Influence of abrasive grain size on surface properties of steel during Abrasive water-jet treatment

Kyushu University	Student member	○ Sanghong PARK
Kyushu University	Fellow member	Shigenobu KAINUMA
IKEDA KOGYO Co., Ltd.	Regular member	Tatsuya IKEDA
West Nippon Expressway Co., Ltd.	Regular member	Yusuke TOYOTA
Sugino Machine Ltd.	Non-member	Takehiko ARAKAWA

1. Introduction In a previous study, it was demonstrated that the Abrasive water-jet treatment (AWT) with the convergent nozzle had the efficiency of removing corrosion products in severely corroded steel members [1]. However, despite the corrosion removal effect, there are problems such as the narrow treatment range, the remarkable reduction of the steel plate, and the significantly large roughness of the treated surface, which could negatively affect the adhesion of the surface and paint during painting after treatment. Prior to this study, in a preliminary study, a divergent nozzle suitable for surface treatment during AWT was developed to overcome these problems. Through preliminary experiments, it was proved that the use of the divergent nozzle could solve the problem of steel surface characteristics that occur during AWT using the convergent nozzle. However, the effect of particle size of abrasive materials on surface properties when applying this technology has not yet been systematically investigated. Therefore, this study aimed to examine the effect of the particle size of the abrasive materials on the surface properties during AWT. The difference in surface properties was assessed in terms of treatment range, maximum erosion depth, surface roughness, and residual abrasive materials. In addition, the technology was applied to the significantly corroded structures to examine the corrosion removal efficiency.

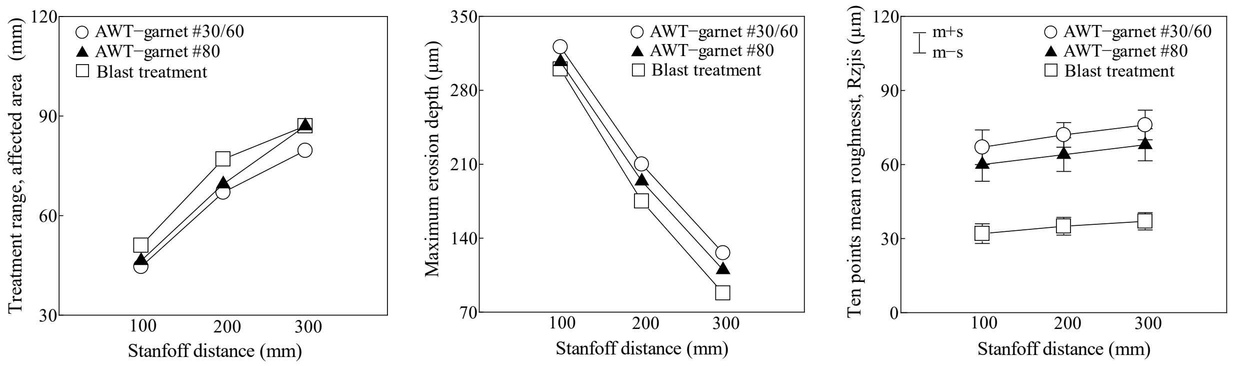
2. Specimen and test method The specimens for evaluating the surface properties were made from carbon steel plates (JIS G3106 SM490A) with dimensions of 70 × 70 × 6 mm. AWT processing was performed using garnet with different particle sizes (mesh size: 30/60 and mesh size: 80), while the abrasive for blasting was garnet #30/60. Mesh sizes and material details of garnet are shown in Table 1. AWT was carried out under the conditions (abrasive supply: 600 g/min, pressure: 230 MPa, traverse speed machining: 1 m/min, water flow: 11.9 L/min, and nozzle diameter: 5 mm). For the AWT, the developed divergent nozzle used in the preliminary experiment was used. For the blasting conditions, the pressure, angle, and time of blast treatment were set at 0.7 MPa, 90°, and 5 seconds to be compared to AWT. Both AWT and blast treatment were treated from a standoff distance of 100 mm to 300 mm. Moreover, the surface profile and roughness of AWT and blasted specimens were measured using a laser scanning microscope. Meanwhile, the surface profile means the treatment range and the maximum erosion depth of the treated steel surface after both surface treatments. To analyze residual abrasive materials and chloride removal efficiency, Al, Si, and O as the principal component of garnet as the abrasive materials, and the corrosion component, Cl at both treated surfaces were examined and analyzed using SEM-EDX. The specimens for surface measurement were IIMURE bridge samples (Materials: SMA400AW, Construction year: 1998) in order to investigate the chloride removal efficiency after all surface treatments. The IIMURE bridge has located 5 km from the coastal area of Kagoshima (Lat. 31°61'71" N, Long. 130°38'59" E). Therefore, it had corrosion forms in which chlorides were attached due to the influence of airborne chlorides. The sample dimension was 120 × 60 × 6 mm. For both AWT and blast treatment, the standoff distance was set at 300 mm, and garnet #80 was used for the abrasive materials. Other treatment conditions are the same as those introduced above.

3. Test result Figure 1(a) shows the treatment range of the treated steel surface after all treatments. The treatment range after AWT tended to be 10-15 % smaller than that of the blast treatment. In the case of AWT, the difference in the treatment range according to the grain size of the abrasive materials was about 5-10 %, which slightly increased as the particle size was smaller. Particularly, under the 300 mm standoff distance condition, garnet #80 had a treatment range about 10 % larger than garnet #30/60. It means that the smaller the particle size, the more similar the treatment range to the blast treatment. This is because in a situation where water and abrasives are mixed, the smaller the particles, which have the smaller the ratio of inertia and drag force compared to larger particles, have sprayed further from the nozzle axis to the outward [2]. In addition, under all treatment conditions, the treatment range tended to increase as the distance increased. The results of the maximum erosion depth are illustrated in Fig.1(b). After AWT, the maximum erosion depth was 1.2 to 1.6 times larger than that of blasting, and for AWT, garnet #30/60 shows that the erosion depth is 5 to 10 % greater than garnet #80. This can be explained by the smaller the particles at the same pressure, the more they are dispersed from the nozzle axis, which can reduce the impact concentration (the number of repeated strikes) on the substrate [2]. In addition, small particles have a small mass, so they have a lower kinetic energy than large particles, resulting in a smaller erosion depth. Under all treatment conditions, the maximum erosion depth tended to decrease as the standoff distance increased. Figure 1(c) exhibits the surface roughness values after all treatments. From the figure,

Table 1 Specification of abrasive materials for AWT processing.

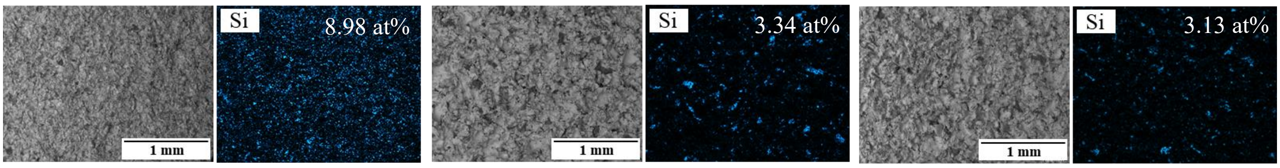
Abrasive materials	Particle diameter (μm) (Sieve analysis)	Bulk density (t/m^3)	Specific gravity	Hardness (Mohs)	Material
Garnet #30/60	150-425 (99.0 %)	2.3	4.1	7.5	Non-metallic
Garnet #80	106-300 (99.8 %)	2.5			

Keywords: Abrasive water-jet treatment, particle sizes, surface properties, corrosion removal efficiency
Contact address: 744 Motooka , Nishi-ku, Fukuoka, 819-0395, Japan, Tel: +81-092-802-3392



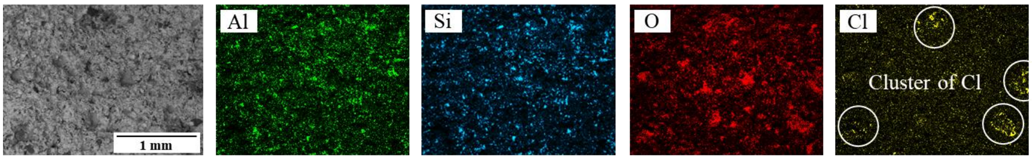
(a) Treatment range (b) Maximum erosion depth (c) Surface roughness

Fig.1 Surface profile of the treated specimens.

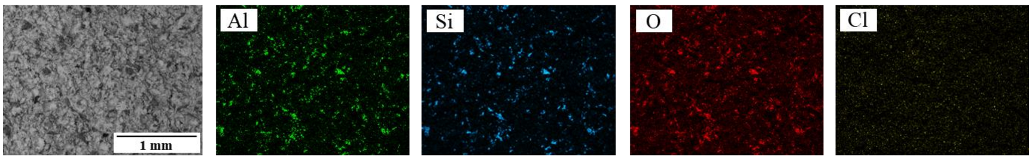


(a) Blast treatment (b) AWT-garnet #30/60 (c) AWT-garnet #80

Fig.2 Residual abrasive materials of the treated specimens.



(a) Blasted specimen



(b) AWT-treated specimen

Fig.3 Distribution of residual chloride on the blasted and AWT-treated surfaces.

it was found that all AWT-treated specimens had 1.5-2 times greater roughness than that of the blasting. Obviously, it means that AWT allowed greater roughness than blast treatment because huge energy reaching the substrate is greater than blasting. Meanwhile, it can be seen that the roughness of garnet #80 during AWT had a roughness value closer to the roughness of the blast treatment than that of garnet #30/60. This is because the larger particles the greater the collision energy in contact with the substrate, and thus cracks or rough surfaces of the substrate are formed. Under all treatment conditions, roughness also tended to increase as the standoff distance increased. As the standoff distance increase, the dispensing of the jet spreads more widely. This reduces the energy density transferred to the target material, thereby reducing the degree to which existing roughness peaks are destroyed and increasing roughness [3]. Figure 2 shows the analysis of residual abrasive materials, corresponding EDX results in the mapping of the elements at the treated steel surfaces. The atomic percentage of Si was used as the amount of residual abrasive materials. The residual amount of the abrasive materials after AWT was three times smaller than that of the blast treatment, and there was no difference in the residual abrasive materials according to the grain size during the AWT. Due to ultra-high pressure water, abrasive materials are not left well on the steel surface because the abrasive materials penetrate below the steel surface. The efficiency of removing corrosion products and chloride after both treatments is shown in Fig.3. The residual Cl on the surface after AWT was significantly eliminated. In particular, it was confirmed that the cluster of Cl, which existed on the surface before processing, was removed, while the cluster of Cl still remained on the steel surface after blast treatment.

4. Summary 1) Under all treatment conditions, AWT had a smaller treatment range and a larger maximum erosion depth and roughness than those of the blast treatment. Also, the amount of residual abrasive materials was significantly smaller than the blasting. 2) The smaller the particles during the AWT, the larger the treatment range of the treated steel surface and the smaller the maximum erosion depth and surface roughness. However, the amount of residual abrasive materials was almost constant regardless of particle size. 3) The removal efficiency of chloride and corrosion products indicated that AWT has better efficiency than blasting.

References 1) S. Park, S. Kainuma, T. Ikeda, T. Asano and Y. Morita: Characterizing Steel Surface Features Affected by Abrasive Waterjet Treatment, Journal of Constructional Steel, Vol. 29, p.585-592, 2021. 2) V.B. Nguyen, Q.B. Nguyen, Y.W. Zhang, C.Y.H. Lim, B.C. Khoo, Effect of particle size on erosion characteristics, Wear, Vol. 348-349, p.126-137, 2016. 3) L, Fenggang. Experimental and numerical investigation of abrasive waterjet polishing technology. New Jersey Institute of Technology, 1996.