Evaluation on the surface properties and adhesive strength of blasted steel plate used for CFRP/steel joint

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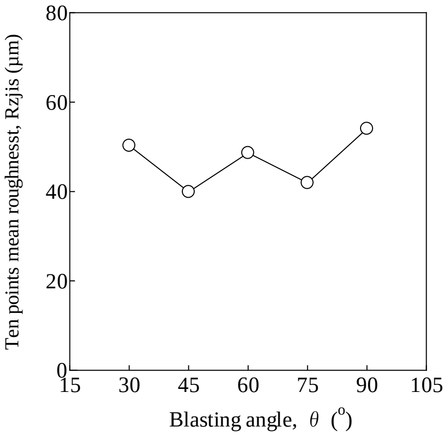
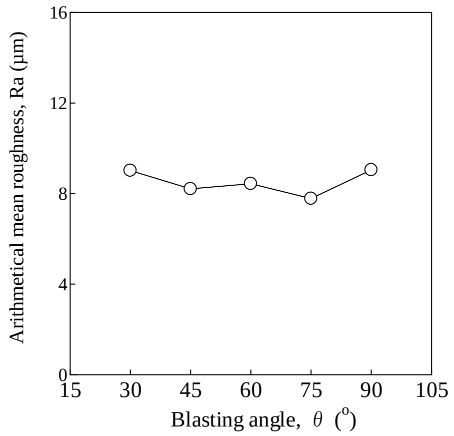
1. Introduction Over the past decades, Carbon Fiber Reinforced Polymer (CFRP) has been established as an excellent strengthening material to use in the steel structures. The performance of CFRP strengthened steel members is directly dependent on the quality and integrity of the adhesive bond. However, insufficient knowledge on the bond behavior of the CFRP/steel bonded joints is the major drawback in the lack of applications of this system. Lots of the previous researches [1)] have studied the effect of grit blasting on surface properties for adhesion in mild steel and alloys. From their conclusion, the variation in the adhesive strength significantly depends on the physical and chemical properties of the substrate surface from the grit blasting [2)]. In this study, different blasting angles were compared, the surface properties and the adhesive strength of blast treated steel plates were discussed. The surface roughness, amount of residual Al at the steel surface, and adhesion strength according to the adhesion test were performed to determine the effect of blasting angles on the adhesive bonding behavior of CFRP/steel composite member.

2. Test method The specimens are made from carbon steel plates (JIS G3106 SM490A) with dimensions of 150×70×6 mm [3)]. After milling (cutting diameter: 50 mm, cutting speed 215 m/min, revolutions per minute:1369 (rev./min), blade material: cermet) so that the surface roughness of the specimen before blasting does not affect the surface properties after blasting, and the surface of the specimen is polished before the blast treatment. After polishing, only the steel plates met the requirement of surface line roughness were used for the subsequent specimen preparation, which Rzjis and Ra should less than 30 μm and 3 μm, respectively. The nozzle orifice is 8 mm. The pressure and distance of blasting treatment were set as 0.7 MPa and 300 mm, which are generally employed in Japan. The angles were changed to 30, 45, 60, 75, and 90º to compare the surface characteristics according to the angles. After blast surface treatment, surface roughness was measured through a 3D laser microscope. Line roughness was calculated based on an average of 11 lines with a base length of 10 mm. Line roughness is also evaluated for ten-point mean roughness Rzjis corresponding to the height direction of the surface undulation, arithmetic mean roughness Ra, and mean length of contour curve element RSm corresponding to the width of the surface undulation. Besides, Al as the principal component of the abrasive material, its residual amount, and element mapping at the center zone of the blasted surface was detected and analyzed using SEM-EDX (Resolution: 3.5 nm (30 kV), Acceleration voltage: 20 kV) under low vacuum condition, and element analysis was performed by EDX (Fe, O, Al). Adhesion testing was performed using MSC-10/500-2, which is desktop tension-compression testing machine for the measurement of adhesion strength, tensile speed in this study is 0.5 mm/min. A two-liquid epoxy resin with a mixture of 1:1 was used as adhesive. The dolly (JIS H 4000 Aluminum alloy A2017, diameter: 20mm) was bonded to the center of blasted feature in specimens. After the blast treatment, applied uniform compressive stress of 0.9 MPa to the dolly and maintained for 30 min to adhere it to the steel surface. Then, curing the dolly specimen for one hour under an environment of 80℃ temperature and 60 RH(%). After the curing process of adhesive, the adhesion test of the bond specimen was performed to assess the effect of the blasting condition on adhesion strength.

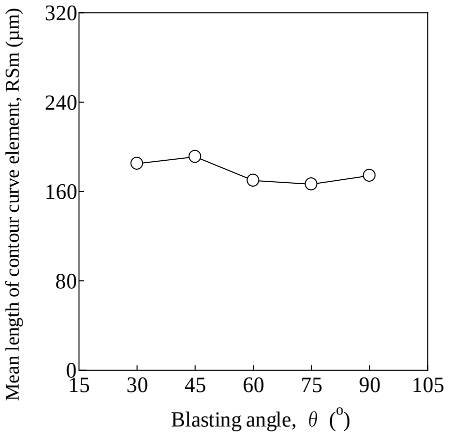
3. Test results The relationship of surface line roughness parameters Rzjis, Ra and RSm to the blasting angle θ as shown in Fig.1. According to the various blasting angles, especially for Rzjis, the results showed considerable randomness. As for Ra and RSm, results exhibited a tendency of decline according to angle increased from 30º to 75º, but the difference in the values of the angles is very small. In particular, Ra and RSm reached the minimum at 75º compared to other angles.



(a) Rzjis



(b) Ra



(c) RSm

Fig.1 Variation of Rzjis, Ra, RSm according to blasting angles

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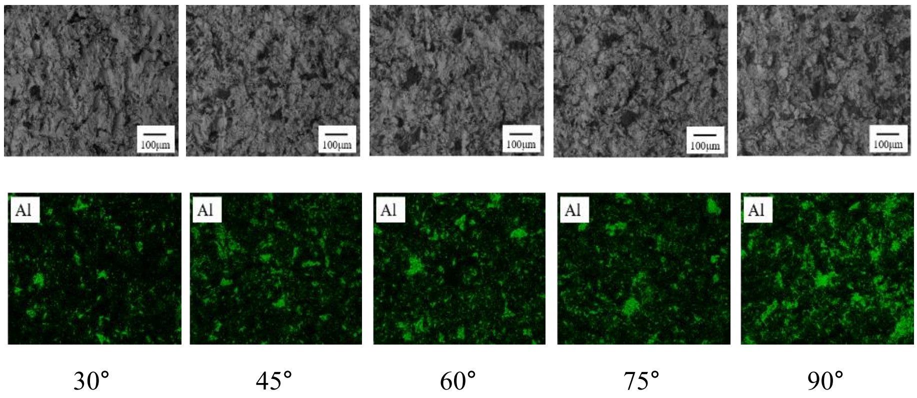
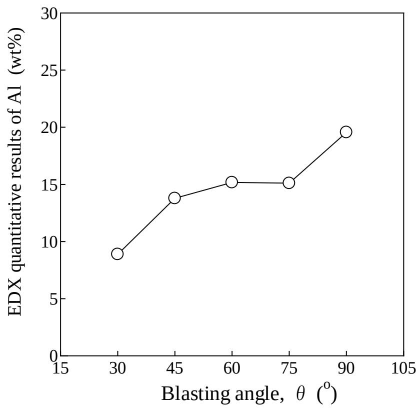
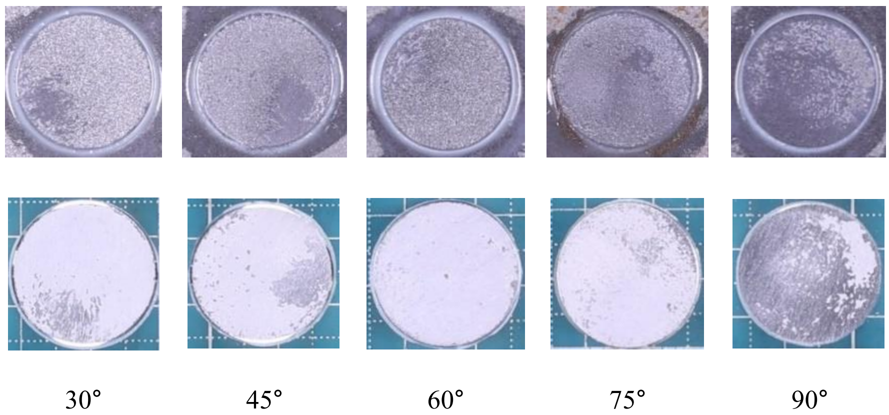


(a) SEM images and Al element mapping by EDX analysis

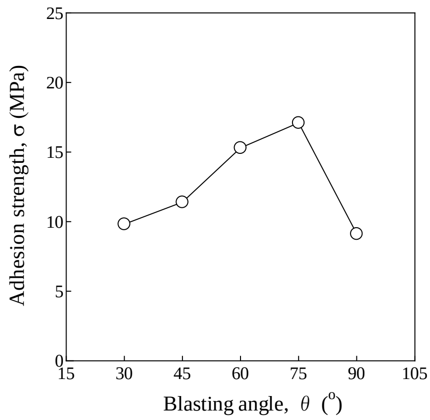


(b) EDX quantitative results

Fig.2 The results of SEM-EDX



(a) Fracture surface conditions (upside: steel plate; downside: dolly)



(b) Adhesion strength

Fig.3 Adhesion test results of bond specimen

The SEM photos and corresponding EDX quantitative results of residual Al element mapping at the steel surfaces are shown in Fig.2(a). Fig.2(b) shows the weight percentage of Al remaining on the surface at each angle. It is evident that the weight percentage of the residual Al element increased along with θ increases from 30° to 90°. Particularly, the amount of residual Al is less than 10 wt% in the 30° blasted specimen, while it is around 20 wt% in the 90° blasted specimen. Thus, residual abrasive material is a non-ignorable influence factor during the surface roughness and bond behaviors evaluation. In addition, when blasting angle changing in the range from 45° to 75°, there is no significant difference in the amount of residual abrasive material at the steel surface. It was indicated that a positive correlation but not a linear relationship existed between the blasting angle and residual Al element. The adhesion test results of the bond specimens according to various blasting angle θ, are shown in Fig.3.The steel and dolly surface after the adhesion test as shown in Fig.3(a). The adhesion strength results as shown in Fig.3(b). The adhesion strength was enhanced when the blasting angle increased from 30° to 75°, and their failure modes all tend to be the interface failure. Notably, 75° blasted specimen owned the biggest interface failure, approximately two times of that in the 30° and 90° cases. The failure mode of 90° specimen showed to be different from others, which the adhesion strength of steel/adhesive tends to be greater than that of adhesive/dolly.

The relationship between residual amount of Al in Fig.2(b) and the adhesion strength in Fig.3(b) tends to increase overall from 30° to 75°. On the other hand, for 90°, the residual amount of Al is the highest, but the adhesion strength is 9.12 N/mm^2, which is the lowest compared to other angles. This is might be reduced the adhesion of the steel to the adhesive if the residue of the remaining Al in the steel exceeds a certain amount. Furthermore, it showed that the blasting angle is a parameter that would affect the roughness and chemical composition of the blasted steel plate surface. It allows the determination of the adhesion strength between the steel/adhesive agents prior to the formation of the CFRP/steel composite and suggests a blasting angle of less than 75° for good adhesive properties.

4. Summary 1) In this study, the blasting angle of 75° or less is proposed for steel surface treatment. Test results showed that in the case of 75°, low roughness surface condition, proper residual abrasive amount, and the largest adhesion strength could be obtained. 2) The blasting angle would affect the surface roughness and surface chemical composition of steel plate, also determine the adhesion strength of CFRP/steel composite.

References 1) A.C. Thomas, K. Baskar. Testing and Evaluation of Bond Surface Profile Influencing the CFRP Strengthening of Steel Members. Journal of Testing and Evaluation, Vol.46(6), pp: 2569-2583, 2018. 2) A.F. Harris, A.Beevers. Effects of grit-blasting on surface properties for adhesion, International Journal of Adhesion and Adhesives, Vol.19, pp: 445-452, 1999. 3) Japanese Standards Association, Japanese Industrial Standard (JIS) G3106: Rolled Steels for Welded Structure, 2008.