EFFECTS OF WORKPIECE HARDNESS ON HARD TURNED SURFACES OF ALLOY STEELS

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ABSTRACT

Nowadays, hard turning is widely applied in Vietnam industry and it is usually the finished operation so the quality of the machined surface plays a very important role to the use today and in the future. This paper presents results of a research on hard turning of 9XC and X12M alloy steels to explore the influence of workpiece's hardness on machined surface roughness and topography at selected cutting conditions. It is evident that the surface roughness was directly proportional to the increase of the workpiece's hardness from HRC = around 50 to higher than 60. Moreover, lower hardness resulted in worse surface roughness. Even though when the cutting speed increased by twice, the best surface roughness still achieved at the workpiece's hardness of HRC= around 50. The cause is predicted to be involved with a change in chip/ rake face interactions depending on workpiece's hardness and tools wear.

Keywords: *Hard turning, furface roughness, topography, workpiece, tool wear*.

INTRODUCTION

Precision machined components can be manufactured by hard turned or ground operations. Surface integrity is a qualitative and quantitative description of both the surface and subsurface component including surface topography, surface and subsurface hardness, microstructure and residual stresses, etc. The work of Schwach and Gue [1] used a stylus instrument to measured surface roughness created by hard turn stated that surface roughness decreased when feed rate reduced. Decreasing feed rates makes the surface residual stress more compressive and its maximal one closer to the surface. Moreover, tools wear increased surface roughness except at moderate mode. Sharp cutting tool is recommended for hard turn to get better surface integrity. Chou [2] stated that fine structure of the workpiece PM M50 steel resulted in lower wear rate by delay of delamination wear and this effect is much stronger in intermittent cutting.

Barbacki and co-workers [3] carried out experiments to compare the microstructural changes in the surface layer of hardened steel by hard turning and grinding found that both operations offered high surface quality of the machined components. According to them, favorable surface integrity can be achieved both technologies and properly way to apply. Several parameters such as thickness of white layer, its hardness and stress level can be determined as a function of cutting parameters and tools wear.

Kishawy and Elbestawi [4] studied effects of process parameters on material side flow during hard turning showed the formation of material side flow based on two possible mechanisms. First, the workpiece material was squeezed between flank face and the machined surface and it is clear when chip thickness is less than minimal chip thickness. Second, under high pressure and temperature, the plastically deformed material was pressed aside. The trailing edge notch was caused by the chip edge serration. They also found that feed rates, tools wear, tool nose radius and edge preparation all have effects on material side flow and of course on surface topography. The formation of white layer on the machined surface of hard turning was studied by Chou and Evans [5], they stated

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that the surface layer consists of two layer the white outmost and dark layer just below. The formation of white layer involves dominantly with a rapid heating – cooling process. Plastic deformation also helps grain refinement and phase transformation to facilitate its formation.

The study in this paper concentrated on the effects of workpiece's hardness on the surface integrity particular on surface roughness and its topography in the relation with certain cutting conditions and tools wear.

EXPERIMENTAL PROCEDURE

Tool and Machine tool

The tools used in the study were PCBN equal triangle inserts made in Korea. Machine tool is a turning center CNC-HTC2050 made in China. The tool was set up on tool handle and then on the machine with: rake angle γ = - 6°; flank angle α = 6°; clear angle: $\varphi_1 = \varphi_2$ = 30°.

Workpiece

Two types of workpieces were used namely X12M and 9XC hardened steels (Russian standards). Their chemical compositions were analyzed by spectrographic method shown in table 1 and 2. The hardness of the two workpieces was divided into three categories: HRC=47÷50; HRC=54÷57 and HRC=60÷63.

The microstructures of the two types of steels were analyzed on optical microscopy corresponding to the three categories of hardness shown in Figure 1. When the hardness of X12M steel increased from HRC 47÷50 to 54÷57 and 60÷63, the carbides were observed to be elongated in shape, concentrated in lines and increased from 3-5 μm to 10-25 μm with high density. However, the carbides in 9XC steels kept quite stable with small size of approximately 1 μm when the hardness increased from HRC 47 to HRC 63.

Table 1. *Chemical composition of X12M steel*

Element	**C**	**Si**	**P**	**Mn**	**Ni**	**Cr**	**Mo**
Percentage %	1,4916	0,3589	0,0112	0,2404	0,2125	11,393	0,3803
Element	Cu	Ti	Al	Fe	V		
Percentage %	0,3383	0,0063	0,0249	85,396	0,1799		

Table 2. *Chemical composition of 9XC steel*

Element	**C**	**Si**	**P**	**Mn**	**Ni**	**Cr**	**Mo**
Percentage %	0,823	1,2351	0,0241	0,5862	0,0332	1,113	0,0192
Element	Cu	Ti	Al	Fe	V		
Percentage %	0,2876	0,1768	0,0299	0,0011	95,447	0,1499	

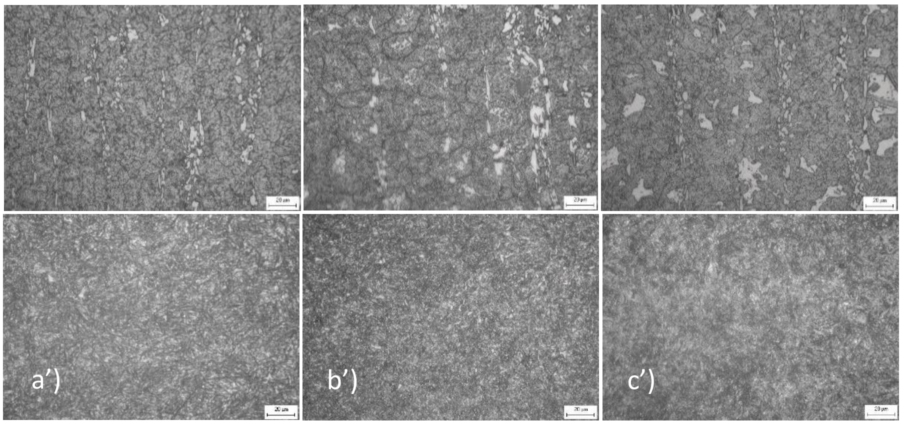

Figure 1. *The microstructure of X12M (a, b, c) and 9XC (a', b', c') steels with the hardness approximately HRC=47÷50; HRC=54÷57 and HRC=60÷63, respectively*

Cutting conditions

The cutting conditions were selected as follows:

Cutting speed: v_1 = 110 m/p; Feed rate: s_1 = 0.12 mm/rev; un-depth of cut: t_1 = 0.15 mm.

Cutting speed: v_2 = 220 m/p; Feed rate: s_2 = 0.12 mm/rev; un-depth of cut: t_2 = 0.15 mm.

RESULTS AND DISCUSSION

Surface integrity

Surface roughness

When the first cutting condition was applied the surface roughness measured by stylus surface roughness divide, Mitutoyo SI-201 showed that the surface roughness was better for 9XC steel compared with X12M in the range R_a = 0.55 – 1.06 µm and R_a = 0.75 – 1.37 µm, respectively. The trends of surface roughness of the two types of steels are shown in Figure 2. It is clear that the higher hardness of the steel was, the higher surface roughness was. The surface roughness was the lowest at the hardness of the workpiece of HRC= 47÷50 with the value of approximately R_a =0.55 µm. This result kept the same when cutting speed increased by double value (the second cutting condition). It is very interesting to note that when lower workpiece hardness was applied (HRC=40-43) for testing both 9XC and 12XM steels, the surface roughness was much higher than at the hardness of HRC= 47÷50 with the value around R_a=0.75 µm and 0.91 µm, respectively. An effect of a change type of chip formation at the workpiece's hardness of HRC=47÷50 might be the major factor.

Moreover, the longer cutting time was, the higher surface roughness was, especially when the cutting time increased by three times, the surface roughness could increase nearly twice. This indicated that tools wear has strong effect on increasing surface roughness.

The surface topography was taken on Scanning Electron Microscopy (SEM) shown in Figure 3 with different workpiece hardness in the range HRC=43÷45; HRC=47÷50 and HRC=60÷63. It is very clear that the side effects are more serious at figure 3(a,c) and much less effect in Figure 3(b) leading to the best surface finish in this case. In Figure 3(a), the type of plastic deformation in chip formation is predominant and in Figure 3(c), the type of cleavage in chip formation is clearly observed. The evidence in Figure 3 supports for the ideas of a change of chip formation at the workpiece's hardness of around the value of HRC=50. The ploughing effect to smear work material on the machined surface is also evident in this figure.

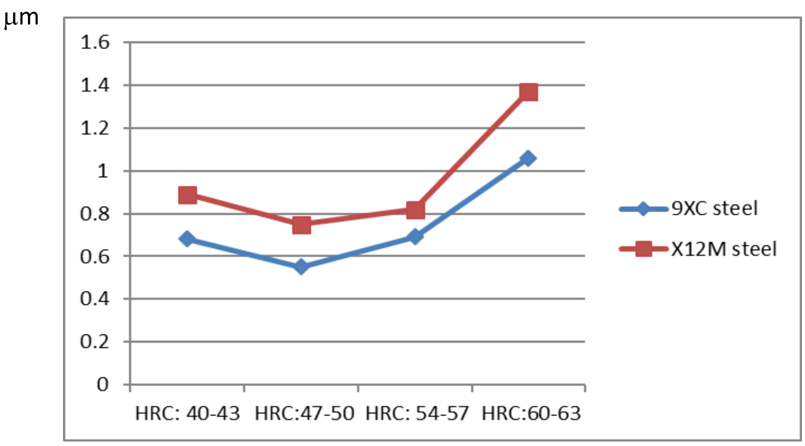

Figure 2. *Graphs showing increases of surface roughness of 9XC and X12M hardened steels depending on the workpiece's hardness; cutting speed: v_1 = 110 m/p; feed rate: s_1 = 0.12 mm/rev; un-depth of cut: t_1 = 0.15 mm*

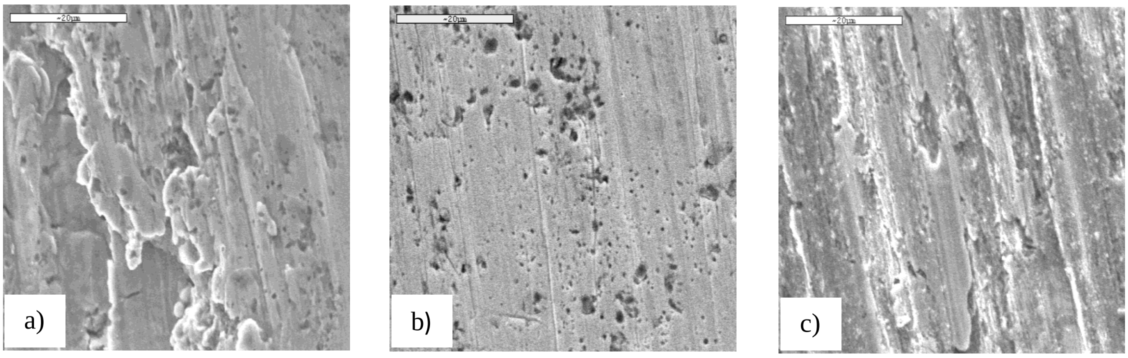

Figure 3. *SEM micrographs showing the surface topography after hard turning of X12M steel with different hardness of workpiece: HRC=43÷45; HRC=47÷50 and HRC=60÷63; Cutting speed:* v_1 *= 110 m/p; Feed rate:* s_1 *= 0.12 mm/rev; un-depth of cut:* t_1 *= 0.15 mm*

The micro-hardness measurements on cross section of the workpiece from the depth of 15 µm to 300 µm showed evidence the effects of smearing on the machined surface resulting in an increase in surface hardness at a very narrow layer with the depth less than 15 µm. It is reasonable because the depth of cut here is quite small t = 0.15 mm at the level of precision cutting and consistent with other authors' results.

Frictional Interactions between chip and rake face

It is evident in Figure 4(a) that at low workpiece's hardness (HRC=43÷45), the length of contact is the longest (l = 300 µm) and mainly covered by the work material. However, the length of contact is reduced by a half (l = 150 µm) shown in Figure 4(b) when workpiece with the hardness of HRC=50÷54 were machined. The rake face is nearly free of material transfer. Moreover, when the hardness of the workpiece was HRC=60÷63, the length of contact increased gain as shown in Figure 4(c) with l = 280 µm.

The main different compared with Figure 4(a) is that material transfer is much less and concentrated on the rear rake face. From evidence in Figure 4, it is clear that there is a change in frictional interactions between chip and tool from mainly plastic type to cleavage one in chip formation when the hardness of the workpiece varied from around HRC=45 to 60.

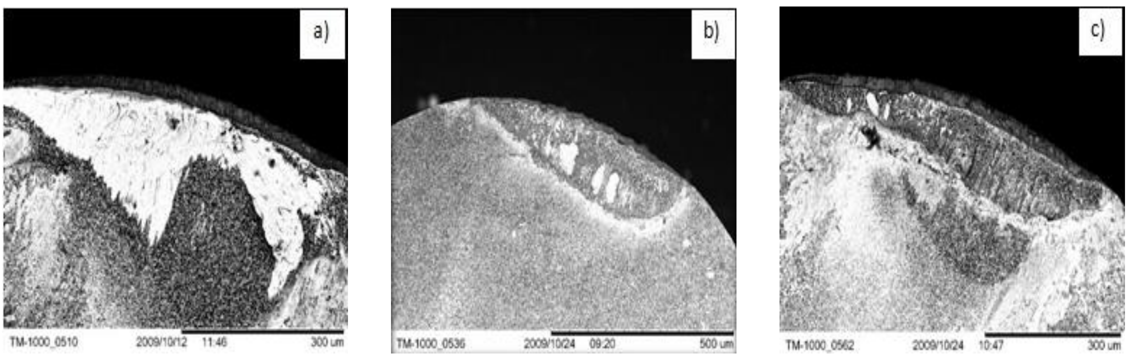

Figure 4. *SEM micrographs showing the rake face of PCBN inserts after hard turning of X12M steel with different hardness of workpiece: HRC=43÷45; HRC=50÷54 and HRC=60÷63; Cutting speed:* v_1 *= 110 m/p; Feed rate:* s_1 *= 0.12 mm/rev; un-depth of cut:* t_1 *= 0.15 mm*

Discussion

From the results mentioned above in the study, the best surface roughness (R_a = approximately 0.55 µm) was achieved when X12 and 9XC steel with the hardness of HRC = around 50 was machined by the first and second cutting conditions. With the hardness HRC = around 45 and higher than 55, the surface hardness was much worse. The fact can be explained by the change in chip formation from plastic type toward cleavage type similar to machining brittle materials as shown in Figure 4. This also involves with the type of frictional chip/rake face interactions. Short chip/rake contact and free of material transfer results in low surface roughness and better surface topography. Long chip/rake face length of contact and more material transfer in both near the cutting edge and at the region where chip breaks from contact with the rake face cause the higher surface roughness and worse surface topography. This is completely consistent with the ideas that the length of chip/rake face contact is directly proportional to the value of cutting force and surface roughness as a result of the level of adhesion between chip and tool.

The hardness of the workpiece could change the frictional contact on the rake face. When the hardness reached HRC=60÷63, the first crater with short length of contact formed near the cutting edge and then the second crater appeared at the rear of the first crater. The harder of the chip shortened the length of chip/tool contact on the rake face and after a while when the crater developed enough it formed the second one due to the depth of the first crater changed the frictional contact on the rake face.

CONCLUSION

From this study, conclusions can be derived as follows:

The surface integrity estimated by surface roughness and surface topography is consider to the best for both type of workpiece materials at the hardness HRC= 47÷50. The surface topography shows that at low hardness of HRC = 47÷50 chip formation mainly in plastic type and at high hardness of HRC = 55 and above the chip formation changed toward cleavage similar to brittle materials in cutting.

The frictional chip/tool interactions are also changed depending on the workpiece's hardness. The lower hardness the longer chip/tool contact is with full of material transfer on the contact area. However, when the hardness of the workpiece is higher than HRC = 55, the contact length is shortened with free material transfer and after a duration of cutting, the second crater appears at the rear of the first crater with not much material transfer.

REFERENCES

1. D.W. Schwach and Y.B. Guo.; "Feasibility of producing optimal surface integrity by process design in hard turning", Materials Science and Engineering, A 395 (2005), pp. 116-123.
2. Y.K. Chou., "Hard turning of M50 steel with different microstructure in continuous and intermittent cutting", Wear 255 (2003), pp. 1388-1394.
3. A. Barbacki, M. Kawalec, A. Hamrol., "Turning and Grinding as a source of of microstructural changes in the surface layer of hardened steel, Journal of Materials Processing Technology, 133 (2003), pp. 21-25.
4. H.A. Kishawy and M.A. Elbestawi., "Effects of process parameters on materials side flow during hard turning", International Journal of Machine Tools & Manufacture, 39 (1999), pp. 1017-1030.
5. Y.K. Chou and C.J. Evans., "White layers and thermal modeling of hard turned surfaces", International Journal of Machine Tools & Manufacture, 39 (1999), pp. 1863 -1881.
6. N.T.Q. Dung., "A study of hard turning process with the use of PCBN inserts", PhD Dissertation, Thai Nguyen University of Technology, 2012.

TÓM TẮT
ẢNH HƯỞNG CỦA ĐỘ CỨNG PHÔI TRONG QUÁ TRÌNH TIỆN CỨNG THÉP HỢP KIM

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Hiện nay, công nghệ tiện cứng đã được ứng dụng rộng rãi trong công nghiệp ở Việt Nam.
Tiện cứng thường là quá trình gia công lần cuối nên chất lượng bề mặt gia công đóng vai trò rất quan trọng đối với việc sử dụng công nghệ tiện cứng trong hiện tại và tương lai. Bài báo này trình bày kết quả một nghiên cứu về quá trình tiện cứng thép hợp kim 9XC và X12M nhằm xác định ảnh hưởng của độ cứng phôi đến hình học và nhám bề mặt gia công trong điều kiện công nghệ xác định. Kết quả cho thấy trong dải độ cứng từ 50 đến 60HRC nhám bề mặt tỉ lệ thuận với độ cứng phôi. Tuy nhiên ở độ cứng thấp hơn chất lượng bề mặt giảm và nhám bề mặt tăng. Nhám bề mặt đạt giá trị tốt ở độ cứng xấp xỉ 50HRC ngay cả khi tốc độ cắt tăng gấp đôi. Hiện tượng này được cho là có liên quan đến việc thay đổi tương tác tiếp xúc giữa phôi và mặt trước của dao phụ thuộc vào độ cứng phôi và mòn dụng cụ.

Từ khóa: *Tiện cứng, nhám bề mặt, hình học, phôi, mòn dụng cụ.*

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