The Effect of Cutting Speed on The Machinability of Thyrodur 2379 Mold Steel on Vertical Machining Center

Abdullah ALTIN

ABSTRACT
The experimental study presented in this paper aims to select the most suitable cutting and offset parameter combination for milling process in order to get the desired surface roughness value for the machined workpiece. A series of experiments have been performed on thyrodur 2379 X155 CrVMo 12 1 steel material of cutting width 30 mm with round uncoated cemented carbide insert on 5.5 kW engine power Jhonford VMC550 CNC vertical machining center without cutting fluid. Metal cutting processes were carried out by using four different cutting speeds (70, 90, 110, 130 m/min.) at constant depth of cut (1 mm) and feed rate (0.3 mm/rev.) and the effects of cutting speeds on primary cutting force and surface roughness were discussed. The study of the influence of workpiece material on milling process shows that hardening of material increased by machining up. Cutting force (Fc) and surface roughness decreases with improving workpiece material machinability. From the experiments, the lowest average primary cutting force was obtained as 591,943 N at cutting speed of 130 m/min and the highest primary cutting force was obtained as 695.89 N at 70 m/min cutting force depending on cutting speed. The lowest average surface roughness has been obtained as cutting speed of 0.24 µm at 90 m/min, and the highest average surface roughness was obtained as 0.305 µm at 130 m/min., and chip form is narrow and short step.

Keywords: Machinability, uncoated cemented carbide insert, cutting speed, cutting force, surface roughness
INTRODUCTION

Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures (red-hardness). According to P. Fallböhmer et al. (2000) Tool steel is generally used in a heat-treated state. Die and mold manufacturing is a significant area of application of cast steels and alloy steels. With a carbon content 12% Thyrodur 2379 mould steels are manufactured under carefully controlled conditions to produce the required quality. The manganese content is often kept low to minimize the possibility of cracking during water quenching. However, proper heat treating of these steels is important for adequate performance, and there are many suppliers who provide tooling blanks intended for oil quenching. A study by M.A. Elbestawi et al. (1997) Thyrodur 2379 for the ledeburite high-carbon high-chromium steel, high wear resistance and toughness, strong impact resistance, sharp edges are maintained in good and retain the tempering, and by special treatment can be nitride. According to J. Vivancos et al, (2004), Thyrodur 2379 for all kinds of heavy blanking dies, cold extrusion dies and deep drawing dies with high wear resistance and used widely for making various high precision, long-life cold work dies, such as: punch mold, cold squeezing mold; drawing dies and mandrels; tools for cold extruding tubes; circular shear blades; profiling rollers and cold rolls; woodworking segments and tools. Gauges; wearing parts; guide rails and bushings. The machining and polishing operations represent approximately two thirds of the total manufacturing costs.

MATERIALS AND METHODS

Experiment specimens

Specimens of Thyrodur 2379, which has been industrial usage, are prepared as the dimension of 100X50X30 mm and then used for the experiments. Chemical compositions and mechanical properties of specimens are given in Tables 1 and 2,
respectively. Typical SEM analysis are given in Fig 1., and metallurgical structure of the mechanical workpiece material Thyrodur 2379 steel are given in Fig 2.

**Cutting parameters, cutting tool and tool holder**

Four different cutting speeds are selected as 70 m/min., 90 m/min., 110 m/min and 130 m/min. Uncoated carbide cutting insert (RPHX1204MOEN) qualities and cutting parameters (feed rate of 0, 3 mm/rev and cutting depth of cut 1 mm) are used as recommended by manufacturing companies. In this study to purpose of which is to investigate the effects of tool geometry and material quality on main cutting force taking into account the cutting speed.

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<th>Mo</th>
<th>V</th>
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<td>12.00</td>
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**Table 2: Mechanical properties of Thyrodur 2379 steel**

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<th>Hardness HB</th>
</tr>
</thead>
<tbody>
<tr>
<td>830_860</td>
<td>At stove</td>
<td>Max. 250</td>
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</table>

<table>
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<td>1000_1050</td>
<td>Weather, lubricant or hot bath 500_550°C</td>
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<tr>
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<th>300</th>
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<tr>
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<td>63</td>
<td>61</td>
<td>58</td>
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<td>58</td>
<td>60</td>
<td>56</td>
<td>50</td>
<td></td>
</tr>
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</table>
Fig. 1 Typical SEM analysis of the mechanical workpiece material Thyrodur 2379 steel

Fig. 2 Typical SEM analysis and metallurgical structure of the mechanical workpiece material Thyrodur 2379 steel
Cutting diameter is 50 mm and cutting width is 30 mm. The experiments were carried out with 90° lead angle milling cutter and only one cutting insert was used in the milling cutter. The used tool geometry was as follows rake angle =0°, clearance angle 7°. Full factorial design was applied in the experimental study.

Table 2: Mechanical properties of Thyrodur 2379 steel

<table>
<thead>
<tr>
<th>Temper annealing °C</th>
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</tr>
<tr>
<td>Crystallizing</td>
<td>°C</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>HRC</td>
<td>63</td>
</tr>
</tbody>
</table>

Table 3: Technical properties of dynamometer

| Force interval (Fx, Fy, Fz)  | -5….10 kN                   |
| Reaction                     | <0.01 N                     |
| Accuracy Fx, Fy              | ~ 7.5 pC/N                  |
| Fz                           | ~ 3.5 pC/N                  |
| Natural frequency fo(x,y,z)  | 3.5 kHz                     |
| Working temperature          | 0….70 °C                   |
| Capacitance                  | 220 pF                      |
| Insulation resistance at 20 °C | >1013 Ω                    |
| Grounding insulation         | >108 Ω                      |
| Weight                       | 7.3 kg                      |
Table 4. General specifications of the CNC vertical machining center used in experiments

<table>
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<tr>
<th>Model</th>
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<tr>
<td>Travel X,Y,Z,</td>
<td>500x450x450 mm.</td>
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<tr>
<td>Table Dimensions</td>
<td>705x450 mm.</td>
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<tr>
<td>Tool Changer</td>
<td>18 Tools</td>
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<tr>
<td>SPIRISIN</td>
<td>Divisor with tiltable axis</td>
</tr>
<tr>
<td>Phase number:</td>
<td>3</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Max revolution number</td>
<td>10,000 rev./min.</td>
</tr>
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**Machine tool and measuring instrument of cutting forces**

The machining trials were carried out on 5, 5 kW engine power Jhonford VMC550 CNC vertical machining center without cutting fluid. Tree orthogonal cutting forces (Fx, Fy, Fz) acting on the cutting tool in the X, Y, Z directions were measured. By a tree component piezoelectric dynamometer (Kistler brand 9257 B) under tool holder with appropriate tool amplifier. Data acquisition software was also used. This allows direct and continuous recording and simultaneous graphical visualization of the tree orthogonal cutting forces. The technical features of a dynamometer are listed in Table 3 and the schematically figures of a dynamometer are given in Fig.3. The resultant cutting force was the calculated to evaluate the machining performance in this study. General specifications of the CNC vertical machining center used in experiments are given in Table 4. Reference system (Fx,Fy) fixed to the cutting tool in the rotating dynamometer and milling process under orthogonal cutting conditions are given in Fig. 4. And graphical visualization of the three orthogonal cutting forces are given in fig. 5.
Fig. 3. System architecture. Left: Schematic system scheme. Right: Data sampled and recorded, each record is composed by 12 values [(Fxmax,Fy,Fz), (Fx,Fy,Fz), (Fx,Fy,Fzmax), x, y, z].

Fig. 4. Reference system (Fx,Fy) fixed to the cutting tool in the rotating dynamometer and milling process under orthogonal cutting conditions[1].
RESULTS AND DISCUSSION

In this research, the experiments have been performed in order to investigate the effects of cutting parameters on surface roughness in the milling process for the 2379 material. The experiments have been successfully carried out and practical results for the milling process have been obtained. The change of main cutting force depending on cutting speed and uncoating material of cutting tool. After prepared test specimens were cut for experimental purposes, they were measured with a three-component piezoelectric dynamometer to obtain the main cutting force. The lowest main cutting force is observed at 130 m/min cutting speed and from the experiments, main cutting force values with respect to cutting speed are given in Fig. 2. Fig. 2 indicates that the increasing cutting speed decreases the main cutting force, excluding the area between 90 m/min and 110 m/min. The obtained main cutting force values at the cutting speeds of 70 m/min, 90 m/min, 110 m/min, and 130 m/min are 224 N, 209 N, 214 N and 192
N, respectively. The results of Fig. 2 show that the cutting speed must be increased in order to reduce the main cutting forces. However, in this study, a decrease is observed in the main cutting force between 70 m/min and 90 m/min. According to J. Paul Degarmo et al (1997), Muammer Nalbant et al. (2007), Çakır, C et al. (2000), it is considered that this case is caused by plastic deformation, flank edge, crater and notch wear that are formed at the cutting tool because of high temperatures of shear area when using uncoated carbide tools having low density at high cutting speeds. According to Sandvik handbook (1994), the effect of uncoated carbide inserts was found important on the main cutting force but the effect of cutting speeds was not important in the analysis of variance. The main cutting force increases in spite of increasing the cutting speed at 130 m/min. As a result of an increase of 85.7 % in cutting speed (130 m/min) while working at low cutting speeds (70 m/min) a decrease of 14.2 % has been found in the main cutting force. According to Shaw MC. (1984), high temperature at flow region and decreasing contact surface area caused the main cutting force to decrease in comparison to the increased cutting speed. Decrement of cutting force depends on material type, working conditions and cutting speed range. It is found that by increasing the cutting speed from 110 m/min to 130 m/min by 18.8%, the main cutting force decreases by 10.2%. Since rake angle changes due to breaking of the cutting tool, decreasing of main cutting force in spite of increasing the cutting speed can be attributed to the tool wear. According to Paul Degarmo E et al. (1997), Çakır, C. (2000), tool breaking affects the rake angle negatively that causes an increase of main cutting force. Cutting speed has to be increased for decreasing cutting force. High temperature at flow region and decreasing contact area and chip thickness cause cutting force to decrease depending on cutting speed. According to Shaw MC. 1984, King RI. (1985), material properties, working conditions and cutting speed affect cutting force decrement. As a result of experimental data, (Fig.5) main cutting force decrement by 14.9% with increasing cutting speed by 85% is observed at low cutting speeds (70 m/min). The scatter plot between surface roughness and cutting speed as shown in Fig. 6 indicated that there is a nonlinear relationship between surface roughness and cutting speed. The results of Fig.
show that average surface roughness decreases with increasing cutting speed from 70 m/min. to 90 m/min. increasing the cutting speed from 90 to 130 m/min by 22% average surface roughness increases by 27%. Average surface roughness values are found to be 0.3, 0.24, 0.285, 0.305 µm the cutting speeds of 70, 90, 110, and 130 m/min, respectively. According to Paul Degarmo E (1997) – Çakır, C. (2004), Shaw MC (1984), as widely known, cutting speed must be increased to improve average surface roughness. The change of 3 axis cutting forces in (1mm) constant depth of cut and (3mm/rev.) constant feed rate are given in Fig 7 and Chip formation at V=90 m/min according to the round type insert are given in Fig 8 and regression analysis in Table 5.

Fig. 5. Cutting force (Fx max) values (N) respect to cutting speeds on the constant feed rate

\[ y = 0.0014x^3 - 0.0432x^2 + 41.876x - 457.97 \]
\[ R^2 = 1 \]
Fig. 6. The surface roughness values (µm) respect to cutting speeds on the constant feed rate

\[ y = -3E-06x^3 + 0.0009x^2 - 0.0887x + 3.2138 \]

\[ R^2 = 1 \]

Fig. 7. The change of 3 axis cutting forces in (1mm) constant depth of cut and (3mm/rev.) constant feed rate. According to the round type insert
CONCLUSION

According to King RI (1985), R.C. Dewes, et al. (1997), cemented carbide is the most commonly used cutting tool material for the machining of steels. Despite their high toughness, cemented carbide tools have low hardness values, which restrict their use in the HSM of hardened steels. According to Trent EM. et al. (1984), Boothroyd G, (1981), the change of main cutting force depending on cutting speed and uncoating material of cutting tool]. After prepared test specimens were cut for experimental purposes, they were measured with a three-component piezoelectric dynamometer to obtain the main cutting force. Cemented carbide tools for cutting of Thyrodur 2379 mold steels show a low performance at high cutting speeds. In this study, since Thyrodur 2379 mold steel is used, poor performance is seen with cemented carbide tools. The results of this experimental study can be summarized as follows:

The effect of cemented carbide on the main cutting force is much clearer than the effect of cutting speed. There is an increment–decrement relationship between cutting speed and main cutting force. Increasing cutting speed by 85, 7% (70–130 m/min) causes the main cutting force to decrease by 14.2% and increasing cutting speed by 28,5% causes main cutting force to increase by 0.06%. Minimum main cutting force value 192 N is obtained at a cutting speed of 130 m/min. Breaking and breaking on chip contact surface, tool has affected rake angle in a negative way. The negative chip angle has caused an increase in the main cutting force. An increasing relation between cutting speed and arithmetic average surface roughness as well as between coating number and average surface roughness is observed. In the case of coated tools, the effect of cutting speed on Surface roughness is much more pronounced than the effect of different cemented carbide inserts. The experimental results can be used in industry in order to select the best suitable parameter combination to get the required surface.
Table 5: Regression analysis

Regression analysis: cutting force versus cutting speed: table feed

- Table feed is highly correlated with other x variables
- Table feed has been removed from the equation
- The regression equation is cutting force = 992-2.19 cutting speed

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<tr>
<th>Predictor</th>
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<td>28.25</td>
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<td>Kesme hızı</td>
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<td>-6.38</td>
<td>0.024</td>
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\[ S=15.3213 \quad R-Sq=95.31 \quad R-sq(adj)=93.01 \]

Analysis of variance

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<th>SS</th>
<th>MS</th>
<th>F</th>
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<td>9550.6</td>
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<td>Residual Error</td>
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<td>469.5</td>
<td>234.7</td>
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<td>Total</td>
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<td>10020.1</td>
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<table>
<thead>
<tr>
<th>Source</th>
<th>Df</th>
<th>Sum of squares</th>
<th>Mean square</th>
<th>F ratio</th>
<th>Probability</th>
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<tr>
<td>Regression</td>
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Table 5: Analysis of variance of main cutting force

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<td>Error</td>
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<td>195697.0</td>
<td>24462</td>
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Total 14 1357422.4

Fig 8: Chip formation at V=90 m/min. According to the round type insert

REFERENCES


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