Abrasive water jet machining is renowned over other technologies due to the absence of heat generation in the work piece during the process. Moreover, scarce research has been carried out over Ni-Cr alloy which is therefore considering the current study. Our experimental observations made during water jet machining of Ni-Cr alloy are: super surface finish is attained on considerably lower transverse speed and jet pressure while stand-off-distance has no effect; higher material removal rate is achieved at higher transverse speed while jet pressure and stand-off-distance has negligible effect. A mathematical model is developed successfully using regression analysis a prediction accuracy of 92.31% and 92.61% is attained for surface roughness and material removal rate respectively. In addition ANOVA analysis revealed optimal machining conditions for response variable surface roughness and material removal rate.

I. INTRODUCTION

A super alloy, or high-performance alloy, is an alloy that exhibits several key characteristics: excellent mechanical strength, resistance to thermal creep deformation, good surface stability and resistance to corrosion or oxidation. Nickel-based alloys generally have better high-temperature strength than alloy steels. Nickel is the base metal. The principal alloying elements are chromium and cobalt; lesser elements include aluminum, titanium, molybdenum, niobium (Nb), and iron. Some familiar names in this group include Inconel, Nimonic, Hastelloy, and Rene 41.

In this research work NIMONIC C263 super alloy is used as work piece material. In the recent years researchers are carried out on the NIMONIC C 263 alloy on various Non Conventional machining processes like Die sinking[1-3] to evaluate the Material Removal rate, Surface roughness and Tool Wear rate.

II. EXPERIMENTAL SETUP

2.1. Material:
The work piece used is Nimonic C-263 super alloy having a chemical composition as shown in Table 1. The dimensions considered are a flat plate of 30mm X 15 mm with a thickness of 3 mm.

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Ni</th>
<th>Cr</th>
<th>Co</th>
<th>Mo</th>
<th>Ti</th>
<th>Al</th>
<th>Fe</th>
<th>Cu</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight %</td>
<td>49.0</td>
<td>19.0-</td>
<td>19.0-</td>
<td>5.6-</td>
<td>1.9-</td>
<td>&lt; 0.6</td>
<td>0.7</td>
<td>0.2</td>
<td>0.04-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21.0</td>
<td>21.0</td>
<td>6.1</td>
<td>2.4</td>
<td>max</td>
<td>max</td>
<td>max</td>
<td>0.08</td>
</tr>
</tbody>
</table>
2.2. Equipment used:
Water jet machine widely used for cutting plastic, cloth, rubber, paper and leather, because of the lack of heat it produces kerf very narrow, and if set up correctly produce very smooth edges no scraps or burrs. Water jet machine is a very clean job with no dust or noise, door and very little, in fact, the health and safety and environmental impact is minimal, almost.

The water jet cutting machine uses a stream of water and abrasive particles, such as garnet, to perform the cutting operation. The water jet cutter takes city water (typically 80 psi), and through the use of an intensifier-type pump, pressurizes the water to 55,000 psi. When the abrasive jet cutting head is enabled, the water flows through a 0.010-inch diameter orifice into a mixing chamber. As the water jet stream enters the mixing chamber, it creates a partial vacuum that draws the flow of abrasive particles through the abrasive delivery line. The abrasive particles combine with the water jet stream to create the high energy abrasive jet cutting stream. This stream exits the cutting head at a velocity of up to 3,000 feet per second. Today’s water jet cutting machines are CNC controlled for accuracy, repeatability and ease of setup.
2.3. Surface Roughness Tester:
Surface roughness, for purposes of this forum, is the result of some machining process and its effect on the material surface in question.

Skid type surface roughness testers are common instruments used on the shop floor. A diamond stylus is traversed across the specimen and a piezoelectric pickup records all vertical movement. Peaks and valleys are recorded and converted into a known value of a given parameter.

Parameters differ in how they approach looking at peaks and valleys. The most popular parameter is “Ra”. Ra is commonly defined as the arithmetic average roughness. While the Ra parameter is easy and efficient, there are other parameters that can be more specific and useful depending on the application requirements. It is the parameters that enable us to define surface roughness.
III. DESIGN PLAN

Table 2: L27 orthogonal array

<table>
<thead>
<tr>
<th>S.No</th>
<th>Jet Pressure</th>
<th>Transverse Speed</th>
<th>Stand-off Distance(SOD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>240</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>240</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>240</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>240</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>240</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>240</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>240</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>240</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>240</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>210</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>210</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>210</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>210</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>210</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>210</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>16</td>
<td>210</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td>210</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>18</td>
<td>210</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>19</td>
<td>180</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>180</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>21</td>
<td>180</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>22</td>
<td>180</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>23</td>
<td>180</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>24</td>
<td>180</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>25</td>
<td>180</td>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>26</td>
<td>180</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td>27</td>
<td>180</td>
<td>30</td>
<td>3</td>
</tr>
</tbody>
</table>
3.1. Material Removal Rate:
The Material Removal Rate (MRR) was calculated using the formula given below

\[
MRR = \frac{\text{Material lost per each slot (gm/sec)}}{\text{Time taken per each slot}}
\]

Material lost per each slot = \(\frac{\text{Before cutting weight} - \text{after cutting weight (gm/sec)}}{\text{Number of slots}}\)

The Regression equation is

\[
MRR = -0.00263 + 0.000011 \text{ JP} + 0.00104 \text{ TS} + 0.000252 \text{ SOD}
\]

\[
S = 0.00116475 \quad R-Sq = 98.4\% \quad R-Sq(adj) = 98.2\%
\]

\[
\begin{array}{|c|c|c|c|c|}
\hline
\text{Predictor} & \text{Coef} & \text{SE Coef} & \text{T} & \text{P} \\
\hline
\text{CONSTANT} & -0.002629 & 0.002085 & -1.26 & 0.220 \\
\text{JET SPEED} & 0.00001089 & 0.00000915 & 1.19 & 0.246 \\
\text{TRASVERSE SPEED} & 0.00103683 & 0.00002745 & 37.77 & 0.000 \\
\text{STAND OF DISTANCE} & 0.0002522 & 0.0002745 & 0.92 & 0.368 \\
\hline
\end{array}
\]

\[
\begin{array}{|c|c|c|c|c|c|}
\hline
\text{SOURCE} & \text{DOF} & \text{SEQSS} & \text{ADJ SS} & \text{Adj Ms} & \text{F} & \text{P} & \% \text{Contribution} \\
\hline
\text{JP} & 2 & 0.0000019 & 0.0000019 & 0.0000010 & 0.65 & 0.531 & 0.0964 \\
\text{PS} & 2 & 0.0019351 & 0.0019351 & 0.0009675 & 658.53 & 0.000 & 98.26 \\
\text{SOD} & 2 & 0.0000030 & 0.0000030 & 0.0000015 & 1.00 & 0.384 & 0.152 \\
\text{ERROR} & 20 & 0.0000294 & 0.0000294 & 0.0000015 & & & \\
\text{TOTAL} & 26 & 0.0019693 & & & & & \\
\hline
\end{array}
\]

3.2. Conclusion:
For Material removal rate, Transverse speed is the most prominent factor with a percentage contribution of 98.26 followed by stand of distance with percentage contribution of 0.152. Jet pressure has negligible influence on Material removal rate as illustrated by fig.6.
3.3. Surface Roughness:
The regression equation is
\[
SR = 1.90 + 0.00400 \text{JP} + 0.0589 \text{TS} + 0.0312 \text{SOD}
\]

\[
\boxed{\begin{array}{c|c|c|c|c}
\text{Predictor} & \text{Coef} & \text{SE Coef} & \text{T} & \text{P} \\
\hline
\text{CONSTANT} & 1.9025 & 0.7063 & 2.69 & 0.013 \\
\hline
\text{JET PRESSURE} & 0.003996 & 0.003100 & 1.29 & 0.210 \\
\hline
\text{TRANSVERSE SPEED} & 0.058889 & 0.009301 & 6.33 & 0.000 \\
\hline
\text{STAND OF DISTANCE} & 0.03117 & 0.09301 & 0.34 & 0.741 \\
\hline
\end{array}}
\]

\[
S = 0.394591 \quad R^2 = 64.5\% \quad R-Sq(adj) = 59.9\%
\]

\[
\begin{array}{c|c|c|c|c|c|c}
\text{SOURCE} & \text{DOF} & \text{SEQSS} & \text{ADJ SS} & \text{Adj MS} & \text{F} & \text{P} \\
\hline
\text{JET PRESSURE} & 2 & 0.8128 & 0.8128 & 0.4064 & 2.89 & 0.079 \quad 8.04 \\
\hline
\text{TRANSVERSE SPEED} & 2 & 6.4510 & 6.4510 & 3.2255 & 22.91 & 0.000 \quad 63.87 \\
\hline
\text{STAND OF DISTANCE} & 2 & 0.0197 & 0.0197 & 0.0099 & 0.07 & 0.933 \quad 0.2 \\
\hline
\text{ERROR} & 20 & 2.8160 & 2.8160 & 0.1408 & & \quad 27.88 \\
\hline
\text{TOTAL} & 26 & 10.0996 & & & & \quad \\
\hline
\end{array}
\]

3.4. Conclusion:
In surface roughness Transverse speed is the most prominent factor with a percentage contribution of 63.87 followed by jet pressure with percentage contribution of 8.04. Stand of distance has negligible influence on Surface roughness.
Fig. 10: Main effects plot for SR

Fig. 11 & 12: Signal to Noise ratio plot for (a) MRR, (b) SR

Table 8: Validation of Performance Results

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>OPTIMUM CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>MRR</td>
<td>JET PRESSURE- 240</td>
</tr>
<tr>
<td></td>
<td>TRANSVERSE SPEED-30</td>
</tr>
<tr>
<td></td>
<td>STAND OF DISTANCE- 3</td>
</tr>
<tr>
<td>SR</td>
<td>JET PRESSURE- 180</td>
</tr>
<tr>
<td></td>
<td>TRANSVERSE SPEED- 10</td>
</tr>
<tr>
<td></td>
<td>STAND OF DISTANCE- 1</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

The machining was carried out on nimonic alloy work piece for full factorial design of 27 values using on abrasive water jet machining in order to predict material removal rate and surface finish. Based on analysis conclusions are drawn.

V. MATERIAL REMOVAL RATE

- Regression analysis was successfully applied to predict the material removal rate in water jet machining.
- It has been observed from plot of material removal rate that Material removal rate is going to have slight increase with increase in jet pressure and stand of distance.
- Material removal rate increases drastically with increase of transverse speed.
VI. SURFACE FINISH

- Regression analysis was successfully applied to predict surface roughness in water jet machining.
- It has observed from plots of surface roughness that surface roughness increases to some extent and decreases linearly with increase of jet pressure.
- Material removal rate increases drastically with increase in transverse speed.
- Finally material removal rate shows minimum variations with increase in stand of distance.

REFERENCES


