# Effect of corroded surface preparation on adhesive behavior of CFRP-steel single strapped joints

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**1. Introduction** With the high strength-to-weight ratio, good resistance to fatigue and ease of installation, the popularity of carbon fiber-reinforced polymer (CFRP) composite materials in aged steel structures has risen as the and benefits of strengthening and remediation activities. It has been proved effectiveness and widely accepted. However, premature debonding of the CFRP laminate from the steel structure of external strengthening, especially of bonded joints, remains a significant concern source, which puts the bond stress transfer between materials at risk and is not desired in engineering applications[1)]. The surface preparation before repairment is regarded as one of the most essential factors in causing premature debonding. There are several surface preparation methods are adopted in the field works, such as abrasive blast treatment, the most effective method for achieving a chemically active surface but associated health, pollution, and contamination hazards. Compared to it, power tool cleaning generates much less amount of dust and is easily conducted in the narrow parts or local areas of steel structures but has weak cleaning ability for the hole of corrosion pits. Recently, an abrasive water jet treatment (AWT) is also attracting more and more attention for its higher salt removal efficiency. In this study, the main objective is to assess the effect of surface preparation methods on the corroded steel plates, by discussing the adhesive behavior of CFRP-steel single strapped joints.

**2. Specimen and test method** In this experiment, carbon steel plates (JIS G3106 SM490A) with dimensions of 150×70×6 mm, a unidirectional normal modulus carbon fiber materials, Mitsubishi MRK-M2-20, were commonly produced as dry fiber tow sheets, and an impregnated adhesive XL800 were used to prepare the test specimens. The initial state of steel plate was prepared by abrasive blasting treatment (ABT) to remove the casting surface. The blasting pressure, angle, distance and abrasive materials of ABT are 0.7 MPa, 60°, 300 mm and steel grit. As for the preparation of corroded steel plates, firstly corroded plates were prepared by combined cycle corrosion test (CCT). The accelerated exposure tests were carried out using Cycle-D specified in JIS K 5600-7-9. The whole cycle takes 6 h, cyclic conditions are shown in Fig. 1. After 120 cycles of CCT, the mean corrosion depth was approximately 0.106 mm calculated from the weight loss of steel plate, and the maximum corrosion depth is 0.327 mm using the measurement method of a laser focus scanning system[2)].

After the CCT, three surface cleaning treatments of corroded steel plates were evaluated: 1) SB: a surface conditioning abrasive disc named scotch-brite™ was installed to electric rotating disk sander to simulate the actual manual processing at the site of the remediation works. 2) ABT: steel grit blast controlled with the pressure of 0.7 MPa for at least 20 s with a stand-off distance of 300 mm. 3) AWT: the abrasive was shot mixed with 245 MPa pressure water at the degree of 90° to the corroded surface from 100 mm distance. All prepared steel substrates were then followed by compressed air cleaning. Surface roughness measurements were carried out using a non-contact laser scanning confocal microscopy (LSCM). After that, the scanning area of laser microscope was set as 10×0.6 mm with pitch of 1.8 μm in both directions. Three most applied line roughness parameters (Ra, Rzjis, RSm) of steel plates cleaned by the three preparations are measured. Next, three layers of carbon fiber sheets were impregnated with adhesive while pasted on the steel surface, and cured at 35°C for more than five days as shown in Fig. 2. The CFRP-steel single strapped joints were tensioned by a universal testing machine with displacement control at a rate of 0.01 mm/sec.

**3. Test results** The roughness parameters Ra, Rzjis, RSm of corroded steel surface after SB, ABT, and AWT were shown in Table 1. It shows the ABT and AWT cases have a similar surface morphology, whose Rzjis are more than 6 times larger than that of SB. Moreover, the roughness factor RSm is the arithmetic mean value of the widths of the peak and valley in the corrosion removal surface, so a larger distance between peaks and valleys in the RSm calculation will result in a more significant value. It

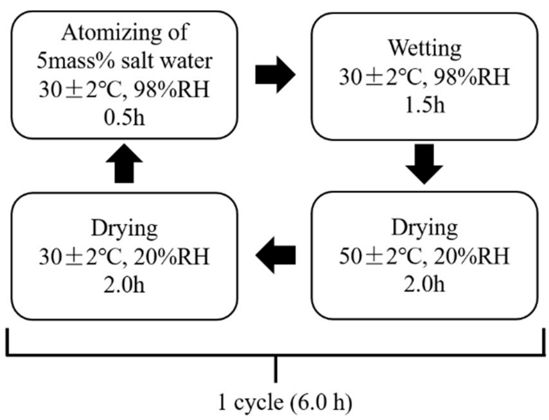


Fig. 1 Corrosion cycle applied during the accelerated exposure tests

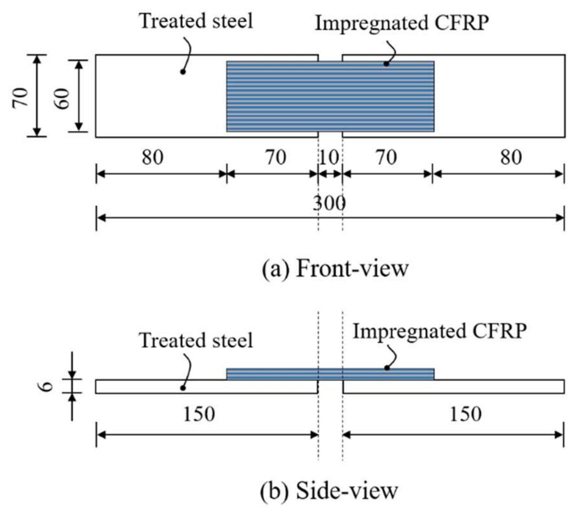


Fig. 2 Geometry of CFRP-steel single strapped joint (unit: mm)

Table 1 Surface roughness of treated steel plates

| Treatment | SB | ABT | AWT |
|---|---|---|---|
| Ra (μm) | 8.73 | 18.3 | 21.0 |
| Rzjis (μm) | 16.8 | 102 | 110 |
| RSm (μm) | 970 | 367 | 379 |

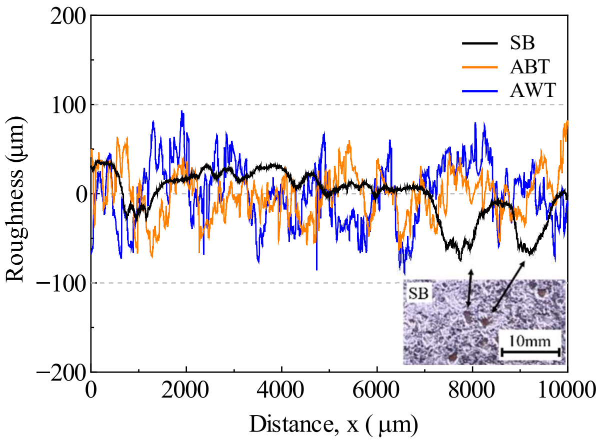


Fig.3 Line edge roughness profiles of specimens

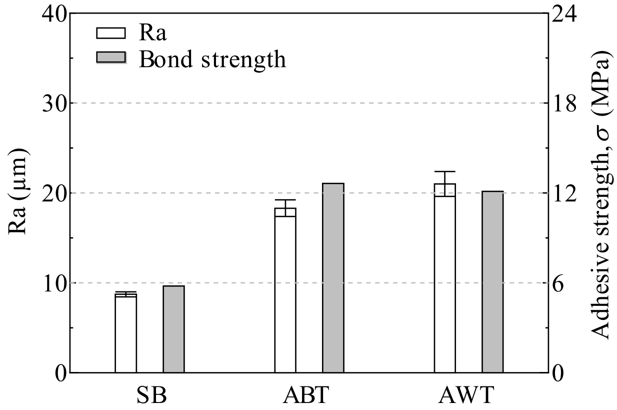


Fig.4 Ra and bond strength of specimens

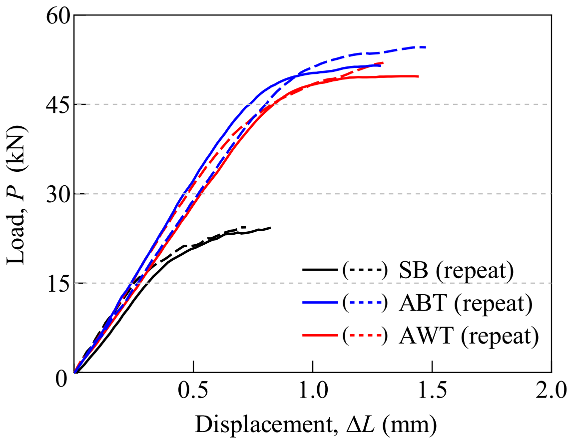


Fig.5 Load-displacement curves of specimens

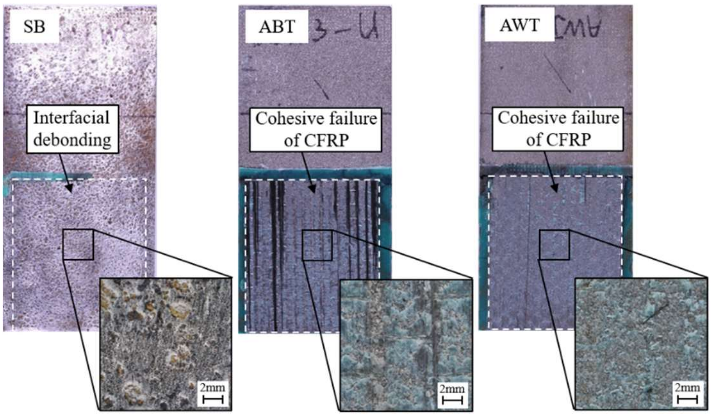


Fig.6 Failure surfaces after tensile tests

shows the RSm of SB case is much larger than that of ABT and AWT cases. It is speculated that the hit of the abrasive under high pressure will form a relatively rough surface. On the other hand, the SB rotary grinding will make the uniform part of the surface flat but cannot reach the hole of corrosion pits, which leads to a larger RSm. In addition, randomly selected line edge roughness profiles of the SB, ABT, and AWT surfaces are shown in Fig. 3. The surface undulation of the ABT and AWT cases are much larger than that of SB case. Besides, for the SB case, the roughness is smaller than the other two cases except for the corrosion pits area, corresponding to the roughness parameters calculation results.

The adhesive strength of specimens acquired by extracting the ultimate load of the load-displacement curve, and Ra were discussed as Fig.4 shows. It can be seen that with the Ra increase, the adhesive strength increase, while the adhesive strength of ABT and AWT is close and 2.18 times and 2.09 times that of SB case. The load-displacement from tensile test results of CFRP-steel single strapped joint are illustrated in Fig.5. For all specimens, the displacement first linearly increased with the load and subsequently became nonlinear. An almost identical slope was observed in the linear stage, which implies that the surface preparation has a less detrimental effect on the stiffness in the elastic stage. The debonding area appeared in the softening stage and slowly expanded as the load increased. Fig.6 displays images of failure surfaces and local magnified image taken by microscope after the tensile test. Both ABT and AWT showed a cohesive debonding between epoxy resin and carbon fiber sheet with the residual remaining. In the case of SB, CFRP was completely debonding from the surface for the weak bond activity and roughness corresponding to the premature failure shown in Fig.5.

**4. Summary & Findings** For corroded steel, after the surface preparation by abrasive blasting treatment and abrasive water jet treatment, it will form similar and more proper roughness in CFRP reinforcement than power tool scotch-brite™, which may lead to interfacial debonding and premature failure in CFRP-steel single strapped joints.

**Reference** 1) Yang, M., Xie, J., Kainuma, S., and Liu, W. :Improvement in Bond Behavior and Thermal Properties of Carbon Fiber-reinforced Polymer Strengthened Steel Structures, *Composite Structures*, Vol.278, 114704, 2021. 2) Jeong, Y. S., Kainuma, S. and Ahn, J. H.: Assessment of the Corrosion Characteristics of the Carbon Steel under Different Atmospheric Environments, *Advanced Materials Research*, Vol. 684, pp.116-119, 2013.