Experimental Exploration on Surface Roughness in Abrasive Water Jet machining using Response Surface Methodology

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Abstract. This paper presents research work involved in AWJ machining of AZ91 mg alloy material. AWJ critical has been confirmed to be an operative technology for processing numerous engineering materials. Surface abnormality of machined quantities is single and the most significant machining appearances that play an significant role in responsible the quality of machineries. Procedure parameters namely, traverse speed, water density and stand-off distances are measured in the current study. The properties of these parameters on surface quality have been studied based on the investigational results. Extreme pressure and lowest stand-off distance cause falling down in the surface quality in AZ91 magnesium alloy.

1. Introduction
Abrasive water jet machining (AWJM) is mostly using modern machining technique, which is used to produce the particular components in the aerospace, automotive, missile construction and marine applications. In AWJM cutting, material abstraction takes place through the disintegration process, during which water jet accelerates the abrasive molecules at high speed, causes impingement on the marked material. It offers a extensive range of benefits such as less/no thermal stress, less material distortion, ability to cut any materials, the minimum cutting force can be applied on the target material [1,2]. The magnesium alloy AZ91 has main composition of 0.3% Maganese, 1% Zinc and 9% Aluminum. This alloy is having high power to weight ratio, high precise modulus and shows excellent castability. But it loses its strong point and other possessions above 120\degree. This occurs due to the unstiffening of the \(\beta\)-phase. Therefore, this sample material can only be used where the temperature doesn’t exceed 120\degree. Many composites additions are done to increase the high-temperature usability such as Pb, Sb, Ca, etc. But we have to take care of that taken that other properties are not fulfilled. Different types of Magnesium composition AZ91 have been made, namely: AZ91A, AZ91B, AZ91C, AZ91D and AZ91E. Here, the last alphabet identifies the no of specific composition registered with the same primary composition. Even though AWJM is well established in soft materials, a limited works were carried on the difficult to cut the elements such as die steel, is observed. So, this paper main purposes to investigate the surface quality of AZ91 magnesium alloy by AWJM.
2. Experiments setup and process
The test in the present examination was conducted using OMAX High-pressure water jet machining apparatus supported with 30 Hp direct energy pump with the controlling the pressure of 100 MPa to 345 MPa. The specimen used for conducting testing was cast AZ91 mg alloy. The cutting factors such as water jet force; traverse speed and were frequently use and optimized in several kinds of literature [3-4]. From the past literature of the AWJM, it very well may be discovered that no researchers have made attempts to research the AWJM cutting performance on AZ91 magnesium alloy. Hence, this study purposes to investigate the surface quality of AZ91 material after machining with AWJM. Surface roughness was studied by [5-6]. The process parameters were selected as traverse speed, water pressure and standoff distance. The experiment was designed using response surface methodology Box-Behnonen method [7].

![Workpiece after machining.](image)

Table 1. Process variables and its Levels.

| Real Factor | Factors     | Level |
|-------------|-------------|-------|
| TS          | Traverse speed |       |
| WP          | Water pressure |       |
| SOD         | Stand of distance |   |
|             | -1          | 0     | 1   |
| 100         | 140         | 180   |
| 120         | 200         | 280   |
| 1           | 2           | 3     |

3. Process Variables effect on surface quality
The AWJM experimentations were piloted, with the procedure parameter stages set as given in Table 1, to study the impact of procedure parameters over the surface quality. The analysis was performed according to the trial environments specified by the 2nd order BBD design. Trial results are given in Table 2 for surface quality. Altogether 15 experiments were conducted using response surface procedure. The regression calculations were developed using the analysis data (Table 2) and were plotted to investigate the impact of procedure factors on different response characteristics. The regression conditions for the surface quality as a component of 5 input process factors were developed using analyzed data and is given below.

The surface quality is shown in Figures 2-7. From Figure 2&5, the surface roughness is found to have a decreasing tendency with the growth of water pressure, it declines with the rise of traverse speed. From the figure, 3&6 the surface quality is found to have an increasing trend with the increase of traverse speed, and at the same time, it decreases with the rise of stand of distance. From figure, 4&7 the surface
irregularity is found to have a decreasing tendency with the growth of water pressure, it increases with the rise of traverse speed.

The surface quality is the majorly influenced by the amount of water pressure. The surface roughness depends on the water pressure. Normal probability plot is shown in Figure 8. The ANOVA for surface irregularity (Table 3) indicates that the traverse speed (A), the water pressure (B) and stand of distance (C) are significant parameters affecting surface roughness. The slope function graphs and bar graphs (Figures 10 – 11) had drawn using Design Expert solver show the desirability for each factor and each response. Bar graphs show the desirability function (di) of each of the surface quality; di varies from 0 to 1 depending upon the closeness of the response towards target [8]. Optimum conditions are shown in Table 3.

**Table 2.** Experimental values (Surface quality).

| Std | run | Block 1 | TS  | WP  | SOD | SR  |
|-----|-----|---------|-----|-----|-----|-----|
| 12  | 1   | Block 1 | 140 | 280 | 3   | 4.65|
| 11  | 2   | Block 1 | 140 | 120 | 3   | 5.98|
| 14  | 3   | Block 1 | 140 | 200 | 2   | 5.12|
| 13  | 4   | Block 1 | 140 | 200 | 2   | 5.23|
| 4   | 5   | Block 1 | 180 | 280 | 2   | 4.65|
| 3   | 6   | Block 1 | 100 | 280 | 2   | 4.46|
| 8   | 7   | Block 1 | 180 | 200 | 3   | 5.34|
| 6   | 8   | Block 1 | 180 | 200 | 1   | 5.78|
| 10  | 9   | Block 1 | 140 | 280 | 1   | 4.85|
| 1   | 10  | Block 1 | 100 | 120 | 2   | 4.96|
| 15  | 11  | Block 1 | 140 | 200 | 2   | 5.13|
| 2   | 12  | Block 1 | 180 | 120 | 2   | 5.45|
| 9   | 13  | Block 1 | 140 | 120 | 1   | 5.72|
| 5   | 14  | Block 1 | 100 | 200 | 1   | 4.81|
| 7   | 15  | Block 1 | 100 | 200 | 3   | 4.96|

SR =+1.30187+0.049688 * TS+7.01563E-003 * WP-0.19000 * SOD-2.34375E-005 * TS * WP-3.68750E-003 * TS * SOD-1.43750E-003 * WP * SOD-1.11719E-004 * TS-0.58203E-005 * WP2+0.24125 * SOD2
Table 3. ANOVA - surface roughness.

| Source   | Sum of Squares | df | Mean square | F value | P-value Prob> F | Significant |
|----------|----------------|----|-------------|---------|-----------------|-------------|
| Model    | 2.62           | 9  | 0.29        | 8.07    | 0.0166          | significant |
| A-TS     | 0.52           | 1  | 0.52        | 14.3    | 0.0129          |             |
| B-WP     | 1.53           | 1  | 1.53        | 42.52   | 0.0013          |             |
| C-SOD    | 6.61E-03       | 1  | 6.61E-03    | 0.18    | 0.6861          |             |
| AB       | 0.022          | 1  | 0.022       | 0.62    | 0.4651          |             |
| AC       | 0.087          | 1  | 0.087       | 2.42    | 0.1808          |             |
| BC       | 0.053          | 1  | 0.053       | 1.47    | 0.2797          |             |
| A2       | 0.12           | 1  | 0.12        | 3.28    | 0.1301          |             |
| B2       | 0.038          | 1  | 0.038       | 1.05    | 0.3523          |             |
| C2       | 0.21           | 1  | 0.21        | 5.97    | 0.0585          |             |
| Residual | 0.18           | 5  | 0.036       |         |                 |             |

Lack of Fit
| 0.17 | 3 | 0.058 | 15.56 | 0.061 not significant |

Pure Error
| 7.40E-03 | 2 | 3.70E-03 |

Cor Total
| 2.8 | 14 |

Figure 2. Effect of TS and WP on surface quality.

Figure 3. Effect of TS and SOD on surface quality.
Figure 4. Impact of WP and SOD on surface quality.

Figure 5. Impact of WP and TS on surface quality.

Figure 6. Impact of SOD and TS on surface quality.

Figure 7. Impact of SOD and WP on surface quality.

Figure 8. Impact of SOD and WP on surface quality.

Figure 9. Impact of SOD and WP on surface quality.
Table 4. Desirability values (surface roughness).

| S.No. | TS  | WP  | SOD  | SR    | Desirability |
|-------|-----|-----|------|-------|--------------|
| 1     | 100 | 279.35 | 2.34 | 4.29752 | 1 Selected   |
| 2     | 100 | 262.64 | 1.39 | 4.45382 | 1            |
| 3     | 100 | 275.01 | 1.26 | 4.42177 | 1            |
| 4     | 100 | 269.83 | 1.78 | 4.34126 | 1            |
| 5     | 100 | 271.69 | 1.41 | 4.39655 | 1            |
| 6     | 100 | 253.58 | 1.95 | 4.4379  | 1            |
| 7     | 100 | 276.15 | 1.32 | 4.39511 | 1            |
| 8     | 100 | 258.26 | 2.32 | 4.44654 | 1            |
| 9     | 100 | 269.24 | 1.71 | 4.35304 | 1            |
| 10    | 100 | 270.18 | 1.91 | 4.33196 | 1            |
| 11    | 100 | 278.11 | 1.17 | 4.43791 | 1            |
| 12    | 100 | 270.82 | 2.67 | 4.44857 | 1            |
| 13    | 100 | 257.77 | 2.08 | 4.41735 | 1            |
| 14    | 100 | 274.69 | 2.52 | 4.37222 | 1            |
| 15    | 100 | 263.22 | 2.01 | 4.37804 | 1            |
| 16    | 100 | 269.68 | 2.63 | 4.44224 | 1            |
| 17    | 100 | 270.02 | 1.6  | 4.36337 | 1            |
| 18    | 100 | 276.82 | 2.52 | 4.35682 | 1            |
| 19    | 100 | 271.05 | 2.34 | 4.35918 | 1            |
| 20    | 100 | 278.97 | 2.86 | 4.45191 | 1            |
| 21    | 100 | 273.32 | 2.43 | 4.3601  | 1            |
| 22    | 100 | 265.01 | 2.12 | 4.37244 | 1            |
| 23    | 100 | 277.22 | 1.15 | 4.45101 | 1            |
| 24    | 100 | 259.75 | 2.42 | 4.45572 | 1            |
| 25    | 100 | 272.85 | 2.08 | 4.31621 | 1            |
| 26    | 100 | 258.33 | 1.69 | 4.42121 | 1            |
| 27    | 100.61 | 251.57 | 1.83 | 4.45998 | 0.996        |
| 28    | 100 | 199.91 | 1.49 | 4.73038 | 0.907        |
| 29    | 100 | 186.47 | 2.15 | 4.81132 | 0.877        |
4. Conclusion
The impact of machining factors on surface quality was investigated based on the investigational results. The decisions are drawn for productive machining of AZ91 magnesium alloy by the abrasive jet cutting method. The extreme pressure & smallest stand-off distance cause a decrease in the surface quality in AZ91 mg alloy. The minimum surface quality was obtained at a water pressure, 280 bar and traverse speed of 100 mm/min & standoff distance of 2 mm, with Ra values of 4.29 microns. It was validated with a confirmation experiment.
5. References

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