H. SERT, A. CAN, K. HABALI, F. OKAY

RESEARCH

Wear Behavior of PVD TiAlN, CVD TiN Coated and Cermet Cutting Tools

This study represents the surface roughness and dimensional deviations when machining the AISI 5140 steel with PVD- TiAlN, CVD- TiN coated and uncoated Cermet cutting tool. All the surface roughness and dimensional data related by machining time for all cutting speed. While the machining time, as a function of tool wear caused the surface roughness and dimensional deviation increasing. Tool life depended on surface roughness is achieved for three type of cutting tool. The suitable cutting conditions were appeared, tool type-cutting speed. TiAlN coated carbide tools are suitable under the speed of V=200 m/min. TiN coated cutting tools are more suitable than TiAlN coated cutting tool at cutting speed of V=250 m/min. Minimum tool wear is achieved from TiN coated cutting tool at highest speed of cutting V=250 m/min. Cermet cutting tool has the biggest value of wear rate at all speed of cutting from V=100 to 250 m/min. It is achieved from the experiments result that, serial machining tests are the best way to investigate the wear behavior, tool life, surface roughness, and dimensional deviation of cutting tools.

Keywords: *Surface roughness, Dimensional deviation, Tool wear, TiN Coating*

1. INTRODUCTION

Surface roughness and dimensional accuracy play an important role in the performance of a machined component. In actual machining processes, however the quality of the work piece (either roughness and dimensions) are greatly influenced by the cutting conditions, tool geometry, cooling conditions, tool material, machining process, chip formation work piece material, tool wear and vibration during cutting [1-3]. The incorrect cutting conditions may cause the premature failure of tool and made out of the work pieces that out of the tolerances. Quality control of surface roughness and dimensional accuracy is the most important factor to faultless/perfect machining in production process. The measuring of dimensional accuracy of the work pieces, can be done easily by simple measurement tools (micrometer, compass etc.) in serial machining. But we can’t do it same thing for the surface roughness measurement. Mostly, measurement of surface Roughness is ignored in production process. Quality control operations are increasing the cost of the components and slow down the manufacturing speed. However, another thing that increases the cost of produce and slows down the manufacturing is, rejecting or remachining of products that has no dimensional accuracy and better roughness.

In metal cutting operations, it is more desirable to study the tool wear, dimensional accuracy, surface roughness and the parameters that affect the tool life and the method of the tool life is important.

Therefore, a lot of study about determining the suitable cutting conditions to monitor the tool wear, surface roughness, and dimensional accuracy. Some researchers [4-5] have studied the different cooling conditions. Some researchers have studied tool wear by measuring the flank and rake face wear by using the optical methods. On the other hand, flank wear is estimated by relating it to a measured variable such as the variation of the work piece dimensions (like this study), cutting forces, temperature, vibrations acoustic emissions and surface roughness. The correlation, empirical model, and prediction of the tool wear-cutting conditions (tool type - geometry, cutting parameter, vibrations, cutting forces) are studied by some statistical models, artificial neural networks, etc. [6-14]. Some of the researchers [15-16] studied the optimization of the cutting conditions for minimal cost of production.

Hasan SERT[a], Ahmet CAN[b],
Kasım HABALI[a], Faik OKAY[a]
a- Faculty of Technical Education Gazi University, Besevler Ankara, TURKEY
b- Technical College of Cihanbeyli, Selcuk University, Cihanbeyli Konya, TURKEY

On the other hand some researchers [17-21] are focused on the tool material and coating technology. The result of the experimental study focused on the coating techniques (PVD- CVD), and coating material (TiN-TiAlN, TiCN etc.), shows that the thin and hard coatings on the tool body are increasing the tool life and productivity by decreasing the tool wear.

This study presents a different approach to investigate the correlation tool life, tool wear, dimensional deviation and surface roughness in the serial machining operations. This idea is to establish the tool wear progression by relating with dimensional deviation and surface roughness in serial machining. Since the tool wear influences the surface roughness and dimensional deviation, the propagation of wear also influences the value of surface roughness and work piece dimensional deviation as shown in Fig.1(a)-(b). This study investigates the correlation between the wear of PVD-TiAlN, CVD-TiN coated, and uncoated cermet cutting tools and the change of work pieces surface roughness and dimensional deviation during serial machining process. Nearly 950 pieces of specimen were used in these serial machining experiments.

The formation of the surface roughness with nose radius “r”and feed rate “f” is shown in Fig. 1(a). After the tool wear propagate, the change of surface roughness and dimensional deviation is shown in Fig.1 (b). The simple wear propagation on single point cutting edge is shown as 3D image in Fig.1(d). This figure shows the wear zone in primary and secondary cutting area on tool edge.

Fig. 4(d) shows the wear zone in primary and secondary cutting area on tool edge. Wear length (d) in the primary cutting are can not be larger than chip passes depth. The front face wear amount “VA” propagates on secondary cutting edge. This wear begins to propagate from the point where the nose radius of the tool is tangent to diameter of work pieces while turning. This wear amount causes the dimensional deviation on turning parts. In serial operation, especially, in CNC lathes it is a big problem for dimensional accuracy and manufacturing speed. This wear also causes the surface roughness increase for increased vibration and the deformed tool nose radius.

The simple mathematical equations of the total tool front face wear amount (VA) can be calculated as in serial operation;

$$VA = (Dw - Do) / 2 \quad (1)$$

Where *Dw* is the diameter of the parts during serial operations, *Do* is the diameter of the first part that machined with nonweared tool. In addition, dimensional deviation can be calculated as

$$Dd = Dw - Do = 2 \ x \ VA \quad (2)$$

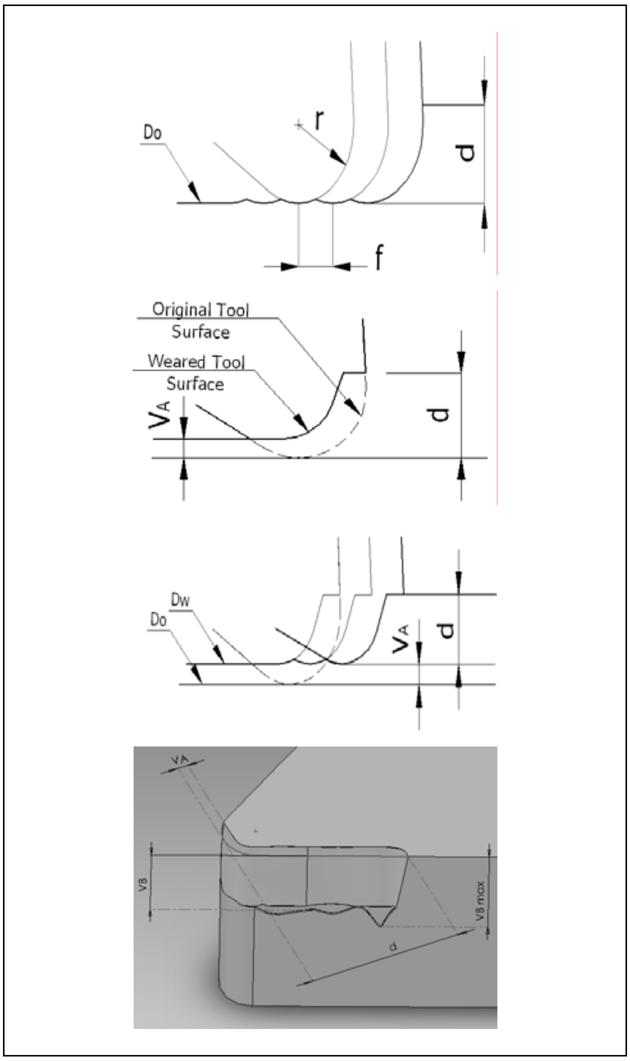

Figure 1: (a). The formation of the surface roughness with no wear sharp cutting tool (b) Tool Wear (c), Change of surface roughness and dimensional deviation after the tool wear propagate. (d) Simple wear propagation on single point cutting edge.

2. EXPERIMENTAL

Pittler NF 300 CNC lathe with the motor power of 48 Kw was used in the experiments. The material used in the experiment was AISI 5140 (DIN 41Cr4) in the form of round bar 55 mm in diameter and 120 mm in length. Chemical composition of AISI5140 is listed in Table 1.

The specimens were fixed with chuck and tailstock of 14-bar pressure. The experiments were carried out using the cutting conditions that shown in Table 2.

Table 1. The chemical composition for AISI 5140 steel.

C	Cr	Si	Mn	S	P	Sn	Cu	Al	Co	Ni	Mo	Fe
0,394	1,111	0,212	0,707	0,019	0,009	0,730	0,169	0,003	0,012	0,160	0,033	97,14

Table 2. Experimental cutting conditions

<table>
<tr><th>Test Group</th><th>Cutting Speed V (m/min)</th><th>Tool type</th><th>Dept of cut in rough turning (mm)</th><th>Depth of cut in finish turning (mm)</th><th>Tool Nose Radius (mm)</th><th>Feed at rough turning (mm/rev)</th><th>Feed at finish turning (mm/rev)</th></tr>
<tr><td>1</td><td>V=100</td><td rowspan="2">TiAlN
TiN
Cermet</td><td rowspan="2">2,5</td><td rowspan="2">1</td><td rowspan="2">0,8</td><td rowspan="2">0,3</td><td rowspan="2">0,1</td></tr>
<tr><td>2
3
4</td><td>V=150
V=200
V=250</td></tr>
</table>

The used three type of cutting tool was P10, uncoated cermet, tungsten carbide based PVD-TiAlN, CVD – TiN coated. According to ISO standard, the tool is designated as DNMG - 150608, 55^o rhomboid (manufacturer: ISCAR®). The insert was rigidly attached to a holder of ISO designation of PDJNR 2525 M15. The combination of the insert and the tool holder provided 93^o cutting edge angle, -6^o rake angle. In all test group the part diameter of the specimens were machined from diameter 55 to diameter 25 in length of 90 mm and as shown in Table 2. Dept of cut in rough turning was 2,5 mm at feed rate 0,3 mm/rev. Than finish turning is done, by the conditions of dept of cut 1 mm and 0,1 mm/rev after rough turning and finished with the same tool by using three type of cutting tool as shown in the Table 2. Specimens were measured by Mitutoyo Digital Micrometer (1μm sensitive) and Mitutoyo Surf Test SJ 201 Surface Roughness Measurement by using the mean arithmetic deviation (Ra). And Ra= 10 μm is tool life criteria. Dimensional deviation is derived from equation (2).

3. NUMERICAL RESULTS

Fig. 2-4 show plots of experimental results. The surface roughness- machining time curves are presented in Fig. 2 a-d at various cutting tools.

As expected, with the increase of machining time, surface roughness increased. Overall, the performance of cermet tool was found to be very poor in all cutting conditions. In the cutting speed 250 m/min, tool life depended on surface roughness (Ra=10 μm) was very short in three type of cutting tools. The highest tool life achieved was about 734 min at 100 m/min with PVD-TiAlN coated tool. 185 specimens were machined by this tool at this cutting speed.

In the group of cutting speed at 100,150,200 m/min, TiAlN coated tool has the longer tool life than the other TiN coated and cermet cutting tool. Cutting speed at 250 m/min TiN coated cutting tool has the longer tool life than the TiAlN coated and cermet cutting tool. In the group of cutting speed at 150 m/min, TiAlN coated tool has 364 min tool life by machining of 138 specimen on condition that Ra<10 μm. These values are 245 min-93 specimens for TiN and 100 min- 38 specimens for cermet cutting tool. In the group of cutting speed at 200 m/min, TiAlN coated tool has the longest tool life at 162 min, by machining 82 specimen on condition that Ra<10 μm. These values are 134 min-68 specimens for TiN and 45 min- 23 specimens for cermet cutting tool. At the maximum cutting speed 250 m/min, TiN coated tool has the longest tool life at 75 min, by machining 48 specimen on condition that Ra<10 μm. These values are achieved 41 min-26 specimens for TiAlN and 22 min- 14 specimens for cermet cutting tool.

Dimensional deviation – machining time curves are presented in Fig. 3 a-d. The wear rate – cutting speed curves are presented in Fig. 4(a). and tool life – cutting speed curves are presented in Fig. 4 (b).

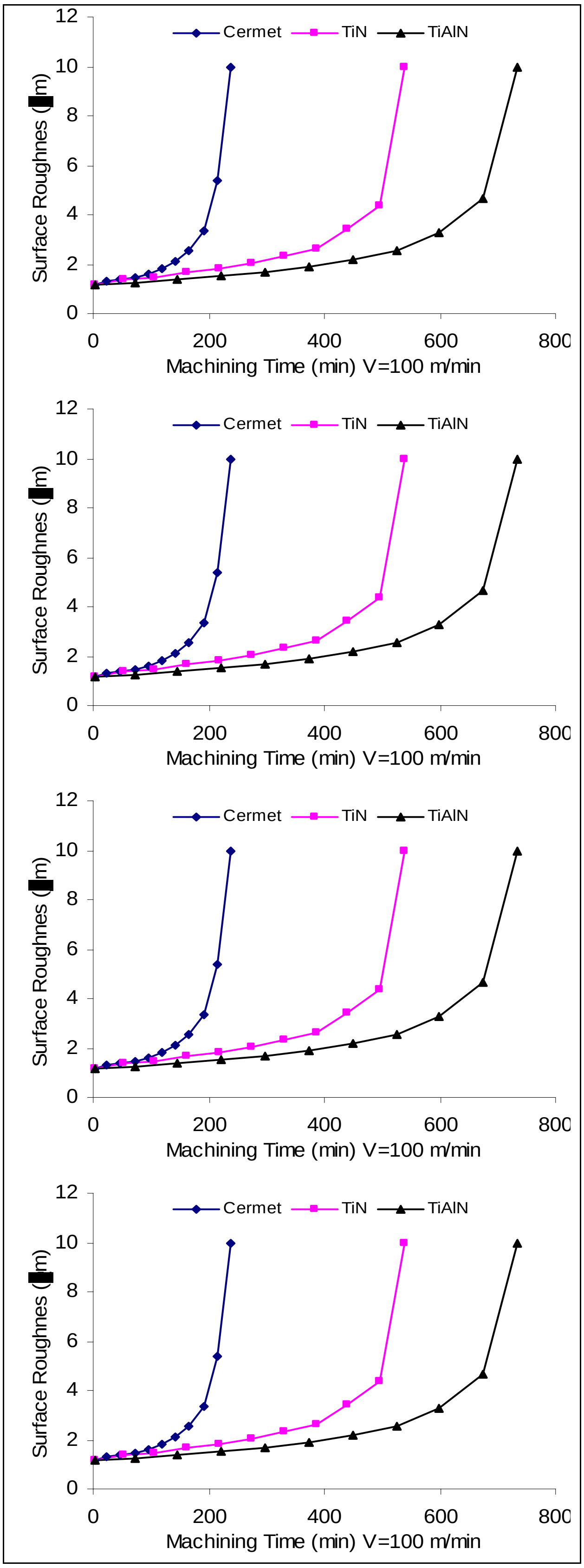

Figure 2: Variation of surface roughness with machining time at various cutting tool. (a) V=100 m/min (b) V=150 m/min (c) V=200 m/min (d) V=250 m/min

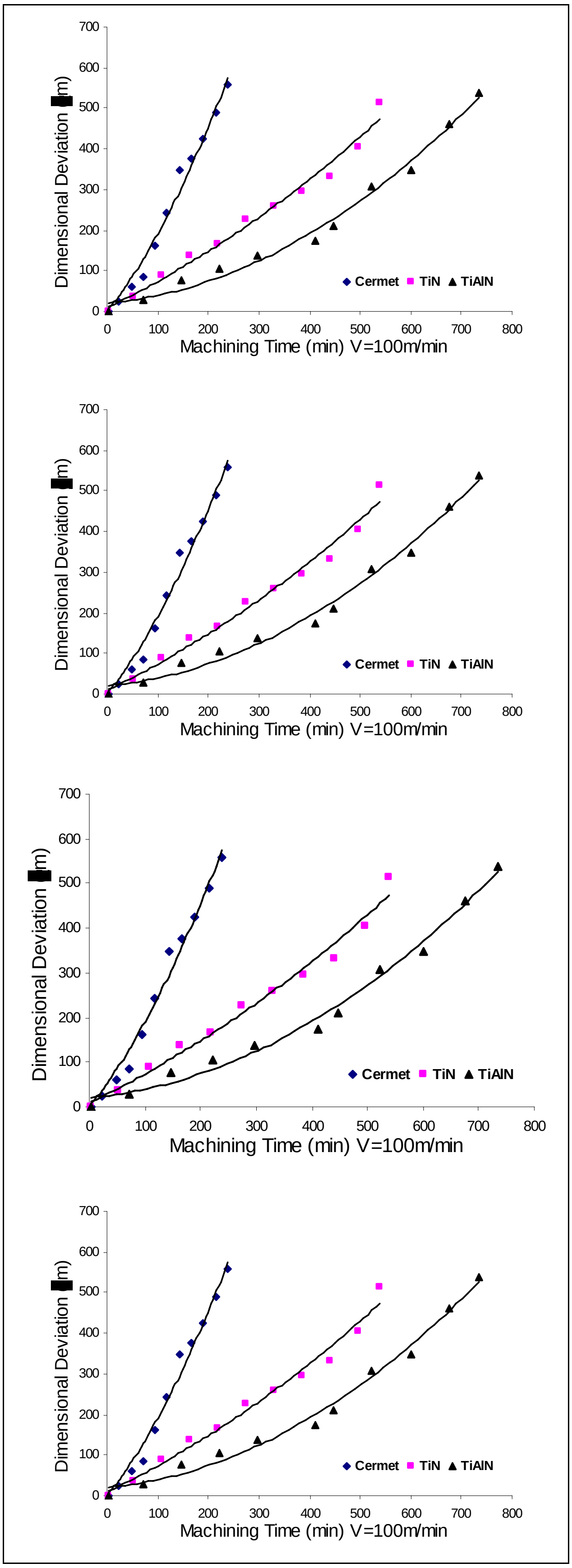

Figure 3: Variation of dimensional deviation with machining time (a) V=100 m/min (b) V=150 m/min (c) V=200 m/min (d) V=250 m/min at various cutting tool.

As shown in Fig. 3 (a)-(d) the dimensional deviations are presented. As shown Fig. 3 (a)-(c) and as expected with the increase of machining time, dimensional deviation increased. The highest dimensional deviation was achieved 712 μm from TiN coated tool at cutting speed 250 m/min. The Minimum dimensional deviation achieved 515 μm from TiN coated tool at cutting speed 100 m/min. Dimensional deviation is the best indicator of tool wear. We can calculate the tool wear amount by using the equation (2). So in the range of cutting speed 100-200 m/min tool wear is about 250-350 μm.

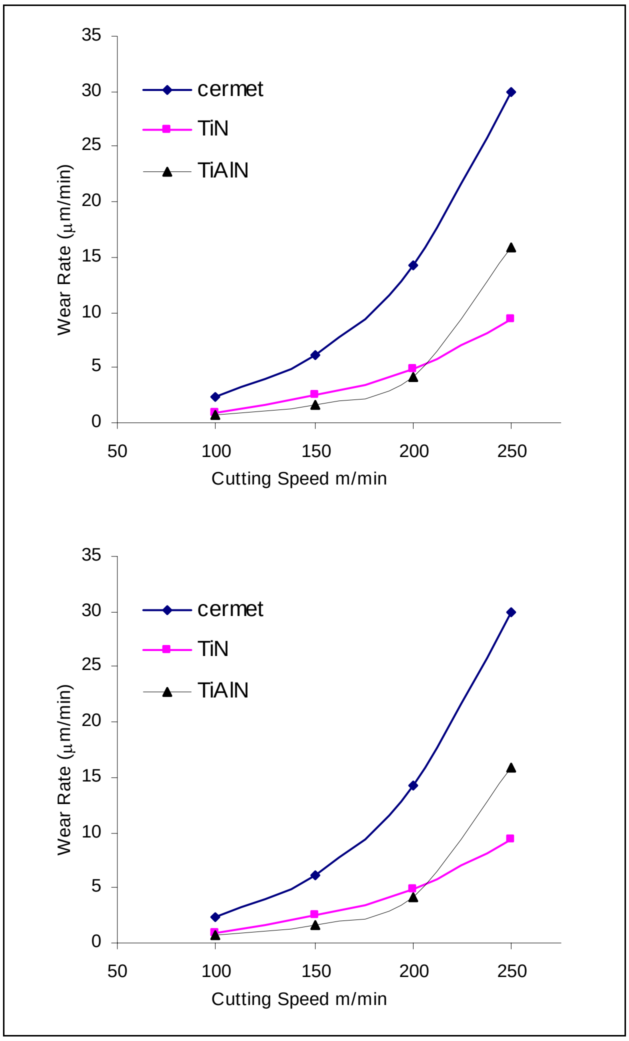

Figure 4: (a) Variation of wear rate with cutting speed (b) Variation of tool life with cutting speed

Fig. 3 a-d shows that tool wear amount was nearly same in three type of cutting tools at all cutting speed. But Fig 4 (a) show that the tool wear rate is different for three types of cutting tool and at all cutting speed. In addition, wear rate of these tools are increased by increasing the cutting speed. The highest tool wear rate is achieved from cermet tool about 30 μm/min at speed of 250 m/min. At this cutting speed, minimal wear rate is achieved from TiN coated cutting tool. In all cutting speed the minimal wear rate is achieved from TiAlN coated cutting tool by the cutting speed at 100 m/min. Fig 4 (b) represent that tool life (depended on surface roughness) and cutting speed curves. As shown in Fig. 4 (b) the tool life decreasing by increasing the cutting speed because of remaining wear rate. Increased wear rate increases the surface roughness. So remaining the surface roughness is good indicator for tool life. For determining the tool life In Fig. 4 (b) Ra<10 condition were accepted.

As shown in Fig. 4-a wear rate is increased with increasing the cutting speed. The higher wear rate is occurred in cermet cutting tool on the cutting speed of 250 m/min. the minimum wear rate is occurred on the TiAlN cutting tool between the cutting speed of 100 to 200 m/min. The minimum wear occurred on TiN coated cutting tool on the cutting speed of 250 m/min. Tool lifes depended on surface roughness (Ra<10) are shown in Fig. 4-b. Tool life is decreased with increasing the cutting speed. The maximum tool life is realized on PVD TiAlN cutting tool between the cutting speeds of 100 to 250 m/min. The minimum tool life is observed on cermet cutting tools on all cutting speeds.

4. CONCLUSIONS

Based on the experiment of turning of AISI 5140 steel using TiAlN, TiN (P10) and cermet cutting tool, following conclusions can be drawn:

1. The performance of cermet cutting tool at low and high cutting speed turning of AISI 5140 does not seem to be promising. The rapid wear of cermet inserts caused the work pieces high surface roughness and high dimensional deviation during turning. Although the minimal surface roughness values achieved from this tool, before wear started in the beginnings part, the rapid wear behavior of the inserts suggests that this tool is not suitable for machining 5140 steels.

2. The surface roughness of the work part is influenced by the tool wear. In addition, dimensional deviation is too.

3. Tool wear rate is influenced by speed of cutting. In addition, cermet cutting tool have the biggest value of wear rate at speed of cutting at 250 m/min.

4. The suitable cutting conditions were appeared, tool type-cutting speed. TiAlN coated carbide tools are suitable under the speed of V=200 m/min. At higher speed of cutting, TiN coated carbide tools are more suitable than TiAlN coated tools for machining AISI5140 steels.

5. The tool life depended surface roughness is decreased with increase of speed of cutting. The maximum tool life achieved from TiAlN coated carbide tool at speed of 100 m/min. At maximum speed of cutting value 250 m/min, the maximum tool life achieved from TiN coated carbide tool.

6. The experimental data is used with the industrial serial machining applications easily. And serial machining tests are very useful for predicting the surface roughness and dimensional deviation. If we can guess the dimensional deviation before you machine the part, you can change the tool offset value on CNC lathes. And if we can guess the surface roughness before turning the part we can change the tool or cutting conditions before machining the part. For example the feed rate of tool can be decreased gradually during the machining by a factor that derived from the roughness graphics.

REFERENCES

[1] C.X. Feng, Development of empirical models for surface roughness prediction in finish turning, International Journal of Advanced Manufacturing Technology, 20 (2002) 742-756.

[2] M. B. Karamis, H. Sert, The role of PVD TiN coating in wear behaviour of aluminum extrusion die, Wear, 217 (1998) 46-55.

[3] M. Bayrak, The effect of cutting conditions on surface roughness and comparison with expert system, Msc. thesis, Gazi University, Dept. of Mechanical Eng., Ankara, 2002 pp.12-52.

[4] S. Paul, N.R. Dhar, Beneficial effects of cryogenic cooling over dry and wet machining on tool wear and surface finish in turning aısı 1060 steel, Journal Of Material Processing Technology, 116 (2001) 44-48.

[5] N.R. Dhar, S.Poul, Machining of AISI 4140 steel under cryogenic cooling – tool wear surface roughness and dimensional deviation, Journal Of Material Processing Technology, 123 (2001) 483-489.

[6] O.B. Aboulatta, Surface roughness prediction based on cutting parameters and tool vibrations in turning operations, Journal Of Material Processing Technology, 118 (2001) 269-277.

[7] W. Gong, W. Li, T. Shirakashi, T. Obikava, An active method of monitoring tool wear states by impact diagnostic excitation, International Journal of Machine tools & Manufacture 44 (2004) 847-854.

8] K.A.Risbood, U.S. Dixit, Prediction of surface roughness and dimensional deviation by measuring cutting forces and vibration in turning process, Journal Of Material Processing Technology, 132 (2003) 203-214.

[9] W.S.Lin, B.Y. Lee, Modeling the surface roughness and cutting forces during turning, Journal Of Material Processing Technology, 108 (2001) 286-293.

[10] G.D. Buckner, Intelligent sliding mode control of cutting force during single-point turning operations, Journal of Manufacturing science and Engineering, 123 (2001) 206-212.

[11] A.K. Ghani, I.A. Choudhury, Study of tool life surface roughness and vibration in machining nodular cast iron with ceramic tool, Journal Of Material Processing Technology, 127 (2002)17-22.

[12] G.P. Petropoulos, A.A.Torrance, C.N. Pandazaras, Abbott curves characteristics of turned surfaces, International Journal of Machine Tool & Manufacture 43 (2003) 237-243.

[13] C. Feng, X. Wang, Development of emprical models for surface roughness prediction in finish turning, International Journal Of Advanced Manufacturing Technology, 20 (2002) 742-756.

[14] Y.K. Chou.H. Song, Tool nose radius effects on finish hard turning, Journal of Material Processing Technology, in press (2004).

[15] A.E. Diniz, A.J.Oliveira, Optimizing the dry cuting in rough turning steel operations, International Journal of Machine Tool & Manufacture, in press (2004).

[16] G. Adem, M.C. Çakır, Yüzey pürüzlülüğünün optimum talaş kaldırma faktörleri ve üretim maliyetleri üzerine etkisi, in: Makine İmalat Teknolojileri Sempozyumu, Konya, 14-15 Sept., 1999 pp.1-9.

[17] S. Paldey, S.C. Deevi, Single layer and multilayer wear resistant coatings of Ti,Al,N a review, Material Science and Engineering, 342 (2003) 58-79.

[18] W. Park, K.H. Kim, Coatings material of TiN, TiAlN and TiSiN by plasma enhanced chemical vapour deposition for mechanical applications, Journal Of Material Processing Technology, 130-131 (1998) 254-259.

[19] H.G. Prengel, P.C. Jindal, K.H. Wendt, A new class of high performance PVD coatings for carbide cutting tools, Surface and Coatings Technology, 139 (2001) 25-41.

[20] C. Ranea, Wear resistance of thin coatings based on titanium, in: International Conference on Tribology, Kayseri, 15-18 July, 2002, p783-788.

[21] H.Sert, Ç. Karataş, A. Özdemir,Y. Kılınç, M. Dağ, G. Samtaş, Thin and thick hard coating of metals, their environments and performance comparisons, in: International Conferance on Tribology, Kayseri, 15-18 July, 2002, p45-58.