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# Erosion Testing and Surface Preparation Using Abrasive Water-Jetting

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**Erosion testing and surface preparation are studied using a 3-axis Computer Numerical Control (CNC) abrasive water jetting (AWJ) apparatus. The effects of erosion time $t$, impingement angle $\alpha$ and pressure $p$ on the erosion rate $E$, average surface roughness $R_a$, and surface hardness Rockwell C Hardness (HRC) were investigated in detail. Compared with conventional grit blasting, AWJ can reduce grit embedment in the target material due to the action of the high-pressure water. AWJ also has the advantage of generating a higher average surface roughness $R_a$ over water jetting (WJ) due to the action of abrasive particles. In addition, AWJ increases the surface hardness HRC of the substrate material. The obtained higher degree of average surface roughness is helpful for improving the bonding strength between the coating and the substrate material. The erosion testing and the surface preparation are numerically controlled by a 3-axis CNC system; therefore precise and detailed results for various operating parameters can be obtained.**

**Keywords** abrasive water-jetting, average surface roughness, erosion, surface hardness

## 1. Introduction

Metals and alloys are often used in outdoor or harsh environments, in which the synergy of water and sand may result in eventual erosion of the materials. In the selections of materials to be used in above environments, one needs to consider their erosion resistance. Thus, how to test the erosion resistance of materials is important.

Surface preparation is essential prior to coating due to its capability to promote mechanical bonding between the coating and substrate. A rough surface is normally preferred if mechanical bonding is concerned.[1]

Grit blasting is a common method of erosion testing and surface preparation.[2,3] However, there exist some disadvantages that are related to the grit blasting process[1]: (a) grit embedding; (b) residual grit in the microscopic range; (c) dust formation during performance; (d) problems with grit handling and disposal. The error in erosion testing is inevitably introduced due to grit embedding and residual grit. In surface preparation operations, these disadvantages affect the surface quality; and ultimately the bonding strength between the coating and the substrate.

Previously, water jetting was used in surface preparation studies, and surface quality features of water-jetted materials, such as average roughness, hardness, and wetting ability, were investigated.[1,2] However, abrasive water-jetting (AWJ) can improve pertinent surface characteristics, leading to a higher degree of surface roughness due to the action of abrasive particles.[4]

In this paper, the erosion testing and the surface preparation of AISI 1018 were investigated using a 3-axis Computer Numerical Control (CNC) abrasive water-jetting (AWJ) apparatus. In abrasive water jetting,[4,5,6] the erosion of material is done primarily through the action of the abrasive particles, which are accelerated in a thin jet of high velocity water and directed through an AWJ nozzle. Compared with conventional grit blasting, AWJ reduces grit embedding and the formation of residual grit, and results in good surface quality due to the action of high-energy water,[4] therefore reducing measurement errors typically observed in gas jet erosion testing. AWJ also leads to a higher degree of surface roughness over water jetting operations.

In this research, AWJ is numerically controlled by a 3-axis CNC system. Different parameters of AWJ, such as erosion time $t$, impingement angle $\alpha$, and water pressure $p$, were changed. The effect of changing these parameters on erosion rate $E$, average surface roughness $R_a$, and surface hardness Rockwell C Hardness (HRC) was then studied in detail.

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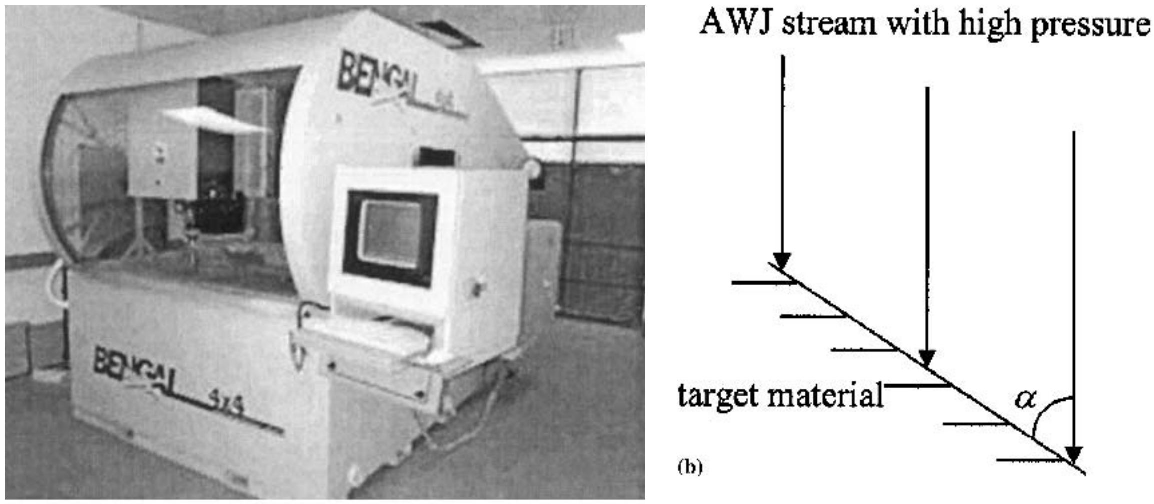
## 2. Experimental

### 2.1 Equipment Setup and Parameters

The 3-axis CNC abrasive water-jet machine and the schematic of AWJ are shown in Fig.1(a) and 1(b), respectively. The abrasive water-jet machine includes the following basic components: high-pressure pump, abrasive water-jetting head, abrasive delivery system, abrasive material and water catcher, and $x$-$y$-$z$ positioning table controlled by the CNC controller. The abrasive water-jetting head consists of an orifice, abrasive water-jetting nozzle, and mixing chamber. The experimental parameters of AWJ in the paper are: erosion time $t$, impingement angle $\alpha$ , water pressure $p$, feed orifice diameter $D$, standoff distance $H$ between the nozzle and the target material, and abrasive particle size (grit).

### 2.2 Erosion Testing and Surface Preparation

Several methods are used to evaluate the erosion resistance of materials: (a) weigh specimens before and after erosion and



(a)

**Fig. 1** **(a)** 3-axis CNC abrasive water-jet machine; **(b)** schematic of AWJ

calculate their mass loss; (b) test the Vickers hardness, before or after erosion; (c) test the flow stress and regard it as an indicator of ductile erosion resistance; (d) test the melting points of materials; and (e) test the elastic modulus of a material.

The erosion rate $E$ is used in this case to calculate the erosion of materials. Let the sizes of all the specimens be the same and the areas subjected to erosion also be equal. Thus, we can define the erosion rate $E$ with the following formula:

$$E = \frac{\Delta V}{V \cdot t} \qquad \text{(Eq 1)}$$

which can be expressed by

$$E = \frac{\Delta W}{W \cdot t} \qquad \text{(Eq 2)}$$

In these equations $\Delta V$ is the volume loss of a specimen; $V$ is the original volume of the specimen; $t$ is the time of erosion process. $\Delta W$ is the mass loss; $W$ is the original sample mass. In Eq 1 and 2, the relative mass loss $\Delta W/W$ is equal to the relative volume loss $\Delta V/V$. Weigh the specimens before and after erosion by abrasive water jetting, and then calculate the relative mass loss (relative volume loss) and the erosion rate. In this research, the main focus is on determining the erosion rates at various impingement angles and various water pressures, respectively.

Surface quality features of materials after surface preparation include average surface roughness $R_a$, surface hardness, wettability, etc. In this paper, we mainly focus on studying the effects of erosion time $t$, impingement angle $\alpha$, and water pressure $p$ on erosion rate $E$, average surface roughness $R_a$, and surface hardness HRC.

AISI 1018 is cut into specimens with dimensions 25.4 × 25.4 × 6.35 mm. For each specimen, the area subjected to AWJ is 25.4 × 25.4 mm. The original weight $W$ of each specimen is 31.5g. The abrasive particle is garnet with the size (diameter) equivalent to 120 grit. All AWJ parameters are given in Table 1.

## 3. Results and Discussion

### 3.1 Relative Volume Loss $\Delta V/V$ and Erosion Rate $E$

The relationship between the relative volume loss $\Delta V/V$ and erosion time $t$ at an impingement angle of $\alpha = 60°$ and a pressure $p = 50$ ksi (345 MPa) is illustrated in Fig. 2. The relationship can be approximately described using a linear function if the line is extended to the origin ($t = 0$). Hence, the erosion rate $E$ does not change with the erosion time $t$, keeping constant with erosion test time. The result also demonstrates that the definition of erosion rate $E$ in Eq 1 and 2 is reasonable.

Figure 3 illustrates the effect of impingement angle $\alpha$ on erosion rate $E$ at the erosion time $t = 20$ s and a water pressure $p = 50$ ksi (345 MPa). The maximum erosion rate occurs when the impingement angle $\alpha$ is 60°.

The effect of pressure $p$ on erosion rate $E$ (erosion time $t = 20$ s and impingement angle $\alpha = 60°$) is shown in Fig. 4. In this case, the higher the water jet pressure is the greater the erosion rate. Between 45 ksi (310 MPa) and 50 ksi (345 MPa), the erosion rate $E$ goes up greatly as the pressure $p$ increases.

### 3.2 Surface Roughness

The original average surface roughness $R_a$ before surface preparation is 2.67 μm. The average surface roughness $R_a$ after AWJ for various erosion times $t$ [$\alpha = 60°$, $p = 50$ ksi, (345 MPa)] is shown in Fig. 5. It can be seen that $R_a$ increases with time and is at a maximum when $t$ is 20 s. $R_a$ then decreases gradually, but it is still much greater than the original average surface roughness.

Figure 6 shows $R_a$ ($t = 20$ s, $p = 50$ ksi) is at its maximum value when the impingement angle $\alpha$ is at 60°. $R_a$ ($t = 20$ s, $\alpha = 60°$) increases with increasing pressure $p$ (see Fig. 7).

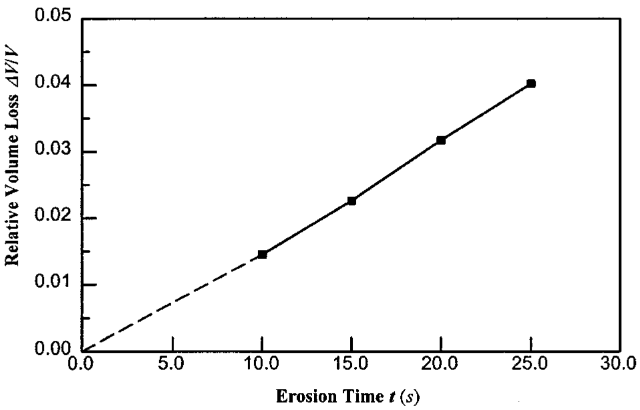



**Fig. 2** Relative volume loss $\Delta V/V$ versus erosion time $t$ ($\alpha = 60°$, $p = 50$ ksi)

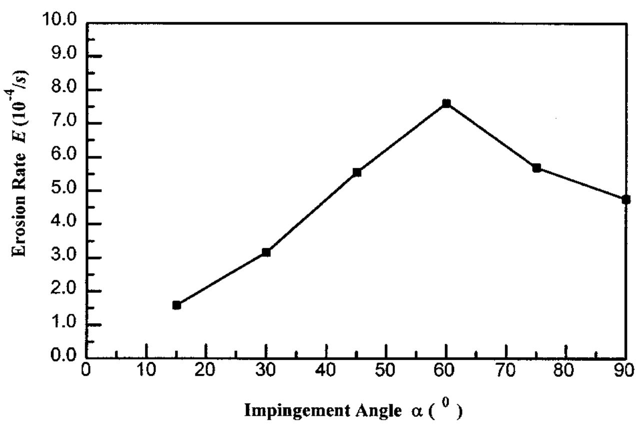



**Fig. 3** Effect of impingement angle $\alpha$ on erosion rate $E$ ($t = 20$ $s$, $p = 50$ ksi)

**Table 1 Experimental Parameters**

| AWJ Parameter | Values |
|---|---|
| Feed orifice diameter $D$ (mm) | 6.248 |
| Standoff distance $H$ (mm) | 811.28 |
| Erosion time $t$ ($s$) | 10, 15, 20, 25 |
| Impingement angle $\alpha$ (degree) | 15, 30, 45, 60, 75, 90 |
| Water pressure $p$ (ksi) | 30, 35, 40, 45, 50 |
| (MPa) | 207, 241, 276, 310, 345 |

### 3.3 Surface Hardness HRC

Surface hardness before erosion was HRC 21.8. Figure 8 shows that the HRC value [$\alpha = 60°$, $p = 50$ ksi (345 MPa)] increases as $t$ increases. The HRC ($t = 20$ s, $p = 50$ ksi) is a maximum when the impingement angle $\alpha$ is 45° (shown in Fig. 9). The higher the pressure, the greater the HRC value (shown in Fig.10, $t = 20$ s, $\alpha = 60°$).

## 4. Conclusions

AWJ can be used to both conduct erosion tests and roughen the surfaces of materials. Erosion time $t$, impingement angle $\alpha$,

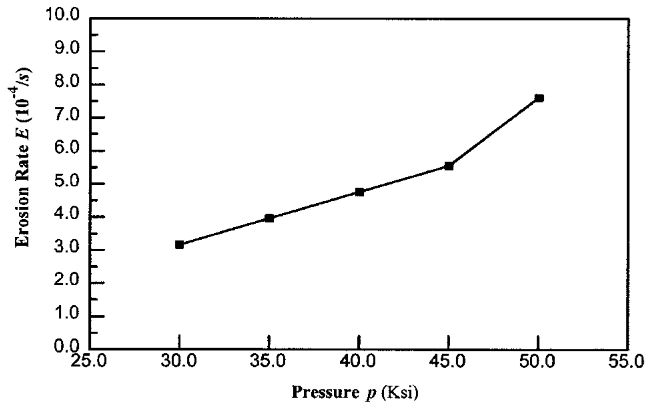



**Fig. 4** Effect of pressure $p$ on erosion rate $E$ ($t = 20$ s, $\alpha = 60°$)

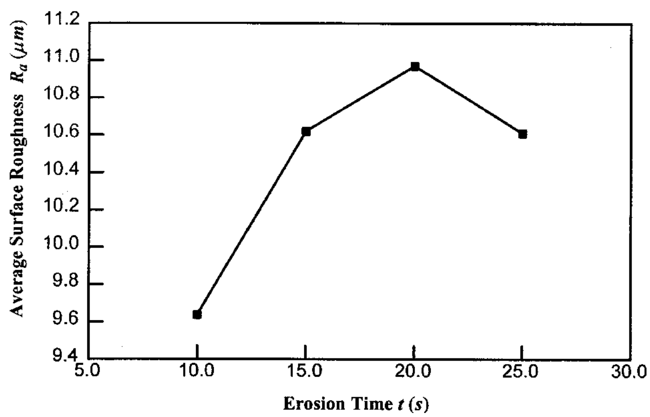



**Fig. 5** Average surface roughness $R_a$ versus erosion time $t$ ($\alpha = 60°$, $p = 50$ ksi)

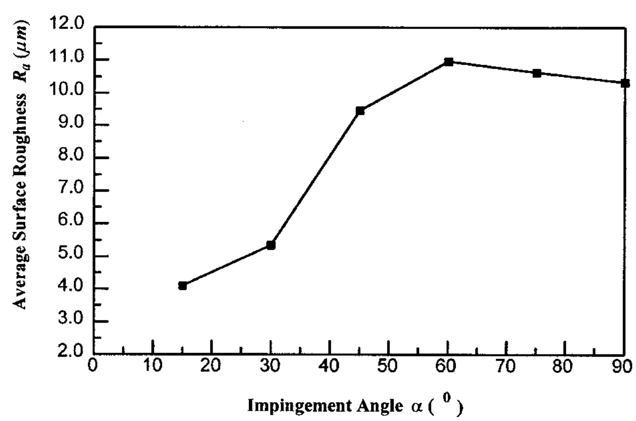



**Fig. 6** Average surface roughness $R_a$ versus impingement angle $\alpha$ ($t = 20$ s, $p = 50$ ksi)

and pressure $p$ have the following effects on the erosion rate $E$ and surface features (average surface roughness $R_a$ and surface hardness HRC) of tested material AISI 1018:

(1) The relationship between the relative volume loss $\Delta V/V$ and erosion time $t$ [impingement angle $\alpha = 60°$, pressure

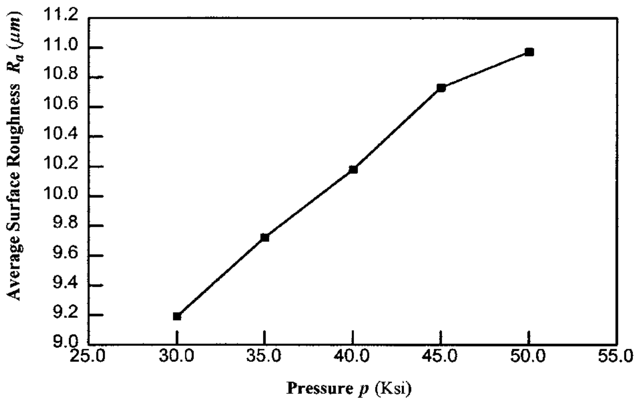



**Fig. 7** Average surface roughness $R_a$ versus pressure $p$ ($t = 20$ s, $\alpha = 60°$)

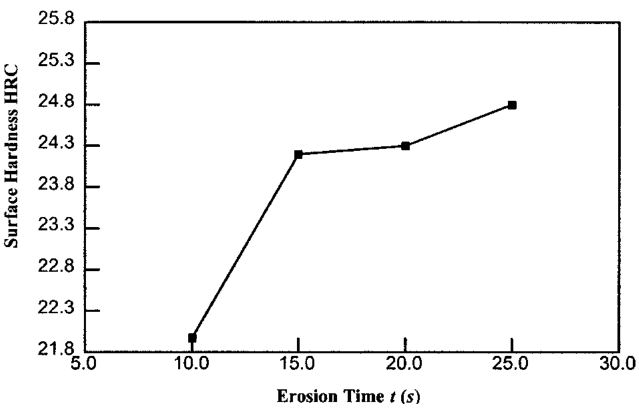



**Fig. 8** Surface hardness HRC versus erosion time $t$ ($\alpha = 60°$, $p = 50$ ksi)

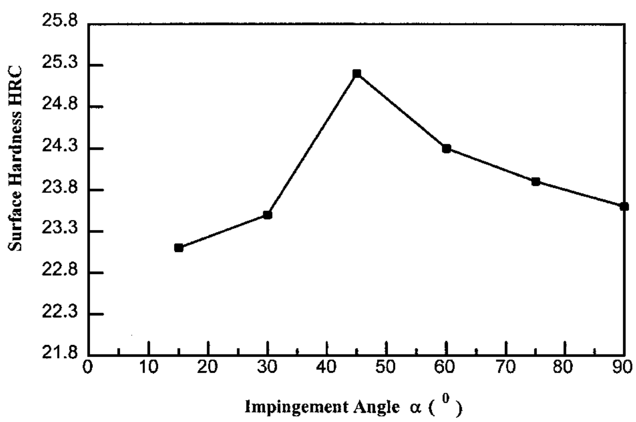



**Fig. 9** Surface hardness HRC versus impingement angle $\alpha$ ($t = 20$ s, $p = 50$ ksi)

$p = 50$ ksi (345 MPa)] is approximately a linear relationship. The erosion rate $E$ is approximately a constant at various times.

(2) The maximum of the erosion rate $E$ occurs at the impingement angle $\alpha = 60°$ [$t = 20$ $s$, $p = 50$ ksi (345 MPa)].
(3) The higher the pressure, the greater the erosion rate.
(4) The average surface roughness $R_a$ increases with increasing test time $t$ and is a maximum when $t$ equals 20 s. $R_a$ then decreases gradually, but it is still much greater than the original average surface roughness ($\alpha = 60°$, $p = 50$ ksi).

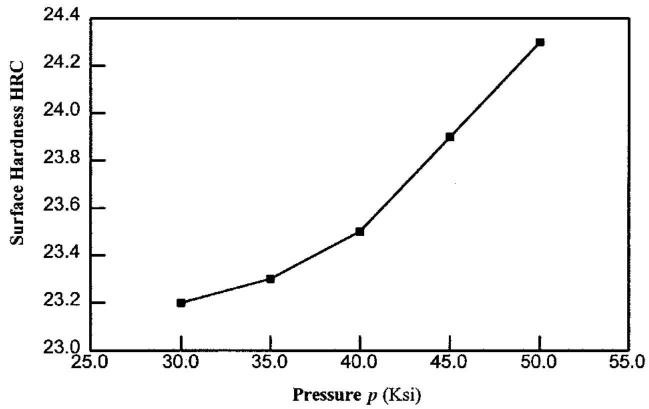



**Fig. 10** Surface hardness HRC versus pressure $p$ ($t = 20$ s, $\alpha = 60°$)

(5) $R_a$ is at its the maximum value when the impingement angle $\alpha$ is 60° ($t = 20$ s, $p = 50$ ksi).
(6) $R_a$ increases with the increase in AWJ pressure $p$.
(7) The HRC value increases when $t$ increases.
(8) The HRC ($t = 20$ s, $p = 50$ ksi) is at its maximum value when the impingement angle $\alpha$ is 45°.
(9) The higher the pressure, the greater the HRC value.

Compared with conventional grit blasting, AWJ can reduce grit embedment in the target material due to the action of high-pressure water, therefore improving the precision of erosion testing. AWJ generates a higher degree of average surface roughness $R_a$ over water jetting (WJ) due to the action of abrasive particles. A major difference is the increase in surface hardness HRC for materials subjected to AWJ. The higher degree of average surface roughness is helpful for improving the bonding strength between a coating and the substrate material.

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## References

1. A.W. Momber, Y.C. Wong, E. Budidharma, and R. Tjo: "Surface Profiling of Low-Carbon Steel With Supersonic Waterjets," *Wear,* 2001, *249,* pp. 853-59.
2. J.K. Knapp and T.A. Taylor: "Waterjet Roughened Surface Analysis and Bound Strength," *Surf. Coat. Technol.* 1996, *86-87,* pp. 22-27.
3. C.K. Fang and T.H. Chuang: "Erosion of SS41 Steel by Sand Blasting," *Metall. Mater. Trans. A,* 1999, *30A,* pp. 941-48.
4. R. Kovacevic, M. Hashish, R. Mohan, M. Ramulu, T. J. Kim, and E.S. Geskin: "State of the Art of Research and Development in Abrasive Water-jetting Machining," *Trans. ASME, J. Manuf. Sci. Eng.,* 1997, *119,* pp. 776-85.
5. J. Zeng and T.J. Kim: "An Erosion Model for Abrasive Waterjet Milling of Polycrystalline Ceramics," *Wear,* 1996, *199,* pp. 275-82.
6. Eric Ness, Ron Zibbell: "Abrasion and Erosion of Hard Materials Related to Wear in the Abrasive Waterjet," *Wear,* 1996, *196,* pp. 120-25.