Characterizing corrosion properties of carbon steel affected by Abrasive Waterjet Treatment

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1. Introduction Surface cleaning is an important procedure to maintain the quality of steel structures in long-term usage. The durability of painting and under coating corrosion primarily depends on steel surface condition after treatment. Currently, abrasive blasting treatment is one of the most accepted methods for steel surface preparation. However, it has poor cleaning efficiency in the bottom of corrosion pit of severe corroded steel member. The initial corrosion under the painting and film occurred due to chloride or corrosion products that have not been removed is another disadvantage of blast treatment. In contrast, abrasive waterjet treatment (AWT), developed originally in the 1980s as a new type of special treatment technology for steel cutting, is a potential surface preparation method to overcome such problems. A recent study showed that abrasive waterjet was used for polishing steel surface by controlling the operating parameters. AWT has the potential to achieve desirable surface conditions and can affect the properties of the steel surface by touching the energy of ultra-high pressure water during treatment. The properties of that changed steel surface may influence corrosion resistance. This study was intended to investigate changes in steel surface characteristics treated by AWT according to standoff distance (SOD). Those properties were compared to the ones produced from blast treatment in terms of surface roughness, surface hardness, plastic deformation of surface layer, and corrosion resistance.

2. Specimen and test method The specimens are made from carbon steel plates (JIS G3106 SM490A) with dimensions of 70×70×6 mm. AWT and the blast treatment were performed using garnet, one of the abrasive materials (Mesh size: #30-60). For the blasting conditions, the distance, pressure, angle and time of blast treatment were set at 200 mm, 0.7 MPa, 90° and 5 seconds to be compared to AWT. To evaluate the effect of SOD of AWT on the steel surface. AWT is carried out under the conditions (SOD: 100 to 300 mm, Abrasive supply: 600 g/min, Pressure: 230 MPa, Traverse speed machining: 1 mm/min, Water flow: 11.9 L/min, and Nozzle diameter: 0.75 mm). For the nozzle, water jet convergent nozzle used for cutting metals was selected. AWT specimens according to SOD 100, 200, and 300 mm were labeled as AWT-1, AWT-2, and AWT-3. The surface roughness of AWT and blasted specimens were measured using a laser scanning microscope. Microhardness measurements were performed by machining of microhardness. Microstructure images after both treatments were observed by a microscope. Electrochemical tests were performed by a potentiostat. All electrochemical test measurements were performed on the reference electrode (Ag/AgCl) and counter electrode (platinum foil) with the evaluation area of 100 mm^2. Open circuit potential (OCP), polarization curve (PC), and electrochemical impedance spectroscopy (EIS) measurements were performed in a 3.5 wt% NaCl solution for all test specimens. The open circuit potential of the test specimen was measured with an AC amplitude of 10 mV until the potential stabilizes, and the polarization curve test was tested in the range of -250 to +250 mV at a scanning rate of 10 mV/min. Corrosion current (i_{corr}) and corrosion potential (E_{corr}) were measured using Tafel extrapolation. Electrochemical impedance spectroscopy (EIS) was conducted in the range of 10 mHz to 100 kHz respecting E_{ocp}.

3. Test result Figure 1 illustrates the roughness (Ra, Rzjis) results after AWT and blast treatment. It was indicated that AWT specimens had a higher roughness than the blasted specimen, and that of AWT tended to decrease slightly as SOD increased. AWT contains great energy effects from ultra-high pressure water and abrasive materials. Therefore, the energy absorbed by the steel plate during the AWT was analyzed by the change in hardness below the surface of the specimens. The microhardness value graph of the specimens is shown in Fig.2. It can be seen in this graph that the untreated specimen had an average hardness value of 150-200 HV. After AWT, the hardness of AWT treated specimens increased and the maximum values were obtained on the specimen surface. AWT-1 specimen which is the smallest SOD obtained the largest value of 268 HV. AWT-2, AWT-3, and blasted specimens obtained 253 HV, 242 HV, and 224 HV hardness values respectively. The increase in microhardness values can be attributed to hardening of the surface of steel plates. The change in surface deformation after treatment is shown in Fig.3. After both treatments, a plastically deformed surface layer was formed in each specimen, and the hardness value increased. During AWT, as the energy in touch with the surface increases, hardness increases, maximum plastic deformation, and maximum compressive residual stress is generated in the maximum plastic deformation part [1)]. In terms of the AWT specimens, as the SOD decreased, the deformation of the surface and deformed area were larger. However, in the case of blast treatment, it was found that the deformation and deformed area were smaller than AWT. The OCP values for all specimens are shown in Fig.4a. The highest OCP value was obtained from AWT-1 specimen, therefore it can be said that this specimen is the noblest potential value. The most cathodic potential value belonged to the blasted specimen. Fig.4b presents the PC values obtained using the Tafel extrapolation method of all specimens. E_{corr} values of -724, -732 -753, and -836 mV$_{Ag/AgCl}$ were obtained for AWT-1, AWT-2, AWT-3, and blasted specimens, respectively. When the i_{corr} value was investigated, the difference in the i_{corr} values of the AWT

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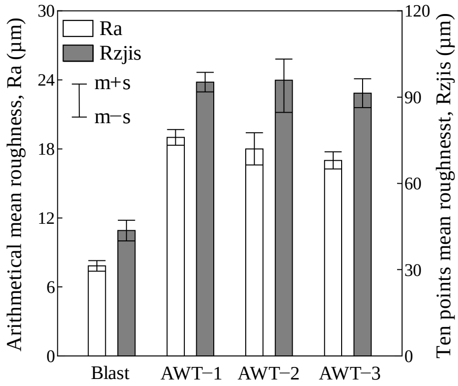


Fig.1 Surface roughness

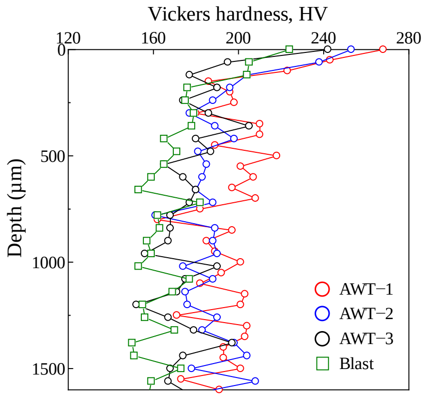


Fig.2 Microhardness values

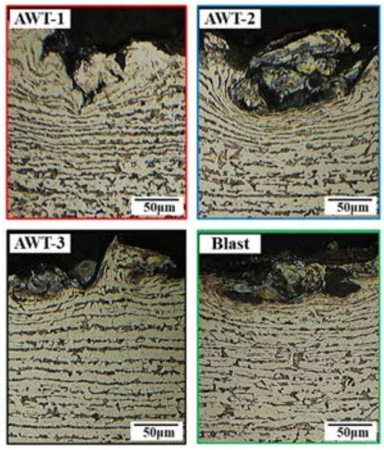
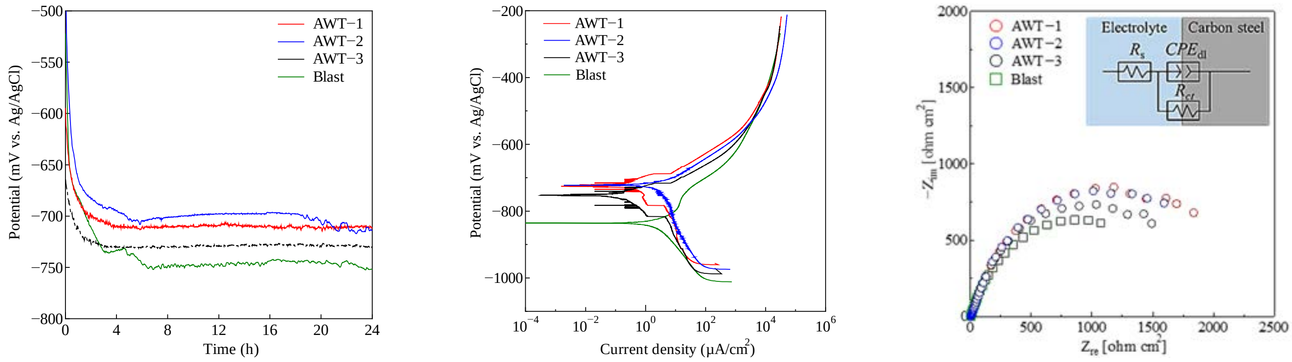


Fig.3 Microstructure images



(a) Open circuit potential (b) Polarization curve (c) EIS test by Nyquist plots

Fig.4 Electrochemical test of AWT and blasted specimens in 3.5 wt% NaCl solution

Table 1 Fitted impedance parameters from EIS of AWT and blasted specimens.

Specimens	R_s (Ω cm²)	n	CPE_{dl} (Ω^{-1} s^n cm^{-2}) ×10^{-3}	R_{ct}(Ω cm²)	*Chi-squared* χ^2 ×10^{-3}
AWT-1	8.08	0.746	1.64	2,910	4.94
AWT-2	6.63	0.731	1.91	2,800	11.0
AWT-3	9.03	0.750	2.30	2,610	8.41
Blast	9.13	0.762	2.87	2,490	5.19

specimens according to SOD was very small. However, it can be found that a large active area was displayed because the blasted specimen had the highest i_{corr} (2.17 μA/cm²) than those of AWT (0.1 to 0.5 μA/cm²). This result shows that the blasted specimen indicates the lowest corrosion resistance. The higher corrosion resistance of AWT specimens mainly is contributed to changes in the properties of steel surface due to the plastic deformation of steel surface layer. The EIS results and electrical equivalent circuit of all specimens are shown in Fig.4c. Therefore, the AWT specimens were higher corrosion resistance than that of the blasted specimen. And in the case of AWT, corrosion resistance tended to increase. This circuit contains solution resistance (R_s), double layer capacitance (CPE_{dl}), and charge transfer resistance (R_{ct}). Table 1 shows that the R_{ct} values of the AWT and blasted specimens. AWT specimens had a larger R_{ct} value than the blasted specimen, and in the case of AWT, the R_{ct} value was increased as the SOD decreased. It was indicated by the larger the R_{ct} value, the greater the corrosion resistance value. In general, as the roughness of the steel surface increases, the corrosion rate increases [2]. However, in Fig.1, the roughness of the AWT treated specimens was more than three times that of the blasted specimen, but as illustrated in Fig.4, the corrosion resistance of the AWT specimens was higher than that of the blasted specimen. In terms of AWT, roughness and corrosion resistance also increased as SOD decreased. It can be indicated that the formation of a deformed surface layer and hardening in the AWT has a desirable influence on corrosion resistance.

4. Summary 1) Surface roughness by the AWT is larger than the abrasive blasting treatment on the condition of this research. In terms of AWT, the roughness increases as the standoff distance (SOD) decreases. 2) The smaller the SOD after AWT, the hardness increases. The steel treated by AWT is characterized by larger hardness, as compared to the blasted steel. It is indicated that the hardness is increased as occurring the maximum plastic deformations. 3) The formation of a deformed surface layer in the AWT has a desirable influence on corrosion resistance.

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