Mechanical Characteristics of CFRP Reinforcement for Corroded Steel under Axial Tension

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ABSTRACT

Carbon fiber reinforced polymer (CFRP), which has some properties of light weight, high strength and high durability, has been applied to many concrete structures as repair, strengthening and seismic retrofitting. In recent days, the studies on its application to steel structures have also been developing for opened sectional members such as I-shaped beams. However, nowadays, it is a remarkable attention that the mechanical performance of steel members are degraded due to corrosion by decreasing cross-sectional area of steel pipe inside the section along with time. Then the repairing of the corroded steel pipes on the outside section is particularly required and CFRP has expected to apply in repairing and strengthening procedure.

In this paper, the strength of corroded steel plates and the effect of repair with CFRP are investigated through finite element analyses (FEA) and longitudinal tensile tests. First, the tensile tests of steel plates having partial loss of area are carried out. Second, strength, yield load and behavior of stress concentration are made clear through the tensile tests and FEA. Finally, CFRP is adhesively bonded to corroded steel plate on the other side of corrosion, and then the effects of repair with CFRP are discussed in detail. The results confirmed that axial stiffness and yield stress increases using FRP even if it is adhesively bonded to corroded steel plate on the other side of corrosion. It would be suggested that the present repairing method provides the reasonable and useful procedure for reinforcing the corroded steel members.

KEYWORD

FRP reinforcement, corroded steel, axial tension, FEA
1. INTRODUCTION

Carbon fiber reinforced polymer (CFRP), which has some properties of light weight, high strength and high durability, has been applied to many concrete structures as repair, strengthening and seismic retrofitting. Recently, the studies on its application to steel structures have also been developing for opened sectional members such as I-shaped beams or angle members [1, 2]. These papers show that the CFRP reinforcement have a possibility of a reducing the stress of steel members. However, the remarkable attention is that the mechanical performance of steel members is degraded due to corrosion [3]. For such a closed section as steel pipe, whose cross-sectional area has been decreasing from inner side, the repairing process becomes more difficult. Then the repairing of its on the outside section is particularly required and CFRP has expected to apply in repairing and strengthening procedure.

In this paper, the fundamental study of CFRP reinforcement on the other side of corrosion, the strength of corroded steel plates and the effect of repair with CFRP are investigated through finite element analyses (FEA) and longitudinal tensile tests. First, the correspondence between the steel plates, having partial loss area, under tensile test and its simulation are carried out. Second, strength, yield load and behavior of stress concentration of the steel plates, which modeled as one side corroded and the other side reinforced by adhesive as well as CFRP, are made clear through tensile test and FEA. From the result the effects of repair with CFRP are discussed in detail.

2. TENSILE TESTS OF CORRODED STEEL PLATES

In experiment, firstly the maximum strength of specimen under tension test has been carried out. Secondly, material parameter using in section 3.1 has been estimated through material test. The experiment specimens are of 500mm length, 100mm width, 3mm thickness with round and ellipse corroded shapes in order to avoid stress concentration, as shown in Fig.1. In this paper, the results of 3 models are mentioned. Here, the name of model w20h100d50 means the size of the corroded area that is placed on center of specimen with length, h, 100mm, width, w, 20mm and corrosion depth of 50% thickness. From the results, maximum strength was decided by effective sectional area and could be calculated as expectation. However, yielding stress was strongly affected by stress concentration. The larger corrosion width w is the smaller yielding stress and the longer corrosion length, the higher yielding stress. It is shown that easing stress concentration could increase yielding stress.

(a) w20h20d50
(b) w50h20d50

Fig. 1 Experimental setup

3. FEA SIMULATIONS

3.1 FEA of Corroded Steel Plates under Axial Tension

Through correspondence between experimental and FEA result the propriety of FEA simulation has been checked here. The adopted steel material have Young’s module 214.3GPa and yield stress 337MPa obtained by the material test through ISO6892. The analytical models are the same to the experimental specimen as shown in Fig.2 (without reinforced layer). Fig.3 combines the load-deformation curves of experimental and simulation results. Due to the steel’s modulus after yielding has been set as zero, load-deformation curves of FEA result divided into two parts, the forepart as before yielding and the latter one was parallel to horizontal axis. Again, due to effective area the maximum strength changes accordingly, however in experiment for w20h20 case, it is considered that a strain hardening was occurred early after yielding due to stress concentration nearby partial loss. For case of w50h100, by the effect of larger corroded height the redistribution process came after reducing of the stress to stable state. To conclude this section, the results shows that FEA analyses have good agreement with experimental one and could be used for further simulations.

3.2 FEA of CFRP Reinforcement

In this section, FRP is adhesively bonded to steel plate on the other side of corrosion, and then the effects of repair with FRPs are discussed using FEA. The analysis model has partial loss area,
which has various sizes by changing width and height shown in Fig. 2 and Table 1. The reinforced layer of 300mm length and 0.5mm thickness for adhesive and 1mm thickness for FRP have been adopted. Differing from above, here the mechanical properties of steel in Table 1 were listed as elastic modulus 205GPa, yield stress 235MPa. Poisson’s ratio 0.3 were adopted for all material, elastic modulus of FRP were 1/2 and 1/10 that of steel and adhesive was 1/100 as shown in Table 2. The commercially available finite element program, LUSAS, has been used in this study; due to the symmetry of the model, only 1/2 of plate is analyzed. Boundary conditions are as shown in Fig. 2, in which loading are placed at both ends of steel plate. The solid finite elements with eight-nodes are adopted for steel plate, CFRP surface skins and adhesive bond layer. Incremental analysis also material and geometrical nonlinearity were used, however steel’s modulus after yielding is zero.

As shown in Fig. 4, average tensile load as well as total deformation of model was plotted on vertical axis and horizontal axis, respectively. It is seen that the greater corrosion width makes maximum strength decreasing accordingly. Also the greater corrosion width decreases the axial stiffness gradually caused by yielding in load – deformation curves. The result of reinforcement became clear and it is likely to have more effectiveness in the case of greater corrosion width. However, in use for design, yielding stress is considered first and its estimation through axial stiffness will be noted in next section.

4. DISCUSSION ABOUT CFRP REINFORCEMENT

4.1 Effects to Yielding Stress
As discussed in 3.2 about yielding stress for design, the decrease ratio of axial stiffness is defined as \( R_{as} \) and \( R_{as} = 10\% \) is regarded as yielding point. The decrease ratio of axial stiffness, \( R_{as} \), is as follows.
Table 3 Yield Stress (MPa)

<table>
<thead>
<tr>
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<th>h10</th>
<th>h20</th>
<th>h50</th>
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<tr>
<td>w10</td>
<td>220.1</td>
<td>221.1</td>
<td>220.6</td>
<td>220.5</td>
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<tr>
<td>w20</td>
<td>208.9</td>
<td>207.1</td>
<td>202.6</td>
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<tr>
<td>w50</td>
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<td>154.7</td>
<td>154.2</td>
<td>162.1</td>
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<tr>
<td></td>
<td>F_A</td>
<td>F_B</td>
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<td>F_B</td>
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</table>

Table 4 Increase Ratio of Yield Stress by FRP

<table>
<thead>
<tr>
<th></th>
<th>h10</th>
<th>h20</th>
<th>h50</th>
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<tr>
<td>w10</td>
<td>1.003</td>
<td>0.998</td>
<td>1.000</td>
<td>1.001</td>
</tr>
<tr>
<td>w20</td>
<td>1.008</td>
<td>1.016</td>
<td>1.025</td>
<td>1.031</td>
</tr>
<tr>
<td>w50</td>
<td>1.093</td>
<td>1.084</td>
<td>1.066</td>
<td>1.061</td>
</tr>
</tbody>
</table>
The conclusions are as follows.

(1) FEA simulation could be dealing with experimental model quit well in this study.

(2) It was confirmed that axial stiffness and yield stress increase using FRP even if it is adhesively bonded to corroded steel plate on the other side of corrosion.

(3) By gluing FRP and regarded 10% axial stiffness reduction as yielding point, the maximum 9.3% and 34.5% of improving loading capability were confirmed as well as the high intensity FRP were recommended to severe corroded condition.

ACKNOWLEDGEMENT

The authors acknowledge the supports of Mikimoto Co. and Toray construction Co.

REFERENCES


4.2 The Moment Impact

In Fig.2, that shown analysis model, two points A and A’ are selected. At $p=50N/mm^2$, the change of axial force and strain along thickness through steel, adhesive, FRP layer are plotted. Two models, w50h20 have severe stress concentration and w50h100 have easing stress concentration, are mentioned here. For each case of model as shows in Fig.6, the results include the non-reinforced, reinforced with $F_A$ and $F_B$ type. The results shows that axial force and strain are decreasing by FRP reinforcement, also the stronger FRP type has more effectiveness. Fig.6 also shows that, for example when w50h20 is reinforced by $F_B$ the moment have 33% effect of axial force.

5. CONCLUSIONS

In this present paper, through various FEA model for corroded steel plate as well as those with CFRP reinforcement layer, the correspondence between experiment and FEA simulation, also the prospect of new repair method for corroded steel member by CFRP have been investigated in detail. The conclusions are as follows.

(1) FEA simulation could be dealing with experimental model quit well in this study.

(2) It was confirmed that axial stiffness and yield stress increase using FRP even if it is adhesively bonded to corroded steel plate on the other side of corrosion.