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Mechanical properties of steel-CFRP composite specimen under uniaxial tension

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Abstract. This paper introduces new specimens of Steel-Carbon Fibre Reinforced Polymer composite developed in accordance with standard test method and definition for mechanical testing of steel (ASTM –A370). The main purpose of this research is to study the behaviour of steel-CFRP composite specimen under uniaxial tension to use it in beams in lieu of traditional steel bar reinforcement. Eighteen specimens were prepared and divided into six groups, depending upon the number of the layers of CFRP. Uniaxial tensile tests were conducted to determine yield strength and ultimate strength of specimens. Test results showed that the stress-strain curve of the composite specimen was bilinear prior to the fracture of CFRP laminate. The tested composite specimens displayed a large difference in strength with remarkable ductility. The ultimate load for Steel-Carbon Fibre Reinforced Polymer composite specimens was found using the model proposed by Wu *et al*. (2010) and nonlinear FE analysis. The ultimate loads obtained from FE analysis are found to be in good agreement with experimental ones. However, ultimate loads obtained applying Wu model are significantly different from experimental/ F E ones. This suggested modification of Wu model. Modified Wu's model which gives a better estimate for the ultimate load of Steel-Carbon Fibre Reinforced Polymer (SCFRP) composite specimen is presented in this paper.

Keywords: CFRP laminate; steel strip; tensile load; modified model; specimen

1. Introduction

A composite material is one that attains its physical and mechanical characteristic through the integration of other material. Generally, a composite material combines the most desirable characteristic of its constituents to create a superior material, Fawzia *et al*. (2007). In last a few decades, a lot of attention has been given to fibre-reinforced polymers (FRP) as a replacement material for steel reinforcement. FRP products have certain deficiencies such as elastic behaviour until failure and big differences between longitudinal and transverse mechanical characteristics, as well as between tensile and compressive stresses. Main deficiencies of FRP, when compared to steel reinforcement, are their non-ductile behaviour and creep rupture Soric *et al*. (2010). With

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these deficiencies, FRP has high strength, low elasticity modulus, poor ductility, good durability and lightweight while steel is the opposite, Rizkalla and Hassan (2002). Combining the advantages of the two, a new composite material is expected to have outstanding comprehensive properties such as high strength, a high elastic modulus, good ductility and low cost, Wu (2006), Wu *et al*. (2009). Recently, attempts are being made (there are many tries) to take advantage from these characteristics of the two materials (steel and FRP) by combining together to create superior material to be used for strengthening, repairing existing structures and even as replacement for traditional steel reinforcement.

Wu *et al.* (2010) introduced a new reinforcing material of steel-fibre-reinforced (FRP) composite bar (SFCB). The composite bar consists of different amount of fibre (bundle) wrapped around steel rebar of 10 mm diameter. Tests under uniaxial tension and cyclic tension were conducted to determine the initial elastic modulus, post yield stiffness, yield strength, ultimate strength, unloading stiffness, and residual deformation. Test results showed that the stress-strain curve of the (SFCB) was bilinear before the fibre fractures and a post yielding stiffness achieved.

In this research, a new reinforcing material has been developed. The new reinforcing material is a composite of linear elastic CFRP and elastic-plastic steel strip. The behaviour of this composite is found similar to SFCB under uniaxial tension.

Being a try to reduce the total dependence on the traditional steel reinforcement, a little amount of steel has been used to manufacture the new specimens of steel-carbon fibre reinforce polymer (SCFRP) composite. Following are the key goals of using a little amount of steel.

(1) To achieve a ductility for specimens after fracture of CFRP laminates.
(2) To protect CFRP laminate from possible damage by surrounding concrete during its placing and mechanical compaction.
(3) To provide stiffness so that it can be configured to any desirable form like a bend at the end, a stirrup or a hoop.

Woven carbon fibre fabric (Sika Wrap®-300C) and 2-part epoxy impregnation resin (Sikadur®-330) were used to make the steel-CFRP composite specimens. Single layered to five layered, three of each type, total fifteen composite specimens were prepared. These fifteen specimens of steel-CFRP composite and three standard specimens of pure steel were tested under uniaxial tension test. The ultimate load for steel-carbon fiber reinforced polymer (SCFRP) composite specimens was found using the model proposed by Wu *et al*. (2010) and nonlinear FE analysis. The ultimate loads obtained from FE analysis are found to be in good agreement with experimental ones. However, ultimate loads obtained applying Wu model are significantly different from experimental / F.E. ones. This suggested modification of Wus model. Modified Wu’s model which gives a better estimate for the ultimate load of steel-carbon fiber reinforced polymer (SCFRP) composite specimen is presented in this paper.

2. Objective of study

In this paper, objective of the present work is to:

(1) Study the behaviour of this new composite under uniaxial tension.
(2) Work out whether this can be configured to replace conventional flexural and shearing reinforcing steel bars.
(3) Propose an improved model which gives better estimate of ultimate tensile load of this composite.

Fig. 1 Stirrups and longitudinal composite bars

Above mentioned objectives are the preliminary requisite of a broader objective of continuing work on the study of the response of concrete beams reinforced with the composite in lieu of conventional reinforcing steel bars under quasi-static loading. To cast the concrete beams reinforced with the composite, stirrups and longitudinal bars have been made. Fig. 1 shows the stirrups and longitudinal bars that would be used to reinforce concrete beams in the continuing work.

3. Material properties

Three materials have been used to prepare the specimens. These are CFRP, adhesive and steel strips. Their specified properties are listed in Table 1.

3.1 CFRP

In the present research, SikaWrap®-300C was used. It is a unidirectional woven carbon fibre. The main characteristic of carbon fibre is its tensile strength and Young's modulus.

3.2 Adhesive

It is desirable to use 2- part epoxy whenever possible because most will cure within 16-24 h under ambient condition. However, the trade-off of this relatively simple curing is a limited pot life (working time) of adhesive, which can range anywhere from 30 to 90 minutes. The single

Table 1 Properties of material

Material	CFRP	Adhesive	Steel strip
Tensile strength (MPa)	3900	30	388
Tensile E-modulus (MPa)	230000	4500	150000
Elongation at break	1.5%	0.9%	30%
Thickness (mm)	0.166	-	1.5

component adhesive offers a much longer pot life, yet they often require elevated temperature to ensure cross-linking of the polymers and, hence, a fully cured adhesive. Under laboratory condition, it is relatively easy to perform a high-temperature cure, however, this task can be difficult to implement in the field, Fawzia *et al*. (2007). In this research, sikadure-330 was used. It is two part epoxy (A+B) impregnation resin. Part A is the resin while part B is hardener.

3.3 Steel strips

No standard is available to test the composite developed in the present research work. Therefore, ASTM A370-02 has been followed to test the specimens under uniaxial tension. Fig. 2 shows the dimensions of test specimens. 1.5 mm thick, mild steel plate cut to 200 mm long and 20 mm wide strips. Lathe machine was used for configure the final shape of specimens. Fig. 3 illustrates the final shape of the specimens. Tensile tests were conducted on the steel strip specimens to calculate yield stress, ultimate stress and the modulus of elasticity of steel strips.

4. Composite specimens' preparation

Surface preparation of the metal substrate is indispensable to achieve a good bond between the metal and the CFRP. The strength of the adhesive bond is directly proportional to the quality of the surfaces it mates. ASTM provides guidance for the surface preparation of metals for adhesive bonding. While there are many methods available within the guidance, they are generally applicable to small-scale laboratory applications. It is necessary to keep in mind that the method selected for

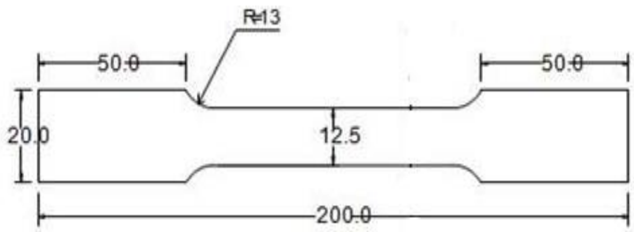


Fig. 2 Dimensions of test specimen

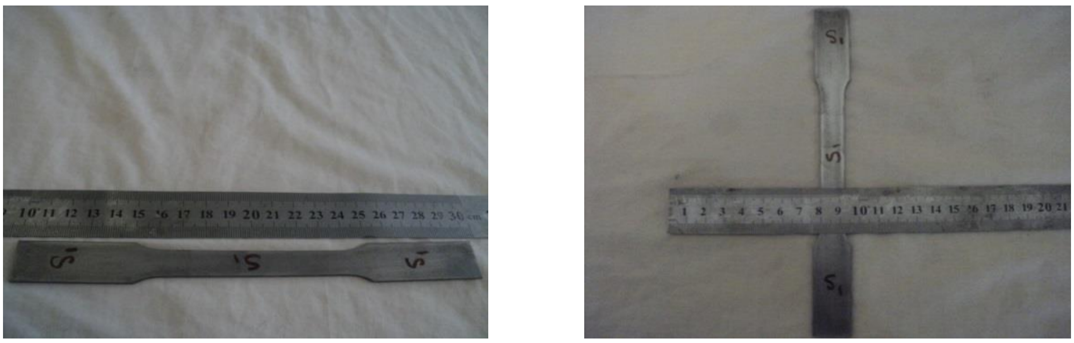
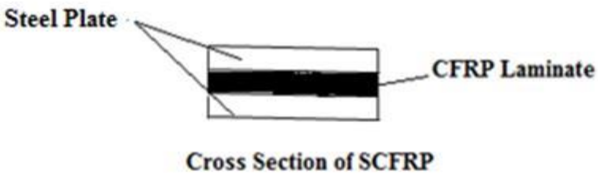


Fig. 3 Final shape of steel plate

surface preparation must be easily applicable in the field, Fawzia *et al*. (2007). Surface preparation involved the following:

(1) Mild surface grinding to remove all scaling, rust, paint, and primer from the steel plate is done using grinder.
(2) Specified SikaWrap®-300C fabric cut to the desired dimensions.
(3) Resin and hardener (Sikadur®-330) were correctly proportioned and thoroughly mixed together.
(4) The Sikadur®-330 was applied to the prepared substrate using a brush.
(5) The SikaWrap®-300C fabric was placed in the required direction onto the Sikadur®-330.
(6) The excess epoxy and air was removed applying mild pressure by a plastic roller moving in the direction of the fibre.
(7) For additional layers of SikaWrap®-300C fabric, Sikadur®-330 were applied to previously applied layer wet on wet within 60 minutes (at +23°C) after application of the previous layer and repeated the laminating procedure.
(8) The final stage of preparing the specimen was to put the second steel plate. Parallel clamps were tightened to hold the CFRP laminate between steel plates together to ensure removal of any air that might be entrapped in between. Fig. 4(a) illustrates the parallel clamps used and Fig. 4(b) illustrates the cross section of SCFRP.

(a) Parallel clamps



(b) Cross section of SCFRP

Fig. 4 Parallel clamps and cross section of (SCFRP) specimen

Fig. 5 The six groups of specimens

Fig. 6 Typical test setup

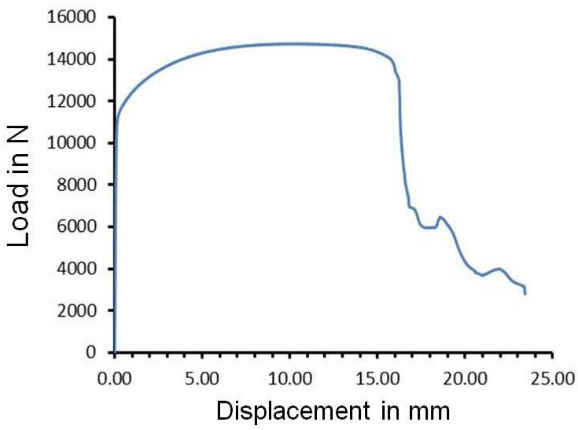
5. Specimens and test set up

Prepared specimens for testing are shown in Fig. 5 Each specimen was tested in tension in a 500kN capacity Zwick Roell universal testing machine with a loading rate of 2 mm/min. The test continued until the fracture of steel plate of the composite specimen. Fig. 6 shows typical test setup.

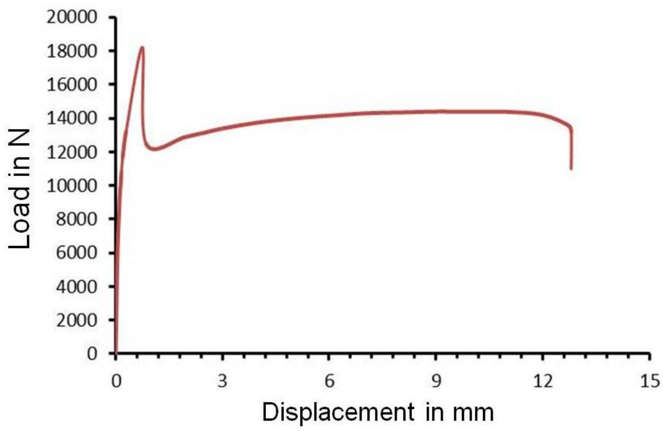
6. Behaviour and test results of specimens under uniaxial tensile load

6.1 Behaviour of specimens under uniaxial tensile load

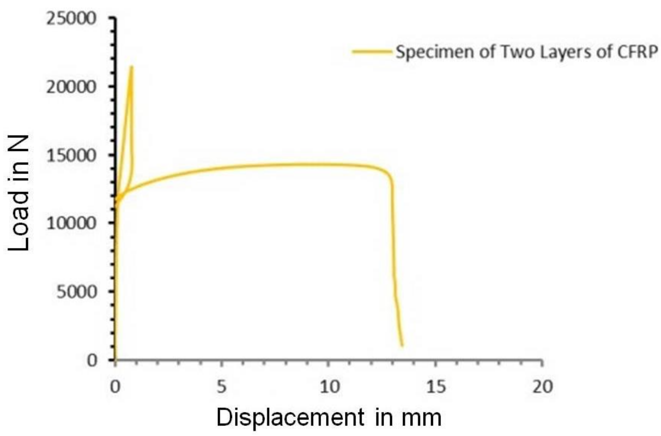
Fig. 7 shows the load-displacement curves of one specimen for each type under tensile load while Fig. 8 shows the stress-strain curves of the uniaxial tensile test on specimens. At the initial stage of loading, the load was shared by steel and CFRP laminates. The specimen appeared to yield when the strain reached about 0.002. Because the steel strips had already yielded, they were not available to share additional load. As the load capacity of specimen reached to its peak value



(a) Steel strips without CFRP

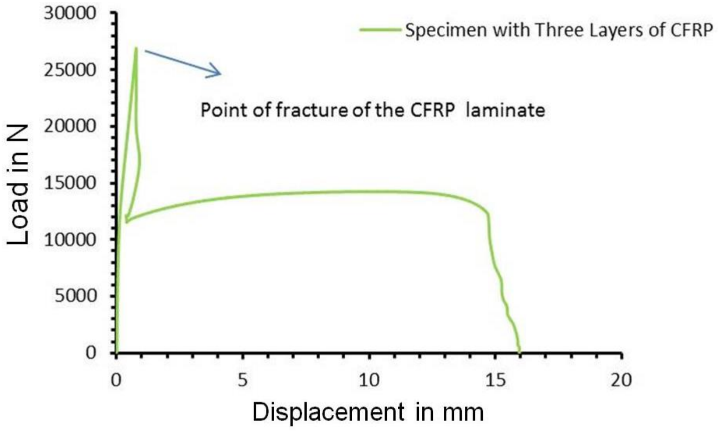


(b) Specimen with one layer of CFRP

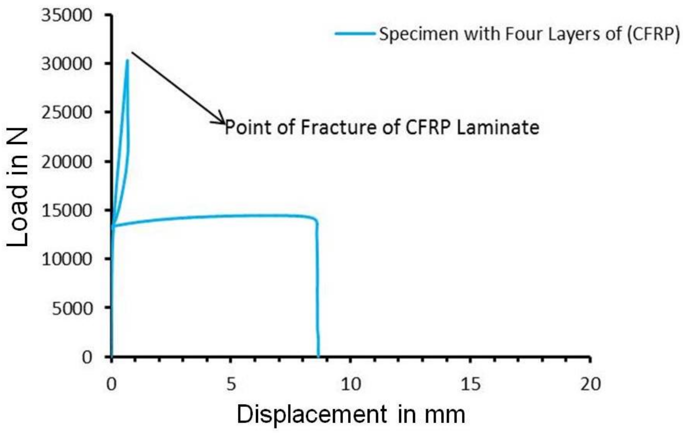


(c) Specimen with two layers of CFRP

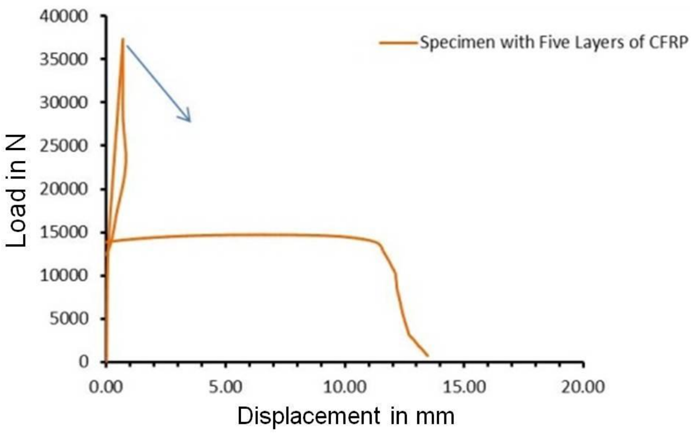
Fig. 7 Load-displacement curves of specimens



(d) Specimen with three layers of CFRP



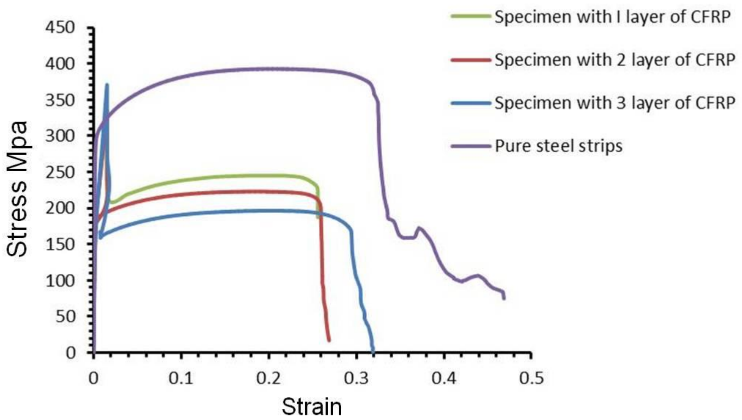
(e) Specimen with four layers of CFRP



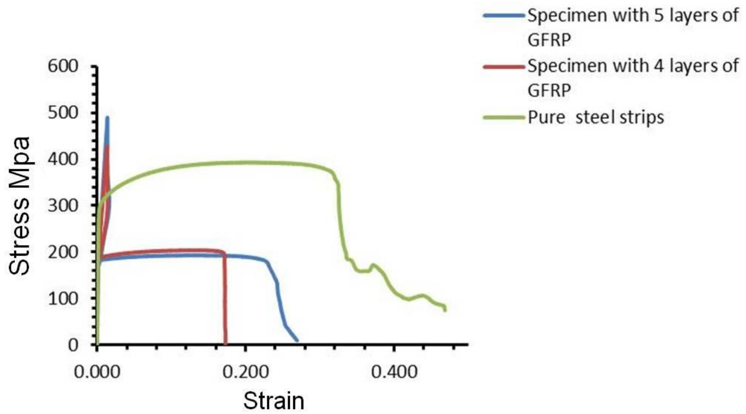
(f) Specimen with five layers of CFRP

Fig. 7 Continued

where the CFRP laminate fractured, the load decreased rapidly and the steel strips carried the entire load until it fractured. The specimen showed the ideal failure mode of steel yielding first, followed by CFRP laminate fracture and, finally, followed by tensile failure of steel. It was noticed that no cracks or slipping between the epoxy and two strips have occurred before the fracture of CFRP laminates. Immediately after the fracture of laminate, the laminate comes out of specimen in the region of fracture. Fig. 9 shows the fractured specimens. It is worth mentioning that all the values of stress, strain and displacement of tested specimens have been obtained from output data file of the Zwick Roell, a computerized universal testing machine, after completing the tests. In Fig. 8, it could be seen that the stress-strain curves of steel-CFRP composite after fracture of CFRP laminate don't match with stress-strain curve of steel specimen. This happened as a result of the gross area of specimen supplied to the computer of the testing machine and the software of the machine used the same gross area even after fracture of CFRP. Using the area of steel strip alone for the load carried by the composite specimens after fracture of laminate, the stress-strain curves for the composite specimen have been plotted and shown in Fig. 10.



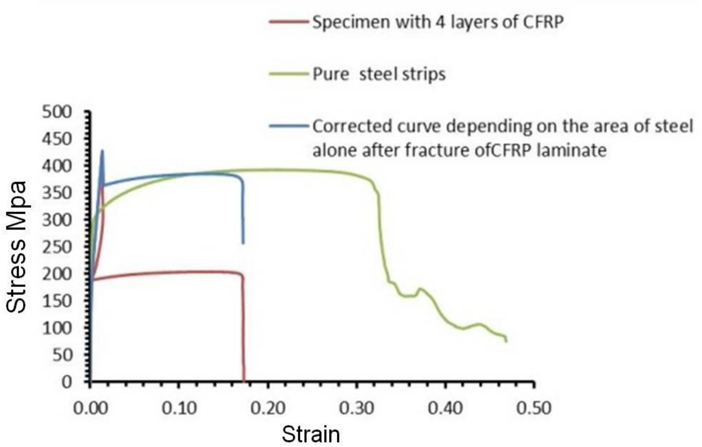
(a) Stress-strain curves of specimens with 1,2,3 layers of CFRP and pure steel strips



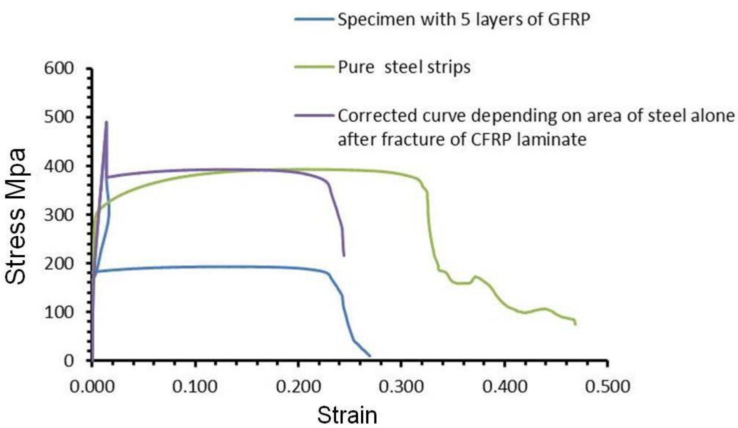
(b) Stress-strain curves of specimens with 4,5 layers of CFRP and pure steel strips

Fig. 8 Stress-strain curves of steel-CFRP specimens and steel strips

Fig. 9 Fractured specimens



(a) Stress-strain curves of specimen with 4 layers of CFRP and pure steel strips



(b) Stress-strain curves of specimen with 5 layers of CFRP and pure steel strips

Fig. 10 Comparison between original and corrected curves of specimens with 4, 5 layers of CFRP laminate

Table 2 The strengthening effects of bonding CFRP laminate to the steel strips

Specimens	Yielding load (N)	Increase in Yielding load %	Ultimate load (N)	Increase in Ultimate load %
Steel (two strips)	11175	–	14540	–
With one layer (CFRP)	12251	11	18213	12.5
With laminate of two layers	12789	14	21250	46
With laminate of three layers	14164	27	26750	83
With laminate of four layers	15904	42	29450	102
With laminate of five layers	17628	58	33750	132

6.2 Test results

Table 2 shows the values of yielding and ultimate load of specimens. The values represent the average of values of three specimens.

From Table above, Fig. 7 and Fig. 8 following observations can be drawn:

(1) The yield and ultimate loads increased with the increase of the number of layers of CFRP.

(2) The stress-strain curve for all the specimens was bilinear before the laminate fractures.

(3) After fracture of laminate the steel carries on displaying its intrinsic ductility but with its yield load.

7. FE model geometry, boundary conditions and loading

The ANSYS finite element program (*ANSYS* version 10) is used in this study to simulate the behaviour of the composite specimens tested under uniaxial tension. The simulation was done by running nonlinear analysis solver to account for the nonlinear properties of the materials. By taking advantage of the symmetry of the specimens, a quarter of the full specimen was used for modelling. This approach reduced computational time and computer disk space requirements significantly. Planes of symmetry were required at the internal faces. At a plane of symmetry, the displacement in the direction perpendicular to that plane was held at zero. The displacements in the plane of loading were achieved by providing rollers along the axes of symmetry. A quarter of the beam model is shown in Fig. 11.

All constituent materials of the specimens were modelled with eight-nodded brick elements. SOLID 45 was used to model the steel strips, adhesive and CFRP, Mohammad and Omran (2008). Up to five layers of CFRP were used in simulation. Each layer has thickness 0.166 mm as given by the manufacturer. The adhesive thickness for each specimen has been calculated based on equal thickness epoxy between steel strip and CFRP and between each of the CFRP layers, as follows

$$t_e = \frac{(T - 2t_s - n \cdot t_f)}{(n+1)} \tag{1}$$

where t_e, T, t_s, t_f are thickness of one layer of epoxy, total thickness of specimen, thickness of steel strips and thickness of CFRP respectively; n, number of layers of CFRP.

8. Finite element results and discussions

The idealization of Steel-CFRP composite specimens is done by subdividing the composite specimen into a number of elements as shown in Fig. 11. A convergence study on quarter model of the specimen without CFRP laminate was carried out first to determine an appropriate mesh density. The convergence of results is obtained when an adequate number of elements are used in a model. Fig. 12 Show the convergence of theoretical and experimental stress-strain behaviour of pure steel strips specimen. The same numbers of element divisions in longitudinal and transverse directions to model steel strip and Steel-CFRP composite specimens have been used. Fig. 13 Show the convergence between experimental and theoretical stress-strain behaviour of steel-CFRP composite specimens.

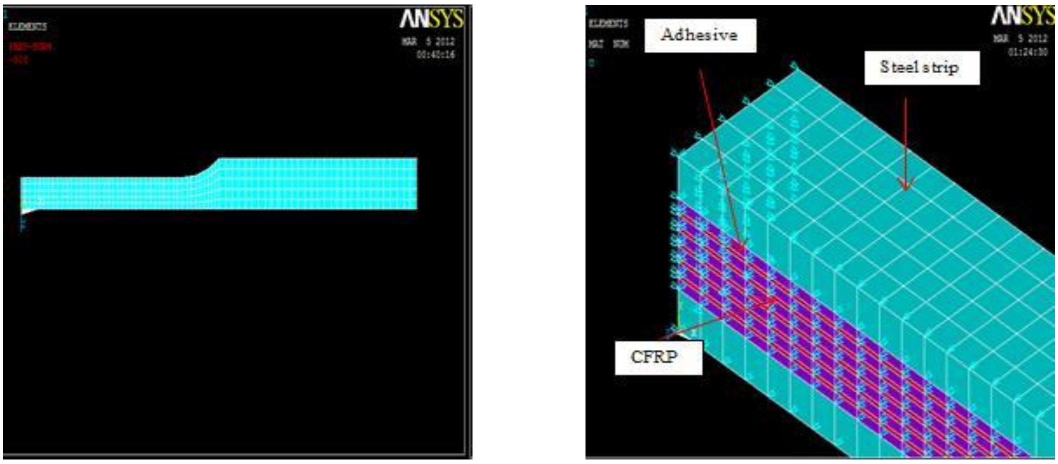


Fig. 11 Specimen modelling

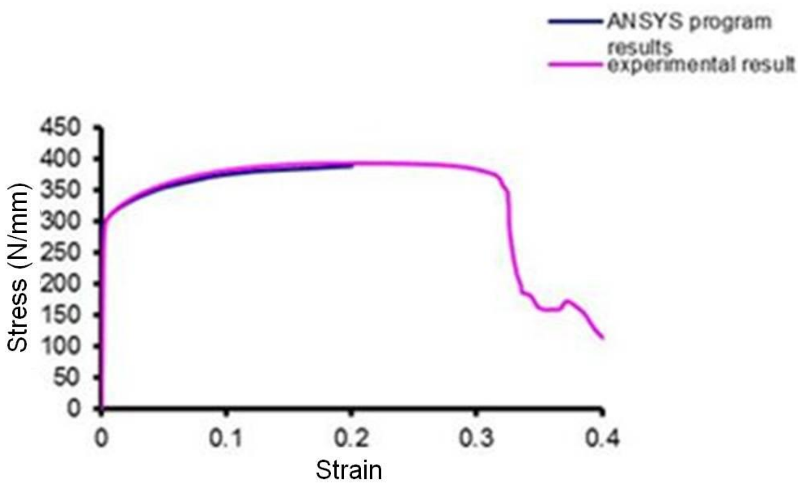
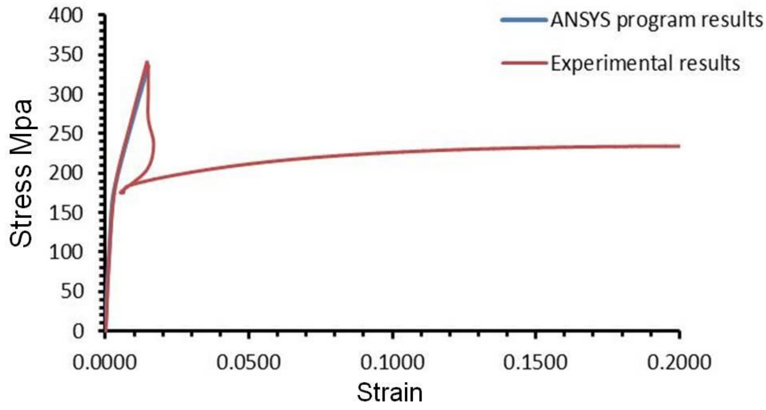
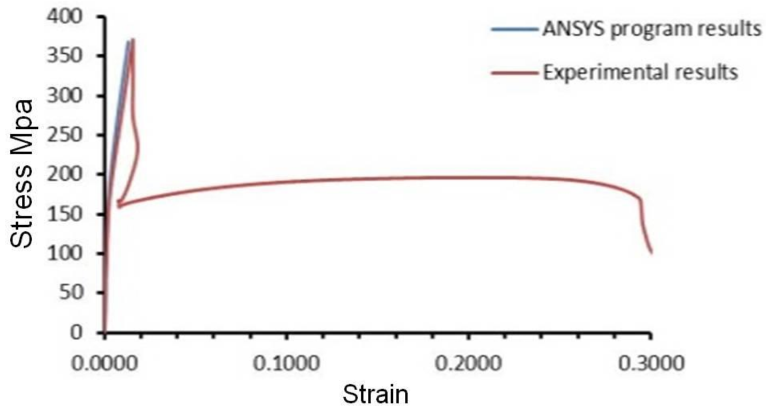


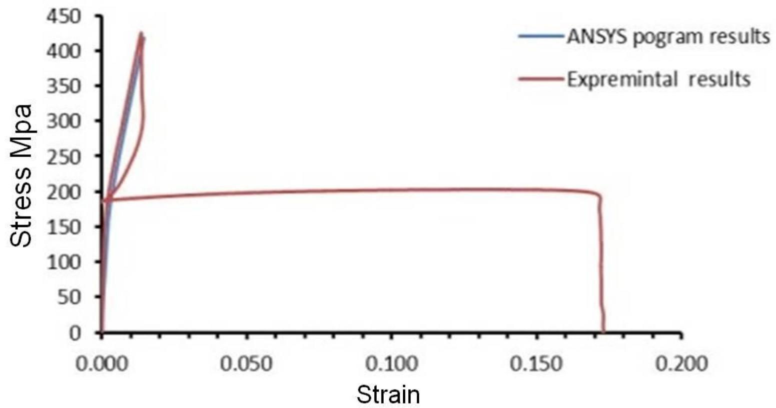
Fig. 12 Comparison between ANSYS program and experimental results of steel plate



(a) Specimen with 2 layers of CFRP

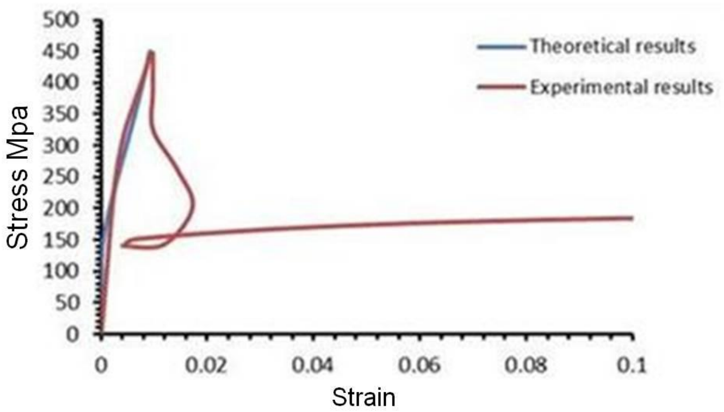


(b) Specimen with 3 layers of CFRP



(c) Specimen with 4 layers of CFRP

Fig. 13 Experimental and theoretical stress-strain behaviour of composite specimens



(d) Specimen with 5 layers of CFRP

Fig. 13 Continued

Table 3 theoretical (ANSYS) and experimental values of ultimate stress

Type of test	One layer CFRP specimen	Two layer CFRP specimen	Three layer CFRP specimen	Four layer CFRP specimen	Five layer CFRP specimen
Theoretical ultimate stress (MPa)	282	336	385	417	450
Experimental ultimate stress (MPa)	305	333	389	413	442

The theoretical stress-strain curves have stopped almost near the top point of the experimental ones that represents the fracture of CFRP laminates, Figs. 13. Reaching approximately to this point, the program terminated. In the FE programs, when the solution does not converge at specific load, the program terminates. So all these theoretical points (values) in which the program has stopped running represent the load of fracture of CFRP laminate. Table 3 shows the convergence of theoretical and experimental values of the ultimate stress.

9. The modified model and its relationship with (SFCB) model

9.1 Theoretical modle of steel-fiber-reinforced polymer compsite bar (SFCB)

Wu *et al*. (2010) presented theoretical model for steel-fibre-reinforced polymer composite bar (SFCB) under a uniaxial tensile load. Based on factory production of SFCB, uniaxial tensile test and cycle tensile test were conducted to determine the initial elastic modulus, post yield stiffness, yield strength, ultimate strength, unloading stiffness and residual deformation. Test results showed that the stress-strain curve of the SFCB was bilinear fibre fractures. Detailed explanation of manufacturing of SFCB can be found in Wu *et al*. (2010). According to mixture rule, Wu *et al*. (2010) explained that the value of tensile property of SFCB could be obtained from those of steel and fibre. Depending on the model, the total strain was divided into three intervals as shown in Fig. 14.

The strain interval *I* was from zero to the yielding of the steel; the equations for tensile stress σ_t and elastic modulus E_1 are as follows

$$\sigma_1 = \varepsilon \frac{(E_s A_s + E_f A_f)}{A}, \qquad 0 \le \varepsilon \le \varepsilon_y \tag{2}$$

$$E_1 = \frac{(E_s A_s + E_f A_f)}{A}, \qquad 0 \le \varepsilon \le \varepsilon_y \tag{3}$$

where A_s, E_s and ε_y are elastic modulus, cross section area and yield strain of steel, respectively; E_f and A_f = elastic modulus and, cross section area of fibre; and $A = A_s + A_f + A_r$, where A_r is the area of resin in SFCB.

Strain interval *II* was from the yielding of steel to fracture of fibre. The equation for the tensile stress is as follow

$$\sigma_{II} = \frac{(f_y A_s + \varepsilon E_f A_f)}{A}, \qquad \varepsilon_y \le \varepsilon \le \varepsilon_{fu} \tag{4}$$

where, f_y = yield of stress of steel, and ε_{fu} = fracture strain of the FRP.

Finally, strain interval *III* was from the fracture of fibre to the fracture of steel. Without considering the strengthening effect of steel, equation for the tensile stress is as follow

$$\sigma_{III} = \frac{f_y A_s}{A}, \qquad \varepsilon_{fu} \le \varepsilon \le \varepsilon_{s,\max} \tag{5}$$

where, $\varepsilon_{s,\max}$ = fracture strain of steel.

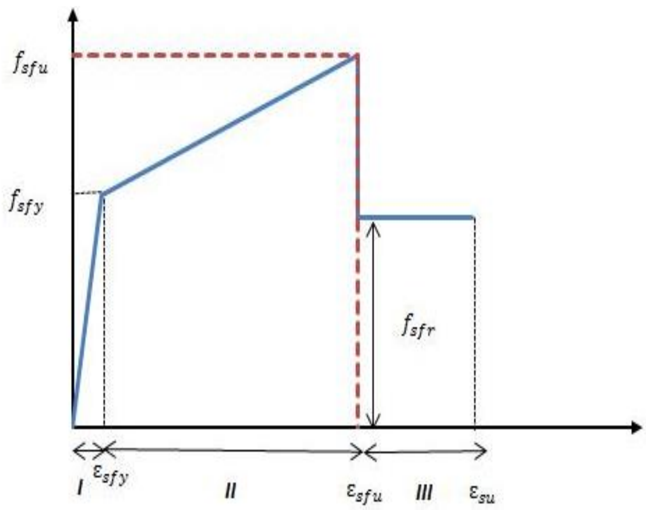


Fig. 14 Stress-strain relationship of SFCB

9.2 Modified model for steel-CFRP composite CFRP laminates are sandwiched between two steel plates)

The theoretical model of SFCB presented above was derived for steel-FRP composite bar. Crescent-rib steel rebar with a diameter of 10 mm was used as inner steel bar. Different fiber amounts (bundles) were wrapped around the rebar. The stress-strain behavior of all specimens was bilinear before the fiber fractured. The specimen showed the ideal failure mode of steel yielding first, followed by the outside fiber fracture and, finally, followed by tensile failure of steel in region near the fractured fiber. To derive the theoretical model for steel-CFRP, Wu *et al*. (2010) assumed perfect bonding between innermost fibre and steel bar. Wu *et al*. (2010) compared the theoretical and experimental results and stated that the theoretical model had fine precision except for several specimens. They explained that the errors may result from the assumption that there was no slip occurred, that is, a perfect bond exists on the interface between the fibre and steel bar. Specimens of steel–CFRP composite tested in uniaxial tension presented in this study show exactly the same behaviour that of SFCB under tensile load. Therefore, the equations derived to calculate the yield stresses and elastic modulus of samples by Wu *et al*. (2010) are valid to use as main equations to calculate the stresses and elastic modulus for specimens of steel–CFRP composite presented in this study. Table 4 shows the convergence between the theoretical and experimental results of the present study according to Eqs. (2)-(3). The same convergence could be seen in study of Wu *et al*. (2010).

However, the difference between theoretical ultimate tensile stress using Eq. (4) and experimental results reported by Wu *et al*. (2010) is noticeably large. So is the case with present study on steel-CFRP composite, Table 5. From this table, Theoretical values of ultimate stress using Eq. (4) are found to be 1.02, 1.2, 1.22, 1.35 and 1.39 times of respective experimental values of composite specimens with 1, 2, 3, 4 and 5 layers respectively. The difference increases with increasing the number of layers of CFRP laminate. To have a better estimate of the ultimate loads and stresses of specimens, Eq. (4) has been modified. The second term of Eq. (4) is the most important one that makes the value of the ultimate tensile load of the specimen to increase depending upon the number of layers of CFRP. In order to derive an expression of ultimate tensile load in terms of number of layers, non-dimensional ultimate load of CFRP laminates verses number of layers have been considered to plot best fitting curve represented by the following equation, Fig. 15.

Table 4 theoretical and experimental results according to Eqs. (1) and (2)

Specimen	Area (mm^2)	Theoretical elastic modulus E_1 (GPa)	Experimental elastic modulus (GPa)	Theoretical yield stress σ_1 (MPa)	Experimental yield stress (MPa)
With one layer (CFRP)	58.75	103.8	98	207	202
With laminate of two layers	63.75	103.2	100	206.4	202
With laminate of three layers	68.75	102.6	102.9	205.2	206
With laminate of four layers	71.25	105.7	110	211.4	218
With laminate of five layers	76.25	105	115	210.13	225

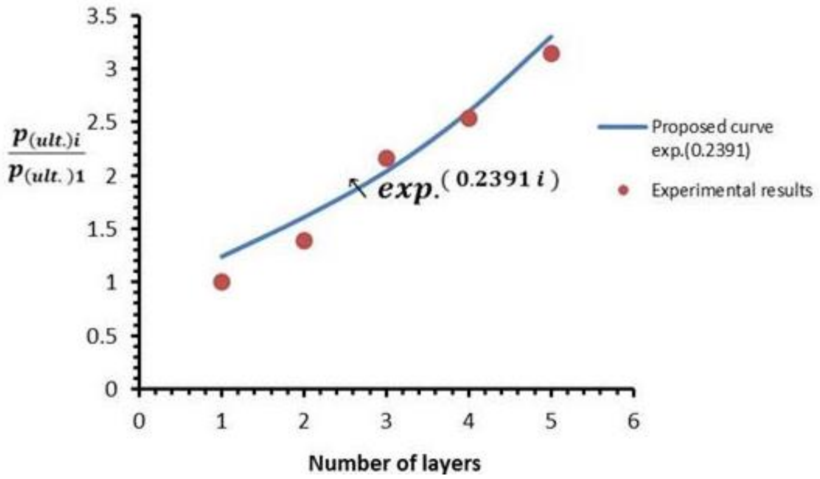


Fig. 15 Non-dimensional ultimate load of CFRP laminate versus CFRP layer numbers

Table 5 ultimate tensile load; experimental, Wu's model and modified Wu's model

Specimen	Area (mm^2)	Experimental results of steel-CFRP		*Theoretical results of modification Wu's model		Theoretical results of Wu's model	
		P (kN)	σ (MPa)	P (kN)	σ (MPa)	P (kN)	σ (MPa)
With one layer of CFRP	58.75	18.2	305	20.3	346	18.4	313
With laminate of two layers	63.75	21.25	333	22.7	356	25.49	399
With laminate of three layers	68.75	26.75	389	25.8	375	32.65	474
With laminate of four layers	71.25	29.45	413	29.9	418	39.81	558
With laminate of five layers	76.25	33.75	442	34.8	456	46.96	613

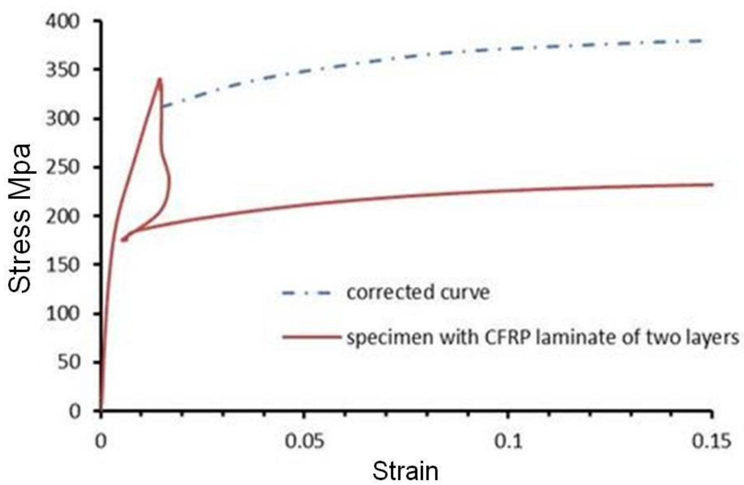


Fig. 16 Corrected stress-strain curve of specimen

$$p_{(ult.)i} = \exp.^{(0.239 i)}\, p_{(ult.)1} \tag{6}$$

where, i is the number of layers of CFRP, $p_{(ult.)i}$ represents the ultimate tensile load of CFRP laminates depending on number i and $p_{(ult.)1}$ is the ultimate tensile load of one layer of CFRP.

The ultimate load using modified model is

$$p_{ult.} = f_y A_S + e^{(0.239 i)} \varepsilon E_f A_{f,1} \tag{7}$$

In addition, the ultimate stress can be written as

$$\sigma_{ult.} = \frac{f_y A_S + e^{(0.239 i)} \varepsilon E_f A_{f,1}}{A}, \tag{8}$$

where, $A_{f,1}$ is the area of one layer of CFRP.

To validate these formulae, a comparison between the experimental and theoretical results has been done. The results obtained using the model of SFCB proposed by Wu *et al*. (2010) and the results obtained by using modified Eqs. (7)-(8) for the present study on steel-CFRP composite are shown in Table. 5. After modification of Eq. (4), the theoretical values of ultimate stress become 1.13, 1.06, 0.09, 1.01 and 1.03 times of respective experimental values of composite specimens with 1, 2, 3, 4 and 5 layers respectively.

The strain interval *III* in the model of Wu *et al*. (2010) and the interval after fracture of CFRP laminate of stress-strain curves of (SCFRP) specimens presented in this study need more attention. It was from the fracture of the fiber to the fracture of the steel. The total area of specimen during this interval after the fracture of fiber must not include the area of fiber. Therefore, the stress-strain curve of this interval for each specimen needs to rise up according to the new area of specimen represented by the area of steel alone. Fig. 16 shows the corrected curve of specimen with CFRP laminate of two layers.

As mentioned above, Eq. (5) simply becomes

$$\sigma_{III} = f_y \tag{9}$$

10. Conclusions

In this paper, the experimental tensile strength of the developed specimens of carbon reinforce polymer sandwiched between two steel strips called steel-CFRP composite have been presented. Sandwiched CFRP was also used in the form of laminate consisting of a number of layers up to five glued together using epoxy resin between layers of fibre and between outermost layers of fibre and steel strips. This new type of composite developed in accordance with standard test method and definition for mechanical testing of steel (ASTM –A370). Through the uniaxial tensile test, yield loads and ultimate loads were studied. Test results showed that the stress-strain curve of sandwiched specimens were bilinear before laminate fractures. A ductility after fracture of laminate was observed but with lower load than the ultimate load. The ultimate load for steel-carbon fiber reinforced polymer (SCFRP) composite specimens was found using the model proposed by Wu *et al*. (2010) and nonlinear FE analysis. The ultimate loads obtained from FE analysis are found to be in good agreement with experimental ones. However, ultimate loads obtained applying Wu model are significantly different from experimental / F E ones. This suggested modification of Wu's model. Modified Wu's model which gives a better estimate for the ultimate load of steel-carbon fiber reinforced polymer (SCFRP) composite specimen is presented in this paper.

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