INTRODUCTION

Composite laminate possess superior properties like higher strength to weight ratio, higher stiffness, lower thermal expansion over other conventional materials. Therefore, composite laminates like GFRP find its place in aerospace industries, aircraft structural components [1]. Machining of GFRP has always been difficult because of multitude of difficulties like fiber pull out, fiber fuzzing, matrix burning, fiber-matrix detachment which result in subsurface damage, reduced strength and short product life. Many researchers have established that GFRP can be machined easily by HSD but detailed mathematical models representing the influence of predominant machining variables on machinability are yet to be established. This paper attempts to develop these empirical models, using response surface methodology. Linear regression models developed may be of interest to process planners dealing with such materials.

Experimental Work

GFRP composite was prepared using hand layup technique. Lapox L-12 with hardener K-6 was used for specimen preparation. Wax was sprayed on the mold surface to avoid the sticking of resin to the surface. Thin polyester films were used at the top and bottom of the mold to get good surface finish.

ABSTRACT

This paper reports the experimental investigation of high speed drilling of glass fiber reinforced composite. The relevance of this study is that it establishes empirical relations as a function of machining variables, relevant to analyse the machinability of glass fiber reinforced composite. The response functions considered delamination factor at entry and exit and the machining variables are point angle, cutting speed and feed rate. Experiments are conducted on the basis of response surface methodology technique. Empirical models correlating process variables and their interactions with the said response functions have been established. The models developed reveal that point angle is the most significant parameter. These models can be used for selecting the values of process variables to get the desired values of response parameters.

ARTICLE INFO

ABSTRACT

This paper reports the experimental investigation of high speed drilling of glass fiber reinforced composite. The relevance of this study is that it establishes empirical relations as a function of machining variables, relevant to analyse the machinability of glass fiber reinforced composite. The response functions considered delamination factor at entry and exit and the machining variables are point angle, cutting speed and feed rate. Experiments are conducted on the basis of response surface methodology technique. Empirical models correlating process variables and their interactions with the said response functions have been established. The models developed reveal that point angle is the most significant parameter. These models can be used for selecting the values of process variables to get the desired values of response parameters.

INTRODUCTION

Composite laminate possess superior properties like higher strength to weight ratio, higher stiffness, lower thermal expansion over other conventional materials. Therefore, composite laminates like GFRP find its place in aerospace industries, aircraft structural components [1]. Machining of GFRP has always been difficult because of multitude of difficulties like fiber pull out, fiber fuzzing, matrix burning, fiber-matrix detachment which result in subsurface damage, reduced strength and short product life. Many researchers have established that GFRP can be machined easily by HSD but detailed mathematical models representing the influence of predominant machining variables on machinability are yet to be established. This paper attempts to develop these empirical models, using response surface methodology. These linear regression models developed may be of interest to process planners dealing with such materials.

Experimental Work

GFRP composite was prepared using hand layup technique. Lapox L-12 with hardener K-6 was used for specimen preparation. Wax was sprayed on the mold surface to avoid the sticking of resin to the surface. Thin polyester films were used at the top and bottom of the mold to get good surface finish.

KEYWORDS:
Glass fiber reinforced composite (GFRP), Response Surface Methodology (RSM), High Speed Drilling (HSD)

*Corresponding author: Ketulkumar R. Patel
Department of Mechanical Engineering, Babaria Institute of Technology, Varnama, Vadodara, Gujarat, India
The digital images of drilled hole were analysed using Image J (Version 1.5 118) public domain software to calculate delamination factor at entry and exit.

### Table 1 Input Parameters used for experimentation and their levels

<table>
<thead>
<tr>
<th>Input Parameter</th>
<th>Coding</th>
<th>Level 1 (-1)</th>
<th>Level 2 (0)</th>
<th>Level 3 (+1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting Speed (mm/min)</td>
<td>X₁</td>
<td>175</td>
<td>205</td>
<td>235</td>
</tr>
<tr>
<td>Feed rate (mm/min)</td>
<td>X₂</td>
<td>150</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td>Point Angle (Degree)</td>
<td>X₃</td>
<td>90</td>
<td>104</td>
<td>118</td>
</tr>
</tbody>
</table>

### Mathematical Modeling

According to the experimental plan a total of 27 experiments are conducted, each having the combination of various values of process variables X₁, X₂, X₃. Each of the responses is fitted into a linear equation represented by:

\[ \hat{y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \]

where, \( \hat{y} \) is the response and \( X_1, X_2, X_3 \) are coded levels of variables. The coefficients \( \beta_0, \beta_1, \beta_2 \) and \( \beta_3 \) can be calculated by solving the following equation:

\[ \beta = (X^T X)^{-1} X^T Y \]

where, \( \beta \) is the matrix of parameter estimates, \( X \) is the matrix of independent variables, \( X^T \) is the transpose of \( X \) matrix and \( Y \) is the matrix of measured responses. Table 2 gives the design matrix and the responses. Analysis of variance (ANOVA) is performed to test the adequacy of the proposed models.

### Table 2 Design matrix and responses

<table>
<thead>
<tr>
<th>S.No</th>
<th>Point Angle</th>
<th>Cutting Speed</th>
<th>Feed rate</th>
<th>Delamination at Entry</th>
<th>Delamination at Exit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>90</td>
<td>175</td>
<td>150</td>
<td>1.133</td>
<td>1.152</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
<td>175</td>
<td>200</td>
<td>1.145</td>
<td>1.150</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>175</td>
<td>250</td>
<td>1.159</td>
<td>1.171</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
<td>205</td>
<td>150</td>
<td>1.136</td>
<td>1.146</td>
</tr>
<tr>
<td>5</td>
<td>90</td>
<td>205</td>
<td>200</td>
<td>1.140</td>
<td>1.160</td>
</tr>
<tr>
<td>6</td>
<td>90</td>
<td>205</td>
<td>250</td>
<td>1.186</td>
<td>1.183</td>
</tr>
<tr>
<td>7</td>
<td>90</td>
<td>235</td>
<td>150</td>
<td>1.150</td>
<td>1.155</td>
</tr>
<tr>
<td>8</td>
<td>90</td>
<td>235</td>
<td>200</td>
<td>1.169</td>
<td>1.164</td>
</tr>
<tr>
<td>9</td>
<td>90</td>
<td>235</td>
<td>250</td>
<td>1.166</td>
<td>1.213</td>
</tr>
<tr>
<td>10</td>
<td>104</td>
<td>175</td>
<td>150</td>
<td>1.186</td>
<td>1.238</td>
</tr>
<tr>
<td>11</td>
<td>104</td>
<td>175</td>
<td>200</td>
<td>1.219</td>
<td>1.228</td>
</tr>
<tr>
<td>12</td>
<td>104</td>
<td>175</td>
<td>250</td>
<td>1.169</td>
<td>1.275</td>
</tr>
<tr>
<td>13</td>
<td>104</td>
<td>205</td>
<td>150</td>
<td>1.197</td>
<td>1.215</td>
</tr>
<tr>
<td>14</td>
<td>104</td>
<td>205</td>
<td>200</td>
<td>1.214</td>
<td>1.228</td>
</tr>
<tr>
<td>15</td>
<td>104</td>
<td>205</td>
<td>250</td>
<td>1.176</td>
<td>1.237</td>
</tr>
<tr>
<td>16</td>
<td>104</td>
<td>235</td>
<td>150</td>
<td>1.140</td>
<td>1.220</td>
</tr>
<tr>
<td>17</td>
<td>104</td>
<td>235</td>
<td>200</td>
<td>1.171</td>
<td>1.213</td>
</tr>
<tr>
<td>18</td>
<td>104</td>
<td>235</td>
<td>250</td>
<td>1.180</td>
<td>1.249</td>
</tr>
<tr>
<td>19</td>
<td>118</td>
<td>175</td>
<td>150</td>
<td>1.258</td>
<td>1.266</td>
</tr>
<tr>
<td>20</td>
<td>118</td>
<td>175</td>
<td>200</td>
<td>1.271</td>
<td>1.260</td>
</tr>
<tr>
<td>21</td>
<td>118</td>
<td>175</td>
<td>250</td>
<td>1.229</td>
<td>1.284</td>
</tr>
<tr>
<td>22</td>
<td>118</td>
<td>205</td>
<td>150</td>
<td>1.250</td>
<td>1.250</td>
</tr>
<tr>
<td>23</td>
<td>118</td>
<td>205</td>
<td>200</td>
<td>1.294</td>
<td>1.231</td>
</tr>
<tr>
<td>24</td>
<td>118</td>
<td>205</td>
<td>250</td>
<td>1.241</td>
<td>1.299</td>
</tr>
<tr>
<td>25</td>
<td>118</td>
<td>235</td>
<td>150</td>
<td>1.269</td>
<td>1.231</td>
</tr>
<tr>
<td>26</td>
<td>118</td>
<td>235</td>
<td>200</td>
<td>1.236</td>
<td>1.259</td>
</tr>
<tr>
<td>27</td>
<td>118</td>
<td>235</td>
<td>250</td>
<td>1.255</td>
<td>1.306</td>
</tr>
</tbody>
</table>

First order linear equations are obtained and regression analysis is done for the stated responses delamination at entry and exit. Also, analysis of variance is carried out for a confidence level of 95%.

### Delamination at Entry

First order linear equation:

\[ \text{Delamination at Entry} = 0.822 + 0.00365 (\text{Point Angle}) - 0.000061 (\text{Cutting Speed}) + 0.000047 (\text{Feed Rate}) \]

### Table 3 Analysis of Variance

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>3</td>
<td>0.047079</td>
<td>0.015693</td>
<td>27.82</td>
<td>0.000</td>
</tr>
<tr>
<td>Residual Error</td>
<td>23</td>
<td>0.012973</td>
<td>0.000564</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
<td>0.060501</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S = 0.0237493 R-Sq = 78.4% R-Sq(adj) = 75.6%

Table 3 shows the analysis of variance for Delamination at Entry. The P-value of regression equation indicates that the regression model is significant. The coefficient of determination (R²) which indicates the goodness of fit for the model and the value of R² = 78.4% indicates the significance of the model.

Figure 1 shows the normal probability plot for Delamination at Entry. This graph indicates that the residual follows a straight line and there are no unusual patterns or outliers. As a result, the assumptions regarding the residual were not violated and the residuals are normally distributed.
RESULTS AND DISCUSSION

The effects of input factors on responses are analyzed by observing main effects plots and using analysis of variance (ANOVA) General Linear Model.

Delamination at Entry

The important information that can be obtained from the table is the percentage influence of all factors over responses. P value less than 0.0500 indicate model terms are significant. Values greater than 0.1000 indicate the model terms are not significant.

Delamination at Exit

The main effects plots and anova tables for delamination at entry and delamination at exit clearly indicate that the point angle is the most significant factor affecting both delamination at the entry and delamination at exit. The important information that can be obtained from the table is the percentage influence of all factors over responses. P value less than 0.0500 indicate model terms are significant. Values greater than 0.1000 indicate the model terms are not significant.

The percentage contribution by each of the process parameter in the total sum of squared deviation can be used to evaluate the importance of the process parameter change on the quality characteristic. Here, the contribution of point angle is highest for delamination at entry (82.66%) and for delamination at exit (78.92%).

CONCLUSION

From this analysis, it can be concluded that the most significant high speed drilling process variable influencing all the stated machinability parameters of glass fiber reinforced polymer composite is point angle. The order of significance of other parameters are feed rate followed by cutting speed. These models can be effectively utilized by the process planners to select the level of parameters to meet any specific high speed drilling machining requirements on glass fiber reinforced polymer composite within the range of experimentation.

References

Weixing Xu, Liangchi Zhang & Yongbo Wu, "Effect of tool vibration on chip formation and cutting forces in the


How to cite this article:
DOI: http://dx.doi.org/10.24327/ijrsr.2018.0911.2889

********