USING GENETIC ALGORITHM OPTIMIZING THE CUTTING PARAMETERS OF AWJM PROCESS FOR ALUMINIUM 6061 ALLOY

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Abstract: For the past years we have witnessed a rapid progress in the development of harder, tough and complex to machine metals and alloys. Abrasive water jet machine is one of the recently developed hybrids, nontraditional machining process in processing different kinds of hard-to-machining the materials nowadays. It is a reasonable method to process the heat sensible material without generation of heat while machining. Machining limitations play the lead role in defining the machine economics and quality of machining. In this study the significance of Pressure, Abrasive flow rate, Orifice diameter, focusing nozzle diameter and Standoff distance, process parameters, on metal removal rate and Strontium of Aluminium 6061 alloy which is machined by Abrasive water jet machine was experimentally completed and analyze. According to Response Surface Methodology design, different experiments were conducted with the combination of input parameters on this alloy. This paper presents the Prediction and Optimization of metal removal rate and Strontium on Aluminium 6061 alloy using multi objective Genetic Algorithm.

Keywords: Response surface methodology, Genetic Algorithm, Material Removal Rate, Surface Roughness.

I. LITERATURE SURVEY

AWJC is the recently developed processes. This method is suitable for machining of brittle materials similar to glass, ceramics and stones as well as for composite materials and ferrous and non-ferrous materials. From the literature review of Adel A. Abdel-Rahman [1] in 2011 an elastic-plastic erosion model was implemented to build up an abrasive waterjet model for machining brittle materials. C. Ma, R.T. Deam [2] in 2006 reviewed that kerf geometry have been measured by the use of an optical microscope. With these measurements, an empirical correlation for kerf profile shape under various traverse speed have been developed that fits the kerf shape well. H. Liu,J.Wang, N. Kelson, R.J. Brown [3] in 2004 in their research Computational fluid dynamics (CFD) prototype for ultrahigh velocity waterjets and abrasive waterjets (AWJs) are established by the use of Fluent6 solver. Hashish [4] used erosion model of Finnie to develop a model to predict combined depth of cut due to cutting and deformation wear for ductile materials only. Hashish [5] developed an improved erosion model by expanding Finnie’s model to include the effects of abrasive particle size and shape (expressed by sphericity and roundness numbers), which was weakness of the earlier model [4]. Hashish used this model to predict depth of cut due to cutting wear, while the prediction of depth of cut due to deformation wear was based on Bitter’s model. But, this model neglected the variation in kerf width along the depth of cut. Using the same improved erosion model, Paul et al. [6] developed analytical model of generalized kerf shape for ductile materials considering variation in kerf width along its depth. Same authors [7] also developed a complex mathematical model for total depth of cut for polycrystal-line brittle materials accounting for the effects of abrasive particle size and shape, but neglecting variation of kerf width along the depth.
of cut. Choi and Choi [8] developed an analytical model for AWJM of brittle materials. Expression developed by them to predict volume of work material removed by a single abrasive Particle is not in terms of process parameters and moreover involves constant of proportionality.

II. Experimental Work

A. Material

Aluminium 6061 alloy, an American element is a precipitation hardening aluminium alloy which is available in several forms such as tube, ingot, ribbon, wire, foil, bar, pipe and rod. It is one of the cheapest American element alloy. The important factor in selecting Aluminium 6061 alloy is their high strength to weight ratio, appearance, and their non magnetic properties. Some of the applications of Aluminium 6061 alloy include Marine fittings, aerospace maintenance, transport, bicycle frames, brake components, valves couplings etc. It is also applied in paint removal, surgery, peening, drilling turning etc. It has good surface finish and can be anodized. Its density is 2.7 g/cm³ and its Modulus of Elasticity E = 80 GPa. The dimension chosen to cut the Aluminium 6061 alloy for this study is 150mm x 50mm x 50mm is depicted in figure 1.

B. Response Surface Methodology

RSM is a set of mathematical and statistical techniques which are useful for modeling and investigation of problems. In the present study five process parameters are chosen and varied in three levels as shown in Table 1.

Based on response surface methodology, Box-Behnken design 46 sets of experimental design was selected and was shown in Figure 2. The parameters and its levels were selected based on the review of certain journals that have been acknowledged on AWJC on materials like 6063-

| Levels | Water Pressure (P) Bar | Abrasive Flow Rate (m) Kg/m³ | Orifice Diameter (d₁) mm | Focusing Nozzle Diameter (d₂) mm | Stand Off Distance (s) mm |
|--------|------------------------|-----------------------------|--------------------------|-------------------------------|-------------------------|
| Low    | 3400                   | 0.4                         | 0.3                      | 0.9                           | 1                       |
| Intermedi ate | 3600                  | 0.55                        | 0.33                     | 0.99                          | 2                       |
| High   | 3800                   | 0.7                         | 0.35                     | 1.05                          | 3                       |

Figure 1 Aluminium 6061 alloy

Figure 3 Experimental Setup of AWJM with Mixing Chamber
T6 aluminum alloy [9], Metallic coated sheet steels [10] Metal Matrix Composites [11] and Ceramics [12].

III. Data Collection and Experimentation

The machine used to cut the American element Aluminium 6061 alloy was the AWJC machine is set with KMT ultrahigh pressure pump with the designed pressure of 4000 bar, gravity feed form of abrasive hopper, an abrasive feeder system, a pneumatically valve and a work piece table. The controller static in the control stand is used to correct the SOD for different experiments. The abrasive water jet machine is programmed using numerical control code to change the transverse speed and manage the supplement of abrasives. After the water is pumped at very high pressures resulting in high velocity of water jet of 1000 m/s as it comes out of focusing nozzle cuts the materials of the desired size and shape. The KMT abrasive water jet cutting machine with its mixing chamber is shown in figure 3.

For performing the experiments we have to design the combination of input parameters for each experiment and how many experiments has to be done. For this purpose using minitaab software according to the Box-Behnken design of Response surface methodology design of experiments, with five input parameters, 46 experimental design is selected and performed experimentally and machining time is observed for all experiments as shown in Table 2. The MRR is calculated by the formula:

\[ \text{MRR} = \frac{(m_f - m_i)}{t} \]

Where, \( m_f \) = mass of the material after machining, \( m_i \) = mass of the material before machining.
### Table 2 Scheduling Matrix of the Experiments with the Optimal Model Data

| Sl. No | Pressure (Bar) | Abrasive Flow Rate (Kg/min) | Orifice Diameter (mm) | Focusing Tube Diameter (mm) | Stand Off Distance (mm) | MRR mm/mi n | SR (μm) |
|--------|----------------|-----------------------------|-----------------------|-----------------------------|-------------------------|-------------|--------|
| 1      | 3400           | 0.55                        | 0.33                  | 0.99                        | 3                       | 48.6111     | 3.57   |
| 2      | 3600           | 0.55                        | 0.33                  | 0.9                         | 1                       | 53.6399     | 2.08   |
| 3      | 3600           | 0.55                        | 0.3                   | 1.05                        | 2                       | 51.8519     | 2.21   |
| 4      | 3600           | 0.55                        | 0.33                  | 0.9                         | 3                       | 50.8352     | 2.55   |
| 5      | 3800           | 0.55                        | 0.33                  | 0.9                         | 2                       | 62.2222     | 1.90   |
| 6      | 3600           | 0.55                        | 0.33                  | 0.99                        | 2                       | 51.8519     | 2.19   |
| 7      | 3400           | 0.4                         | 0.33                  | 0.99                        | 2                       | 45.7516     | 3.20   |
| 8      | 3600           | 0.7                         | 0.35                  | 0.99                        | 2                       | 53.6399     | 1.80   |
| 9      | 3800           | 0.55                        | 0.33                  | 0.99                        | 3                       | 61.2423     | 2.07   |
| 10     | 3800           | 0.55                        | 0.3                   | 0.99                        | 2                       | 62.2222     | 2.05   |
| 11     | 3600           | 0.55                        | 0.33                  | 0.99                        | 3                       | 51.1696     | 2.54   |
| 12     | 3400           | 0.55                        | 0.33                  | 1.05                        | 2                       | 47.7164     | 3.08   |
| 13     | 3600           | 0.4                         | 0.33                  | 0.99                        | 1                       | 50.1792     | 1.99   |
| 14     | 3600           | 0.55                        | 0.33                  | 0.99                        | 2                       | 52.9101     | 2.17   |
| 15     | 3600           | 0.55                        | 0.35                  | 0.9                         | 2                       | 54.3901     | 2.08   |
| 16     | 3600           | 0.55                        | 0.3                   | 0.9                         | 2                       | 51.8519     | 2.79   |
| 17     | 3400           | 0.55                        | 0.33                  | 0.9                         | 2                       | 48.6111     | 3.30   |
| 18     | 3600           | 0.55                        | 0.33                  | 0.99                        | 2                       | 52.9101     | 2.19   |
| 19     | 3600           | 0.4                         | 0.3                   | 0.99                        | 2                       | 47.7164     | 2.36   |
| 20     | 3400           | 0.55                        | 0.35                  | 0.99                        | 2                       | 48.3092     | 2.95   |
| 21     | 3800           | 0.4                         | 0.33                  | 0.99                        | 2                       | 58.4785     | 1.89   |
| 22     | 3600           | 0.7                         | 0.33                  | 0.99                        | 3                       | 54.7731     | 2.25   |
| 23     | 3600           | 0.7                         | 0.33                  | 0.99                        | 1                       | 56.3607     | 1.68   |
| 24     | 3600           | 0.4                         | 0.35                  | 0.99                        | 2                       | 49.2264     | 2.29   |
| 25     | 3600           | 0.4                         | 0.33                  | 0.9                         | 2                       | 48.9168     | 2.36   |
| 26     | 3600           | 0.55                        | 0.35                  | 0.99                        | 3                       | 51.1696     | 2.50   |
| 27     | 3600           | 0.7                         | 0.33                  | 0.9                         | 2                       | 55.9552     | 2.14   |
| 28     | 3400           | 0.55                        | 0.33                  | 0.99                        | 1                       | 49.2264     | 2.65   |
| 29     | 3600           | 0.7                         | 0.3                   | 0.99                        | 2                       | 56.7721     | 2.18   |
| 30     | 3600           | 0.55                        | 0.33                  | 1.05                        | 1                       | 50.8352     | 1.90   |
| 31     | 3600           | 0.55                        | 0.3                   | 0.99                        | 1                       | 51.8519     | 1.99   |
| 32     | 3800           | 0.7                         | 0.33                  | 0.99                        | 2                       | 64.8148     | 1.70   |
| 33     | 3600           | 0.4                         | 0.33                  | 1.05                        | 2                       | 48.6111     | 2.40   |
| 34     | 3600           | 0.55                        | 0.3                   | 0.99                        | 3                       | 52.1999     | 2.68   |
| 35     | 3600           | 0.55                        | 0.33                  | 0.99                        | 2                       | 52.9101     | 2.20   |
| 36     | 3800           | 0.55                        | 0.33                  | 1.05                        | 2                       | 59.8291     | 1.99   |
| 37     | 3400           | 0.7                         | 0.33                  | 0.99                        | 2                       | 51.8519     | 2.80   |
| 38     | 3600           | 0.55                        | 0.35                  | 1.05                        | 2                       | 51.1696     | 2.34   |
| 39     | 3400           | 0.55                        | 0.3                   | 0.99                        | 2                       | 48.9168     | 3.23   |
| 40     | 3600           | 0.4                         | 0.33                  | 0.99                        | 3                       | 48.3092     | 2.69   |
| 41     | 3600           | 0.55                        | 0.33                  | 0.99                        | 2                       | 53.2725     | 2.18   |
| 42     | 3600           | 0.55                        | 0.35                  | 0.99                        | 1                       | 52.5526     | 1.80   |
| 43     | 3800           | 0.55                        | 0.35                  | 0.99                        | 2                       | 59.3724     | 1.82   |
| 44     | 3600           | 0.7                         | 0.33                  | 1.05                        | 2                       | 56.7721     | 2.03   |
| 45     | 3600           | 0.55                        | 0.33                  | 1.05                        | 3                       | 51.1696     | 2.73   |
| 46     | 3800           | 0.55                        | 0.33                  | 0.99                        | 1                       | 61.2423     | 1.72   |
and t = Machining Time. The surface roughness for the machined Aluminium 6061 alloy is measured using Portable surface roughness tester in National College of Engineering, Tamilnadu, India, is shown in Figure 4.

The mathematical model for the experimental data by cutting the Aluminium 6061 alloy using abrasive water jet machine for MRR and SR is developed using linear regression analysis through Minitab software. The developed regression equations are given below.

Material Removal Rate = 195.719 - 0.360226 A + 99.1877 B + 1516.21 C + 364.430 D - 0.410467 E + 0.0102446 A*B - 0.0265738 A*D + 0.000769113 A*E - 300.422 B*C + 15.6465 B*D + 0.470717 B*E - 438.266 C*D - 18.4785 C*E + 10.3697 D*E

Surface Roughness = 179.473 - 0.0589755 A + 6.28678 B - 132.385 C + 94.7475 D + 1.76521 E + 7.04007E-06 A*E - 2.89173 B*B + 32.5335 C*C + 19.3324 D*D + 0.0255693 E*E + 0.00175000 A*B + 0.00161011 A*C + 0.00528029 A*D - 7.12500E-04 A*E - 19.9095 B*C - 3.55958

IV. Optimization of MRR and SR by Genetic Algorithm

GA is the most advanced evolutionary computational intelligence based optimization techniques for optimizing real world multimodal problems. GA, a known advanced method that was build up by Kennedy and Eberhart. It shows general evolutionary computation characteristics together with the initialization of population with arbitrary solution and finding the optima by filling in the generations. Potential energy solutions are known as particles. They are subsequently “flown” via the critical gap followed by the present optimum particles. Every particle keeping the follow with the coordinates in the critical space achieved an excellence solution. This significance is known as ‘pBest’. One more excellent value which is followed by the global version of the GA is taken as a whole best value and its location received till that instant by means of any of the particle in the population. This location is known as “gBest”. The GA idea contains, every step, varying the velocity (i.e. accelerating) of every particle towards its both the pBest and gBest locations. Random term weighs acceleration with individual arbitrary numbers are being produced for acceleration towards both the pBest and gBest locations. Updating the particles are established by adopting the below equations.

\[ V_{i+1} = w \times V_i + c_1 \times r_1 \times (pBest_i - X_i) + c_2 \times r_2 \times (gBest_i - X_i) \]

\[ X_{i+1} = X_i + V_{i+1} \]

Equation (1) gives a original velocity \( V_{i+1} \) for all particles depending on the preceding velocity, along with pBest and gBest. Equation (2) gives the update individual particles location \( X_i \) in solution hyperspace. The numbers that are in random \( r_1 \) and \( r_2 \) in Equation (1) are independently produced in the range \((0, 1)\). During AWJM, Material Removal Rate and Surface Roughness achieved by the process is the main concern of the engineers. To cut a particular thickness of material, optimum setting of control parameters such as water pressure, abrasive flow rate, orifice diameter, focusing nozzle diameter and stand off distance is very necessary. In this Genetic
Algorithm process, the Mathematical Modeling equation is considered as objective functions for MRR and SR. The table 3 shows the comparison between the Predicted Values of MRR and SR with the actual values and their corresponding error values is also shown in the same table.

The Comparison between Predicted and actual values of MRR and SR using GA is depicted in Figure 5 and 6 and the predicted values are found very closer to the experimental values. The figure 7 and 8 shows the bar chart for RSM and GA Error values for Material removal rate and Surface roughness for Aluminium 6061 Alloy by cutting through Abrasive water jet machining process which shows that the error values for GA is very lower than that of RSM. Table 4 shows the comparison of RSM and GA Least Mean Square Error Values for MRR and SR which shows that the Least Mean Square Error for GA is very less while compared to RSM.
Table 4. Comparison of RSM and GA Least Mean Square Error for MRR and SR

| S. N. | Error MRR using RSM | Error MRR using GA | Least Mean Square MRR | Error SR using RSM | Error SR using GA | Least Mean Square SR |
|------|---------------------|--------------------|-----------------------|-------------------|------------------|---------------------|
| 1    | 0.14080             | 1.170103           | 0.13271               | 0.22129           | 0.44818          | 0.178674            |
| 2    | 0.22388             | 1.118383           | 0.11844               | 1.6361            | 1.73077          | 0.161674            |
| 3    | 1.45588             | 1.975626           | 0.12714               | 1.20364           | 0.0526           | 0.12714             |
| 4    | 0.25550             | 0.582273           | 0.11844               | 0.86209           | 1.65625          | 0.06494             |
| 5    | 0.69819             | 1.506536           | 0.11844               | 1.95643           | 1.27778          | 0.11844             |
| 6    | 0.41977             | 0.145992           | 0.11844               | 0.16391           | 0.19324          | 0.11844             |
| 7    | 2.56409             | 2.075507           | 0.11844               | 1.39366           | 0.34146          | 0.11844             |
| 8    | 0.50632             | 0.307530           | 0.11844               | 1.27126           | 0.90551          | 0.11844             |
| 9    | 0.29358             | 1.142347           | 0.11844               | 1.01542           | 0.06494          | 0.11844             |
| 10   | 0.12061             | 0.822696           | 0.11844               | 1.39366           | 0.34146          | 0.11844             |
| 11   | 1.54391             | 2.304884           | 0.11844               | 1.27126           | 0.90551          | 0.11844             |
| 12   | 1.52144             | 0.013412           | 0.11844               | 1.01542           | 0.06494          | 0.11844             |
| 13   | 0.72729             | 1.223614           | 0.11844               | 0.40004           | 0.1005           | 0.11844             |
| 14   | 0.14600             | 1.527496           | 0.11844               | 1.79693           | 0.36866          | 0.11844             |
| 15   | 0.07038             | 0.733773           | 0.11844               | 2.00431           | 0.24038          | 0.11844             |
| 16   | 0.55435             | 1.793569           | 0.11844               | 2.52001           | 0.75269          | 0.11844             |
| 17   | 0.08528             | 3.288137           | 0.11844               | 0.34481           | 1.45455          | 0.11844             |
| 18   | 0.13708             | 1.546018           | 0.11844               | 2.12195           | 0.63927          | 0.11844             |
| 19   | 1.90753             | 0.184632           | 0.11844               | 0.14304           | 1.73729          | 0.11844             |
| 20   | 0.89915             | 2.309704           | 0.11844               | 1.09612           | 0.23729          | 0.11844             |
| 21   | 1.61904             | 0.624332           | 0.11844               | 0.36569           | 1.21693          | 0.11844             |
| 22   | 0.09159             | 1.789016           | 0.11844               | 0.99553           | 0.13333          | 0.11844             |
| 23   | 0.13984             | 0.002484           | 0.11844               | 0.66169           | 0.29762          | 0.11844             |
| 24   | 1.00225             | 0.477589           | 0.11844               | 0.39509           | 0.82969          | 0.11844             |
| 25   | 1.16609             | 2.030386           | 0.11844               | 1.30973           | 0.55085          | 0.11844             |
| 26   | 0.62                | 1.100653           | 0.11844               | 0.35867           | 0.12             | 0.11844             |
Figure 9 Marching Steps for Maximum MRR and Minimum SR

Figure 9 shows the marching steps for maximum material removal rate and minimum surface roughness and found that the optimized value of MRR and SR using multi objective Genetic Algorithm is shown in table 5.

Table 5 Optimized Value of MRR and SR using Genetic Algorithm

| S  | Pre | Ab | Ori | Foc | Sta | Ma | Surf |
|----|-----|----|-----|-----|-----|----|------|
| 27 | 0.26092 | 1.361803 |     |     |     |     |      |
| 28 | 0.90579 | 2.492971 |     |     |     |     |      |
| 29 | 0.82164 | 1.500208 |     |     |     |     |      |
| 30 | 0.03452 | 0.039146 |     |     |     |     |      |
| 31 | 0.19001 | 0.000192 |     |     |     |     |      |
| 32 | 0.06460 | 1.114714 |     |     |     |     |      |
| 33 | 1.39037 | 0.522308 |     |     |     |     |      |
| 34 | 0.06732 | 0.296935 |     |     |     |     |      |
| 35 | 0.42849 | 0.038744 |     |     |     |     |      |
| 36 | 0.27581 | 1.398316 |     |     |     |     |      |
| 37 | 0.56061 | 0.036642 |     |     |     |     |      |
| 38 | 0.79068 | 0.134650 |     |     |     |     |      |
| 39 | 0.36117 | 0.042316 |     |     |     |     |      |
| 40 | 0.51678 | 1.124423 |     |     |     |     |      |
| 41 | 0.71134 | 1.245670 |     |     |     |     |      |
| 42 | 0.93965 | 0.126920 |     |     |     |     |      |
| 43 | 0.99167 | 0.750111 |     |     |     |     |      |
| 44 | 0.07276 | 1.296411 |     |     |     |     |      |
| 45 | 0.77092 | 0.000586 |     |     |     |     |      |
| 46 | 0.90028 | 0.083602 |     |     |     |     |      |
| 0.88189 | 1.58879 |     |     |     |     |      |
| 0.12 | 0.15094 |     |     |     |     |      |
| 0.69401 | 0.9633 |     |     |     |     |      |
| 2.39642 | 2.36842 |     |     |     |     |      |
| 0.02388 | 0.25126 |     |     |     |     |      |
| 0.56586 | 1.29412 |     |     |     |     |      |
| 0.4587 | 2.20833 |     |     |     |     |      |
| 0.83406 | 2.72388 |     |     |     |     |      |
| 0.13962 | 0.31818 |     |     |     |     |      |
| 1.86871 | 0.75377 |     |     |     |     |      |
| 1.00533 | 0.10714 |     |     |     |     |      |
| 0.99448 | 0.34188 |     |     |     |     |      |
| 1.24783 | 1.73375 |     |     |     |     |      |
| 0.76675 | 2.45353 |     |     |     |     |      |
| 2.48599 | 1.2844 |     |     |     |     |      |
| 2.17561 | 0.05556 |     |     |     |     |      |
| 0.20328 | 0.16484 |     |     |     |     |      |
| 0.61716 | 1.72414 |     |     |     |     |      |
| 0.00119 | 0.43956 |     |     |     |     |      |
| 1.19214 | 1.33721 |     |     |     |     |      |

V. Conclusion

In this paper, using linear regression analysis a mathematical model is developed for Aluminium 6061 Alloy through Abrasive water jet machining process by Minitab software is done. Then the prediction of material removal rate and surface roughness for Aluminium 6061 Alloy by cutting through Abrasive water jet machining process by the tool named GA is done which illustrates that the experimental values are closer to the predicted values. The error comparison between RSM and GA is also studied which shows the least MSE is very less in GA while compared with RSM. Also the...
Prediction and Optimization of Material Removal Rate and Surface roughness on Aluminium 6061 alloy using multi objective Genetic Algorithm is presented in this paper and found that the optimized value of MRR and SR is 60.99 mm³/min and 1.47 µm.

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