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Effects of Blasting Parameters on Removability of Residual Grit

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This article shows the quantitative evaluation of the residual grit on a blasted substrate, and the removability of the residual grit is examined. Carbon steel plates were blasted by white alumina grit with mean diameters of 338 to 1106 μm. The velocity and the number of grit particles were measured during blasting. The residual grit was removed from a substrate surface by the dissolution of the blasted substrate surface. A mixed acid solution was used as the dissolution solution. The residual grit weight was 7 to 17 g/m^2. The amount of the residual grit and the penetration depth of the embedded grit increased with increasing grit size. The penetration depth was 5 to 9% of the mean diameter of the grit. The residual grit weight and the penetration depth increased with the increase of the momentum of the grit particle.

Keywords blasting, grit embedment, grit removal, grit size, penetration depth, residual grit

1. Introduction

To promote the adhesion between a sprayed coating and a substrate, a blasting process is a highly important pretreatment, because adhesion increases with, for example, the anchor effect and the formation of a diffusion layer. After the blasting process, the substrate surface is roughened and cleaned. However, some researches have shown that residual blasting material existed on the blasted substrate (Ref 1-5). Wigren (Ref 1) evaluated the amount of residual grit by x-ray spectrometry with a calibration curve. Mellali et al. (Ref 2) evaluated the amount of the residual grit by image analysis of the contamination of the blasted surface. Amada et al. (Ref 3) measured the area fraction of the constitutional element of the residual grit on the blasted surface by scanning electron microscopy (SEM) with wavelength dispersive x-ray spectroscopy (WDX). Momber and colleagues (Ref 4, 5) also measured the area fraction of the residual grit by SEM in backscattered mode. Though there has been some research evaluating the residual grit by surface analysis of the blasted substrate, there have been few studies on the residual grit weight and the penetration depth of the embedded grit.

In the abrasive water-jetting process, there have been many reports about residual grit (Ref 6, 7). Hashish (Ref 6) showed that the embedded grit was partially or totally covered by overlying metal. Such grit was difficult to remove, though deposited particles can easily be removed by cleaning (Ref 6). Fowler et al. (Ref 7) wrote a review of this area and showed that the embedded grit was totally covered over by metal being deformed over the grit by subsequent impacts and that the embedded grit size was substantially smaller than the average original grit size. Fowler et al (Ref 7) also assumed that the grit embedment was controlled by both grit particle number and grit momentum.

In this study, the residual grit was removed by the dissolution of the blasted substrate surface, and the residual grit weight and the substrate thickness at the finish time of residual grit removal were evaluated. The velocity and the number of the grit particles were measured during blasting. The effects of blasting particle size on the residual grit weight and the penetration depth of the embedded grit were investigated.

2. Experimental Procedure

2.1 Specimen and Blasting Equipment

A cold-rolled carbon steel (JIS; S45C) plate with dimensions of 25 × 25 × 6 mm was used as a substrate. The substrate was roughened by grit blasting. The blasting material was white alumina grit. The mean diameters of the grits were 338 μm (46 mesh), 555 μm (30 mesh), and 1106 μm (16 mesh). The blasting equipment was a suction-head abrasive blasting device. The inner diameter of the nozzle was 6 mm. The pressure of air, as the grit carrier gas, was fixed at 0.4 MPa. The blasting angle, which was the angle between the blasting direction and the substrate surface, was 90°. The blasting time and the blasting distance were fixed at 25 s and 150 mm, respectively. The velocities of the grit particles were measured by high-speed camera observation. The number of particles being fed per second was also measured by the collection of all grit from the blasting nozzle.

2.2 Quantitative Evaluation of Residual Grit

The residual grit weight and the penetration depth of the embedded grit were quantitatively evaluated by the following method. Figure 1 shows a diagram of the device used for residual grit removal by the dissolution of the blasted substrate surface. The equipment consists of an ultrasonic cleaning machine, a glass beaker with a mixed acid solution, a rubber tube, and a wire for hanging a substrate. The medium used for ultrasonic vibra-

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tion was water. A 20% hydrochloric acid and a 20% nitric acid water solution were used as the mixed acid solution. By attaching the rubber tube to the side of the roughened substrate, only the substrate surface was dissolved. The residual grit weight was evaluated by the measurement of the removed grit from the blasted substrate. The residual grit was removed by dissolving the substrate surface in the mixed acid with ultrasonic vibration. During dissolving of the substrate surface, the mixed acid solution was changed every 2 min. The amount of each solution was 50 mL. The removed grit was filtered during every change of the solution. A crucible-type glass filter was used. The filter opening was 20 to 30 μm. Whenever the solution was changed, the removed grit was weighed and the substrate thickness was measured. The penetration depth of the embedded grit was determined from the substrate thickness at the time that all residual grit was removed. Additionally, the penetration depths thus obtained were compared with those evaluated in cross-sectional images of the blasted substrate observed with an optical microscope.

3. Results and Discussions

3.1 Appearance of Blasted Substrate Surface

Figure 2 shows the appearance of the residual grit on the blasted substrate. The roughened substrate was photographed horizontally at the substrate surface using a stereoscopic microscope. As shown in Fig. 2, the residual grit was embedded in the substrate surface. The size of the embedded grit seems to be smaller than the mean diameter of the grit. Blasted grit might be broken by impact on the substrate. The penetration depth of the embedded grit could not be known by these images.

Figure 3 shows a cross-sectional optical micrograph of the blasted substrate. The penetration depths of the embedded grit are 10 to 50 μm and 40 to 50 μm, respectively, for mean grit diameters of 555 and 1106 μm. Some grit is covered with the substrate. The embedded grit size is much smaller than the original grit size. Similar results have been reported in Ref 6 and 7.

3.2 Inspection of Removal Method With Mixed Acid Solution

Figure 4 shows the change in substrate thickness with dissolution time. The substrate was a carbon steel without blasting. Solid plots represent the time of the change of the mixed acid solution. The substrate thickness decreases with increasing dissolution time. There is a linear relationship between the substrate thickness and dissolution time. Thus, the dissolution capability of the mixed acid solution was a constant every 2 min. To inspect the dissolution of the carbon steel substrate surface, the dissolution solution was filtered. Figure 5 shows the relationship between the dissolution time and the cumulative weight of the filtered particles. Solid and open plots represent the results for the blasted and the nonblasted substrates, respectively. Even in the case without blasting, the weight increased with increasing dissolution time. This result indicates that the dissolution of the carbon steel substrate cannot be neglected. In other words, the filtered particles include the residual grit as well as the constituents of the substrate. Using this dissolution method, precipitation can hardly be avoided. Thus, it is concluded that the residual grit weight minus the precipitate should be evaluated properly by using the result without blasting. In the case with blasting, the cumulative weight of the filtered particles also increases with increasing dissolution time. The slopes of the cumulative weight decrease over certain periods of dissolution time, as shown in the "Finish time of residual grit removal" in Fig. 5. The slopes over those periods of time are equal to those for the nonblasted substrate. Thus, the cumulative weight for the nonblasted substrate subtracted from that for the blasted substrate is the cumulative weight of the removed grit of the blasted substrate.

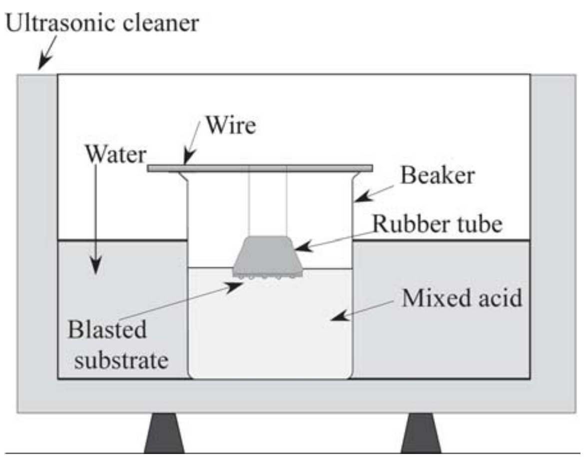

Fig. 1 Diagram of the equipment used for the removal of residual grit by the dissolution of the blasted substrate surface

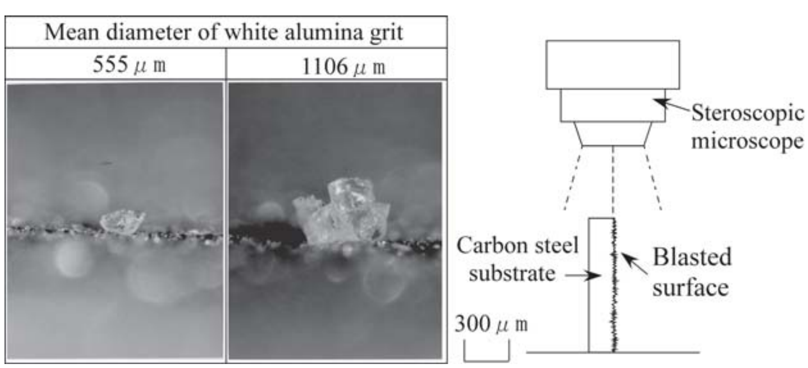

Fig. 2 Appearance of the residual grit on the blasted substrate using a stereoscopic microscope

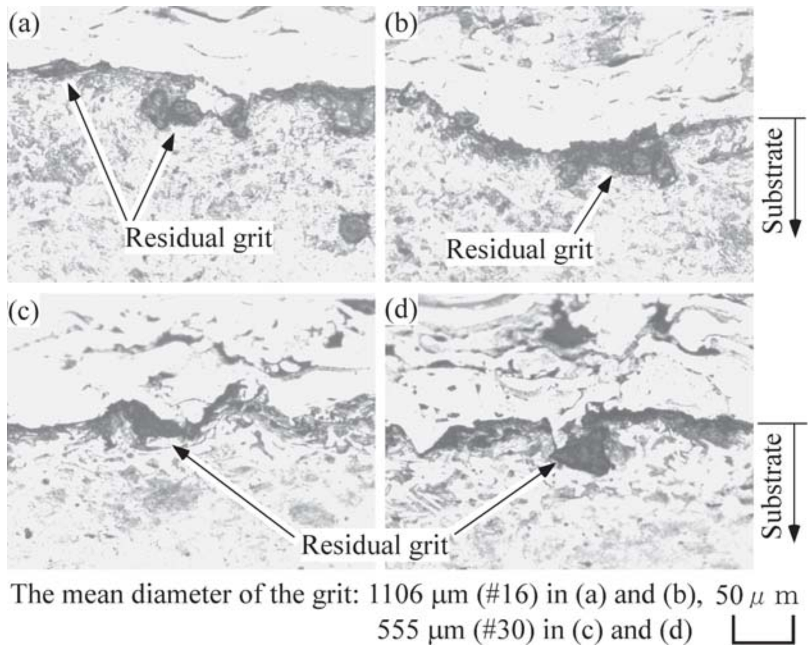

Fig. 3 Cross-sectional optical micrograph of the blasted substrate. (a) and (b) mean diameter of the grit is 1106 μm; (c) and (d) mean diameter of grit is 555 μm

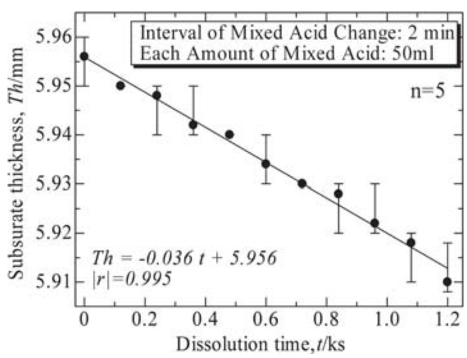

Fig. 4 Change in substrate thickness with dissolution time. The substrate was a carbon steel plate without blasting. Solid plots represent the time of mixed acid change.

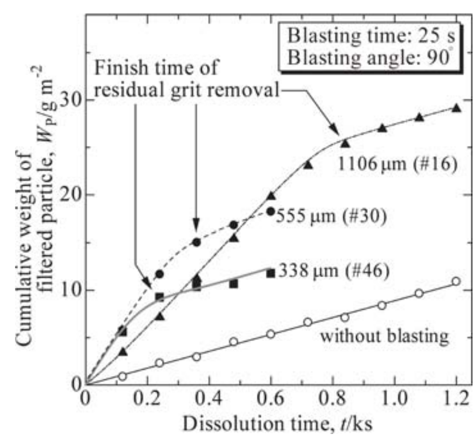

Fig. 5 Relationship between dissolution time and the cumulative weight of the filtered particles. The mean diameters of the grits are 338, 555, and 1106 μm. Blasting time and blasting angle are 25 s and 90°, respectively. The filtered particles include the residual grit as well as the constituents of the substrate.

3.3 Evaluation of Residual Grit Weight

Figure 6 shows the effect of the mean diameter of the grit on the weight of the residual grit. The weight increases with increases in the mean diameter of the grit. Mellali et al. (Ref 2) showed that the area fraction of the residual grit on the blasted grit increased with increasing grit size. The results in Fig. 6 show the same result. The amount of the residual grit was 7 to 17 g/m^2.

For an understanding of grit embedment, it is necessary to know the grit particle velocity, the blasted particle number, the impact time, the elastic energy of the grit and the substrate, the yield stress of the substrate, and the plastic deformation energy of the grit and the substrate. However, the elastic and plastic deformation of the substrate are complex during the impact. The measurement of impact time is so difficult. It is useful to measure the velocity and the blasted particle number to understand this result. Fowler et al. (Ref 7) suggested that grit embedment is controlled by both the grit particle momentum and the fed number of the grit particle. Figure 7 shows the effect of the mean diameter of the grit on the velocity and the momentum of the grit. With increasing grit size, the change in velocity was almost negligible. The momentum was calculated by the following assumption, and is shown in the lower part of Fig. 7. It was assumed that the shape of the grit particle was spherical, and the mass was calculated from the mean diameter of the grit and the white alumina density of 3.9×10^3 kg/m^3. The momentum increases with increasing grit size. The grit mass is proportional to the cube of the grit diameter. Thus, the larger grit embeds more due to an increment of the grit mass. Figure 8 shows the effect of

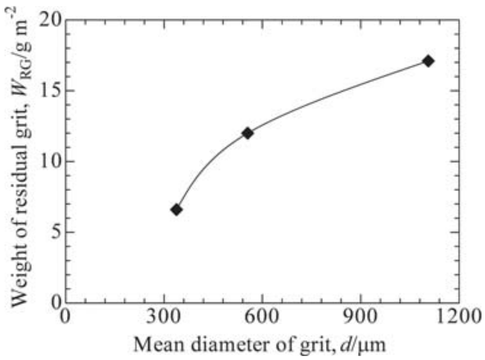

Fig. 6 Effect of the mean diameter of the grit on the weight of the residual grit

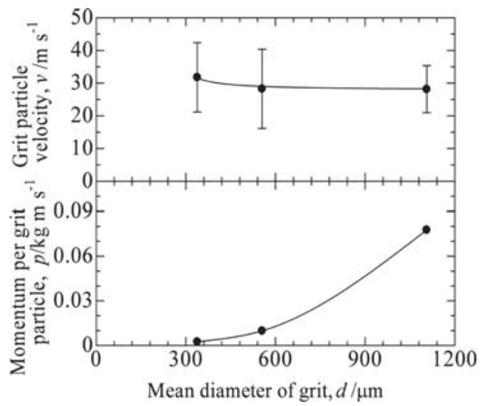

Fig. 7 Effect of the mean diameter of the grit on the velocity and the momentum of the grit particle

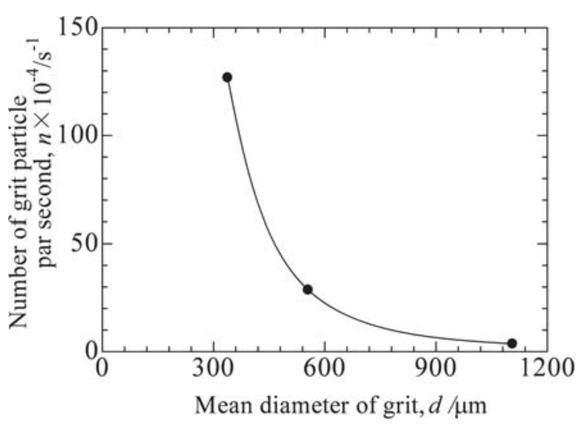

Fig. 8 Effect of the mean diameter of the grit on the number of particles blasted per second

the mean diameter of the grit on the number of blasted particles per second. The number of blasted particles decreases with increasing grit size. In contrast, the residual grit weight increases with increasing grit size, as shown in Fig. 6. This suggests that there might be a number of small particles the momentum of which may be too low to induce plastic deformation of the substrate, and thus fail to be embedded. The momentum of small particles might not be enough to overcome the substrate yield stress in this work condition.

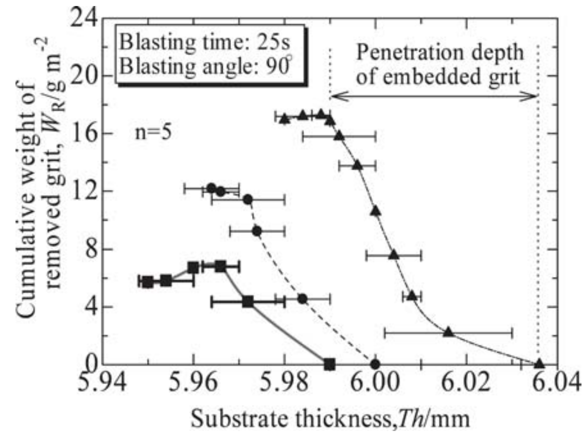

Fig. 9 Relationship between substrate thickness and the cumulative weight of the removed grit

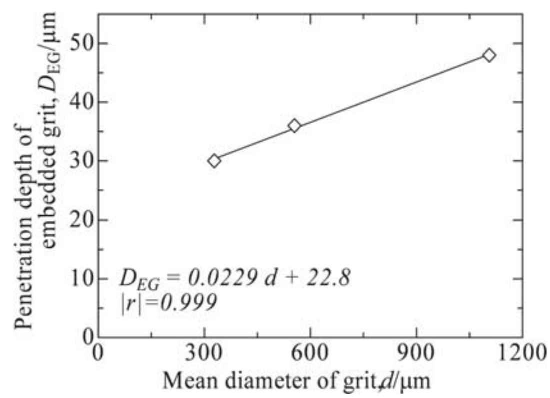

Fig. 10 Relationship between the mean diameter of the grit and the penetration depth of the embedded grit

3.4 Evaluation of Penetration Depth of Embedded Grit

As shown in Fig. 5, the finish time of the residual grit removal increases with the increasing mean diameter of the grit. The increase in dissolution time represents the decrease of substrate thickness. Thus, it is necessary to know the correspondence between dissolution time and substrate thickness. Fig. 9 shows the relationship between substrate thickness and the cumulative weight of the removed grit. The blasted substrate thickness, the plots of the cumulative weight of which is on the *x*-axis, increases with increasing grit size. The reason for the increase is that surface roughness increases with increasing grit size. The smaller the cumulative weight, the larger the change in the substrate thickness. Thus, it is considered that there are easily removable grits, of which the penetration depth is shallow and the projection height is large. The penetration depth of the embedded grit was evaluated by the thickness difference between before and after the removal of the grit, as shown in "Penetration depth of embedded grit" in Fig. 9.

Figure 10 shows the relationship between the mean diameter of the grit and the penetration depth of the embedded grit. The penetration depth increases with the increasing mean diameter of the grit. As shown in Fig. 7, the momentum of the grit particle increases with increasing grit size because the grit particle velocity is almost negligible. Fowler et al. (Ref 7) assumed that particle size did not affect particle shape, and the depth of indentation would depend on the impulse of the particle momentum. In suction-head abrasive blasting, the most effective parameter is the grit size, because the grit particle velocity is almost the same. The velocity, of course, may be changed by the change in the suction pressure.

As shown in Fig. 3, the penetration depths are 10 to 20% larger than those shown in Fig. 10. It is assumed that the embedded grit is removed before the substrate surface level reaches the level of the penetration depth. Using this method (the dissolution of the blasted substrate), an ultrasonic vibration should be avoided. In an assumption based on the result of Fig. 3 and 10, the penetration depth is 5 to 9% of the mean diameter of the grit.

4. Conclusions

The residual grit weight in a blasted substrate and the penetration depth of the residual grit were quantitatively evaluated. The grit embedment phenomena was discussed from the point of view of the momentum and the number of the grit particles. Carbon steel plates and white alumina grit with mean diameters of 338, 555, and 1106 µm were used as a substrate and a blasting material, respectively. The residual grit was removed from the blasted substrate by the dissolution of the substrate surface with an ultrasonic vibration. A mixed acid-water solution was used as the dissolution solution. The following results for the evaluations and conclusions were obtained:

- The residual grit weight was 7 to 17 g/m^2. The weight increases with increasing grit size.
- The penetration depth of the embedded grit increased with increasing grit size.
- The penetration depth was smaller than the mean diameter of the grit. The depth was 5 to 9% of the diameter.
- The momentum of the grit particle increased with grit mass (i.e., grit particle size), because the change in the velocity of the grit particle was negligible with the change in particle size. These are the reasons for the effect of the grit size on the residual grit weight and the penetration depth of the embedded grit.

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