Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 2 (2023) 326-337
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**RTCEBE**

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

# Finite Element Analysis of Glass Fiber Reinforced Plastic Concrete Beam Strengthened with Polymer Plate

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DOI: https://doi.org/10.30880/rtcebe.2023.04.02.037
Received 06 January 2022; Accepted 15 January 2023; Available online 20 July 2023

**Abstract**: The uses of the steel reinforced concrete beam in construction are popular. However, the major problem of using the conventional beam structure is due to the corrosion that tends to produce a damaged structure affected by the cracking and leads to reducing the service life of the structure. GFRP bar was chosen to replace the steel reinforcement in concrete structures because of its superior corrosion resistance, high tensile strength, lightweight, low thermal conductivity, and high specific strength. Unfortunately, the GFRP bar has produced a larger deflection and cracking due to the low modulus of elasticity. To overcome this problem, strengthening materials have been used to improve the ductility, flexural, and shear capacity of the structural elements. In this study, four types of different fiber polymer plates such as carbon, aramid, glass, and kenaf are used to investigate the flexural behaviour of the beam structure and determine the type of failure that occurred. Each type of material was investigated by placing the polymer plates under the beam with different length ratios and different weights to determine the ultimate load for each beam. The study was conducted by using ATENA Software and the result has been validated with the experimental data. The result obtained showed that the CFRP plate with a length ratio of 0.8 is suitable to be used as the strengthening material to minimize the deflection of the GFRP concrete beam structure.

**Keywords**: GFRP Bar, Flexural Behaviour, Cracking Pattern

## 1. Introduction

Regularly, the uses of the steel-concrete beam in construction are popular including in civil engineering works. A combination of steel reinforcement that is strong in tension with concrete that is strong in compression can become a highly durable structure. However, the steel reinforced concrete structure also can lead to corrosion due to the cracking that happened on the structure. Corrosion is a common problem that always happened to steel reinforcement and it will affect the whole structure behaviour then collapse probably happen. Thus, the GFRP bar has been used to replace the steel reinforcement

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because of its superior corrosion resistance, high tensile strength, lightweight, low thermal conductivity, and high specific strength [1]. However, the lack of using GFRP is low in elasticity along with their non-yielding properties and leads to massive deflection and extensive cracking. However, strengthening materials were used to improve the ductility, flexural, and shear capacity of all structural elements [2]. The common FRP materials used for the strengthening and repairing material were carbon fiber reinforced polymer (CFRP) compared to glass fiber reinforced polymer (GFRP), aramid fiber reinforced polymer (AFRP), or kenaf fiber reinforced polymer (KFRP). It is widely used in the construction industry due to its superior mechanical qualities, as well as greater tensile strength, stiffness, and durability.

The purpose of this study was to model the glass fiber reinforced plastic concrete beam strengthened with polymer plate by using finite element software, to verify the finite element modeling with experimental data in term of flexural behavior, and to investigate the effects of strengthening glass fiber reinforced plastic (GFRP) concrete beam with various materials and lengths of plates. This study was conducted by using ATENA Software by designing a beam structure reinforced with GFRP bar and different FRP plates such as carbon, aramid, glass, and kenaf were placed under the beam with the different length ratios. The result of each specimen has been compared to find a suitable plate to prevent the large deflection and cracking that occurred on the GFRP concrete beam structure.

## 2. Literature Review

### 2.1 Glass Fiber Reinforced Polymer (GFRP)

Glass fiber reinforced polymers (GFRP) is a composite that made up of polyester resins which contain fiber filament and resin matrix where it used as matrix binder because of their low viscosity, rapid treatment time, dimensional stability, high chemical resistance, and low cost compared to other materials [3]. Thus, as a binding agent, matrix or polyester resin has been added to establish dimensional stability and hold fiber together. Besides, because of its outstanding corrosion resistance, high tensile strength combined with low elastic modulus and elastic brittle stress-strain relationship up to failure, and superior non-magnetization qualities, the application of FRP reinforcements in concrete structures has expanded quickly [4]. GFRP bars are also extremely durable with tensile strength up to 5-6 times than structural steel.

### 2.2 Fiber Reinforced Polymer (FRP)

The composites reinforced with the fiber of synthetic or natural material are becoming increasingly popular as the market grows in demand for lightweight materials with high strength for specific purposes [5]. Fiber Reinforced Plastic or Fiber Reinforced Polymer (FRP) is a composite material composed of a polymer matrix reinforced with fibers. The polymer that is usually used is epoxy, vinyl-ester, or polyester-thermosetting plastic, as well as phenol formaldehyde resins [6]. The replacement into fiber reinforced plastic composites as the strengthening material gives more advantages to the structure compared to conventional methods such as can reduce the construction cost, maximizing the speed of the construction process, effecting the minimizing the environmental impact [7]. It is also high strength to weight ratio which is leading to ease of installation and become faster in transportation as well as have excellent qualities including great durability, stiffness, damping property, flexural strength, and corrosion resistance, wear, impact, and fire [8]. In addition, FRP composites tend to extend the service life of existing structures while also safeguarding new structures from aging, corrosion, and deterioration in the service environment compared to conventional materials [9].

### 2.3 Finite Element

Finite element analysis (FEA) is the process of simulating the behaviour for some given condition. ATENA Software is used as it is excellent in verifying the critical load of reinforcement design. Furthermore, ATENA's modeling is accomplished in two stages that consist of pre-processing and post-processing where geometrical models, material choices, and boundary conditions are all included in the pre-processing stage and the model for finite element analysis has been generated with the fully automated mesh generator [10]. The specimen's FE model is studied in a plane stress condition with non-linear constitutive rules for concrete and reinforcement.

## 3. Methodology

### 3.1 Finite Element Model

In this study, a three-dimensional scheme of finite element analysis was used to simulate GFRP reinforced concrete beams strengthening with different plates in this ATENA Software. Only one-quarter of the beam was simulated due to the symmetry of the geometry, loading, and boundary condition in two perpendicular planes. So, computational cost can be minimized due to modeling only the half of the beam's length. By using the completely automated mesh generator, the analytical model of the finite element analysis is produced during pre-processing [11]. Figure 1 shows the geometry of the FE mesh of the beams strengthened with the plate.

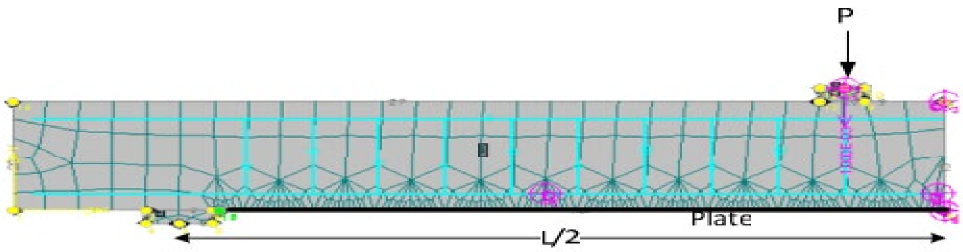


**Figure 1: Geometry of the FE mesh of the beams strengthened with plate**

### 3.2 Details of Specimen

This study was focused only on a simply supported beam that used pinned and roller supports at the end of the beam. All specimens were 2800 mm long span with a rectangular cross-section of 200 mm x 250 mm and 30 mm of the concrete cover was used. For the control beam that uses the steel reinforcement bar, 12 mm of diameter steel bar has been placed at the bottom of the beam structure while the diameter of 8 mm has been used for the compression bar and 8 mm diameter of the steel bar also has been used as the stirrups for the concrete beam with the spacing of 100 mm. However, the diameter used for the GFRP reinforcement bar is 13 mm. Then for the strengthened GFRP reinforced concrete beam, there are sixteen specimens included which were strengthened with different types, and lengths of plates have been constructed and analyzed. The different plates used included carbon, aramid, glass, and kenaf fiber plates, and each plate was placed with a different length which is 2100 mm, 1680 mm, 1260 mm, and 840 mm at the middle of the beam.

Each plate used for this beam was designed with a thickness of 1.4mm and the epoxy paste called SikaCarboDur30 used was 3 mm of thickness which acts as the adhesive for bonding the concrete beam and the plate. The gap between the middle of support and the plate placed was started with 50 mm depending on the ratio of length. To analyze the deflection of each beam, there were two-point loads have been placed at the middle of the beams and the ultimate load for each beam can carry been recorded and presented in graphs. Figure 2 shows the cross-section of the GFRP reinforced concrete beam while Table 1 shows the material properties for control reinforcement bars used.

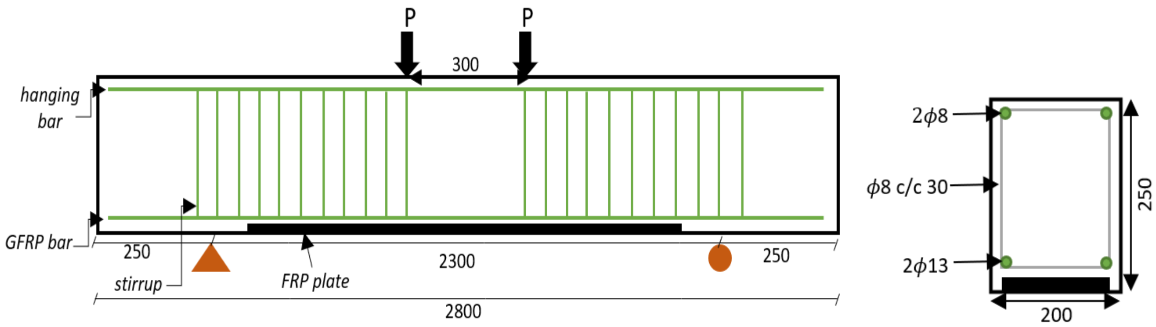


**Figure 2: Cross-section of the GFRP reinforced concrete beam**

**Table 1: Material properties of control reinforcement bars**

| Type of reinforcement | Steel Bar | GFRP Bar | Stirrups |
|---|---|---|---|
| Stress-strain Law | Bilinear | Linear | Bilinear |
| Diameter of bar, *d* (mm) | 12 | 13 | 8 |
| Elastic Modulus, *E* (MPa) | 200000 | 44100 | 162000 |
| Tensile Strength, σ (MPa) | 617 | 920 | 277 |

3.3 Strengthening Material

Different types of plates materials used as the strengthening consist of Carbon Fiber Reinforced Polymer (CFRP), Aramid Fiber Reinforced Polymer (AFRP), Glass Fiber Reinforced Polymer (GFRP), and Kenaf Fiber Reinforced Polymer (KFRP). For this study, the mechanical properties for each material used in ATENA Software are shown in Table 2.

**Table 2: Material properties of strengthening material**

| Type of fiber | CFRP | AFRP | GFRP | KFRP |
|---|---|---|---|---|
| Modulus of elasticity (MPa) | 165 | 124 | 73 | 53 |

3.4 Geometric Study

The ratio of the plate produced from this formula will consist 1.0, 0.8, 0.6, and 0.4. For this purpose, the type of failure that occurred at a certain length are recorded and analyzed.

$$Plates\ ratio: \frac{L_{plates}}{L_{beam}} \qquad Eq.\ 1$$

Thus, the load-deflection relationship data of the control beam obtained from the finite element analysis software which was from ATENA were validated against the experimental results [4]. Also, the results obtained for the strengthened beam for each plate have been compared including the load-deflection curves and the mode of failure that occurred.

## 4. Results and Analysis

This study was to determine the effects of strengthening the glass fiber reinforced plastic (GFRP) concrete beam with various materials and length of plates in terms of ultimate load deflection and cracking pattern occurred.

4.1 Validation of Control Beam

The result from ATENA Software has been validated with experimental data conducted in the laboratory using linear variable displacement transducer (LVDT) which was the equipment used to measure the large displacement [12]. Figure 3 and figure 4 show the comparison of the control beam graph for the GFRP bar and steel bar obtained from ATENA and experimental data.

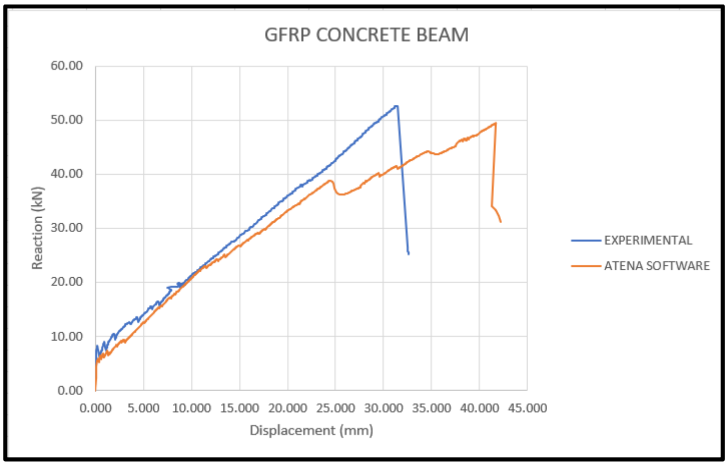


**Figure 3: Graph of control beam of GFRP bar**

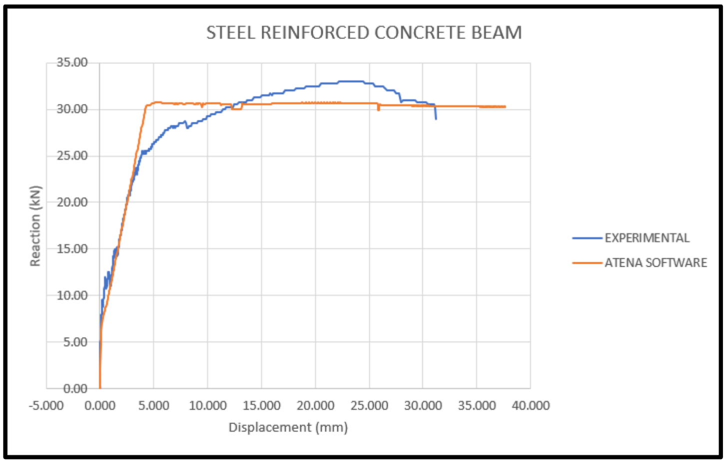


**Figure 4: Graph of control beam of steel bar**

The result from the graph in Figure 3 shows that the control beam of the GFRP bar that was analyzed by conducting an experiment has slightly different in terms of loading which was compared to ATENA Software. The ultimate load that applied for the GFRP bar in experimental is 52.50 kN with the deflection produced is 31.33 mm while the result for ATENA is 49.41 kN and deflection is 41.70 mm. Then the beam structure that uses the steel bar as shown in Figure 4, the ultimate load applied for experimental analysis is 33.00 kN with the deflection occurred was 22.19 mm. Also, the maximum load applied in ATENA Software is 30.80 kN with a deflection of 5.32 mm. The result for both data is slightly different due to some error occurred during running the experimental in the laboratory such as human error, machinery error or perimeter used is slightly different during running the software including the mechanical properties of materials.

GFRP bar was used to replace the steel reinforcement bar in the concrete beam structure due to the corrosion resistant provided to make the structure strong for a long period. However, the stiffness of the GFRP was lower than the steel bar and leads to a larger deflection. Figure 5 below shows the graph of the load-deflection relationship of the steel bar and GFRP bar. The deflection produced by the GFRP bar concrete beam was 41.70 mm with a load was 49.41 kN while the deflection for the steel bar was

5.32 mm with the load was 30.80 kN. Based on the comparison, there was a large difference between the deflection that occurred for both bars used and leads to a wider crack width of the beam.

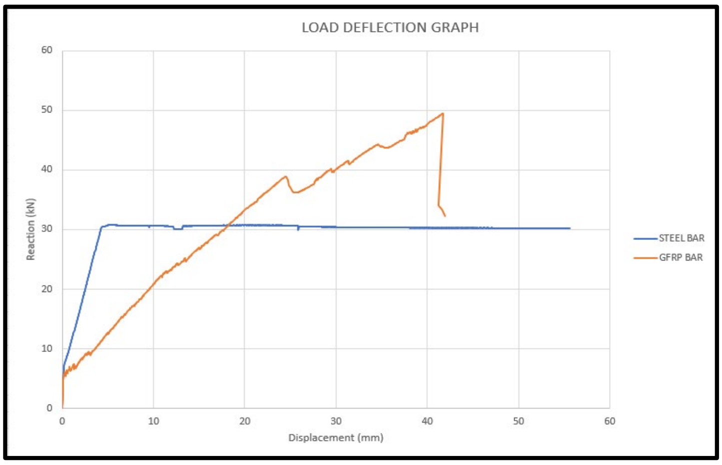


**Figure 5: Graph of control beam of steel bar and GFRP bar**

4.2 Data Collection

Table 3 illustrates the ultimate load, deflection value, and the types of failure for each specimen. The data shows that the optimum length of the plate that can be used as the strengthening material for the glass fiber reinforced plastic concrete beam (GFRP) is 0.8 or 1680 mm over 2300 mm with the overall type of failure being internal debonding.

**Table 3: Data collection**

| Group | Type of Materials | Specimen | Plate Ratio | Ultimate Load (kN) | Deflection at Ultimate Load (mm) | Type of Failure |
|---|---|---|---|---|---|---|
| - | STEEL BAR | CONTROL | - | 30.80 | 5.32 | Flexural |
| - | GFRP BAR | CONTROL | - | 49.41 | 41.70 | Flexural |
| 1 | CFRP | CFRP 1 | 1.0 | 107.60 | 25.81 | Flexural |
| | | CFRP2 | 0.8 | 111.60 | 85.74 | Debonding |
| | | CFRP 3 | 0.6 | 99.26 | 130.80 | Debonding |
| | | CFRP 4 | 0.4 | 77.33 | 157.90 | Debonding |
| 2 | AFRP | AFRP 1 | 1.0 | 100.90 | 28.91 | Flexural |
| | | AFRP 2 | 0.8 | 96.08 | 47.66 | Debonding |
| | | AFRP 3 | 0.6 | 70.26 | 45.79 | Flexural |
| | | AFRP 4 | 0.4 | 71.21 | 150.20 | Debonding |
| 3 | GFRP | GFRP 1 | 1.0 | 91.66 | 37.06 | Flexural |
| | | GFRP 2 | 0.8 | 94.94 | 50.47 | Flexural |
| | | GFRP 3 | 0.6 | 91.39 | 137.70 | Debonding |
| | | GFRP 4 | 0.4 | 57.14 | 78.88 | Debonding |
| 4 | KFRP | KFRP 1 | 1.0 | 87.49 | 41.70 | Flexural |
| | | KFRP 2 | 0.8 | 95.90 | 56.53 | Flexural |
| | | KFRP 3 | 0.6 | 83.99 | 116.80 | Debonding |
| | | KFRP 4 | 0.4 | 52.00 | 62.58 | Debonding |

4.3 Load Deflection with Various Types of Material Strengthening

Based on the finding, the GFRP concrete beam strengthened with carbon fiber reinforced polymer (CFRP) plate produced the highest load carried compared to the other three materials which are aramid, glass, and kenaf. While aramid is the second material that is able to carry the larger load and followed by glass and kenaf fiber. Carbon can carry the largest load with appropriate deflection occurred even in different length ratios which are 1.0, 0.8, 0.6, and 0.4. It is proved that CFRP plate has a great mechanical quality such as high tensile strength, more stiffness, and durability as well as has the highest modulus of elasticity. Figure 6, 7, 8 and 9 show the graph produced from the data obtained from the ATENA Software analysis for each material and length.

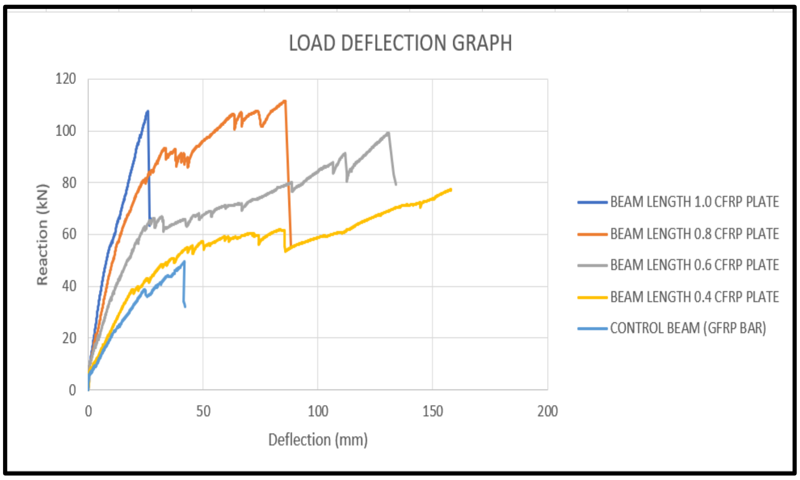


**Figure 6: Comparison length of CFRP plate**

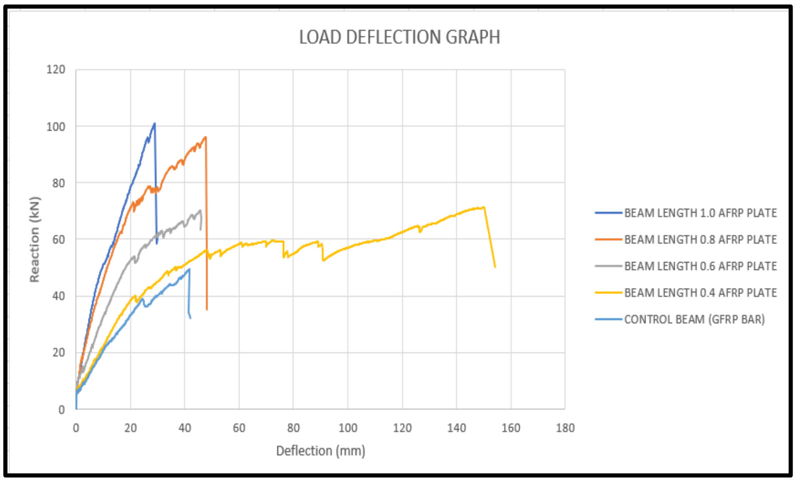


**Figure 7: Comparison length of AFRP plate**

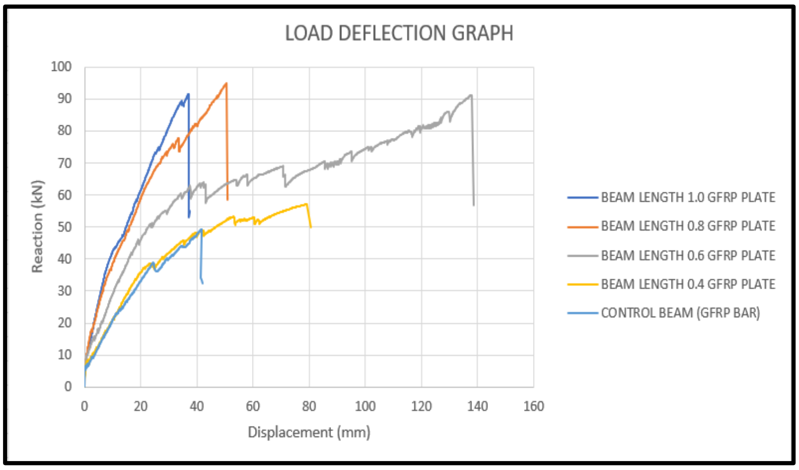


**Figure 8: Comparison length of GFRP plate**

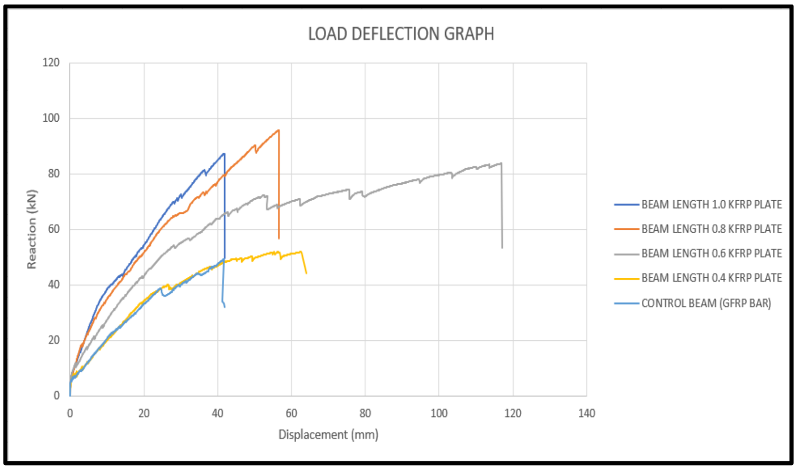


**Figure 9: Comparison length of KFRP plate**

According to the graph produced, another material that was able to carry a large load compared to CFRP plate is AFRP then followed by GFRP and KFRP. This is because the mechanical properties of AFRP especially the elastic modulus is greater than GFRP and KFRP. Figure 10 shows the graph of the optimum length ratio produced during the analysis for each plate.

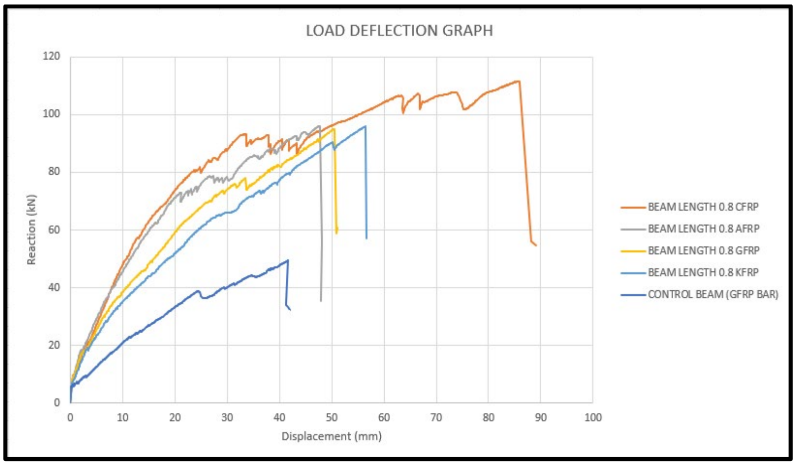


**Figure 10: Graph of optimum length ratio**

In this study, each beam that strengthened with polymer plates with the length ratio of 0.8 can be considered as the optimum length ratio were it able to carry the largest load compared to 1.0 as well as the other short plates which are 0.6 and 0.4 and it also suitable to be used for the strengthening material to support the beam structure. This is because the plates with short lengths were only able to carry a minimum load and produced a large deflection compared to the long-span plate. This issue is related to the capability of the plate that is not strong enough to carry more pressure or reaction which is leading to produce a large cracking.

4.4 Cracking Pattern

Generally, the type of failure or the cracking pattern that happened on the GFRP concrete beam structure during the analyzing process were FRP debonding, shear failure and flexural failure. However, the failures that occurred for this study are FRP debonding and flexural failure and these types of failures occurred depending on the length and the type of material of the plate used as the strengthening or repairing object for the GFRP concrete beam structure. Figure 11, 12, 13 and 14 show the failure that occurred for each plate with a length ratio is 0.8.

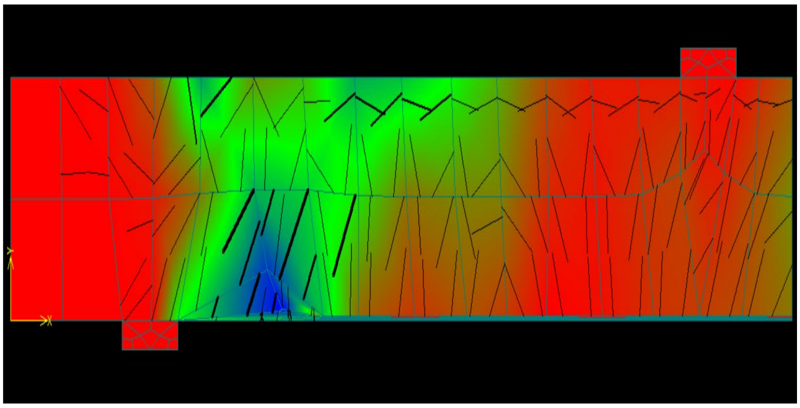

**Figure 11: CFRP plate failure**

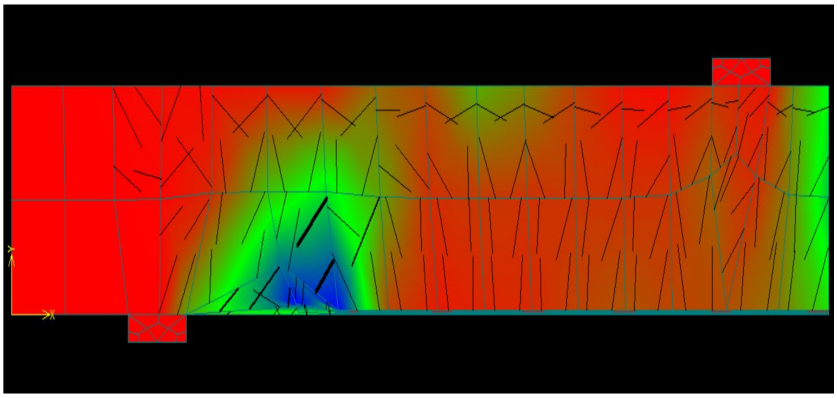

**Figure 12: AFRP plate failure**

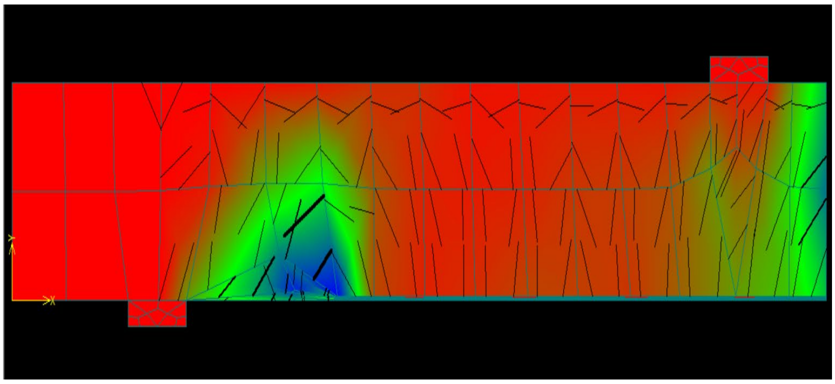

**Figure 13: GFRP plate failure**

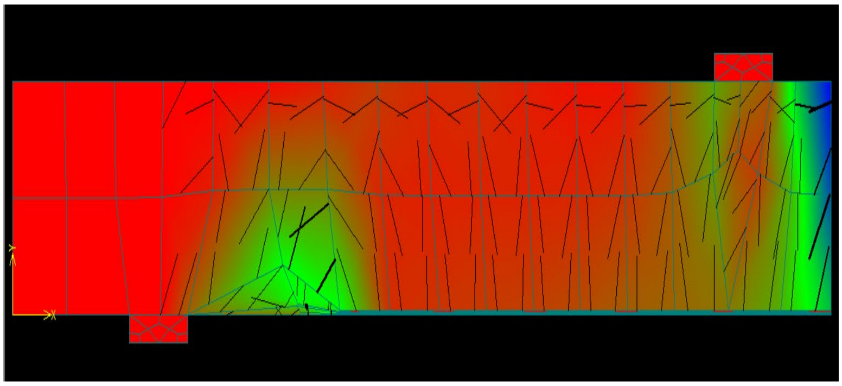

**Figure 14: KFRP plate failure**

Based on these figures, the type of failure that occurred on the beam structure strengthened with the CFRP, AFRP, and the GFRP plate were induced by interfacial FRP debonding failure while the KFRP plate was due to flexural failure. The debonding failure occurred when the load was continuously applied until the beam reached the concrete crushing in the top of the compression zone. The debonding failure between the concrete and the plate occurred without any indication of delamination. If the interfacial stresses are too great for the concrete to withstand, FRP debonding was able to occur. Debonding occurs most frequently near the concrete FRP contact, where there is a large concentration of stress. The FRP plate on one side of the beam was separated from the concrete component after ultimate failure, with a thin coating of concrete adhered to its surface which is indicating that the debonding failure happened mostly within the concrete.

However, the GFRP reinforced concrete beam strengthened with KFRP plate has occurred the flexural failure at midspan of the beam and it was shown that the plate produced is perfect bonding. The GFRP bar reinforcement and plate attached were performed well and made the beam structure stronger.

### 4.5 Summary

From the result that has been analyzed, it can be proved that carbon fiber reinforced plastic (CFRP) was more suitable to be used as the strengthening material for the GFRP concrete beam as it has the greatest mechanical properties compared to the other materials. CFRP plate was able to carry the largest load compared to other materials with the optimum length ratio was 0.8 and had the failure mode in interfacial debonding.

## 5. Conclusion

During this study, the flexural performance and cracking pattern of GFRP concrete beam strengthened with different materials of plates have been investigated. From the result obtained, it can be proved that carbon fiber reinforced plastic (CFRP) was suitable to be used as the strengthening material for the

GFRP concrete beam as it has the greatest mechanical properties compared to the other material. It was also a stronger material that was able to carry the ultimate load up to 100 kN and has a deflection value was 85.74 mm with the optimum plate length of 0.8 or 1680 mm as well as having the cracking pattern of interfacial debonding. According to the result, it has been proved that the objectives for this study were fulfilled.

5.1 Recommendations

Based on the result, some suggestions for improvement can be provided to ensure that the next research produces more accurate results and data than before. Here are some of the recommendations:

- Increase the thickness of the concrete cover and the tensile strength for the GFRP concrete beam to make sure the structure is stronger.
- Increase the size of the GFRP bar used for the concrete beam structure before analyzing the process.
- Other software can be used to make some more comparisons between ATENA and experimental data to find the optimum and accurate data for each material.

**Acknowledgement**

The authors would also like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support.

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