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Experimental Study on Fatigue Behavior of Tensile Steel Plates Strengthened with CFRP Plates

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Abstract

Fatigue experiments of six steel plates strengthened with CFRP plates are presented in this paper. The specimens are loaded in tension. The factors that may influence the effect of strengthening are discussed, including the amount ot strengthening CFRP plates, the one face or two faces mode strengthening and the stress range. Experimental results show that the fatigue lives of steel plates can be greatly increased with externally bonded CFRP plates when they are compared with un-strengthened specimens.

Keywords

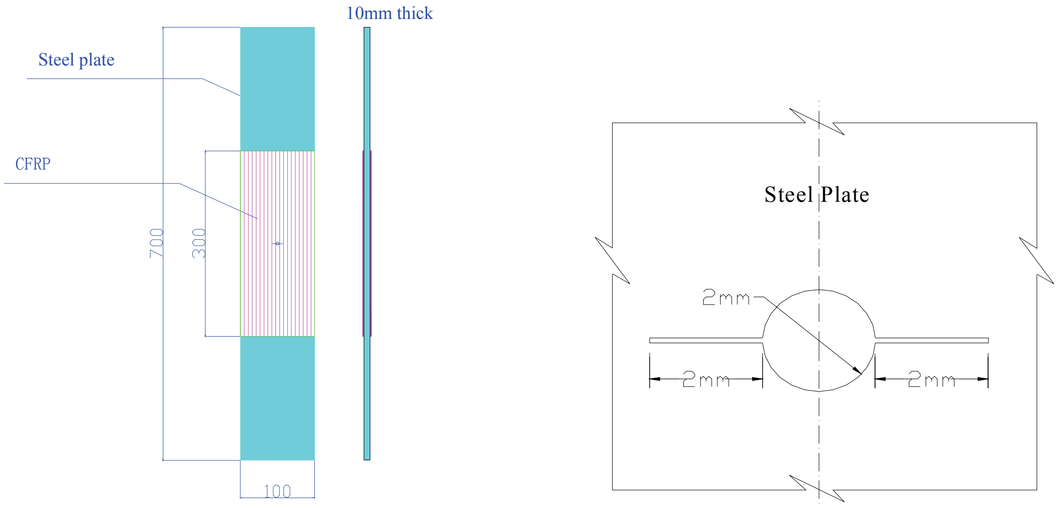
CFRP, Steel plate, Tensile, Fatigue life, Strengthening

1. INTRODUCTION

Due to the light weight, high strength, good durability and excellent fatigue performance, Carbon Fibre Reinforced Polymer (CFRP) is widely used in last decade to strength concrete structures. And in recent years, more attentions have been given on strengthening steel structural elements with CFRP. Most of such steel strengthening researches are focused on the enhancement of static load capacity. Very limited work can be found in the existing literatures on the fatigue strengthening [Zheng et al. 2005]. Colombi et al. (2003) suggested that CFRP patching would be a good solution for strengthening steel structural elements with fatigue damage, and prestressed CFRP patches would have a better performance on interfacial debonding. However, in practices, prestressed CFRP strengthening is not widely welcomed due to the inconvenience of construction. Tavakkolizadeh & Saadatmanesh (2003) studied the fatigue strength of 21 specimens made of W127×4.5 steel beams. The clear spans of all specimens were 1220mm and were all tested under four-point bending with 200mm spacing between the loading points. For all stress ranges considered in their work, this strengthening technique improved the fatigue lives of the strengthened specimens by about 2.6~3.4 times higher than those of un-strengthened specimens. Sean et al. (2003) reported their fatigue experiments on 21 specimens with edge notches and 8 specimens with center holes. Though their test results scattered greatly, CFRP strengthening still shows a promising increase on the fatigue lives of steel elements. However, the above existing works have a common drawback that the initial faults in the steel elements are not real fatigue damages, but mechanical cutting notches or holes. Hence, in this work, pre-cracking cycle loads were imposed firstly on the steel plates to give a same level of real fatigue damage. And then the specimens were tested under different levels of tension load to get a more realistic simulation of fatigue strengthening.

2. EXPERIMENTAL TEST SETUP AND SPECIMENS

The steel plates used in this study is made of 16Mn whose yield strength is 435MPa. The size of the steel plates are 700mm in length, 100mm in width and 10mm in thickness, as shown in Figure 1a. The initial cracks are introduced by cutting 2 notches with a length of 2mm on opposite sides of the 2mm hole in diameter which is located at the centers of the plates, as shown in Figure 1b. Two kinds of CFRP plates with different thickness and stiffness are adopted in the tests. One is 1.0mm thick with a normal modulus of 165GPa and another is 1.4mm thick with a higher modulus of 320GPa. The adhesive used was a two-part thixotropic epoxy resin adhesive (Araldite 2015),with a shear modulus of 0.9 GPa.



(a) Specimen geometry (b) Initial crack

Figure 1 Specimen Geometry

The six specimens tested in this work were shown in Table 1. Following 3 parameters are considered: stress range, strengthening method and stiffness of CFRP. Specimens PC120 and PC90 are un-strengthened control ones with different stress range of 120MPa and 90 MPa. Specimen PS120 and PD120 were both tested under a stress range of 120MPa but the former one was strengthened with high modulus CFRP on single side whilst the later one was strengthened on both side. Specimen PD90 has the same strengthening scheme with PD120 but was tested under a stress range of 90MPa. Specimen PD120a has the same strengthening scheme and stress range with PD120 but normal modulus CFRP is used. Pre-crack cycle load with a stress range of 200MPa were give to all specimens to guarantee the fatigue cracks would propagate from the initial notches and to induce a 10mm length of fatigue cracks along the two notches on opposite sides of the hole. CFRP strengthening was installed after pre-cracking load. Then the fatigue testing of all the specimens was conducted under the cyclic tensile loads. A constant amplitude sine wave of 500 times/min frequency with stress ratio of 0.4 was applied.

Table 1 Specimen Details

Specimen numbers	Stress range /MPa	N_{max}/N_{min} /kN	Repaired Mode	CFRP Type	Stiffness Ratio (S)
PC120	120	200/80	Without strengthening	None	0
PC90	90	150/60	Without strengthening	None	0
PS120	120	200/80	Single Side	High Modulus	0.22
PD120	120	200/80	Double sides	High Modulus	0.43
PD90*	90	150/60	Double sides	High Modulus	0.43
PD120a	120	200/80	Double sides	Normal Modulus	0.16

Note: Stiffness ratio (S) is defined as: $S = \frac{\sum E_{CFRP} t_{CFRP}}{E_{Steel} t_{Steel}}$.

Table 2 Test results of fatigue lives of specimens

Stress Range（MPa）	Specimen	Repairing Mode	Stiffness Ratio (S)	Fatigue Lives（$\times 10^4$）	Increased life (%)
120	PC120	/	0	18.2	Baseline
	PS120	Single side	0.21	46.4	155
	PD120	Double Sides	0.43	100.0	450
	PD120a	Double Sides	0.16	65.0	260
90	PC90	/	0	48.4	Baseline
	PD90	Double Sides	0.43	331.2	580

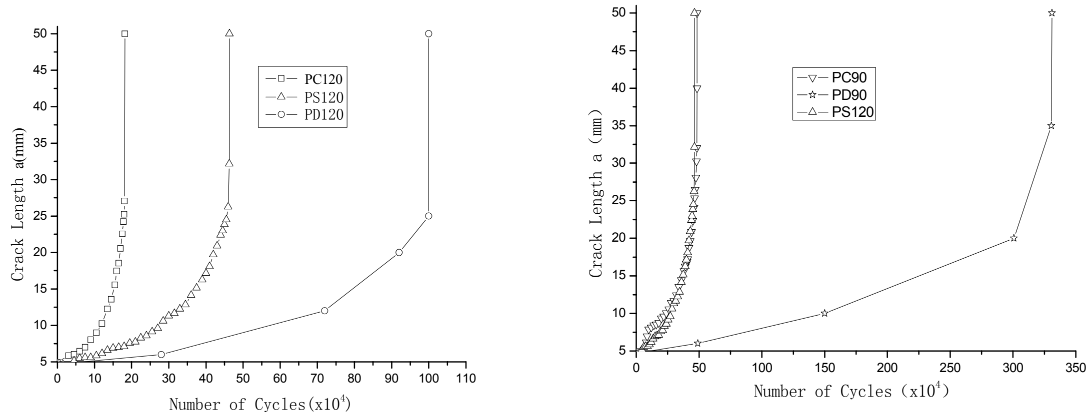
3. EXPERIMENTAL RESULTS

The fatigue lives of all the specimens were listed in Table 2. It can be shown that fatigue lives of strengthened specimens were increased by 155~580% over un- strengthened specimens.

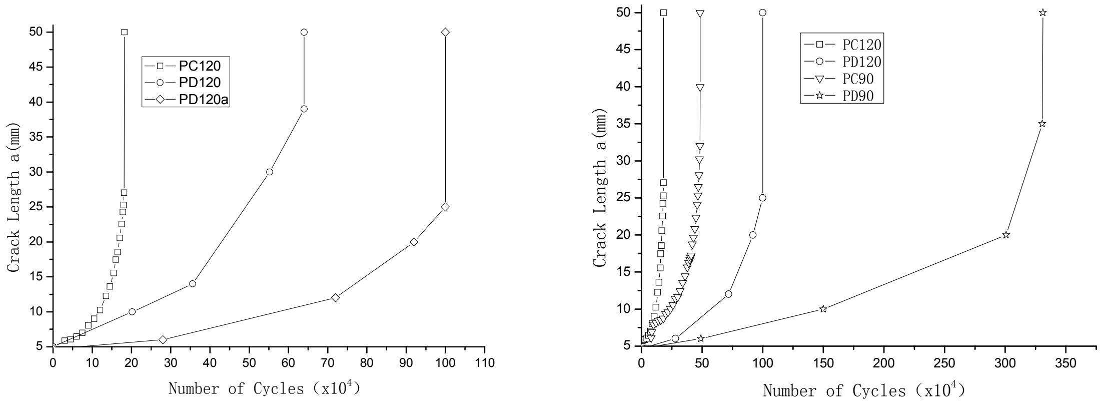
Figure 2 shows comparisons on the propagation of fatigue cracks. Different strengthening modes are compared in Figure 2a which illustrates that double bonded specimen (PD120) results in a much slower crack propagation speed than un-strengthened one (PC120) and the single side boned one (PS120), even though the interfacial debonding of PD120 was much worse than other two specimens due to poor quality installation of CFRP plates. Figure 2b shows a better example on the increment on fatigue life because no interfacial failure happened in the specimens. The strengthened specimen PD90 has an additional 3 million cycles longer fatigue life than the un-strengthened specimen PC90. Figure 2c shows the influence of stiffness of CFRP plates to the fatigue life. Higher stiffness results in a longer fatigue life. Figure 2d shows the influence of the stress range to the fatigue life. Larger stress range will heavily reduce the fatigue life.

4. CONCLUSIONS

In this study, the fatigue behavior of six steel plates strengthened with external bonded CFRP plates was investigated. It is shown that, (1) the fatigue life of strengthened specimens was increased by 155~580% over un-strengthened specimens, which indicated that fatigue life can be improved effectively by external bonded CFRP to the steel structures with fatigue crack; (2) The strengthening is more effective when CFRP plates with higher modulus are bonded to both sides of the steel plates; (3) De-bonding of CFRP from steel plate took place so early during the test of specimen PD120 that the retrofitted effect is not good. Therefore the quality control of bonding technique is very important and some measures should be made.



(a)Different strengthening mode (b) Different strengthening mode



(c)The influence of stiffness of CFRP plate (d)The influence of the stress range

Figure 2 Fatigue crack propagation curves

5. ACKNOWLEDGEMENT

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