A study on the effect of feed rate and cutting speed on surface roughness and material removal rate of mild steel

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Abstract. In any machining process, achieving a good surface quality and maximization of material removal rate are absolute importance. This paper provides an insight to the effect of feed rate and cutting speed on NOVIANO and conventional cutting tool in term of surface roughness and Material Removal Rate (MRR). The output of the machining during slot milling of Mild Steel with 17 HRC were measured. Mitutoyo surface tester were used to measure average mean surface roughness (Ra) of the slot milling surface. For the MRR measurement, mathematical formula was used to calculate and evaluate the different weight of workpiece before and after milling. The result shows that, when the feed rate and cutting speed increase, better surface roughness and MRR will be occur. However, the comparison between both cutting tools found that the NOVIANO cutting tool produce much better result than conventional cutting tool where surface roughness and MRR is 13.97% and 51.62%.

1. Introduction
Mild steel or plain-carbon steel is currently the most well-known type of steel, since its price is moderately low compare to other material while it gives material properties that are adequate for some applications. Mild steel is one of the most versatile and resilient materials, and it forms the backbone of wide varieties of heavy machines as well as for various industries due to low cost and good mechanical strength [1]. Low-carbon steel contains around 0.05–0.25% carbon making it ductile and malleable. Generally, mild steel has low elasticity. However, it is easy to form when machining. There are many applications of mild steel were used in daily life such as mounting plates, tool and die sets. It also can provide a soft core and high surface hardness to parts that include machinery parts, special bolts and many more.

Milling is one the machine that widely used to machining this type of materials. This type of cutting operation is capable of producing different types of shapes with the use of multi-tooth cutting tools. The cutting action of the many teeth around the milling cutter provides a fast method of machining. In the milling process, a multi-tooth cutter rotates along various axes with respect to the workpiece. Among various sorts of milling processes, end milling is a standout amongst the most indispensable and regular metal cutting operations utilized for machining parts as a result of its ability to remove materials at faster rate with a sensibly good surface quality. Different application of end milling process can be found in almost every industry ranging from small tool maker units to large production industries. Components and parts made out of steel have to experience wide assortments of manufacturing operations including machining before they are used in auxiliary and also non-structural applications. This last stage of fabrication (lathing, milling, turning, grinding, etc.) tends to cause severe plastic deformation and extensive shearing effect, which removes the top-most layer of work-piece in the form of thin chips [2].
The machining process of metal work-piece is affected enormously by the relative velocity between the workpiece and the edge of the cutting tool. The integration of rotating and translator movement both of the workpiece or the cutting tool or both created the relative movement in the machining operations. The translator displacement of the cutting edge of the tool along the work surface during a given period of time is called 'feed', while the rate of traverse of the work surface past the cutting edge is designated as 'cutting speed' [3]. The most important interactions, that effect surface roughness & MRR of machined surfaces, were between the cutting feed and depth of cut, and between cutting feed and cutting speed [4]. Surface roughness is one of the significant characteristics in metal cutting that is being detected in machining processes. Surface roughness is defined as a group of irregular waves in the surface, measured in micrometres. It is produced by the fluctuations of short wavelengths characterized by asperities (local maxima) and valleys (local minima) of varying amplitudes and spacing [5]. Material Removal Rate is the main output factor for the productivity of machining. MRR is a measurement of productivity & it can be expressed by analytical derivation as the product of the width of cut, the feed velocity of milling cutter and depth of cut [6]. So, in this paper the effect of feed rate and cutting speed on NOVIANO and conventional cutting tool in term of surface roughness and Material Removal Rate (MRR) will be discussed.

2. Methodology
All the tests were carried out by using CNC Milling Machine Sodick MC 430L as shown in figure 1. This CNC machine can improve the productivity and increase the profit with it capability to machine the workpiece such as it can reach precision up to ± 1 µm. It also the only CNC milling machine that can rotate spindle up to 40000 rpm. In this experiment, two types of cutting tool had been chosen and apply throughout the experiments which is conventional and NOVIANO cutting tool manufactured by HPMT industries as shown in figure 2. The meaning of NOVIANO is “No Vibration and Noise” which apply at it particular geometry of the cutting tool makes it anti-vibration. The NOVIANO cutting tool composes a four-flute tungsten carbide tool with TiSi (Titanium-Silicon) multilayer coating, helix angle of 40°, and with maximum application of temperature below than 1200 °C. The conventional cutting tool composes a four-flute micro grain carbide and with helix angle of 35°. Both cutting tool were designed to machine carbon steels, tool steels, alloy steels and stainless steels. Table 1 show a detail terminology of two different cutting tool.

![Figure 1. Sodick MC430L.](image1)

![Figure 2. Cutting tool (a) Conventional (b) NOVIANO.](image2)
Table 1. Cutting tool terminology.

| Terminology         | Conventional | NOVIANO |
|---------------------|--------------|---------|
| Tool Diameter (mm)  | 6            | 6       |
| Tool Length (mm)    | 50           | 57      |
| Length of Cut (mm)  | 16           | 13      |
| Flute               | 4            | 4       |
| Helix Angle (°)     | 35           | 40      |
| Tool Material       | Micro Grain Carbide | Tungsten Carbide |
| Coating             | Coated       | Coated with TiSi Based-Multilayer |

Table 2. Machining Parameter.

| Type of Cutting Tool | Feed Rate (mm/min) | Cutting Speed (m/min) |
|----------------------|--------------------|-----------------------|
| Conventional         | 140                | 2.24                  |
|                      | 280                | 4.48                  |
|                      | 560                | 8.95                  |
| NOVIANO              | 179                | 2.74                  |
|                      | 359                | 5.51                  |
|                      | 718                | 11.00                 |

In this research, Mild Steel was used as a material for the workpiece where it is categorized as world-wide usage material in structural component. Mild steel has an element of C, Si, Mn, S, P, Cr, Mo, V and Fe. One of the material advantage is contain high ductility and low carbon. On the other hand, mild steels are also used in applications such as boiler and pressure vessel. It also can withstand and experience high temperature up to 600-700 °C. The mild steel was cut into small rectangular plate with length, width and thickness dimension of 90 x 50 x 10 mm for slot milling process.

The slot milling was conducted using conventional and NOVIANO cutting tool on mild steel of 17 HRC rectangular block with the dimension of 90 x 50 x 10 mm. Workpiece was clamped on the machine worktable as demonstrated in figure 3 and the same chuck (tool holder) will be applied in this experiment. The inspection of the flatness on the workpiece were done before cutting operation started using mitutoyo 513-404T Dial Indicator as shown in figure 4. The 513-404T Dial Indicator series from Mitutoyo are horizontal type. These indicators were easy to use in a narrow or cramped area and still give an accurate measurement.

The measurement of surface roughness was done using Mitutoyo SJ-400 surface roughness tester as shown in figure 5. The measurement will be based on Japan International Standard (JIS 1994) with cut off length of 0.8 mm x 5. Measurement will be repeated at three different spots for each sample which is first, middle and last surface as shown in figure 6. Every test of the measurement will be printed on printed paper which showing the graph value for surface roughness and the average value of mean surface roughness was calculated and plotted in the graph for analysis.
Before cutting process started, the mass for each of the workpiece was measured using Mettler Toledo Weighting Balance as shown in figure 7(a). It has sensitivity of three decimal places. The MRR measurement will be conducted by referring to Chahal et al., (2013). The equation can be presented as in equation (1):

\[
\text{Mass}_{\text{remove}} = \text{Mass}_{\text{before cut}} - \text{Mass}_{\text{after cut}}
\]  

(1)

Where, the unit of mass remove in kg. The result gain from equation (1) will be represent to the volume remove model as in equation (2). That is,

\[
\text{Volume}_{\text{remove}} = \text{Density} \times \text{Mass}_{\text{remove}}
\]  

(2)

Where, the unit of volume remove in mm\(^3\). The density of mild steel of 17 HRC had been analyze using Mettler Toledo Density kit as shown figure 7(b) which result 7.8360 g/cm\(^3\). The relationship between MRR and machining independent variables (length of tool traveled and feed rate) can be written as:

\[
\text{MRR} = \frac{\text{Volume}_{\text{remove}}}{(\text{Length of tool traveled} / \text{feed rate})}
\]  

(3)

Where, the length of tool traveled had been set constant as 70 mm on the machine.
3. Results and Discussion

3.1 Surface Roughness

Figure 8 shows the graph for surface roughness under various of feed rate using conventional and NITICO cutting tool. It can be observed that, with higher feed rate will produce lower surface roughness value for both cutting tool. Furthermore, at the depth of cut of 0.3 mm for both type of cutting tool show that the surface roughness slightly decreased when the feed rate increased. Figure 8(a) show the graph for surface roughness under various of feed rate using NITICO cutting tool. Based on figure 8(a), the minimum level of feed rate and cutting speed for NOVIANO cutting tool at 179 mm/min and 2.74 m/min will produce 0.520 µm average surface roughness. Apart from that, the medium level of feed rate and cutting speed at 359 mm/min and 5.51 m/min produce the output of 0.430 µm for average surface roughness. For the maximum level of feed rate and cutting speed at 718 mm/min and 11.00 m/min, it will produce 0.333 µm for average surface roughness. Furthermore, comparison from minimum level to medium level shows decrement of 18.95% for average surface roughness produce. Apart from that, the medium level to maximum level show decrement of 25.43% for average surface roughness occur. For minimum level to maximum level, occur large differences which have 43.85% of decrement for average of surface roughness value.

Figure 8(b) show the graph for surface roughness under various of feed rate using conventional cutting tool. Based on Figure 8(b), the minimum level of feed rate and cutting speed for conventional cutting tool is 140 mm/min and 2.24 m/min which give the value of 0.620 µm for average surface roughness. The medium level of feed rate and cutting speed at 280 mm/min and 4.48 m/min for conventional cutting tool produce 0.467 µm for average surface roughness. The maximum level of feed rate and cutting speed for conventional cutting tool at 560 mm/min and 8.95 m/min which give the value of 0.383 µm for average surface roughness.

From the comparison between both of the cutting tool, it shows that NOVIANO cutting tool produce better surface finish of end slot milling compare to conventional cutting tool within the feed rate and cutting speed suggest by each tool manufacturer. With the special geometry of NOVIANO cutting tool with 40° of helix angle compare to 30° of helix angle for conventional cutting tool, it assisted in improvement of surface finish. This supported by previous researcher that the increase in helix angle of the end mill cutter resulted in better surface finish [7]. Surface roughness will deteriorate if there any disruption occurs during machining process such as BUE and chip formation which stuck of the surface. But, a large helix angle can reduce tool deflection by transferring stress vertically which allows the end mill by produce vertical chip ejection. A high helix angle can effectively help the chip extraction away from the cutting zone whilst reducing the stuck-chip disruption [8].
3.2 Material Removal Rate

Figure 9 shows the graph for material removal rate under various feed rates using conventional and NITICO cutting tool. It can be observed that, the MRR slightly increase when feed rate increases for both cutting tool. Furthermore, at the depth of cut of 0.3 mm for both type of cutting tool show that the MRR slightly increase when the feed rate increased. Figure 9(a) show the graph for MRR under various feed rate using NITICO cutting tool. Based on figure 9(a), the minimum level of feed rate and cutting speed for NOVIANO cutting tool at 179 mm/min and 2.74 m/min will produce 74.413 mm³/min MMR. Apart from that, the medium level of feed rate and cutting speed at 359 mm/min and 5.51 m/min produce the output of 223.917 mm³/min MMR. For the maximum level of feed rate and cutting speed at 718 mm/min and 11.00 m/min, it will produce 634.917 mm³/min MRR. Furthermore, comparison from minimum level to medium level shows decrement of 100.12% for MRR produce. Apart from that, the medium level to maximum level show decrement of 95.82% for MRR occur. For minimum level to maximum level, occur large differences which have 43.85% of decrement for MRR value.

Figure 9(b) show the graph for material removal rate under various feed rate using conventional cutting tool. Based on Figure 9(b), the minimum level of feed rate and cutting speed for conventional cutting tool is 140 mm/min and 2.24 m/min which give the value of 49.6 mm³/min for MRR. The medium level of feed rate and cutting speed at 280 mm/min and 4.48 m/min for conventional cutting tool produce 123.2 mm³/min for MRR. The maximum level of feed rate and cutting speed for conventional cutting tool at 560 mm/min and 8.95 m/min which give the value of 374.4 mm³/min for MRR.

![Graph](image)

**Figure 9.** Material removal rate versus feed rate (mm/min)

(a) NOVIANO (b) Conventional.

It can be observed from the comparison between for both cutting tool that NOVIANO cutting tool remove better value of MRR compare to conventional cutting tool. NOVIANO cutting tool highest recommendation was 718 mm/min compare to conventional which is 560 mm/min in term of feed rate. Higher feed rate will produce higher MRR [9]. Also, at higher feed rate, tool traverses the work piece too fast, resulting high MRR [10]. The fact that must be considered is that, as feed increases, the maximum chip thickness also increased, thus MRR will also increase. Moreover, the difference of MRR produce due to the geometry and type of material of tool applied on NOVIANO cutting tool. As NOVIANO cutting tool had larger helix angle, it will minimize better formation of burr compare to conventional cutting tool. Other factor that expect to differentiate the result of MRR between NOVIANO and conventional cutting tool was type of material used as NOVIANO used Tungsten Carbide (WC). In fact, blunt tool with produce more heat that contribute the form of burr. It was proved that wear pattern in the tungsten carbide tool had lower effect to the sharpness of cutting edge compare to other material tool. The tool remains sharp as it will reduce the possibility of tool softening.
which reduce the formation of burr compare to conventional cutting tool. Furthermore, reduction of burr also will increase the MRR.

4. Conclusions
The main objective of this research was successfully achieved. The effect of feed rate and cutting speed on surface roughness and Material Removal Rate (MRR) of mild steel of 17 HRC using slot milling for conventional and NITICO cutting tool were evaluated. In term of different cutting tool, it showed the improvement in surface roughness and MRR using NOVIANO cutting tool. The following conclusion can be drawn:

- Surface roughness improved due to the increasing for both feed rate and cutting speed by taking maximum consideration tool manufacturer’s suggestion.
- By increasing feed rate and cutting speed, higher Material Removal Rate (MRR) can be achieved by taking maximum consideration tool manufacturer’s suggestion.
- The performance of NOVIANO cutting tool give better surface roughness and higher MRR compare to conventional cutting tool.
- The influence of special geometry and material used applied in NOVIANO cutting tool give better result compare to conventional cutting tool.
- The higher helix angle and Tungsten Carbide used on NOVIANO were the main factor it have better performance than conventional cutting tool.

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