Experimental investigation of milling process under optimum lubricant use

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Abstract. Performance of the machining and the efficiency of milling operation depend on several process variables among which hardness of work material is of great significant. In this study, experimentation was carried out to investigate the effect of work hardness on end milling process. Workpiece material hardness is used as a noise factor. Input parameters used are spindle speed, feed; depth of cut and tool diameter. The experiments performed under wet and minimum Quantity lubrication and results of both compared, further for getting optimal lubricant conditions the experiments performed for various levels of flow rates of minimum quantity lubrication to get the best optimal setting. Output parameters are surface roughness, material removal rate, cutting force and tool wear. Design of Experiment (DOE) with Taguchi L27 Orthogonal Array (OA) has been explored to produce 27 specimens on Al2024 aluminium by end milling operation at three different levels of hardness of material. The experiments performed under wet and minimum quantity lubrication condition and results compared. Further for optimal lubricant condition the experiments performed at various flow rate of Minimum Quantity Lubrication and “best” optimal setting is identified.

Keywords: Al2024-T4 workpiece material, GRA, Taguchi Method, ANOVA, S/N ratio

1. Introduction

[1] “Due to the development of new engineering materials and high-speed cutting, cutting fluid plays an important role in machining. Commonly, the cutting fluid can decrease cutting temperature, reduce the friction between tool and work piece, extend tool life, and improve machining efficiency and surface quality. These effects of cutting fluid were mainly obtained from its basic functions including cooling, lubrication, corrosion protection, and cleaning”. If cutting fluids, correctly selected and applied, it reduces the problems associated with the high temperature and high stresses. Unfortunately, waste cutting fluids create process-generated pollution. Conventional cutting fluid leads to environmental pollution and also health problems. Therefore, the use of cutting fluids is an important part of a machining process system. Without cutting fluid, tools have only a short life, which makes the machining process costly. Solid tools need regrinding so that they can be reused and insert-type cutting tools require the cutting edges to be rotated so that a new cutting edge is ready to cut. These processes add extra costs.
Nowadays various techniques are employed for improving lubricating in machining process [12]. In dry machining process the cutting operation done without any lubricant. In wet marching process which is done in most of the industry the lubricant used in continuous basis on large quantity and hence go waste. Hence it will also increase the production time and cost.

2. Experimentation

2.1 Definition of the problem

It is important to have the knowledge of the product/process before conducting the experiment. Objectives of the quality characteristics should be identified first.

2.2 Identification of noise factors

Identification of noise factor is very important because it may deviate the performance of quality characteristics. The desired values of responses can be achieved by neglecting effect of noise factor.

2.3 Selection of response variables

It is also important to select the proper response variables of the process under study.

2.4 Selection of control parameters and their levels

Selection of control parameters are very crucial and important because it defines the whole nature of output. Also if the selected levels of parameters are not significantly affecting the response parameters, then that level will be in no use.

2.5 Identification of control factor interactions

If there is a chance of significant effect of combined input parameters on response, then it is important to identify that combined parameters.

2.6 Selection of Orthogonal Array (OA)

In selecting an appropriate OA, the pre-requisites are as given below.

- Evaluation of process parameters selected.
- Identification of number of levels for the selected parameters.

2.7 Conducting the matrix experiments

As per Design of Experiment (DOE), the adjustment of cutting parameters is done of machine tool. Total 162 experiments were performed. The end mill operation is performed over a length of 75 mm. By setting different parameters and changing the different tool diameter and tool type under wet and MQL lubrication at three different levels work material hardness in terms of hardness (43- 48 HRB, 49- 53 HRB and 54-58 HRB).

3. Analysis

3.1 Single Optimization by Taguchi Method

Taguchi method is used for single objective optimization. The S/N is used by Taguchi approach to analyse experimental data. In single objective optimization, Taguchi method provides the individual
optimal setting for each output parameters. The data analysis and optimization of surface roughness, material removal rate, cutting force and tool wear are performed as follows:

Table 1. Response Table for S/ N Ratios.

| Level | Spindle Speed | Feed | Depth of cut | Tool Diameter | Tool Type |
|-------|---------------|------|--------------|---------------|-----------|
| 1     | -8.632        | -7.7879 | -0.546       | -6.207        | -6.64     |
| 2     | -6.252        | -5.4787 | -6.786       | -6.073        | -6.007    |
| 3     | -3.065        | -4.6825 | -10.62       | -5.67         | -5.302    |
| Delta | 5.567         | 3.1054  | 10.07        | 0.537         | 1.339     |
| Rank  | 2             | 3      | 1            | 5             | 4         |

From the ANOVA table of S/N ratio, for 95 % confidence level, the P-value for spindle speed, feed, depth of cut, tool diameter and tool type is less than 0.05 i.e. (< 0.05), hence all the input parameters are significant to surface roughness. Also depth of cut has the highest percentage contribution (69.94 %) to surface roughness.

Figure 1. Main effect & Residual plot for SN ratio (Smaller the better).
“The results of ANOVA for Surface roughness indicate that depth of cut is the most significant machining parameters in affecting the Surface roughness followed by spindle speed, feed, tool type and tool diameter. Based on the above discussion and the main effect plot of S/N ratio, the optimal machining parameters are the spindle speed at level 3 ($A_3 = 1500\text{rpm}$), feed at level 3 ($B_3 = 550\text{mm/min}$), depth of cut at level 1 ($C_3 = 0.5$), tool diameter at level 3 ($D_3 = 12 \text{mm}$), and tool type at level 3 ($E_3 = \text{PVD coated}$) or $A_3 B_3 C_1 D_3$ and $E_3$ in short”.

| Process Parameters Code | level1  | level2  | level3  |
|-------------------------|---------|---------|---------|
| Spindle Speed (RPM)     | A       | 1000    | 1250    | 1500    |
| Feed (mm/min)           | B       | 350     | 450     | 550     |
| Depth of cut (mm)       | C       | 0.5     | 1       | 1.5     |
| tool diameter (mm)      | D       | 8       | 10      | 12      |
| Tool type               | E       | HSS     | CVD     | PVD     |

3.2 Predicted Value of Surface Roughness

Output parameter at optimal setting can be predicted by additive model

$$\mu_{pred} = \bar{Y} + \sum (\bar{Y}_i - \bar{Y}) \quad (1)$$

By using additive model, predicted value of surface roughness at optimal setting $A_3 B_3 C_3 D_2 E_1$ is calculated as follows:

$$\mu_{sr} = Y_{sr} + (A_3 - Y_{sr}) + (B_3 - Y_{sr}) + (C_3 - Y_{sr}) + (D_3 - Y_{sr}) + (E_3 - Y_{sr})$$

$$= 2.29 + (1.70-2.29) + (2.06-2.29) + (1.16 - 2.29) + (2.40 - 2.29) + (2.16 - 2.29)$$

$$= 0.321 \text{ um}$$

3.3 Conformity Test

Conformity test is used to check whether the experimental value of output parameter at optimal setting is within the range given by confidence interval or not.

3.3.1 Confidence Interval (CI)

For the 95 % confidence level, CI is calculated as below:

$$CI = \sqrt{\frac{F_{\alpha}(1, f_e) N}{n_{eff}}}$$

Where $F_{\alpha}(1, f_e)$ = The F ratio at the confidence level of (1-$\alpha$) against ‘1’ and error of freedom $f_e$. 

Table 3. Values of Process Parameters at Optimum Level [13]
\[ n_{ef} = \frac{N}{1 + \text{DOF associated in the estimate of mean response}} \]

\[ \frac{81}{1 + 10} = 7.3636, \]

\[ N = \text{Total number of results} = 27 \times 3 = 81 \]

\[ f_e = \text{error DOF} = 4 \]

\[ F_{0.05}(1, 4) = 7.71 \text{ (Tabulated F value (Ross, 1996))} \]

The 95% confidence level of the population is: \([\mu - CI] < \mu < [\mu + CI]\]

Where, \(\mu\) is the predicted mean of response characteristic.

Error variance \(V_e = 0.0706\) (from Table 6.2)

Therefore, \(CI = \pm 0.2718\)

The 95% confidence interval of the population is: \([\mu_{SR} - CI] < \mu_{SR} < [\mu_{SR} + CI]\)

Minimum Surface Roughness (0.321 um) is achieved when spindle speed is 1500 rpm, feed 550 mm/min, depth of cut 0.5 mm and CVD Coated tool of diameter of 12 mm.

Under MQL Minimum Surface Roughness (0.107 um) is achieved when spindle speed is 1500 rpm, feed 550 mm/min, depth of cut 0.5 mm and CVD Coated tool of diameter of 12 mm.

![Surface Roughness Bar Chart](image)

**Figure 2.** Residual plot for SN ratio.

In order to compare different flow rates of MQL for optimal lubricant use, the experiments performed at optimal setting obtained from grey relational analysis, the results compared and is found that the best results obtained at 80 ml/hr.

**4. CONCLUSION**

**4.1 For wet lubrication:**

a) Depth of cut (69.94 % contribution) is the most affecting process parameter in affecting the Surface roughness. [12] “It is followed by spindle speed, feed, tool type and tool diameter”.

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**Figure 2.** Residual plot for SN ratio.
4.2 For Minimum Quantity lubrication

a) Depth of cut (68.84 % contribution) is [12] “the most significant machining parameter in affecting the Surface roughness. It is followed by spindle speed, feed, tool type and tool diameter”

The values of responses at various flow rates are discussed in chapter 8. Hence, best results for multi-response optimization of the S/N responses and using the optimized process setting obtained through the application of this method (A3B3C3D2E3) would enable the machine operator to realize highly robust process performance. By comparing the results at all flow rates of MQL such as 70, 80, 90,110,120,130 ml/hr respectively, it is found that the responses in terms of surface roughness, material removal rate, cutting force and tool wear are best at the flow rate of 80ml/hr.

5. Possible Contribution to the Society

This research study may contribute to the society in following way

- The present study can be used for implementing the Minimum Quantity Lubrication Technique in place of conventional Wet Lubrication.
- This MQL techniques will definitely helps to reduce the health hazards of workers working on machine and also reduces the environmental pollution.
- This work can signify the importance of Material hardness. The optimal setting obtained can be applicable for all the hardness of material Al2024.

6. References

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