension and compression face of the beam while the stirrups are made with 8mm diameter deformed bars. The details of the reinforcement for longitudinal section and cross section are depicted as below shown in Fig-1.

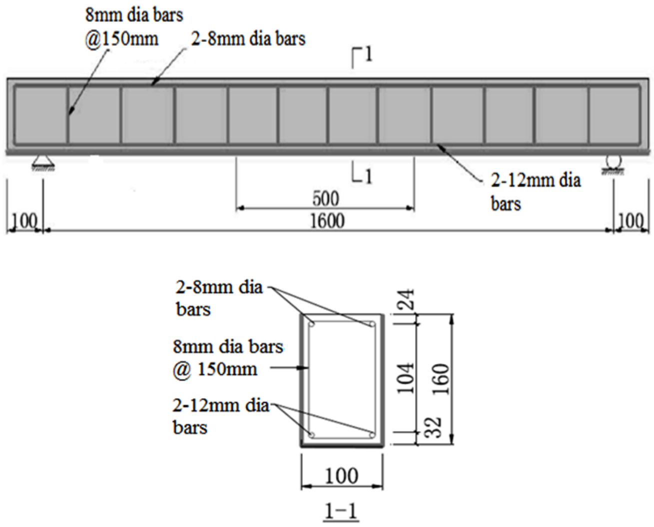


**Fig -1**: Longitudinal and cross section details of the beam

ANSYS requires material properties for concrete, reinforcement, FRP and MMC input data as shown below in Tables 1, 2, 3 and 4

**a) Material 1:-**Concrete Grade: M20

**Table 1:** Material properties of concrete

| Material 1 | Element Type | Modulus of Elasticity (Mpa) | Poisson Ratio |
|---|---|---|---|
| Concrete | Solid 186 | 22360.6 | 0.25 |

**b) Material 2:-** Steel Grade: Fe 415

**Table 2:** Material properties of reinforcement

| Material 2 | Material Model | Modulus of Elasticity (Mpa) | Poisson Ratio |
|---|---|---|---|
| Steel | Linear Elastic | 200000 | 0.3 |

**c) Material 3:-** For each laminates thickness: 3mm

**Table 3:** Material properties of GFRP and CFRP

| Material 3 | Material Model | Modulus of Elasticity (Gpa) | Poisson Ratio |
|---|---|---|---|
| GFRP | Linear Elastic | 79.7 | 0.13 |
| CFRP | Linear Elastic | 221.7 | 0.21 |

**d) Material 4**

**Table 4:** Material properties of MMC

| Type | Density ($g/cm^3$) | Modulus of Elasticity (Gpa) | Poisson Ratio |
|---|---|---|---|
| Al–SiC MMCs | 3.198 | 419.4 | 0.16 |

The testing is divided into 3 groups of analysis according to their configurations. Group 1 comprises bottom configuration consisting of MMC, GFRP and CFRP respectively. Group 2 comprises U shape hybrid profile consisting of combinations of MMC with GFRP, MMC with CFRP. Group 3 comprises L shaped hybrid beam consisting of 1 bottom plate and side plate comprising of MMC with GFRP, MMC with CFRP as shown below in Table 5.

**Table 5:** Groups of Analysis

| **Group 1** | **Bottom Configuration** |
|---|---|
| | D. Bottom Configuration MMC |
| | E. Bottom Configuration GFRP |
| | F. 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) |

## 2.2 Modelling, Meshing, Loads and Boundary Conditions

The test specimen CB (control beam) is modelled in ANSYS design modeler as shown in Fig-2. The wireframe model as shown in Fig-3 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. The CAD model of beam with bottom face with 3mm feature is individually analyzed for MMC, CFRP and GFRP respectively as shown in Fig-4. The CAD model shown in Fig - 5 shows encasing in mid span between the load application geometry. The longitudinal encasing is assigned with GFRP or CFRP material. 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 as shown in Fig-6. The model is meshed using hexahedral elements as shown in Fig-7. 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 as shown in Table-6 and Fig-8.

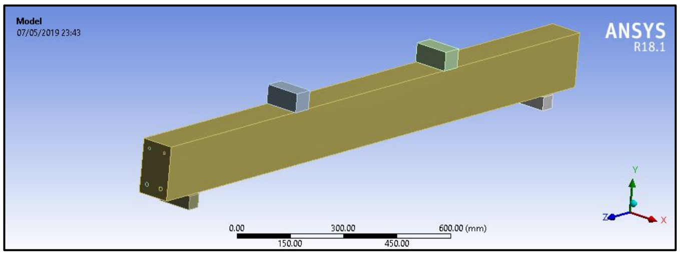

**Fig -2:** CAD model of control beam (without encasing)

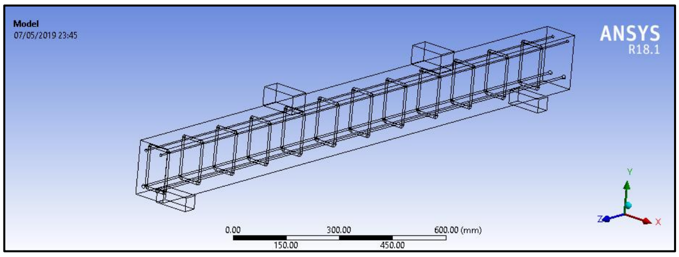

**Fig -3:** Wireframe model of control beam

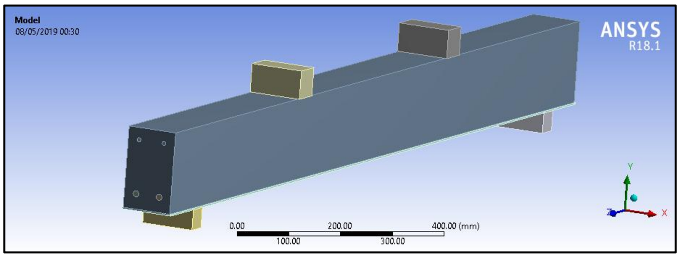

**Fig -4:** Bottom Face Geometry

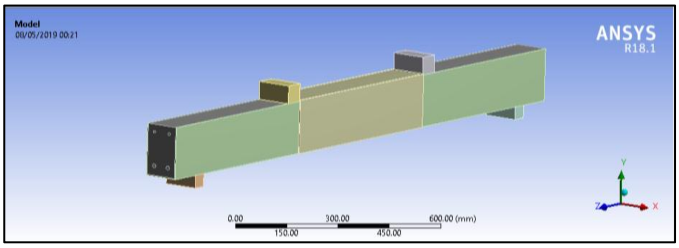

**Fig -5:** Mid span encasing (GFRP/CFRP + MMC encasing)

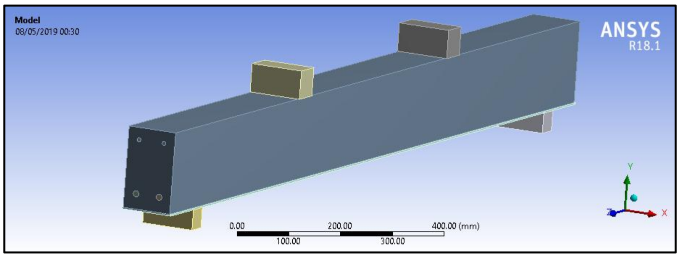

**Fig -6:** L shaped Geometry

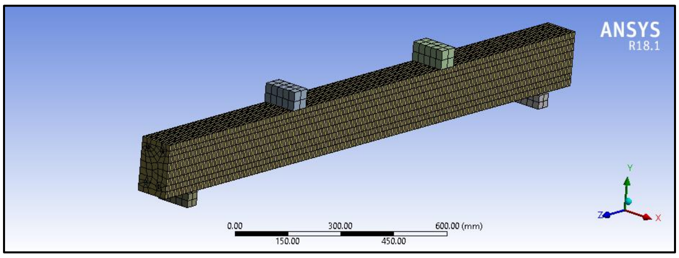


**Fig -7:** Meshed Model in ANSYS

**Table 6:** Applied loads at different load steps

| LOAD STEPS | APPLIED LOAD (N) |
|---|---|
| 1 | 5000 |
| 2 | 10000 |
| 3 | 20000 |
| 4 | 30000 |
| 5 | 40000 |
| 6 | 50000 |

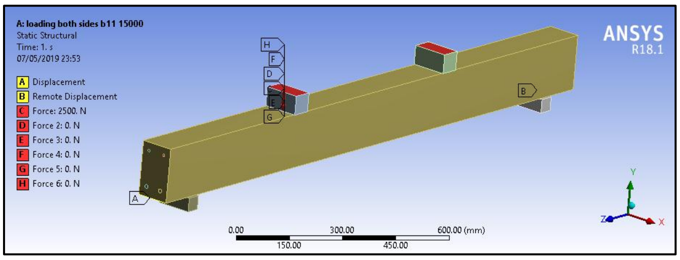


**Fig -8:** Loads and Boundary Conditions in ANSYS

## 3. RESULTS AND OBSERVATIONS

The results and observations from the above Analytical study of the controlled specimen are compared with the results of GFRP, CFRP and MMC laminates. The deformation contours of all RC beam cases obtained from FE analysis using ANSYS 18.1 Workbench software have been shown in Fig- 9 to Fig- 22 and values obtained against loading are represented in Table-7 to 10. Load deflection curves are plotted for better understanding and comparison of the all groups of RC beams as shown in Chart -1 to Chart -5.

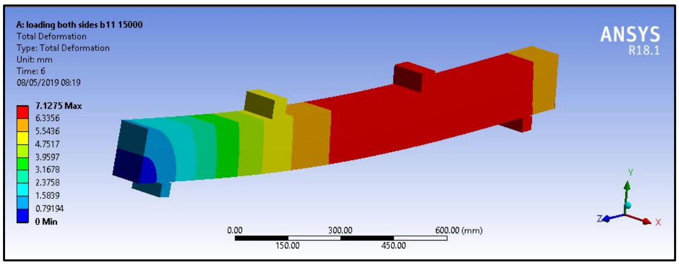


**Fig -9**: Deformation in RCC beam without composites

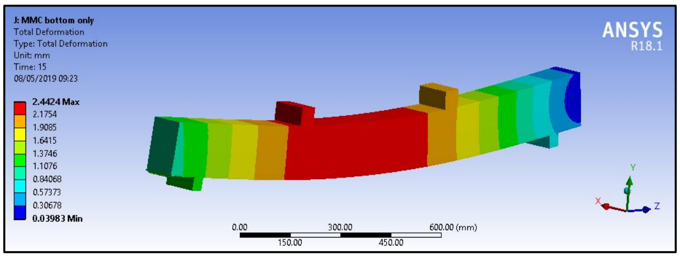


**Fig -10**: Deformation with single plate bottom (MMC)

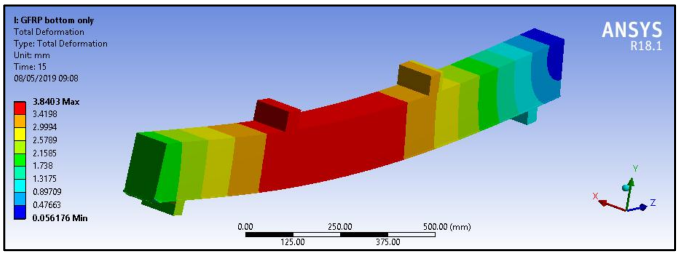


**Fig -11**: Deformation with single plate bottom (GFRP)

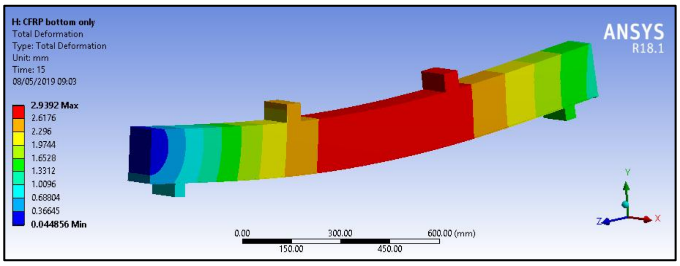


**Fig -12**: Deformation with single plate bottom (CFRP)

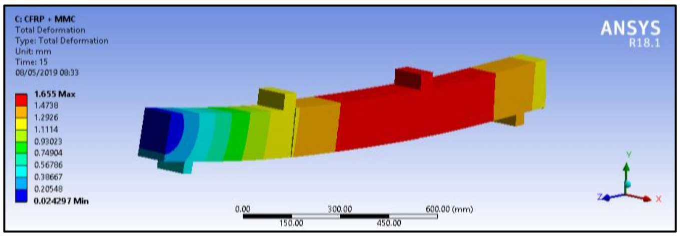


**Fig -13**: Deformation (U shape CFRP+ Mid-section MMC)

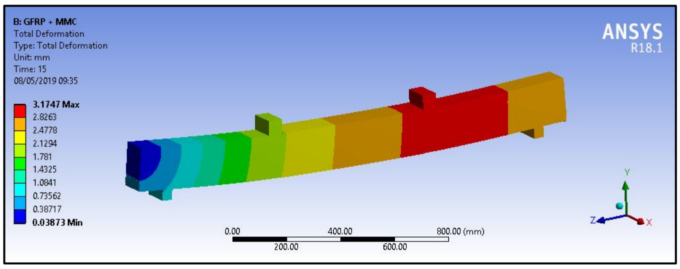


**Fig -14**: Deformation (U shape GFRP +Mid-section MMC)

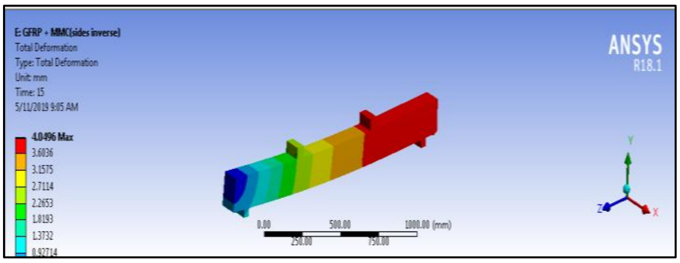


**Fig -15**: Deformation (U shape GFRP bottom +MMC sides)

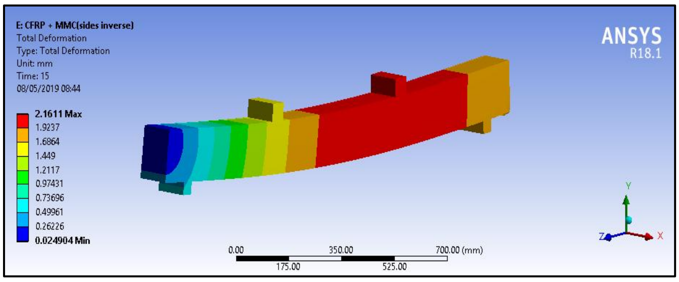


**Fig -16**: Deformation (U shape CFRP bottom +MMC sides)

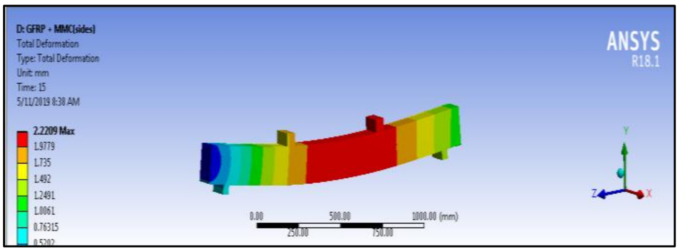


**Fig -17**: Deformation (U shape MMC bottom +GFRP sides)

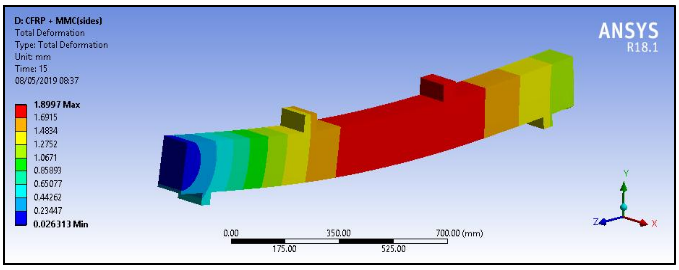


**Fig -18**: Deformation (U shape MMC bottom +CFRP sides)

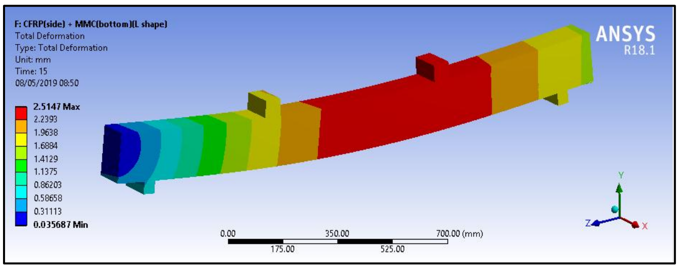


**Fig -19**: Deformation (L shape CFRP side +MMC bottom)

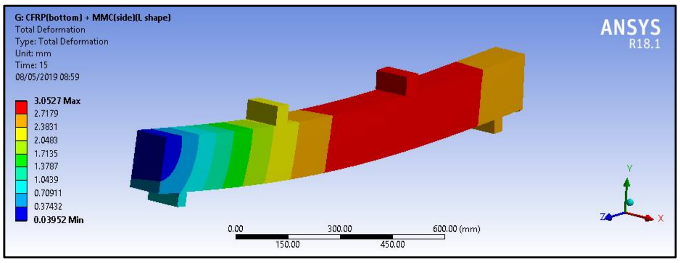


**Fig -20**: Deformation (L shape CFRP bottom +MMC side)

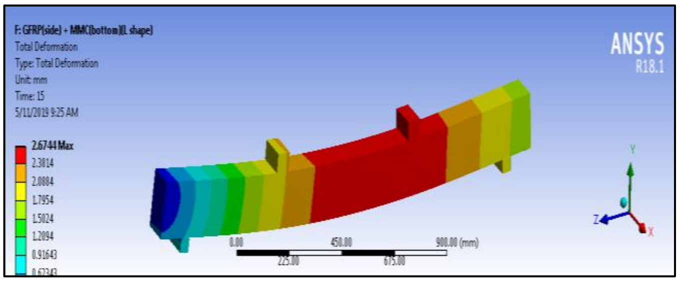


**Fig -21**: Deformation (L shape MMC bottom +GFRP side)

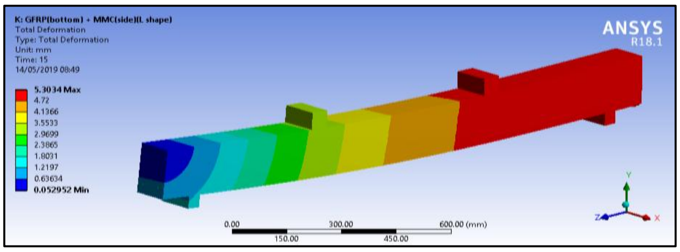


**Fig -22**: Deformation (L shape GFRP bottom +MMC side)

The load vs deformations shown in Table 6 clearly depict that RC beam wrapped with single plate of GFRP have higher deformations as compare to wrapped with single plate of CFRP and MMC. In case of U shape profile, the RC beam wrapped with GFRP longitudinally from bottom and sides in which mid-section of the beam is wrapped with MMC have higher deformations as compare to CFRP shown in Table 7. Using U shape hybrid beam MMC at the bottom and CFRP at sides has lowest deformation among all other patterns shown in Table 8. Similarly in L shape hybrid beam MMC at the bottom and CFRP at sides has lowest deformation as shown in Table 9. The combined observations of all cases are graphically shown in Chart-5.

**Table 7**: Deformations for Group 1 (Bottom Profile)

| LOADS (N) | DEFORMATION (mm) for Group 1 | | |
|---|---|---|---|
| | Group 1D | Group 1E | Group 1F |
| 5000 | 0.24348 | 0.3811 | 0.29266 |
| 10000 | 0.48 | 0.76 | 0.58 |
| 20000 | 0.97 | 1.52 | 1.17 |
| 30000 | 1.37 | 2.27 | 1.65 |
| 40000 | 1.95 | 3.06 | 2.34 |
| 50000 | 2.44 | 3.84 | 2.93 |

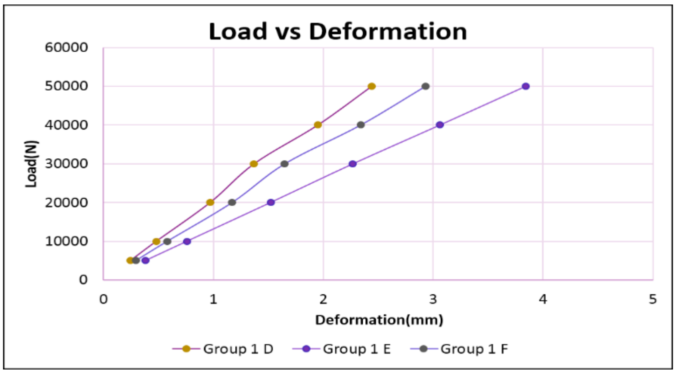


**Chart – 1:** Load vs Deformation curves for Group 1

**Table 8**: Deformations for Group 2 (U shape Mid-section)

| LOADS (N) | DEFORMATION (mm) for Group 2 | |
|---|---|---|
| | Group 2H | Group 2I |
| 5000 | 0.16421 | 0.30989 |
| 10000 | 0.32 | 0.62 |
| 20000 | 0.65 | 1.25 |
| 30000 | 0.99 | 1.88 |
| 40000 | 1.32 | 2.52 |
| 50000 | 1.65 | 3.17 |

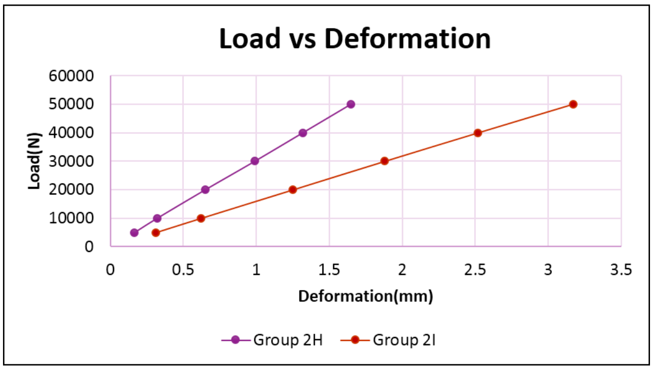


**Chart – 2:** Load vs Deformation curves for Group 2

**Table 9**: Deformations for Group 2 (U Shape Profile)

| LOADS (N) | DEFORMATION (mm) for Group 2 | | | |
|---|---|---|---|---|
| | Group 2J | Group 2K | Group 2L | Group 2M |
| 5000 | 0.404 | 0.21568 | 0.22217 | 0.1902 |
| 10000 | 0.808 | 0.43 | 0.44446 | 0.38 |
| 20000 | 1.618 | 0.86 | 0.88875 | 0.76 |
| 30000 | 2.428 | 1.29 | 1.3327 | 1.14 |
| 40000 | 3.239 | 1.72 | 1.7767 | 1.52 |
| 50000 | 4.04 | 2.16 | 2.2209 | 1.89 |

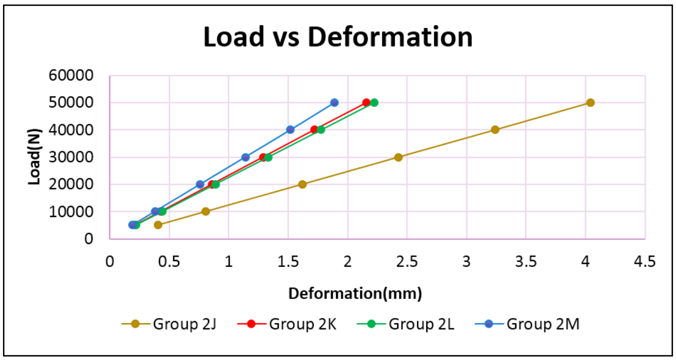


**Chart – 3:** Load vs Deformation curves for Group 2

**Table 10**: Deformations for Group 3 (L Shape Profile)

| LOADS (N) | DEFORMATION (mm) for Group 3 | | | |
|---|---|---|---|---|
| | Group 3N | Group 3O | Group 3P | Group 3Q |
| 5000 | 0.25057 | 0.30364 | 0.2664 | 0.52643 |
| 10000 | 0.5 | 0.6 | 0.53303 | 1.0545 |
| 20000 | 1 | 1.21 | 1.0672 | 2.1144 |
| 30000 | 1.5 | 1.82 | 1.6024 | 3.1769 |
| 40000 | 2.01 | 2.43 | 2.1381 | 4.2406 |
| 50000 | 2.51 | 3.05 | 2.6744 | 5.3034 |

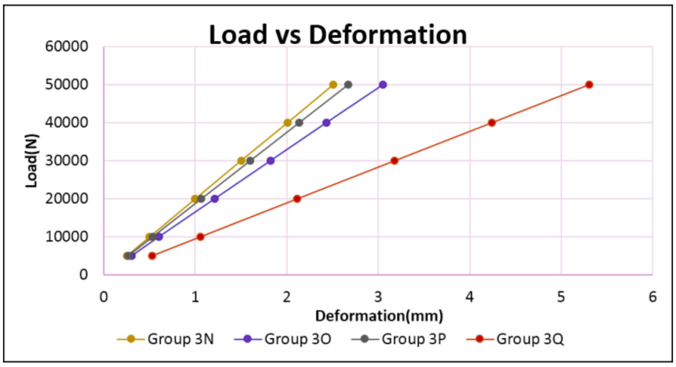


**Chart – 4:** Load vs Deformation curves for Group 3

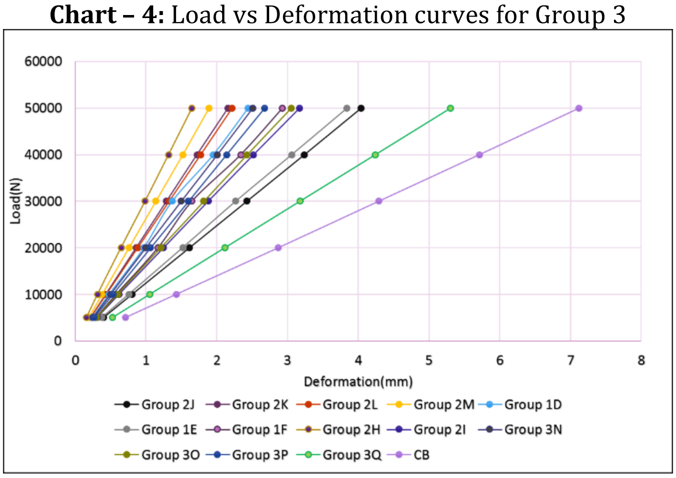


**Chart – 5:** Load vs Deformation curves of all RC beams

Area under the load deformation curve is calculated to obtain the energy absorption capacity of all RC beams. The values are shown in Table 11 and Chart - 6

**Table 11**: Energy Absorption Values of all RC beams

| Group Name | Energy absorbed (N-mm) |
|---|---|
| Group 1D | 61000 |
| Group 1E | 96000 |
| Group 1F | 73250 |
| Group 2H | 41250 |
| Group 2I | 79500 |
| Group 2J | 101000 |
| Group 2K | 54000 |
| Group 2L | 55500 |
| Group 2M | 47250 |
| Group 3N | 62750 |
| Group 3O | 76250 |
| Group 3P | 66000 |
| Group 3Q | 132500 |
| CB | 65450 |

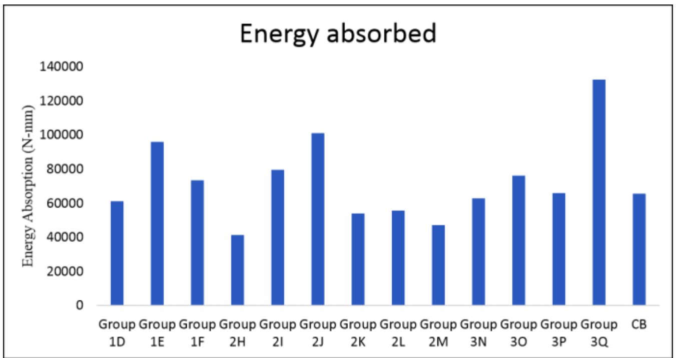


**Chart – 6:** Energy absorption plot

## 4. CONCLUSIONS

Finite Element Analysis of beam under various reinforcement profile is performed using ANSYS 18.1 software. The analysis type is contact non-linear and elastic behavior is analyzed under various loads. The main objective of this research is to study the effect of GFRP, CFRP and MMC on beam and to find out the best wrapping technique among fourteen models of RC beam. Also check the combination of GFRP, CFRP and MMC over single beam.
The detailed conclusion are as follows:

- 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
- The maximum reduction percentage of deformation in group 1 Bottom configuration is obtained for group 1D (MMC bottom) configuration with 65.7% reduction.
- The maximum reduction percentage of deformation in group 2 U shape Hybrid Beam is obtained for group 2H (CFRP + Mid-section MMC) configuration with 76.8% reduction.
- The maximum reduction percentage of deformation in group 3 L shape is obtained for group 3N (MMC bottom + CFRP side) configuration with 64.74% reduction.
- RC beam wrapped with L shape profile having GFRP at bottom and MMC sides having more absorption capacity.
- It can be concluded that RC beam wrapped CFRP at sides and mid-section is covered with MMC proves to be most effective design and material configuration.

## REFERENCES

[1] L. Huang, C. Zhang, L. Yan, and B. Kasal, "Flexural Behavior of U-shape FRP Profile-RC Composite Beams with Inner GFRP Tube Confinement at Concrete ", Elsevier science Publishers Ltd, Composite Structures, vol. 184, no. October, pp. 674–687, 2018

[2] Akhil R, "A Study on Recent Trends in the Applications of MMC ," vol. 6, no. V, pp. 172–180, 2018

[3] N. Sundar, "Flexural Behavior OF RC Beams with Hybrid FRP Strengthening," Elsevier science Publishers Ltd, Materials & Design, vol. 7, no. 6, pp. 427–433, 2016.

[4] S. Muniamuthu, "Investigation on Mechanical Properties of MMC," vol. 7, no. 6, pp. 474–482, 2016.

[5] S. S. Shetty and K. M. Malipatil, "Analytical Analysis on Reinforced Concrete Beam Strengthened by FRP Laminate using ANSYS," vol. 3, no. 05, pp. 1209–1212, 2015.

[6] K. S. S. Aradhya and M. R. Doddamani, "Characterization of Mechanical Properties of SiC / Ti-6Al-4V Metal Matrix Composite (MMC) Using Finite Element Method," American Journal of Material Science, vol.no 5, pp. 7–11, 2015.

[7] R. A. Hawileh, H. A. Rasheed, J. A. Abdalla, and A. K. Al-tamimi, "Behavior of reinforced concrete beams strengthened with externally bonded hybrid fiber reinforced polymer systems," Material Description, vol. 53, pp. 972–982, 2014.

[8] D. Sujan, Z. Oo, M. E. Rahman, M. A. Maleque, and C. K. Tan, "Physio-mechanical Properties of Aluminium Metal Matrix Composites Reinforced with Aluminium oxide and SiC," International Journal of Material and Metallurgical Engineering, vol. 6, no. 8, pp. 678–681, 2012.

[9] J. Dong, Q. Wang, and Z. Guan, "Structural behaviour of RC beams with external flexural and flexural – shear strengthening by FRP sheets," Composites : Part B, vol. 44, pp. 604–606, 2013.

[10] N. Attari, S. Amziane, and M. Chemrouk, “Flexural strengthening of concrete beams using CFRP, GFRP and hybrid FRP sheets,” Construction and Building Materials, vol. 37, pp. 746–757, 2012.

[11] A.K. Bhargava, "Engineering Materials", International Publishers, New Delhi, 2010

[12] S. Kumar, C. Water, and S. B. Vumethala, “Elastic modulus of Al – Si / SiC metal matrix composites as a function of volume fraction, IOP science , 2009.

[13] Jonathan A. Lee, Donald L. Mykkanen, "Metal and Polymer Matrix Composites," Noyes Data corporation, United States, 1987

[14] ANSYS, ANSYS Help Viewer, Release 18.1