International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

Chief Editor
Dr. J.B. Helonde

Executive Editor
Mr. Somil Mayur Shah

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EXPERIMENTAL INVESTIGATION OF STRENGTHENED CRUCIFORM WELDED JOINTS USING FRP

Elyamani A Arabi[*1], Elsharif M Ibrahiem[1] & Mohamed, S.B.A.[2]
[1]Department of Civil Engineering, Faculty of Engineering, University of Nyala, Sudan
[2]Department of Civil Engineering, Faculty of Engineering, Alzaiem Alazhary University, Sudan

DOI: https://doi.org/10.29121/ijesrt.v10.i6.2021.3

ABSTRACT

This paper presents an experimental study on the fatigue strength using fiber reinforced polymers (FRP)to repair load-carrying cruciform full penetration welded joints with weld toe failures. Fatigue tests were carried out on a total of 15 specimens. Five specimens as control, the other five specimens were retrofitted with FRP materials only, and the last five were retrofitted with FRP materials fixed with bearing plate and bolts. All specimens were loaded with different stress range values. During tests the fatigue failure mode and the corresponding fatigue life were recorded. Test results showed that, the patching of FRP materials prolongs fatigue life with sufficient values and at the same time debonding was prevented in case of bearing plate and bolts.

KEYWORDS: fatigue life, stress intensity factor (SIF), FRP materials, load-carrying cruciform, welded joint, weld toe crack.

1. INTRODUCTION

Fatigue cracking in existing steel structures such as bridges is becoming an increasingly important due to the natural aging of these structures. In the welded joints, areas of high stress concentration are the most adopted points for fatigue cracks initiation and propagation which are the main reasons of catastrophic failure. These welded joints are weak points for fatigue resistance.
Structural retrofitting with CFRP materials in comparison with conventional retrofitting techniques provides an environmentally friendly and economic way to save and utilize the infrastructures, and, therefore, it became one of the primary interests in civil engineering applications.

In the last decade, several researches showed that the fatigue lifetime of cracked steel members can be extended using externally bonded Carbon fiber reinforced polymer (CFRP) material. Repair with composite patches reduces the stress field near the defects and retards the crack propagation was considered by[1], [2]. FRP has been used to strengthen deteriorated bridges suffering from fatigue cracks to increase fatigue life of bridge girders and truss joints as stated in[3].Large amount of research has been carried out on CFRP bonded steel plates. Experimental results demonstrated that CFRP materials could effectively extend fatigue of defective specimens. [4] investigated that the retrofitting efficiency was highly dependent on bond configuration, CFRP stiffness, prestress level and initial damage degree. Stress intensity factor (SIF) at crack tip and fatigue crack propagation have also been studied numerically by [5], where the parametric analysis was performed to optimize this strengthening method. Fatigue design criteria for strengthening metallic beams with CFRP materials were also proposed[6], which extended the understanding of CFRP-repaired steel beams.[7] conducted testing of steel plates with longitudinal weld attachments on one side, with a particular focus on the application of ultra-high modulus CFRP materials and the influence of strengthening scheme. The fatigue life of the welded joints retrofitted on a single side was increased up to 141% over control ones.

However, studies on the fatigue behavior of load-carrying cruciform welded joints strengthened by FRP materials are limited. Generally, fatigue damage of welded joints is due to weld-induced imperfections and stress concentration produced by geometric discontinuity. [8]constructed finite element models of non-load-carrying cruciform welded joints. SIF were analyzed to evaluate the strengthening efficiency.[9]carried out an experimental study of non-load carrying cruciform welded joints subjected to fatigue loading. The study showed the effect of

IJESRT is licensed under a Creative Commons Attribution 4.0 International License.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

using CFRP sheets as rehabilitation method. Results demonstrated that the fatigue life was twice after adding one layer of CFRP sheet.

This paper covers experimental investigation on load-carrying cruciform full penetration welded joints repaired with FRP materials fixed with bearing plate & bolts. A total of fifteen specimens were tested axially under tensile fatigue loading. The effect of using FRP materials fixed with bearing plate in enhancing the resistance of cruciform welded joints to fatigue failure and mode failures were demonstrated.

2. EXPERIMENTAL SECTION

An experimental study was performed on load-carrying cruciform full penetration welded joints strengthened by FRP materials. The specimens were patched with five layers of FRP materials. The first layer was GFRP sheet which was used as insulator layer between steel and CFRP sheets as suggested by[10];[11]. The other four layers were CFRP sheets. The details of experimental program including the full designing of test specimens and properties of materials as shown below.

Material Properties

Subheading should be 10pt Times new Roman, justified. EN 10025-3- S355N/NL steel rolled plates of 6 mm thick conforming to the European Committee for Standardization Eurocode3[12]were used as the base materials in the experiment. An ultimate strength of 489 MPa, a yield strength of 391 MPa and elongation of 28.6% were obtained from standard coupons tensile test. Sika Wrap_430GandSika Wrap_300C with same nominal thickness of 0.17 mm, were selected in the test program as GFRP sheets and CFRP sheets, respectively. Epoxy adhesive, Sikadur_330, was used to bond the composite. The properties of repairing materials were provided by the manufactures and listed in Table 1.

Table 1. Properties of retrofitting materials

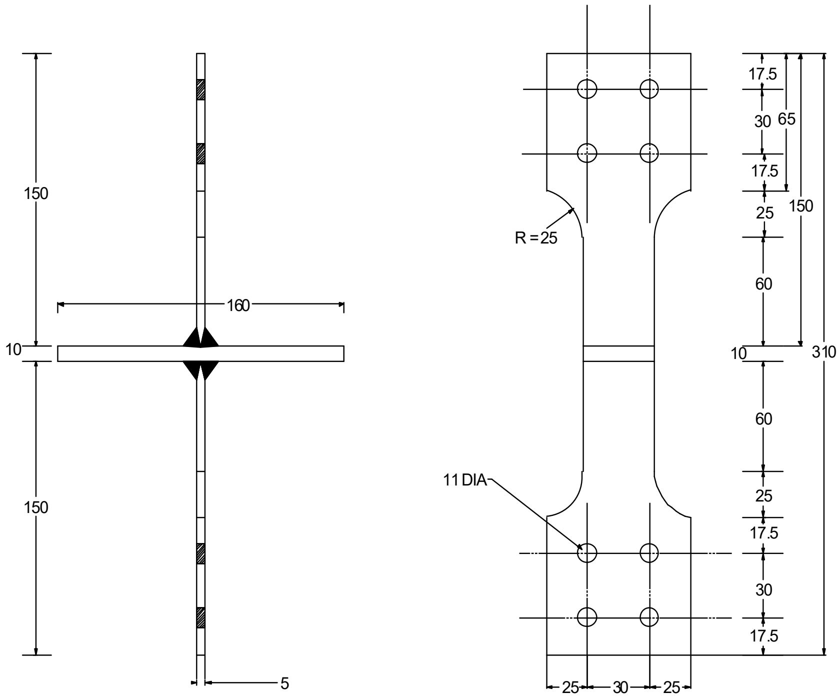
Materials	Tensile strength (MPa)	E-Modulus (MPa)	Thickness (mm)	Strain at break of failure (%)
SikaWrap_430G(GFRP)	2300	76000	0.17	2.8
SikaWrap_300C(CFRP)	3900	230000	0.17	1.5
Sikadur_330 (Epoxy)	30	4500	-	1.2

Configuration and Preparation of Test Specimen

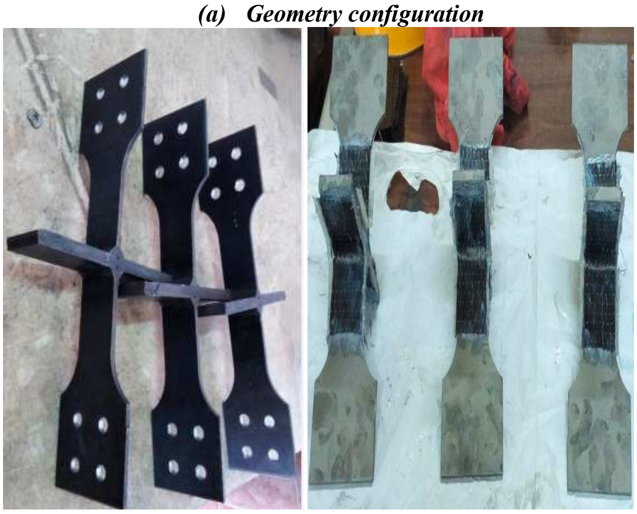
Cruciform specimen is composed of stiffener plate (160mm×40mm×10mm) welded to two main plates(150mm×40mm×6mm), with the test section of a dog-bone shape as shown in Fig.1. The first layer of GFRP is bonded to the steel surface within 24 hours after sandblasting and cleaning with acetone. Therefore, one GFRP layer and four CFRP layers of 120*40mm each, were patched using wet lay-up method to the cruciform joint surfaces as shown in Fig. 1(c). The applied thickness of epoxy was restricted to around 0.5mm[13]. Finally, the specimens were cured for two weeks at room temperature.

IJESRT is licensed under a Creative Commons Attribution 4.0 International License.

[Arabi *et al.,* 10(6): June, 2021]
IC™ Value: 3.00
ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7



(a) Geometry configuration

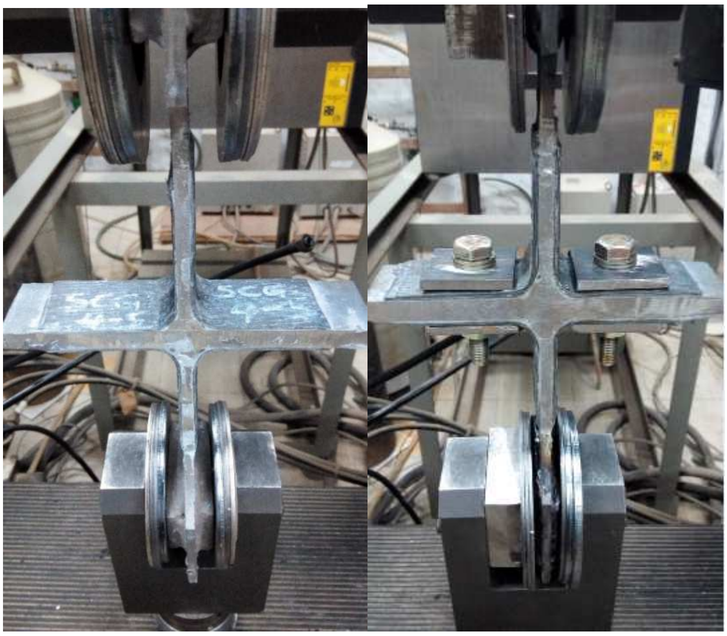


(b) control specimens (c)retrofitting specimens
Figure 1. Cruciform welded joint

Fatigue test procedure
The fatigue test program was conducted on an shimadzo servopulser machine model "EHFED100Kn-20L". Loads were applied sinusoidally with a frequency of 10 Hz and a stress ratio (R= σmin/σmax)of 0.1.The test set-up is shown in Fig.2. Load frequency was kept constant for all tests. The specimens were tested with five stress range levels as presented in Table 2. "SS" indicates specimen without retrofitting and "SCG" indicates that steel specimen reinforced with GFRP& CFRP sheets. SCG-HB denotes specimens repaired with GFRP & CFRP fixed with head plate and bolts. The first number refers to specimen ID and the second number refers to number of CFRP layers added.

IJESRT is licensed under a Creative Commons Attribution 4.0 International License.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7



(a)Strengthening with FRP materials only (b) Strengthening with FRP and bearing plate and bolts
Figure 2. Fatigue test set- up

3. RESULTS AND DISCUSSION

Table 2presents a total of fifteen cruciform welded joints that were designed and tested, of which five were not retrofitted taken as control specimens. The fatigue life is determined as the number of cycles corresponding to the point when a crack initiate then propagate till failure through plate thickness.

Fatigue life

The detailed test program of all specimens and fatigue life enhancement for different stress range are listed in Table 2. Tests results showed that fatigue life of retrofitted specimens with RFP materials only and FRP materials fixed with bearing plate bolts increased up to 6.95 times compared with that of the un strengthened specimens. In addition, for the five stress range levels adopted in this paper, it was demonstrated that stress range was an important parameter that influenced the fatigue behaviour in terms of fatigue life. For specimens retrofitting with FRP materials, using large stress range loading (270MPa) fatigue life is enhanced by 110%, while using small stress range (180MPa) fatigue life is improved by 517%. In addition, for specimens retrofitting with FRP materials fixed with head plate and bolts, using large stress range loading (270MPa) fatigue life is enhanced by 120%, while utilizing small stress range (180MPa) fatigue life is improved by 437%. The effectiveness of strengthening at the high stress range (270 MPa) showed to be less significantly compared to that at the low stress range (180MPa). It means that FRP materials distributed stresses away from high stress concentration region at low stress range which subsequently reduced the stress intensity factor around toe crack tip.

Table2.Experimental program and testing results

Specimens	Thickness (mm)	Width (mm)	Tension Stress Range on Weld Toe (MPa)	Fatigue Life (Cycles)	Enhancement (%)
SS-1	6	40	270	66463	--
SCG-1-5	6	40	270	72639	110
SCG-HB-1-5	6	40	270	80104	120
SS-2	6	40	252	71098	--
SCG-2-5	6	40	252	79521	112
SCG-HB-2-5	6	40	252	87293	123
SS-3	6	40	225	95444	--
SCG-3-5	6	40	225	577860	605

IJESRT is licensed under a Creative Commons Attribution 4.0 International License.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

SCG-HB-3-5	6	40	225	485968	509
SS-4	6	40	198	118040	--
SCG-4-5	6	40	198	939312	695
SCG-HB-4-5	6	40	198	791824	506
SS-5	6	40	180	222816	--
SCG-5-5	6	40	180	1152765	517
SCG-HB-5-5	6	40	180	973155	437

Modes of Failure

The cracks of all fatigue failure mechanism were observed to start from the intersection of the fusion line with the weld surface at the weld toe. Fatigue cracks propagating and growth from stress concentration point. Failure mode of both un retrofitted and retrofitted specimen were occurred in the same position at the weld toe as shown in Figs.3 to5.Crack initiation and propagation were at the weld toe, where the critical stress concentration point. By comparing the failure shape of the two cases of strengthening, failure surface of retrofitted specimens with FRP materials only shows FRP debonding, while in existence of head plate no debonding occurred and high stroke with alarm sound through FRP rupture were observed. For all failure mode shapes, it can be observed that the crack surface had an apparent smooth region where the crack propagated steadily and a rough region where the specimen fractured suddenly.

Figure 3. Fatigue failure showing crack propagation through weld toe

Figure 4. Failure of retrofitted specimen with FRP materials only with sign of debonding

IJESRT is licensed under a Creative Commons Attribution 4.0 International License.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Figure 5. Failure of retrofitted specimen and bearing plate with bolts with no sign of debonding

S-N Curve of Strengthened Cruciform Welded Joints

Several international standard and design guides as IIW [14], [15]recommended that, the classification method is commonly used to evaluate their fatigue design of welded joint is based on structural details. Fatigue design curves for different detail categories are recommended by Structural Welding Code (AWS 2002). S-N plot for test results and (AWS 2002) specification for stress categories A, B, B', C, D, E and E' are shown in Fig. 6. The data points determined from unretrofitted and retrofitted specimens are also plotted in Fig. 6. It observed that the fatigue behavior of specimens strengthened with stress range of 225MPa, 198MPa and 180MPa were significantly enhanced after retrofitting, while for specimens reinforced with stress range of 270MPa and 252MPa showed limited enhancement of fatigue behavior. It cleared that the data points for un retrofitted specimens are approximately located between categories D and C, while the retrofitted data points for most specimens, were situated between category B and A. This implies that the fatigue life was significantly extended after bonded by FRP materials.

IJESRT is licensed under a Creative Commons Attribution 4.0 International License.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

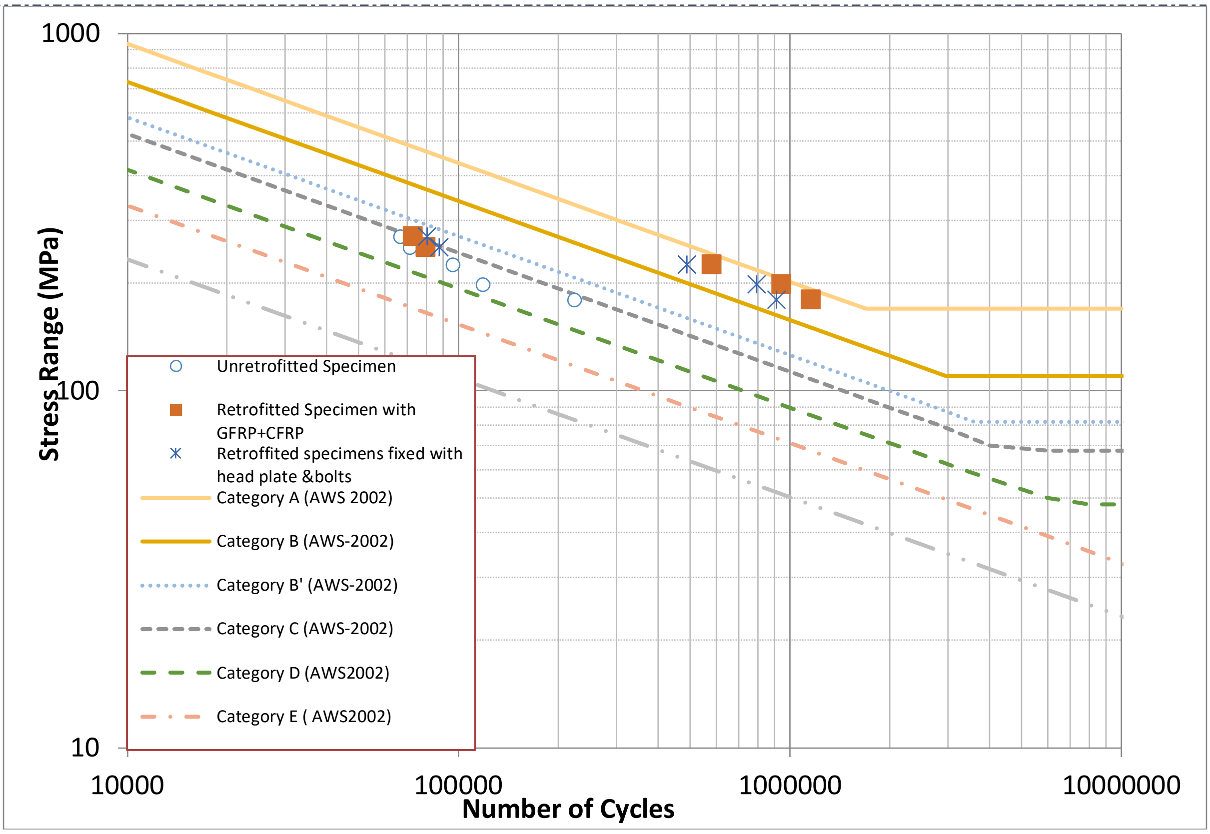


Figure 6. S-N plot for test results and AWS 2002 detail categories

4. CONCLUSION

In this paper, experimental testing of load-carrying cruciform welded joints retrofitted with FRP materials fixed with bearing plate & bolts were investigated. The improvements in fatigue life were validated with test results, that means that strengthening of steel structures composite material is an efficient way. The main observations and conclusions investigated from the experimental results can be drawn:

1) The fatigue life of repaired specimens was significantly extended, and the crack growth rate can be decreased significantly by the FRP reinforcements, compared to that of control specimens. For cruciform joint retrofitted with five layers by FRP materials, experimental results showed that, the fatigue life increased by about 110% to 695% compared with un retrofitted joint.
2) Using retrofitted FRP materials fixed with bearing plate and bolts, surface debonding was prevented compared with specimens using FRP materials only.
3) Applying bearing plate fixed with bolts on FRP materials of the specimen did not further improve the fatigue life over that of the equivalent specimen retrofitted on FRP material only.
4) Fatigue life of the most repaired specimens was upgraded from category D to category B according to fatigue categories listed in AWS2002 specifications.

REFERENCES

[1] [X.-L. Zhao and L. Zhang, “State-of-the-art review on FRP strengthened steel structures,” Eng. Struct., vol. 29, no. 8, pp. 1808–1823, Aug. 2007.
[2] J. G. Teng, T. Yu, and D. Fernando, “Strengthening of steel structures with fiber-reinforced polymer composites,” J. Constr. Steel Res., vol. 78, pp. 131–143, Nov. 2012.
[3] X.-L. Zhao, FRP-strengthened metallic structures. CRC Press, 2013.
[4] Jones Sean C. and Civjan Scott A., “Application of Fiber Reinforced Polymer Overlays to Extend Steel Fatigue Life,” J. Compos. Constr., vol. 7, no. 4, pp. 331–338, Nov. 2003.
[5] P. Colombi, G. Fava, and L. Sonzogni, “Fatigue crack growth in CFRP-strengthened steel plates,” Compos. Part B Eng., vol. 72, no. Supplement C, pp. 87–96, Apr. 2015.

IJESRT is licensed under a Creative Commons Attribution 4.0 International License.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[6] E. Ghafoori, M. Motavalli, A. Nussbaumer, A. Herwig, G. S. Prinz, and M. Fontana, "Design criterion for fatigue strengthening of riveted beams in a 120-year-old railway metallic bridge using pre-stressed CFRP plates," Compos. Part B Eng., vol. 68, no. Supplement C, pp. 1–13, Jan. 2015.
[7] C. Wu, X. L. Zhao, R. Al-Mahaidi, M. R. Emdad, and W. H. Duan, "Fatigue tests on steel plates with longitudinal weld attachment strengthened by ultra high modulus carbon fibre reinforced polymer plate," Fatigue Fract. Eng. Mater. Struct., vol. 36, no. 10, pp. 1027–1038, Oct. 2013.
[8] T. Chen, Q.-Q. Yu, X.-L. Gu, and G.-H. Nie, "Stress intensity factors (KI) of cracked non-load-carrying cruciform welded joints repaired with CFRP materials," Compos. Part B Eng., vol. 45, no. 1, pp. 1629–1635, Feb. 2013.
[9] T. Chen, Q.-Q. Yu, X.-L. Gu, and X.-L. Zhao, "Study on fatigue behavior of strengthened non-load-carrying cruciform welded joints using carbon fiber sheets," Int. J. Struct. Stab. Dyn., vol. 12, no. 01, pp. 179–194, Jan. 2012.
[10] J. M. C. Cadei, T. Stratford, W. G. Duckett, L. C. Hollaway, and C. I. R. and I. Association, Strengthening metallic structures using externally bonded fibre-reinforced polymers. CIRIA, 2004.
[11] Tavakkolizadeh M. and Saadatmanesh H., "Fatigue Strength of Steel Girders Strengthened with Carbon Fiber Reinforced Polymer Patch," J. Struct. Eng., vol. 129, no. 2, pp. 186–196, Feb. 2003.
[12] British Standards Institution and European Committee for Standardization, Eurocode 3, design of steel structures: part 1-1 : General rules and rules for buildings. London: British Standards Institution, 2005.
[13] S. Mall and G. Ramamurthy, "Effect of bond thickness on fracture and fatigue strength of adhesively bonded composite joints," Int. J. Adhes. Adhes., vol. 9, no. 1, pp. 33–37, Jan. 1989.
[14] B. S. Institution, B. S. I. Staff, and R. Confiant, Code of Practice for Fatigue Design and Assessment of Steel Structures. British Standards Institution, 1993.
[15] A. Hobbacher, Recommendations for Fatigue Design of Welded Joints and Components. Cham: Springer International Publishing, 2016.
[16] S. J. Maddox, "An analysis of fatigue cracks in fillet welded joints," Int. J. Fract., vol. 11, no. 2, pp. 221–243, Apr. 1975.

IJESRT is licensed under a Creative Commons Attribution 4.0 International License.