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Flexural Behaviour of Sand Coated GFRP Bar Reinforcement Beam Strengthened with Fiberglass Epoxy Flat Strip

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Abstract: *This paper presents an experimental and analytical investigation of sand coated Glass Fiber-Reinforced Polymer(GFRP)barreinforcedbeamandsandcoatedGFRP-RCbeamstrengthenedwithFiberglassEpoxyFlatStrip. Inthiswork,threebeamswerecastandtested.ThebeamsweredesignatedasB1,B2,and,B3.B1wascastwithsteel reinforcement, B2 was cast with GFRP and, B3 was cast as B2 and the Fiberglass Epoxy Flat Strip was fixed using Epoxy Resin at the bottom surface. All three Beams were tested under static loading and observed the load-carrying capacity, deflection, and crack patterns. The experimental results showed that the GFRP strip could improve the structural performance of the sand coated GFRP-RC beam by increasing the load-carryingcapacity. The analytical investigation was done using the "ABAQUS" software. The outcome got from ABAQUS software was compared to experimentalresults.*

Key Word*: Reinforced concrete beams, Sand Coated GFRP bars, Fiberglass epoxy flat strip, strength, and load-deflection.*

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I. Introduction

Glass Fiber Reinforced Polymer (GFRP) is a major development in strengthened concrete structures. GFRP rebars are synthesized by using the longitudinal glass fibers and unsaturated polyester resin with 1% MEKP (Methyl Ethyl Ketone Peroxide) via manual process [1-11]. High- performance reinforced concrete (RC) structures major requirements are durability, corrosion resistance, and blast and impact resilience [1-5]. Corrosion related damage and deterioration, Fiber Reinforced Polymer (FRP) bars are considered to be an option for concrete structures as opposed toTMTbarreinforcement[1-5].FRPbarsarenon-corrosivebehavior.FRPbarsaremajorlyusedin coastal environments, bridge decks, high-performed structures, roofs, and slabs. Polymers are mostlyslippingfromconcretehencethesandcoatedtypeisusedhearandsandcoatedtypeGFRP bars are more comfort bonding to concrete. GFRP bars were used as tensile longitudinal reinforcement, 8mm dia. bars are used as shear reinforcement. Two numbers of 10mm diameter bar used as top hanger reinforcement and three numbers of 12mm diameter bar bottom reinforcement. GFRP bars are lightweight reinforcing material comparing to TMT bar reinforcement.M30gradeofconcretewasused(1:0.75:1.5)andW/Cratiois0.45.Experimental investigationoftheflexuralresponseofsandcoatedGFRPreinforcedbeamandstrengthenedwith Fiberglass epoxy flat strip. To predict the concrete and the behavior of strengthened concrete (GFRP-RC beam) using Fiberglass epoxy flat strip for strengthening schemes under monotonic increasing load. Under static loading (Flexural loading), the influence of concrete strength and reinforcement ratio on load-carrying capacity, deflection, crack pattern and failure mode of the GFRP-RC beams and strengthened with Fiberglass epoxy flat strip isinvestigated.

In this part represents the FEMs which solve the RC beams in the experimental program and the FEMs used to have the following features three-dimensional layered elements to model Fiberglass epoxy flat strip, the presence of the steel reinforcement in the tension and the compression zones, material nonlinearity of concrete, yielding of reinforcement and linearity of stress-strainrelationoftheFiberglassepoxyflatstrip.Thefullbondstrengthbetweentheconcrete and steel reinforcement was considered and the full bond was to show theABAQUS model investigated and the strengthened models. The deformation of beams is analyzed by ABAQUS software.

II. Experimental Program

2.1. Materialproperties

Concrete cylinders and cubes were cast to measure the concrete compressive strength according to the Indian Standard ofIS 516 – 1959 and IS 456 - 2000. It provides the details ofconcrete mix designs for concrete of nominal compressive strengths of 30MPa for M30 grade of concrete. Two different diameters of sand coated GFRP reinforcement bars were used. The 10mm(4NO.S) and12mm(6NO.S)diameterandtwometerslengthareinstrandedsizes.Averagetensilestrength (fu), modulus of elasticity (Ef) and rupture strain (εfu) using the universal testing machine. The GFRP reinforcement bars were loaded until failure at the rate of 1 mm/min. Strains in the bars were measured using a 100mm extensometer attached to the sand coated GFRP bars within the free length. The stress-strain behavior of the sand coated GFRP bars were found to be linear.For10mm sand coated GFRP reinforcement bars, fu=1761 MPa, εfu=3.16% and Ef=55.4 GPa. For 12mm sand coated GFRP bars, fu=1600 MPa, εfu=3.28% and Ef=47.5 GPa. Steel stirrups were used as shear reinforcement. An 8mm diameter steel reinforcement bar wasused.

2.2. Details of sand coated GFRP and TMT RCbeams

A total of two numbers of sand coated GFRP RC beams and one number of TMT beam was constructed and tested under static loading. Three beams tested under static loading to investigate the influence of the tensile GFRP reinforcement bars and TMT reinforcement bars on the flexural behavior of beams [1-5]. Three beams were constructed with M30 grade of concrete nominal compressive strength of 30MPa. TMT beam is constructed and tested because, of the experimental study of comparisons. Study comparison between TMT and GFRP RC beams.And, fiberglass epoxy flat strip was used in the sand coated GFRP beam for gained a lot of popularity overthepasttwodecades[5-9].Thiscomesdowntotheinherentmaterialpropertiesofthe FRP[9]. TMTRCbeamsdenotedasB1,GFRPRCbeamsdenotedasB2and,GFRPRCbeamswith fiberglass epoxy flat strip are denoted as B3. Test parameters investigated include midspan deflection, bending resistance, failure mode and crack patterns.

The beams are 200mm long, 228.6mm wide, 228.6mm deep. FRP flat strip is 2000mm length, 228.6mm width and 5mm deep. The reinforcements for B1 are 2NO.S of 10mm dia TMT bars as top longitudinal reinforcement, 3NO.S of 12mm dia TMT bars as bottom longitudinal reinforcementand,08mmdiaTMTbarstirrupsusedforshearreinforcements.Thereinforcements for B2 and B3 are 2NO.S of 10mm dia sand coated GFRP bars as top tensile longitudinal reinforcement, 3NO.S of 12mm dia sand coated GFRP bars as bottom tensile longitudinal reinforcement and, 08mm dia TMT bar stirrups used for shear reinforcements. Overall individual longitudinalreinforcementsare2mlength.TheTMTstirrupsare6inchsx6inchesandhooklength of 3inches. And, 7inches C/C spacing and 3inches start and end spacing. Totally 11NO.S of stirrups were used per beam. FRP strip was shown in Fig.2. The reinforcing cages are shown in Fig.(1)AsideviewandC/SoftheRCbeams(B1&B2)showninFig.3andforB3showninFig.(4). And, the area of FRP strip was shown in Fig.(5).

(a) B1reinforcement (b)B2reinforcement (c) B3reinforcement

Fig.(1) Reinforcement cages.

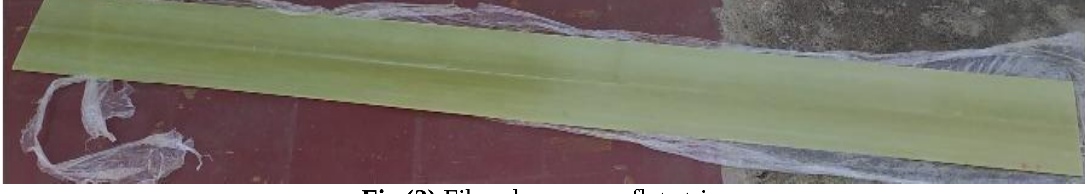

Fig.(2) Fiberglass epoxy flat strip

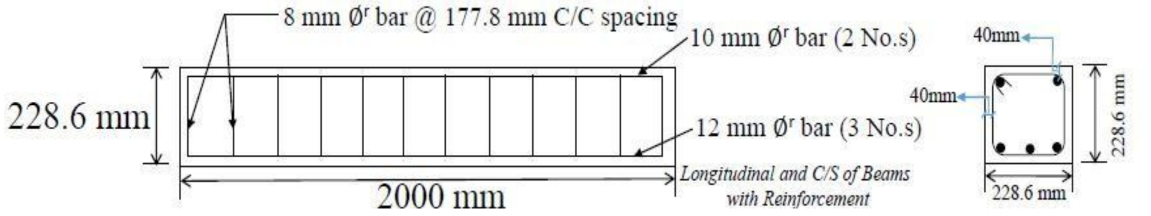

Fig.(3) Schematic of the RC beams (B1&B2)

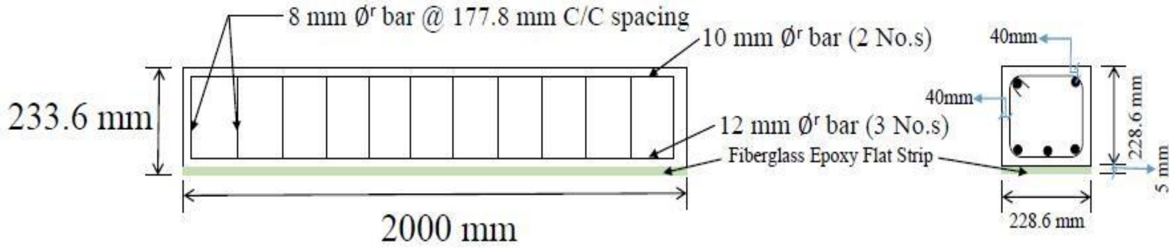

Fig.(4) Schematic of the RC beams (B3)

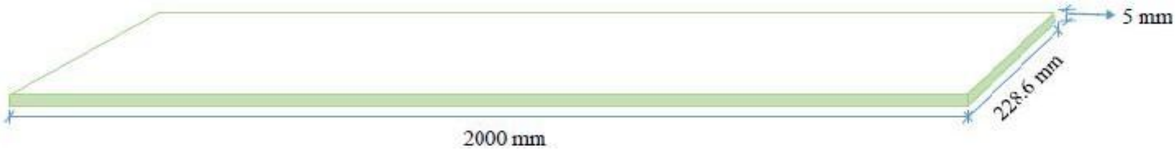

Fig.(5) Area of Fiberglass epoxy flat strip

2.3. Preparing strengthening beam specimens

The three-beam specimens were constructed are shown in Fig.(6). The strengthening of the GFRP-RC beam (B3) specimen by using a Fiberglass epoxy flat strip. The FRP flat strip was placed at the bottom surface of the concrete to study the flexural response of the GFRP-RC beam and how was the strength gained while comparing the other two beams. The bottom surface of the beam and top surface of the FRP flat strip is softened by grinding byusingan angle grinder with a disk cup blade. The epoxy resins (ARALDITE GY257 and ARADUR 140) were used to fix the FRP strip on concrete. The epoxy resins are shown in Fig.(7). The smoothened surface of the beam and coated with epoxy resin are shown in Fig.(8). And, the smoothened surface of the FRP strip and coated with epoxy resin are shown in Fig.(9). The fiberglass epoxy flat strip was fixed at the bottom surface of the beam (B3) specimen and is shown in Fig.(10) (the beam specimen is shown in Fig.(10) is inan inverted position). Now beam specimens are ready for testing.

Fig.(6) Beam(B1, B2, andB3)specimenswereconstructed

Fig.(7) EpoxyResins (ARALDITEGY257andARADUR 140)

Fig.(8) The smoothened surface ofbeam(B3)specimenwere coatedwith epoxyresin

Fig.(9) The smoothened surface ofFiberglass epoxy flatstripwascoatedwith epoxyresin

Fig.(10) Fiberglass epoxy flat stripwas fixed on beam(B3)specimen

III. Experimental Setup

3.1. Static Loading (Flexural Loading Test)

Thesetupforthebeamsareflexuralloadinginvolvedplacingthebeamsbetweentwosteel I-sectionbeamwithaspandistancesof2000mm.Thebeamsweresimplysupported(rollersupport at one end and hinged support at the other end). Then it is subjected to flexural load testing in the loading frame with 1000kN capacity of a load cell. The load was then applied manually by the hydraulicactuator.Theloadisdistributeda15mmthickironroduniformlyL/3distancesoverthe beam and I-beam (spreader beam) placed on the iron plate at the distance of L/3. Also, LVDTs werekeptatthebottomofthebeamstorecordthedeflectionofthebeams.Forcewasappliedand till the major deflection occurs. The loading frame setup was shown in Fig.(11) and, the flexural loading setup is shown in Fig.(12).

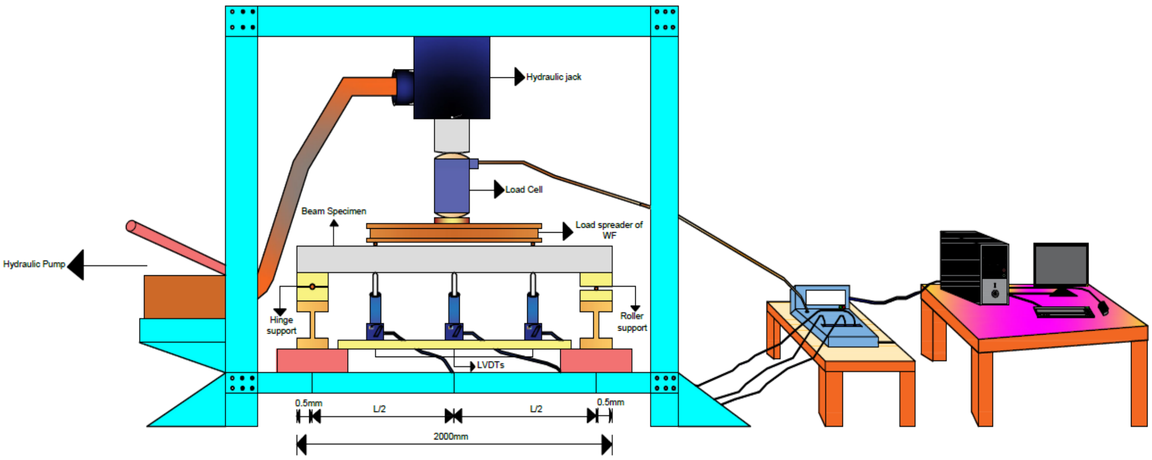

Fig.(11) Loading frame setup

Fig.(12) Flexural loading setup

3.2. Failure modes

TheRCbeamsweredesignedandfailuremodesunderflexuralloadingtest.Duringthetest beamsaredesignedunderreinforcementshowedverticalflexuralcracking,whichinitiallyformed at mid-span distance of L/3. The major cracks are formed at the distance of L/3 towards roller support. B1 fails at 40.5kN and deflection of 13mm. The sand coated GFRP RC beams fail becauseoftheruptureofGFRPreinforcementbars.B2failsat23.2kNanddeflectionof16.4mm. Thefiberglassepoxyflatstripwasplacedonthetensileconcretesurfaceofthebeam(B3).FRP flat strip debond at the endpoint of the center and spreads towards the center. It happens when a critical diagonal crack (CDC) the main shear crack interacts with the FRP flat strip closes to the end and spreads from that point [9] to at the center. B3 fails at 54kN and deflection of 32.9mm.

3.3. Crack pattern and Flexural load results

Beam1 fails at the max load of comparing of B2 because of ductility. And, B1 deflection is also very less comparatively B2. In beam2 (B2) depth and width of cracks are little more than B1.But,inB3CracksaremorecomparingthoseB1andB2andalsothestrengthoftheB3ismore than those beams. Crack patterns of the beam are shown in Fig. (13 – 15). Flexural results are tabulated in Table 1 and load vs deflection are plotted and shown in Fig.(16 –18). In, Beam1 (B1) cracks are very less and crack width is 0.1cm to 0.5cm. Beam2 (B2) crack width is 0.1 to 6cm and maximum crack depth at the point of L/3 towards the roller support. Beam3 (B2) crack width is 0.1cm to 2cm and maximum crack depth at the point of L/3 towards the roller support.

Fig.(13) The crack pattern of B1

Fig.(14) The crack pattern of B2

Fig.(15) The crack pattern of B3

Table no 1 Details of flexural test results.

Specimens	LOAD (kN)	DEFLECTION (mm)
B1	40.5	13
B2	23.2	16.4
B3	54	32.9

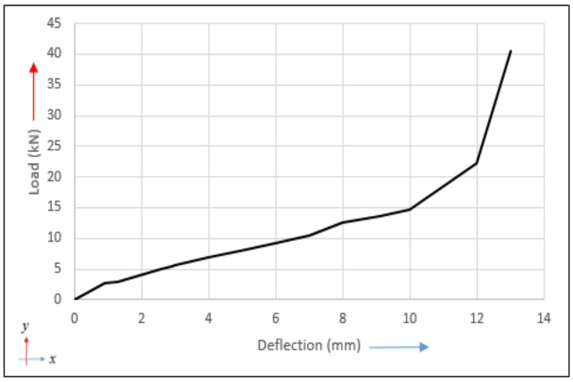

Fig.(16) Load vs DeflectionB1

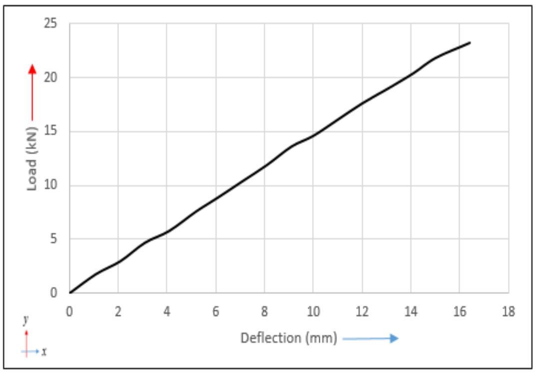

Fig.(17) Load vs Deflection B2

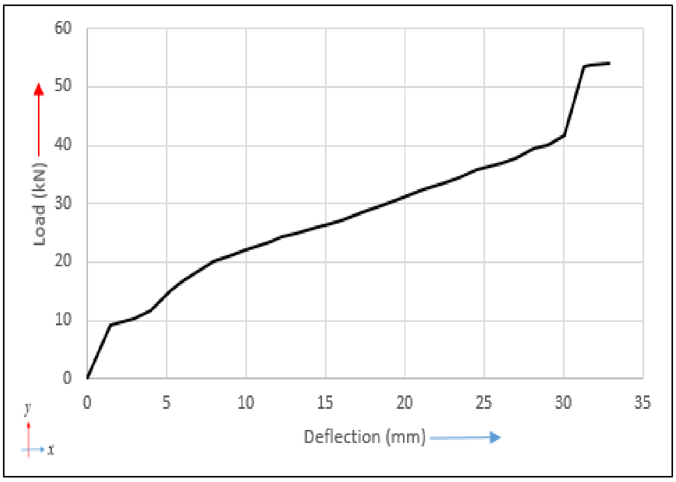

Fig.(18) Load vs Deflection B3

In experimental results beams (B1, B2, B3) graphs show the flexural results of load vs deflection. In the graph, B1 shows the max load of 40.5kN and deflection of 13mm. In the graph, B2 shows the max load of 23.2kN and deflection of 16.4mm. In the graph, B3 shows the max load of 54kN and deflection of 32.9mm. While comparing B1 and B2 the Beam1 are high load and deflection is very less in numbers. Because ductility TMT bars are used in B1 and hence it leads to a large amount of load is applicable than B2. But, B2 GFRP bars high in tensile strength and its non-bendable (Prefabricated standard bends and other shapes) hence concrete are more deflection while comparing to B1. And, comparing B1 and B3 the Beam3 have high load and deflection value because of the Fiberglass epoxy flat strip.

IV. Analytical

4.1. Analyzed in ABAQUS software

4.1.1. General

In order to simulate the actual behavior of the RC beams, all its components, concrete beams, steel bars, sand coated GFRP bars, steel stirrups, and fiberglass epoxy flat strip has to be modeled property [12-16]. By, choosing the element type, assigning property, load, supports, and meshing is important. It provides accurate results with reasonable computation time. RC beams are created as shown in Fig.(19).

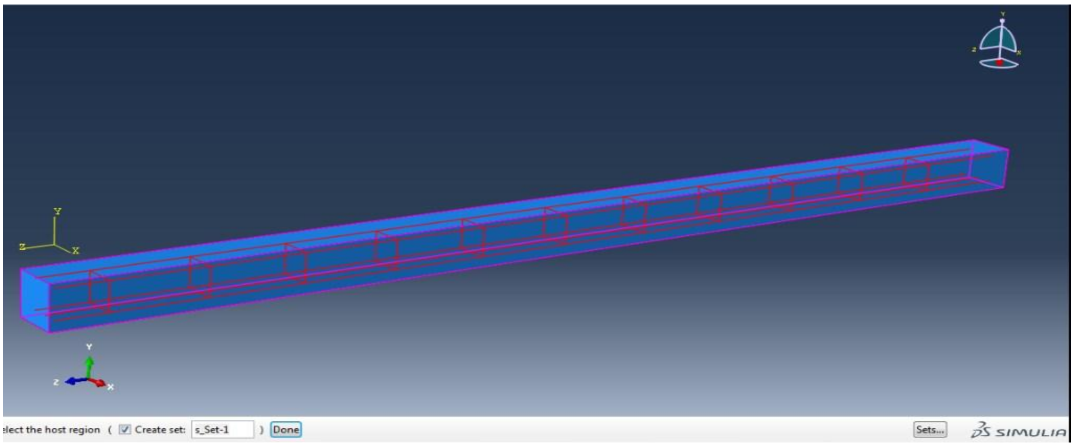

Fig.(19) ABAQUS model of RC beam

4.2. Material mode

The material type and properties of the components were assigned. The property of the RC beam shown in Table.2 and property of FRP strip shown in Table.3. The beams, reinforcement and FRP flat strip models are created by using create a part. Concrete and reinforcement property are assigned by using creating material and create the section. FRP flat strip is created and properties were assigned by using creating material and create composite layup. Reinforcement andconcretearemergedtogetherbyusingstepandinteraction.Hingedsupportandrollersupport were created by using a load. Loads were applied by using create boundary conditions. FRP strip is placed on the concrete by usinginteraction.

Table no 2 Materials properties of RC beams.

Elements	Poisson's ratio	Young's modulus (N/mm^2)
Concrete	0.2	28000
TMT bar	0.3	200000
Sand Coated GFRP bar	0.32	65000

Table no 3 Elastic (Type: Lamina) Properties of FRP flat strip.

	E1	E2	Nu12	G12	G13	G23
1	17000	900	0.34	4800	4800	4500

4.3. Meshing

Meshingisprobablythemostimportantpartofanyofthecomputersimulationsbecauseit shows the drastic change in results we get. Meshing means to create a mesh of some grid-points called 'nodes'. It's done with a variety of tools and options available in the software. The results arecalculatedbysolvingtherelevantgoverningequationsnumericallyateachofthenodesofthe mesh.Thegoverningequationsarealmostalwayspartialdifferentialequations,andfiniteelement methodisusedtofindsolutionstosuchequations.Thepatternandrelativepositioningofthenodes also affects the solution, the computational efficiency and time. In this research beam specimen, reinforcement, Fiberglass epoxy flat strip were meshed and analyzed. Meshed model of the RC beam is shown in Fig.(20).

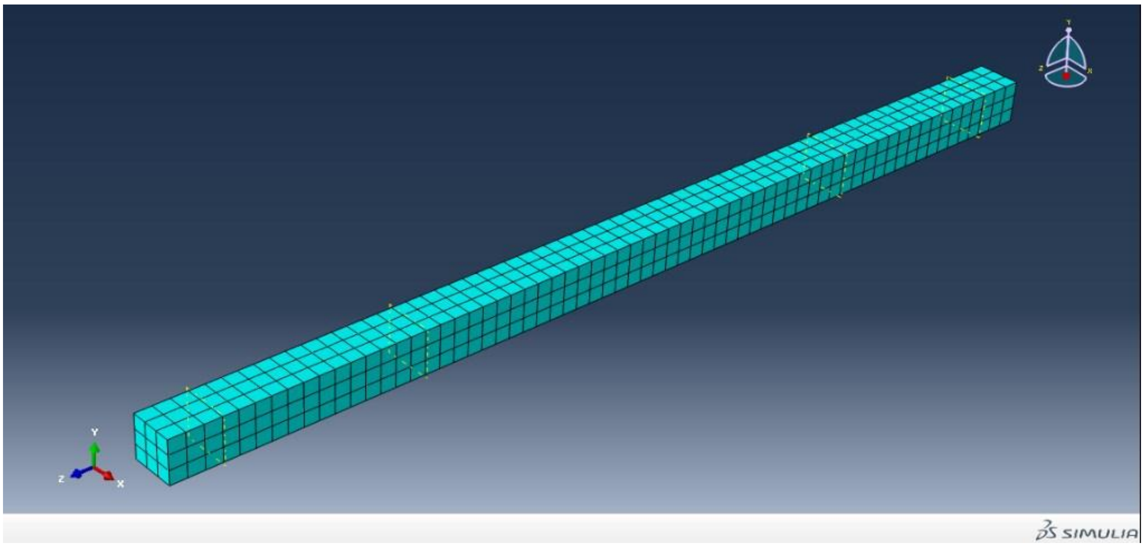

Fig.(20) Mesh model of RC beam

4.4. Method for fixing the GFRP flat strip at the bottom surface of RC beam

After creating the GFRP epoxy flat strip with its properties then, go to Model – Assembly and select Translate option to transfer the GFRP flat strip. Select the whole elements – Done. Select the end node point of GFRP and GFRP-RC beam then it got fixed. Now go to Model – Step and enter the maximum number of increments. In Module – Interaction and select Create Constrain and select the type Tie then select continue. Select the Surface option and select the GFRP flat strip – Done. Again, select the Surface option and now select only the top surface of the GFRP epoxy flat strip only – Done then select Brown for an internal face. Edit Constraint option will appear, deselect the Tie rotational DOFs if applicable and select the Use analysis default – OK. These, are the methods to fix the GFRP epoxy flat strip.

4.5. Flexural loading analysis of beam

In this analysis, beams were kept horizontal and force is as uniform pressure on the top surface of the beams. Hinged and Roller support was given side faces of the beams. Force was applieddataofexperimentalresults.Thedeflectionwasplottedintheloadvsdeflectiongraph.B1 deflectionasshowninFig.(21).B2deflection asshowninFig.(22). And,B3deflectionasshown in Fig.(23).

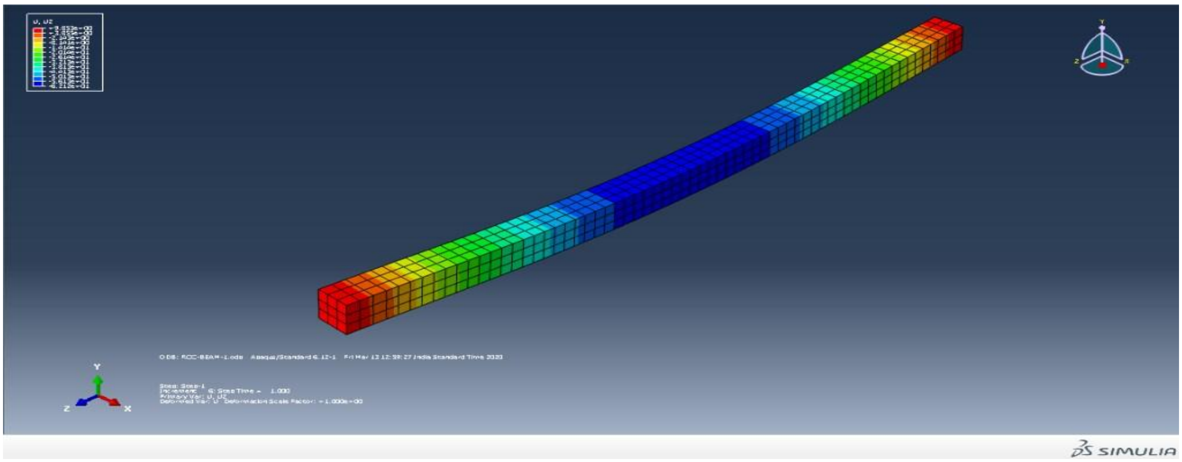

Fig.(21) Deflection of RC beam (B1) in 3D and load of 40.5kN.

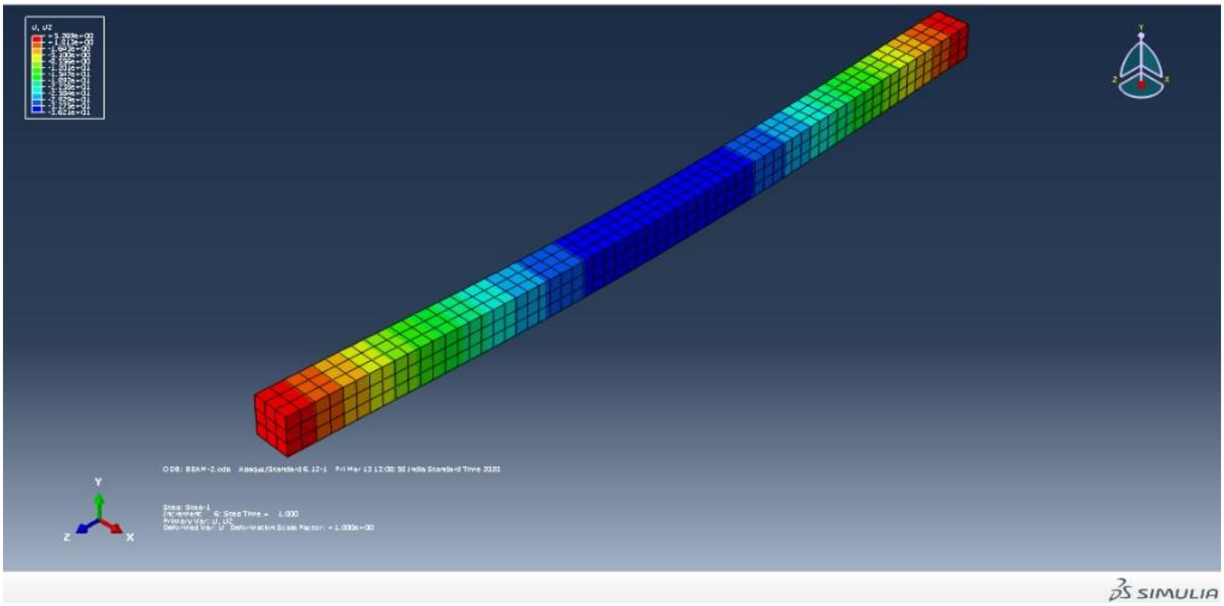

Fig.(22) Deflection of RC beam (B2) in 3D and load of 23.2kN.

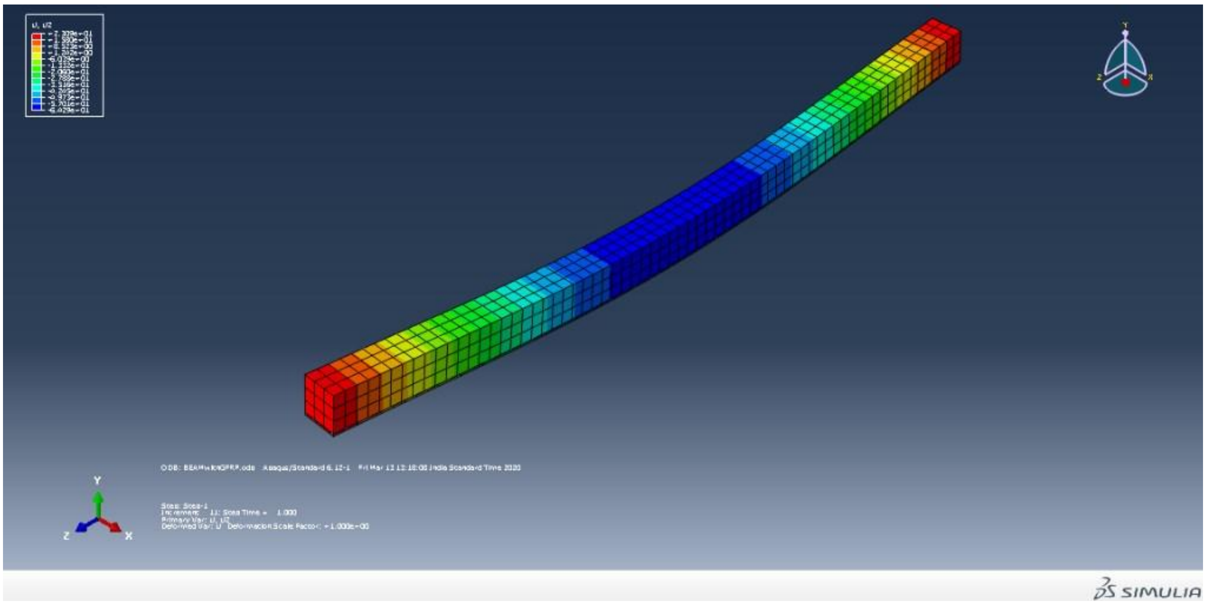

Fig.(23) Deflection of RC beam (B3) with FRP strip in 3D and load of 54kN.

4.6. Flexural loading test results

In analytical results, Beam1 fails at the max load of comparing of B2 because of ductility. And, B1 deflection is also very less comparatively B2. But, in B3 Cracks are more comparing those B1 and B2 and also the strength of the B3 is more than those beams. Flexural results are tabulated in Table 4 and load vs deflection are plotted and shown in Fig.(24 – 26).

Table no 4 Analytical results of flexural loading test

STEP	LOAD (kN)	DEFLECTION (mm)
1	40.5	7.03792
2	23.2	14.6838
3	54	20.1966

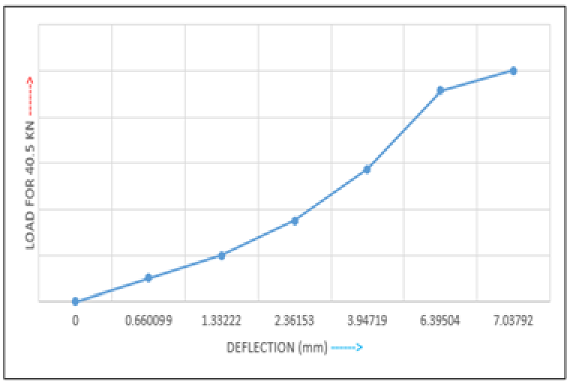

Fig.(24)A flexural loading test result of B1 @40.5kN.

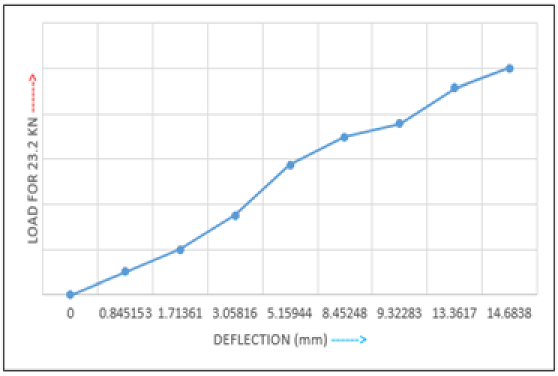

Fig.(25) A flexural loading test result of B2@23.2kN.

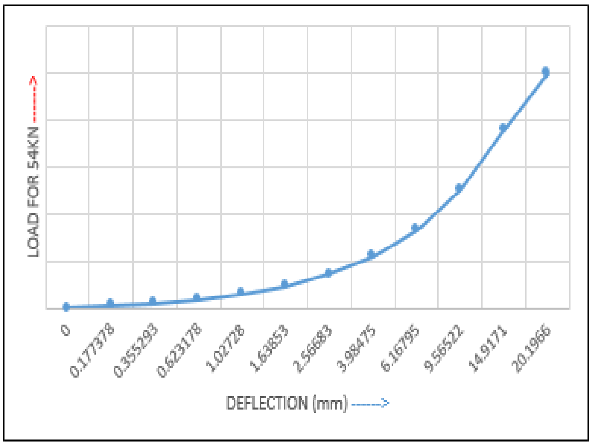

Fig.(26) A flexural loading test result of B3 @54kN.

In analytical results beams (B1, B2, B3) graphs show the flexural results of load vs deflection. In the graph, B1 shows the max load of 40.5kN and deflection of 7.03792mm. In the graph, B2 shows the max load of 23.2kN and deflectionof14.6838mm.Inthegraph,B3showsthemaxloadof54kNanddeflectionof20.1966mm.Whilecomparing B1andB2theBeam1arehighloadanddeflectionisverylessinnumbers.BecauseductilityTMTbarsareusedinB1 and hence it leads to a large amount of load is applicable than B2. But, B2 GFRP bars high in tensile strength and its non-bendable (Prefabricated standard bends and other shapes) hence concrete are more deflection while comparing toB1.And,comparingB1andB3theBeam3havehighloadanddeflectionvaluebecauseoftheFiberglassepoxyflat strip.

V. Result and Discussion

The structural behavior of the RC beams was observed by measuring the deflection by flexural loading. The performance of beams is described through flexural loading, load-carrying capacity, load-deformation response, influencing of longitudinal reinforcement, and crack patterns. A comparison of experimental and analytical results for flexural loading was tabulated and shown in Table 5.

- A good correlation was found between the analytical and experimentalresults.
- Comparisonofexperimentalandanalyticaldeflectionresultserrorpercentageisalsocalculatedandtabulated.
- Crack patterns are studied andmeasured.

Table no 5 Comparison of experimental and analytical results for flexural loading

Specimens	**Experimental results**		**Analytical results**		**Error Percentage**
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	(%)
B1	40.5	13	40.5	7.03792	5.96208
B2	23.2	16.4	23.2	14.6838	1.6838
B3	54	32.9	54	20.1966	12.7034

VI. Conclusion

The following conclusions have been drawn based on the observations from the experimental results and analytical results;

1. The failure mode of Sand coated GFRP-RC beams under static loading for flexural behavior test can be determined using a sectional analysis used for beams reinforced with a steel reinforcementbar.
2. The structural performance of sand coated GFRP-RC beams strengthened with GFRP epoxy flat strips is evaluated.
3. The experimental results showed that the GFRP strip could improve the structural performance of the sand coated GFRP-RC beam by increasing the load-carryingcapacity.
4. The improvement of structural performance due to adhesive arose from the deflection along with the GFRP- concreteinterface,inparticularthereductionindeformationconcentrationatthecenter,andbothends are fixedtightly.
5. And, deforms to the concrete structure, at maximum load of 54kN and it is notbraked. Finally,theresultsandsolutionfor GFRPflatstripsareusedforpredictingfromdeflectionofstrengthenedRC members and its type to be a novel construction material as applicable for high strength concrete and fiber reinforcedconcrete.
6. Comparing those beams in experimentally and analytically TMT-RC beam is high in flexure strength compare to the GFRP-RC beam because of ductility. But, the TMT-RC beam is compared to the GFRP-RC beam with GFRP epoxy flat strip, the FRP striped beam have higher flexuralstrength.
7. The main disadvantage of the GFRP Bar is cost because it is 20% more expensive than the TMTbar. However, GFRPbarsaremoreeffectiveintensilestrengthandyieldstrengthishigherthantheTMTbars. And, the GFRP epoxy flat strip is cheap compare to other FRPsheets.

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