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TENSILE TEST OF CRRP BONDED STEEL PLATE WITH HEAT RESISTANCE EPOXY RESIN

Yuya Hidekuma[1], Akira Kobayashi[1] and Atsuya Komori[1]
[1] Composites Company, NIPPON STEEL & SUMIKIN MATERIALS Co., Ltd, Japan

ABSTRACT

Steel structures are often corroded by various mechanisms, and their performance decreases dramatically due to corrosion. In recent years, as a repairing method for corroded steel members, a method bonding the carbon fiber sheets with resin to the steel member has been applied. However, the temperature of the steel member may rise near 60 degrees Celsius by solar radiation. Therefore, site curable heat resistance epoxy resins which have high glass transition temperature (T_g) greater than 60 degrees Celsius were developed. The objective of this study is to confirm the reinforcing effect and debonding characteristic of CFRP bonded steel plate at warm temperature. The tensile tests of CFRP bonded steel plate with the new heat resistance epoxy resin and the conventional epoxy resin at room temperature (23 degree Celsius) and warm temperature (60 degree Celsius) were conducted. As the results, in the case of using the new epoxy resin, the same test results were obtained at room temperature and at warm temperatures. The results showed that the new heat resistance epoxy resins were suitable for reinforcing of the steel members for CFRP.

KEYWORDS

CFRP strand sheets, steel, strengthening, heat resistance, tensile tests.

INTRODUCTION

In recent years, as the strengthening or repairing method of steel structure, a method bonding a CFRP with epoxy resin to the steel structure has been applied. Extensive research has shown that bonding the CFRP to steel with epoxy resin has sufficient bonding strength and strengthening effect at room temperature (e.g. Hidekuma *et al.* 2011, 2012). However, the temperature of the steel structure may rise near 60 degrees Celsius by solar radiation. There are some issues in the steel structure strengthened with CFRP at warm temperature. First one is the thermal stress caused by the difference of thermal expansions between the steel and the CFRP. The debonding shear stress induced by temperature change has been proposed by some researchers such as Ishikawa et al. 2007. Another one is the temperature dependence of the mechanical properties of the ambient-cure epoxy resins. The mechanical properties of the ambient-cure epoxy resins decrease dramatically over the glass transition temperature of the epoxy resin. Some research described that the stiffness and debonding strength reduced significantly at elevated temperature (e.g. Tien *et al.* 2011, Tim *et al.* 2010).

In this study, in order to clarify the effect of deference of the glass transition temperature of epoxy resin on the stiffness and debonding strength of CFRP, the tensile tests of steel plate strengthened with CFRP strand sheets at room temperature (23 degree Celsius) and warm temperature (60 degree Celsius) were performed. The CFRP strand sheet (Figure 1) which consists of bunch of individually hardened continuous fiber strands does not require impregnation process. For the strengthening of steel by using strand sheets, a primer and an adhesive resin like putty is required. In the study, two type resin system were used. One is the normal resin system which has the heat resistance similar to the resin for RC strengthening. Another one is the newly developed heat resistance resin system which has high glass transition temperature than the normal resin system. Each material is placing on the market by the NIPPON STEEL & SUMIKIN MATERIALS.

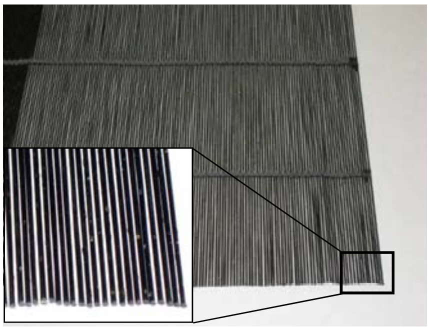


Figure 1. CFRP strand sheet

MATERIALS

As a base metal, SM570 (JIS G3106: Standard Specification is for Rolled Steels for Welded Structure.) steel were used. Its yield stress is 534 MPa and tensile modulus is 200 GPa. The reason for using the high yield strength steel was to observe the debonding characteristic at large strain. The mechanical properties of CFRP strand sheets are shown in Table 1. High modulus type strand sheets are used for these tests.

Every primer and resin is two-component liquid type epoxy resin adhesive and their chemical structure is BisphenolA epichlorohydrin polymer (Resin) / modified aliphatic polyamine (Hardener). Table 2 and Table 3 shows that the mechanical properties at room temperature (23 degree Celsius) and the glass transition temperature (T_g) of the primers and the adhesive resins. Here, the glass transition temperatures were measured by differential scanning calorimeter (DSC, ISO-11357-3).

The mechanical properties of epoxy resin depend on the temperature. Therefore, the temperature dependences of the tensile lap-shear strength (ISO4587) of primers are shown in Figure 2. From this figure, it is found that the tensile lap-shear strength of the normal primer decreases dramatically as the temperature is raised above the glass transition temperature. On the other hand, in heat resistance primer, the tensile lap-shear strength is almost constant until 80 degree Celsius. Furthermore, the temperature dependences of the compressive modulus (ISO604) of heat resistance resin are shown in Figure 3. Although the test temperature is lower than the glass transition temperature, the compressive modulus gradually decreases with increases in test temperature in the heat resistance resin. In the normal resin, the compressive modulus dramatically decreases at 50 degree Celsius.

Table 1. Properties of CFRP strand sheet

Tensile strength (MPa)	Young's modulus (GPa)	Fiber areal weight (g/m^2)
2,760	695	933

Table 2. Properties of primers at R.T.

Type of primer (product name)	Tensile lap-shear strength (MPa)	Comp. Modulus (MPa)	T_g (degree Celsius)
Normal primer (FP-WE7)	20.2	2183	42
Heat resistance primer (FP-N9)	18.2	3221	78

Table 3. Properties of resins at R.T.

Type of resin (product name)	Comp. Strength (MPa)	Comp. Modulus (MPa)	T_g (degree Celsius)
Normal resin (FB-E7S)	68.9	3450	44
Heat resistance resin (FB-E9S)	97.1	3227	81

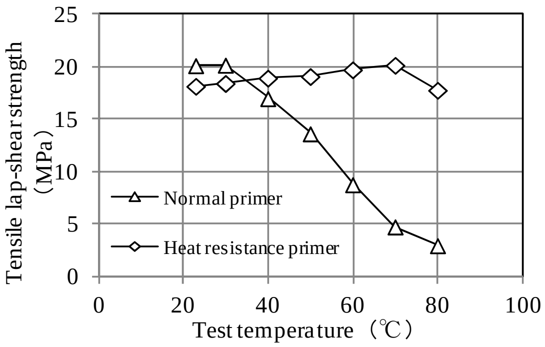


Figure 2. Tensile lap-share strength of primers

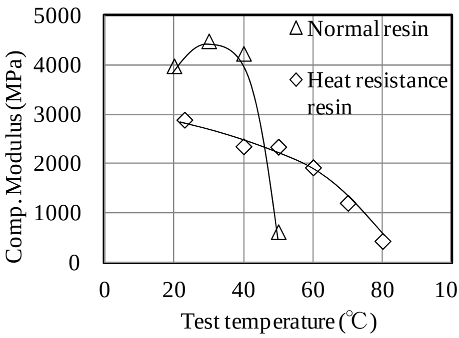
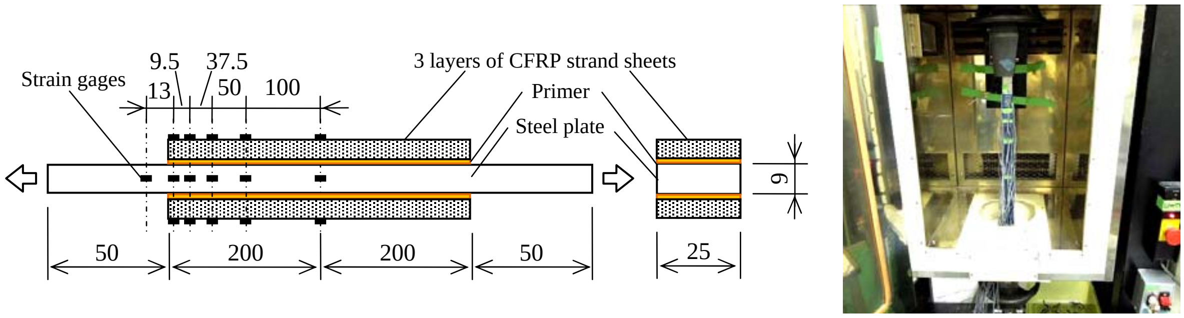


Figure 3. Comp. Modulus of resins

OUTLINE OF TESTS

As shown in Figure 4 (a), three layers of CFRP strand sheets were bonded to both sides of steel plate with normal primer/resin system or heat resistance primer/resin system. The simple tensile tests of the strengthened steels were performed until the applied load reaches 95 kN (steel stress: 420 MPa) at room temperature (23 degree Celsius) and warm temperature (60 degree Celsius). The experimental parameters are shown in Table 4. For warm temperature testing, the environmental chamber was used as shown in Figure 4 (b). The strains in CFRP strand sheets and steel were measured with strain gages and debonding between CFRP strand sheets and steel plate was observed.



(a) (b)

Figure 4. (a) Details of a tensile test specimen (b) Photograph of during testing

Table 4. Experimental parameters of tensile tests

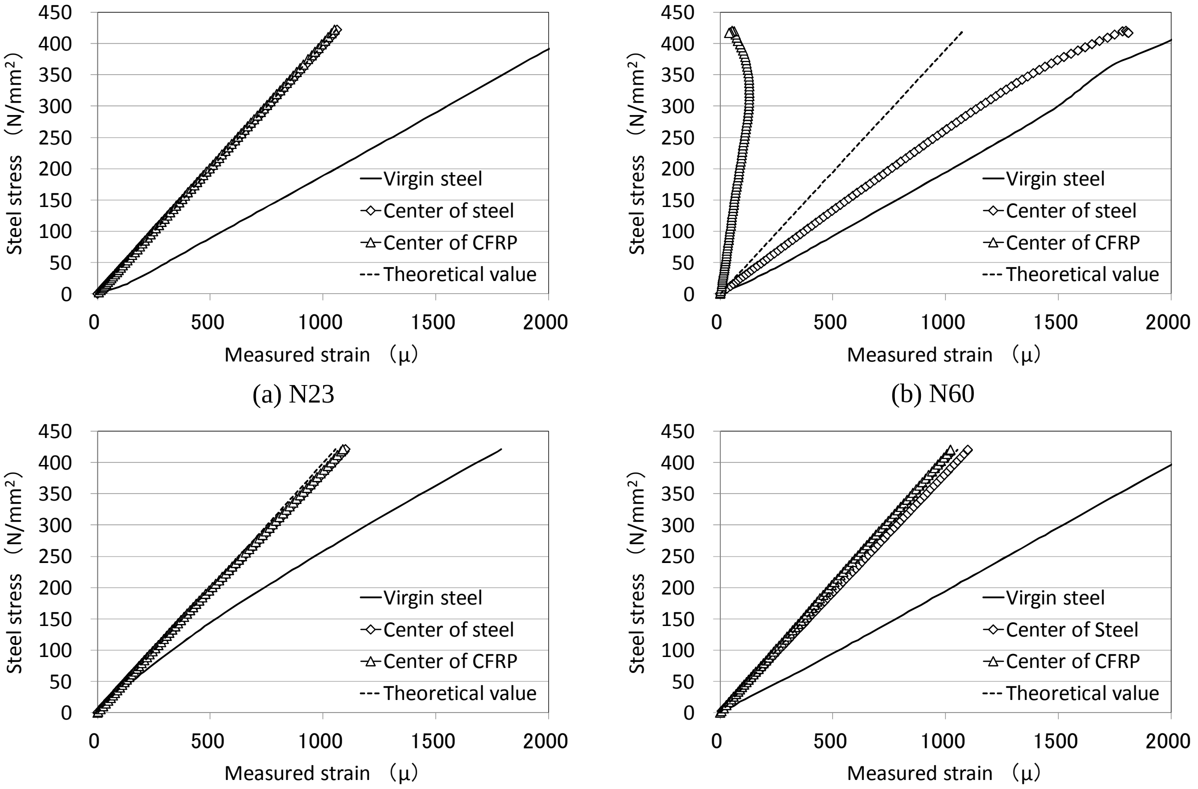
No.	Primer/Resin system	Test temperature (degree Celsius)
N23	Normal	23
N60	Normal	60
H23	Heat resistance	23
H60	Heat resistance	60

RESULTS AND DISCUSSIONS

Strengthening Effect

The stress-strain curves at the center of N23, N60, H23 and H60 are shown in Figure 5. Here, the theoretical values were calculated as complete composite cross section of CFRPs and steel. And the strengthening effect of each specimen is shown in Table 5. From Figure 5, it is found that the strain of steel and CFRPs agree well with the theoretical value in both resin system at room temperature. However, the strengthening effects of both resin system are considerably different at warm temperature.

In the case of N60, the strain of centre of CFRP is quite smaller than theoretical value and the strengthening effect is the almost 65 % of the theoretical value. This is caused by primer and resin become soft in warm temperature. Therefore, it is thought that the low modulus of primer and resin caused low strengthening effect. On the other hand, in H60, the strengthening effect is almost same as that of N23 as shown in Table 5. This is caused that T_g of heat resistance primer and resin is higher than testing temperature. Therefore, even if the steel structures become warm temperature by solar radiation, the sufficient strengthening effect can be obtained by CFRP strengthening with the heat resistance resin system.



(a) N23

(b) N60

(c) H23

(d) H60

Figure 5. Stress and measured strain curves (a) N23, (b) N60, (c) H23, (d) H60

Table 5. Strengthening effect of each specimen

	Theoretical strain / Experimental strain of center of steel (%)			
Stress level	100 MPa	200 MPa	300 MPa	400 MPa
N23	101	99.6	99.3	99.3
N60	68.5	67.7	66.6	62.0
H23	99.0	97.6	96.1	95.7
H60	96.6	96.2	96.0	95.8

Debonding Behaviour

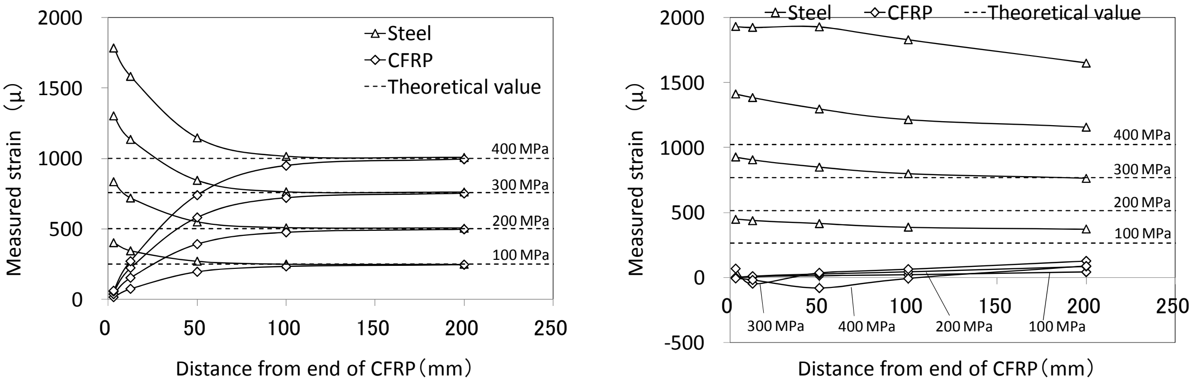
The debonding of CFRP did not occur in all specimens until steel stress reached 420 MPa as shown in Figure 6. It was expected that the debonding of CFRP occur at warm temperature in N60, because the normal primer showed the low tensile lap-shear strength at 60 degree Celsius as shown in Figure 2. However, the debonding of CFRP did not occur in N60. This is caused that the shear force between the CFRP and steel was very small, since the load was not transferred to the CFRP due to low modulus of the resins in warm temperature.

(a) N60 (b) H60

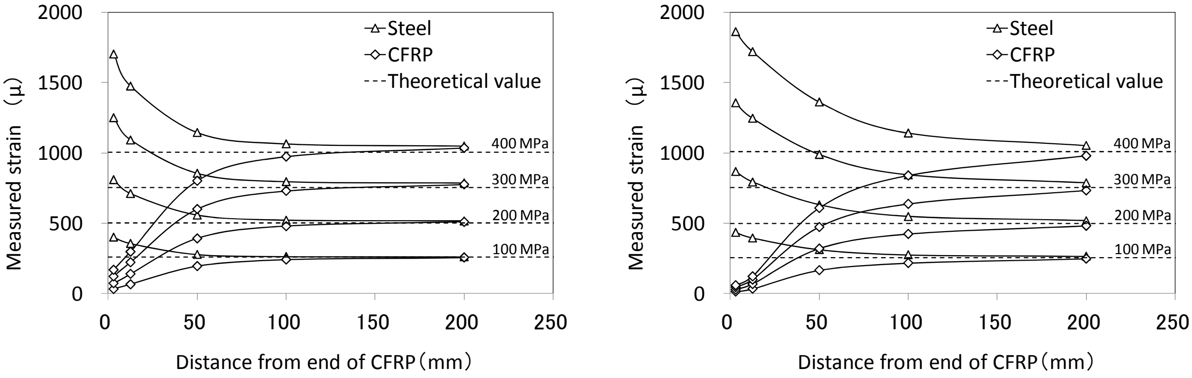
Figure 6. The specimens after testing (a) N60, (b) H60

Effective Bond Length

The strain distribution of CFRP and steel from tip of CFRP to center of each specimen at four stress levels are shown in Figure 7. The theoretical values are calculated as complete composite cross section at each stress level. From these figure, it is found that the effective bond length is around 150 mm at room temperature regardless of difference of the resin in this construction. In the case of N60, the load transfer scarcely occurred from the steel to the CFRPs even if it has bond length of 200mm. In H60, the effective bond length is around 200 mm. It became longer compared with N23. It means that the modulus of the heat resistance primer and resin became smaller even if the T_g of the heat resistance primer and resin are higher than testing temperature. Therefore, the bond length should be decided with the effective bond length at maximum temperature of actual structure on the occasion of strengthening design.



(a) N23 (b) N60

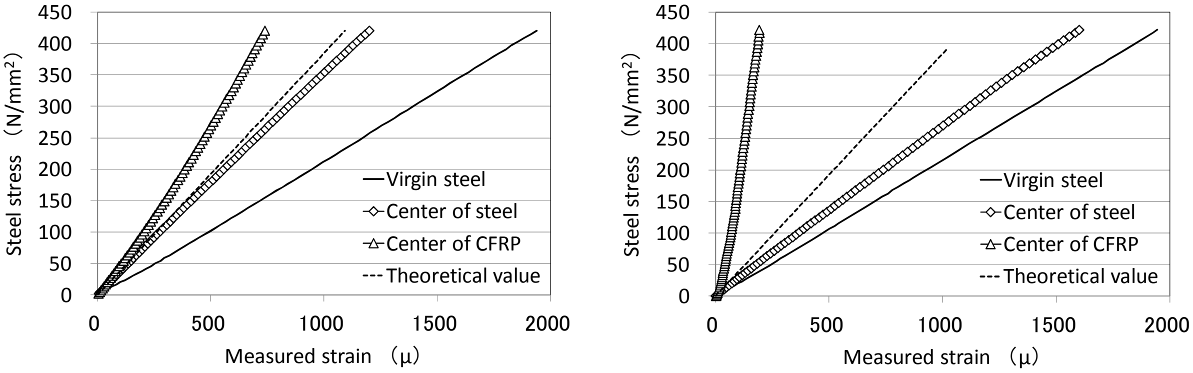


(c) H23 (d) H60

Figure 7. Strain distribution of CFRP and steel (stress level: 100 MPa to 400 MPa)
(a) N23, (b) N60, (c) H23, (d) H60

More elevated temperature

In order to clarify the behavior of the heat resistance resin at more elevated temperature, the tensile tests at 70 and 80 degree Celsius are carried out. The stress-strain curves are shown in Figure 8. From this figure, it is found that the strain of steel and CFRP disagree with the theoretical value at both temperature because the modulus of the heat resistance resin became smaller at these temperature. Consequently, when the temperature of the steel structure becomes more than 70 degree Celsius, the CFRP/Steel adhesively bonded system cannot be designed as a composite cross-section with this bond length (200 mm). However, an enough bond length will result the complete composite cross-section to the CFRP/Steel adhesively bonded system. The debonding of CFRP did not occur at these temperatures.



(a) 70 degree Celsius (b) 80 degree Celsius

Figure 8. Stress and measured strain curves (a) 70 degree Celsius, (b) 80 degree Celsius

CONCLUSIONS

In order to clarify the effect of deference of the glass transition temperature of epoxy resin on the stiffness and debonding strength of CFRP, the tensile tests of steel plate strengthened with CFRP strand sheets at room temperature (23 degree Celsius) and warm temperature (60 degree Celsius) were performed. The results obtained from this research are summarized as follows;

- Using the heat resistance resin system which has around 80 degree Celsius of T_g, the sufficient strengthening effect can be obtained even if the steel structures become warm temperature by solar radiation.
- In this research, the debonding of CFRP did not occur even by using normal resin system because the load was not transferred to the CFRP due to low modulus of the resins in warm temperature.
- The modulus of the heat resistance primer and resin became smaller even if the T_g of the heat resistance primer and resin are higher than testing temperature. Therefore, the bond length should be decided with the effective bond length at maximum temperature of actual structure on the occasion of strengthening design.

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