Application of Grey Relation Analysis for Optimization of Abrasive jet machining on Glass

D.V.Sreekanth¹, M.Sreenivasa Rao²

¹Department of Mechanical Engineering, St.Martin’S Engineering college, Hyderabad,
²Department of Mechanical Engineering, JNTUCE, JNTU, Kukatpally, Hyderabad, India

ABSTRACT
Optimisation of Process parameters of multiple response characteristics of Abrasive jet machining on glass using Grey taguchi Fuzzy- Grey relational analysis is presented in this paper. Response characteristics such as MRR, and KERF are optimized during the machining operation. The investigation is performed by selecting the process parameters including pressure, Stand off distance and Nozzle diameter based on DOE Taguchi L9 orthogonal array. These response characteristics are analysed using Gray taguchi and grey-fuzzy approaches and optimal combination of influential input parameters are obtained. Based on the results of verification experiments it is concluded that Taguchi, Fuzzy-Grey Relational Analysis can efficaciously be used to find the optimal combination of influential input parameters of AJM.

KEY WORDS: AJM, Nozzle, Taguchi, DOE, MRR, KERF, L9.

1 INTRODUCTION
Abrasive jet machining is one of the promising non conventional machining process, where the metal removal takes place due to erosion [2, 6]. Abrasive particles like silicon carbide, Aluminium oxide are made to impinge on the work surface with velocity ranging from 150m/s to 300 m/s [7]. The pressure energy of air is converted into velocity in this process. A separate mixing chamber is used for mixing of compressed air with abrasive particles.

The effective machining parameters influencing the Abrasive jet machining are Pressure, Standoff distance (SOD), Nozzle diameter (ND), Abrasive flow rate (AFR), size of abrasive particle and type of the abrasive used[3,4]. The metal removal rate in AJM is mainly influenced by pressure followed by other parameters. It has been observed that SOD influences the width of cut (KERF) and based on shape, size and coarseness of grain the metal removal varies.

In this paper it is discussed about optimization of Abrasive jet machining process parameters with glass as working material. Borosilicate glass is selected for these experiments [8].

Boro-Silicate glass (or sodium-Boro silicate glass) is made primarily of silica (70-80%) and boric oxide (7-13%) with little quantity of the soluble bases (sodium and potassium oxides) and aluminum oxide. This sort of glass is generally low antacid substance and therefore has both fabulous synthetic sturdiness and warm stun resistance - meaning it doesn’t break while changing temperature rapidly. As a consequence of these properties, sodium borosilicate glass is generally utilized over the synthetic business, pharmaceutical segment for research facility mechanical assembly, for ampoules and other pharmaceutical holders, different high force lighting applications and as glass strands for material and plastic fortification - too, obviously, for basic family broiler and cook wares.
Table 1: Chemical Composition of Borosilicate glass

| Composition    | (percent approx.) |
|----------------|-------------------|
| SiO₂           | 80.6%             |
| B₂O₃           | 13.0%             |
| Na₂O           | 4.0%              |
| Al₂O₃          | 2.3%              |
| Miscellaneous Traces | 0.1%        |

Fig 1: Machining of glass by Abrasive Jet Machining

METHODOLOGY (Grey Relation Analysis)
The Grey Relational Analysis is an effective method in which analyses are done among the sequence groups which should satisfy all sequences comparability conditions. For instance, non-dimension, scaling, and polarization attributes. It can be used for solving the complicated interrelationships among the multi responses. This method is used to analyze the multi-performances in experimental studies and has some advantages over other statistical methods. When the experimental method cannot be carried out exactly, grey relational analysis helps to compensate for the shortcoming in statistical regression. Grey relation analysis is an effective means of analyzing the relationship between sequences with less data and can analyze many factors that can overcome the disadvantages of statistical method.

EXPERIMENTATION Based on Design of Experiments L9 orthogonal array the experiments are conducted.
The parameters like Pressure, Standoff distance and Nozzle diameter are considered as variable parameters and Abrasive grain size and flow rate of abrasive particles are kept constant.

The variable levels that are considered based on the parameters are, a) pressure 6.7,8 kg/cm², b) standoff distance 8,9,10mm and c) Nozzle diameter 2,3,4 mm. The parameters and their levels are mentioned in table 2.

Table 2: Input parameters and levels for experimentation

| Process Parameters | Level 1 (Low) | Level 2 (Medium) | Level 3 (High) |
|--------------------|--------------|------------------|----------------|
| PRESSURE           | 6            | 7                | 8              |
| SOD                | 8            | 9                | 10             |
| ND                 | 2            | 3                | 4              |

The selection of parameters for experimentation is done as per Fractional factorial design. An array for three controllable parameters is used to construct the matrix of three levels of controllable factors. Minitab is used to generate the necessary fraction of experiments out of whole set of experiments possible with four factors at three levels.

By considering the above input parameters experiments are carried out and the Material removal rate, Kerf are calculated. The values of MRR and KERF are mentioned in table 3.

Table 3. L9 Orthogonal Array Design of Experiments

| S.NO | Pressure | SOD | ND | MRR   | KERF |
|------|----------|-----|----|-------|------|
| 1    | 6        | 8   | 2  | 0.0402| 3.5  |
| 2    | 6        | 9   | 3  | 0.0513| 3.1  |
| 3    | 6        | 10  | 4  | 0.08  | 6.2  |
| 4    | 7        | 8   | 3  | 0.0612| 4.1  |
| 5    | 7        | 9   | 4  | 0.0298| 4.8  |
| 6    | 7        | 10  | 2  | 0.0745| 3.6  |
| 7    | 8        | 8   | 4  | 0.1   | 5.3  |
| 8    | 8        | 9   | 2  | 0.0513| 5.8  |
| 9    | 8        | 10  | 3  | 0.0964| 4.4  |

Signal - To - Noise Ratio Calculation
The Taguchi method aims to find an optimal combination of parameters that have the smallest variance in performance. The signal to noise ratio (S/N ratio, η) is an effective way to find significant parameters by evaluating minimum variance.

112
From this experimental setup 9 experiments are conducted to optimize the parameters to get a optimized minimum value of Kerf, and maximum material removal rate. The S/N ratios for each Kerf values is generated with the formulae of “smaller is better” and S/N ratios of MRR are generated with the formulae of “higher-is-better” because the MRR must be always maximum.

Smaller-The-Better : n=–10 Log10 [mean of sum squares of measured data]

Larger-The-Better : n =–10 Log10 [mean of sum squares of reciprocal of measured data].

GREY RELATION GENERATION

At the point when the units in which execution is measured are diverse for various traits, the impact of a few characteristics might be dismissed. This may likewise happen if some execution characteristics have an expansive range. Also, if the objectives and bearings of these qualities are distinctive, this will bring about wrong results during the examination. It is accordingly important to process all execution values for each option into a similarity arrangement, in a procedure comparable to standardization. This preparation is called generating of grey relation in GRA.

For Higher-the-better quality, normalizing data is calculated by

\[ x^*i(k) = \frac{(x^0i(k) - \min x^0i(k))}{(\max x^0i(k) - \min x^0i(k))} \]

For Lower-the-better quality, normalizing data is calculated by

\[ x^\bar{i}(k) = \frac{(\max x^0i(k) - x^0i(k))}{(\max x^0i(k) - \min x^0i(k))} \]

\[ k = 1 \text{ to } n, \ i = 1 \text{ to } 9 \ ]; \ “n” \text{ is the performance characteristic and “i” is the trial number} \]

\[ x^0i(k) \rightarrow \text{is the sequence after data normalizing} \]

\[ x^*i(k) \rightarrow \text{is the original sequence} \]

\[ \max x^0i(k) \rightarrow \text{is the largest value of } x^0i(k) \]

\[ \min x^0i(k) \rightarrow \text{is the smallest value of } x^0i(k) \]

Before generating grey relation coefficients the output data is to be normalised, and the normalised data is given in table 5.

Table 5. Grey relational generation of each Response variable

| S.NO | MRR Normalized | KERF Normalized |
|------|----------------|-----------------|
| 1    | 0.148          | 0.871           |
| 2    | 0.306          | 1               |
| 3    | 0.715          | 0               |
| 4    | 0.447          | 0.677           |
| 5    | 0              | 0.452           |
| 6    | 0.637          | 0.839           |
| 7    | 1              | 0.29            |
| 8    | 0.306          | 0.129           |
| 9    | 0.949          | 0.581           |

The grey relational coefficient is calculated from the normalized experimental data to express the relationship between the ideal and the actual experiment.

\[ I(k) = \frac{(\Delta_{\text{min}} + \psi \Delta_{\text{max}})(\Delta_{\text{oi}} + \psi \Delta_{\text{max}})}{\Delta_{\text{oi}} + \psi \Delta_{\text{max}}} \]

\[ \Delta_{\text{oi}} = \| x^*o(k) - x^*i(k) \| \]

\[ \Delta_{\text{max}} = \max \| x^*0(k) - x^*i(k) \| \]

Where,

\[ x^*0(k) \text{ is the reference sequence} \]

\[ x^*i(k) \text{ is the compatibility sequence} \]

\[ \psi \text{ is 0 to 1, in general } \psi = 0.5 \]
Table 6. Grey relational Coefficient for each output parameter ($\Psi=0.5$)

| S NO | GRC of MRR | GRC of KERF |
|------|------------|-------------|
| 1    | 0.37       | 0.795       |
| 2    | 0.419      | 1           |
| 3    | 0.637      | 0.333       |
| 4    | 0.475      | 0.608       |
| 5    | 0.333      | 0.477       |
| 6    | 0.579      | 0.756       |
| 7    | 1          | 0.413       |
| 8    | 0.419      | 0.365       |
| 9    | 0.907      | 0.544       |

The grey relational grade is computed by averaging the grey relational coefficients corresponding to each process response. The overall evaluation of the multiple process responses is based on the grey relational grade. High Grey relational grade gives the optimal solutions.

The grey relational grade is obtained by:

$$y_i = \frac{1}{n} \sum_{k=1}^{n} \varepsilon_i(k)$$

Where, $y_i$ is the grey relational grade and $n$ is the number of performance characteristics. High grey relational grade gives the optimal conditions. The experiment numbers and the grades with the ranking of larger value of grey relation grade to smaller value are tabulated.

Table 7. Summary of Grey relational grades and their ranks

| Experiment No | Overall grey relational grade | Rank |
|---------------|-------------------------------|------|
| 1             | 0.582                         | 5    |
| 2             | 0.709                         | 2    |
| 3             | 0.485                         | 7    |
| 4             | 0.541                         | 6    |
| 5             | 0.405                         | 8    |
| 6             | 0.668                         | 4    |
| 7             | 0.707                         | 3    |
| 8             | 0.392                         | 9    |
| **9**         | **0.725**                     | **1**|

From table 7, it is observed that the experiment no. 9 has the highest grey relational grade. The levels of machining characteristics in the above experiment are Material Removal Rate (0.0964 g/s), Kerf (4.4 mm).

Table 8. Response table for the Grey Relational Grades

| Level   | PRESSURE | SOD  | ND    |
|---------|----------|------|-------|
| Level 1 | 0.5920   | 0.6100| 0.5473|
| Level 2 | 0.5380   | 0.5020| 0.6583|
| Level 3 | 0.6080   | 0.6260| 0.5323|
| Delta   | 0.0700   | 0.1240| 0.1260|
| Rank    | 3        | 2    | 1     |

However, the relative importance among the machining parameters for the multiple performance characteristics still needs to be known, so that the optimal combinations of the machining parameter levels can be determined more accurately. The main effect plot of GRG is drawn. The ordinate of it represents the means of grey relational grade calculated using larger - the - better criteria. The larger the grey relational grade, the better are the multiple performance characteristics. From the main effects plot graph, the optimal parametric combination is determined. The graph generated shows the optimum combination of parameters with corresponding values. Based on this the main effect plot of means indicates the effect of process parameters on Grey relation and the rank analysis based on the graph of mean. As it is observed that the effect of nozzle diameter influences more and followed by SOD and Pressure.

Fig 2 : Main effect plots of Means indicates the effect of parameters.

114
CONFORMATION OF RESULTS

For the selection of optimal parameters with its levels to evaluate the quality characteristics for Abrasive jet machining on glass, a confirmation test has to be conducted. From the grey relational analysis it shows that the highest grey relation grade (GRG) indicating the initial process parameter set of (A3 B2 C2) for the best multiple performance characteristics among the nine experiments.

The optimal grey relational grade (GRGopt) is predicted by using the following equation:

\[ GRG_{opt} = GRG_{mean} + \sum_{i=1}^{n} (GRG_i - GRG_{mean}) \]

Where
\( GRG_{mean} \) is the average of Grey relational grade,
\( GRG_i \) is the average of grey relational analysis at optimum level
and \( n \) is the significantly affecting process parameters.

The predicted value of optimal grey relational grade is expressed by taking \( n = 3 \) since there are four significant parameters.

The predicted value of optimal Grey Relational Grade is calculated as:

\[ GRG_{opt} = 0.57933 + (0.608 - 0.5793) + (0.626 - 0.5793) + (0.658 - 0.5793) = 0.7248 \]

Table 9. Experimental and predicted values of GRG

| Optimal process parameters | Predicted Value | Experimental Value |
|---------------------------|-----------------|--------------------|
| Level                     | A3 B3 C2        | A3 B3 C2           |
| MRR (gm/sec)              | 0.907           | 0.964              |
| KERF(mm)                  | 3.1             | 3.1                |
| GRG                       | 0.7248          | 0.725              |

ANOVA and its Significance for grey relational grade (GRG)

Analysis of variance method (ANOVA) is used to select significant factors. It is used to evaluate the response magnitude in (%) of each parameter in the orthogonal experiment. It is used to identify and quantify the sources of different trial results from different trial runs (i.e. different machining parameters).

Analysis of Variance

| Source       | DF | Adj SS   | Adj MS   | F-Value | P-Value |
|--------------|----|----------|----------|---------|---------|
| PRESSURE     | 2  | 0.008074 | 0.004037 | 11.95   | 0.902   |
| SOD          | 2  | 0.027294 | 0.013647 | 37.07   | 0.731   |
| ND           | 2  | 0.028635 | 0.014318 | 39.39   | 0.721   |
| Error        | 2  | 0.074112 | 0.037056 |         |         |
| Total        | 8  | 0.138116 |          |         |         |

Regression Equation

Grey Relation Grade = 0.5794 + 0.0129 PRESSURE_6 - 0.0414 PRESSURE_7 + 0.0285 PRESSURE_8 + 0.0307 SOD_8 - 0.0773 SOD_9 + 0.0466 SOD_10 - 0.0322 ND_2 + 0.0793 ND_3 - 0.0471 ND_4

The basic property of ANOVA is that the total sum of the squares (total variation) is equal to the sum of the SS (sums of the squares of the deviation) of all the condition parameters and the error components. The variance with F-Values shows the ANOVA for Grey Relational Grades obtained by using MINITAB software.

ANOVA results in the order of importance of the machining parameters are Nozzle diameter, standoff distance followed by pressure of the AJM machining. The results of the ANOVA for the grey grade values are represented .The ANOVA results of the grade values are obtained through F-Test .The analysis of variance values are similar to the response table of grey relation grade rankings.

Fig 3: Glass sheets drilled by Abrasive jet machine
CONCLUSION

This paper discusses the use of Taguchi Grey relational analysis for the optimization of the Abrasive jet machining process on an Boro-silicate glass with multiple performance parameters or Characteristics. This technique is more convenient and economical to predict the optimal machining parameters. Based on the results, the performance characteristics such as MRR, KERF can be improved through this approach. Experiments were conducted to confirm this approach. Based on the results of the experiments conducted and tests for confirmation of results the following conclusions can be drawn:

- The experimental results for optimal settings showed that there was a considerable improvement in the performance characteristics viz., metal removal rate, Width of cut (KERF).

- The most important factors affecting the AJM process robustness have been identified as Nozzle diameter (ND), Standoff distance (SOD) and Pressure.

- The following factor settings have been identified as to yield the best combination of process variables: A3B2C2.

- The ANOVA results of the grade values are obtained through F-Test. The analysis of variance values are compared and found that they are similar to the response table value of grey relation grade rankings.

REFERENCES:

[1] A P Verma and G K Lal. 'An Experimental Study of AbrasiveJet Machining'. International Journal of Machine Tool Design and Research, vol 24,-110 I, 1984.

[2] I Finnie. 'Erosion of Surface by Solid Particles'. Weir, vol 3,1960.

[3] P K Sarkar and P C Pandey. 'Some Investigations on the Abrasive Jet Machining', Journal of the Institution of Engineers (India), vol 56, ME 6,1976.

[4] R Balasubramaniam, J Krishnan, N Ramakrishnan An experimental study on the abrasive jet deburring of cross-drilled holes, Journal of Materials …, 1999 – Elsevier.

[5] Balasubramaniam, J Krishnan, N Ramakrishnan Preparation of edge radius in AJEM - Journal of Materials …, 2000 – Elsevier.

[6] Morrison, C.T., Scattergood, R.O., Routbort, J.L. (1986). Erosion of 304 stainless steel.Wear 111, 1-13 lsdr33 Elsevier.

[7] Bhaskar Chandra1, Jagtar Singh2 A Study of effect of Process Parameters of Abrasive jet machining- International Journal of Engineering Science and Technology (IJEST) Vol. 3 No. 1 Jan 2011.

[8] V.C.Venkatesh, T.N.Goh, K.H.Wong, M.J.Lim - An empirical study of parameters in Abrasive Jet Machining 1989, Int Journal of Machine Tools and Mfg

[9] D.S. Robinson Smart , 2011. Experimental Investigation of Effect of Abrasive Jet Nozzle Position and Angle on Coating Removal Rate. International Journal of Manufacturing Systems, 1: 57-64