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Research Article

Numerical Analysis of Tensile Performance of Central Cracked Steel Plates Repaired with CFRP Sheets

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Keywords

Port machinery,
Carbon fiber composite,
Crack-repaired method.

Abstract

The crack repair and transformation of port machinery has gradually become a hot-spot research. In this paper, a numerical analysis of tensile performance of central cracked steel plates repaired with CFRP sheets was conducted. The effect of the reinforcement method, the radius of the hole, the length of the fatigue crack and the size of the patch on the repair effect of the steel structure was investigated. The effect of repair was measured by the stress-strain state, load-displacement curve, and stress intensity factor. The results showed that the residual strength of the steel structure was significantly improved after the repair of CFPR materials, and a more reasonable patch size was given. The obtained results provided important methodological and data support for guiding the repairing work.

1. Introduction

In order to extend the remaining life of cracked metal structures, the structures are required to be repaired. Welding, bolted or rivet repair techniques are traditional steel repair methods. For large crane structures with cracks, welding repair techniques are commonly used; however, high temperatures, complex areas, and residual stresses are problems associated with this repair technique. Composite repair technology improves the residual strength, residual stiffness, and residual fatigue life of cracked structures through the absorption of strain energy by fiber-reinforced composites on the surface of the structure. Therefore, it is a promising repair method due to its simple operation and good repair abilities.

Experimental [1-3], numerical [4-6] and analytical [7-9] study of CFRP-repaired steel plates were conducted in recent years. Mohabeddine et al.[10] proposed an analytical model to predict type I fatigue crack extension in steel central cracked tensile specimens with carbon fiber reinforced polymer (CFRP) bonded on both sides of the steel plate. The effect of CFRP on fatigue crack extension is expressed by the SIF and an analytical law based on nonlinear analysis is proposed to evaluate the CFRP to steel ratio, the degree of damage to the steel plate and the location of the patch. Malekan et al. [11] investigated the effect of multiple microcracks with different feature lengths and geometries on fatigue crack extension of the specimens. The crack paths in the geometry were modeled using a modified Forman equation. Toudeshky et al.[12] developed a finite element subroutine for predicting the crack expansion path after patch repair, and the results showed that the fatigue crack life of the repair model agrees well with the experimental results. The crack expansion path is influenced by the direction of the composite fiber alignment, while the effect of thickness on the path is almost negligible. Benachour et al. [13] used the linear elastic theory to develop closed-form solutions for interfacial stresses in prestressed FRP plate subjected to uniform loads, point loads in order to investigate the sensitivity of the interfacial behavior to parameters such as

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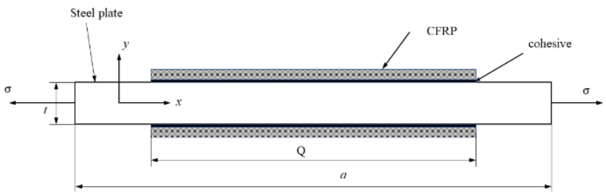
laminate and adhesive stiffness. The results indicate the presence of high shear and positive stresses at the ends of the laminates, which may lead to premature failure at critical locations. García et al. [14] proposed a combination of elasto-plastic and continuum damage models to adequately reproduce the mechanical response of adhesives in finite element analysis. With the Drucker-Prager exponential model for an accurate fit of the nonlinearity of these materials, a continuous damage model is proposed to simulate the material failure process.

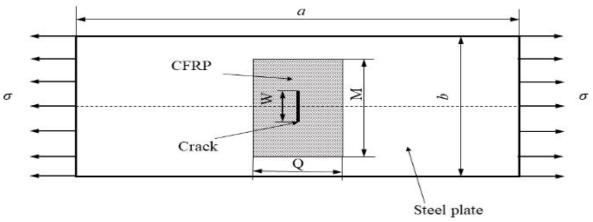
So far, the repair of cracked steel structures with CFPR has not been sufficiently studied. In this paper, the stress variations before and after repair were studied, and the effects of repair factors (thickness, effective paste length, effective paste width, layup) of carbon fiber composites on the repair effect were also analyzed.

2. Configuration of the Specimens

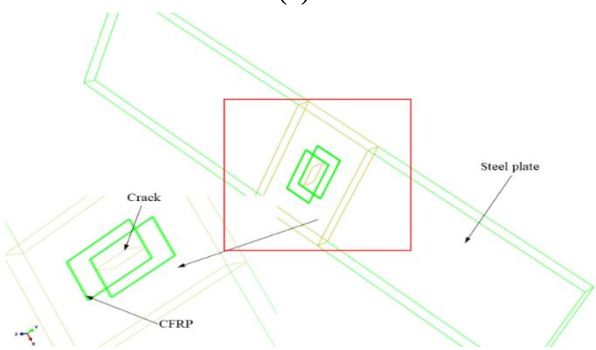
As shown in Figure 1, the specimen was composed of a central cracked steel plate repaired with CFRP sheets (five layers) on each side, the size of the steel plate, CFRP sheets was 100mm×50mm ×3mm and 20mm×10mm ×0.1mm (per ply), respectively. The length, width and thickness of the steel plate are expressed by a, b and t respectively, the length and width degree of CFRP plate are expressed by Q and M respectively, and the crack length is expressed by W.



(a)



(b)



(c)

Figure 1. Details of the specimen geometry

The materials of the steel plates and CFPR are Q235B and T700G, respectively. The details of the materials are given below.

Table 1. Calculation results for window 1 in example building in June

Materials	Properties
Steel plates	E=210Gpa, μ =0.3, ρ =7.85e-9ton/mm
CFRP	G_{xy}=G_{xz}=5GPa, G_{yz}=3GPa μ_{xy}=μ_{xz}=0.28, μ_{yz}=0.35

2. Numerical Analysis

2.1. Convergence Analysis

In order to study the effect of hole edge cell size on stress, finite element models with mesh sizes of 0.2 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.8 mm and 1 mm were established. According to the vonMises stresses around the hole, the proper mesh size of the finite element model is obtained as 0.4mm.

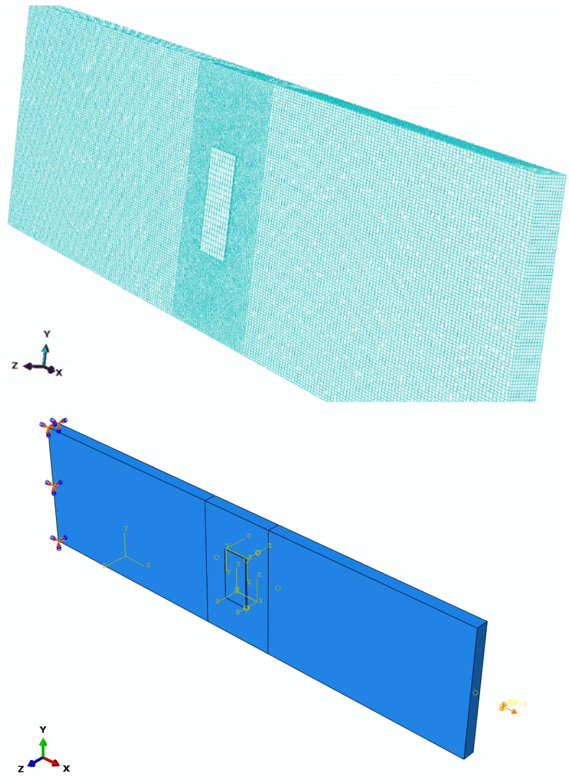


Figure 2. The mesh details and the FE model with boundary conditions

2.2. Parametric Studies of Steel Plates Repaired with CFRP

In this section, the effects of the size and location of the artificial holes on the efficiency of the steel plates repaired with CFRP were considered in order to find out the influence of various parameters on the stress intensity factor and the crack trajectory.

2.2.1. Effect of the Elastic Modules of the CFRP

In order to investigate the effect of elastic modulus of CFRP on the repair effect, three groups of CFRP with different strength were set up. The elastic modulus are 1.5e5

(T300), 2.4e5 (T700G) and 3.4e5MPa (M35J), respectively. The plotted load-displacement curves are shown in Figure 3.

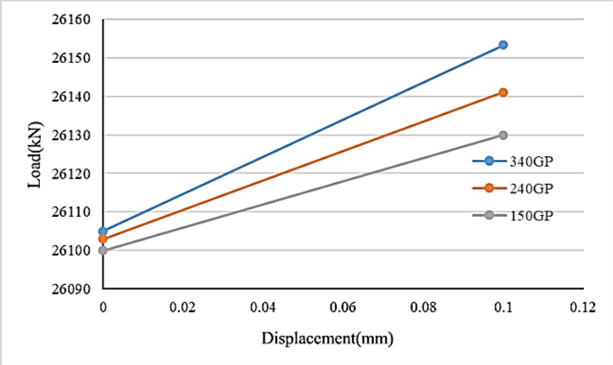


Figure 3. Load-displacement curves of specimens with different elastic modulus

From the Figure 3, it can be seen that the bearing capacity of the specimen increases with the elastic modulus of CFRP. This is because the load-bearing capacity of the specimen is mainly determined by the strength of the CFRP on the surfaces. Therefore, increasing the elastic modulus of CFRP is an effective measure to reduce the stress intensity factor around of the crack tip and increase the residual bearing capacity of the cracked structures.

2.2.1. Effect of the Thickness and Ply Angles

In this paper, specimens with various thicknesses of 0.1mm, 0.15mm, 0.2mm, 0.3mm were arranged to explore the effects of thickness on repair effect. In addition, in order to explore the effect of layup on the repair effect, four layups of CFRP panels with [0º/0º/0º/0º/0º], [0º/90º/0º/90º/0º], [0º/30º/0º/30º/0º], [0º/45º/0º/45º/0º] were designed and studied in this section.

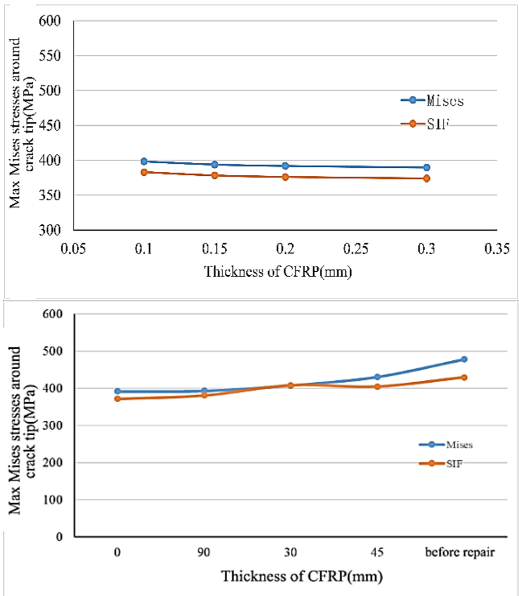
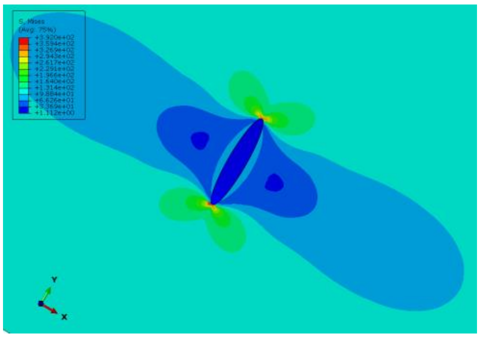
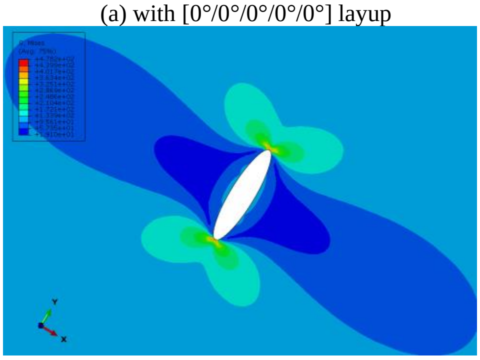


Figure 4. Effect of the thickness and ply angles

It can been seen that the effect of CFPR thickness on the maximum stress at the crack tip is negligible. In addition, the steel plates modeled by each reinforcement scheme show a certain degree of stress concentration at the crack tip when subjected to tension. And the maximum shear force within the CFRP plate with [0°/0°/0°/0°/0°] layup is distributed on both sides of the crack, which can significantly reduce the maximum stress near the crack tip.



(a) with [0°/0°/0°/0°/0°] layup



(b) without CFRP repair

Figure 5. The Mises stresses around the crack of steel plate with and without CFRP repair

2.2.2. Effect of the Length and Width of the CFRP

As the length of CFRP increases, the maximum stress firstly decreases significantly, but when the length increases to about 20 mm, the rate of decline slows down. After that length, increasing the length again will not change the repair effect significantly, that is, the effective bond length of carbon fiber reaches a maximum. In addition, the width of CFRP has a similar trend.

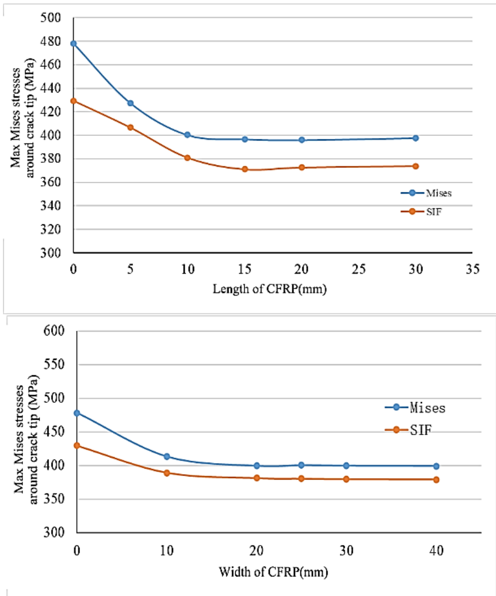


Figure 6. Effect of the length and width of the CFRP

3. Conclusions

In order to investigate the effects of factors such as CFRP size, crack length and lay-up angle on the effect of repairing cracked steel structures, the finite element analysis was conducted by using different dimensional parameters and material parameters to measure the effect of each factor on the repair effect using such as stress intensity factor and stress-strain curves.

The results show that the length, width, and thickness of CFRP as well as the crack length and the modulus of the adhesive layer have a great effect on the load-bearing capacity of the model. The bond width of CFRP has a greater effect on the residual strength than the bond length does. And the increase of the thickness of the adhesive layer will lead to the decrease of the load bearing capacity of the CFRP-repaired structures.

Acknowledgements

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Conflict of Interest Statement

The authors declare no conflict of interest.

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