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A PARAMETRIC EXPERIMENTAL DESIGN STUDY OF ABRASIVE WATER JET MACHINING

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ABSTRACT

In this research work, Grey Relational Analysis was selected to determine the optimal combination of various input parameters of Abrasive Water Jet. A L9 orthogonal array was employed to study the performance characteristics of cutting operation on Al-6061. With the help of Grey Relational Analysis we were able to obtain optimal combination of process parameters for maximum Material Removal Rate (MRR) and minimum Surface Roughness (R_a).

KEYWORDS: Abrasive Water Jet, Grey Relational Analysis, MRR, Orthogonal Array, Surface Roughness

INTRODUCTION

In Abrasive Water Jet, a narrow stream of water carrying abrasive particles, under controlled conditions, is impinged on work piece. The material is removed from the work piece due to small fracture created by the abrasive particles. Abrasive Jet Machining is used for drilling, deburring, etching, and cleaning of hard and brittle metals, alloys, and non-metallic materials. To achieve optimal machining performance the machining parameters should be chosen properly.

Grey Relational analysis is a part of Grey Theory established by Dr. Deng in 1989. Grey relational analyses provide an efficient and valid conclusion to an experiment or model which has incomplete information by establishing a relationship between two discrete sequences. This purpose of this paper is to use Grey relational analysis to obtain optimal combination of machining parameter for maximum material removal rate (MRR) and minimum surface roughness (SR) and to find the individual effect of each machining parameter on material removal rate and surface roughness.

EXPERIMENTAL DETAILS

Material

In the present study, Al 6061 was used as work piece material. Al 6061 possesses high toughness and hardness. Al 6061 founds its application in aerospace components, marine fittings etc.

Design of Experiment

Design of Experiment is a systematic approach to solve engineering problems that applies principles and techniques of data collection stage so as to generate the best combinations of factors by establishing a relationship between factors affecting a process and the output of the process. In this study, three control variable were used namely, pressure, nozzle distance and disk flow rate. In machining parameter design, three level machining parameters were selected, shown in table 2.1.

Table 1: Parameters with Levels of Experiment

S. No.	Process Parameter's	Unit	Level 1	Level 2	Level 3
1.	Stand-off distance	mm	1.0	1.5	2.0
2.	Pressure	MPa	260	300	340
4.	Disk flow size	mm	0.154	0.184	0.215

A mixed orthogonal L9 array was selected for the experiment. Surface roughness and material removal rate were selected as the response parameters. Table 2 and Table 3 shows the orthogonal L9 array with experimental results of Al 6061 and AISI 4340.

Table 2: L9 Array with Input Parameters and Experimental Results for Al 6061

S. No.	Stand-off Distance (mm)	Pressure (MPa)	Disk Flow Size (mm)	MRR (mm^3/sec)	SR (µm)
1.	1.0	260	0.154	1.452	2.726
2.	1.0	300	0.184	1.793	2.400
3.	1.0	340	0.215	2.660	2.223
4.	1.5	260	0.184	1.535	2.916
5.	1.5	300	0.215	2.006	2.266
6.	1.5	340	0.154	2.505	2.660
7.	2.0	260	0.215	1.644	2.536
8.	2.0	300	0.154	1.879	2.513
9.	2.0	340	0.184	2.513	2.343

EXPERIMENTAL ANALYSIS

Grey Relational Analysis

Grey Relational Analysis is part of The Grey Theory established by Dr. Deng in 1989. Grey relational analysis provides an efficient and valid conclusion to an experiment or model which has incomplete information by establishing a relationship between two discrete sequences. The procedure of multiple performance characteristics optimization using grey relational analysis has been illustrated below:

- **Data Pre-processing:** Normalizing the experimental results according to the type of performance measure that is material removal rate and surface roughness.
- **Grey Relational Grade:** Calculating the Grey relational co-efficient and grey relational grade.
- Analyze the experimental result using grey relational grade.

Data Pre-Processing

In data pre-processing we transfer the original sequence to the comparable sequence.. The normalization is done in three different approaches.

- If the target sequence if infinite then it has the characteristics of the "larger the better". The original sequence is as follows:

$$X_i^*(k) = \frac{X_i^*(k) - \min X_i^0(k)}{\max X_i^0(k) - \min X_i^0(k)} \qquad \text{eq.(3.1)}$$

- If the expectancy is "smaller the better". Then the sequence will be as follows:

$$X_i^*(k) = \frac{\max X_i^0(k) - X_i^0(k)}{\max X_i^0(k) - \min X_i^0(k)}$$

eq.(3.2)

- To achieve a target value then the original sequence in the normalized form will be:

$$X_i^*(k) = 1 - \frac{\left| X_i^*(k) - \min X_i^0(k) \right|}{\max X_i^0(k) - X^0}$$

eq.(3.3)

Where X_i^* (k) is the value after data pre-processing, max X_i^0 (k) is the largest value of X_i^* (k), min X_i^0 (k) is the smallest value of X_i^* (k) and X^0 is the desired value.

The sequences can also be normalized by dividing the original sequence by the first value of sequence

$$X_i^*(k) = \frac{X_i^0(k)}{X_i^0(1)}$$

eq.(3.4)

The data is normalized in the range of zero and one. Following the data-processing, we need to establish a relationship between the ideal and the normalized experimental results. For this we have to calculate a grey relational co-efficient.

The Grey relational Co-efficient can be expressed as follows:

$$\xi_i(k) = \frac{\Delta_{min} + \varsigma.\Delta_{max}}{\Delta_{oi}(k) + \varsigma.\Delta_{max}}$$

eq.(3.5)

Where Δ_{oi} (k) is the deviation sequence of reference X_0^*(k) and the comparability sequence X_i^*(k), namely,

$$\Delta_{oi}(k) = \| X_0^*(k) - X_i^*(k) \|$$

eq. (3.6)

$$\Delta_{max} = \frac{\max \ \min \ \| X_0^*(k) - X_i^*(k) \|}{\forall j \in I \quad \forall k}$$

eq.(3.7)

ς is distinguishing or identification co-efficient:

ς∈ [0, 1]; ς=0.5is generally used.

After obtaining grey relational co-efficient, its average is calculated to obtain the grey relational grade.

Grey Relational Grade

In Grey Relational Analysis, grey relational grade is used to show the relationship among sequences. The grey

relational grade also indicates the degree of influence that the comparability sequence could exert over the reference sequence. The Grey Relational Grade is defined as follows:

$$\xi_i(k) = \frac{1}{n}\sum_{k=1}^{n} \xi i(k) \qquad \text{eq.(3.8)}$$

Table 3 shows the Grey Relational Grade and Rank of the optimal combination of process parameters for work piece material Al 6061.

Table 4: Grey Relational Grade and Rank for Al 6061

S. No.	MRR (mm^3/sec)	SR (µm)	GRG	Rank
1.	0.333333	0.407887	0.37061	8
2.	0.410605	0.661891	0.536248	5
3.	1.000000	1.000000	1.000000	1
4.	0.349335	0.333333	0.341334	9
5.	0.480127	0.889602	0.684865	3
6.	0.795784	0.442246	0.619015	4
7.	0.37284	0.525398	0.449119	7
8.	0.436101	0.544383	0.490242	6
9.	0.804261	0.742765	0.773513	2

If two sequences are identical then the value of grey relational analysis will always be unity.

RESULT AND DISCUSSIONS

Optimal Parametric Combination of Single Responses

Individual mean values of S/N ratio of responses of MRR and SR are shown in Table 6 and Table 7 for Al 6061.

Table 6: Mean of S/N Value Ratio of SR for Al 6061

Levels	Stand-off Distance (mm) (A)	Pressure (MPa) (B)	Disk Flow Size (mm) (C)
1	-7.209	-8.154	-7.896
2	-8.300	-7.571	-8.450
3	-8.043	-7.718	-7.376

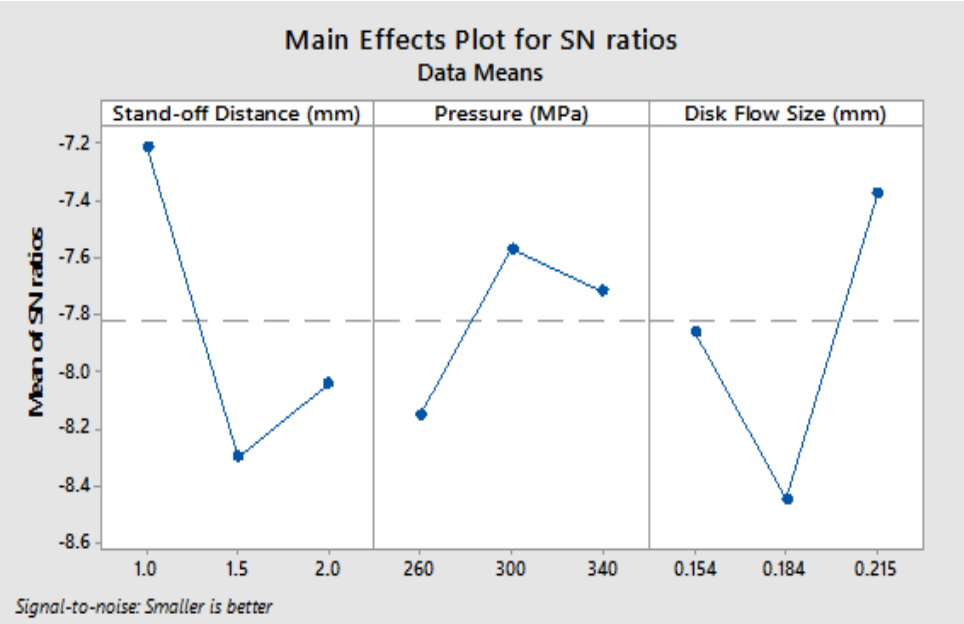

Figure 1: Mean Effect Plot Based on S/N Ratio of SR for Al 6061

Table 7: Mean of S/N Value Ratio of MRR for Al 6061

Level	Stand-off Distance (mm) (A)	Pressure (MPa)(B)	Disk Flow Rate (gm/mm) (C)
1	5.603	3.760	5.565
2	5.915	5.532	5.599
3	5.933	8.159	6.287

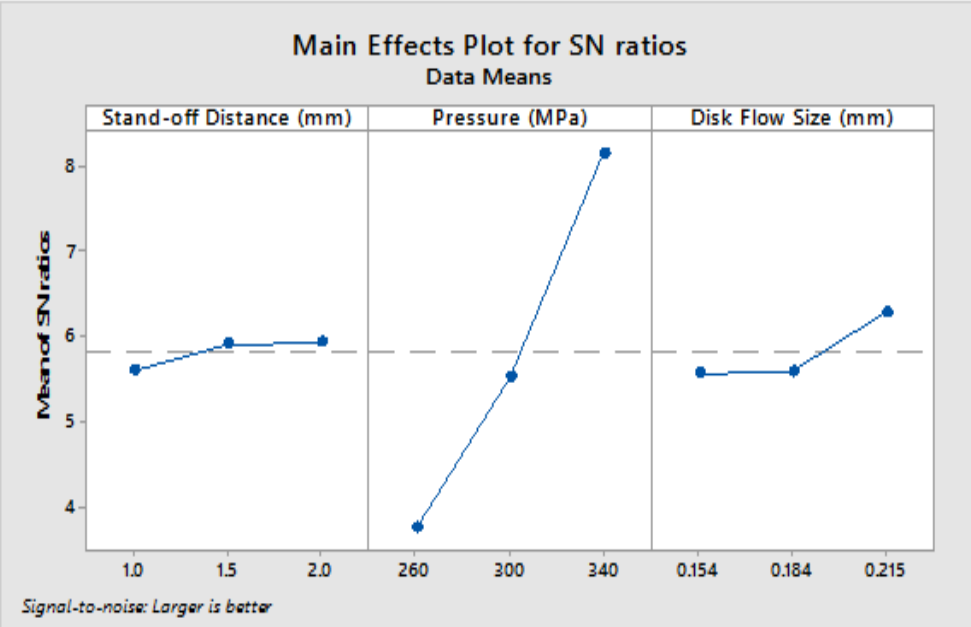

Figure 2: Mean Effect Plot Based on S/N Ratio of MRR for Al 6061

From Table 6 and Table 7 it can be found that optimal level of combination of surface roughness for Al 6061 is A_1, B_2, C_3 and optimal level of combination for MRR is A_3, B_3, C_3.

Optimal Parametric Combination of Multiple Responses

Experiments were conducted based on L9 array. The effect of process parameters on the response parameters was analyzed. Table 8 shows the response of the Grey relational grade from which the optimal levels of combination can be generated.

Table 8: Response Table for Grey Relational Grade Co-Efficient for "Al-6061"

Levels	Factors		
	Stand-off Distance (mm) (A)	Pressure (MPa)(B)	Disc Flow Size (mm)(C)
1.	1.906858	1.161063	1.479867
2.	1.645214	1.711355	1.651095
3.	1.712874	2.392528	2.133984

By observing table 8 we can conclude that A_1, B_3, C_3 are the optimal level of combination for Al 6061.

CONCLUSIONS

The work presented in the paper is an attempt to obtain the optimal combination of process parameters in order to obtain maximum MRR and minimum Surface roughness. The obtained optimal combination single responses for Al 6061 is A_1, B_2, C_3 for SR and optimal level of combination for MRR is A_3, B_3, C_3. For combined responses the optimal combination are A_1, B_3, and C3 for Al 6061.

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