EXPERIMENTAL STUDY ON EFFECTIVENESS OF CFRP BONDING TO CORRODED STEEL MEMBERS

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Abstract

This paper describes an effectiveness of a bonding of carbon fiber reinforced sheets to corroded steel members for the repair. Three types of surface treatment, what we call cleaning, of corroded plate are chosen as parameters. They are “without cleaning”, “removal of painting by brushing” and “complete removal of painting”. From the experimental study, the following findings are obtained. 1) When the steel plate is subjected to tensile force, carbon fiber sheets adhered to the painted steel gives a higher strength against peeling compared to that of the plate without painting, 2) The grade of surface treatment, or cleaning of the corroded steel plate affects the strengthening effect.

Introduction

The deterioration of performance of steel structures is due to various reasons. One of main reasons of such deterioration is the corrosion of steel. In order to keep steel members to be sound for a long time, in most cases, painting has been used under the condition of repainting and its cycle depends on the climatic condition at the construction site. In Japan, unfortunately, many corroded steel bridge members can be seen in many places, and we need an appropriate repair. The main reason is the delay of the repainting work due to lack of the budget for public works.

In this paper, since the carbon fiber reinforced plastic (CFRP)[1] sheet is very light and is easy to handle, we propose a bonding of CFRP sheets to corroded steel member for the repair at the site. In order to confirm the effectiveness of such countermeasure, we carried out experiments, and present the mechanical behavior and also new findings on effectiveness.

A simply supported beam with a H-shaped section is subjected to pure bending. CFRP sheets are adhered to upper (compression) and lower (tension) painted flanges. With respect to the surface treatment, what we call cleaning of the steel plate, three types as follows are dealt with.

1) Without cleaning (direct bonding to the painted steel plate)
2) Painting is removed by brushing (handwork).
3) Painting is completely removed.

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After introduction of proposed repairing procedure, technical subjects to be resolved are explained. Experimental study program follows and main interesting findings obtained are presented and, in addition, the importance of identification of optimal painting volume to be removed from existing corroded member is stressed.

Repairing Procedure for Corroded Part by CFRP Sheets

As countermeasures for the repair of corroded steel plates, instead of steel plate bonding, CFRP sheets(Fig.1) is expected to be powerful solution. Herein, an application of such countermeasure to steel truss members and steel arch rib members is proposed. As shown in Fig.2, repairing procedure consists of following six steps.

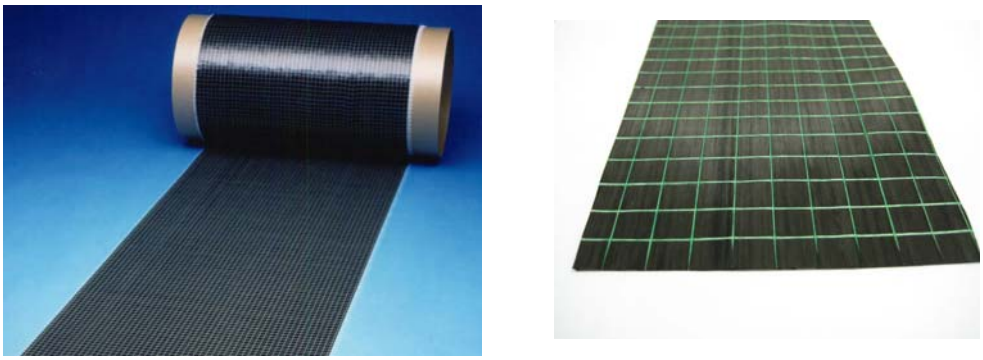

Fig.1 CFRP sheet

1) Removal of painting and cleaning of the corroded plate
2) Primer coating
3) At the portion where a severe damage due to corrosion, such as decrease of thickness of steel plate is observed, a smooth surface is ensured by employing epoxy putty filler.
4) Adhesion of CFRP
5) Aramid fiber (one-layer) sheet is bonded. Since high ductility, high anti-shock and anti-abrasion behaviors, and high shear strength are expected, it is suitable for protecting CFRP sheets and also bonding to members with right-angle corners.
6) Finish painting is conducted. It is also suitable for protecting aramid fiber sheet from deterioration due to ultraviolet rays.

The advantage of above procedure proposing over other method is summarized as follows.
1) Higher durability and anti-corrosion performance can be obtained, since CRFP excludes completely deteriorating factors.
2) Harmful influence from heating on existing members due to site welding and the reduction of effective area of the plate by bolting can be avoided.
3) Since CFRP sheet is a light material, easy handling can be attained, and the increase of both of size and weight of the repaired member is minor.
4) Suitable for the repair of in service bridges.

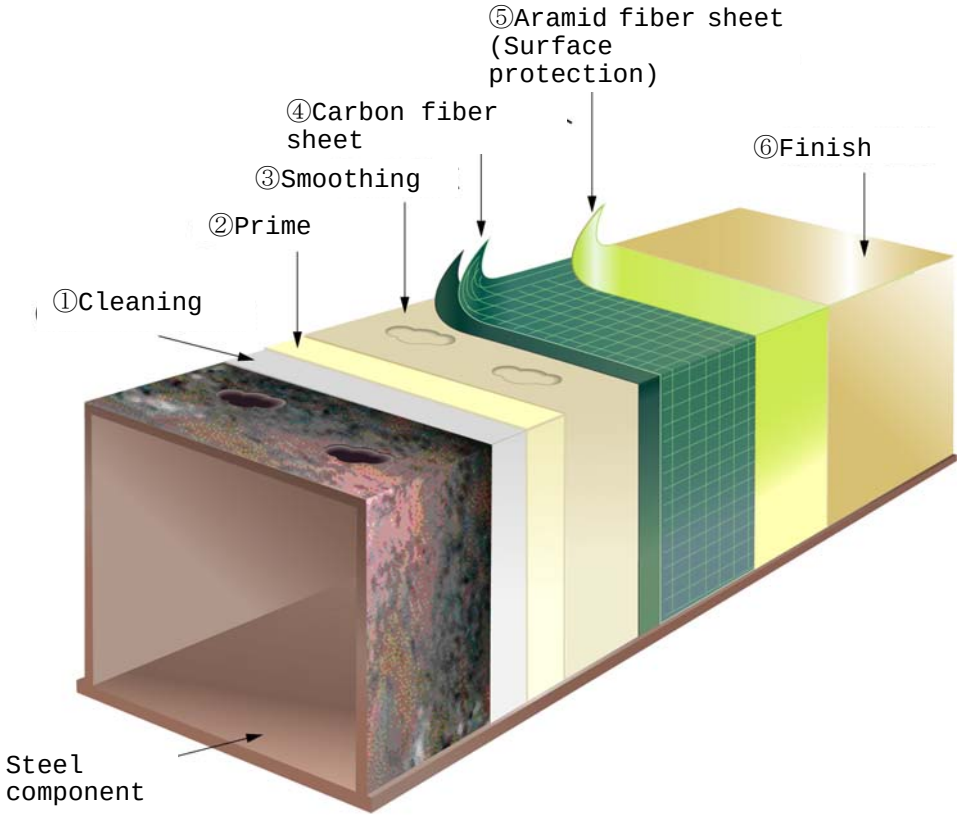

Fig.2 Work procedure for CFRP repair of steel component

Subjects on Application and Research Topics

At actual bridge sites, we may face difficulty in complete cleaning of the corroded members. All of related previous research works had been carried out under the condition that CFRP sheet is bonded to the steel without painting. Hence, from a practical point of view, influence of the grade of cleaning on effectiveness of CFRP bonding has to be examined. In addition, most of research results are those under tensile loading. Only a little information on behavior and strength under compressive loading has been obtained, hence, it is worth accumulating test dates under compressive loading.

Design Parameters and Material Properties

Table 1 shows painting specifications for the model girder with a H-shaped section. Three-step painting has been carried out, and they are called, under, middle and top coatings. This specifications of painting system is called “A-1 system” in Japan.

Table 2 shows parameters dealt with in this experimental study. All CFRP plates have three-layer sheet. CRFP plates of U1 and L1 are directly adhered to painted steel (without cleaning). CRFP plates of U2 and L2 are adhered to steel cleaned by hand

brushing. CFRP plates of U3 and L3 are adhered to completely cleaned steel girder.

Material properties of each component, such as the steel plate, CFRP sheet and epoxy resin are given in Table 3.

Table 1 Painting specifications

Process		Coatings	Number of painting	Coated film thickness (μm/frequency)
A-1 system	Under coating	Red-lead anticorrosive coating	2	35
	Middle coating	Phthalic resin coating	1	30
	Top coating	Phthalic resin coating	1	25

Table 2 Design Parameters

Position of sheet bounding	Number of layer	Cleaning
U1 & L1	3	Without cleaning
U2 & L2	3	With cleaning by brushing
U3 & L3	3	Complete removal of painting

Table 3 Material properties

Steel(SS400)	Yield stress(N/mm^2)	Tensile strength(N/mm^2)	Young's modulus(kN/mm^2)
	286	434	207
CF sheet	Fiber mass per unit area(g/m^2)	Tensile strength(N/mm^2)	Young's modulus(kN/mm^2)
	314	2516	682
epoxy resin	Compressive strength(N/mm^2)	Tensile strength(N/mm^2)	Tensile shear strength (kN/mm^2)
	73.5	51	15

Design Parameters and Material Properties

Fig.3 shows a side view of a model girder subjected to pure bending. Fig.4 is a photo of the model girder under loading. CFRP plate adhered to upper and lower flanges are subjected to compressive and tensile force, respectively. In Fig.5, the pasting position of strain gauges to steel and CFRP sheets are presented.

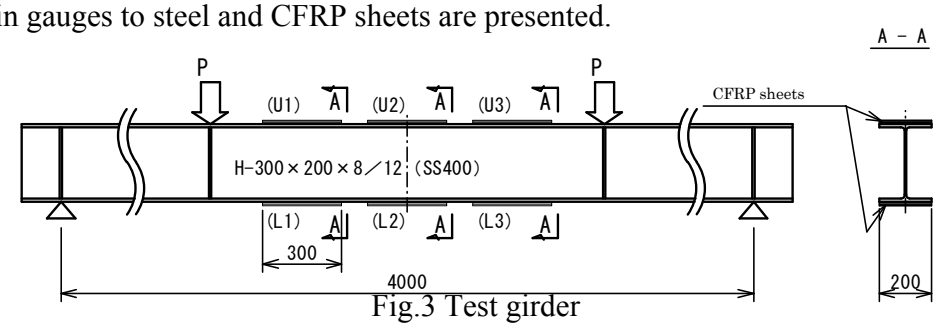

Fig.3 Test girder

Fig.4 Test girder under loading

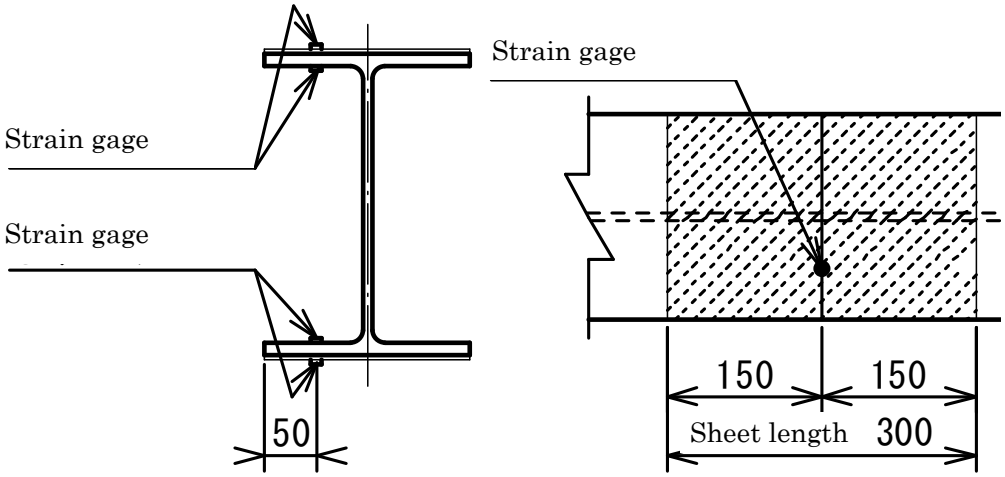

Fig.5 Strain gauge position

Results and discussion

Fig.6 shows the relationship between stress and strain measured at the steel plate subjected to tensile force. Fig.7 shows the stress-strain relationship at CFRP plates. From these results, the followings are obtained.

1) Before the occurrence of the peeling of CFRP plate, theoretical values based on complete composite action coincide with those from experiment.

2) In case of L1 plate, in which CFRP plate adhered directly to painted steel, even though the peeling of CFRP plate is not observed until the strain in the steel plate reaches yield strain, strengthening effect (decrease of stress level) is smaller compared to L2 and L3 cases.

3) The load at the peeling of CFRP plate of L2, in which painting is removed by hand

brushing, is higher than that of L3.

Fig.8 shows the relationship between stress and strain measured at the steel plate subjected to compressive force. Fig.9 is the stress-strain relationship at CFRP plate. The followings can be seen.

1) Regardless of the grade of cleaning, until the strain in the steel plate reaches yield stain, the peeling of CFRP is not observed.

2) Values from experiment show a good agreement with theoretical values based on complete composite action of CFRP and steel plate.

3) Comparing the effect of strengthening of U3 (complete cleaning) to that of U1 and U2, it is known that the former is better.

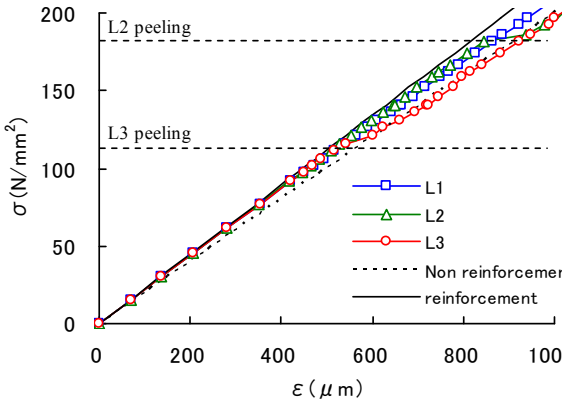

Fig.6 Relationship between stress and strain of steel in tension

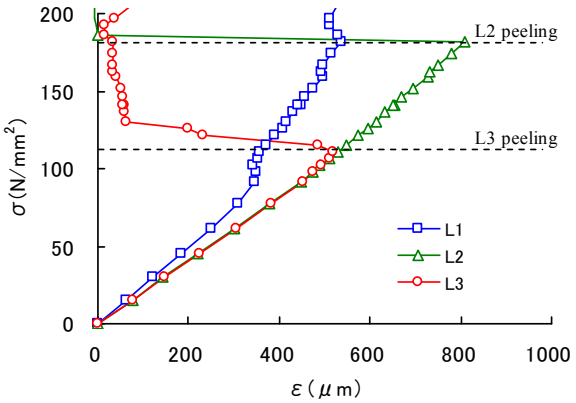

Fig.7 Relationship between stress and strain of CFRP in tension

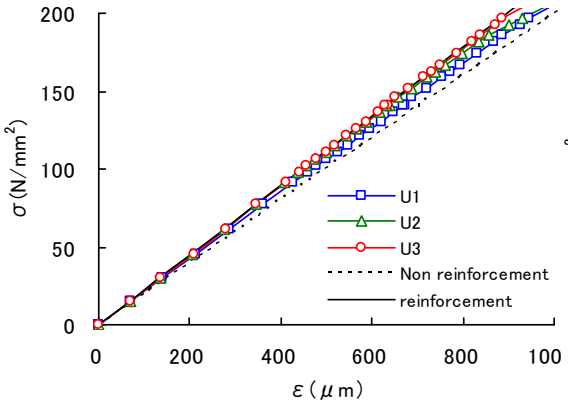

Fig.8 Relationship between stress and strain of steel in compression

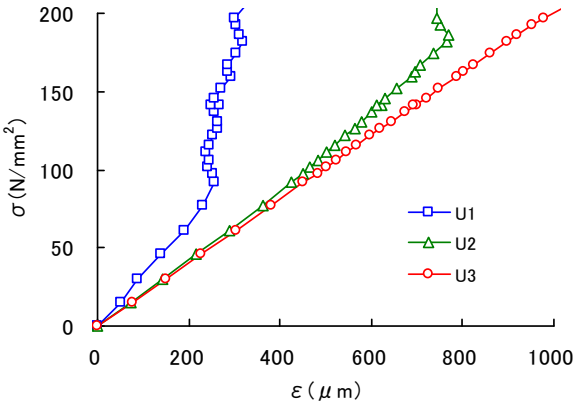

Fig.9 Relationship between stress and strain of CFRP in compression

Concluding Remarks

For the repair and strengthening of corroded steel plate in truss members and arch chords, instead of bonding the steel plate, we proposed a new idea of bonding CFRP plates, which is light and easy to handle.

Since information on mechanical behavior of CFRP-steel combined system has been insufficient, in order to accumulate basic informations, we carried out experimental study. The followings are the summary obtained from this study.

1) Until the peeling of CFRP plates from the steel plate, regardless of compressive and tensile forces, the stress-strain relationship of the steel plate theoretically calculated based on CFRP-steel composite action well agree with that obtained from experiment.

2) When subjected to tensile force, the load at the peeling of CFRP plates adhered to painted steel plate is much higher than that adhered to cleaned steel plate.

3) Regardless of tensile and compressive forces, the strengthening effect becomes weaker by bonding to painted steel without cleaning. The effect depends on the volume of painting.

Finally, it is summarized, in order to get higher effect, that an appropriate cleaning of corroded steel members is very important. However, the peeling-occurrence load of CFRP plate is higher when it is adhered to steel plate with painting. This is supposed that the painting layer mitigates high shear stress concentration between CFRP plate and steel plate.

Therefore, in order to ensure the required performance, we have to identify an optimal painting area and volume to remove.

References

[1] Nippon Steel Composite Co., Ltd, 2004. FORCA TOW SEET Technical Report.