OPTIMIZATION OF PROFILE AND MATERIAL OF ABRASIVE WATER JET NOZZLE

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ABSTRACT

The objective of this work is to study the behaviour of the abrasive water jet nozzle with different profiles and materials. Taguchi-Grey relational analysis optimization technique is used to optimize the value with different material and different profiles. Initially the 3D models of the nozzle are modelled with different profiles by changing the tapered inlet angle of the nozzle. The different profile models are analysed with different materials and the results are optimized. The optimized results would give the better result taking wear and machining behaviour of the nozzle.

INTRODUCTION

Abrasive water jet machining is the process of cutting materials with good finish on the machined surface unconventionally. This process can be implemented in broad range of industries where both hard and brittle materials can be machined effectively using this process [2]. The problem associated with these high speed jet nozzles are wear along the nozzle walls [11]. The wear at the wall of the nozzle is mainly due to the complex function of particle impact and wall properties [3]. Also these complex phenomenons include the geometry of the nozzle and other operating parameters [4]. Jukti et al [5] has done major experiment on this abrasive water jet machining process and said that experiments in future had to be done with various ceramic materials.

The main objective of the work is to study the wear in the nozzle walls with different profile and materials. Junkar et al [6] has concluded from his work that an explicit Finite
Element Analysis can be used for understanding the influences of process parameters on it. The nozzle materials vary differently which depends on the operating pressure and nozzle design [7] and hence there are not large materials available for selection of nozzle material. Ye et al [8] in his paper had concluded that the internal shape of nozzle which is critical to the acceleration of abrasive particles and to the wear of the nozzle. The work also states that the optimized inlet angle can lead to less erosion along the walls. Deepak et al [9] has experimented on abrasive water jet machining technique and concluded that increasing the inlet pressure makes an increase in skin friction coefficient.

By taking these aspects into consideration to improve wear resistance and machining process, nozzle geometry and nozzle materials are taken as parameters. The optimized result gives the perfect result to improve the wear and machining behaviour of the nozzle.

EXPERIMENTS AND METHODS

The 3D model of the nozzle is modelled using the Catia V5 R20 software. The basic dimensions taken for modelling the nozzle are

Diameter  -  1mm

Length  -  20mm

Cylindrical Tube Length  -  6mm

Four models of the nozzle is modelled using four different inlet angles respectively. The four different inlet angles used are 50°, 60°, 70°, 80°.
In the selection process of the materials the main aspects considered are the wear properties of the material. The ability to withstand high pressure within the nozzle and the ability to withstand the abrasive particles striking the walls during the machining process are the main factor considered for selecting the material. The temperature does not affect the material selection as the whole of the process takes place approximately within the room temperature. The materials that are selected also do not react to the water as water is the carrier of abrasive particles. Based on these aspects, the major materials to be considered in this experiment are

- Hardened Steel (HS)
- Silicon Carbide (SiC)
- Titanium Carbide (TiC)
- Tungsten Carbide (WC)

For four different inlet angles and four different materials, the finite element analysis is done using the Ansys 14 software for a constant load. By performing the finite element analysis on the nozzle the total deformation on the nozzle and the maximum stress induced
along the walls of the nozzle can be numerically obtained. Though the numerical analysis
doesn’t give perfect result when compared to practically made experimental results, it gives
proper idea to the perfect results and helps to save cost and valuable time.

The constant load that is used in this project work is 3.5E5 Pa pressure which is
assumed to be acting along the cylindrical tube of the abrasive water jet nozzle.

For the four different materials and four different inlet angles the orthogonal array will
be $2^4$, which is total number of 16 experiments.

The analysis is done and the total deformation and the stress values are noted in the
experimental design tabulation for further optimization process.

![Fig 2: Total Deformation result for 60° inlet angle and Hardened steel material](image)

![Fig 3: Stress result for 60° inlet angle and Hardened steel material](image)
Table 1: Parameters level used in the experiment

| Variables   | Levels |
|-------------|--------|
| Inlet Angle (deg) | 1     | 2     | 3     | 4     |
|             | 50    | 60    | 70    | 80    |
| Materials   | HS    | SiC   | TiC   | WC    |

Table 2: Experimental design with observed results

| Trial | Inlet angle (deg) | Material | Deformation (m) ×10^9 | Stress (pa) ×10^5 |
|-------|-------------------|----------|-----------------------|------------------|
| 1     | 50                | HS       | 2.7003                | 8.8971           |
| 2     | 50                | SiC      | 1.2621                | 9.4299           |
| 3     | 50                | TiC      | 1.3223                | 9.2638           |
| 4     | 50                | WC       | 0.9689                | 8.8581           |
| 5     | 60                | HS       | 2.911                 | 9.3033           |
| 6     | 60                | SiC      | 1.3652                | 9.7185           |
| 7     | 60                | TiC      | 1.4291                | 9.5809           |
| 8     | 60                | WC       | 0.9992                | 9.2765           |
| 9     | 70                | HS       | 2.6866                | 8.5684           |
| 10    | 70                | SiC      | 1.2532                | 9.105            |
| 11    | 70                | TiC      | 1.3143                | 8.9388           |
| 12    | 70                | WC       | 0.9222                | 8.5282           |
| 13    | 80                | HS       | 2.6338                | 8.8344           |
| 14    | 80                | SiC      | 1.2245                | 9.3776           |
| 15    | 80                | TiC      | 1.2862                | 9.2091           |
| 16    | 80                | WC       | 0.9042                | 8.794            |
The optimization process to be used is the Taguchi-Grey relational method as there is more than one response in the experimental design.

The S/N ratio for the observed results are found out using the formula

\[ Y_{ij} = -10\log(y^2) \]

which is the formula for smaller the better

Since the deformation and stress values have to be minimised, the approach that is used in this particular experiment is smaller the better for both the responses.

Table 3: S/N ratios for the responses

| Trail | Deformation | Stress  |
|-------|-------------|---------|
| 1     | 173.372     | -118.985|
| 2     | 177.393     | -119.490|
| 3     | 177.57      | -119.336|
| 4     | 180.274     | -118.947|
| 5     | 170.718     | -119.372|
| 6     | 177.297     | -119.752|
| 7     | 176.899     | -119.628|
| 8     | 180.01      | -119.348|
| 9     | 171.414     | -119.658|
| 10    | 178.041     | -119.186|
| 11    | 177.62      | -119.026|
| 12    | 180.705     | -118.617|
| 13    | 171.588     | -118.924|
| 14    | 178.237     | -118.442|
| 15    | 177.815     | -119.284|
| 16    | 180.877     | -118.884|

The next step is to find out the normalised S/N ratio for the above S/N ratio. The formula for normalised S/N ratio for smaller the better is
\[ X_{ij} = \frac{(\max Y_{ij} - Y_{ij})}{(\max Y_{ij} - \min Y_{ij})} \]

Table 4: Normalised S/N ratio for the responses

| Trail | Deformation | Stress |
|-------|-------------|--------|
| 1     | 0.935       | 0.324  |
| 2     | 0.343       | 0.769  |
| 3     | 0.325       | 0.6334 |
| 4     | 0.059       | 0.291  |
| 5     | 1           | 0.665  |
| 6     | 0.352       | 1      |
| 7     | 0.392       | 0.890  |
| 8     | 0.085       | 0.644  |
| 9     | 0.931       | 0.036  |
| 10    | 0.279       | 0.501  |
| 11    | 0.320       | 0.360  |
| 12    | 0.0169      | 0      |
| 13    | 0.914       | 0.270  |
| 14    | 0.259       | 0.727  |
| 15    | 0.301       | 0.588  |
| 16    | 0           | 0.23   |

The next step is to find out the grey relational grade, which helps in indicating the relational degree between the sequences of the response. The grey relational coefficient can be calculated using the formula

\[ GC_{ij} = \frac{(\Delta_{min} + \Psi \Delta_{max})}{(\Delta_{ij} + \Psi \Delta_{max})} \]
After calculating the grey relational coefficients, the grey relational grade value is calculated by calculating the average value of the grey relational coefficient of both the responses. Grey relational grade gives the relational degree between the sequences.

Table 5: Grey relational coefficient and Grey relational grade

| Trial | Grey coefficient (deformation) | Grey coefficient (stress) | Grey relational grade $G_i$ |
|-------|-------------------------------|---------------------------|-----------------------------|
| 1     | 0.897                         | 0.597                     | 0.768                       |
| 2     | 0.603                         | 0.812                     | 0.707                       |
| 3     | 0.597                         | 0.732                     | 0.665                       |
| 4     | 0.515                         | 0.585                     | 0.55                        |
| 5     | 1                             | 0.749                     | 0.875                       |
| 6     | 0.607                         | 1                          | 0.804                       |
| 7     | 0.622                         | 0.9                        | 0.761                       |
| 8     | 0.522                         | 0.737                     | 0.629                       |
| 9     | 0.935                         | 0.509                     | 0.722                       |
| 10    | 0.581                         | 0.667                     | 0.624                       |
| 11    | 0.595                         | 0.609                     | 0.602                       |
| 12    | 0.504                         | 0.5                        | 0.502                       |
| 13    | 0.921                         | 0.578                     | 0.749                       |
| 14    | 0.574                         | 0.785                     | 0.679                       |
| 15    | 0.589                         | 0.708                     | 0.648                       |
| 16    | 0.5                           | 0.566                     | 0.533                       |

RESULTS AND DISCUSSION

Grey relational grade gives the relational degree between the sequences. After calculating the entire grey relational grade, a response table is created by providing the grey relational grade for each level of the variable.
Table 6: Response table for Grey relational grade

| Variables | Level 1 | Level 2 | Level 3 | Level 4 |
|-----------|---------|---------|---------|---------|
| Angle     | 0.684   | 0.767   | 0.6425  | 0.652   |
| Material  | 0.790   | 0.704   | 0.669   | 0.583   |

The above response table gives the value of the grey relational grade for each variables in every level.

![Grey Relational Grade](image)

**Fig: 4 Grey Relational Grade**

**CONCLUSION**

The Taguchi grey relational analysis optimizes the result to be $70^\circ$ tapered inlet angle and tungsten carbide material. From the experiment the change in wear properties by changing the profile of the nozzle and by changing the material is found out.

The optimised inlet angle and proper selection of material can reduce the wear along the walls of the nozzle. The nano abrasive particles with the nanotechnology can be used for abrasive particles to reduce erosion along the walls of the nozzle and future work can be done in the process of using nano particles for abrasives.
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