

Experimental Study on Strengthening of Steel Structures with Fiber Reinforced Plastic

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Abstract. An experimental study on the strengthening of steel structures with FRP (Fiber Reinforced Plastic) is presented in this paper. Test coupons were prepared by applying FRP patches on both sides of steel coupons. Standard tensile tests were conducted to the test coupons. Two types of CFRP (Carbon Fiber Reinforced Plastic) and one type of GFRP (Glass Fiber Reinforced Plastic) were studied. The load and strain data were recorded, and the stiffness and strength were derived. The results show that CFRP provides better strengthening than GFRP, but there is no significant difference between PAN graphite/epoxy and pitch graphite/epoxy laminates.

Introduction

Steel structures such as bridges, off-shore platforms, large mining equipment and buildings need retrofitting. The conventional method of repairing or strengthening steel structures is to cut out and replace plating, or to attach external steel plates. This requires shut down the structure being repaired and thus time-consuming and costly. An attractive alternative method is to use FRP.

Literature survey shows that there is a great potential for CFRP to be used in the retrofitting of steel structures. However, many issues need to be resolved before this advanced material can be fully utilized to provide confident retrofitting of existing structures [1].

An experimental study on strengthening steel plates with FRP is presented in this paper. Test coupons were prepared by applying FRP patches on both sides of steel coupons. Standard tensile tests were conducted to the test coupons. Two types of CFRP and one type of GFRP were chosen to be studied. The load and strain data were recorded, and the stiffness and strength were derived. The stress was also studied by finite element analysis (FEA).

Experiments

The test coupon used in this study is shown in Fig. 1. FRP patches were applied to both sides of a steel coupon. The FRP patches were prepared using ICC's Sitecure [2] technology. First, a steel coupon is grit blasted and primed. Second, the carbon fiber tape is placed according to the ICC design and a vacuum bag is placed over the top. Using vacuum ensures high fiber content and minimum void levels, and thus improves the strength and durability of repairs. Finally, a steam bag is applied to cure the prepreg. Steam at atmospheric pressure is always 100 °C and therefore the cure of the prepreg is extremely well controlled. After approximately 5 hours of "steaming" the resin has fully cured and the process materials are removed.

Two types of CFRP and one type of GFRP were chosen to be studied, as shown in Table 1. A total of 12 test coupons were prepared and standard tensile tests were conducted to each coupon. Strain gages were placed in the middle of the coupon on both sides to measure the strains of FRP patches. Another strain gage was placed on the side of the coupon to measure the strain of steel. The details of all experiments are shown in Table 2. In each experiment, the load and strain data were recorded.

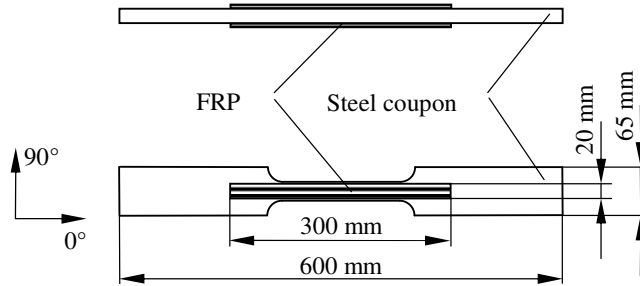


Fig. 1: Test coupon

Table 1: Materials used in experiments

Short ref	Reference	Description
GL	EG UD 250 A	E glass unidirectional 250 gsm [52% fiber by volume]
PA	PAN UD 500 A	PAN unidirectional 500 gsm [50% fiber by volume]
PI	PIT UD 450 A	PITCH unidirectional 450 gsm [50% fiber by volume]

Table 2: Experiments

Experiment	Layup $X_{(x)}^x \dots$	Total Thickness (mm)	Laminate Thickness (mm)
1	$GL_{(2)}^0, PA_{(4)}^0$	16	6
2	$GL_{(2)}^0, PI_{(4)}^0$	15	5
3	$GL_{(2)}^0, PA_{(4)}^0$	16	6
4	$GL_{(2)}^0, PI_{(4)}^0$	15	5
5	$GL_{(2)}^0, PA_{(4)}^0$	16	6
6	$GL_{(2)}^0, PI_{(4)}^0$	15	5
7	$GL_{(4)}^0, PA_{(4)}^0$	17.5	7.5
8	$GL_{(4)}^0, PI_{(4)}^0$	16.5	6.5
9	$GL_{(2)}^0, PA_{(8)}^0$	20.5	10.5
10	$GL_{(2)}^0, PI_{(8)}^0$	18.5	8.5
11	$GL_{(4)}^0$	13	3
12	$GL_{(2)}^0$	11.5	1.5

Results

The strain-load curves of experiments 1 and 2 are shown in Fig. 2. It is seen that in the beginning of both curves, strain linearly increases with load. In experiment 1, after around 89 kN the slope of FRP strains increases and similar trend occurs in experiment 2 at around 101 kN. This indicates failure starts to occur. The most significant failure mode was found to be steel and adhesive interface failure. This is in accordance with [1].

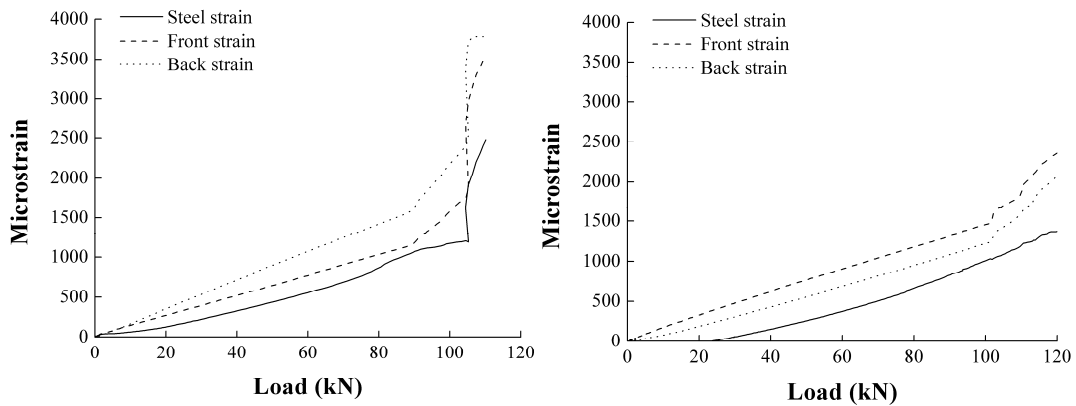


Fig. 2: Strain-load curve (Left: experiment 1; right: experiment 2)

The stress-strain curves of the elastic region of both experiments are shown in Fig. 3. The slope of a stress-strain curve is stiffness. It is seen that the stiffness of pitch graphite/epoxy patched steel

coupons is higher than that of PAN graphite/epoxy patched ones. This is due to the higher stiffness of pitch graphite fibers than PAN graphite fibers.

The effective stiffness of a FRP patched steel coupon is given by the rule of mixture.

$$E = \frac{E_s A_s + E_g A_g + E_c A_c}{A_s + A_g + A_c} \quad (1)$$

where E_s , E_g , and E_c are the stiffness of steel, GFRP, and CFRP, respectively; and A_s , A_g , and A_c are the cross-sectional areas of steel, GFRP, and CFRP, respectively.

The stiffness calculated by Eq. (1) and from experiments is shown in Fig. 4. Good agreement is found except experiments 4 and 6. This discrepancy is due to some problems in these two experiments.

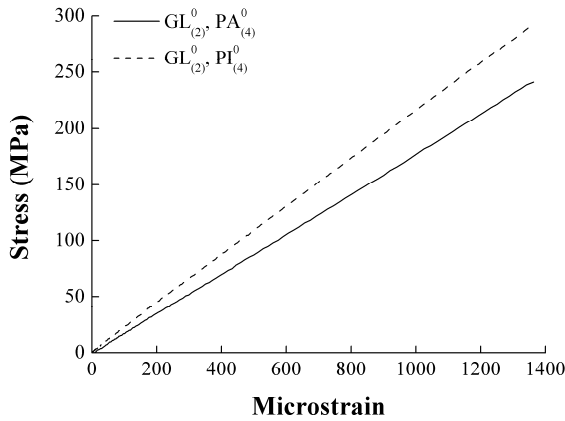


Fig. 3: Stress-strain curves of elastic region

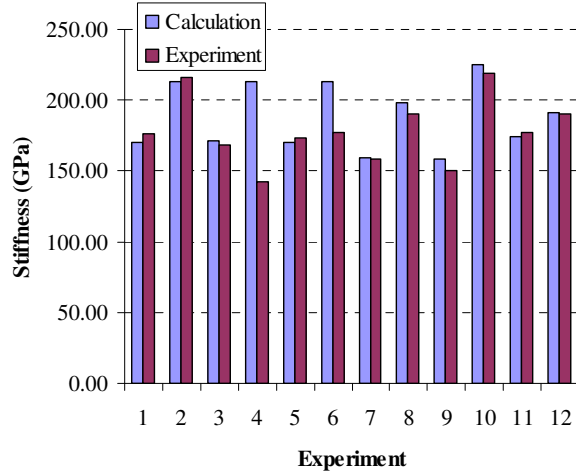


Fig. 4: Stiffness from calculation and experiments

The failure loads derived from the experiments are shown in Table 3. It is seen that CFRP provides better strengthening than GFRP, but there is no significant difference between PAN graphite/epoxy and pitch graphite/epoxy laminates.

Table 3: Failure loads

Layup $X_{(x)}$...	Failure load (kN)
$GL_{(2)}^0, PA_{(4)}^0$	92
$GL_{(2)}^0, PI_{(4)}^0$	101
$GL_{(4)}^0, PA_{(4)}^0$	116
$GL_{(4)}^0, PI_{(4)}^0$	104
$GL_{(2)}^0, PA_{(8)}^0$	102
$GL_{(2)}^0, PI_{(8)}^0$	99
$GL_{(4)}^0$	85
$GL_{(2)}^0$	85

Finite Element Analysis

The stress under tension was analyzed by FEA using ANSYS. A load of 100 kN was assumed. σ_{xx} of $GL_{(2)}^0, PA_{(4)}^0$ and $GL_{(2)}^0, PI_{(4)}^0$ from FEA is shown in Fig. 5, and the distribution of σ_{xx} along the through-thickness direction is shown in Fig. 6. It is seen that the stress is transferred from steel into FRP patches. The stress in steel is inversely proportional to the number of FRP layers. However, when more layers are used, interfacial shear stress increases.

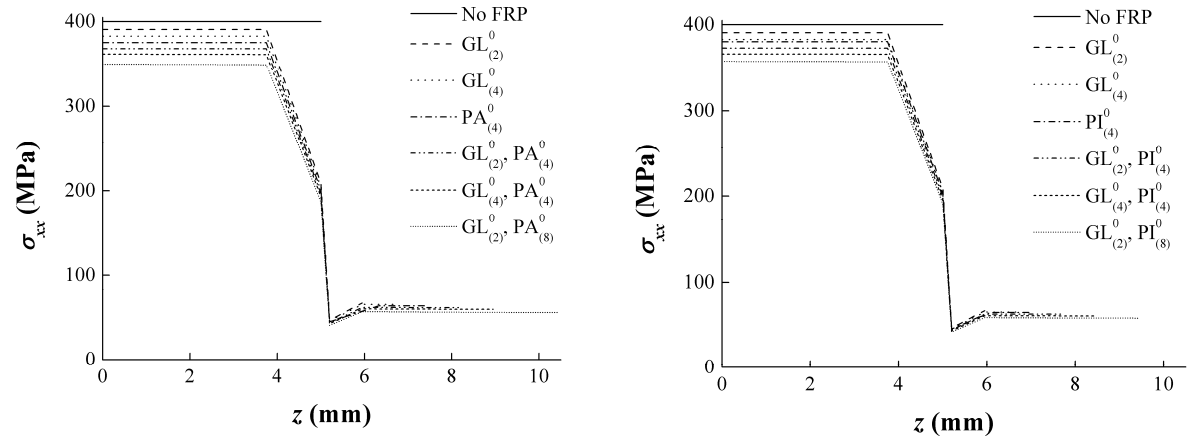
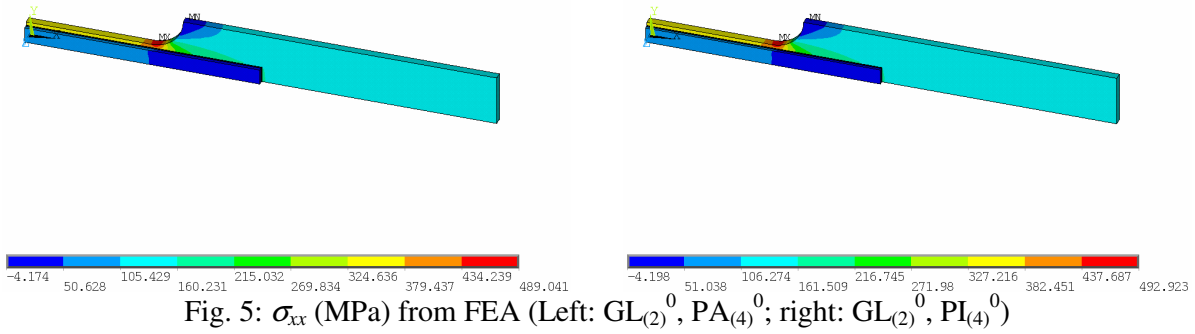


Fig. 6: σ_{xx} distribution in through-thickness direction

Conclusions

An experimental study on the strengthening of steel structures with FRP is presented in this paper. Test coupons were prepared by applying FRP patches on both sides of steel coupons. Standard tensile tests were conducted to the test coupons. Two types of CFRP and one type of GFRP were studied. The load and strain data were recorded, and the stiffness and strength were derived.

As expected, CFRP provides better strengthening than GFRP, but there is no significant difference between PAN graphite/epoxy and pitch graphite/epoxy laminates.

Further study is needed to understand the effect of laminate thickness on strengthening.

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References

- [1] X.-L. Zhao and L. Zhang: Engineering Structures Vol. 29 (2007), p. 1808
- [2] ICC: <http://www.iceng.com.au>