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Optimization of Machining Parameters of AISI 1045 Steel for Better Surface Finish and Tool Life Using TiN Coated Carbide Insert

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ABSTRACT

Surface roughness of machined parts has significant effect on the final part quality which can affect its tolerance and performance. In this work the effect of turning machining operation on surface roughness of AISI 1045 steel using TiN coated carbide insert was investigated. Two different machining parameters with nine variable samples, including different spindle speeds and feed rates, were selected to study the resultant surface finish of the steel samples. The results showed that the lowest Ra value of 4.14 was obtained by using a feed rate of 50 mm/min with a spindle speed of 355 rpm, while the highest surface roughness value of 7.9 was obtained by using a feed rate of 160 mm/min at a spindle speed of 710 rpm. In general, it could be observed that higher spindle speeds resulted in higher Ra, while lower speeds results in lower Ra. The current study provides a good understanding of the effect of turning operation on surface roughness which can be used as a basis to develop a regression model to generate the optimum cutting parameters for turning operations.

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تحقيق الاستخدام الامثل لعمليات التشغيل للفولاذ من نوع ١٠٤٥ للحصول على أفضل انهاء سطحي باستخدام عده مطلية ب تيتانيوم نيترايد

لجين حسين كشكول / قسم هندسة الإنتاج والمعادن / الجامعة التكنولوجية / العراق.

الخلاصة

الخشونة السطحية للأجزاء المشغلة لها تأثير كبير على النوعية النهائية للجزء وهذا بدوره يؤثر على الابعاد النهائية والاداء. في هذا البحث تم دراسة تأثير عمليه التشغيل بالخراطة على الخشونة السطحية للفولاذ من نوع (AISI 1045) باستخدام عده قطع كاربيدية مطلية بـــ (TiN) تم استخدام تسع عمليات تشغيل مختلفة، من ضمنها سرع قطع وتغذية مختلفة لدراسة التأثير على الخشونة السطحية لعينات الفولاذ. النتائج اظهرت بان أفضل خشونة سطحية تم الحصول عليها باستخدام معدل تغذيه (50 ملم بالدقيقة) مع سرعه قطع (355 دورة بالدقيقة)، بينما اعلى خشونة سطحية تم الحصول عليها باستخدام معدل تغذيه (160 ملم بالدقيقة) وسرعه قطع (710 دورة بالدقيقة). بشكل عام تم الملاحظة بان سرع القطع العالية ادت للحصول على خشونة سطحية عالية، بينما السرع القليلة أدت للحصول على قيم خشونة اقل.

1. INTRODUCTION

As geometry and shapes of engineering components become more complex, higher demand for precise machining and dimensional tolerances become more important. The need for better surface finish to meet these requirements has increased and better control of machining operations can help improve the surface finish and part integrity [1][2][3][4][5][6]. Surface roughness is usually denoted with the symbol Ra. Many previous studies investigated the effect of machining parameters on surface roughness (Ra) of different alloys [7][8], Kopac and Bahor [9] investigated the changes in surface roughness based on the process conditions during machining of tempered AISI 1060 and 4140 steels and found that the speed is the most important factor affecting the surface roughness if other operating parameters were chosen randomly. José Luis Cantero et al. [10] studied the finish machining of Inconel 718 alloy using four different Polycrystalline Cubic Boron Nitride (PCBN) tools under dry conditions. Tool wear testes were done, in addition to the measurement of developed forces during machining using different cutting conditions. Surface roughness was also measured. The study revealed that it is not technologically viable using high-speed machining finish of Inconel 718 alloy in a dry environment. Chang-Lin Liang et al. [11] studied Ti-6Al-4V (TC4) and Si (100) wafer substrates coated with multilayered TiN/TiAlN coatings with bilayer periods (λBD) with a thickness of 6 to 30 nm. The coating was deposited using magnetic filtered pulsed vacuum catholic arc plasma method. The electrochemical corrosion tests showed that the coatings effectively improved the TC4 alloy's anti-corrosion properties, especially with λBD equal to 20 nm. Bushlyaa et al. [12] investigated the effect of cutting tools coating on the high-speed turning of Inconel 718 alloy. It was found that the protective functional coatings are effective only at the lower cutting speed range. Also, it was revealed that in comparison with uncoated tools the coated tools may suffer from residual compressive and tensile stresses on the surface. Berruti et al. [13] studied the effects of machining parameters during turning operation of an Inconel 718 alloy turbine shaft using uncoated cutting tools. A characterization of residual stresses on the surface revealed that tensile residual stresses are present on the workpiece's surface, while the stresses are compressive at the subsurface. The residual stresses increased upon increasing the feed rate and cutting speeds. However, this trend did not hold when changing the machining directions. Pankaj Kumar Sahu et al. [14] investigated the effect of different machining parameters on the hardness of the aluminum alloys such as cutting speed, depth of cut, and feed rate. Taguchi technique was employed in experiment design and different turning machining parameters were selected based on that such as different cutting depths and spindle speeds. The main contributing parameters were revealed from the study based on their effect on surface hardness. Deepak and Rajendra et al. [15] utilized Taguchi design method to analyze the affect of different cutting parameters on the surface finish of machined samples. Different feed rates and spindle speeds were used during the experiments. It was concluded that the most influencing factor was the feed rate followed by the cutting speed then cutting depth. Also, it was observed that an increase in surface roughness occurs when the feed rate and cutting depth increase. Mani Lavanya et al. [16] studied the surface finish of parts machined out of AISI 1016 steel after turning operation. Analysis of variance (AOV) method was used to analyze the effect of different machining parameters on surface finish. Different speeds and feeds were selected for AOV analysis and it was concluded that the feed rate has the most prominent effect on surface finish between all other factors. Although different previous studies investigated the effect of machining parameters on surface roughness of different alloys [17][18][19][20][21][22], the research on machining operations effects on AISI 1045 steel using TiN coated carbide inserts are scarce. In this work, study the effect of turning machining parameters on surface finish of AISI 1045 steel was investigated using Titanium Nitride (TiN) coated carbide cutting insert. TiN coatings are characterized by its high wear resistance, and reduced friction coefficient, which helps to keep the friction generated heat between the workpiece and the tool low. TiN coating are used in many different tooling applications due to its high performance. Nine different machining conditions were utilized to investigate the resultant surface roughness and carbide insert tool wear and damage. The outcome of the current study is useful for selection the best cutting parameters when machining AISI 1045 steel using carbide inserts, and this can reduce the cost and increase the performance of the machined parts.

2. EXPERIMENTAL SETUP

AISI 1045 steel is a popular type of carbon steel which is characterized by its good mechanical properties, good corrosion resistance in atmosphere and, and hardenability. In fact, it can be hardened and tempered to be used for making different mechanical parts such as gears, spindles, crankshafts. Due to the popularity of this steel, it was chosen in this work to perform the machining experiments. A 25 mm diameter shaft was used and cut into multiple samples with a length of 80 mm. The chemical composition of the used AISI 1045 steel is shown in Table 1. The chemical analysis was done based on the ASTM E415 using spark atomic emission spectrometry at the ministry of science and technology-Baghdad. While the mechanical properties were characterized using the universal tensile testing machine based on the ASTM E8 standard located in the department of production engineering-university of technology-Baghdad. The measured mechanical properties are shown in Table 2.

Table 1
The chemical composition of AISI 1045 steel:

ASTM A29/29M	C	Si	Mn	P	S
1045	0.43 ~ 0.50	/	0.60~0.90	≤0.040	≤0.050

Table 2
Mechanical Properties of 1045 steel tested based on the ASTM E3 standard:

Properties	Metric	Properties	Metric
Tensile strength	579 MPa	Elongation at break (in 50 mm)	11%
Yield strength	442 MPa	Hardness (HRB)	92
Modulus of elasticity	200 GPa		

Also, a piece of the AISI 1045 steel was cut and prepared for microstructure examination to make sure the structure is uniform with no inclusions or defects that can indirectly affect the current machining investigation. The sample was prepared for metallographic examination based on ASTM E3 standard. The microstructure of the steel is shown in Fig.1 The steel microstructure shows a uniform structure of equiaxed ferrite and pearlite grains with an average grain size of 20 µm. This structure is typical in cold rolled and normalized AISI 1045 steel.

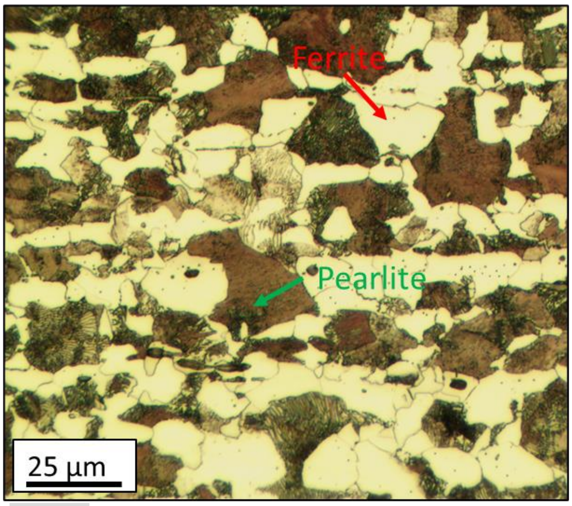

Fig. 1. Optical micrograph image showing the microstructure of the selected AISI 1045 steel sample with equiaxed grains of pearlite and ferrite and an average grain size of 20 µm. The sample is etched with 3% nital.

A TiN coated carbide cutting insert was chosen as the cutting tool and the utilized holder type DDJNR 2525 M15 WIDAX is shown in Fig.2 50 mm was chosen as the machining length to measure the surface roughness after machining. Surface roughness was measured by using Mahr Surf PS1 device by taking at least three readings for each sample and average them. The surface measurement device is shown in operation Fig.3.

Fig. 2. Holder type DDJNR 2525 M15 WIDAX

Fig. 3. (Mar Surf PS1) surface roughness measurement device.

Continuous turning operation was carried in the dry condition on CNC turning Centre equipped with Fanuc CNC controller. Nine samples are machined at three different spindle speeds at (355,560 and 710) m/min and three different feed rates of (50,160 and 260) mm / min. A depth of cut of 1.5 mm was used in all the experiments.

3. RESULTS AND DISCUSSION

Table 3 lists the results of the surface roughness (Ra) for steel samples after machining with different feed rates and spindle speeds. Also, a bar chart graph for the surface roughness values as a function of feed rate and spindle speed is shown in Fig.3 It can be seen that generally Ra increases with increasing the feed rate when the spindle speed is fixed at specific value. The increase in Ra is related to the vibration and local heat generation at the tool tip during cutting. More vibration means more instability of the contact angle between the tool and the work piece which leads to nonuniform chip removal. If the chip removal is not uniform, then the machined surface develops a rough finished surface induced by the local variation in chip removal. The lowest Ra of 4.14 is observed for the steel sample that machined at a feed rate of 50 mm/min and spindle speed of 355 rpm as can be seen from the Table 3. and Fig.4, while the highest Ra can be observed for the steel samples machined at a feed rate of 150 mm/min and a spindle speed of 710 rpm. Intuitively, Ra should decrease with increasing spindle speed at a given feed rate because the cutting speed decreases. However, this is not always the case since decreasing the cutting speed at higher rpm can create local heating on the steel surface during machining. Local heating on the part can initiate local deformation and create more stresses between the part and the cutting carbide insert. Our results are in good agreement with previous studies. Abebe et al. [23] observed that the cutting speed is the most influential factor for improving surface finish, while Abidin et al. [24] concluded that the feed rate is most effective factor that affect the resultant Ra. Although those two previous studies may give two different observations, they approved that the surface finish cannot follow specific machining parameter in all conditions, but Ra shows a dynamic dependence on machining parameters, and this dependence may change by changing other machining factors such as depth of cut and spindle speed. This is what is observed in our study.

Table3

Cutting and machining parameters for the nine steel samples with the measured arithmetic average roughness (Ra).

Sample No.	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm / min.)	Surface roughness Ra
1	355	1.5	50	4.14
2	560	1.5	50	4.31
3	710	1.5	50	4.32
4	355	1.5	160	5.88
5	560	1.5	160	6.32
6	710	1.5	160	7.9
7	355	1.5	260	4.58
8	560	1.5	260	5.83
9	710	1.5	260	5.49

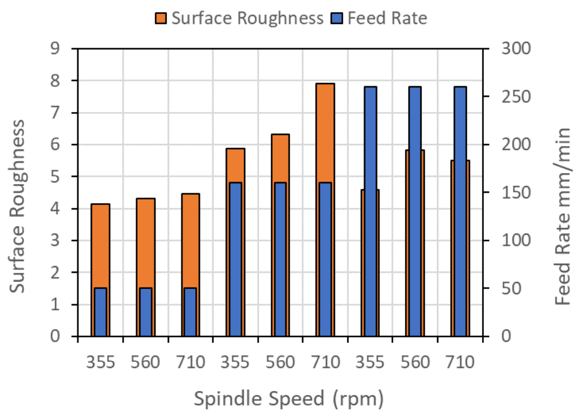

Fig. 4. The relationship between the steel arithmetic average roughness (Ra) with spindle speed and feed rate.

To characterize and correlate the feed rate effect on the carbide inserts wear and chipping damage stereoscopic images were taken for each TiN coated carbide insert after machining operation as shown in Fig.5 It can be observed that some carbide inserts showed more wear and chipping compared to other inserts with different feed rates and spindle speed. Lower wear and chipping damage on the carbide insert surface is seen for samples that have lower Ra values, while higher wear and damage is observed for the carbide inserts that have higher Ra value. This is expected since lower Ra is obtained for the samples machined at lower feed rate where the local stresses and chip geometry results in minimum wear on the coated carbide inserts. On the other hand, higher feed rates can induce local heating on the inserts which can result in TiN coating damage and delamination during cutting operation. The lowest wear and carbide chipping could be observed on the carbide insert No. 1 due to optimum machining parameters, while higher carbide wear and chipping could be observed on insert No. 6 due to higher local heating and vibration which also resulted in highest Ra among all samples. Therefore, optimum cutting parameters not only result in good surface finish, but also can extend the life of the carbide insert and reduce the cost of the final product. As an example of the machined samples Fig.6 shows the photographic images of sample No. 1 and No. 6. As can be seen that Sample No. 1 showed the best surface finish compared to other samples, while sample No. 6 showed low surface finish Ra.

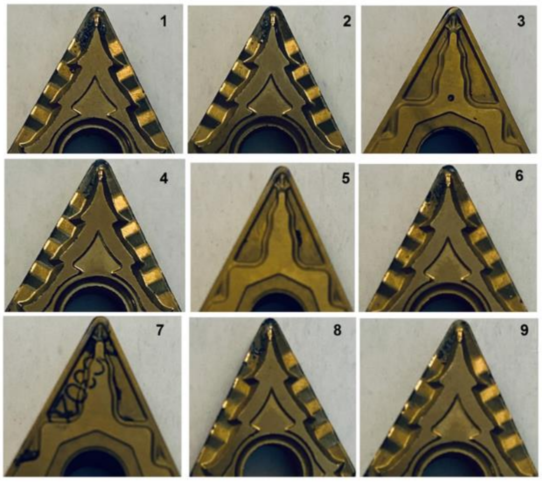

Fig. 5. Stereoscopic images of the TiN coated carbide inserts after each machining operation. The number on the edge corresponds to the sample number in Table 3.

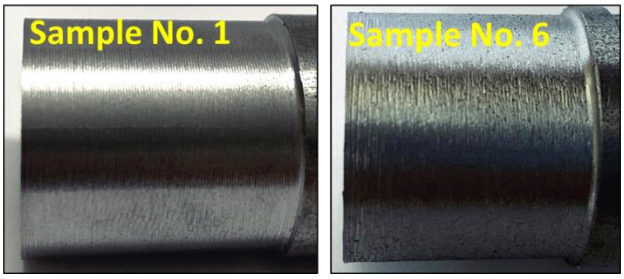

Fig. 6. Photographic images of the machined samples No. 1 and 6.

4. CONCLUSIONS

1. In this work the effect of cutting parameters during turning operation of AISI 1045 steel on the surface roughness and carbide inserts were investigated. Three different feed rates of 50, 160 and 260 mm/min with three different spindle speeds of 355, 560, and 710 rpm were utilized for machining operations.

2. The results showed that the lowest Ra value was obtained by using a feed rate of 50 mm/min with a spindle speed of 355 rpm, while the highest surface roughness was obtained by using a feed rate of 160 mm/min at a spindle speed of 710 rpm.

3. In general, it could be observed that higher spindle speeds resulted in higher Ra, while lower speeds results in lower Ra. This is due to the induced local heating between the cutting tool and the work piece's surface which results in higher contact stresses at friction at the contact area. Higher friction means higher vibration and more damage to the cutting tool during operation.

4. The carbide insert damage was characterized using stereoscopic imaging of the carbide inserts after machining. Higher wear and chipping to the carbide inserts is associated from higher Ra because of the non-optimum cutting parameters, while lower wear and chipping is observed for the inserts that is associated with lower Ra on the machined samples.

5. The lowest wear and damage were observed for carbide insert No. 1, while the highest damage was observed for the carbide insert No. 6.

6. The results of the current work can be used to select the best cutting parameters during turning operation of the AISI 1045 steel. Selecting the optimum cutting parameters can reduce the cost and time associated with manufacturing operations of steel by extending the life of the cutting tool and obtain a good Ra on the final product.

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