Multi Response optimization of drilling parameters in Glass Fiber Reinforced Thermoplastic composites

Srinivasan.T1, Arunkumar. R2, Meghanathan. S2 and Ramu.P2

1Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andra Pradesh, India
2Asst Professor, Department of Mechanical Engineering, Sri Sai Ram institute of science, Technology, Tambaram, Chennai.
Corresponding author: seenusreeja@gmail.com

Abstract: Optimization of drilling parameters in Glass Fiber Reinforced Thermoplastic composites (GFRTP) has been analyzed using grey relational analysis in this research. The goal of this thesis was to investigate the effect of drilling parameters on composites of Glass Fiber Reinforced Thermoplastic composites (GFRTP) using hand layup method. The circularity and surface roughness diminished. In drilling, tests were carried out on Glass Fiber Reinforced Thermoplastic composites with HSS drill bits of 6 mm, 7 mm and 8 mm diameter used in dry conditions using the Taguchi L9 orthogonal array process. ANOVA analysed the effect on output parameters such as surface roughness and circularity of multiple drilling input parameters such as cutting speed, feed, and cutting depth. For finding the best machining condition, Grey relational analysis equations were used. For the drilling of hybrid Glass Fiber Reinforced Thermoplastic composites, the most critical parameter, namely the cutting speed, was found to have affected the thrust power, circularity and surface roughness.

1. Introduction

Drilling is a method of making circular holes in a concrete material or widening existing holes with the use of drills or drill bits called multi-point cutting equipment. Drilling is a method of continued machining. For drilling, various cutting tools are available, but the twist drill is the most common. To serve numerous purposes, a broad range of drilling processes is available. The main problem is the rapidly increasing efficiency and competitiveness of technology. Productivity is concerned with the SR and the product characteristics apply to circularity during machining process and efficiency. By parameter optimization, efficiency and productivity can also be increased. There are a range of research works relating to optimization of drilling parameters to obtain output responses. The primary reactions are surface roughness and circularity of the drill bit.

Raj Mohan et al. [1] performed push drive drilling experiments. In the experiment, the feed was found to be the major parameter controlling the thrust force. The aim is to investigate the impact of the parameter machining for newly reinforced surface MMCs machinability and increased roughness [2-5]. Ramprasad et al [6] analyzed the effect of machining parameters on MRR and SR in wire EDM process parameters of Titanium alloys. The optimal levels are Peak current-20, Pulse on time-105, Pulse off time-95 and Servo voltat-50. Basha et al [7] deliberate the Host alloy C276 using Taguchi Techniques and found the lower values of discharge current and pulse on time, higher values of pulse off time the optimum condition for surface roughness. Venkataiah et al [8] calculated the design model and helped to select optimized parameters with a minimum number of experiments for new lightweight technical applications in the production of grain-refined ZE41 Mg alloy. In order to obtain the optimal MRR and minimum surface roughness (Ra) of the Inconel718, Dharmandera et al [9] analysed the Taguchi orthogonal series. L9 and L16 orthogonal arrays were selected and signal to noise ratios were computed by Suresh et al [10]. The input parameters of velocity, feed, cut depth, drill depth and outcome
parameters of surface roughness, material removal rate and running time were optimized at the end. Using zinc-coated brass wire electrode, A Kumar et al [11] analyzed the material removal rate, surface roughness and corner deviation, where investigated using Inconel 718. The other others are applied the some other optimization techniques and implemented in different materials and the dissimilar results [12-16].

2. Materials and Methods

In this study, Thermoplastic composite laminates of 4 mm thickness is prepared by film stacking process. Six layers of E-glass fibre woven mat (200 gsm) are used as the reinforcing material and the seven layers of polypropylene thermoplastic sheets having 0.5 mm thick is used as the matrix. The polypropylene film sheet and glass fiber woven mat are prepared with a length of 250 mm and width of 250 mm. alternately arranged glass fiber woven mat and polypropylene film sheet have been stacked in a hot compression molding machine in between the moving and fixed platens of the hydraulic press. Suitable releasing agent (silicone spray) is used during the fabrication.

The specimen is heated electrically in all the sides up to the glass transition temperature and Pressure is applied to form the shape (50 kg/cm²). The laminate is hot cured in platens at a temperature of 220°C. Finally, the composite plate is allowed to cool at room temperature under the same pressure. Drilling experiments are carried out with the aid of Vertical Machining Centre (VMC) controlled by the computer by using L9 orthogonal array. Based on the experience of the authors and discussed literature, the drilling variables are chosen. The parameters are taken into account and their values are tabulated in Table 1. The experimentation was carried out with three different step twist HSS drill bits (6 mm, 7 mm and 8 mm diameter). The measurement of surface finish of each drilled hole was done with the assistance of a Video Measuring System (VMS-2010 F), and the measurement of circularity of each drilled hole was done with the help of a computer-controlled surface roughness tester, Kosaka (SE3500), JAPAN. The Machining parameters and experimental values are tabulated in Table 1 and 2.

Table 1. Machining parameters

| Parameters       | Unit   | Level 1 | Level 2 | Level 3 |
|------------------|--------|---------|---------|---------|
| Speed (A)        | rpm    | 750     | 1000    | 1250    |
| Feed (B)         | mm/min | 15      | 25      | 35      |
| Drill diameter (C)| mm     | 6       | 7       | 8       |

3. Grey Relational Analysis

Grey contextual analysis is the best theory used to examine the unpredictability of multiple inputs and discrete information [17, 18]. The estimation of the cumulative value between the two is an evenly weighted grey relational analysis. Sequences that are based on the separation of details. It is being used for measuring a reasonably precise series association by substituting 0.5 for equal weight. The GRG steps explained in the Figure and formulas given from Eq 1-4.
### Table 2. Experimental values

| Speed (rpm) | Feed Mm/min | Drill diameter mm | SR (µm)  | Circularity (mm) | S/N SR | S/N Circularity |
|-------------|-------------|-------------------|----------|------------------|--------|-----------------|
| 750         | 15          | 6                 | 6.52341  | 0.132            | -16.289| 17.589          |
| 750         | 25          | 7                 | 6.52362  | 0.129            | -16.290| 17.788          |
| 750         | 35          | 8                 | 6.52383  | 0.125            | -16.290| 18.062          |
| 1000        | 15          | 7                 | 6.17632  | 0.137            | -15.815| 17.266          |
| 1000        | 25          | 8                 | 6.17653  | 0.134            | -15.815| 17.458          |
| 1000        | 35          | 9                 | 6.40801  | 0.123            | -16.134| 18.202          |
| 1250        | 15          | 9                 | 5.82923  | 0.152            | -15.312| 16.363          |
| 1250        | 25          | 6                 | 6.06071  | 0.1323           | -15.650| 17.569          |
| 1250        | 35          | 7                 | 6.06092  | 0.1391           | -15.651| 17.133          |
| Step | Description |
|------|-------------|
| 1    | Identify the response variables and corresponding S/N ratio |
| 2    | Identification of controllable parameters, interactions and their levels |
| 3    | Identify orthogonal array and assign parameter levels to each column |
| 4    | Conduct the experiment and collect the data for response variables |
| 5    | Data preprocessing by normalizing the S/N ratio for all sequences |
| 6    | Calculate grey relational coefficients for each sequence |
| 7    | Determine the grey relational grade by averaging the grey coefficients |
| 8    | Determine the optimum sequence, from the higher grey relational grade |
| 9    | Determination of optimum parameters |
| 10   | Predication of GRG for optimal parameters |

**Figure 1. Steps for Grey relational Analysis**

*Optimization Steps of GRG and formulas*

**Step 1**
Transform the experimental value into S/N ratio using the appropriate formulae depending on the type of quality characteristics. S/N ratio of s surface roughness and circularity consider as a smaller the better.

\[
S/N \text{ ratio} = -10 \log_{10} \frac{1}{n} \sum Y_i^2
\]  
(1)

**Step 2**
Normalized the value for \(i^{th}\) experimental trial for \(j^{th}\) dependent variable/response
\[ Z_{ij} = \text{Max}(Y_{ij}, i=1,2,3,\ldots,n) - Y_{ij} / \max(Y_{ij}, i=1,2,3\ldots,n) - \text{Min}(Y_{ij}, i=1,2,3\ldots,n) \]  \quad (2)

(to be used for S/N ratio with smaller the better)

Step 3

Compute the grey relational coefficients GC for the normalized S/N ratio values.

\[ GC_{ij} = \frac{(\Delta_{\text{min}} + \lambda \Delta_{\text{max}})}{(\Delta_{ij} + \lambda \Delta_{\text{max}})} \]  \quad (3)

\( GC_{ij} \) - grey relational coefficient.
\( \Delta \) - Absolute difference between \( Y_{oj} \) and \( Y_{ij} \).
\( Y_{oj} \) - optimal performance value.
\( Y_{ij} \) - Normalised values.
\( \Delta_{\text{min}} \) - Minimum value of \( \Delta \).
\( \Delta_{\text{max}} \) - Maximum value of \( \Delta \).
\( \lambda \) - Distinguishing coefficients.

Steps 4 Compute the GRG

\[ \text{GRG} = \frac{1}{m} \Sigma GC_{ij} \]  \quad (4)

Step 5 Use response graph method or ANOVA and select optimal level for the factor based on maximum average GRG value.

4 Results and discussion

Optimization of Drilling Conditions Using Taguchi Analysis

As mentioned above for better surface roughness and circularity, the optimization of drilling parameters in this work is done using Taguchi grey relational analysis. Therefore the experimental results are then converted into an S/N ratio after a series of experiments provided by orthogonal array used in data analysis, and the lower the better is used to evaluate the quality characteristics, as given in equations 1-4. The OA with control factors, experimental results, and the corresponding normalised S/N ratio values. GRC and Grades are shown in Table 3.

SR and circularity enhancement is one of the key features of any machining process. Due to machining procedures, SR and circularity reveals defects in the surface of each workpiece. A high SR and circularity machined component results in unnecessary wear, fatigue, lower ability of material to resist corrosion, and lower corrosion resistance. Production of a substance. The drilling parameters, tool geometry, and relative vibration caused by the tool could affect SR and circularity. The analysis of grade values are shown the Figure 2, as the best combination of parameters can be obtained at speed at level 1 (750 rpm), feed (15mm/min) level 1, and drill diameter is level 3 (8mm).
### Table 3. Normalized, grey relational coefficient and grade values

| Normalised S/N | GRC | Grade |
|----------------|-----|-------|
| SR  | Circularity | SR  | Circularity |
| 0.999 | 0.334 | 0.999 | 0.429 | 0.714 |
| 1.000 | 0.225 | 0.999 | 0.392 | 0.696 |
| 1.000 | 0.076 | 1.000 | 0.351 | 0.676 |
| 0.514 | 0.509 | 0.507 | 0.505 | 0.506 |
| 0.514 | 0.405 | 0.507 | 0.456 | 0.482 |
| 0.841 | 0.000 | 0.759 | 0.333 | 0.546 |
| 0.000 | 1.000 | 0.333 | 1.000 | 0.667 |
| 0.346 | 0.344 | 0.433 | 0.433 | 0.433 |
| 0.346 | 0.581 | 0.433 | 0.544 | 0.489 |

### Table 4. Mean values of Grade

| Factors | Level 1 | Level 2 | Level 3 | max-min |
|---------|---------|---------|---------|---------|
| A       | 0.695   | 0.511   | 0.529   | 0.18386 |
| B       | 0.629   | 0.537   | 0.570   | 0.0919  |
| C       | 0.564   | 0.563   | 0.608   | 0.04457 |

**Figure 2.** Optimal level of Grade
Analysis of variance

In this analysis, ANOVA was used to calculate the significance of each of the method parameters for SR and circularity. The ANOVA results for the SR and HS are shown in Tables 5, respectively. The percent contribution in ANOVA is used to explain how much the output responses are influenced by each process parameter. The P-value will validate the effect on responses of method parameters and indicates that values smaller than 0.05 do not have an effect.

Table 5. ANOVA parameters contribution

| Parameters | SS  | Dof | MS  | % Contribution |
|------------|-----|-----|-----|----------------|
| Speed      | 0.061638 | 2  | 0.0308 | 65.36          |
| feed       | 0.013017 | 2  | 0.0065 | 13.80          |
| Drill bit  | 0.003932 | 2  | 0.002  | 4.17           |
| Error      | 0.004   | 2  | 0.002  | 16.67          |
| Total      | 0.09431 | 8  |       | 83.33          |

SS- sum of the square, Dof –Degree of freedom, MS- Mean square.

Table 7 thus indicates that speed contribution is 65.36 percent and feed contribution 13.80 percent respectively, were the statistic effects of speed, feed and drill bit size. This illustrates that the has greater effect than the speed on hole roughness. However, in the case of speed, the influence of speed was more than the doc and drill size value given in Table 5. Feed percentage share is 13.80 percent, which is higher than drill bit size contribution with a 4.17 percent statistical meaning. The model adequacy checking was conducted after performing an ANOVA analysis to verify the normality assumption of the residual. Figs.3 and 4 shows normal probability plots of the residuals and these figures reveal that almost all the residuals follow a straight line pattern and this agrees well with the results reported. This work will be useful for industries while the selection of process parameters in the drilling of GFRP composite materials, to improve the quality of the drilled holes by reducing the delamination.

The regression equation is surface roughness is given Eq 5 and circularity is given Eq 5.

SR = 7.34 - 0.00106*A + 0.00882*B - 0.0328 *C

Circularity = 0.113 + 0.000024*A - 0.000618*B + 0.00159*C

The regression equation is circularity is
Figure 3: Normal probability plot of residuals for SR

Figure 4: Normal probability plot of residuals for circularity
Conclusions

A research on the optimal selection of glass fiber reinforced thermoplastic composites, especially in this article, the optimization of surface roughness and circularity deviation of drilled holes is carried out for the automobile and aerospace industries. In this regard, the GRA approach is recommended for decision-making on the collection of suitable material, which yields optimum surface roughness values and drilled holes circularity deviation. The output from the Taguchi process was fed to the GRG as an input. Finally, the result generated in GRA suggests the suitable alternative of glass fiber reinforced thermoplastic GRA methods.

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