Surface Roughness Optimization Using Taguchi Method of High Speed End Milling For Hardened Steel D2

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Abstract. The main challenge for any manufacturer is to achieve higher quality of their final products with maintains minimum machining time. In this research final surface roughness analysed and optimized with maximum 0.3 mm flank wear length. The experiment was investigated the effect of cutting speed, feed rate and depth of cut on the final surface roughness using D2 as a work piece hardened to 52-56 HRC, and coated carbide as cutting tool with higher cutting speed 120-240 mm/min. The experiment has been conducted using L9 design of Taguchi collection. The results have been analysed using JMP software.

1. Introduction

High speed end milling for hardened steel is one of the new and advanced machining processes. This advanced process merge three advanced processes: high speed milling, hard milling and dry milling. Increasing speed of machining will increase the material removal rate and then increases the machining productivity. However, maintain the surface roughness should be considered with increasing productivity. The main challenge in high speed end milling of hardened steel is the increasing of flank wear rate that may affect the final surface roughness. Pare et al., [1], mentioned that the factors which influence the final result of the surface roughness can be divided into two categories which are controllable and uncontrollable factors. The controllable factors are cutting speed, feed rate and depth of cut. While the uncontrollable factors are tool geometry and material properties for both work pieces and cutting tool.

There are several researcher had done a researched on the consequence of cutting parameters to the surface roughness, flank wear and tool life. One of the researcher, Ezuwanizam [2] had find the optimal cutting parameters for cutting speed, feed rate and depth of cut in optimize the tool life of carbide insert coated with TiN in milling aluminum 6061. The result shows that tool wear in end milling decreases as the cutting parameters increase. However, axial depth of cut does not give significant effect compared to cutting speed and feed rate. Xuan-Truong and Minh-Duc [3] had explained the effect of cutting parameters on flank wear and surface roughness through the transformation of natural logarithm. They found that cutting speed has given major significant effect...
on flank wear and surface roughness is mostly influenced by feed rate. While for depth of cut, they conclude that it only gives a minor effect for both surface roughness and flank wear especially at low cutting speed and feed rate. However, determining the best cutting parameters to achieve the optimum value that can give higher productivity with maintain minimum surface roughness is the aim for any manufacturer.

2. Taguchi method

Taguchi method is a tool of finding the best combination of an input (cutting parameters, cutting condition, work piece and cutting tool material properties) for producing a high quality of product and services. Malvade and Nipanikar [4] mentioned that Taguchi methods more focus on developing the design for manufacturing process for creating high quality product compared to statistical process control which tries to control the factors that affect the product quality. Based on Moshat et al. researched, they stated that Taguchi method is one of the efficient tools in designing an experiment for creating a high quality product manufactured and was developed by Genichi Taguchi. Taguchi’s orthogonal array (OA) is a step where provides less number of experiment run with high balanced combination of inputs. While Taguchi signal-to-noise ratios (S/N) is statistical measurement for the performance of the experiment for desired output. S/N ratios can be divided into three categories which is Nominal-is-Best (NB), Lower-the-Better (LB) and Higher-the-better (HB) and tits depending on the quality of the product or process being optimize. Highest S/N means the optimal parameters combination (Mahapatra and Chaturvedi, 2009).

3. Research Methodology

The experiment was conducted using the high-speed end milling modeled NEXUS 410A-II with vertical centre. The carbide inserts are attached to a 30 mm diameter of end milling cutter holder, While for the work piece, hard steel material which is D2 are chosen as the work material of this experiment as shown in the figure 13. Work material used is hardened steel D2 with dimension of 200 mm x 100 mm x 50 mm hardened to 52-56 HRC. For this experiment, a fresh carbide inserts will be used for each run of the experiment. The result and analysis of using Taguchi method using JMP statistical analysis software in analyzing and identify the optimizing the machining parameters in high speed end milling. Table 1 shows the experiment design using L9.

| Table 1. Ranges of cutting parameters of the Experiment. |
|--------------------------------------------------------|
| Cutting parameters          | Min. | Max.  |
| Cutting speed (m/min)       | 120  | 240   |
| Feed rate (mm/tooth)        | 0.05 | 0.15  |
| Depth of cut (mm)           | 0.10 | 0.20  |

4. Statistical analysis

Tables 2 and 3 show the statistical details necessary for determining whether a significant relation exist between the variables.
Table 2. Analysis of variance table.

| Source | DF | Sum of Squares | Mean Square | F Ratio |
|--------|----|----------------|-------------|---------|
| Model  | 4  | 0.06781083     | 0.016953    | 16.5830 |
| Error  | 4  | 0.00408917     | 0.001022    | 0.016953|
| C.     | 8  | 0.07190000     | 0.00408917  | 0.0093* |
| Total  |    | 0.07190000     | 0.00408917  |         |

Table 3. Summary of fit table.

|               | RSquare | RSquare Adj |
|---------------|---------|-------------|
|               | 0.943127| 0.886254    |
| Observations (or Sum Wgts) | 9       |             |

Based on the results in tables 2 and 3, the RSquare of 0.943127 is in reasonable agreement with the RSquare Adj of 0.886254 and Values of ‘Prob > F’ less than 0.05 and significant for both models. Therefore, the value of RSquare shows an adequate signal. The S/N ratio were developed using JMP statistical analysis. Table 4 summarizes the results of surface roughness and Figure 1 shows the relationship between the cutting speed, feed rate and depth of cut with the signal to noise ratio. Signal-to-noise ratio is a method used to measure the performance of the experiment. Signal means the desirable effect to the response or mean while noise is an undesirable effect or standard deviation to the response characteristics.

Table 4. Summarize result for analyzing process.

| Vc (m/min) | F (mm/tooth) | DOC (mm) | Roughness Average, Ra (mm) |
|------------|--------------|----------|----------------------------|
| 120        | 0.05         | 0.1      | 0.24                       |
| 120        | 0.1          | 0.15     | 0.29                       |
| 120        | 0.15         | 0.2      | 0.42                       |
| 180        | 0.05         | 0.15     | 0.19                       |
| 180        | 0.1          | 0.2      | 0.32                       |
| 180        | 0.15         | 0.1      | 0.385                      |
| 240        | 0.05         | 0.2      | 0.11                       |
| 240        | 0.1          | 0.1      | 0.27                       |
| 240        | 0.15         | 0.15     | 0.31                       |

Figure 1. S/N ratio for surface roughness.

At the high cutting speed, the surface roughness is improved as the feed rate decrease as shows in the figure 4a. In the other hand, at low cutting speed, surface roughness is increased as feed rate increase. This result was in line with the research done by [7] which also observed similar result that, surface roughness can be minimized by utilizing lower values of feed rate with higher cutting speed. While depth of cut is relatively affect the depth of cut according to figure 4b and 4c which the color of contour was only blue. In order to investigate the effect of cutting parameters combination of high speed end milling on flank wear rate of insert carbide, 3D contour plot were generated using JMP software. Figure 2a, 2b and 2c below shows the interaction between cutting parameters and surface roughness.
The scatter diagram have been created using JMP software. Figures 3a, 3b and 3c show the scatter diagram between the cutting speed, feed rate and depth of cut on the surface roughness and signal to noise respectively.

From the above figures 3a, 3b and 3c, it was found that the most effect factor on surface roughness and signal to noise ratio is the feed rate with correlation equal to 88% and 82% on mean surface roughness and signal to noise ratio respectively.

4.1 Desirability function

Desirability function method has been used to determine the best cutting levels to achieve the minimum surface roughness with reducing the signal to noise ratio. Figure 4 show the desirability function created by JMP software.
The graph shows that the maximum desirability was 83% can give Ra equal to 0.135 and S/n of 17.3. These values can be achieved with cutting speed of 240mm/min, feed rate of 0.05 mm/tooth and depth of cut of 0.2 mm.

5. Summary
The experimental process was successfully done and the data was collected through High Speed End Milling process. It was found that the main effective factor on surface roughness was the feed rate. Increasing the feed rate has a negative effect on the roughness in contrast the cutting speed has a positive effect on the surface roughness while depth of cut is relatively affect.

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