A STUDY ON ABRASIVE WATER JET MACHINING USING ANOVA ON D3 TOOL STEEL

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Abstract

The pressurized high-speed water flows together with the $\text{Al}_2\text{O}_3$ particles forms slurry used in abrasive water jet machining (AWJM) to slice specimens. This approach is particularly appropriate for fragile, soft and strident materials. D3 tool steel used as a sample size of 200 x 200 x 23 mm has excellent strength and is also suitable for high-temperature machining operations. In the present work, the 8 mm diameter hole was created using AWJM. The L27 orthogonal array experiments were conducted with crossover speeds ($T_s$) 80, 100 and 120 mm / min, abrasive mass flow rate ($A_f$) 250, 325 and 400 (g / min) and a standoff distance (Sod) of 1, 1.5 and 2 mm as processing parameters. Optimum parameters have been set from ANOVA to achieve high metal extraction. Optimum Sod, $T_s$, and $A_f$ are 400 g / min, 1.5 mm and 120 mm / min. Experiment number 26 and the 27 processing parameters are the best for the D3 tool steel unit to achieve higher metal extraction.

Keywords : AWJM, D3 Tool Steel, ANOVA, cutting speed, standoff distance, Traverse speed.

I. Introduction

AWJM is a non-conventional machining technique in which pressurized high-speed water flows together with the micron size of $\text{Al}_2\text{O}_3$, SiC, granite particles form slurry used commonly for cutting ferrous, non-ferrous and composite samples. To optimize processing parameters widely using ANOVA with different popularized algorithms [I]. Cutting glass of various kinds of abrasive particles used as grenade, $\text{Al}_2\text{O}_3$, SiC during abrasive water jet practice revealed that increased hydraulic pressure, abrasive mass flow at the same time as a decrease in standoff distance and crossover rate could result in improved machining performance [II]. Composite make with FRP & CFRP after carried out AWJM to optimize the process parameters ANOVA used [III, XVI]. Characterization on parameters were performed using optimization techniques to reduce the minimum flow rate on the surfaces [IV, XIV]. Fuzzy logic technique is preferable for finding the right accuracy on following...
parameters such as mass flow rate, traverse speed and standoff distance for development of width of cut for preferable material [V, XVII]. The enhanced surface roughness can be measured and conditions of the microstructure on the surface at different locations were performed [VI]. Using different types of machining process such as single-pass and multi-pass on the given specimen, the following parameters such as standoff distance and surface roughness can be predicted to optimize the reduction of the material [VII]. The major responses are predicted using ANOVA technique to reduce the optimal condition [VIII]. By using regression technique such as Taguchi method is used to analyze the surface condition of a given composite [IX, XV]. The two different surface roughness such as rough and smooth are considered to find the optimum value by varying the different parameters such as mass flow rate, SOB and traverse speed on given material [X]. Using different types of optimization techniques, the surface roughness can be optimized [XI]. By considering different aspects, the condition of mass flow rate can be minimized and erode the material in sufficient manner is considered to fabricate the structures [XII]. To optimize the surface roughness by using taguchi analysis by considering the different parameters [XIII]. By varying the matrix composition the characteristics were determined and it can be modulated in regression analysis [XVIII].

Using Water jet machining process, the performance of surface roughness can be effective manner [XIX]. Experiments were analyzed using different types of variance methods [XX]. Fabricated aluminum hybrid composites using AWJM [XXI].

The main objective of the abrasive water jet machining is to optimize the material extraction and surface roughness of D3 Tool steel of sample size 200 x 200 x 23 mm using the Taguchi L27 orthogonal array method and ANOVA regression analysis.

II. Experimentation Work

D3 tool steel used as a sample size of 200 x 200 x 23 mm has excellent strength and is also suitable for high-temperature machining operations. Table 1. Indicates the chemical composition of D3 tool steel. In the present work, L27 orthogonal array experiments were performed with the Abrasive Water Jet Machining Setup (Machine Model S3015) seen in Fig. 1. Table 2. indicates Specifications for AWJ Machine. Three machining parameters, such as abrasive flow rate \(A_f\), standoff distance \(Sod\) and jet traverse Speed \(T_s\), are considered for experimental purposes. Table 3. displays Standard machining parameters with different levels. There are three input parameters and three ranges have been assumed for each parameter. For three reasons, three stage experiments, Taguchi specified the L27 orthogonal array for experimentation. The response obtained from the trails of the L27 array experiments was documented and further analyzed.
Table 1: Chemical composition of the work piece.

|   | C    | Mn | Si | Cr  | Ni | W  | V  | P  | S  | Cu |
|---|------|----|----|-----|----|----|----|----|----|----|
|   | 2-2.35 | 0.6 | 0.6 | 11-13 | 0.3 | 1.0 | 1.0 | 0.03 | 0.03 | 0.25 |

Fig. 1: Abrasive Water Jet Machining System (Model S3015)

D3 tool steel used as a sample size of 200 x 200 x 23 mm before machining shown in Fig.2.a. The L27 array experiments were performed with 8mm hole diameter shown in Fig.2.b. The surface roughness (Rₐ) of the hole is assessed by the Talysurf SJ-201P instrument shown in the Fig.2.c. The MRR may describe the "instantaneous" removal speed as the rate at which the cross-section area of the material being removed moves through the work piece. The MRR is determined using the relationship shown in equation below.

\[ MRR = h t \times d n \times V t \]  

(1)
Table 2: Specifications for AWJ Machine

| Item                        | Identification                  |
|-----------------------------|---------------------------------|
| Machine model               | S3015                           |
| Intensifier                 | KMT – SLV 50 HP                 |
| Table size                  | 3 x 1.5 m                       |
| Nozzle diameter             | 1.1 mm                          |
| Jet Impingement/Impact Angle| 90°                             |
| Max. Pressure               | 4200 bar                        |
| Table size                  | 3 x 1.5 m                       |
| Max. Feed                   | 4000 mm/min                     |
| Max. Abrasive Flow Rate     | 700 g/min                       |
| Stand-Off Distance          | More than 1 mm                  |
| Vertical Cut Height         | 300 mm                          |
| Abrasive type               | Garnet Sand                     |
| Abrasive size               | 80 Mesh                         |
| Average diameter of abrasives| 0.20 mm                        |

Table 3: Cutting parameters with different levels

| S.No. | Input Parameters             | Levels | Units     |
|-------|------------------------------|--------|-----------|
|       |                               | 1      | 2         | 3         |
| 1.    | Abrasive mass flow rate      | 250    | 325       | 400       | g/min     |
| 2.    | Standoff distance            | 1      | 1.5       | 2         | Sod       |
| 3.    | Jet traverse speed           | 80     | 100       | 120       | mm        |

Fig. 2.a.: D3 tool steel before machining

Fig. 2.b.: D3 tool steel after machining

Fig. 2.c.: Measuring Ra with Talysurf SJ-201P
III. Results and Discussion

AWJM carried out on D3 tool steel using the L27 experiments tabulated in Table 4. Present analysis for the effect of control parameters on outputs. MRR and Ra are taken as output responses. Ts, Sod and $A_f$ increase, the temperature between the electrode and work-piece increases due to MRR and Ra increases. To get maximum MRR, Transverse speeds influenced primarily lead $A_f$ because of S/N ratio larger is the best shown in Fig.3.a. To get maximum Ra, Sod influenced primarily leads $A_f$ S/N ratio smaller is the best shown in Fig.3.a.

![Fig. 3.a: Material removal rate (MRR): Mean of S/N ratios](image1)

![Fig. 3.b: Surface Roughness (Ra): Mean of S/N ratios](image2)

Table 4: Series of experiments performed with processing parameters along output responses presented

| Trial No. | Jet traverse speed (mm/min) | Abrasive flow rate (g/min) | Standoff distance (mm) | MRR | $R_a$ |
|-----------|-----------------------------|---------------------------|------------------------|-----|------|
| 1.        | 80                          | 250                       | 1                      | 20.6| 2.716|
| 2.        | 80                          | 250                       | 1                      | 20.6| 2.716|
| 3.        | 80                          | 250                       | 1                      | 20.6| 2.754|
| 4.        | 80                          | 325                       | 1.5                    | 21.4| 3.373|
| 5.        | 80                          | 325                       | 1.5                    | 21.4| 3.203|
| 6.        | 80                          | 325                       | 1.5                    | 21.4| 3.353|
| 7.        | 80                          | 400                       | 2                      | 22.6| 4.193|
| 8.        | 80                          | 400                       | 2                      | 22.6| 3.780|
| 9.        | 80                          | 400                       | 2                      | 22.6| 3.740|
| 10.       | 100                         | 250                       | 1.5                    | 23.5| 3.490|
| 11.       | 100                         | 250                       | 1.5                    | 23.5| 2.963|
III.i. Evaluation of MRR

The surface plot for the output response MRR of the steel tool D3 along the y axis, process parameters Af and sod on the horizontal plane as shown in Fig.1. In the surface graph, the MRR increased by 9 percent due to the increase in Af and Sod. Af dominant variable led by Sod on the MRR.

Fig. 4.a: Surface plot of MRR, Af and Sod on steel machine

Fig. 4.b.: Surface plot of MRR, Ts and Sod on steel machine tool D3 tool D3.

Ts and sod combined effect of the MRR shown in Fig.2. The surface plot for the output response MRR of the steel tool D3 along the y axis, the process parameters
T and sod on the horizontal axis shown in Fig.1. In the surface graph, MRR increased by 27.30 per cent due to increases in Ts. Ts primary element led by Sod on the MRR.

Fig. 4.c.: Surface plot of MRR, Af and Ts on steel machine tool D3.

Ts and Af combined influence on the MRR shown in Fig.3. The surface plot for production response MRR of the steel tool D3 along the vertical axis, process parameters Ts and Af on the horizontal axis shown in Fig.1. In the surface plot MRR increased by 37.50% because of increases of Ts and Af. Ts dominant factor followed by Af on MRR. The equation of regression for MRR given below.

\[
\text{MRR} = 5.889 + 0.13750 \, \text{T}_s + 0.013556 \, \text{A}_f + 0.267 \, \text{Sod} \quad (2)
\]

III.ii. Evaluation of Ra

Fig.5.a.Indicates R_a influenced by A_f and Sod
Fig. 5.b.: Indicates Ra influenced by Ts influenced by Ts and Sod

Fig. 5.c.: Indicates Ra and Sod

The dominant element $A_f$ led by Sod on $R_a$ is shown in Fig. 5.a. $R_a$ started at 2.766μm and increased by 33 percent. Sod had a minor impact on $R_a$. The dominant variable $T_s$ followed by Sod on $R_a$ shown in Fig. 5.b. Sod has a minor impact on the $R_a$. $T_s$ impact factor followed by $A_f$ on $R_a$ shown in Fig. 5.c. $R_a$ has risen by 50.25%. $T_s$ and $A_f$ had a great influence on $R_a$. Table.5 indicates lead cutting factors are presented through ANOVA for MRR. The transverse speed itself contributes almost 87.51% whereas $A_f$ and Sod contributes 11.85% and 0.31%. Table.6 indicates lead cutting factors are presented through ANOVA for $R_a$. The transverse speed itself contributes almost 31.57% whereas $A_f$ and Sod contributes 63.84% and 4.13%. $R_a$ affected by $A_f$. The equation of regression for $R_a$ given below.

$$R_a = -1.743 + 0.02507 T_s + 0.008781 A_f + 0.211 Sod$$ \hspace{1cm} (3)

Table 5: Presence of Analysis of variance for MRR

| Source      | DF | Seq SS  | Contribution | Adj SS  | Adj MS  |
|-------------|----|---------|--------------|---------|---------|
| $T_s$       | 2  | 137.527 | 87.58%       | 137.527 | 68.7633 |
| $A_f$       | 2  | 18.607  | 11.85%       | 18.607  | 457.54  |
| Sod         | 2  | 0.487   | 0.31%        | 0.487   | 11.97   |
| Error       | 20 | 0.407   | 0.26%        | 0.407   | 0.407   |
| Lack-Of-Fit | 2  | 0.407   | 0.26%        | 0.407   | 0.407   |
| Pure Error  | 18 | 0.000   | 0.00%        | 0.000   | 0.000   |
| Total       | 26 | 157.02  | 100.00%      |         |         |

R-sq = 99.74%; R-sq(adj)= 99.66%; R-sq(pred)= 99.53%
Table 6: Presence of Analysis of variance for $R_a$

| Source       | DF | Seq SS | Contribution | Adj SS | Adj MS |
|--------------|----|--------|--------------|--------|--------|
| Ts           | 2  | 4.5671 | 31.57%       | 2.2835 | 68.763 |
| Af           | 2  | 9.2368 | 63.84%       | 4.6184 | 457.54 |
| Sod          | 2  | 0.5981 | 4.13%        | 0.2990 | 11.97  |
| Error        | 20 | 0.0656 | 0.45%        | 0.0032 |        |
| Lack-Of-Fit  | 2  | 0.407  | 0.26%        | 0.0020 |        |
| Pure Error   | 18 | 0.0614 | 0.03%        | 0.0034 |        |
| Total        | 26 | 14.467 | 100.00%      |        |        |

R-sq = 99.55%; R-sq(adj)= 99.41%; R-sq(pred)= 99.17%

IV. Conclusion

AWJM is performed using L27 set, which displays output responses such as material extraction and surface roughness with different system parameters such a Jet traverse speed, Abrasive flow rate and standoff range.

- Jet traverse speed has the greatest impact on the level of material removal; abrasive flow rate has the strongest effect on surface roughness.
- For material removal and surface roughness regression equations are created.
- The transverse speed contributes almost 31.57% while $A_f$ and Sod contribute 63.84% and 4.13%. $R_a$ has been affected by $A_f$.
- $R_a$ has risen by 50.25%. Ts and Af had a great influence on $R_a$. 

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