**2007 American WJTA Conference and Expo**
**August 19-21, 2007 • Houston, Texas**
Paper

# PARAMETERS AFFECTING SURFACE PREPARATION

D. Wright, J. Wolgamott, G. Zink
StoneAge, Inc.
Durango, Colorado, U.S.A.

## ABSTRACT

Waterjet surface preparation is typically performed using pressures from 20,000 to 40,000 psi, with rotating nozzle heads varying in diameter from 2 inches to 16 inches. Materials being removed include coatings, oxidation, or scales. The purpose of this research was to determine the effects of variables such as standoff distance, traverse speed, surface speed, rotation speed, and the head design.

**Organized and Sponsored by the WaterJet Technology Association**

## 1. INTRODUCTION

A wide variety of equipment is available for waterjet surface preparation. Most equipment now includes rotating nozzle heads, with handheld rotating guns being the most basic, to self-propelled machines cleaning much wider paths at controlled feed rates. This research was conducted to determine the relative effects of standoff distance, rotation speed, feed rate, and nozzle head design on jet performance and cleaning efficiency in surface preparation. Previous research focused on massive material removal at lower pressures and higher flow rates (Wright et al 1997) but questions have risen whether these results apply at higher pressures and to thin coating removal.

## 2. TESTING

Tests were performed using an air powered rotating assembly that allowed the use of various heads. This assembly was attached to a traversing mechanism with adjustable feed rates; the test arrangement is shown in Figure 1. Test samples were placed underneath at an angle to vary the standoff distance from 9 to 90 mm (.37 to 3.5 inches). Commercial grade coated steel siding trim sections were used as test samples (Figure 2). Effectiveness was rated by visually estimating the percentage removal of the top coating and the primer.

All tests were conducted at 240 MPa (35,000 psi), with flow rates of 11 to 22 lpm (3 to 6 gpm). Jet path diameters of 91, 213, 305, and 366 mm (3.6, 8.4, 12, and 14.4 inches) were used, with rotation speeds from 500 to 3200 rpm. In addition to the different path diameters, two general head types were compared: a one piece bar type (Figure 3) and a multiple piece with individual bent jet arms (Figure 4). The bar heads had each jet port spaced 9.4 mm (.37 inches) apart; the diameters given above are the largest of the jet paths. The majority of the tests were conducted using four .51 mm (.020 inch) or four .38 mm (.015 inch) diameter sapphire orifices. Jet angles exiting the bar head and the quantity of jets were also compared.

## 3. RESULTS

### 3.1 Standoff Distance

The majority of the tests were conducted with the test sample placed at an angle to produce a varying standoff distance. The predominant effect was the ineffectiveness of removing the coating when the standoff distance was too small; every test showed this to some degree. This region of ineffectiveness is attributed to the jet still being coherent, and not having yet broken into droplets. The other measurable effect of standoff distance occurred in relation with rotation speed. The effect of standoff distance relative to multiples of orifice diameter at two different rotation speeds is shown in Figure 5.

The maximum "too close" range varied from 13 to 16 mm (.5 to .63 inches) with the bar head but increased to as much as 25 mm (1 inch) with the bent arm head. In terms of multiples of nozzle diameters, this range varied from 18 to 42 times the orifice diameter for the bar heads and up to 67 times the orifice diameter for the bent arms.

The most effective removal with the bar head occurred beyond 65 to 95 times the orifice diameter; in the fastest rotation speed tests, the jet effectiveness showed rapid deterioration beyond 150 to 160 times the orifice diameter. Slower rotation speeds allowed effective removal out to 230 times the orifice diameter, which was the furthest standoff distance tested. No deterioration at the maximum distance was observed using the bent arms at the fastest rotation speed tested.

### 3.2 Rotation Speed

The purpose of these tests was to determine if there is a rotation speed where jets begin to lose power. The diameter of the jet path affects the velocity that the nozzle tip is moving; a jet path diameter of 91 mm (3.6 inches) rotating at 3000 rpm results in a velocity of 14.3 m/sec (47 ft/sec), while a jet path diameter of 366 mm (14.4 inches) rotating at 1800 rpm results in a velocity of 34.5 m/sec (113 ft/sec). Therefore, it is expected that as the jet path diameter increases, the rotation speed should be slowed to maintain an effective velocity. Equation 1 can be used to calculate the velocity of a head in m/sec, where the head diameter is in millimeters.

$$\text{Velocity} = \text{Pi}/60{,}000 \cdot \text{diameter} \cdot \text{rpm} \qquad \textbf{(1)}$$

Four different parameters varied the effect of rotation speed on performance; these were standoff distance, orifice diameter, feed rate, and head design.

Increasing rotation speed with increasing standoff distance narrowed the effective standoff distance range as explained previously. The relation between rotation speed and the orifice diameter is shown in Figure 6; the jet performance with increasing rotation speed deteriorated faster with a smaller orifice diameter. The effects of rotation speed made a slight difference as the linear feed rate was increased; the relation is shown in Figure 7 for two different feed rates using the 366 mm bar head. The plot for the faster feed rate shows improvement with increasing rotation speed up to a point before performance begins to decrease.

Rotation speed was tested at three different jet path diameters. The 366 mm (14.4 in.) bar head was tested at 500, 1000, and 1800 rpm. The 213 mm (8.4 in.) head was tested at 1000, 1500, and 2000 rpm, and the 91 mm (3.6 in.) head was tested at 2000 and 3200 rpm. The feed rates were adjusted to produce the same rate of coverage; therefore the 91 mm head was advanced at a rate four times that of the 366 mm head. Figure 8 shows that for the head diameters and speeds tested, the results fall on approximately the same curve and deterioration in jet power begins to occur at a velocity greater than 20 m/sec (66 ft/sec).

### 3.3 Feed Rate

These tests showed the feed rate to have the greatest effect of all the parameters on percentage of coating removal. The 366 mm (14.4 in.) bar head was tested with rotation speeds of 500, 1000, and 1800 rpm at feed rates of 508, 762, and 1016 mm/min (20, 30, and 40 in./min), with the optimum efficiency occurring at 1000 rpm and 762 mm/min. The 213 mm (8.4 in.) bar head was tested with rotation speeds of 1000, 1500, and 2000 rpm at feed rates of 1016 and 1524 mm/min

(40 and 60 in./min), with the best performance at 2000 rpm and 1524 mm/min. The 91 mm (3.6 in.) bar head was tested with 2000 and 3000 rpm at 2032 and 3048 mm/min (80 and 120 in./min), with the best performance occurring at 2000 rpm and 3048 mm/min. Figure 9 shows the percentage of coating removed as a function of feed rate for the 366 mm bar head. The efficiency relative to feed rate is shown in Figure 10; the curve for the larger bar head is much more sensitive than the smallest diameter head.

### 3.4 Jet Path Diameter

The efficiency of jet path diameter based on the bar heads tested is shown in Figure 11. For the three to be equal in efficiency, the 91 mm (3.6 in.) diameter head had to have an effective feed rate of three times that of the 366 mm (14.4 in.) head, which held to be true. The greatest efficiency appeared with the 213 mm (8.4 in.) head; it did produce a cleaner pass than either of the two other heads, at a feed rate of twice that of the 366 mm head. Referring back to the curves in Figure 10, the sensitivity of the larger head diameter curve may be another contributing factor in head diameter selection. The efficiencies of these heads are not too far apart, but if the trend continues beyond the diameters tested, one would expect a further loss of efficiency.

The theoretical feed rate can be calculated (Equation 2) based on the number of jets traveling in the same path, the orifice diameter of the jets and the rotation speed; it does not take into account the head diameter. The ratio of the actual feed rate to the theoretical feed rate for the optimum efficiency varied from 1.5 times for the largest bar head to 3 times for the smallest. This means that this theoretical feed rate calculation is missing a variable to account for this, but it is still useful for providing an estimated starting point.

$$\text{Feed Rate} = \text{Orifice Diameter} \bullet \text{Number of Jets} \bullet \text{rpm} \qquad \textbf{(2)}$$

### 3.5 Jet Angle

A 366 mm bar head with 5 degree outward angled ports was compared to a 366 mm bar head with straight downward facing ports. The angled ports removed an estimated15 to 20 percent more coating than the straight ports in this test.

### 3.5 Bent Arm Head Design

The head design shown in Figure 4 was tested and compared to the bar head design. Figure 12 shows the side by side comparison of the two tests; the greatest effect occurred with standoff distance. The bent arm head showed less deterioration due to rotation speed rate as well, and the efficiency of coating removal compared to the bar head improved by 25 to 30 percent. Nearly the same removal was achieved with the .38 mm orifice size in the bent arms as that achieved by the .51 mm orifice size in the bar head. Further testing would be required to determine if this improved efficiency of the bent arm design could be translated directly into increased production rates.

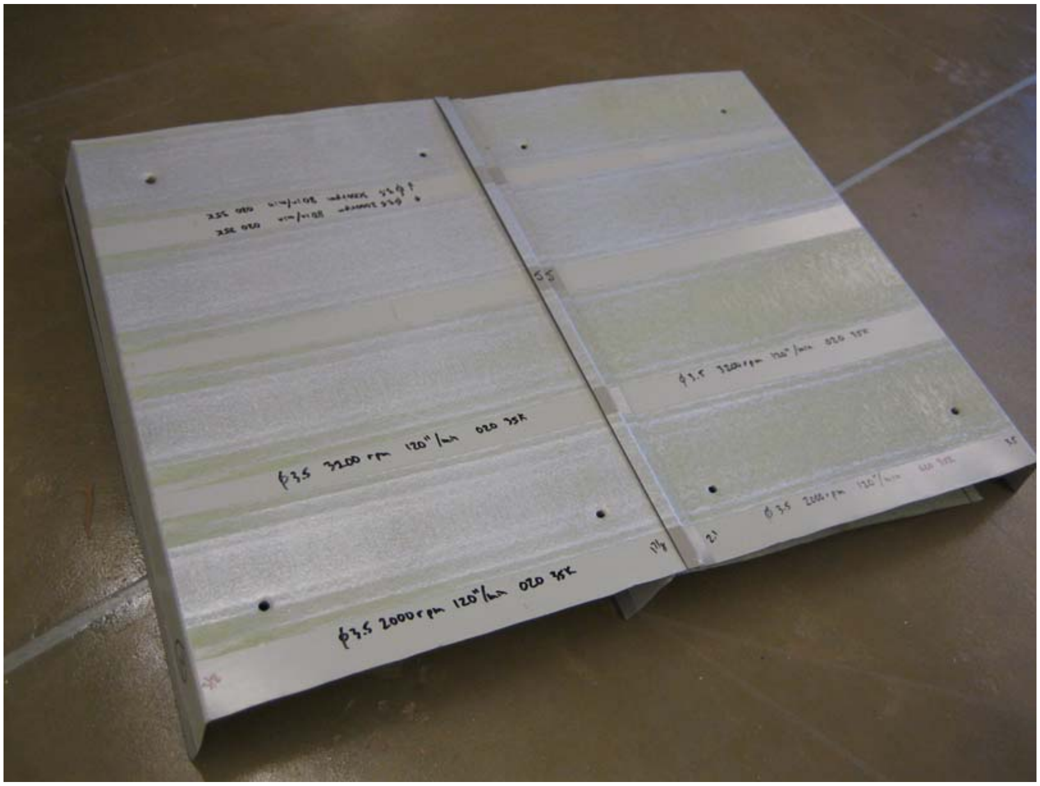
## 4.0 CONCLUSIONS

The relative effects of standoff distance, rotation speed, feed rate, and head design were measured and compared in these tests. Overall, the parameter having the greatest effect on performance was the feed rate, which also directly effects efficiency. The next strongest parameter was the head design; the bent arm head performance was 25 percent better than the bar head design, and jet angle improved performance by 15 percent. Jet path diameter appeared to reach an optimum around the 210 mm size range, although this was not a strong influence. Rotation speed effected performance in several ways, but was not shown to be very influential either. These tests showed that increasing rotation speed is not necessarily a direct path to allowing a faster feed rate; it should be kept within a range to produce a velocity between 10 and 25 m/sec (33 and 82 ft/sec) for optimum performance.

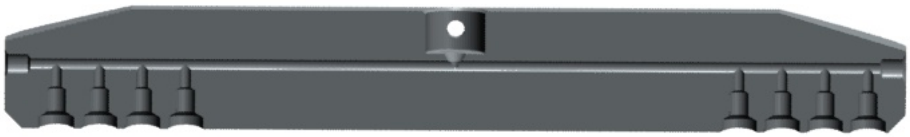
## 5.0 REFERENCES

Wright, D., Wolgamott, J., Zink, G., "A Study of Rotary Jets For Material Removal," *Proceedings of the 9th American Waterjet Conference*, M. Hashish (ed.), pp. 525-539, Waterjet Technology Association, St. Louis, Missouri, 1997.

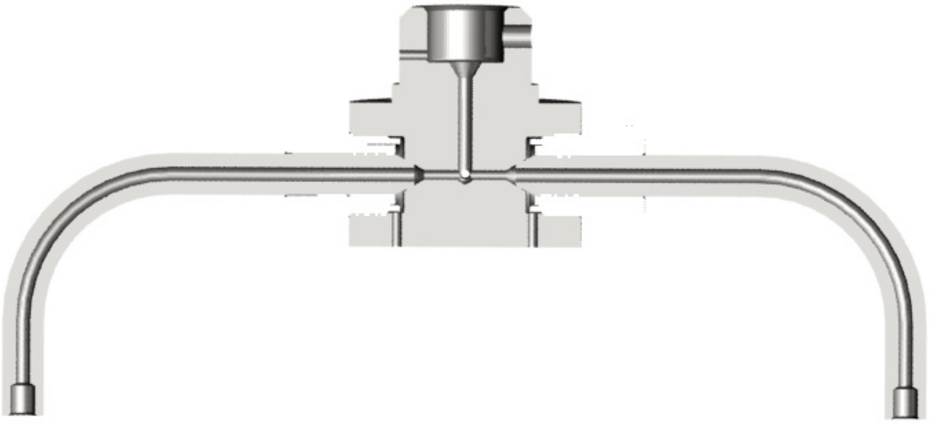
Test Arrangement Consisting of a Rotating Head and Traversing Mechanism
Figure 1.



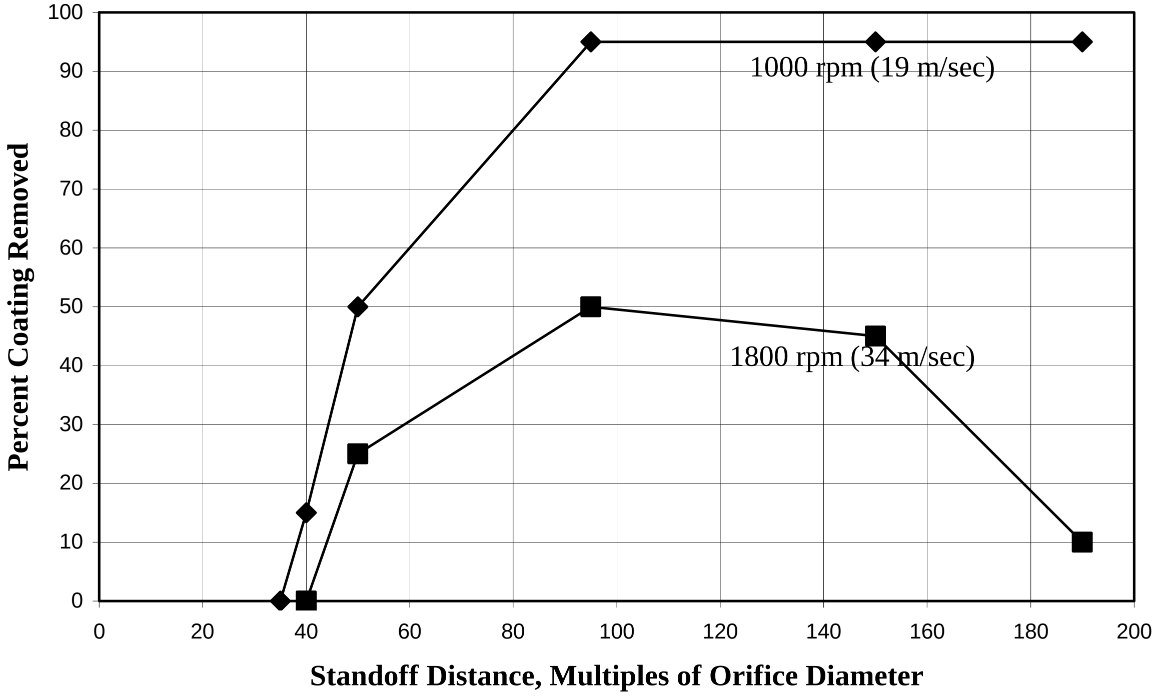
Test Samples of Coated Steel Siding Material
Figure 2.



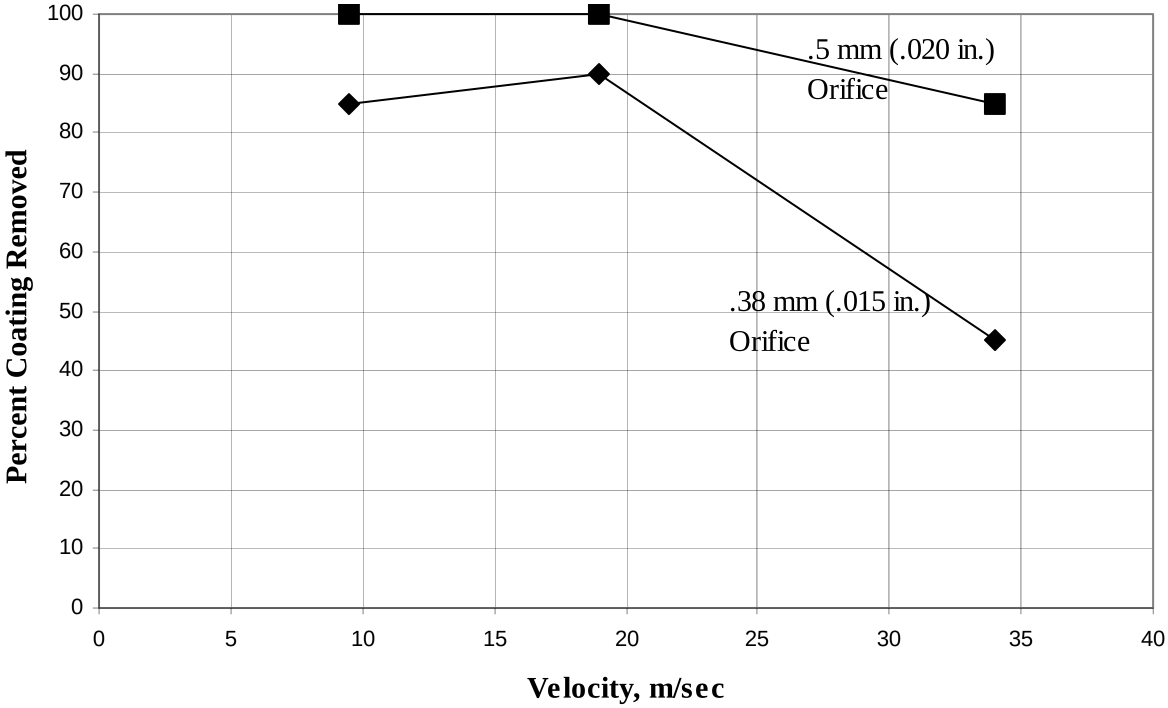
Bar Head Design
Figure 3.



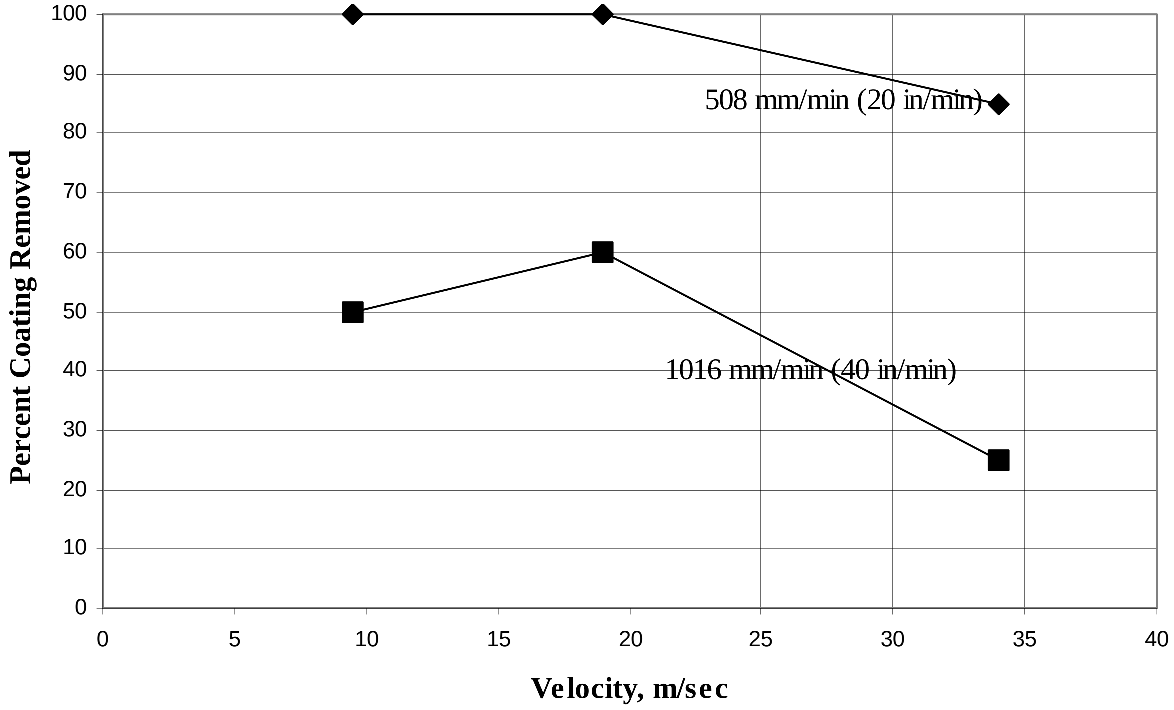
Bent Arm Design
Figure 4.



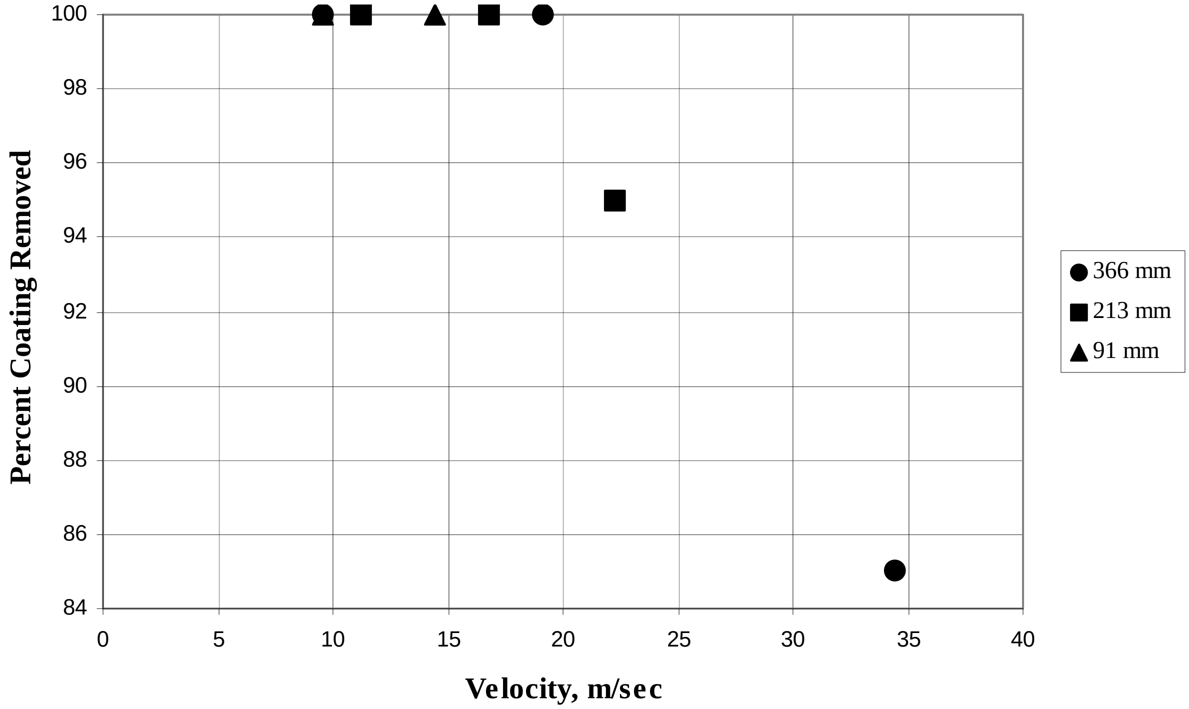
**Effective Standoff Distance with 366 mm (14.4 in.) Bar Head at Two Rotation Speeds**
**Figure 5.**



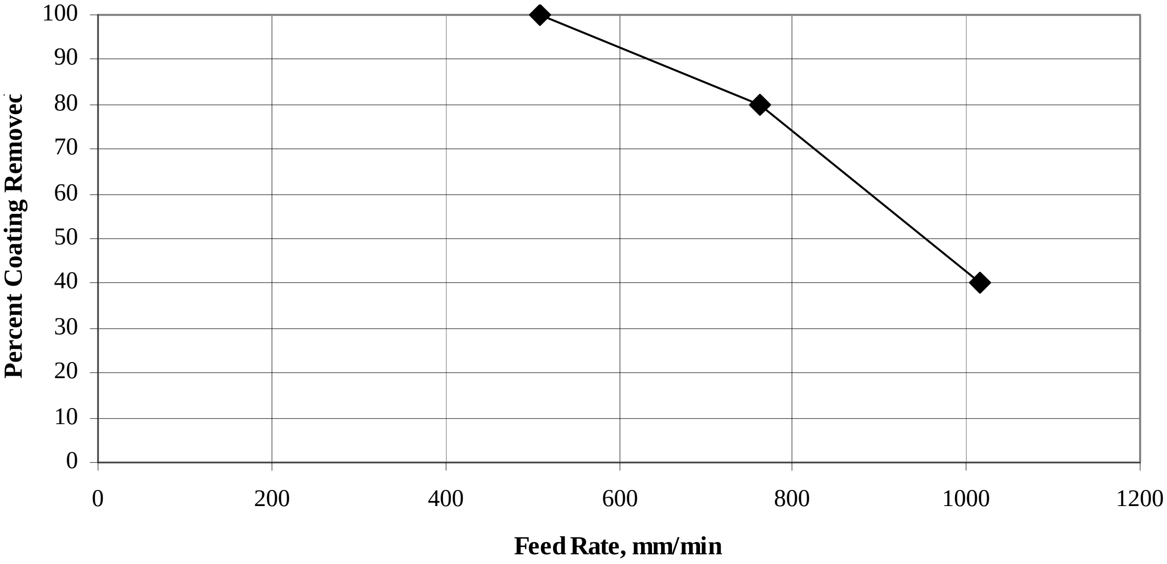
**Relation Between Orifice Size and Rotation Speed Velocity with 366 mm Bar Head**
**Figure 6.**



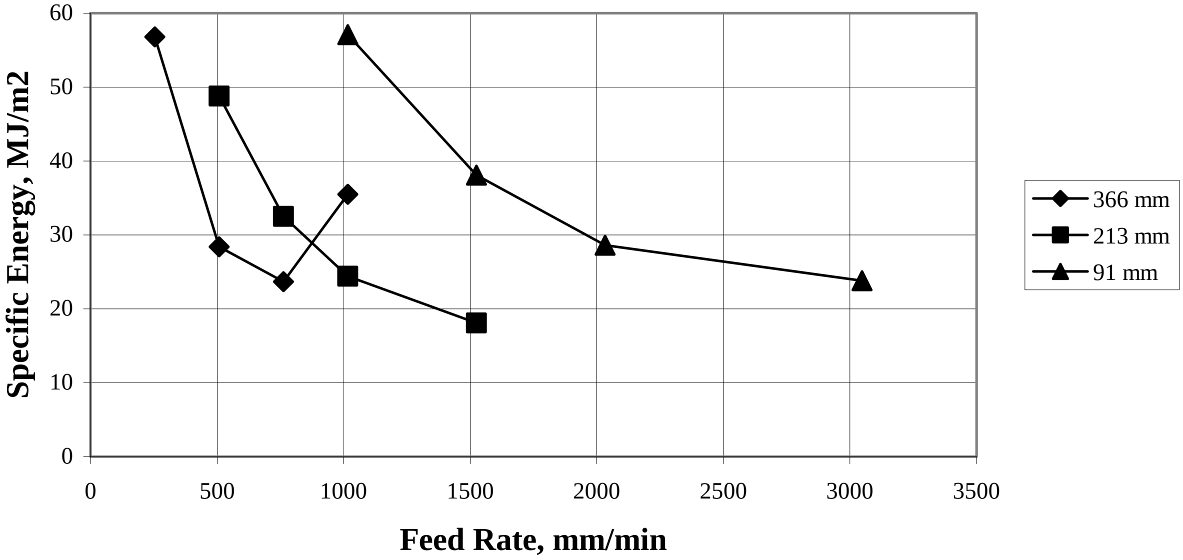
**Relation Between Feed Rate and Rotation Speed Velocity with 366 mm Bar Head**
**Figure 7.**



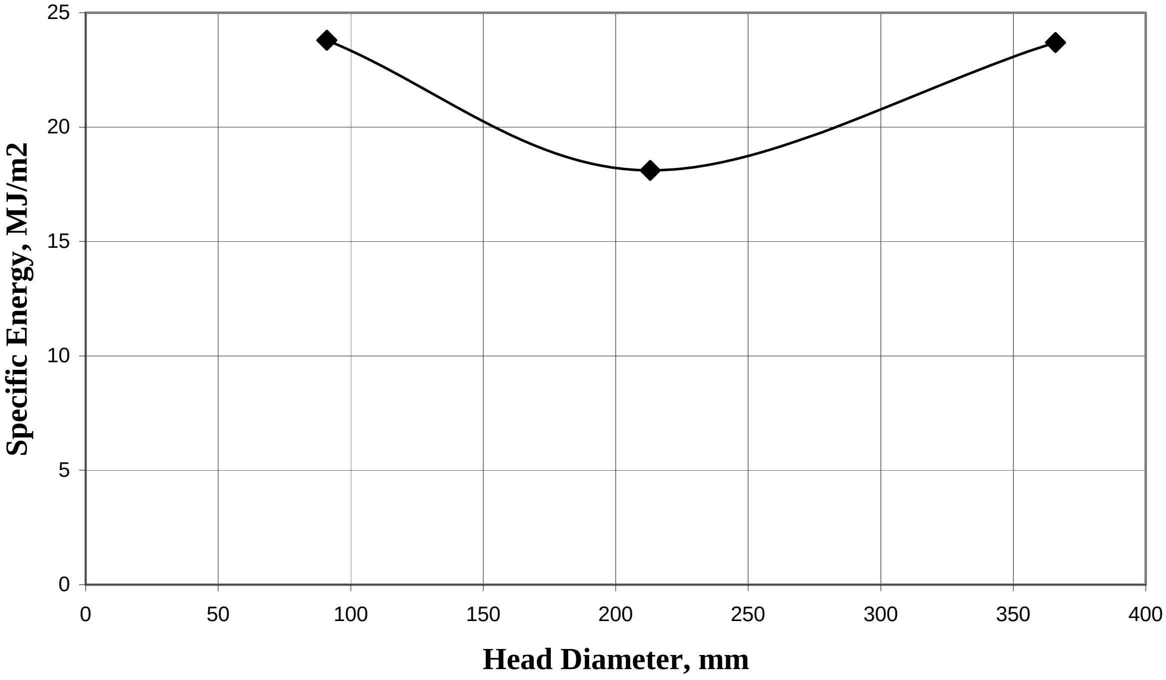
**Rotation Speed Velocity with Three Bar Head Diameters**
**Figure 8.**



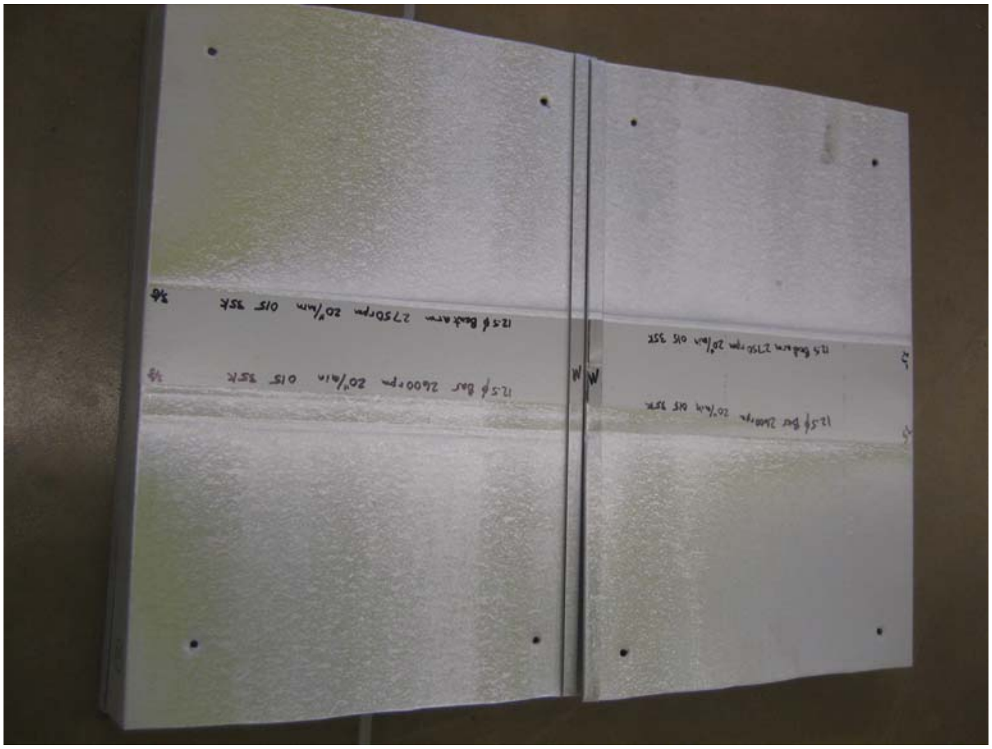
Coating Removal as Function of Feed Rate, for 366 mm Bar Head
Figure 9.



Coating Removal Efficiency as a Function of Feed Rate for Three Bar Heads
Figure 10.



**Efficiency of Coating Removal with Bar Head Jet Path Diameter**
**Figure 11.**



**Bent Arm Head (Top) Compared to Bar Head (Bottom) Moving from Left to Right is Standoff Distance Change from 9 mm to 89 mm**
**Figure 12.**