Effect of High Speed Milling Cutting Parameters to Mould Steel DF2 Surface Roughness Employing Carbide End Mill

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Abstract. The aim of this research is to analyze the effect of high speed milling cutting parameters on to the Mould Steel DF2 surface finish. Deckel Maho Evolution 50 High Speed Milling with pair controlled parameters (spindle speed and feed rate) is employed. Then, the Mould Steel DF2 was tested in order to explore the relationship between the controlled parameters. Within aided from application of Minitab was used to design and analyze the results. As a result, from the ANOVA table it been able to conclude that factor of spindle speed and feed rate does give significant value to the surface roughness (Ra). Its mean this to factor gives the influence of surface. The optimal machining conditions occur at the when the spindle speed is at 16000 rpm and feed rate 200 mm/min. Result of the study can be used by industries as a guide to choose best parameter for the High Speed Milling process.

1. Introduction

A machining process where the workpiece is fed through a rotating cylindrical tool with multiple cutting edges is known as milling. The alignment of turning cutting tool is always vertical to the feed path. The direction concerning the tool axis and the feed path is one of the qualities that differentiate milling from drilling process. In drilling, a path of fed-in is parallel to the cutting tool rotation axis. The term use in milling for cutting tool is a milling cutter whereas the cutting edges are a teeth. The machine tool that conventionally conduct this process is a milling machine. The repeated cutting force and high spindle speed will cause tool chatter due to the machine tool vibration.

The prime domineering parameters in milling process are; spindle speed, depth of cut, feed rate and cutting speed. There is a clear evident that the cutting tool workpiece and the surface quality are correlated with each other [1]. High speed machining (HSM) is a milling process having appreciably higher cutting speeds than in conventional machining operations. Most HSM cutting speed varies between 8000 and 35000 rpm, while the recent spindles are intended to rotate at 100,000 rpm. HSM is categorised as one of the up-to-date technologies, where applying this process will reduce costs and machining time and increase efficiency, accuracy and quality of workpieces in comparison with conservative cutting. HSM is the only milling process conducted at high cutting speed since many other milling operations are conducted using conservative cutting speeds [2].

One of the criteria of HSM is broadly used is its high machining productivity where HSM produces very good surface roughness and lower cutting time. Nonetheless, the surface roughness quality levels are established on appropriate choice of cutting parameters. Carbide tools able to machine metals at
velocities that makes the cutting edge become red hot but still maintaining its hardness or sharpness. Carbide compared to high speed steel (HSS) end mills; has better hardness, rigidity, and cutting temperature endurance [3]. Carbide is a tool material that has a wide range of removing metal applicability at a very low cost.

Mould steel on the other hand is a common functional oil hardening tool steel appropriate for many cold work purposes. It gives high machinability, dimensional stability during hardening and mixture of surface hardness and toughness after hardening and tempering. Mould steel is available in hot rolled, pre-machined, fine machined and precision ground surface performances and also in the form of hollow bar. Surface finish of any machined surface is a characteristic of good machining or product which is also known as a surface texture or roughness. Surface roughness is usually an index to identify the quality of machining surface finish. Surface roughness is controlled by few functional aspects of parts, for example, surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating or resisting fatigue. The surface finish quality is generally quantified, and the selection of appropriate processes are very important.

2. Methodology
2.1. Experimental Design
The factors that affect the surface roughness of conventional milling process are cutting conditions, tool geometries and mechanical stiffness. The most significant cutting parameters on to the surface roughness are feed rate and spindle speed. The relationship between surface roughness against spindle speed and feed rate will be showed by graph plotted. From the experiment, the variation of surface finish is reflected to the spindle speed and the feed rate. Mechanical stiffness primarily caused by cutting material types, in this work it is Mould Steel DF2. Material composition and mechanical properties of Mould steel DF2 is shown in Table 1 and 2. The dimensional changes during hardening and tempering vary depending on temperature, type of equipment and cooling media used during heat treatment.

| Table 1: Material composition of Mould Steel DF2 |
|-----------------------------------------------|
| Characteristics                               |
| Typical Analysis (%)                          |
| C(0.92), Si(0.30), Mn(1.0), P(0.025), S(0.003), Cr(0.6), W(0.6), Ni(0.01), Cu(0.01), V(0.1) |
| Standard specification                       |
| AISI O1, WNr. | 1.250,SKS 3 |
| Delivery condition                            |
| Soft annealed to max. 199-203 HB              |
| Colour code                                   |
| Yellow                                        |

| Table 2: Properties of Mould Steel DF2         |
|-----------------------------------------------|
| Temperature                                  |
| 20°C  | 200°C | 400°C |
| Density, kg/m³                               |
| 7850  | 7750  | 7700  |
| Elasticity Modulus, MPa                      |
| 190000| 185000| 170000|
| Thermal Expansion Coefficient per °C from 20°C| 12.6 x 10⁻⁶| 13.1 x 10⁻⁶|
| Thermal conductivity W/m°C                   |
| 32    | 33    | 34    |
| Specific heat J/kg °C                        |
| 460   | -     | -     |

2.2. Experimental Procedure
Deckel Maho Evolution 50 High Speed Milling was used all over the process. The maximum spindle speed that achieved by the high speed milling capability is 18,000 RPM. This research intended to find the most significant cutting parameters affecting the surface finish. The control parameters chose were spindle speed and feed rate. The other cutting parameter were remained constant such as cutting depth, flute numbers and workpiece material. Only two pieces of solid carbide end square four flutes were selected to be used in machining the pre hardened mould steel metal for the whole of experiments. Design of experiment was used is 2 factor 3 levels as suggested by [4-6]. The Minitab software is used
to generate the run order of experiment and to analyse the data collection. The cutting runs suggested by Minitab are listed in Table 3. This was done to determine the correlation between the chosen cutting parameter, roughness and burr types. During the experiments, both workpiece speed and tool rotating speed were taking into the calculation of cutting speed as:

\[ V = \frac{\pi DN}{1000} \text{ (m/min)} \]  

Where, \( V \) is the cutting speed of workpiece, \( D \) the diameter of cutter and \( N \) is the spindle speed [3].

Table 3. Cutting runs as suggested by Minitab

| Std Order | Run Order | Pt Type | Blocks | Spindle Speed (RPM) | Feed Rate (mm/min) |
|-----------|-----------|---------|--------|---------------------|-------------------|
| 8         | 1         | 1       | 1      | 14000               | 200               |
| 25        | 2         | 1       | 1      | 16000               | 100               |
| 1         | 3         | 1       | 1      | 16000               | 300               |
| 22        | 4         | 1       | 1      | 12000               | 300               |
| 9         | 5         | 1       | 1      | 12000               | 200               |
| 24        | 6         | 1       | 1      | 14000               | 100               |
| 23        | 7         | 1       | 1      | 12000               | 300               |
| 3         | 8         | 1       | 1      | 12000               | 100               |
| 4         | 9         | 1       | 1      | 14000               | 100               |
| 15        | 10        | 1       | 1      | 16000               | 300               |
| 27        | 11        | 1       | 1      | 14000               | 200               |
| 6         | 12        | 1       | 1      | 14000               | 300               |
| 5         | 13        | 1       | 1      | 14000               | 200               |
| 18        | 14        | 1       | 1      | 16000               | 300               |
| 2         | 15        | 1       | 1      | 16000               | 200               |
| 26        | 16        | 1       | 1      | 16000               | 100               |
| 10        | 17        | 1       | 1      | 16000               | 100               |
| 14        | 18        | 1       | 1      | 12000               | 100               |
| 11        | 19        | 1       | 1      | 16000               | 200               |
| 21        | 20        | 1       | 1      | 12000               | 100               |
| 17        | 21        | 1       | 1      | 14000               | 300               |
| 13        | 22        | 1       | 1      | 12000               | 200               |
| 7         | 23        | 1       | 1      | 16000               | 200               |
| 20        | 24        | 1       | 1      | 12000               | 300               |
| 12        | 25        | 1       | 1      | 12000               | 200               |
| 16        | 26        | 1       | 1      | 14000               | 300               |
| 19        | 27        | 1       | 1      | 14000               | 100               |

3. Results and Discussion

Minitab software has been used to generate all the data. All 27 runs were measured to get the surface roughness (Ra) data. By using the data, the pattern of graphs has been known. By using the MINITAB software, the ANOVA table for the two types of factors namely spindle speed and feed rate also can be known. The graphs show clearer view each of the patterns and the optimum parameter to get better surface roughness has been predicted. From the MINITAB software also, the regression model has been produced. When the optimum parameter is obtained, the industry can use it as their references. The optimum parameter for carbide end mill and mould steel material also can be identified result of parameter which consists of temperature, surface roughness and tool wear will measure and record.
using the specific equipment and machine. The result will show the highest and lowest data of each parameter after run the experiment.

![Machined workpiece material.](image)

Mould Steel DF2 workpiece was mill under different cutting conditions and the milling slots are depicts graphically in Figure 1. The corresponding experimental values of the surface roughness (Ra) are shown in Table 4. The surface roughness average was collected by using surface roughness tester Mitutoyo SV 3100 after each machining process.

| Std Order | Run Order | Pt Type | Blocks Speed (RPM) | Feed Rate (mm/min) | Ra (μm) |
|-----------|-----------|--------|-------------------|--------------------|--------|
| 8         | 1         | 1      | 1                 | 14000              | 200    | 0.226 |
| 25        | 2         | 1      | 1                 | 16000              | 100    | 0.174 |
| 1         | 3         | 1      | 1                 | 16000              | 300    | 0.165 |
| 22        | 4         | 1      | 1                 | 12000              | 300    | 0.314 |
| 9         | 5         | 1      | 1                 | 12000              | 200    | 0.339 |
| 24        | 6         | 1      | 1                 | 14000              | 100    | 0.375 |
| 23        | 7         | 1      | 1                 | 12000              | 300    | 0.325 |
| 3         | 8         | 1      | 1                 | 12000              | 100    | 0.243 |
| 4         | 9         | 1      | 1                 | 14000              | 100    | 0.356 |
| 15        | 10        | 1      | 1                 | 16000              | 300    | 0.094 |
Table 4. Experimental values of the surface roughness (Continued...)

| Std Order | Run Order | Pt Type | Blocks | Spindle Speed (RPM) | Feed Rate (mm/min) | Ra (μm) |
|-----------|-----------|---------|--------|--------------------|--------------------|---------|
| 27        | 11        | 1       | 1      | 14000              | 200                | 0.266   |
| 6         | 12        | 1       | 1      | 14000              | 300                | 0.284   |
| 5         | 13        | 1       | 1      | 14000              | 200                | 0.287   |
| 18        | 14        | 1       | 1      | 16000              | 300                | 0.127   |
| 29        | 30        | 1       | 1      | 16000              | 200                | 0.078   |
| 26        | 16        | 1       | 1      | 16000              | 100                | 0.184   |
| 10        | 17        | 1       | 1      | 16000              | 100                | 0.291   |
| 14        | 18        | 1       | 1      | 12000              | 100                | 0.354   |
| 11        | 19        | 1       | 1      | 16000              | 200                | 0.124   |
| 21        | 20        | 1       | 1      | 12000              | 100                | 0.266   |
| 17        | 21        | 1       | 1      | 14000              | 300                | 0.294   |
| 13        | 22        | 1       | 1      | 12000              | 200                | 0.298   |
| 7         | 23        | 1       | 1      | 16000              | 200                | 0.096   |
| 20        | 24        | 1       | 1      | 12000              | 300                | 0.387   |
| 12        | 25        | 1       | 1      | 12000              | 200                | 0.365   |
| 16        | 26        | 1       | 1      | 14000              | 300                | 0.344   |
| 19        | 27        | 1       | 1      | 14000              | 100                | 0.334   |

3.1. Effect of Spindle speed (RPM) to Surface Roughness
The effect of spindle speed on the surface roughness is shown in Figure 2. Spindle speed refers to the rotating speed of the work piece. It is increased from 12000 rpm to 16000 rpm. The depth of cut is kept at 0.05mm. The experiments were conducted under dry cutting. From the graph, the surface roughness is decreases when increasing the spindle speed. The surface roughness is decrease from 0.325 μm to 0.150 μm when spindle speed increase from 12000rpm to 16000rpm. Indeed, low speeds are used for rough cutting and high speeds are employed for fine finishing.

3.2. Effect of feed rate to Surface Roughness
The effect of feed rate on the surface roughness is shown in Figure 3. Feed rate is the rate at which the tool advances along its cutting path. It is increased from 100 mm/min to 300 mm/min by keeping the depth of cut constant at 0.05mm throughout and spindle speed from 12000 rpm to 16000 rpm. The surface roughness is decreased when feed rate from 100 mm/min to 200 mm/min. The roughness is from 0.287 μm to 0.23 μm. When the feed rate is increased from 200 mm/min to 300 mm/min the
roughness is increased. The roughness is from 0.23 μm to 0.26 μm. However, the result is not in line with the theoretical. This is because it has other factor that affect the surface roughness during experimental process. From the past research, surface roughness occurred during the experiment is due to tool vibration. Because of tool vibration, milled surface has been affected due to the dynamic forces occurred on the tool with increases of feed rate. [7]

![Figure 3. Main Effect (Feed Rate).](image)

### 3.3. Analysis of Variance for Ra

From this ANOVA table shows that these two factors which are spindle speed and feed rate are significant to the surface roughness, Ra. As the P-value ANOVA is 0.014 which is less than 0.05, the null hypothesis is rejected. Further, there is a significant interaction between spindle speed and feed rate. Both factors which spindle speed and feed rate have relationships that influence surface roughness of machined surface (Mould Steel DF2). So, by the ANOVA analysis from the Table, it is show that the three levels full factorial with two factors is sufficient to prove that these two factors give significant effect onto to the surface roughness, Ra of the Mould steel DF2.

| Source               | Degree of Freedom | Seq SS  | Adj SS   | Adj MS   | F       | P Value |
|----------------------|-------------------|---------|----------|----------|---------|---------|
| Spindle Speed        | 2                 | 0.166536| 0.166536 | 0.083268 | 51.53   | 0.000   |
| Feed Rate            | 2                 | 0.013781| 0.013781 | 0.006890 | 4.26    | 0.030   |
| Spindle Speed* Feed  | 4                 | 0.027250| 0.027250 | 0.006812 | 4.22    | 0.014   |
| Rate                 |                   |         |          |          |         |         |
| Error                | 18                | 0.029086| 0.029086 | 0.001616 | -       | -       |
| Total                | 26                |         |          |          | -       | -       |

### 3.4. Regression model and Optimum parameter

The regression model has been produced by Minitab software as shown in Equation 2. The value of $x_2$ (spindle speed) is the most significant because partial regression coefficient larger than spindle speed partial coefficient. This result is align with the previous researcher [8].

$$Ra = 0.394778 - 7.7778e^{-6}x_1 + 0.00235x_2 - 1.775e^{-7}x_1x_2$$ (2)

The machining parameters for this research are focus on HSM machine. For the end milling of Mould Steel DF 2, the optimum condition for carbide endmill and material Mould Steel DF 2 is required to
achieve the best surface roughness within predetermined parameters. The optimum values of cutting speed for the carbide tool endmill and pre-hardened mould steel material is 500m/min.

4. Conclusions
The finding on this research is to determine the influence of cutting parameters to the surface roughness on mould steel material by using HSM. In this research, Mould Steel DF2 material is selected and the full factorial design is used as the experimental design to find out the influence of the parameter process. The relationship between machining parameters and surface roughness is reflected in the results and the analysis part has been shown in the graphs. From the ANOVA analysis, it can be concluded that factor of spindle speed does give significant value to the surface roughness (Ra). This is because the P-value for these factors is 0.000 which is below than 0.05. The different value of spindle speed is able to affect the surface roughness. The second factor in this experiment which is feed rate also gave give the significant value proving by P-value is 0.030 which is below than 0.05. Beside that the interaction between those two factors also gives a significant effect on to the surface roughness which P-value is 0.014, which is below 0.05. From that, Minitab software will generate regression model know as mathematical model that can fit to a set of sample data. In some instance, it has been able to use as an exact form of the true functional relationship between spindle speed and feed rate on effect of surface roughness. From the result, the minimum surface roughness is when the spindle speed is at 16000 rpm and feed rate 200 mm/min. The surface roughness of 0.078 μm is produced from the setting of the cutting parameters above.

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