Optimization of multiple quality characteristics for end milling under dry cutting environment using desirability function

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Abstract. Milling AA6082T6 materials is a difficult venture because of their heterogeneity and a slew of problems, inclusive of surface roughness, that get up for the duration of the machining method and are connected to the material's homes and slicing settings. The optimization of machining parameters is a crucial section inside the manufacturing method. This research introduces a unique approach for improving machining settings whilst milling aluminum alloy. A technique notorious as desirability function analysis (DFA) turned into worn to optimize machining parameters. DFA is a effective tool for optimizing multi-reaction problems. Milling research for aluminum alloy were completed using tungsten carbide end milling inserts in dry situations, based totally on Taguchi's L9 orthogonal array. Multi-response issues, along with machining pressure and surface roughness, are used to optimize machining parameters including feed charge, spindle speed, and depth of reduce. person desirability values from the desirability characteristic analysis are used to create a composite desirability cost for the multi-responses. The most effective ranges of parameters had been discovered based at the composite desirability fee and substantial contribution of parameters has been determined the usage of analysis of variance.

Keywords: Aluminum, Desirability function analysis, speed, Machining, feed, doc.

1. Introduction

The aluminum alloy AA6082 is a medium-power alloy among super corrosion conflict. It has the very best electricity a number of the 6000 class alloys. Alloy 6082 is a structural metallic with a high strength-to-weight ratio. The alloy 6082 is the maximum normally used for plate machining, regardless of being a distinctly new alloy, 6082 has displaced 6061 in numerous packages due to its higher power. To control the grain structure, a sizable amount of manganese is introduced, ensuing in a more potent alloy. Machining of composites differs from widespread metal machining because of its anisotropic and non-homogeneous structure [1].

One of the maximum critical machining operations inside the production of FRP products is milling. FRP milling, alternatively, is executed on a notably smaller scale than steel milling, that is characterised by high cloth elimination prices. this is due to the fact FRP additives are often made close to internet shape, with greater milling restricted to deburring, trimming, and attaining contour form perfection [2].
Milling composite materials is complex with the aid of the tendency of composite substances to delaminate when subjected to machining forces which includes reducing pressure, feed force, and depth force [3, 4].

Roughness and delamination are characteristics that could have an effect on dimensional accuracy, mechanical object overall performance, and production costs. As a end result, studies and improvement have been centered on optimizing reducing situations to attain the desired machinability [5]. The impact of slicing circumstances on machining of numerous materials and techniques was investigated with the aid of the author [6-16].

In more or less all attempts to study machining traits and optimize them, traditional tactics inclusive of evaluation of variance (ANOVA), regression analysis, and the usage of other statistical models are carried out. As a result, this study affords a new approach for improving the machining parameters of GFRP composite plates the use of DFA. one of the most widely used methodologies within the enterprise for reinforcing multi-response functions DFA is used to renovate multi-response functions into unmarried-reaction traits. As a outcome, optimizing intricate multi-reaction traits may be decreased to enhancing composite desirability, a single response characteristic. Engineers with out a sturdy statistical history can put it to use because it does now not require sizable mathematical principle or computer systems, as in in advance methods. more than one responses, along with reducing pressure and surface roughness are integrated into composite desirability through want characteristic evaluation.

2. Materials and Methods

The experiment changed into carried out using a conventional milling device with a greatest spindle pace of 2000 rpm, a feed rate of 800 mm/min, and a 3HP force motor in moist slicing occasions. To offer most tension, the workpiece material was AA6082T6 inside the form of a 100 mm (length), 50 mm (width), and 30 mm (height) system desk. To provide most stiffness, the workpiece fabric is set up onto the system table. figure 1 indicates the experimental workpiece arrangement for end milling. Tables 1 and 2 couple of comprise thorough information on the chemical composition and mechanical houses of this AA6082 T6 alloy, respectively. Sandvik uncoated tungsten carbide is utilized for quit milling operations. For better floor excellent, inserts with two aspect teeth are selected. A Kistler multi-component dynamometer changed into used to measure the cutting pressure in the x-course of the slicing forces. The common maximum top to valley (Rz) price became recorded in microns the use of a floor roughness tester (Make - Mityoto ) dimension tool with a reduce-off period of 2.5 mm.

| Table 1. Chemical composition (% Present). |
| Mn | Fe | Mg | Si | Cu | Zn | Ti | Cr | Other | Al |
| 0.40-1 | 0-0.5 | 0.6-1.2 | 0.7-1.3 | 0-0.1 | 0-0.2 | 0-0.1 | 0-0.25 | 0-0.5 | Balance |

| Table 2. Mechanical Property. |
| Mechanical Property | Values |
| Proof Stress | 240 Min MPa |
| Tensile Strength | 295 Min MPa |
| Hardness Brinell | 89 HB |

2.1 Plan of experiments

The Taguchi approach has developed into a robust tool for growing studies and development productivity in order that goods may be created unexpectedly and at a cheap cost. Taguchi's parameter
layout is a useful device for growing robust designs. The Taguchi approach employs a unique orthogonal array design to research the complete parameter space with a limited quantity of experiments. The Taguchi technique is used to implement the plan of experiments for 3 elements at three ranges. The observe calls for six degrees of freedom, and the 9 trial situations are defined using Taguchi’s L9 orthogonal array (OA). The main consequences are the simplest ones that be counted and factor interactions are not regarded into table-three lists the system parameters and levels. The common response values are used for the analysis after every of the 9 trials. Table 4 depicts the experimental setup as well as the common test findings.

![Experimental Setup](image)

**Figure 1.** Experimental Setup.

**Table 3.** Cutting parameter and levels.

| Parameters | Levels |
|------------|--------|
| Feed (mm/min) | L1 | L2 | L3 |
| Speed (rpm) | 40 | 80 | 120 |
| DoC (mm) | 90 | 180 | 270 |
| 0.2 | 0.25 | 0.3 |

**Table 4.** Experimental layout using an L9 orthogonal array and corresponding results.

| Feed (mm/min) | Speed (Rpm) | DoC (mm) | Fx (N) | Rz (µm) |
|---------------|-------------|---------|-------|--------|
| 40            | 90          | 0.2     | 112.763 | 6.563 |
| 40            | 180         | 0.25    | 149.012 | 6.863 |
| 40            | 270         | 0.3     | 183.782 | 7.104 |
| 80            | 90          | 0.25    | 115.82  | 6.463 |
| 80            | 180         | 0.3     | 150.34  | 6.845 |
| 80            | 270         | 0.2     | 170.21  | 6.823 |
| 120           | 90          | 0.3     | 119.43  | 6.428 |
| 120           | 180         | 0.2     | 146.43  | 6.642 |
| 120           | 270         | 0.25    | 182.13  | 6.763 |
3. Desirability Function Analysis

The optimization of output and input parameters lets in for powerful machining. The Taguchi method is a powerful and design of experiment (DOE) technique for figuring out the ideal parameters in a technique. It uses an orthogonal matrix to decide the impact of enter parameters on output parameters in a small range of checks [17]. Derringer and Suich proposed the idea of a desirability function to optimize numerous goals. The principle idea in the back of a desirability characteristic is to lessen multi-goal problems to a unmarried equal objective characteristic even as taking normal desirability into consideration. Individual and basic desirability are used on this concept. The excellent parameter aggregate is shown with the aid of a more overall desirability price [18]. The subsequent steps are worried in the analysis of a desirability characteristic.

Step 1: Using the formula presented by Derringer and Suich, calculate the individual desirability index (di) for the appropriate responses (1980).

(a) **The nominal-the-best:**

\[
\hat{d}_i = \begin{cases} 
\left( \frac{\hat{y} - y_{\text{min}}}{T - y_{\text{min}}} \right)^s, & y_{\text{min}} \leq \hat{y} \leq T; \quad s \geq 0 \\
0, & T \leq \hat{y} \leq y_{\text{max}}; \quad t \geq 0 
\end{cases}
\]

(b) **The larger-the-better:**

\[
\hat{d}_i = \begin{cases} 
0, & y_{\text{min}} \leq \hat{y} \leq y_{\text{max}, r} \\
\left( \frac{\hat{y} - y_{\text{min}}}{y_{\text{max}} - y_{\text{min}}} \right)^r, & y_{\text{min}} \leq \hat{y} \leq y_{\text{max}}, \quad r \geq 0 \\
1, & \hat{y} \geq y_{\text{min}} 
\end{cases}
\]

(c) **The smaller-the-better**

\[
\hat{d}_i = \begin{cases} 
1, & y_{\text{min}} \leq \hat{y} \leq y_{\text{max}}; \quad r \geq 0 \\
\left( \frac{\hat{y} - y_{\text{max}}}{y_{\text{min}} - y_{\text{max}}} \right)^r, & y_{\text{min}, r} \leq \hat{y} \leq y_{\text{max}}, \\
0, & \hat{y} \geq y_{\text{max}} 
\end{cases}
\]

When the goal function needs to be maximized, the larger-is-better type equation is used. ymax denotes the highest value of ‘y,’ ymin denotes the lowest value of ‘y,’ and T denotes the goal value. Weigh criteria of selected responses are represented by the letters s, t, and r.

**Steps 2** calculate the overall desirability (dG)

\[
d_G = (d_1^{w_1} d_2^{w_2} \ldots d_n^{w_n})^{1/w}
\]
Step 3: Resolve the best consideration mishmash and its level. The advanced the composite desirability rating, the higher the quality of the product.
Where the weight \( w_i \) satisfies \( 0 < W_i < 1 \) and
\[
W_1 + W_2 + \ldots + W_n = 1
\]

Step 4: To discover the important parameters, use ANOVA.

Step 5: Estimate the optimum situation that has been forecasted.

Step 6: Carry out the confirmation test.

4. Results and Discussion

In the L9 OA, Table 5 provides the individual and composite desirability scores for each trial. The creation eminence is superior to the composite desirability value. As a outcome, the factor outcome may be approximated using composite desirability, and the best quantity for each opportune factor may be resolute. In Table-6, the mean of the composite desirability for each one level of the parameter is shortened. Table-6 also shows the total signify of the composite desirability for the nine experiments. Figure 2 depicts the composite desirability main possessions plot for various degrees of giving out parameters. The better the many routine attributes, the higher the composite desirability. Conversely, the relative importance of the parameters for the numerous routine characteristics will need to be notorious in order to more precisely resolve the ideal combinations of process parameter levels.

### Table 5. Evaluated results of desirability function.

| Feed (mm/min) | Speed (Rpm) | Doc (mm) | Desirability of Fx | Desirability of Rz | Composite desirability |
|---------------|-------------|---------|-------------------|-------------------|------------------------|
| 40            | 90          | 0.2     | 1.000             | 0.800             | 0.895                  |
| 40            | 180         | 0.25    | 0.490             | 0.357             | 0.418                  |
| 40            | 270         | 0.3     | 0.000             | 0.000             | 0.000                  |
| 80            | 90          | 0.25    | 0.957             | 0.948             | 0.953                  |
| 80            | 180         | 0.3     | 0.471             | 0.383             | 0.425                  |
| 80            | 270         | 0.2     | 0.191             | 0.416             | 0.282                  |
| 120           | 90          | 0.3     | 0.906             | 1.000             | 0.952                  |
| 120           | 180         | 0.2     | 0.526             | 0.683             | 0.600                  |
| 120           | 270         | 0.25    | 0.023             | 0.504             | 0.108                  |
Table 6. Optimal condition of composite desirability.

| Level | Feed   | Speed  | Doc    |
|-------|--------|--------|--------|
| 1     | 0.4375 | **0.9330*** | **0.5920*** |
| 2     | 0.5531 | 0.4807 | 0.4929 |
| 3     | **0.5533*** | 0.1301 | 0.4589 |

Figure 2. Optimal level composite Desirability.

5. Development of Regression Models

The use of regression analysis, pirical fashions for cutting pressure and surface roughness have been mounted. The R2 and R2- correlation coefficients are used to confirm the version's correctness and recognition (adj). The equations for slicing pressure and floor roughness have been generated the use of the Minitab 14 software program and are represented in equations (1) and (2), respectively.

Regression Equation

\[
F_x = 64.13039 + 0.01013 \times \text{feed} + 0.3483 \times \text{speed} + 80.496 \times \text{Doc} \quad (1)
\]

\[
R_z = 6.2510 - 0.0029 \times \text{feed} + 0.00228 \times \text{speed} + 1.1633 \times \text{Doc} \quad (2)
\]

(R-Sqr = 0.996, Adj R-sqr = 0.9881)

(R-Sqr = 0.941, Adj R-sqr = 0.906)
Table 7. ANOVA for composite desirability.

| Factors | SS   | Dof | MS  | % Contribution |
|---------|------|-----|-----|----------------|
| Feed   | 0.026773 | 2   | 0.0134 | 2.58            |
| Speed  | 0.97231  | 2   | 0.4862 | 93.84           |
| DoC    | 0.028695 | 2   | 0.0143 | 2.77            |
| Error  | 0.004    | 2   | 0.002  | 0.81            |
| Total  | 1.036165 | 8   |       | 99.19           |

The geometric ANOVA is used to see which layout parameter has the maximum effect on roughness and slicing pressure. The qualified significance of the machining parameters about roughness and cutting force turned into evaluated the usage of ANOVA to discover the best aggregate of machining parameters. The evaluation is carried out for the extent of importance of 5% (the level of self-assurance is ninety-five%). Table 7 indicates the result of ANOVA evaluation for the machining outputs of alloy. The speed (93.84 percentage) has statistical and physical significance, followed through depth of cut (2.77 percentage), feed rate (2.58 percentage), and error (0.81 percentage).

6. Prediction of Optimum Levels

The very last step is to anticipate and corroborate the development of performance traits the usage of the top-rated level of machining parameters after the standard stage of machining parameters has been selected. The usage of the most fulfilling level of machining parameters, the estimated composite elegance can be determined as:

\[
\hat{\gamma}_o = \gamma_m + \sum_{i=1}^{q} \hat{\gamma}_j - \gamma_m
\]

wherein \(\gamma_m\) denotes the total mean of composite desirability, \(j\) denotes the suggest of composite desirability at the top-quality degree, and \(q\) is the wide variety of machining parameters that have a considerable impact on numerous overall performance elements. using the greatest machining parameters, Equation (3) may be utilized to compute the anticipated composite attractiveness. The consequences of the affirmation experiment employing the foremost machining parameters are proven in Table 8. The slicing pressure is more desirable from 112.763 N to 110.282 N, even as the floor roughness (Ra) is enhanced from 6.563 to six.126 µm. it is virtually shown that a couple of performances.

Table 8. Comparison of predicted results using confirmation experiment.

| Initial machining parameters | OPTIMAL Machining Parameters | Prediction | Experiment |
|------------------------------|------------------------------|------------|------------|
| Setting Level                | A1-B1-C1                     | A3-B1-C1   | A3-B1-C1   |
| Cutting force (N)            | 112.763                      | --         | 110.282    |
| Surface Roughness (Rz) µm   | 6.563                        | --         | 6.126      |
| Composite desirability value (DI) | 1.000                       | 0.9253     |

Improvement =0.0747
7. Conclusion

Tungsten carbide inserts were used in milling studies utilizing the Taguchi technique for AA6082T6 material. Desirability function analysis was used to optimize machining parameters based on the experimentally gathered data. The following results concerning cutting force and surface roughness are drawn from this analysis.

• In milling AA6082T6, the desirability function in the Taguchi approach for multi-response issue optimization is a highly valuable tool for forecasting machining force and surface roughness factor.

• Cutting settings optimized using the utility principle for simultaneous minimization of cutting force and surface roughness at a feed rate of 120 mm/min, 90 rpm, and 0.2 mm depth of cut.

• Cutting speed, followed by the depth of cut, are the key parameters that influence the replies, according to an ANOVA on total utility.

• The findings of the confirmation trials reveal a 95 percent confidence interval, indicating that the optimal cutting settings have been found.

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