A REVIEW OF SHEAR BEHAVIOR OF CONCRETE BEAMS REINFORCED BY FRP BARS

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Abstract: Using fibre-reinforced polymer (FRP) in the concrete structures was rapidly increased throughout the past two decades. Corrosion-free properties and the high ratio of strength-to-weight of the FRP reinforcement has led to the significant increase of structures' service life. In the present work, the earlier studies that are associated with shear behaviour of the beams that have been reinforced by the FRP bars are reviewed. Many researchers have investigated shear behavior of the beams of concrete that have been reinforced by the FRP bars and determined their capacity. Some of them have performed experimental investigations through the testing of several beams with varying some of the parameters, whereas the others have been theoretical for estimating shear capacity of the beam. This study presents as well, a review for all of the codes and researcher equations for shear design of the beams that have been reinforced by the FRP bars.

Keywords: *Steel Fiber, Shear Strength, fiber reinforced polymer.*

1. Introduction

The deteriorations of the concrete structures as a result of steel reinforcement corrosion resulted in the emergence of the necessity for alternative reinforcement type, like the FRP. Stirrups that are utilized for the shear reinforcement are located typically as external reinforcement based on flexural reinforcement, which is why; they have higher susceptibility to the severe environmental factors, because of minimum concrete cover that has been provided. The FRP can be defined as corrosion-free materials and were

utilized lately as reinforcements for avoiding concrete structure deteriorations, which result from the steel reinforcement corrosion. Using FRP as a reinforcement for the concrete structures rapidly increased over the past decade. The reinforcement of the FRP has been made from fibers that have high-tensile-strength, like the aramid, carbon, glass, and others embedded in the polymeric matrices and produced as bars, ropes, strands, grids and tendons, in many different shapes and properties. The reinforcement of the FRP is utilized as pre-stressed, non-pre-stressed and shear reinforcement for the structures of concrete. Numerous analytical and experimental research programs were carried out for investigating flexural behavior of the concrete members reinforced and/or pre-stressed by the reinforcement of FRP. Using FRP as shear reinforcement for the structures of concrete was not entirely explored yet, and data that are currently available are insufficient for the formulation of rational guidelines for the design [1-7]. The reinforced and pre-stressed concrete member flexural behaviors were studied thoroughly and then rationalized to simple equations of compatibility and equilibrium in the majority of current codes. None-the-less, there has not been a clear definition of the shear mechanism and is considered to be one of the most

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complex mechanisms for rationalization to a simple mod-el. numerous models have been presented by various codes using several assumptions related to the material properties and the internal mechanism. In general, shear failure of reinforced and pre-stressed members of concrete is disastrous in nature, which is why, a considerable safety margin is normally utilized. Despite the many experimental research decades and using highly advanced analytical tools, the shear failure has not been entirely understood yet. The shear transfer in the beams of concrete is highly dependent upon compressive and tensile strength of concrete. Which is why, it is no surprise that a failure that results from the shear is brittle generally. In addition to that, in the case where the shear reinforcement has not been provided suitably for the pre-stressed or reinforced beams of concrete, shear failure will possibly occur suddenly, and with no prior distress warning. Which is why, the beams of concrete are reinforced, in general, with the shear reinforcement for ensuring that the flexural failure will take place prior to shear failure in a case of the overloading conditions for the purpose of ensuring the ductile failure. The literature about the concrete beams' shear behavior is highly extensive, due to the fact that it started from the be-ginning of the century. Which is why, it's be-yond this study's scope for encompassing all of the earlier works concerning this subject. A detailed review has been provided by ASCE-ACI Task Committee 426 (1973) [8-19].

2. Provisions of the Shear Design for the FRP-RC Member

2.1. ACI 440.1R-15 Design Guidelines

Shear capacity V_{cf} of the concrete of the flexural members utilizing FRP as basic reinforcement may be specified as [20]:

$$V_{cf} = \frac{2}{5} \sqrt{f_c'} b_w c \quad (1)$$

Where f_c' represents the compressive strength of the concrete; c represents depth of cracked transformed section neutral axis; and b_w represents the width of the web;. For the single reinforced rectangular cross sections, $c = kd$ and k can be computed from the following equation:

$$k = \sqrt{2\rho_f n_f + (\rho_f n_f)^2} - \rho_f n_f \quad (2)$$

ρ_f = FRP ratio of reinforcement and $n_f = E_f / E_c$, E_c and E_f represent elasticity moduli of concrete and longitudinal FRP bars, respectively).

Shear resistance that has been provided by the stirrups of the FRP, which are perpendicular to the member V_{sf} axis may be calculated from the equation:

$$V_{sf} = \frac{A_{fv} f_{fv} d}{s} \quad (3)$$

d represents the effective depth; A_{fv} represents the total cross-section region of the shear reinforcement in distance s ; s represents the spacing of the shear reinforcement; f_{fv} represents the stress level of design in shear reinforcements of the FRP at ultimate and may be computed as:

$$f_{fv} = 0.004 E_v \leq f_{fu bent} \quad (4)$$

Bend capacity f_{fb} may be specified based on the equation:

$$f_{fu bent} = \left(0.05 \frac{r_b}{d_b} + 0.3\right) f_{fu} \leq f_{fu} \quad (5)$$

In the case of using the continuous FRP rectangular spirals as shear reinforcement (then, s represents pitch and α represents the spirals' inclination angle), Eq. (2-6) gives a contribution of FRP spirals:

$$V_{sf} = \frac{A_{fv} f_{fv} d}{s} \sin \alpha \quad (6)$$

2.2. The Canadian Standard Code CAN/CSA-S 6-14

CAN/CSA-S 6-14, 2014 utilizes identical basic formulas to the CSA A 23.3-4 (2004) for the steel-RC shear designs, however, it has been modified for the FRP through the introduction of a factor for accounting for lower FRP vs. steel elastic modulus in the case where longitudinal strain at member mid-height has been calculated. The updated CSA S6-14 equation version that has been suggested in 2008 by Benmokrane and El-Sayed has been given in Eq. (4-7) [21]

$$V_{cf} = 2.5 \left(\frac{0.4}{1 + 1500\varepsilon_x} \cdot \frac{1300}{1000 + s_{ze}} \right) \phi_c f_{cr} b_w d_v \quad (7)$$

Where

$$\varepsilon_x = \frac{V_f \left(\frac{a}{d} + 1 \right)}{2(E_f A_f)} \quad (8)$$

$$A_{v,min} = \frac{0.3 \sqrt{f'_c} b s}{f_{fv}} \quad (9)$$

$$\text{If } A_v > A_{v,min}, s_{ze} = 300 \text{ mm}$$

$$\text{If } A_v < A_{v,min}, s_{ze} = 35s_z / (15 + a_g) > 0.85s_z,$$

Where s_z represents the parameter of the crack spacing and will be considered as d_v or as distance between distributed longitudinal layers of the reinforcements, where every one of the intermediate layers of this reinforcement has an area that is at least of $0.003bs_z$.

For the members with the transverse reinforcement of the FRP, which is perpendicular to member axis V_{sf} has been estimated with the use of:

$$V_{sf} = \frac{A_{fv} f_{fv} d_v (\cot \theta + \cot \alpha) \sin \alpha}{s} \quad (10)$$

$$d_v = \text{Greater value of } 0.75 D \text{ or } 0.9d$$

Here, d represents effective depth; A_{fv} represents the total cross-section region of the shear reinforcement in the distance s ; s

represents the shear reinforcement's spacing; f_{fv} represents the stress level of the design in FRP shear reinforcement at ultimate and may be computed with the use of the following equation:

$$f_{fv} = 0.004E_v \leq f_{fu \text{ bent}} \quad (11)$$

The f_{fb} bend capacity may be found based on the equation below:

$$f_{fu \text{ bent}} = \left(0.05 \frac{r_b}{d_b} + 0.3 \right) \frac{f_{fu}}{1.5} \quad (12)$$

The maximal f_{fv} stress has been taken as lower than $0.005E_v$, $0.4f_{fu}$, or 1200MPa, and a θ represents the diagonal compressive stress angle, which can be estimated based on:

$$\theta = (30 + 7000) \left(0.888 + \frac{s_{ze}}{2500} \right) \quad (13)$$

2.3. JSCE Shear Design Approach

The shear capacity of the design that has been provided with the concrete V_{cf} may be specified based on the equation below [22]:

$$V_{cf} = \frac{\beta_d \beta_p \beta_n f_{vcd} b_w d}{\gamma_b} \quad (14)$$

The γ_b value represents the factor of strength reduction; β_d , β_p , and β_n represent the factor of the size effect, factor that considers tensile reinforcement stiffness, and aspect that considers axial force on cross section,

Where

$$f_{vcd} = 0.2(f'_c)^{1/3} \leq 0.72 \frac{N}{mm^2} \quad (15)$$

$$\beta_d = \left(\frac{1000}{d} \right)^{1/4} \leq 1.5 \quad (16)$$

$$\beta_p = (100 \rho_f E_f / E_s)^{1/3} \leq 1.5 \quad (17)$$

$$\beta_n = 1 + \frac{M_o}{M_d} \leq 2 \quad \text{for } N'_d \geq 0 \quad (18)$$

$$\beta_n = 1 + \frac{2M_o}{M_d} \leq 0 \quad \text{for } N'_d \geq 0 \quad (19)$$

Where M_o represents the decompression moment; N'_d represents the design axial compressive force and M_d represents the design bending moment. The shear contribution of the design V_{sf} by vertical stirrups of the FRP is represented as:

$$V_{sf} = [A_{fv} E_v \varepsilon_{fv} / s] \frac{z}{\gamma_b} \quad (20)$$

In the case where the rectangular stirrups of the FRP have been inclined with the angle α that has been formed by the member axis and shear reinforcement, shear contribution V_{sf} can be represented as:

$$V_{sf} = [A_{fv} E_v \varepsilon_{fv} (\sin \alpha + \cos \alpha) / s] \frac{z}{\gamma_b} \quad (21)$$

$$\varepsilon_{fv} = 0.0001 \sqrt{\left(\frac{h}{300}\right)^{-1/10} \cdot f'_{cd} \frac{\rho_f E_f}{\rho_{fv} E_v}} \leq \frac{f_{fu \text{ bent}}}{E_v} \quad (22)$$

$$f_{fu \text{ bent}} = \frac{(0.05 \frac{r_b}{d_b} + 0.3) f_{fu}}{1.3} \quad (23)$$

Where A_{fv} represents shear reinforcement's total cross-sectional area, E_v represents Young modulus of the shear reinforcement, ρ_{fv} represents shear reinforcement ratio, ε_{fv} represents design value of the strain of the shear reinforcements at the ultimate limit state, z represents distance between action points of compressive and tensile resultant forces and it equals $d/1.15$, $f_{fu \text{ bent}}$ represents design strength of FRP stirrup bent portion, f_{fu} represents the straight portion's shear reinforcement tensile strength, and h represents the member's total depth.

2.4. Equation of shear design

The shear design for the longitudinally and transversally reinforced beams by FRP bars are listed in Table 1.

Table 1. Shear design formulas	
Prediction methods	Shear Strength Equations

ACI 440.1R- 15[20]	$V_c = \frac{2}{5} \sqrt{f'_c} b_w k d$ <p>Where,</p> <p>V_c = Shear resistance that is provided by the concrete</p> <p>f'_c = compressive strength of the concrete, MPa</p> <p>b_w = web width, mm</p> <p>$c = kd$, depth of the cracked transformed section neutral axis, mm</p> <p>d = effective depth, mm</p> <p>$k = \sqrt{2\rho n + \rho n^2} - \rho n$</p> <p>$\rho = \frac{A}{b_w d}$</p> <p>$A$ = Area of tensile reinforcement, mm²</p> <p>$V_f = \frac{A_{fv} f_{fv} d}{s}$</p> <p>Where,</p> <p>$A_{fv}$ = shear reinforcement area within the stirrups spacing s, mm²</p> <p>V_f = Shear resistance that is provided by the stirrups of the FRP.</p> <p>s = FRP stirrup spacings.</p> <p>f_{fv} = FRP's tensile strength, which has been considered as smallest of the tensile strength of design f_{fu}, bent portion strength of FRP stirrups f_{fb}, or stress, which corresponds to $0.004E_f$ (MPa).</p>
	<p>CSA S806- 12[23]</p> <p>$V_c = 0.05 \lambda k_m k_r (f'_c)^{\frac{1}{3}} b_w d_v, \text{ for } d \leq 300 \text{ mm}$</p> <p>such that</p> <p>$0.11 \sqrt{f'_c} b_w d_v \leq V_c \leq 0.22 \sqrt{f'_c} b_w d_v$</p> <p>$k_m = \sqrt{\frac{V_f d}{M_f}} \leq 1, \text{ where } \left(\frac{V_f d}{M_f}\right) \text{ is an}$</p>

	<p>equivalence to $(\frac{d}{a})$</p> $k_r = 1 + (E_f \rho)^{\frac{1}{3}}$ <p>E_f = elastic modulus of longitudinal reinforcement of FRP</p> <p>d_v is taken as greater of 0.90 d or 0.72h, where h represents the general member thickness</p> <p>M_f = ultimate moment</p> <p>V_f= ultimate shear,</p> $V_f = \frac{0.4\Phi_f A_{fv} f_{fu} dv}{s} \cot \theta$ $f_{fu} \leq 0.005 E_f$ $\theta = 30^\circ + 7000 \varepsilon_l$ <p>provided that $30^\circ \leq \theta \leq 60^\circ$</p> $\varepsilon_l = \frac{M_f dv + V_f + 0.5 N_f}{E_f A_{fv}},$ <p>N_f=axial load normal to cross section of the member. In this case=0</p>	<p>reinforcement</p> $z = \frac{d}{1.15}$ $\gamma_{bs} = 1.15$ $\varepsilon_{fwd} = 0.0001 \left(f'_{mcd} \left(\frac{\rho E_f}{\rho_w E_{fv}} \right) \right)^{\frac{1}{2}} \left[1 + 2 \left(\frac{\sigma_n}{f'_{mcd}} \right) \right]$ $\rho_w = \frac{A_{fv}}{b_w s}$ $f'_{mcd} = (\frac{h}{0.3})^{\frac{1}{10}} f'c$
ISIS [24]		<p>-07</p> $V_c = 0.2 \lambda \sqrt{f'_c} b_w d \sqrt{\frac{E_f}{E_s}}$ $V_f = \frac{A_{fv} f_{fv} dv \cot \theta}{s}$ $d_v = 0.9d$ $f_{fv} = \frac{(0.05(\frac{rb}{db}) + 0.3) f_{fu v}}{1.5},$ <p>or $f_{fv} = E_{fv} \varepsilon_{fwd1}$</p> $\varepsilon_{fwd} = 0.0001 \left(f'_{mcd} \left(\frac{\rho E_f}{\rho_w E_{fv}} \right) \right)^{\frac{1}{2}} \left[1 + 2 \left(\frac{\sigma_n}{f'_{mcd}} \right) \right]$
JSCE97 [22]	$V_c = \beta_d \beta_p \beta_n f_{vcd} b_w d / \gamma_b$ $\beta_p = (\frac{1000}{d})^{\frac{1}{4}} \leq 1.5$ $\beta_p = (\frac{1000 \rho E}{E_s})^{\frac{1}{4}} \leq 1.5$ <p>E_s= steel elastic modulus ($\frac{200KN}{mm^2}$)</p> <p>β_n=1 if there aren't any applied axial forces</p> <p>f_{vcd}=0.20$\sqrt{f'_c}$ considering that $f_{vcd} \leq 0.72 \frac{N}{mm^2}$</p> $\gamma_b = 1.3$ $V_f = [A_{fv} E_{fv} \varepsilon_{fwd} (\cos \alpha_s + \sin \alpha_s) / s] z / \gamma_{bs}$ <p>E_{fv}=elastic modulus of FRP shear reinforcement α_s=angle that is between the member axis and the shear</p>	<p>Optimized equation: If $\frac{a}{d} \geq 2.5$:</p> $V_c = 2.1 (\frac{f'_c \rho_{fI} d}{a} \frac{E_{fI}}{E_s})^{0.23} b d$ <p>If $\frac{a}{d} < 2.5$:</p> $V_c = 2.1 (\frac{f'_c \rho_{fI} d}{a} \frac{E_{fI}}{E_s})^{0.23} b d \times \frac{2.5d}{a}$ $\rho_{fI} = \frac{A_{fI}}{b d}$ $V_{fv} = 0.74 (\rho_{fv} f_{fv})^{0.51} b d$ $\rho_{fv} = \frac{A_{fv}}{b s}$
Nehdi et al. [25]		

Nehdi et al. [25]	<p>Optimized equation: If $\frac{a}{d} \geq 2.5$:</p> $V_c = 2.1 \left(\frac{f'_c \rho_{fI} d}{a} \frac{E_{fI}}{E_s} \right)^{0.3} b d$ <p>If $\frac{a}{d} < 2.5$: $V_c =$</p> $2.1 \left(\frac{f'_c \rho_{fI} d}{a} \frac{E_{fI}}{E_s} \right)^{0.3} b d \times \frac{2.5d}{a}$ $\rho_{fI} = \frac{A_{fI}}{b d}$ $V_{fv} = 0.5 (\rho_{fv} f_{fv})^{0.5} b d$ $\rho_{fv} = \frac{A_{fv}}{b s}$	$I = \frac{h^3 b}{12}$ $f_{cr} = 0.6 \lambda \sqrt{f'_c}$ $k = \sqrt{2 \rho_{fl} n_f + (\rho_{fl} n_f)^2} - \rho_{fl} n_f$
Hoult et al. [26]	$V_c = \beta \sqrt{f'_c} b d_v$ $\beta = \frac{0.30}{0.5 + (1000 \varepsilon_x + 0.15)^{0.7}} \times \frac{1300}{1000 + s_{ze}}$ $d_v = 0.9 d$ $s_{xe} = \frac{31.5 d}{16 + a_g} \geq 0.77 d$ $a_g = \begin{cases} a_g, & \text{if } f'_c < 60 \\ a_g - \frac{a_g}{10} \times (f'_c - 60), & \text{if } 60 \leq f'_c \\ 0, & \text{if } f'_c > 70 \end{cases}$ $\varepsilon_x = \frac{\left(\left(\frac{M_f}{d_v} \right) + V_f \right)}{2(E_s A_s)}$	
Tureyen and Frosch [27]	<p>Calculations have been performed in the English units.</p> $V_c = \left(\sqrt{16 + \frac{4 \sigma_m}{3 \sqrt{f'_c}}} \right) \sqrt{f'_c} b c$ $c = k d$ $\sigma_m = \frac{f_{cr} I k d}{I_{cr} \left(\frac{h}{2} \right)}$ $I_{cr} = b \left(\frac{k d}{3} \right)^3 + n_f A_f (d - k d)^2$	<p>3. Previous Work</p> <p>3.1. Shear Behavior with FRP Stirrups</p> <p>Li, et. al. (2020) [28] the shear behavior of the 15 concrete beams that have been reinforced in the shear by the CFRP-MF (mesh fabric) configuration or with/with no steel stirrups (as the control samples) has been studied in that paper. Section dimensions of samples have been 300mm (high) x 150mm (wide). Concrete beam lengths ranged as per shear span-to-effective depth ratio. There have been 3 different ratios of shear span-depth (a/d ratio) submitted for dividing samples to 3 groups (i.e. A, B and C) Table (2). Shear span-depth ratio values have been 1.00, 2.50, and 3.50 and beam lengths have been 1,800mm, 1,800mm and 2,200mm, respectively. CFRP-MF reinforced concrete beam's failure mode remained dependent upon shear span/depth ratio of the beams of concrete. The CFRP-MF has been ruptured either near flexural reinforcements or crossing through the dominating diagonal crack. Stirrups of the CFRP-MF have been found to have higher effectiveness at the confining of the core concrete compared to the steel stirrups, as a result, obtaining a larger factor of efficiency in the deep beams.</p>

Table 2. Summary of the parameters of specimen [28]

Group Name	Specimen ID	Shear span-to-depth ratio	Nominal area of the transversal shear reinforcement (mm ²)	Center-to-center spacing of the stirrups (mm)	Nominal shear resistance of shear reinforcements	shear reinforcement ratio (%)
A	AC	1.0	-	-	-	0
	AS		66.4	150	31	0.293
	A150		8.0	150	31	0.036
	A80		8.0	80	58	0.067
	A55		8.0	55	84	0.097
B	BC	2.5	-	-	-	0
	BS		66.4	150	31	0.293
	B150		8.0	150	31	0.036
	B80		8.0	80	58	0.067
	B55		8.0	55	84	0.097
C	CC	3.5	-	-	-	0
	CS		66.4	150	31	0.293
	C150		8.0	150	31	0.036
	C80		8.0	80	58	0.067
	C55		8.0	55	84	0.097

Jumaa, et. al. (2019) [29] 6 high-strength large-scale beams of concrete that have been reinforced by the bars of the basalt FRP (BFRP) and stirrups and 3 equivalent beams with no stirrup have been made and tested for

the shear failure under a 4-point bending. Basic parameters that have been taken under consideration were beam effective depth (300mm, 500mm, and 700mm) and stirrup spacing Table (3).

Table 3. Details of beam specimens [29]

NO	Specimen #	Height; h, mm	Width; b, mm	Depth; d, mm	Length; L, mm	Shear span; a, mm	a/d	Concrete Comp. Strength; f_c' , MPa	Reinf. Ratio; ρ_f %	Stirrup Spacing $\varnothing$ 8 mm	ρ_{fv} % = A_{fv}/bs
1	SHR3	300	200	234	2550	610	2.61	73.4	2.97	—	—
2	MHR3	500	200	408	3050	1070	2.62	73.4	2.93	—	—
3	LHR3	700	200	602	3850	1570	2.61	73.4	2.7	—	—
4	SHR3S1	300	200	234	2550	610	2.61	73.4	2.97	120	0.42
5	MHR3S1	500	200	408	3050	1070	2.62	73.4	2.93	200	0.25
6	LHR3S1	700	200	602	3850	1570	2.61	73.4	2.7	300	0.17
7	SHR3S2	300	200	234	2550	610	2.61	73.4	2.97	80	0.63
8	MHR3S2	500	200	408	3050	1070	2.62	73.4	2.93	135	0.37
9	LHR3S2	700	200	602	3850	1570	2.61	73.4	2.7	200	0.25

Result showed that shear and flexural crack spacing at the mid-height of the beams with and with no stirrup have been proportionate to effective depth of a beam, d . The existence of the BFRP stirrups resulted in reduction of crack spacing to $0.36d$, in comparison with $0.52d$ in the beams with no stirrups. Which is why, crack spacing remains associated with depth of the beam, confirming the fact that the beam depth impact on the crack spacing isn't entirely eliminated, even though it has been considerably enhanced. The reduction of stirrup spacing from $d/2$ to $d/3$ has led to decreasing shear crack width, in particular, in the medium and small beams. The average reductions in the width of the shear crack for the large, medium, and small beams have been 4%, 24.50%, and 37%, respectively.

Osman, et al. (2018) [30] have tested 7 RC beams under 4 points loading with a variety of the shear span-to-depth ratio (a/d), vertical and longitudinal ratios of reinforcements. Each one of the RC beams has been constructed by a rectangular cross section of 100mm in width, 300mm in height, and a total length of a 1500mm. One of those beams has been taken under consideration as control beam, whereas the (RC1–RC6) beams have been reinforced by a variety of the reinforcement ratios. (RC0 & RC1) beams have been reinforced by $2\emptyset 12$ mm, RC2 Beam has been reinforced by $4\emptyset 12$ mm, and (RC3–RC6) Beams have been reinforced by $6\emptyset 12$ mm deformed bars at tension face, whereas all beams have been reinforced by $2\emptyset 10$ mm distorted bars at compression face Table 4. Vertical and longitudinal reinforcement ratios have been studied experimentally, reinforcement ratio of the stirrups has a massive impact on crack depth and shear strength compared to the other factors. Primary shear crack inclination influences contribution of the shear reinforcement's shear strength. Results that have been obtained with the use of the ANSYS finite element has been rather similar

to experimental ones, with a maximal variation of 5% in each one of the samples. A comparison between results of FE and ACI standard code has shown computational models' validity in the capture of structural responses of the contribution of the FRP with a variation that ranged at (12–20) %, (10–16) %, and (13–19)% respectively for the U-jacketing, full wrapping, and side bonding.

Table 4. Specimen details [30]

N0	Specimen	a/d	Bott. steel	Top steel	stirrup
1	RC0	1.5	$2\emptyset 10$	$2\emptyset 10$	-
2	RC1	1.5	$2\emptyset 10$	$2\emptyset 10$	$\emptyset 6@150$
3	RC2	1.5	$4\emptyset 10$	$2\emptyset 10$	$\emptyset 6@150$
4	RC3	1.5	$6\emptyset 10$	$2\emptyset 10$	$\emptyset 6@150$
5	RC4	2.0	$6\emptyset 10$	$2\emptyset 10$	$\emptyset 6@150$
6	RC5	2.0	$6\emptyset 10$	$2\emptyset 10$	$\emptyset 6@100$
7	RC6	1.5	$6\emptyset 10$	$2\emptyset 10$	$\emptyset 6@100$

Kim,et al.(2015) [31] studied the shear capacity of the concrete beams that have been reinforced by plates of GFRP as the shear reinforcement. For the purpose of examining shear performance, they have produced and tested totally 8 samples. The test variables included GFRP strip-width-to-spacing ratio and opening array type. A specimen with the GFRP plate with 3×2 opening array has shown the maximum value of the shear strength, the test included 6 type A, 1 type B, and 1 type C (Figure1). They found that the height and width of an opening have to be larger than 100 mm, and the openings' area ratio has to be higher than 50% for the purpose of obtaining an effective shear performance, 3 different results from 3 different reinforcing plate shapes have shown that the increase of bonded area between concrete and GFRP plate results in increasing shear reinforcement efficiency.

Figure 1. Designs of the 2 experimental plates of the GFRP [31]

Abdul Hamid et. al. (2013) [32] this research presented the test results of the simply supported beams of concrete, which have been reinforced longitudinally either through the steel or the GFRP. There have been totally 16 large-scale beams of concrete with steel stirrups that have been constructed and tested under 4-point monotonic load until the point of the failure.

Half of the beams have been reinforced longitudinally by the GFRP bars, whereas the rest of them have been reinforced by the conventional bars of steel as control samples, the beams have been cast on same day from same ready-mix batch of concrete with a 24MPa compressive strength on a 28 day period, with maximal 20mm aggregate size. The conventional steel reinforcing bars and sand-coated V-Rods of the GFRP have been utilized as longitudinal reinforcements in the concrete beams. There have been 2 beam types constructed and tested, which are: GFRP RC beams (BGM) and steel RC beams (BSM).

Table 5. Details of test beams and variables [32]

Specimens	a (mm)	a/d	L (mm)	La (mm)	Ltotal (mm)	Shear Reinforcement (mild steel 8 mm dia.)		Longitudinal Reinforcement Bars			
						s (mm)	ρ_s (%)	Type	N	$A_s \& A_s'$	$\rho_s \& \rho_s'$ (%)
BSM-01	550	1.5	1500	250	2000	50	1.01	Steel	2	402.1	0.6
BSM-02	550	1.5	1500	250	2000	50	1.01	Steel	3	603.2	0.8
BSM-03	550	1.5	1500	250	2000	150	0.34	Steel	2	402.1	0.6
BSM-04	550	1.5	1500	250	2000	150	0.34	Steel	3	603.2	0.8
BSM-05	1100	3.0	2600	200	3000	50	1.01	Steel	2	402.1	0.6
BSM-06	1100	3.0	2600	200	3000	50	1.01	Steel	3	603.2	0.8
BSM-07	1100	3.0	2600	200	3000	150	0.34	Steel	2	402.1	0.6
BSM-08	1100	3.0	2600	200	3000	150	0.34	Steel	3	603.2	0.8
BGM-01	550	1.5	1500	250	2000	50	1.01	GFRP	2	402.1	0.6
BGM-02	550	1.5	1500	250	2000	50	1.01	GFRP	3	603.2	0.8
BGM-03	550	1.5	1500	250	2000	150	0.34	GFRP	2	402.1	0.6
BGM-04	550	1.5	1500	250	2000	150	0.34	GFRP	3	603.2	0.8

3.2. Shear Behavior without FRP Stirrups

Kotynia et. al. (2018) [33] have performed experimental tests on 12 T-shaped beams of concrete that have been reinforced by the GFRP or the steel bars with no stirrups. The objective of this study has been analyzing the impact of a longitudinal reinforcement type (steel or GFRP) on the deformability and the shear capacity of the concrete beams with no stirrups and for investigating a dowel impact of reinforcement on shear strengths. Beams have mostly varied according to the flexural reinforcement type, its ratio of reinforcement (ρ_l) corresponds to approximately: 1%, 1.40% and 1.8%, the diameter of the bars, number of bars, and the number of layers of reinforcement (1 or 2). The test program comprised 12 T-section single span, simply supported beams of concrete with an 1800mm clear span, which have been tested in 3-point monotonic load. The shear span to depth ratio, (a/d_{eq}) has been nearly three in all of the beams, 2 main beam series have been reinforced by the longitudinal steel bars (5 beams) and GFRP bars (7 beams) of diameter: 12mm, 16mm and 18mm. All of the straight steel bottom bars have been welded on vertical plate of steel, whereas the bars of GFRP have been anchored in steel box that has been filled by epoxy resins. Top longitudinal reinforcement included 2 straight bars of a diameter of 10mm (steel or GFRP, respectively to the series). There have not been any stirrups along the shear span that has been tested, whereas opposite nontested shear span has been reinforced by the steel stirrup that have a diameter of 8mm at 130mm or 150mm spacing and 14mm diameter steel bent bars for the prevention of shear failure in that support, all of the beams have failed as a result of shear. Diagonal cracks have been formed in shear span that has been developed along longitudinal tensile reinforcements. The 1st flexural crack had happened in the mid-span of a beam. Throughout the increase in the

load, the flexural cracks have developed and diagonal crack emerged in shear area. After that, with the development of the shear crack its width has been increased to the shear failure point. Test results have been listed in Table6, steel reinforced beams have reached a considerably greater ultimate shear strength compared to beams that have been reinforced by the GFRP, the shear crack stress has been influenced mostly by reinforcement type and strength of the concrete.

Issa ,et. at. (2016)[34] have researched shear strength and behaviors of concrete beams that have been reinforced by the basalt FRP bars with and with no shear reinforcement. A total of 6 of 200mm x 300mm (8x12 in) and 6 of 300mm x 200mm (12x8 in) the concrete beams have been made respectively with and with no shear reinforcements of the basalt FRP table (6). This work has included 12 of the BFRP RC-beams of which six 300m x 200mm (12x8 in) beams have been non shear reinforced (NSR) and six 200mm x 300mm (8x12 in) the beams have been shear reinforced (SR) by 10mm of the stirrups of BFRP and No3 of the steel stirrups. The maximal length of the span for beams has been determined from Table (7) of ACI440.1 R (ACI 2006). Even though a/d ratios (7 & 5.65) has been high in the NSR-beams, they have not succeeded in the shear-tension mode. Failure has been noticed to be more brittle for the NSR-beams with greater ratio values of $\rho_f = \rho_{fb}$. All shear reinforced beams with a/d ratio of ≤ 2.50 have failed in the failure mode of shear-compression except for 3-13-SB1 beam, whereas 3-16B-3 beam had experienced a diagonal tension failure. The area of the damage has been increased with the increase in $\rho_f = \rho_{fb}$ ratio with a more noticeable BFRP stirrup failure at higher $\rho_f = \rho_{fb}$ ratios and/or higher a/d ratio.

4. Conclusions

1. The present work has shown that the predictions of shear strength of the FRP reinforced beams with and with no stirrups of the FRP have been in agreement with the shear properties of the reinforced concrete beams with other bars of FRP (CFRP, AFRP and GFRP). For the future works, more investigations are suggested in SR FRP beams of reinforced concrete in the case of the use of the FRP stirrups; in addition to that, a larger number of the parameters must be included like the beam dimension and the concrete strength.
2. FRP applications of the longitudinal tensile reinforcement in 2 layers have resulted in delaying shear failure and increasing shear strength by approximately 28%.
3. The beams that have been reinforced by the reinforcement of the GFRP has shown higher ductility compared to beams that have been steel reinforced.
4. Shear stirrups considerably enhanced the shear strength in beams, increasing the shear resistance in FRP stirrups has been less noticeable when $\rho_f = \rho_{fb}$ ratio.
5. The models of the finite element have been capable of the accurate prediction of load capacity values for simulated reinforced concrete beams in shear with the composites of FRP. Which confirms the developed FE model validity and FE simulation reliability.
6. There has been an increase in shear capacity with an increase of $\rho_f = \rho_{fb}$ under an identical ratio of the span to depth ($a=d$), whereas there has been a decrease in the shear capacity with increasing span to depth ratio ($a=d$).
7. The existence of the FRP stirrups doesn't entirely suppress size effects, as initial shear crack, shear resistant components analysis, shear crack width, normalized shear strength and strain in BFRP stirrups are still impacted by depth of the beam.
8. CSA S6-14 included a higher degree of the scatter.
9. ISIS-M03 has given unreliable results in calculation of concrete shear strength.
10. The equation that was designed by Nehdi et al. has been more superior in comparison with other design processes.
11. JSCE and ACI 440.1R-15 have resulted in the production of more conservative results in the calculation of transverse shear strength.

Conflict of Interest

The authors confirm that the publication of this article causes no conflict of interest.

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