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# Studies on Flexural Behaviour of Concrete Beams Reinforced with GFRP Bars

S. Yamini Roja[1], P. Gandhi[2], DM. Pukazhendhi[2] and R. Elangovan[3]

**Abstract**— Corrosion is a crucial problem in steel reinforcement which deteriorates the material when it reacts with the environment. Glass Fibre Reinforced Plastic (GFRP) rebar emerged as a promising alternative to traditional steel reinforcement with excellent results in terms of corrosion resistance. Its advantages include high longitudinal strength and tensile strength, resistance to corrosion and chemical attack, light weight and electromagnetic neutrality. In this background investigations on static behaviour of concrete beams reinforced with GFRP beams were carried out to study the flexural behaviour under static monotonic loading. Concrete beams of dimensions 1500 mm x 200 mm x 100 mm reinforced with GFRP bars were investigated to study the behaviour. For comparison purpose, concrete beams of identical dimensions reinforced with TMT bars were also investigated. The investigations were carried out using ±100 kN capacity fatigue rated MTS actuator. The various data obtained during the tests include the load, displacement, deflections at three locations along the span, rotation of the beam, strains in main reinforcement and on concrete beam surface. This paper presents the details of experimental investigations and the results.

**Index Terms**— Flexural behaviour, GFRP bar and reinforced concrete beams, TMT bar

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## 1 INTRODUCTION

In the construction industry, there is a vast demand for construction materials due to increase in population. Also, it has been reported that corrosion is one of the foremost problems in deteriorating the life of reinforced concrete structures. Though several methods have been found to overcome corrosion problems in steel, appropriate solution is not obtained. Hence it is the time to find some alternate materials as a substitute for steel reinforcement.

Fiber Reinforced Polymer (FRP) is emerging as a promising alternative for steel in preventing the corrosion problems. They are made of polymers reinforced with fibers. They are having high tensile strength, light weight and non corroding in nature. Different types of FRPs include Carbon Fiber Reinforced Polymer (CFRP), Basalt Fiber Reinforced Polymer (BFRP), Aramid Fiber Reinforced Polymer (AFRP) and Glass Fiber Reinforced Polymer (GFRP). Among these, GFRP is cost effective and proficient in structural applications.

Hence, investigations on GFRP bars are being carried out across the globe as a substitute for steel reinforcement. However, their extensive use in reinforced concrete structural engineering has been very limited, due to lack of research data and design specifications [1-5].

In this background, the investigations carried out at CSIR-SERC in the present study have thrown some light on the serviceability aspects of concrete beams reinforced with GFRP bars. Also, the present study will augment the research finding already available in this area. Further studies are being carried out on the fatigue behaviour of concrete beams with GFRP bars.

This paper investigates the flexural behaviour of concrete beams reinforced with both GFRP and TMT rebars under static monotonic loading. The load, displacement, deflection and the corresponding strain data were obtained during the static monotonic tests were also included. Load vs. deflection, load vs. strain curves and deflection profiles have been plotted based on test data.

## 2 DETAILS OF THE EXPERIMENTAL INVESTIGATIONS

### 2. 1 Test Specimens

The experimental investigations include casting and testing of six full-size beams (1500 mm length, 100 mm width and 200 mm depth). Beams were simply supported at their ends with an effective span of 1350 mm. A view of longitudinal section and cross section of a typical beam specimen is shown in Fig. 1 and Fig. 2. Hanger bars of 12 mm diameter TMT bars and 13 mm diameter GFRP bars were used for TMT reinforced and GFRP reinforced concrete beams respectively. Conventional steel stirrups (TMT) of 8 mm diameter were used at a spacing of 125 mm centre to centre on the shear span. Bottom and top concrete cover of 25 mm was maintained for all beams.

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[1] *Project Student, Dr. Mahalingam College of Engineering and Technology, Pollachi. E-mail:yaminiroja@gmail.com*
[2] *Scientist, CSIR - Structural Engineering Research Centre, Council of Scientific and Industrial Research, Taramani, Chennai. E-mail:*
[3] *Assistant Professor, Dr. Mahalingam College of Engineering and Technology, Pollachi*

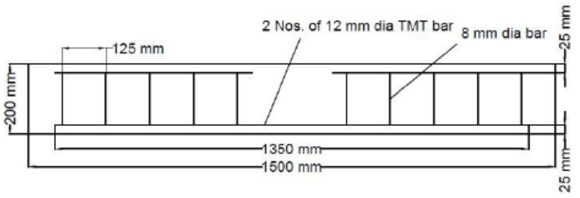

Fig. 1. A view of longitudinal cross section of the beam

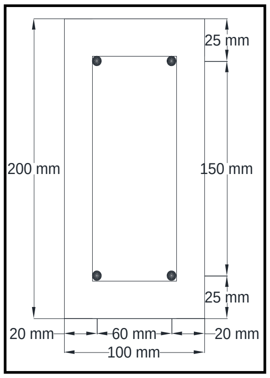

Fig. 2. A view of cross section of the beam

## 2.2 Material Properties

### 1) *Concrete*

All the test specimens were cast using a design concrete mix with a targeted 28-days concrete compressive strength of 40 MPa. The type of cement used was 53 grade Ordinary Portland Cement (OPC). The mix proportion designed as per ACI 211-4R-08 was 1 : 2.68 : 3.76 with water cement ratio of 0.55 [6]. The concrete composition for 1.0 $m^3$ of fresh concrete was 677.4 kg coarse aggregate (20 mm), 451.6 kg coarse aggregate (10 mm), 804 kg fine aggregate and 300 kg OPC. All the beams were cast and kept in the curing tank for 28 days. The average compressive strength, split tensile strength and flexural strength after 28 days were 39.6 MPa, 3.7 MPa and 5.2 MPa.[7]

### *2) Reinforcement*

Two types of reinforcing bars were used in this study: Sand-coated GFRP rods and Fe 500 grade TMT bars. The GFRP bars made of continuous E-glass fibers are manufactured by pultrusion process. Table I summarizes all the mechanical properties of the materials used in this study.

TABLE I
MECHANICAL PROPERTIES OF THE GFRP AND STEEL REINFORCING BARS USED IN THIS STUDY

| Bar type | Bar diameter (mm) | Bar area ($mm^2$) | Modulus of elasticity (GPa) | Ultimate tensile strength (MPa) |
|---|---|---|---|---|
| Fe 500 Gr. TMT | 12 | 113.1 | 200 | 630 |
| GFRP | 13 | 132.7 | 42 | 673 |

## 2.3 Reinforcement Cage

The main reinforcement bars and hanger bars were placed at correct positions and the stirrups were tied properly with binding wires before casting the concrete beams. The reinforcement cage of GFRP bars before casting is shown in Fig. 3 and that of TMT bars is shown in Fig. 4.

In total six beams were casted among which three beams were reinforced with GFRP bars and the remaining three beams were reinforced with TMT bars.

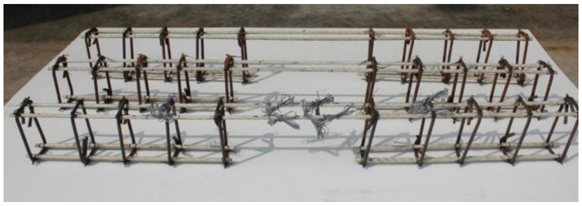

Fig. 3 A view of GFRP reinforcement cages

Fig. 4. A view of TMT reinforcement cages

In order to obtain the strains at the reinforcement level, five strain gauges of gauge length 5 mm were fixed to each of the tension reinforcement bars. Concrete surface strains were measured at a distance of 25 mm from the extreme compression face and at a distance of 25 mm from the extreme tension face by fixing strain gauges of gauge length 60 mm on the beam surface. Fig. 5 shows the plan view of locations of strain gauge on the tension reinforcement and Fig. 6 shows a view of strain gauge fixed to the surface of the concrete. The strain gauges were fixed to the reinforcement using a cyanoacrylic based adhesive and to the surface of the beams using C-N type adhesive and covered with a protective coating material.

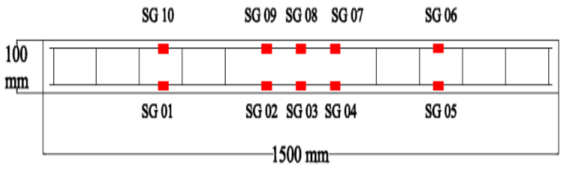

Fig. 5. Plan view of the locations of strain gauge on rebars (tension side)

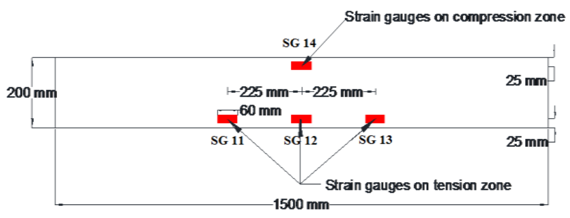

Fig. 6. Strain gauges locations on surface of concrete

## 2.4 Loading Arrangement

The beams were simply supported with an effective span of 1350 mm. Two point loads were applied at a distance of 225 mm from the centre of the beams to get pure flexure at the middle third portion of the beams.

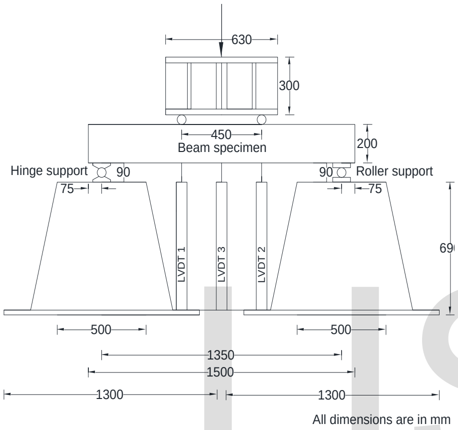

Fig. 7. Schematic diagram of loading arrangement

The deflection readings were taken using three numbers of Linear Variable Differential Transformers (LVDT). The loading arrangement is shown in Fig 7. The load was applied through a servo hydraulic actuator of ± 100 kN capacity. The various data acquired during the test include the load, deflection of the beams at three locations, strains in the main reinforcement and on the concrete surface.

## 2.5 Experimental Set-Up

The beams were tested using a servo controlled hydraulic actuator of ±100 kN capacity. The beams were simply supported with an effective span of 1350 mm. To measure the deflection, three Linear Variable Differential Transformers (LVDT) and three dial gauges were used for GFRP and TMT reinforced concrete beams respectively. For GFRP reinforced concrete beam, one LVDT was placed at the mid span of the beam and the other two LVDTs were placed at a distance of 225 mm from the mid span of the beam. Similarly dial gauges were placed instead of LVDTs in case of TMT reinforced concrete beams. For all beams, three surface strain gauges were fixed on concrete surface tension zone and one in compression zone of gauge length 60 mm to measure the variation of strain during loading. Initially a jack load of 2 kN was applied and released to check whether all the LVDTs are working. The jack load was gradually increased from zero to the load till the ultimate load at a loading rate of 0.02 mm/ sec. After the test was over the cracks on the surface of the beams was marked with a marker and then photographs were taken. Fig. 8 shows a view of test setup.

# 3. TEST RESULTS AND OBSERVATION

## 3.1 General Observations

Three numbers of concrete beams reinforced with GFRP bars and three numbers of concrete beams reinforced with TMT bars were subjected to static monotonic loading to study their flexural behaviour. Cracks were initiated on the tension face of the beams and propagated towards the compression face with the increase in load. The concrete beams reinforced with GFRP bars failed catastrophically due to snapping of the GFRP bars in the pure bending zone whereas the concrete beams reinforced with TMT bars failed gradually in the pure bending zone. The various observations during the static monotonic tests on three beams reinforced with GFRP bars and three beams with TMT bars are given in Table II.

Fig. 8 Experimental set up

## 3.2 Analysis Of Test Results On Flexural Behaviour Of Concrete Beams Reinforced With GFRP And TMT Bars

The performance of the GFRP and TMT reinforced concrete beams were analyzed using various parameters like deflection, displacement, strain variation in the reinforcement as well as on the concrete surface, moment, curvature, etc.

*1) Load vs. deflection relationship*

The deflection at mid span of the beams at crack initiation and ultimate load is given in Table III.

The load vs. deflection curves at the mid span of the beam are shown in Fig. 9 for the specimens GFRP-1S, GFRP-2S, GFRP-3S, TMT-1S, TMT-2S and TMT-3S respectively.

### 2) *Ultimate load*

The load carrying capacities of the beams are given in Table IV. The average value of ultimate loads for all the beams reinforced with GFRP bars was 82.9 kN. GFRP-1S reached the highest ultimate load. Similarly in case of beams reinforced with TMT bars, the average value of ultimate loads was 97.6 kN. TMT-3S reached the highest ultimate load.

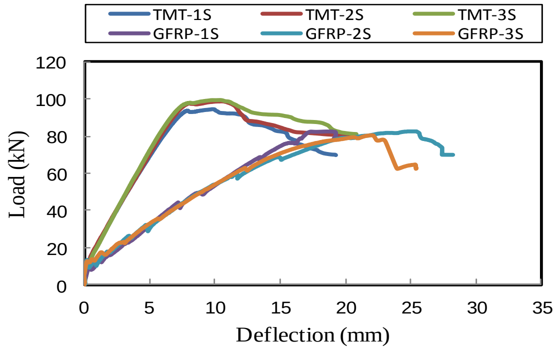

Fig. 9. Load vs. deflection at mid span

TABLE II
OBSERVATIONS OF READINGS AT ULTIMATE LOAD

| Beam designation | Ultimate load *(kN)* | Bending moment *(kN-m)* | Deflection *(mm)* | Tensile strain *(μm/m)* |
|---|---|---|---|---|
| GFRP-1S | 85.9 | 19.3 | 20.2 | 14049 |
| GFRP-2S | 82.5 | 18.6 | 25.2 | 16886 |
| GFRP-3S | 80.3 | 18.1 | 22.0 | 16672 |
| TMT-1S | 94.7 | 21.3 | 9.8 | 6534 |
| TMT-2S | 98.6 | 22.2 | 10.6 | 5245 |
| TMT-3S | 99.5 | 22.4 | 10.4 | 3945 |

No.1, 2 and 3 denotes the beam designation number; S denotes the static test

TABLE III
DEFLECTION AT MID SPAN OF THE BEAM

| Sl. No. | Beam designation | At crack initiation $\delta_{cr}$ (mm) | At ultimate load $\delta_u$ (mm) |
|---|---|---|---|
| 1 | GFRP – 1S | 0.9 | 20.2 |
| 2 | GFRP – 2S | 1.1 | 25.2 |
| 3 | GFRP – 3S | 0.2 | 22.0 |
| 4 | TMT – 1S | 0.6 | 9.8 |
| 5 | TMT – 2S | 1.2 | 10.6 |
| 6 | TMT – 3S | 1.0 | 10.4 |

TABLE IV
LOAD CARRYING CAPACITIES OF THE BEAMS

| Sl. No. | Beam designation | Crack initiation load ($P_{cr}$) in *kN* | Ultimate load ($P_u$) in *kN* |
|---|---|---|---|
| 1 | GFRP – 1S | 10.1 | 85.9 |
| 2 | GFRP – 2S | 12.0 | 82.5 |
| 3 | GFRP – 3S | 12.1 | 80.3 |
| 4 | TMT – 1S | 15.9 | 94.7 |
| 5 | TMT – 2S | 24.0 | 98.6 |
| 6 | TMT – 3S | 20.6 | 99.5 |

### 3) *Deflection profile of beam specimens*

The deflection profile of GFRP reinforced concrete beams at ultimate load was drawn to recognize its flexural behaviour. Fig. 10 shows the deflection profile for ultimate load of GFRP reinforced beams.

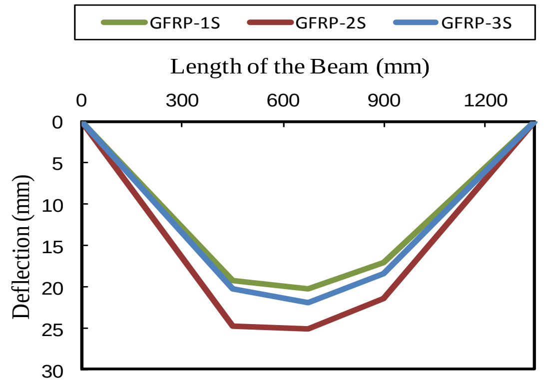

Fig. 10. Deflection profile for ultimate load of GFRP beams

For comparison purpose, the deflection profile of TMT reinforced concrete beams at ultimate load was drawn to recognize its flexural behaviour. Fig. 11 shows the deflection profile for ultimate load of TMT reinforced beams.

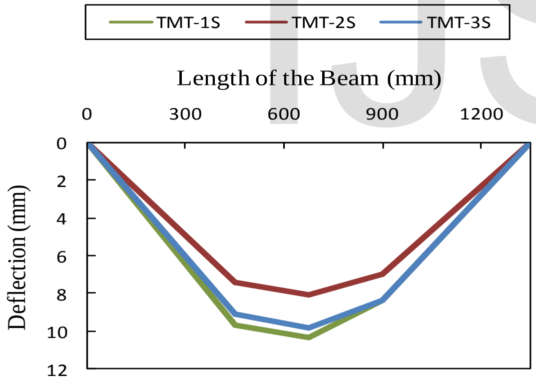

Fig. 11. Deflection profile for ultimate load of TMT beams

### 4) *Strain distribution*

The strain in the tension bars was observed with the help of strain gauges fixed on the tension reinforcement. The strain variation in the compression and tension faces of the beam was observed from the strain gauges fixed on the concrete surface. From the load – strain curves, it can be seen that after crack initiation there was a considerable increase in the strain value of GFRP bars. Ultimate compressive strain in concrete and tensile strain in the reinforcement is shown in Table V.

Load vs. strain behaviour for typical GFRP and TMT reinforced beam is discussed below.

#### i) *Beam specimen GFRP–1S*

The load vs. strain behaviour of GFRP-1S at the reinforcement is shown in Fig. 12(a) and Fig. 12(b). The load vs. strain behaviour of GFRP-1S at concrete surface is shown in Fig. 13. It was observed that there was a steady increase in the strain values. It was also observed that strain 2 and strain 10 reached the maximum strain values at the tension reinforcement and strain 12 reached the maximum strain at the concrete surface.

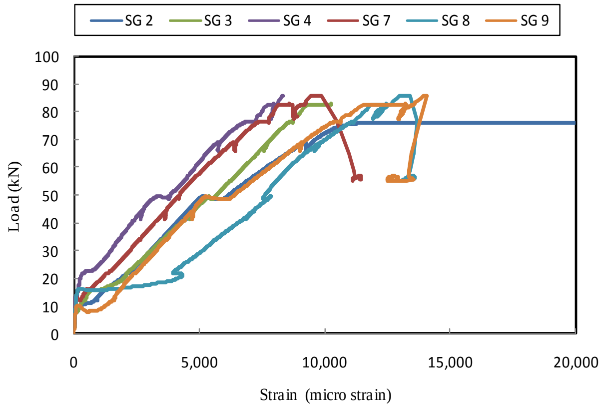

Fig. 12(a). Load vs. strain at the reinforcement for specimen GFRP1S (Refer Fig. 5)

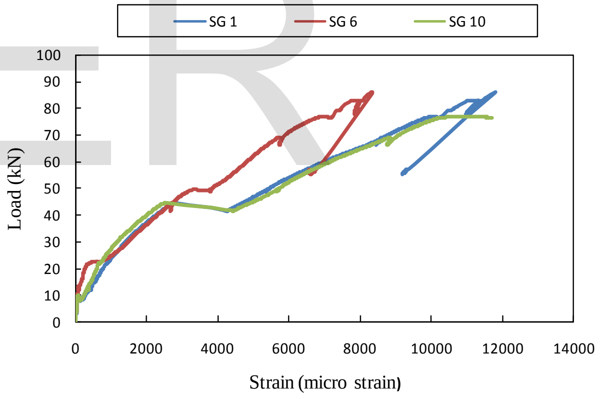

Fig. 12(b). Load vs. strain at the reinforcement for specimen GFRP-1S (Refer Fig. 5)

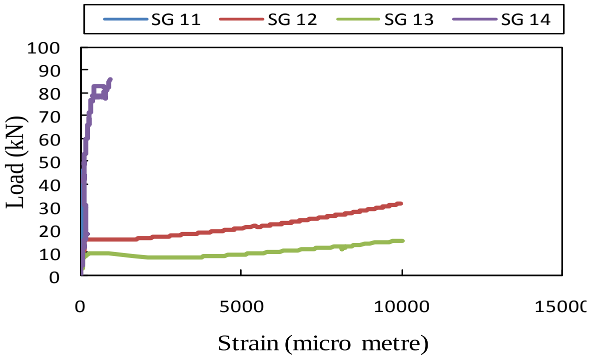

Fig. 13. Load vs. strain at concrete surface for specimen GFRP-1S (Refer Fig. 6)

### *ii) Beam specimen TMT–1S*

The load vs. strain behaviour of TMT-1S at the reinforcement is shown in Fig. 14(a) and Fig. 14(b). The load vs. strain behaviour of GFRP-1S at concrete surface is shown in Fig. 15. It was observed that there was a steady increase in the strain values. It was also observed that strain 3 and strain 8 reached the maximum strain values at the tension reinforcement and strain11 reached the maximum strain at the concrete surface.

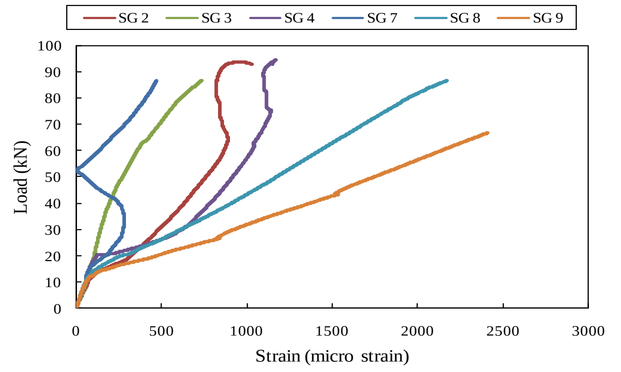

Fig. 14(a). Load vs. strain at the reinforcement for specimen TMT-1S (Refer Fig. 5)

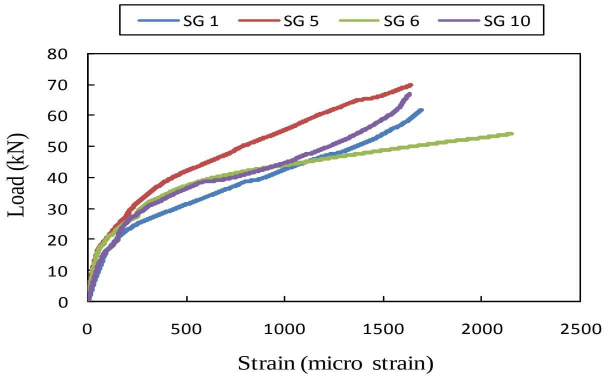

Fig. 14(b). Load vs. strain at the reinforcement for specimen TMT-1S (Refer Fig. 5)

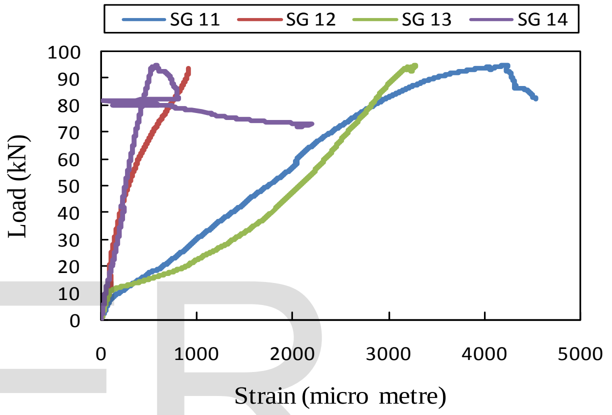

Fig. 15. Load vs. strain at concrete surface for specimen TMT-1S (Refer Fig. 6)

## TABLE V
## ULTIMATE COMPRESSIVE STRAIN ON CONCRETE SURFACE AND TENSILE STRAIN IN THE REINFORCEMENT BARS

| Sl. No. | Specimen | Compressive strain of concrete corresponding to ultimate load (micro strain) | Tensile strain of reinforcement corresponding to ultimate load (micro strain) |
|---|---|---|---|
| 1 | GFRP-1S | 880 | 14049 |
| 2 | GFRP-2S | 241 | 16886 |
| 3 | GFRP-3S | 821 | 16672 |
| | Average | 647 | 15869 |
| 4 | TMT-1S | 598 | 6534 |
| 5 | TMT-2S | 964 | 5245 |
| 6 | TMR-3S | 53 | 3945 |
| | Average | 538 | 5241 |

### *5)Moment curvature behaviour*

The moment curvature relationship for the beams reinforced with GFRP bars are shown in Fig. 16 and the beams reinforced with TMT bars are shown in Fig. 17. Moment at crack initiation and ultimate moment of resistance for all the beams is shown in the Table 6. The curvature Φ (rotation per unit length) was determined using the relation:

$$\Phi = \frac{(\varepsilon_c + \varepsilon_{st})}{d}$$

Where

$\varepsilon_c$ is the compressive strain in the extreme concrete fiber;

$\varepsilon_{st}$ is the strain in the tension steel;

d is the effective depth of the beam section.

TABLE VI
MOMENT AT FIRST CRACK AND ULTIMATE LOAD

| Sl. No. | Beam ID | Moment at first crack (kN–m) | Moment at ultimate load (kN-m) |
|---|---|---|---|
| 1 | GFRP-1S | 2.3 | 19.3 |
| 2 | GFRP-2S | 2.7 | 18.6 |
| 3 | GFRP-3S | 2.7 | 18.1 |
| 4 | TMT-1S | 3.6 | 21.3 |
| 5 | TMT-2S | 5.4 | 22.2 |
| 6 | TMT-3S | 4.6 | 22.4 |

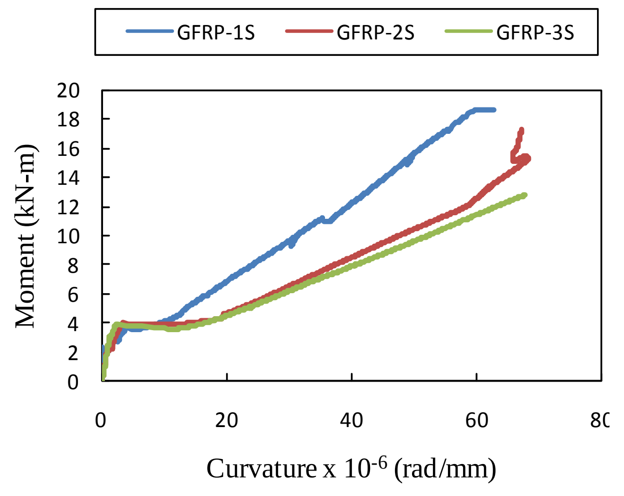

Fig. 16. Moment vs. curvature of GFRP reinforced beams

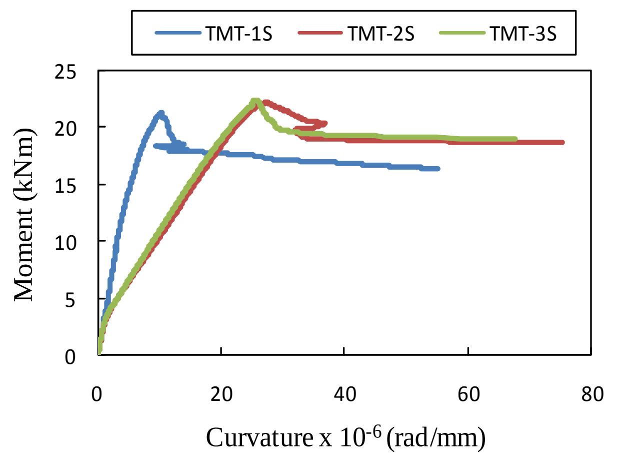

Fig. 17. Moment vs. curvature of TMT reinforced beams

## 4. CONCLUSION

Due to the low modulus of elasticity of GFRP bars, the crack initiation load was found to be early in beams with GFRP reinforcement when compared to beams with conventional TMT reinforcement. The average values of crack initiation loads for beams with GFRP and TMT reinforcement were 11.4 kN and 20.1 kN respectively. Similarly, the average values of ultimate load carrying capacity for beams with GFRP and TMT reinforcement were 82.9 kN and 97.6 kN respectively.

A reduction of 15.1 percent in ultimate load carrying capacity was found in beams with GFRP reinforcement when compared with the conventional beams with TMT reinforcement. Similarly, an increase in average deflection at the ultimate load to an extent of 54.2 percent was observed in beams with GFRP reinforcement when compared with the conventional beams with TMT reinforcement.

Currently, the usage of the GFRP bars is limited only to a few structures, due its limitation of serviceability criteria and further research is in progress across the globe on the acceptability of GFRP bars in the construction industry.

## 5. ACKNOWLEDGEMENT

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