

Investigation of cutting parameters affecting on tool wear and surface roughness in dry turning of Ti-6Al-4V using CVD and PVD coated tools

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Abstract There are some problems in the machining of titanium alloys with excellent properties such as high strength, good corrosion resistance, long service life and low weight. The leading problem appears to be the fast tool wear and the bad machining surface. Therefore, in this study, it was investigated whether cutting parameters have effect on tool wear and surface roughness by turning under dry cutting condition of Ti-6Al-4V alloy with excellent properties. CVD (TiCN + Al₂O₃ + TiN) and PVD (TiAlN) coated WC tools were used in the experiments. Then the Ti-6Al-4V alloy turned with the combinations of the different cutting speed, feed rate, cutting long and depth of cut. We observed that the tools wear in both CVD and PVD coated WC tools increased with increasing the cutting speed, feed rate, depth of cut and cutting length. However, while tools wear increased with increasing cutting speed, the surface roughness reduced to an optimum level. Especially, the surface roughness was worsened above the optimum level changing with increasing the feed rate, cutting length and depth of cut. The tool wear with PVD coated

WC tools was observed to be less than the CVD coated WC tools. However, the values of the surface roughness obtained with PVD coated WC tools with increase in depth of cut, feed rate and cutting length has given us higher values when compared to CVD coated WC tools.

Keywords Wear · Roughness · Turning · Titanium

1 Introduction

Titanium and its alloys are widely used in various applications such as aircraft industry, automotive, sports equipment, biomedical, oil industry and marine applications [1, 2]. These alloys have some excellent properties as high strength, strength-to-weight ratio, high temperature resistance, low thermal conductivity, good corrosion resistance, a longer service life [2–4]. Because of these properties, titanium and its alloys are especially used in aerospace industry for reducing fuel consumption [5]. However, machinability of titanium and its alloy is poor owing to low thermal conductivity, low modules of elasticity and high chemical reactivity between tool and workpiece in comparison to other metallic materials [6, 7].

There are a lot of problem in the machining of titanium and its alloys. These problems are high temperature, high cutting pressures, rapid tool wear, poor surface quality, chatter, etc. Since titanium and its alloys are reactive material and being tendency to weld on cutting tool during the machining, premature tool wear occurs. High temperatures and pressure occur between edge of cutting tool and workpiece due to low thermal conductivity and small contact area between workpiece/tool during machining. This situation causes rapid wear of the cutting tool [6, 8, 9]. In studies made on tool wear; Jawaid et al. [3] studied tool wear characteristic in turning

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Table 1 The chemical composition of the workpiece (wt%)

| | N | C | H | Fe | O | Al | V | Ti |
|-----------|------|------|-------|------|------|----------|---------|---------|
| Ti-6Al-4V | 0.05 | 0.08 | 0.015 | 0.40 | 0.20 | 5.5–6.75 | 3.5–4.5 | Balance |

of Ti-6246. They used uncoated cemented carbide tools and selected as 60, 75, 100 m/min of cutting speeds, 0.25, 0.35 mm/rev of feed rate and 2 mm of depth of cut under dry cutting conditions for turning experiments. Additionally, they measured the tool wear with an optical microscope and carried out the SEM analysis to determine tool wears mechanisms on the worn tool. In the experimental results, they found that longer tool life was obtained from fine grain sized and a honed edged tool. Venugopal et al. [10] investigated tool wear in cryogenic turning of Ti-6Al-4V. They carried out experiments with microcrystalline uncoated carbide tools in the cutting speed of 70–100 m/min under dry, wet and cryogenic cooling (liquid nitrogen) environments. They stated that cryogenic cooling made significant improvements in tool life and reduced the adhesion–dissolution–diffusion tool wear and kept at a desirable level the machining temperature at cutting zone. Sun et al. [11] evaluated tool wear and cutting forces during dry turning of Ti-6Al-4V. They investigated the correlations between cutting forces and tool wear at different cutting speeds in their study. They determined plastic deformation, flank wear and crater wear at the edge of cutting tools. Cutting forces dramatically increased with increasing cutting speeds. Liang et al. [12] experimentally studied the wear of WC-10Ni₃Al and WC-8Co tools in dry turning of Ti-6Al-4V. By looking the morphologies and compositions of worn surfaces of the tools, they investigated the cutting performances and wear mechanism. They found that average width of flank wear and crater wear of WC-10Ni₃Al tool slightly smaller than that of WC-8Co tool at same cutting speeds.

The quality of the machined surface is one of an important factor in manufacturing engineering. Good surface quality prevents fatigue failure and reduces frictions, assembly and operating costs. Surface quality changes with changing of cutting parameters in machining. It is also effected whether a cutting fluids is used or not. In this context, surface quality of titanium and its alloy used in high specific application areas is required to be well. For these reasons, researches have made many studies related on surface quality of machined surface. Ezugwu et al. [13] investigated surface integrity during machining of Ti-6Al-4V with PCD tools using conventional and high pressure coolant. They took measurements for the microstructure of the machined surface with a scanning electron microscope. They showed that main damages of machined surface were micro-pits and re-deposited workpiece. Ramesh et al. [14] researched the effect of cutting parameters on the surface roughness in turning of aerospace titanium alloy using

Table 2 The mechanical properties of Ti-6Al-4V alloy

| Properties | Values |
|----------------------------------|---------|
| Tensile strength, ultimate (MPa) | 895 |
| Tensile strength, yield (MPa) | 828 |
| Elongation at break (%) | 10 |
| Reduction of area (%) | 25 |
| Modulus of elasticity (GPa) | 105–120 |
| Poisson ratio | 0.31 |

**Fig. 1** Turning of Ti-6Al-4V alloy

response surface methodology. They found that feed rate was the most effective factor which affects surface roughness. Sharman et al. [5] studied surface integrity in finish turning of gamma titanium aluminides. The effect of machining parameters on surface integrity was examined by them. Additionally, they were evaluated microstructure alterations, strain hardening, surface roughness on the machined surface/subsurface. Upadhyay et al. [15] studied the effect of different cutting parameters such as cutting speed, feed rate, and depth of cut on surface roughness in turning of Ti-6Al-4V with cemented carbide tools using vibration signals. They developed the regression model including cutting parameters (cutting speed, feed, and depth of cut) and vibration. The developed model provided good prediction accuracy of surface roughness. For tool wear behaviour and workpiece surface integrity, Pretorius et al. [16] conducted a turning experiment on Ti-6Al-2Sn-4Zr-6Mo at a cutting speed of 200 m/min, a feed rate of 0.15 mm/rev and a depth of cut of 0.25 mm using PCD

Table 3 The tool wears and surface roughness values obtained in turning of Ti-6Al-4V alloy

| Exp num | Cutting parameters | | | Cutting length <i>L</i> | CVD coated WC | | PVD coated WC | | Exp num | Cutting parameters | | | Cutting length <i>L</i> | CVD coated WC | | PVD coated WC | |
|---------|--------------------|----------|----------|----------------------------|---------------|-----------|---------------|-----------|---------|--------------------|----------|----------|----------------------------|---------------|-----------|---------------|-----------|
| | <i>a</i> | <i>V</i> | <i>f</i> | | <i>Ra</i> | <i>VB</i> | <i>Ra</i> | <i>VB</i> | | <i>a</i> | <i>V</i> | <i>f</i> | | <i>Ra</i> | <i>VB</i> | <i>Ra</i> | <i>VB</i> |
| 1 | 1 | 30 | 0.052 | 40 | 1.82 | 0.110 | 1.32 | 0.047 | 43 | 1.5 | 60 | 0.162 | 40 | 4.16 | 0.237 | 4.18 | 0.178 |
| 2 | | | | 80 | 1.94 | 0.127 | 1.54 | 0.079 | 44 | | | | 80 | 4.32 | 0.289 | 4.4 | 0.207 |
| 3 | | | | 120 | 2.12 | 0.16 | 1.68 | 0.083 | 45 | | | | 120 | 4.75 | 0.369 | 4.52 | 0.253 |
| 4 | | | 0.104 | 40 | 2.15 | 0.135 | 2 | 0.07 | 46 | | 90 | 0.052 | 40 | 2.4 | 0.218 | 1.94 | 0.177 |
| 5 | | | | 80 | 2.18 | 0.139 | 2.4 | 0.092 | 47 | | | | 80 | 2.58 | 0.226 | 2 | 0.36 |
| 6 | | | | 120 | 2.48 | 0.173 | 2.6 | 0.093 | 48 | | | | 120 | 2.6 | 0.243 | 2.06 | 0.567 |
| 7 | | | 0.162 | 40 | 3.3 | 0.14 | 3.72 | 0.086 | 49 | | | 0.104 | 40 | 2.47 | 0.3 | 2.2 | 0.313 |
| 8 | | | | 80 | 3.6 | 0.143 | 4.1 | 0.093 | 50 | | | | 80 | 2.54 | 0.409 | 2.36 | 0.376 |
| 9 | | | | 120 | 3.8 | 0.186 | 4.18 | 0.094 | 51 | | | | 120 | 3.16 | 0.466 | 3.02 | 0.597 |
| 10 | | 60 | 0.052 | 40 | 1.76 | 0.172 | 1.3 | 0.11 | 52 | | | 0.162 | 40 | 4.16 | 0.318 | 4.22 | 0.331 |
| 11 | | | | 80 | 1.9 | 0.184 | 1.45 | 0.12 | 53 | | | | 80 | 4.78 | 0.517 | 4.6 | 0.507 |
| 12 | | | | 120 | 2.04 | 0.201 | 1.5 | 0.123 | 54 | | | | 120 | 5.1 | 0.597 | 5.26 | 0.602 |
| 13 | | | 0.104 | 40 | 1.9 | 0.189 | 1.76 | 0.115 | 55 | 2 | 30 | 0.052 | 40 | 2.38 | 0.147 | 2.4 | 0.09 |
| 14 | | | | 80 | 2.1 | 0.232 | 1.98 | 0.126 | 56 | | | | 80 | 2.39 | 0.18 | 2.45 | 0.12 |
| 15 | | | | 120 | 2.3 | 0.261 | 2.16 | 0.132 | 57 | | | | 120 | 2.6 | 0.203 | 2.8 | 0.123 |
| 16 | | | 0.162 | 40 | 3.5 | 0.214 | 4.12 | 0.121 | 58 | | | 0.104 | 40 | 2.4 | 0.154 | 2.65 | 0.126 |
| 17 | | | | 80 | 3.85 | 0.279 | 4.22 | 0.128 | 59 | | | | 80 | 2.52 | 0.186 | 2.76 | 0.13 |
| 18 | | | | 120 | 4.1 | 0.330 | 4.34 | 0.15 | 60 | | | | 120 | 2.64 | 0.210 | 2.92 | 0.134 |
| 19 | | 90 | 0.052 | 40 | 1.4 | 0.183 | 1.28 | 0.121 | 61 | | | 0.162 | 40 | 4.12 | 0.227 | 4.46 | 0.135 |
| 20 | | | | 80 | 1.6 | 0.221 | 1.4 | 0.21 | 62 | | | | 80 | 4.45 | 0.23 | 4.98 | 0.175 |
| 21 | | | | 120 | 2.3 | 0.234 | 1.68 | 0.308 | 63 | | | | 120 | 4.65 | 0.235 | 5.06 | 0.183 |
| 22 | | | 0.104 | 40 | 2.25 | 0.235 | 1.94 | 0.19 | 64 | | 60 | 0.052 | 40 | 1.98 | 0.199 | 2.25 | 0.123 |
| 23 | | | | 80 | 2.3 | 0.287 | 2.24 | 0.283 | 65 | | | | 80 | 2.1 | 0.203 | 2.3 | 0.15 |
| 24 | | | | 120 | 2.7 | 0.361 | 2.44 | 0.321 | 66 | | | | 120 | 2.45 | 0.216 | 2.44 | 0.256 |
| 25 | | | 0.162 | 40 | 4 | 0.242 | 4.68 | 0.201 | 67 | | | 0.104 | 40 | 2.46 | 0.238 | 2.68 | 0.133 |
| 26 | | | | 80 | 4.3 | 0.383 | 4.74 | 0.297 | 68 | | | | 80 | 2.62 | 0.261 | 2.89 | 0.275 |
| 27 | | | | 120 | 4.9 | 0.586 | 5.08 | 0.38 | 69 | | | | 120 | 2.84 | 0.318 | 3.01 | 0.47 |
| 28 | 1.5 | 30 | 0.052 | 40 | 2.04 | 0.128 | 2.02 | 0.086 | 70 | | | 0.162 | 40 | 4.65 | 0.248 | 4.68 | 0.184 |
| 29 | | | | 80 | 2.1 | 0.169 | 2.2 | 0.112 | 71 | | | | 80 | 4.7 | 0.32 | 5.1 | 0.425 |
| 30 | | | | 120 | 2.15 | 0.17 | 2.4 | 0.116 | 72 | | | | 120 | 4.76 | 0.415 | 5.56 | 0.56 |
| 31 | | | 0.104 | 40 | 2.18 | 0.148 | 2.24 | 0.115 | 73 | | 90 | 0.052 | 40 | 2.4 | 0.255 | 2.3 | 0.273 |
| 32 | | | | 80 | 2.2 | 0.18 | 2.32 | 0.121 | 74 | | | | 80 | 2.42 | 0.265 | 2.38 | 0.454 |
| 33 | | | | 120 | 2.58 | 0.185 | 2.72 | 0.132 | 75 | | | | 120 | 2.68 | 0.269 | 2.75 | 0.620 |
| 34 | | | 0.162 | 40 | 3.64 | 0.158 | 4.16 | 0.126 | 76 | | | 0.104 | 40 | 2.54 | 0.372 | 2.92 | 0.390 |
| 35 | | | | 80 | 4.24 | 0.19 | 4.32 | 0.142 | 77 | | | | 80 | 2.7 | 0.425 | 3.24 | 0.56 |
| 36 | | | | 120 | 4.5 | 0.193 | 4.4 | 0.148 | 78 | | | | 120 | 3.2 | 0.650 | 3.45 | 0.680 |
| 37 | | 60 | 0.052 | 40 | 1.82 | 0.181 | 1.64 | 0.111 | 79 | | | 0.162 | 40 | 4.98 | 0.555 | 5.34 | 0.412 |
| 38 | | | | 80 | 1.98 | 0.186 | 1.7 | 0.129 | 80 | | | | 80 | 5.02 | 0.7 | 5.55 | 0.601 |
| 39 | | | | 120 | 2.06 | 0.214 | 1.86 | 0.14 | 81 | | | | 120 | 5.4 | 0.891 | 5.92 | 0.710 |
| 40 | | | 0.104 | 40 | 2.08 | 0.221 | 2 | 0.126 | | | | | | | | | |
| 41 | | | | 80 | 2.15 | 0.252 | 2.26 | 0.138 | | | | | | | | | |
| 42 | | | | 120 | 2.47 | 0.276 | 2.4 | 0.16 | | | | | | | | | |

a depth of cut (mm), *V* cutting speed (m/min), *Ra* average surface roughness (μm), *f* feed rate (mm/rev), *VB* tool wear (mm), *L* cutting length (mm)

| Cutting Parameters | Cutting Tools | | | | | | |
|------------------------------|----------------|--|----------------|--|----------------|--|-----|
| | CVD | | PVD | | CVD | | PVD |
| V=60 m/min f=0.104 mm/rev | | | | | | | |
| | a=1 mm | | a=1.5 mm | | a=2 mm | | |
| V=90 m/min a=1 mm | | | | | | | |
| | f=0.052 mm/rev | | f=0.104 mm/rev | | f=0.162 mm/rev | | |
| f=0.052 mm/rev a=2 mm | | | | | | | |
| | V=30 m/min | | V=60 m/min | | V=90 m/min | | |

Fig. 2 Optical micrograph of tool wears at different cutting parameters

tools with different diamond grain size. They found that tool life improved with increasing grain size and the basic wear mechanisms of the cutting tool were crater formation and workpiece adhesion.

The aim of this study is to investigate experimentally effects of cutting parameters and cutting tool coating method on the tool wear and surface roughness in the turning of Ti-6Al-4V alloy.

2 Experimental procedures

Ti-6Al-4V alloy with ASTM B348 standard number from most preferred titanium alloy is selected for the turning experiments. This alloy has a diameter of 40 mm and a length of 400 mm. The chemical composition and the mechanical properties of the workpiece are given in Tables 1 and 2, respectively.

The experiments were conducted on a JETCO brand JML-3010Y model universal lathe machine that has a variable spindle speed (60–1500 rpm). In order to investigate the effects of coating methods of cutting tool, it was chosen TiCN + Al₂O₃ + TiN CVD coated WC from ZCC. CT brand TNMG 160408-DM model YBC251 grade and TiAlN PVD coated WC from ZCC. CT brand TNMG 160408-EF model YBG 205 grade as cutting tools. It was mounted on a MBC brand MTJNR 20 × 20 K16 tool holder with approach angle 93°, rake angle −6°, angle of inclination −6° and relief angle 0°.

Time brand TR 200 model instrument was used to the surface roughness measurements on the machined surface of Ti-6Al-4V. Roughness measurements were made to be parallel to the workpiece axis. Average surface roughness (Ra) was determined by taking 3 measurements from machined surface. NADE brand NMM-800 TRF model

| Cutting Tool | Cutting Length (mm) | | |
|---|---------------------|----|-----|
| | 40 | 80 | 120 |
| CVD | | | |
| PVD | | | |
| V = 60 m/min, f = 0.104 mm/rev and a = 2 mm | | | |

Fig. 3 Optical micrograph of tool wears depending on the cutting length

optic microscope at a magnification of ×5 and JEO brand JSM-7001F model scanning electron microscope (SEM) were used for measurements of tool wear.

In turning of Ti-6Al-4V alloys, cutting parameters were selected as cutting speeds of 30, 60 and 90 m/min, feed rate of 0.052, 0.104 and 0.162 mm/rev, depth of cut of 1, 1.5 and 2 mm and cutting length of 40, 80 and 120 mm. Experiments were conducted under dry cutting conditions (Fig. 1). In the total, 162 experiments were performed. 54 pieces CVD and PVD coated cemented carbide tools were used.

3 Experimental results and discussions

The results of turning Ti-6Al-4V alloy are divided into two sections. The first section include tool wear, the second section include surface roughness. The tool wear and the average surface roughness values obtained from experimental

studies depending on cutting parameters and cutting length are given in Table 3.

3.1 Analysis of tool wear

The optical micrograph of tool wears of CVD and PVD coated WC tools at different cutting parameters such as cutting speeds, feed rates and depth of cuts are given in Fig. 2, and the optical micrograph of tool wears depending on cutting length at a cutting speeds of 60 m/min, feed rate of 0.104 mm/rev and depth of cut 2 mm are given in Fig. 3. Additionally, tool wear graphics depending on experimental results are given in Fig. 4.

Turning of Ti alloys are affected from cutting parameters such as cutting speed, feed rate and depth of cut, and different other parameters. Ginting and Nouari [17] expressed that low thermal conductivity, high temperatures strength, high strain hardening and high chemical reactivity effect the machining of Ti alloys.

From Fig. 4, we can see that the tool wear increased with increasing cutting speeds when turning Ti-6Al-4V alloy with CVD and PVD coated WC tools. In the turning with high cutting speeds of Ti-6Al-4V alloy, high cutting temperature is occurred due to relatively its low thermal conductivity. It was stated by Gorczyca [18] and Astakhov [19] that the temperature increased due to shorter contact area between tool edge–chip interfaces, and the rising temperature increased the tool wear. Additionally, the increase in both feed rate and depth of cut increased the tool wear at same cutting speeds. It has been known that the forces and the pressure on tool increase with increasing feed rate and depth of cut. Therefore, when the feed rate, depth of cut and cutting length increased, it was thought to accelerate the tool wear. Sun et al. [20] reported that feed rate affected the cutting amount per unit time and the cutting temperature increased with increasing feed rate. From the previously study, wear rate of cutting tool is based on cutting temperature [19, 20]. The high cutting temperature speed up the tool wears. When the CVD coated tools were compared with PVD coated tools depending on cutting parameters, it was seen that wear of the PVD coated tools were lower than wear of the CVD coated tools up to 60 m/min cutting speed for 1 mm and 1.5 mm depth of cut. When the cutting speed reached to 90 m/min, tool wear seriously increased for cutting tools coated with both methods. However, it was seen that the values of wear for the tools coated with CVD method were found to be lower than the values of wear for the tools coated with PVD method. The tools were seriously worn in 60 m/min cutting speed and 2 mm depth of cut.

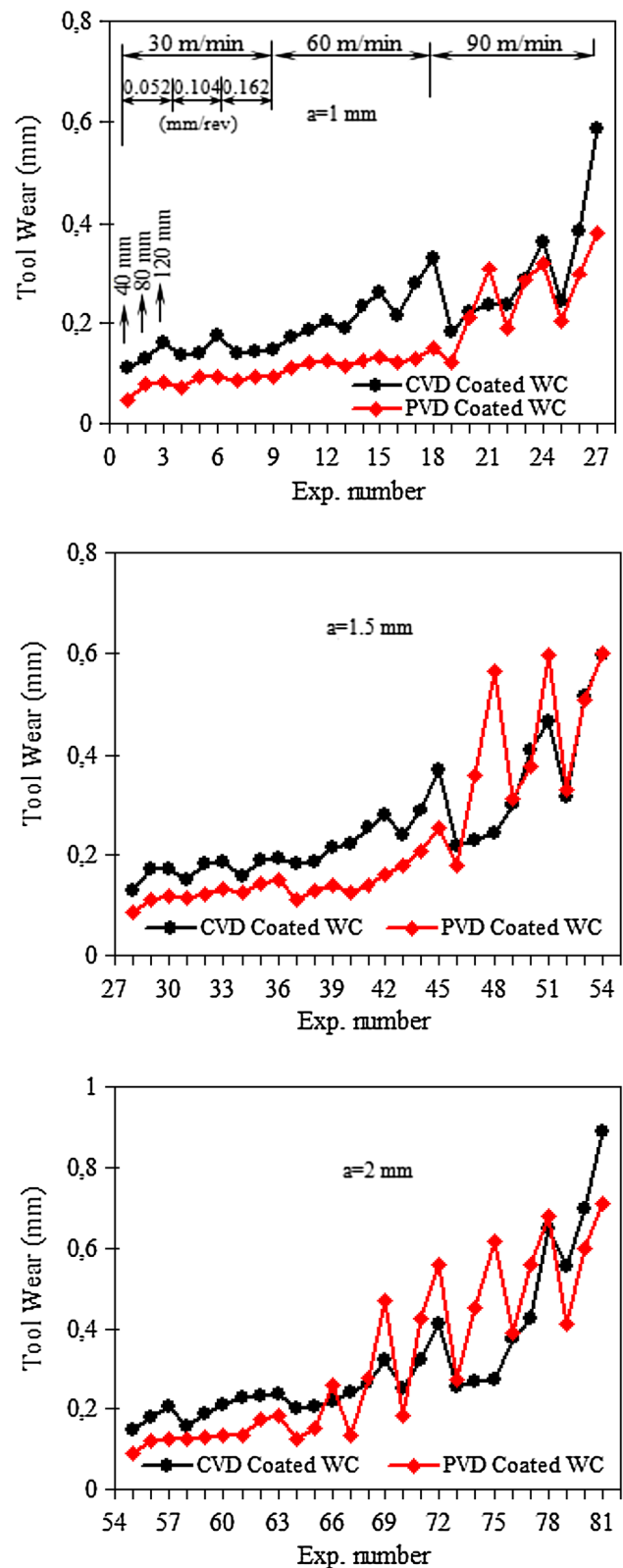


Fig. 4 The tool wears graphics depending on the experimental study

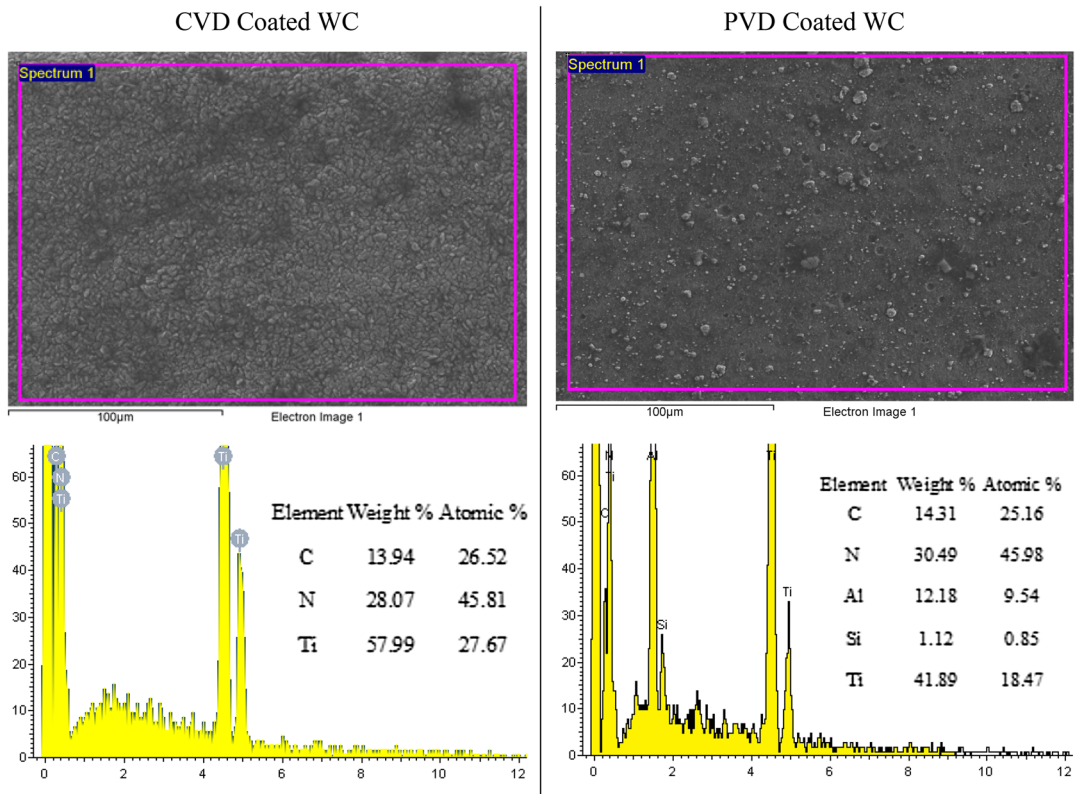


Fig. 5 Chemical composition and SEM photographs of CVD and PVD cutting tools

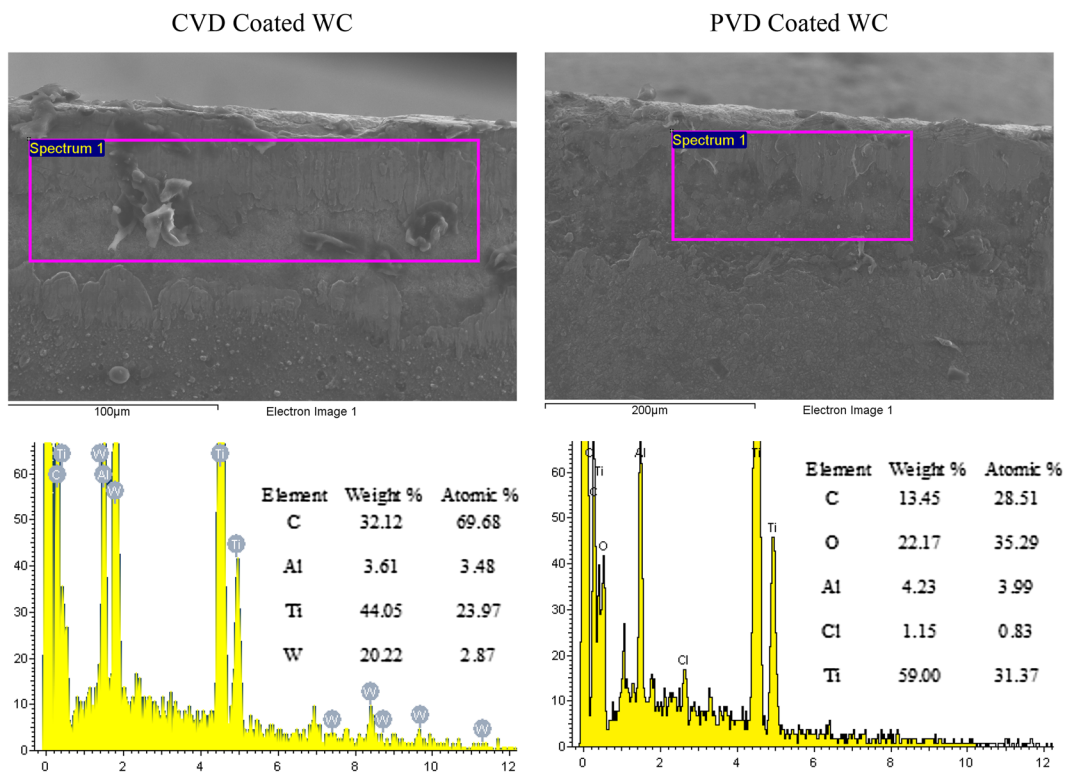


Fig. 6 Chemical composition and SEM photographs of cutting tools for 30th experiment

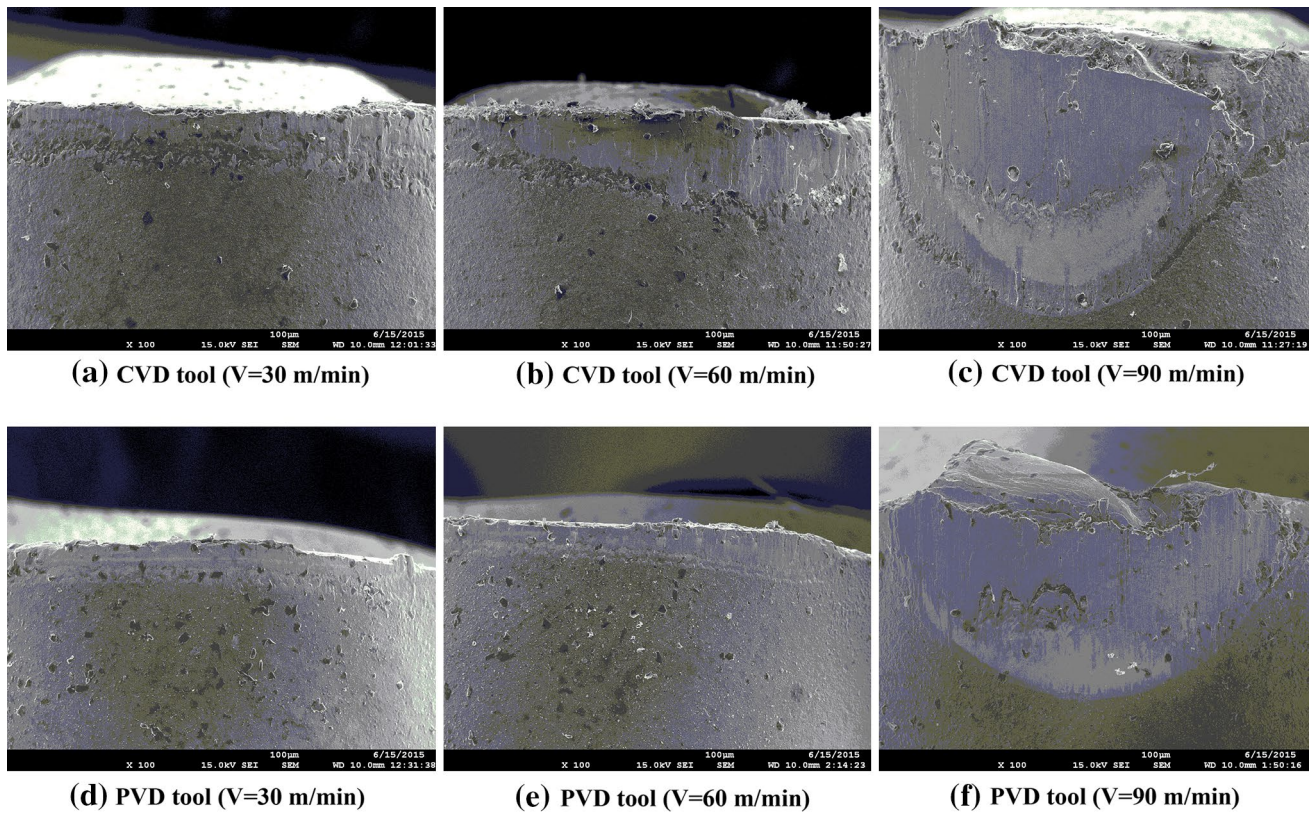


Fig. 7 SEM images of cutting tools for 0.104 mm/rev feed rate, 1.5 mm depth of cut

Chemical composition and SEM photographs of unused CVD and PVD cutting tools are given in Fig. 5.

Figure 6 shows chemical composition and SEM photographs of CVD and PVD coated WC tools in the 30 m/min cutting speed, 0.052 mm/rev feed rate and 1.5 mm depth of cut for 120 mm cutting length. As seen from Fig. 6, chemical composition of area spectrum-1 includes 32.12 wt% C, 3.61 wt% Al, 44.05 wt% Ti and 20.22 wt% W for CVD coated WC. Chemical composition of area spectrum-1 of PVD coated WC contains 13.45 wt% C, 4.23 wt% Al, 59 wt% Ti, 22.17 wt% O and 1.15 wt% Cl. When the used cutting tools in 30th experiment were compared with the unused cutting tools, it was seen that some of the elements decreased while the others increased. The reason for these variations is considered to be the wearing of cutting tool and sticking of workpiece on cutting tool.

Some of the SEM images belonging to wear of CVD and PVD tools are shown in the Fig. 7 for 120 mm cutting length. When Fig. 7a, d are compared, it is seen that tool wear of PVD coated WC is less than tool wear of CVD coated WC for the same cutting conditions. The same expressions for both cutting tools are also true for the 60 m/min cutting speed (Fig. 7b, e). However, in the cutting speed of 90 m/min, wear for the CVD coated WC tools is lower than wear of the PVD coated WC tools and

CVD tools has showed a stable structure (Fig. 7c, f). This situation is thought to result from the coating method and functionality.

Adhesion–dissolution–diffusion have occurred on cutting tools in the high cutting parameters, since high cutting parameters effect chemical reactivity, cutting temperature and pressure between the tool and workpiece. Especially, the workpiece materials are adhered to the tool faces as seen in Fig. 7f. The high chemical reactivity and contact pressure of tool/workpiece interfaces causes the formation of the adhered workpiece materials [20]. This adhesion of workpiece materials and tool caused to be broken together. Also, crater wear on tool occurred due to the diffusion wear mechanism. When the SEM images of the CVD and PVD tools were examined, flank wear observed in both cutting tools due to friction between the tool and the workpiece.

3.2 Analysis of surface roughness

Surface finish of the machined parts is an important criteria and plays on very vital role in manufacturing industries. The surface roughness is an important part of the surface quality. High form accuracy and low surface roughness in machined part can significantly improve the quality, the range and ability of functions, and increases value of the

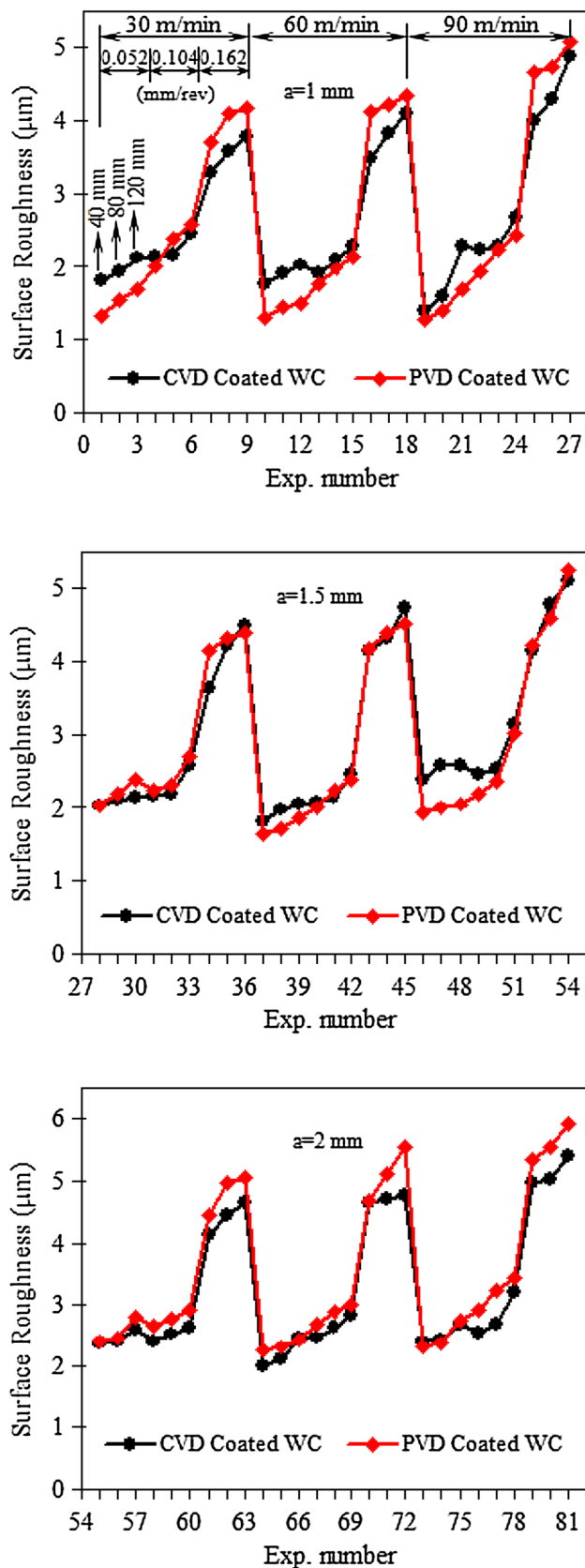


Fig. 8 The surface roughness graphics depending on the experimental study

final production [21]. Also, the surface roughness affects some properties such as fatigue strength, creep life, corruptions resistance, wear resistance, etc. of the work piece. It is necessary to protect the machined parts from the effects of this negativity. Therefore, the factors affecting the surface roughness must be controlled. There is a direct relation between the surface roughness and cutting parameters such as cutting speed, feed rate, depth of cut, etc. To determine this relationship, a series of experiments were performed and effects of cutting parameters on surface roughness were determined. Cutting parameters like cutting speed, feed rate and depth of cut on surface roughness are shown in Fig. 8 for TiCN + Al₂O₃ + TiN CVD and TiAlN PVD coated WC tools and cutting length of 40, 80 and 120 mm.

As seen in Fig. 8, although the surface roughness was stable at low cutting speed, the surface roughness increased with increasing cutting speed. The highest surface roughness was found as 5.92 µm at cutting speed of 90 m/min, the feed rate of 0,162 mm/rev and the depth of cut of 2 mm for TiAlN PVD coated WC tools. This increase in surface roughness is probably due to high tool wear at the cutting speed of 90 m/min. Che-Haron [6] described this situation as the wear on the cutting tool or adherence of the workpiece material at tool nose. The surface roughness increased with increasing feed rate. It was seen that the surface roughness at turning of Ti-6Al-4V alloy were affected at high feed rate, cutting length and depth of cut.

4 Conclusions

A number of experimental studies were conducted to investigate the machinability of Ti-6Al-4V alloy at different machining parameters. The following results were obtained;

- The increase in factors such as cutting speed, feed rate, depth of cut and cutting length increased tool wear. Excessive tool wear occurred at high cutting parameters. Ti-6Al-4V alloy must be machined at low cutting parameters.
- When tool wear values depending on the cutting parameters in CVD and PVD tools were compared, the wear values of TiAlN PVD coated WC tools were much lower than the wear values of TiCN + Al₂O₃ + TiN CVD coated WC tools under same low cutting parameters. But, the wear values of PVD coated WC tools were higher than that CVD coated WC tools under the same high cutting parameters. These variations are caused by chemical effect between cutting tool/workpiece.
- The surface roughness obtained at low cutting parameters was found much better than that obtained at high cutting parameters. However, to obtain an accept-

able surface after turning of Ti-6Al-4V alloys, a final machining operation such as grinding are required for these alloys.

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