A Study on Surface Roughness in Circular Pocket Machining of SCM415 Steel

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SCM415 강의 원형포켓 가공시 표면 거칠기에 관한 연구

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ABSTRACT

In this study, we study the change of surface roughness during cutting machining by changing the cutting conditions such as feed rate and spindle velocity with chromium molybdenum steel (SCM415) material and TiCN and TiAlN coated end mill tools. The surface roughness value of the test specimen for SCM415, was found to be 3,000 rpm in TiCN coated end mill and 0.634 $\mu$m in surface roughness at a feed rate of 100 mm/min. In the TiAlN coated end mill, 300 mm/min, the surface roughness was the best at 0.699 $\mu$m. The overall average surface roughness of each coating tool was better than that of TiAlN.

Keywords : End Mill(엔드 밀), Surface Roughness(표면거칠기), Cutting Speed(절삭속도), Dimensional Tolerance(치수공차)

1. Introduction

The influence of cutting conditions of main spindle speed and feed rate during the machining of chromium molybdenum steel—which recently has been used in quantity as material for gears, axles, and defense industry manufacturing in industrial sites—on surface roughness, shape characteristics, and hardness variation is considerable. In addition, chromium molybdenum steel appears to be an appropriate material for improving productivity through machining because its hardness variation with tempering even at high temperature (200°C or higher) and problems associated with high-speed machining are minimal, and in some cases, it exhibits thermal resistance and its mechanical properties even improve\(^{[1-5]}\).

Major factors affecting accuracy of machining include cutting speed, feed rate, and cutting depth. Generally, form error increases when feed rate increases, while the life of the equipment becomes shorter when the speed of main spindle increases\(^{[6,7]}\).

Surface roughness refers to regular or irregular unevenness that inevitably occurs in the process of machining, and it greatly affects not only external appearance but also the product function of wear.
resistance, corrosion resistance, fatigue strength, and dimensional accuracy[8].

Greenhow et al[9-11] stated that the higher the main spindle speed and the lower the feed rate per edge of the cutting tool, the lower the residual stress and surface roughness.

The present study investigated changes in surface roughness during the cutting process as the cutting conditions such as feed rate and main spindle speed are changed using chromium molybdenum steel (SCM415) and TiCN- and TiAlN-coated end mills.

2. Experimental apparatus and materials

2.1 Experimental apparatus

The experimental apparatus used in the present study and their specifications are presented in Table 1 and Fig. 1 shows the schematic diagram. The specification details of the surface measuring instrument are presented in Table 2. Fig. 2 shows the surface roughness measuring instrument, and Fig. 3 shows the schematic diagram of the measurement locations of circular pocket production material.

Table 1 Machining Center specification

| Item                  | Specification                        |
|-----------------------|--------------------------------------|
| Manufacturer          | Doosan infracore                     |
| Model                 | VX500                                |
| Table size [mm]       | 1200 × 550                           |
| Main spindle speed [rpm] | 8,000(12,000)                       |
| Main spindle taper     | BT No. 40                            |
| Stroke [mm]           |                                       |
| X-axis                | 1020                                 |
| Y-axis                | 510                                  |
| Z-axis                | 625                                  |

Fig. 1 Schematic diagram of experimental apparatus

Table 2 Specification of surface roughness measurement instrument

| Item                  | Specification                        |
|-----------------------|--------------------------------------|
| Manufacturer          | Kosaka laboratory corporation(Japan) |
| Model                 | SurfCorder - F501                    |
| Driving method        | One reciprocation                    |
| Driving speed [mm/sec]| Measurement : 0.002~10 Auto return : 2~10 |
| Measuring values      | Ra,Rz,Rmax(Ry),Pq,Ps,Rq,Rt,Ry        |
| Cut-off values available | 0.08, 0.25, 0.08, 8, 25              |
| Dimension [mm]        | 600 × 395 × 593                      |

Fig. 2 Photograph of surface roughness tester

1, and Fig. 1 shows the schematic diagram. The specification details of the surface measuring instrument are presented in Table 2. Fig. 2 shows the surface roughness measuring instrument, and Fig. 3 shows the schematic diagram of the measurement locations of circular pocket production material.

Fig. 3 Measurement site of surface roughness after processing circular pocket
2.2 Cutting tools

The cutting tools used in the present study were TiCN- and TiAlN-coated two-flute end mills, and one tool was used per circular pocket. The shapes and specification details are presented in Table 3 and Fig. 4. The methods of tool-coating deposition are classified into chemical vapor deposition (CVD) and physical vapor deposition (PVD). Table 4 shows the advantages and disadvantages of the two vapor deposition methods.

2.4 Experimental materials

The material used in the present study was chromium molybdenum steel, which is created by adding 0.15-0.35% Mo to chrome steel to improve tempering characteristics and reduce sensitivity to tempering brittleness. It is mainly used in gears, heavy-duty bolts, axles such as a large crankshaft, automotive equipment, and defense equipment.

The workpiece used as a specimen was cut into 12 pieces of 80x80x40 mm hexahedrons. Their appearances before and after processing are shown in Fig. 5 and Fig. 6, respectively, and the chemical composition is shown in Table 5.

| Dimension and shape of end mill(mm) |
|---|---|---|
| D | l | L |
| 10 | 26 | 80 |

Table 3 Dimension and shape of end mill(mm)

Fig. 4 TiAlN and TiCN tools

Table 4 Deposition of advantages and disadvantages

| deposition method | Advantages | Disadvantages |
|------------------|------------|---------------|
| CVD              | Possible atmospheric pressure process, High purity / ultra-precision thin-film formation, Option vapor deposition, Excellent step coverage | High reaction temperature, Various reaction variables, Use of hazardous substances, Complex equipment |
| PVD              | Low reaction temperature, A variety of materials | High vacuum, Simple surface, Low deposition density, Low step coverage |

Table 4 Deposition of advantages and disadvantages

Fig. 5 Previous experiments

Fig. 6 After the experiments
3. Experimental method and considerations

3.1 Experimental methods

The present study created circular pockets by modeling them using Hyper CAD, CNC processing software, creating processing data (NC data) using Hyper Mill, and then transmitting the data to the machining center. First, workpiece material was firmly fixed to avoid vibrating or escaping from the vise during machining, and the coated end mill was inserted into the collet chuck so that a 38-mm cutting edge protruded from the chuck.

For machining, helical circular interpolation method was used with 5-mm depth per cut, which was repeated a total of three times. Eight holes per experimental sample and 12 samples in total were processed using cutting oil. Changes in processing conditions are shown in Table 6.

3.2 Surface roughness measurement

The condition for the ideal roughness of the machined surface after machining was measured and investigated.

The measurements of machined surface of the TiCN-coated tool are presented in Fig. 7, and that of the TiAIN-coated tool are presented in Fig. 8. As shown in Fig. 7, the ideal value was found when the surface roughness was $R_s 0.643 \mu m$ at 3,000

**Table 5 Chemical composition of SCM415**

| Element | SCM415(%) |
|---------|-----------|
| C       | 0.13 ~ 0.18 |
| Si      | 0.15 ~ 0.35 |
| Mn      | 0.6 ~ 0.9 |
| P       | 0.03 or less |
| S       | 0.03 or less |
| Cr      | 0.9 ~ 1.2 |
| Ni      | 0.25 or less |
| Mo      | 0.15 ~ 0.3 |
| Cu      | 0.3 or less |

**Table 6 Experimental conditions of cutting process**

| Workpiece | Spindle speed (rpm) | Feed rate (mm/min) | Depth of cut (mm) |
|-----------|---------------------|-------------------|------------------|
| SCM415    | 1,000               | 50                | 5                |
|           | 2,000               | 100               |                  |
|           | 3,000               | 150               |                  |
|           | 4,000               | 200               |                  |
|           | 5,000               | 250               |                  |
|           | 6,000               | 300               |                  |
|           |                     | 350               |                  |
|           |                     | 400               |                  |

Fig. 7 Measurement of the surface roughness ($R_s$) of the TiCN coating end mill tool

Fig. 8 Measurement of the surface roughness ($R_s$) of the TiAIN coating end mill tool
rpm and feed rate of 100 mm/min, and the worst value was found when the surface roughness was $R_a 2.932 \mu m$ at spindle speed of 6,000 rpm and 5,000 rpm and the feed rate of 50 mm/min.

In addition, the analysis of the surface roughness using the average data by the main spindle speed from 1,000 rpm to 6,000 rpm showed that the roughness was the worst at the spindle speed of 2,000 rpm, followed by 3,000, 4,000, 1,000, 5,000, and 6,000 rpm.

As shown in Fig. 8, the best surface roughness of $R_a 0.699 \mu m$ was seen for 1,000 rpm and 300 mm/min feed rate, while the worst surface roughness of $R_a 2.739 \mu m$ was seen for 6,000 rpm and feed rate of 100 mm/min.

In addition, the analysis of the surface roughness using the average data by the main spindle speed from 1,000 rpm to 6,000 rpm showed that the roughness was the worst at the spindle speed of 2,000 rpm, followed by 3,000, 4,000, 1,000, 5,000, and 6,000 rpm.

4. Conclusion

The present study obtained the following conclusions on surface roughness through an experiment in which circular pockets were created using SCM415 steel by changing cutting conditions such as cutting speed and feed rate using TiCN- and TiAlN-coated end mills.

1. For TiCN-coated end mills, the best surface roughness of $R_a 0.634 \mu m$ was obtained for 3,000 rpm and 100 mm/min feed rate, while for TiAlN-coated end mills, the best surface roughness of $R_a 0.699 \mu m$ was obtained for 1,000 rpm and 300 mm/min feed rate.

The overall average surface roughness of TiCN-coated tools was better than that of TiAlN-coated tools.

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