NIPES

Advances in Engineering Design Technology

Journal homepage: www.nipesjournals.org.ng

# U-Wrapped Configuration Variation on Shear Strengthening of RC Beam by Carbon Fiber Reinforced Polymer Fabric

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**ARTICLE INFORMATION**

*Article history*:
Received 21 November 2022
Revised 04 December 2022
Accepted 20 December 2022
Available online 27 Dec. 2022

*Keywords*:
*Shear, strengthening, Beams; U-Wrapped, Ductility index, Stiffness*

https://doi.org/10.5281/zenodo.7487257

**ABSTRACT**

*The demand to upgrade deficient structural members has grown over the years. According to experimental and numerical publications in this area, the application of fiber-reinforced polymer (FRP) to strengthen reinforce concrete (RC) elements in shear is an effective means. Strengthening RC beams with carbon FRP has several advantages over the steel plate strengthening method, for instance, ease of application, weight to high strength ratio, and durability. This paper studies the effect of U-wrapped configuration variation on the shear strengthening of RC beams by carbon FRP fabrics. Three shear strengthening U-wrapped configurations of CFRP fabric were studied: 200 g/m2 and 300 g/m2 of CFRP fabric strips of 100 mm by 400 mm applied as U-wrapped, spaced 250 mm center to center as a model of the prototype; 200g/m2 and 300 g/m$^2$ of CFRP fabric measured 250 mm by 367 mm applied as U-wrapped in the shear spans from the bottom of the beam as a model of the prototype; 200 g/m2 and 300 g/m$^2$ CFRP fabric strips of 300mm by 400mm applied as strip U-wrapped, spaced 375 mm center to center as a model of the prototype. Thirteen (13) RC beams (100 x 150 x 1100 mm) with flexural internal reinforcement (As =2Φ10 mm), compression reinforcement (AS =2Φ8 mm) and shear reinforcement (Asv =Φ6 mm @ 220 mm c/c). The beams were strengthened in shear as described above with bond thickness of 2 mm, 4 mm, and 6 mm. All the beam samples were subjected to two-point load application to examine the CFRP contribution to shear strength. The beams strengthened by U-wrapped CFRP fabrics improved the shear capacity of the control beam by 40%. The U-wrap configurations, which were designed to simulate the conventional method of shear reinforcement placement along the longitudinal axis of the beam, provided the best results compared to the other U-wrap configurations. The CFRP fabric to bond thickness ratio should not be more than 0.069. According to ACI 440 2R 17, a complete-wrapping configuration provides the best result in terms of increasing the shear strength of the strengthened RC beams. However, the study proves that in the absence of complete-wrapped configurations, U-wrap configurations simulating the conventional shear reinforcement placement along the horizontal axis can also be employed effectively. Bond thickness was also observed to have a significant impact on the shear strength of RC beams.*

# 1. Introduction

Faced with the difficulty of renovating an ever-increasing number of aged and substandard structures on a budget, local and federal governments have invested in this sector which has resulted in various studies and implementation. Externally bonded (EB) fiber reinforced polymer (FRP) composites have been proven to enhance the intended response of a structural element, for instance, shear capacity, bending capacity, stiffness, ductility, fatigue loading, and environmental durability, in both experimental and theoretical research [1, 2, 3, 4, 5, 6]. However, due to cost and design issues, the approach has yet to become a common application. The material and type of the member to be strengthened play a bigger role in the applicability and effectiveness of FRP composites. Bonding of FRP sheets to reinforced concrete (RC) structures has become a common technology for retrofitting [7, 8, 9]. The effectiveness of the FRP-to-concrete interface in enabling good stress transfer is critical in this strengthening technology. FRPs are preferred in upgrading concrete elements because of their many advantages over steel plate strengthening methods, [10, 11]. The majority of available publications on RC beams strengthened with FRP externally have concentrated on the flexural behaviour [12, 13, 14]. Shear failure in RC beams is appalling and happens with little or no signal, a better structural understanding of this problematic failure mode is required. The vast bulk of earlier research works had concentrated on using carbon CFRP composites to investigate the shear strengthening of simply-supported beams [15]. In the literature, there are only a few investigations on variations of U- shape configuration with CFRP sheets.

## 1.1 Review of Models for FRP Contribution to Shear Strength

Most recognized mathematical model in predicting shear contribution of FRP-strengthened beam elements adopt the superposition method presented in the design guidelines which described the total shear strength as the summation of three (3) parts: internal shear bar (Vs), concrete (Vc), and FRP strips ($V_f$). The total shear resistance ($V_n$) of a RC beam EB by FRP is given as follows:

$$V_n = V_C + V_S + V_f \qquad (1)$$

The behaviour of shear strengthening with fiber reinforced polymer was studied by Bousselham and Chaallal [16]. Due to the complexity, developing reliable shear strength models that are acceptable for practice is challenging. However, various efforts to develop shear models have indeed been performed, as reviewed below.

The first mathematical expression for determining FRP contribution to shear was developed for shear wings, shear strips, and U-jackets was as [17];

$$V_f = \frac{2F_f d}{S_f} = \frac{2\left[\tau_{ave}\frac{t_s h_s}{2}\right]d}{S_f}(for shear strips) \qquad (2)$$

$$V_f = 2F_f = 2\left[\tau_{ave}\frac{dh_w}{2}\right](for shear wings) \qquad (3)$$

$$V_f = 2F_f = 2\left[\tau_{ult}\frac{dh_j}{2}\right](for shear wings) \qquad (4)$$

Where;

$V_f$ = FRP contribution to shear (kN), $S_f$ = spacing of FRP (mm), $\tau ult =$ interface shear strength(MPa), $\tau_{ave} =$ average shear strength, ((MPa), $t_s$ = the width of a strip, $h_s$ = depth of a strip, $h_w$ = Depth of a wing, $h_f$ = Depth of a jacket.

Chajes et al. [18], developed a mathematical model in predicting FRP contribution to shear strength from laboratory data which consist of 12 beam elements without transverse reinforcement were studied. U-wrapped schemes were used and fiber directions of 45° and 90° to longitudinal beam axis of the concrete beam members. The analytical models were proposed as:

$$V_f = A_f E_f \varepsilon v_{cu} d(fiber oriented at 90^0) \qquad (5)$$

$$V_f = A_f E_f \varepsilon v_{cu} d\sqrt{2}(fiberorientedat 45^0) \quad (6)$$

Where;

$V_f$ = FRP contribution to shear (kN), $A_f$ = Area of FRP, $E_f$ = Tensile modulus of FRP, $\varepsilon v_{cu}$ = Average vertical FRP strain value.

Based on the experimental investigation, an average vertical FRP strain value at failure was given as $\varepsilon v_{cu}$ = 0.005.

Shear contribution by FRP was developed by Hutchinson and Rizkalla [19], and it was based on a $45^0$-shear crack. As a result, the angle of the shear cracks is not really a factor in the analytical models for the computation of FRP contribution to shear.

The shear contribution of FRP, according to Triantafillou [20], is found in the study of an effective strain of FRP $\varepsilon_{frp,e}$. From regression data analysis of 40 laboratory test results acquired from several articles, the effective strain of the FRP was calculated. The effective strain created in the FRP may be calculated by the length of development and is a measure of the axial stiffness $\rho_f E_f$ of the FRP, according to the author's analytical model.

$$V_f = \rho_f E_f \varepsilon_{fe} b_w 0.9d(1 + cot\beta)sin\beta (\text{Eurocode format}) \quad (7)$$

$$V_f = \frac{A_f f_{fe}(sin\beta + cos\beta)d_f}{S_f} (\text{ACI format}) \quad (8)$$

Where;

$\varepsilon_{f_e}$ = Effective FRP strain , $S_f$ = Spacing of FRP strips , $d_f$ = depth of overall section with FRP $\rho_f$ = FRP Ratio, $\beta$ = angle between FRP reiorcement fibres and horizonal axis of the beam,

$f_{fe}$ = Effective stress in FRP shear reinforcement

$f_{fe}$ = Effective stress in FRP shear reinforcement

$$\varepsilon_{f_e} = 0.0119 - 0.0205(\rho_f E_f) + 0.0104(\rho_f E_f)^2 for\ 0 \leq \rho_f E_f \leq 1GPa \quad (9)$$

$$\varepsilon_{f_e} = 0.00245 - 0.00065(\rho_f E_f) for \rho_f E_f > 1GPa \quad (10)$$

Triantafillou [20] analytical expression was revised by Khalifa et al [21] to accommodate the different types of FRP used and presented strain limitations as a result of shear crack opening. The authors developed a revised effective strain in the FRP for fiber debonding failure and FRP rupture, by presenting tensile stress reduction factor’s (R) expression for the FRP. Khalifa et al [21] developed and recommended the strain reduction factor (R) in predicting the FRP contribution to shear strength.

$$R = 0.5622(\rho_f E_f)^2 - 1.2188(\rho_f E_f) + 0.778 \leq 0.5 \quad (FRPrupture) \quad (11)$$

$$R = \frac{0.0042\langle f_c^I \rangle^{2/3} w_{fe}}{\langle E_f t_f \rangle^{0.58} \varepsilon_{f_u} d_f} (debondingfailure) \quad (12)$$

Where;

R = ratio of effective to ultimate strain in FRP

$\varepsilon_{f_u}$ = ultimate tensile strain in FRP ,

$w_{fe}$ = width of FRP shear reinforcement strip

$$f_{f_e} = R f_{f_u} \quad (13)$$

Triantafillou and Antonopoulos [22] formulated expressions for $\varepsilon_{f_{ek}}$ founded on a regression examination of 75 RC beam experimental test data. For a fully wrapped CFRP sheet, the typical effective strain in the FRP $\varepsilon_{f_{ke}}$ is represented as:

$$\varepsilon_{fke} = 0.8 \times 0.17(f_c^{2/3}/\rho_f E_f)^{0.3} \times \varepsilon_{f_u} \quad (14)$$

and for U and side wrapped configuration is given by

$$\varepsilon_{fke} = min\left[0.8 \times 0.65(f_c^{2/3}/\rho_f E_f)^{0.56} \times 10^{-3}; 0.8 \times 0.17(f_c^{2/3}/\rho_f E_f)^{0.3} \times \varepsilon_{f_u}\right] \quad (15)$$

In Technical Report (TR) 55, published in 2004, the concrete society (2003) released revised design requirements for FRP shear strengthening RC beam [23]. The amended design criteria were Denton et al [24].'s experimental findings and replace TR55's original standards. TR55 [24] expresses the FRP's shear contribution as follows:

$$V_f = \frac{A_f}{s_f}\left(d_f - \frac{n_s}{3} l_{tmax} cos\beta\right) E_{fd}\varepsilon_{fe}(sin\beta + cot\beta) \quad (16)$$

where n is taken as 0, 1 for complete wrap configuration and 2 for side wrap

$$l_{max} = 0.7\sqrt{\left(E_{fd}t_f/f_{ct}\right)} \quad (17)$$

Where:

$l_{max} isthe$ the anchorage length

$f_{ct} = tensilestrengthofconcrete = 0.21 f_{ck}^{2/3}$

Khalifa and Nanni [25] published a mathematical expression for strain reduction (R) formulated for the debonding failure mode as given in equation (18). The design parameters investigated were: end anchorage, quantity of CFRP, wrapping system, and fiber direction.

$$R = \frac{(f_c^I)^{2/3} w_{f_e}}{\varepsilon_{f_u} d_f}\left[738.93 - 4.06\left(\rho_f E_f\right)\right] \times 10^{-6} \quad (18)$$

The shear behavior of RC beams reinforced with carbon FRP hasn't been completely examined despite a number of exciting investigations, and the data in TR55 concrete society [24] and ACI Committee 440. 2R-17 [26], isn't sufficient to offer comprehensive design guidance. The three most frequent FRP configuration approaches for shear are full wrapping, U-wrapping, and complete side wrapping of the section. Full wrapping is no longer an option since concrete beams are often built with the slab at the top. Additionally, perhaps only a small piece of the beam requires strengthening. This paper describes the findings of an experimental study aimed at filling in some of the gaps in the existing literature by improving our knowledge of RC beam members strengthened with CFRP fabric.

## 2. Materials and Method

In accordance with ACI 444 [27], beam samples were designed as prototypes and modelled with a scale ratio of 2.5. Thirteen (13) RC model beams were produced, each beam had a length of 1100 mm with a cross section of 100 x 150 mm and was internally reinforced with 2Φ10 mm and 2Φ8 mm in the zones presumed to go into tension and compression, respectively, and shear reinforcement (Asv =Φ6 mm @ 220 mm c/c). One of the beams was not strengthened and served as a control, as depicted in Figure 1 (a), while the remaining beam samples were strengthened with carbon FRP fabric U-wrap configuration, as shown in Figure 1b, 1c, and 1d. Beam sample designations and wrap configurations are presented in Table 1.

Beams VA-2 and VA-4 were strengthened with 200 g/m$^2$ CFRP fabric measuring 250 mm by 367 mm with 2 mm and 4 mm adhesive thickness, respectively, and were applied as U-wrapped in the shear spans from the tension side of the beam as presented in Figure 1(b).

Beams VB-2 and VB-4 were strengthened with 200 g/m$^2$ CFRP fabric strips of 100 mm by 400 mm and 2 mm and 4 mm adhesive thickness, respectively, and applied as U-wrap, spaced 250 mm center to center as a model of the prototype as shown in Figure 1(c).

As a model, beams VC-2 and VC-4 were strengthened with 300 g/m$^2$ CFRP fabric measuring 250 mm by 367 mm and 2 mm and 4 mm adhesive thickness, respectively, and applied as U-wrap in the shear spans from the tension side of the beam as presented in Figure 1(b).

Beams VD-2, VD-4, and VD-6 were strengthened with 300 g/m$^2$ CFRP fabric strips of 100 mm by 400 mm with 2 mm 4 mm, and 6 mm adhesive thickness, respectively, and applied as U-wrap, spaced 250 mm center to center as presented in Figure 1(c), while beams VE-2 and VF-2 were strengthened with 200 g/m$^2$ and 300 g/m$^2$ CFRP fabric strips of 300 mm by 400 mm, respectively, with 2 mm adhesive thickness and applied as U-wrap, spaced 375 mm center to center as a model of the prototype as shown in Figure 1d.

**Table 1. Beam designations and wrap schemes**

| Sample ID | CFRP Fabrics | Epoxy Thickness(mm) | Beam section details | | Wrap configuration |
|---|---|---|---|---|---|
| | | | b (mm) | h (mm) | |
| Type-FA-0 | - | - | 100 | 150 | - |
| Type-VA-2 | 200g/m$^2$ | 2 | 100 | 150 | U-Wrapped |
| Type-VA-4 | | 4 | 100 | 150 | U-Wrapped |
| Type-VB-2 | | 2 | 100 | 150 | U-Wrapped |
| Type-VB-4 | 200g/m$^2$ | 4 | 100 | 150 | U-Wrapped |
| Type-VB-6 | | 6 | 100 | 150 | U-Wrapped |
| Type-VC-2 | 300g/m$^2$ | 2 | 100 | 150 | U-Wrapped |
| Type-VC-4 | | 4 | 100 | 150 | U-Wrapped |
| Type-VD-2 | | 2 | 100 | 150 | U-Wrapped |
| Type-VD-4 | 300g/m$^2$ | 4 | 100 | 150 | U-Wrapped |
| Type-VD-6 | | 6 | 100 | 150 | U-Wrapped |
| Type-VE-2 | 200g/m$^2$ | 2 | 100 | 150 | U-Wrapped |
| Type-VF-2 | 300g/m$^2$ | 2 | 100 | 150 | U-Wrapped |

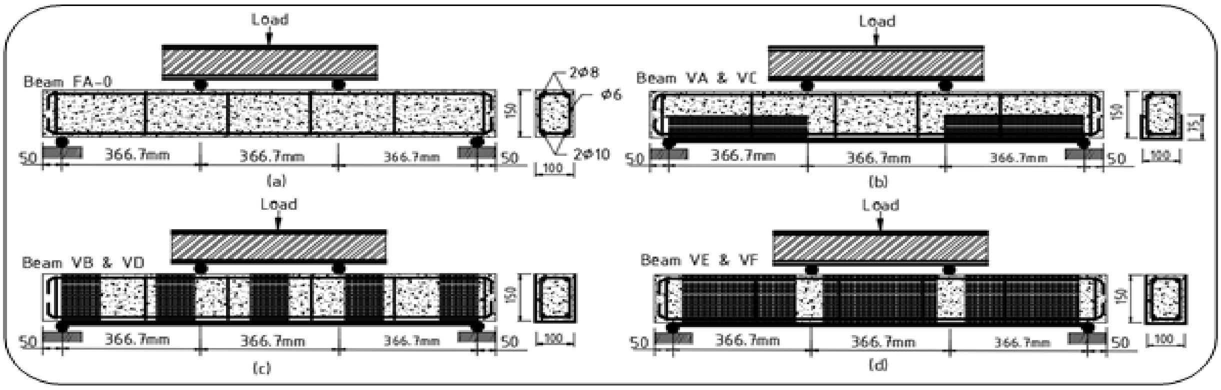


**Figure 1**: Beam configurations

**Table 2: Properties of the Materials**

| Material | Thickness (mm) | Tensile Strength (MPa) | Tensile Modulus of Elasticity (MPa) | Elongation at Break (%) | Bending Strength (MPa) |
|---|---|---|---|---|---|
| 200g/m$^2$ | 0.111 | 3964 | $2.3 \times 10^5$ | 1.74 | 744 |
| 300g/m$^2$ | 0.167 | 3964 | $2.3 \times 10^5$ | 1.74 | 744 |
| Epoxy resin | - | 15 – 20 | 3300 | 4.3 | 30 – 40 |

### 2.1 Material properties

The 200 g/m$^2$ (0.111 mm) and 300 g/m$^2$ (0.167 mm) CFRP fabric wraps were sourced from Shanghai Horse Construction Technology Co., Ltd. Table 2.0 shows the engineering properties of carbon FRP fabric wrapped and epoxy resin. The strength of concrete for the beam samples was recorded by testing 12 concrete cube samples at 28 days after casting. The strength ($f_{ck}$) of concrete was estimated to be 20 MPa. Internal reinforcement had yield strength of 400 MPa and an elastic modulus of 210 GPa. The epoxy resin of Sikadur(R)-31 was considered for bonding the CFRP fabrics to the beams.

### 2.2 Strengthening process

All beam samples were machined to generate a rough surface for better adherence with carbon FRP and were clean as depicted in Figure 2 (a). The sections where the carbon FRP fabric was to be EB were marked. The epoxy paste was then made by mixing the two parts of the epoxy adhesive Sikadur(R)-31 in a 2:1 ratio as shown in Figure 2 (b). The carbon FRP fabrics were cut to the desired lengths and the surfaces of the beams to be bonded were brushed to obtain a dirt-free surface. Lastly, CFRP fabric strips were bonded to the beam samples with Sikadur(R)-31 epoxy adhesive as depicted in Figure 2c and 2d.

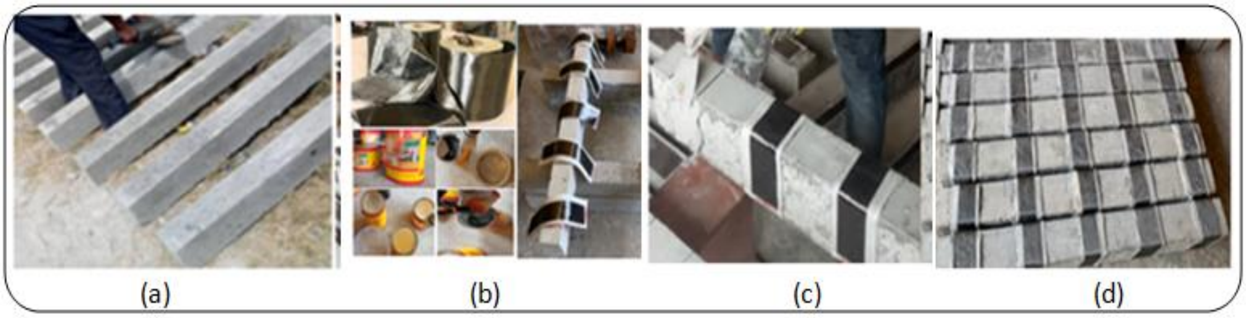

**Figure 2: (**a) Surface preparation; (b) Material; (c) Strengthening process; (d) Beam samples

### 2.3 Instrumentation and test procedure

As shown in Figure 1, the beam samples were set-up as simply supported on a 20-ton reactant frame with a two-point load application over an effective span of 1100 mm. At appropriate locations, two steel rollers were used to support the beam samples, and a dial gauge was positioned at the tension face of the beam specimens. The beam samples were loaded by a hydraulic jack and was read by a load cell. The data was recorded at each 9.81 kN load step up to the failure load. The beam samples were subjected to a static load.

## 3. Results and Discussion

Results as presented and discussed are those of the prototypes. Table 3 shows the yield load, mid-span deformation, and failure load of all the beam samples. Also, the load against deformation plot of the beams is presented in Figure 3. Table 4 presents the CFRP contribution to shear capacity. Percentage increase in shear strength and ductility index compared to the reference beam are presented in Table 5.

### 3.1 Failure load

Results presented in Table 3 reveals that the load resistance of RC beams can be considerably improved by strengthening with carbon FRP fabric as U-wrapped. It is obvious referring to Table 3 that the ultimate load capacity contributed by the CFRP fabric for beams VA-2, VA-4, VC-2, VC-4, VB-2, VB-4, VB-6, VE-2, VD-2, VD-4, VD-6, and VF-2 were 29.18kN, 16.68kN, 24.18kN, 26.92kN. 29.18kN, 31.68kN, 7.22kN, 17.18kN, 36.68kN, 29.42kN, 7.3kkN, and 31.68kN, respectively, compared with the reference beam, FA-0, which is 31.20, 17.80, 25.90, 28.80, 20.50, 33.90, 7.70, 18.40, 39.30, 31.50, 7.80, and 33.9%. Comparing the results, beam VD-2 which was strengthened with 300 g/m2 CFRP fabric strips of 100 mm by 400 mm with 2 mm thickness, and applied as U-wrapped, spaced 250 mm center to center was found to be higher over all the beams. In the course of loading, it was observed that the CFRP fabric stopped crack from propagating. Table 5 shows that the ductility index was improved by 27 to 96 %. Modes of failure are shown in Figure 4.

Table 3: Test Results of CFRP U-Wrapping

| Sample ID | Yield Load (kN) | Deformation at Yield load (mm) | Failure Load (kN) | Deformation at Failure load (mm) | Mode of Failure |
|---|---|---|---|---|---|
| FA-0 | 71.85 | 9.63 | 93.33 | 10.13 | Flexure |
| VA-2 | 71.13 | 11.08 | 122.50 | 17.45 | Flexure |
| VA-4 | 73.88 | 11.13 | 110.00 | 15.65 | Flexure |
| VC-2 | 97.25 | 9.70 | 117.50 | 17.53 | Flexure |
| VC-4 | 74.75 | 10.20 | 120.25 | 20.93 | Flexure |
| VB-2 | 95.60 | 12.70 | 122.50 | 22.63 | Flexure |
| VB-4 | 87.50 | 17.38 | 125.00 | 23.33 | Flexure |
| VB-6 | 72.50 | 10.88 | 100.55 | 22.45 | Flexure |
| VE-2 | 74.45 | 10.50 | 110.50 | 19.40 | Flexure and shear |
| VD-2 | 96.25 | 12.70 | 130.00 | 18.63 | Flexure |
| VD-4 | 97.50 | 16.38 | 122.75 | 22.05 | Flexure |
| VD-6 | 72.25 | 13.30 | 100.63 | 19.50 | Flexure |
| VF-2 | 92.5 | 13.88 | 125.00 | 19.63 | Flexure and shear |

Table 4: CFRP Contribution to shear strength

| Sample ID | Failure Load $P_{u,}$ (kN) | Experimental Shear Force $V_{exp,}$ (kN) | CFRP Contribution to Shear, $V_{f, exp,}$ (kN) |
|---|---|---|---|
| FA-0 | 93.33 | 46.67 | - |
| VA-2 | 122.50 | 61.25 | 14.59 |
| VA-4 | 110.00 | 55.00 | 8.34 |
| VC-2 | 117.50 | 58.75 | 12.09 |
| VC-4 | 120.25 | 60.13 | 13.46 |
| VB-2 | 122.50 | 56.25 | 14.59 |
| VB-4 | 125.00 | 62.5 | 15.84 |
| VB-6 | 100.55 | 50.28 | 3.61 |
| VE-2 | 110.50 | 55.25 | 8.59 |
| VD-2 | 130.00 | 65.0 | 18.34 |
| VD-4 | 122.75 | 61.38 | 14.71 |
| VD-6 | 100.63 | 50.32 | 3.65 |
| VF-2 | 125.00 | 62.5 | 15.84 |

## 3.2 Shear strength

Table 5 shows the effect of varying U-wrapped configurations on the shear capacity and ductility index for beams strengthened in shear. The shear contributions were obtained by computing the difference between the shear capacities of both the control and the strengthened beams. The results in Tables 4 and 5 showed that externally bonding CFRP fabric increased the shear strength of RC beams significantly. The shear strength contribution by CFRP fabric strips for beams VA-2, VA-4, VC-2, VC-4, VB-2, VB-4, VB-6, VE-2, VD-2, VD-4, VD-6, and VF-2 were 14.59kN, 8.38kN, 12.09kN, 13.46kN, 14.59kN, 15.84kN, 3.61kN, 8.59kN, 18.34, 14.71kN, 3.65kN, and 15.84kN, respectively, when compared with the reference beam. Table 5 shows that CFRP fabric can increased shear strength by 40%. According to the test results, without excessive loss in shear contribution, the surface area of carbon fiber reinforced polymer can subsequently be reduced still achieving desire results.

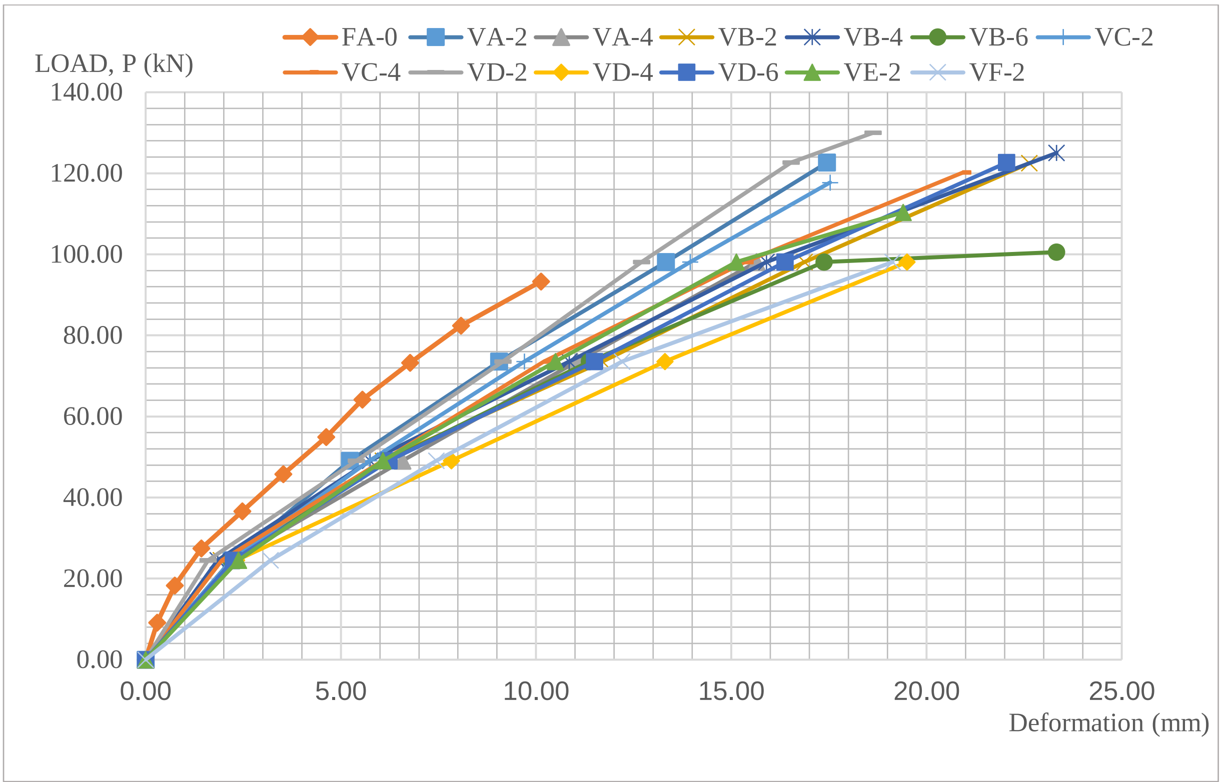


**Figure 3:** Load versus deformation

**Table 5:** Summary of results

| Sample ID | Shear Capacity kN | % Increase in Shear Capacity, kN | % Increase in Ductility Index |
|---|---|---|---|
| FA-0 | 46.67 | - | - |
| VA-2 | 61.25 | 31.20 | 49.71 |
| VA-4 | 55.00 | 17.80 | 33.67 |
| VC-2 | 58.75 | 25.90 | 71.80 |
| VC-4 | 60.13 | 28.80 | 95.06 |
| VB-2 | 56.25 | 20.50 | 69.39 |
| VB-4 | 62.5 | 33.90 | 27.61 |
| VB-6 | 50.28 | 7.70 | 96.15 |
| VE-2 | 55.25 | 18.40 | 75.64 |
| VD-2 | 65.0 | 39.30 | 39.45 |
| VD-4 | 61.38 | 31.50 | 27.97 |
| VD-6 | 50.32 | 7.80 | 39.38 |
| VF-2 | 62.5 | 33.90 | 34.44 |

### 3.3 Load–deformation behaviour

The load against mid-span deformation response is also used to examine the behaviour of CFRP strengthened beams and the response is depicted in Figure 3. Also, the serviceability of the reinforced concrete beam member is usually evaluated through deformation and crack width. In every load step, the deformation was recorded. Table 3 depicts measured results related to the deformations of all beams at yield load and ultimate failure load. Figure 3 confirms that the control beam, FA-0 has better resistance to deformation than the CFRP fabric strengthened beams. This was also reported by Ahmad et al [28]. The beams exhibit very consistent load-deformation behaviour. However, the deformation at failure was lower for FA-0. The maximum mid-span deformations for beams FA-0, VA-2, VA-4, VC-2, VC-4, VB-2, VB-4, VB-6, VE-2, VD-2, VD-4, VD-6, and VF-2 were 10.13, 17.45, 15.65, 17.53, 20.93, 22.63, 23.33, 22.45, 19.40, 18.63, 22.05, 19.50, and 19.63 mm respectively. Results showed the CFRP can significantly improve the ductility index.

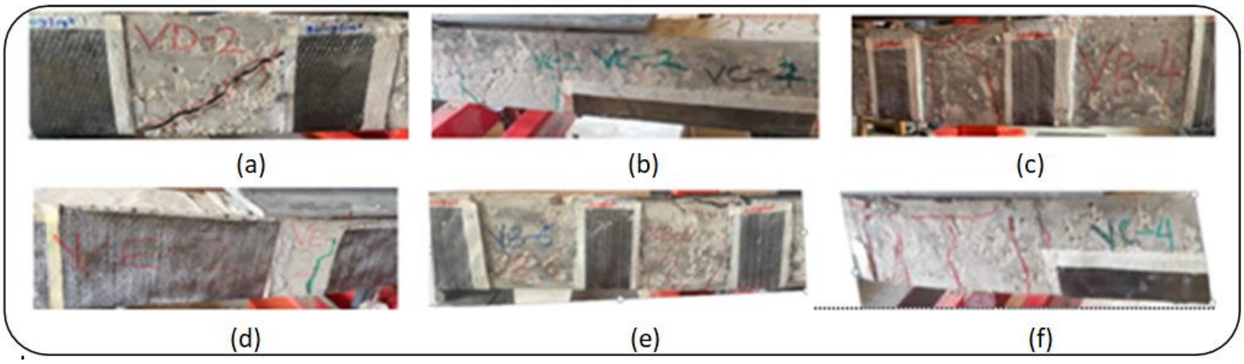


**Figure 4: Modes of failure for reference beam**

## 4. Conclusion

The following conclusions were made in light of the study's findings on the effects of U-wrap configurations on the shear strength of RC beams strengthened with carbon FRP fabrics:

- For externally bonded CFRP to be structurally adequate, the CFRP fabric thickness to adhesive layer thickness ratio should be less than 0.069 for U-wrapped.
- The U-wrap configurations designed to simulate the conventional method of shear reinforcement placement along the horizontal axis of the beam provided the best results compared to the other U-wrap configurations.
- The U-wrap scheme for shear strengthening increased the shear strength by 40%.
- Bond thickness was observed to have a significant impact on the shear strength of RC beams.
- According to ACI 440.2R -17, a complete-wrapping configuration provides the best result. However, the study proves that in the absence of complete-wrapped configurations, U-wrap configurations simulating the conventional shear reinforcement placement along the horizontal axis can also be employed effectively.

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