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RESEARCH ARTICLE - MECHANICAL ENGINEERING

High Speed Turning of Inconel 718 Using Ceramic and Carbide Cutting Tools

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Abstract Inconel 718 is one of the most difficult-to-cut materials because of its low thermal diffusive property, high hardness, and high strength at high temperature. In this study, the effects of cutting speed, feed rate and depth of cut on surface roughness and tangential cutting force when high speed turning Inconel 718 by ceramic and carbide cutting tools in dry turning have been investigated. After preparing the turning process, design of the experiment was chosen as full factorial. The experiment results in high speed turning using ceramic tool indicated that cutting speed and feed rate in compared to depth of cut more effectively on surface roughness. Moreover, depth of cut and feed rate in compared to cutting speed more effectively on tangential cutting force. High speed turning using carbide tool indicated that cutting speed and feed rate in compared to depth of cut more effectively on surface roughness. Moreover, cutting speed and feed rate in compared to depth of cut more effectively on tangential cutting force. Comparison of ceramic and carbide tools shows that force and average surface roughness in ceramic tools is lower than carbide tool. Comparison cutting speed chart shows that for the ceramic tools optimum surface roughness exists and it is the best machining conditions.

Keywords Inconel 718 · High speed turning · Cutting force · Ceramic tool · Carbide tool

الخلاصة

إنكونل 718 هي واحدة من أكثر المواد التي يصعب قطعها بسبب انخفاض خاصية الانتشار الحراري فيه ، وكذلك الصلابة والقوة العاليتين عند درجة حرارة مرتفعة . وفي هذه الدراسة، تم التحقيق في آثار سرعة القطع، ومعدل التغذية وعمق القطع على خشونة السطح وقوة القطع العرضية عند التحول بسرعة عالية إنكونل 718 من قبل أدوات قطع سيراميك وكربيد في التحويل الجاف. وبعد إعداد عملية التحويل، تم اختيار تصميم التجربة كمضروب كامل. وأشارت نتائج التجربة أنه عند التحويل بسرعة عالية واستخدام أداة السيراميك أن سرعة القطع ومعدل التغذية في مقابل عمق القطع هما على نحو أكثر فعالية على خشونة السطح. وأكثر من ذلك، فإن عمق القطع ومعدل التغذية في مقابل خفض السرعة هما على نحو أكثر فعالية على قوة القطع العرضية. وأشارات سرعة التحويل العالية باستخدام أداة الكربيد أن سرعة القطع ومعدل التغذية في مقابل عمق القطع هما على نحو أكثر فعالية على خشونة السطح. وعلاوة على ذلك، فإن خفض السرعة ومعدل التغذية في مقابل عمق القطع هما على نحو أكثر فعالية على قوة القطع العرضية. ومن خلال مقارنة أدوات السيراميك بالكربيد تبيّن أن القوة ومتوسط خشونة السطح في أدوات السيراميك هما أقل من أداة الكربيد ، وتُظهر مقارنة الرسم البياني لسرعة القطع أن لأدوات السيراميك خشونة سطح مثلى وهذه هي أفضل ظروف قطع.

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1 Introduction

Almost 80 % of super alloys used in the aerospace industry are nickel-based alloys and others alloy-based on Iron and Cobalt. Nearly 45–50 % of materials are used in the manufacture of gas turbines, is nickel alloy. Also it used in generators, chemical industries, and petroleum [1,2].

Research on how machining these materials, due to its unique properties, are continuing. The investigations began in 1967 [3]. Researchers such as P. Warbaton in 1967 and

M.B. Kramer in 1981 began to study the problems which related to the machining of super alloys.

Darvish et al. [4] in 2000 was investigated the effect of tool material and machining parameters on surface roughness for Inconel 718. Based on their research, regardless of tools material used, feed rate is the most important factor affecting surface roughness, as increased feed rate can reduce surface roughness. Moreover, depth of cut is the second important factor on surface roughness and the effect of depth of cut in maximum feed rate is more than minimum feed rate.

Li et al. [5] in 2002 was investigated the high speed cutting of Inconel 718 with coated carbide and ceramic inserts. They offered that in high speed turning of Inconel 718 should use ceramic inserts of KY2000 with negative rake angle and carbide inserts of KC7310.

Pudsinski et al. [6] in 2004 with the preparation of a review, their review was based on machining Inconel 718 Super Alloy in dry conditions and high speed. Based on their research, machining nickel-based alloys with low cutting speeds (20–30 m/min), usually cemented carbide tools are used. For cutting speeds higher than the 100 m/min without lubrication conditions, typically, carbide tools cover with PVD are used. Advantages of these tools are resistance to oxidation, chemical stability at high temperature, high resistance temperature and low temperature transfer coefficient. For machining super alloys with high cutting speed (200–700 m/min) ceramic tools, because of having resistance to high temperatures, is used. In addition, the low temperature transfer coefficient of ceramic tools and sensitiveness to thermal shocks, it is recommended for use in conditions without lubrication.

In 2008, Fang [7] research to compare the machining forces during turning on Inconel 718 and Ti-6Al-4V by carbide tools with circular geometry were performed. Based on their research, for both alloys with increasing cutting speed, machining forces are increased and for both alloys with increasing feed rate, machining forces are increased too. At the same machining conditions, the machining forces for Inconel 718 are higher than Ti-6Al-4V.

In 2008, Gaitonde et al. [8] evaluated the machinability in hard turning of AISI D2 cold work tool steel with conventional and ceramic wiper inserts. From this paper it is found that the CC650WG wiper ceramic insert performs better with reference to surface roughness and tool wear, while CC650 conventional ceramic insert is useful in minimizing the machining forces.

Thakur et al. in 2009 [9], a general study on the capability of turning high-speed machining of super alloys Inconel 718 have done. Tungsten carbide tools are the tools used and the effect of machining parameters on cutting force, specific cutting pressure, cutting temperature, tool wear, and final levels have been investigated. According to their study, the final surface roughness in cutting speed 45–55 m/min, feed rate 0.08 mm/rev, and the depth of cut 0.5 mm will be optimal.

According to studies, the investigation for high speed turning super alloy by different tools has not been done completely. Cutting speed higher than 60 m/min is high speed turning [10]. In this study, the effects of cutting speed (V_c), feed rate (f) and depth of cut (a_p) on surface roughness and tangential cutting force during high speed turning Inconel 718 by ceramic and carbide cutting tools have been investigated. The design of experiments was chosen full factorial. After preparing process and doing the experiments, the effect of turning parameters on machining forces and surface roughness by carbide and ceramic cutting tools were investigated.

2 Experimental Set-Up

In this section, there will be a brief description of the equipment and material used to carry out the turning Inconel 718 experiments. Also, the design factors used in this work will be outlined. The experimental set-up is presented in Fig. 1.

2.1 Turning Machine

Turning machine used in this experiment was TN50D manufactured by Tabriz–Iran Technologies with 7.5 hp of power in the spindle motor. Since the machine tool is of conventional type, to have desired cutting speeds an inverter and a tachometer (Kimo CT100-C) were used. The photograph of tachometer is shown in Fig. 2.

2.2 Dynamometer Set

Cutting forces were measured online by a Kistler 9257B three component dynamometer.

Fig. 1 Experimental set up

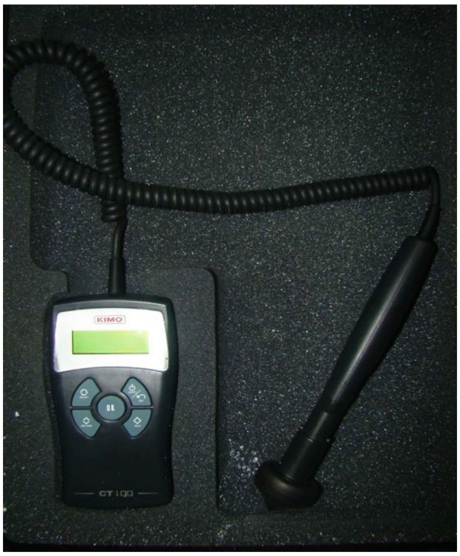

Fig. 2 Tachometer used

Fig. 3 Perthometer machine used

2.3 Roughness Measurement Machine

A perthometer (produced by Mahr Co., Model M2) for measuring the surface roughness was used in this study. The accuracy of this equipment was 0.001 microns.

There are various simple surface roughness amplitude parameters used in industry. Measurements were based on R_a method and the sampling length ($L_c = 0.8$ mm), measuring length ($L_m = 4$ mm) and traverse length ($L_t = 5.6$ mm) are taken, respectively. Surface roughness was measured three times and its average value was calculated. The photograph of Perthometer is shown in Fig. 3.

2.4 Materials Used in the Experiments

The workpiece material was a Nickel-based super alloy Inconel 718 that was supplied by forging process then treated in solution annealed condition. This specimen was prepared as a bar with a diameter of 72 mm and a length of 400 mm. Two types of cutting tool were used for the present work. One of the cutting tools was the CC650 grade that according to SANDVIK is an alumina-based mixed ceramic (Al_2O_3 + TiN) insert and the cutting tool type was CNGA 12 04 08 T01020 [11]. The other cutting tool was the TS2500 grade that according to SECO is a carbide insert using a physical vapour deposition (PVD) method with TiAlN-coating and the insert types were CNMG 12 04 08 [12]. The insert was rigidly attached to a tool holder of ISO designation of DCLNR 2525 M12. The geometry angles of insert seating: orthogonal rake angle −6°, inclination angle −6°, orthogonal clearance angle 6°, auxiliary cutting edge angle 80°, auxiliary cutting edge angle 95° and 0.8 mm nose radius. The experimental conditions are presented in Table 1.

Table 1 Experimental conditions

Machine tool	Lathe machine, 7.5 hp	
Work specimens	Inconel 718	
Material	(Ni 50.81 %, Cr 18.9 %, Mn 0.05 %, P 0.004 %, Si 0.27 %, B 0.003 %, Cu 0.06 %, S 0.001 %, C 0.04 %, Mo 2.90 %, Al 0.45 %, Nb 4.77 %, Ti 1.03 %, Co 0.01 %)	
Hardness	35RC	
Size	ϕ 72 × 400 mm	
Density (g/cm^3)	8.4	
Young's modulus (GPa)	206	
Ceramic insert	Uncoated, ISO CNGA 12 04 08T01020, CC650 grade (alumina-based mixed ceramic [Al_2O_3 + TiN]), manufactured by SANDVIK	
Carbide insert	PVD-coated carbide, ISO CNMG 12 04 08, TS2500 (using a physical vapour deposition (PVD) method with TiAlN-coating), manufactured by SECO	
Tool holder	DCLNR 2525M12	
Working tool geometry	Inclination angle	− 6°
	Orthogonal rake angle	− 6°
	Orthogonal clearance angle	6°
	Auxiliary cutting edge angle	80°
	Principal cutting edge angle	95°
Nose radius	0.8 mm	

3 Experimental Procedure

According to the cutting speed higher than 60 m/min is high speed turning, the design of experiments for high speed turning Inconel 718 by ceramic and carbide inserts were done.

The tangential cutting force is major cutting force and feed force in compression with tangential cutting force is trifling.

Radial force is zero so in this article the mean of tangential cutting force is cutting force.

3.1 Design and Procedure of Experiment for Ceramic and Carbide Insert

In this experiment, the effects of cutting speed, feed rate and depth of cut on surface roughness and machining force of super alloys Inconel 718 by ceramic and carbide inserts in dry turning has been investigated. Machining parameters in Table 2, according to the recommendation by manufacturer tool were determined and 36 tests on the workpiece for each insert were carried out.

In the experiments an unused cutting edge was employed for each cutting speed, feed rate and depth of cut. Then surface roughness values (R_a) and cutting forces were measured. These values for ceramic insert are presented in Table 3, respectively.

After doing the experiment by carbide insert like ceramic insert according to machining parameters, surface roughness values (R_a) and cutting forces insert were measured and are presented in Table 4, respectively.

Table 2 Machining parameters

Type insert	a_p (mm)	f (mm/rev)	V_c (m/min)
Ceramic	0.4–0.6–0.8	0.05–0.08–0.11	150–200–250–300
Carbide	0.5–1–1.5	011–0.16–0.2	55–75–95–115

4 Analyse the Results of Experiments

According to experiments, different charts of results were achieved that the first, results of experiment by ceramic insert and then results of experiment by carbide insert in this section were analysed.

4.1 Analyse the Results of Experiment by Ceramic Tool

This section first reviews and analyzes the results for the surface roughness and then cutting force to be paid.

Minitab software was used to analyze the results. Statistical analysis of the results (if $R^2 > 0.950$ and $R^2(\text{adj}) > 0.950$) showed the accuracy of regression model [13].

Table 5 showed the value of R^2 and R^2(adj) regression models on R_a values. It can be inferred from the Table 1 that regression model degree 3 has less error than regression model degree 2 and regression model degree 1 is not acceptable. Regression models are shown in Table 5.

So for this experiment, regression model degree 3 is proposed for R_a, the equation for this model is shown in Eq. (1):

$$\begin{aligned} R_a = {} & 9.43 - 0.0673V_c - 70.3f + 0.12a_p \\ & + 0.000194V_c^2 + 400f^2 - 0.148a_p^2 + 0.169V_c f \\ & - 0.00055V_c a_p + 0.3 f a_p - 0.000064V_c^2 f \\ & - 0.817V_c f^2 - 0.000001V_c^2 a_p + 0.00069V_c a_p^2 \\ & + 0.26a_p^2 f - 5.2a_p f^2 + 0.0009V_c f a_p \end{aligned} \quad (1)$$

Table 3 Results of the surface roughness (R_a) and cutting force (F) for ceramic insert

Tests	V_c	f	a_p	R_a (µm)	F (N)	Tests	V_c	f	a_p	R_a (µm)	F (N)
1	150	0.05	0.4	1.561	118.80	19	250	0.05	0.4	1.187	143.05
2	150	0.05	0.6	1.560	181.46	20	250	0.05	0.6	1.189	165.04
3	150	0.05	0.8	1.558	213.85	21	250	0.05	0.8	1.193	378.54
4	150	0.08	0.4	1.237	186.97	22	250	0.08	0.4	0.956	195.01
5	150	0.08	0.6	1.234	221.22	23	250	0.08	0.6	0.950	195.02
6	150	0.08	0.8	1.235	309.00	24	250	0.08	0.8	0.953	213.16
7	150	0.11	0.4	1.428	220.69	25	250	0.11	0.4	1.139	166.02
8	150	0.11	0.6	1.434	342.95	26	250	0.11	0.6	1.135	253.04
9	150	0.11	0.8	1.426	377.93	27	250	0.11	0.8	1.142	285.00
10	200	0.05	0.4	1.113	122.18	28	300	0.05	0.4	1.608	128.24
11	200	0.05	0.6	1.112	184.52	29	300	0.05	0.6	1.607	212.05
12	200	0.05	0.8	1.117	221.44	30	300	0.05	0.8	1.605	384.79
13	200	0.08	0.4	0.894	168.75	31	300	0.08	0.4	1.356	170.90
14	200	0.08	0.6	0.898	189.43	32	300	0.08	0.6	1.359	263.09
15	200	0.08	0.8	0.896	264.33	33	300	0.08	0.8	1.362	284.09
16	200	0.11	0.4	1.025	222.58	34	300	0.11	0.4	1.558	176.19
17	200	0.11	0.6	1.022	279.51	35	300	0.11	0.6	1.554	276.13
18	200	0.11	0.8	1.024	118.80	36	300	0.11	0.8	1.559	342.85

Table 4 Results of the surface roughness (R_a) and turning force (F) for carbide insert

Tests	V_c	f	a_p	R_a (μm)	F (N)	Tests	V_c	f	a_p	R_a (μm)	F (N)
1	55	0.11	0.5	0.907	296.22	19	95	0.11	0.5	0.955	265.94
2	55	0.11	1	0.892	612.38	20	95	0.11	1	0.963	509.61
3	55	0.11	1.5	0.914	835.52	21	95	0.11	1.5	0.967	767.86
4	55	0.16	0.5	1.089	349.56	22	95	0.16	0.5	1.411	378.80
5	55	0.16	1	1.075	712.18	23	95	0.16	1	1.413	677.45
6	55	0.16	1.5	1.079	1074.74	24	95	0.16	1.5	1.418	1114.39
7	55	0.2	0.5	1.334	406.10	25	95	0.2	0.5	1.617	385.42
8	55	0.2	1	1.339	804.42	26	95	0.2	1	1.628	727.78
9	55	0.2	1.5	1.349	1191.09	27	95	0.2	1.5	1.626	1149.62
10	75	0.11	0.5	0.909	307.63	28	115	0.11	0.5	1.138	287.86
11	75	0.11	1	0.912	587.05	29	115	0.11	1	1.145	535.74
12	75	0.11	1.5	0.918	868.08	30	115	0.11	1.5	1.158	843.92
13	75	0.16	0.5	1.116	428.07	31	115	0.16	0.5	1.753	361.88
14	75	0.16	1	1.129	836.65	32	115	0.16	1	1.771	664.25
15	75	0.16	1.5	1.134	1261.19	33	115	0.16	1.5	1.792	1040.29
16	75	0.2	0.5	1.367	369.88	34	115	0.2	0.5	1.854	373.09
17	75	0.2	1	1.382	754.02	35	115	0.2	1	1.992	713.69
18	75	0.2	1.5	1.374	1071.86	36	115	0.2	1.5	2.051	1093.59

Table 5 Regression models for R_a

Regression models	R^2	R^2(adj)
Degree 1	0.432	0.430
Degree 2	0.993	0.991
Degree 3	0.995	0.995

Figure 4 shows the effect of different parameters on surface roughness by ceramic tool.

The result of Fig. 4 shows that the cutting speed and feed rate have higher significant influences than the depth of cut on surface roughness in turning with ceramic tool. By increasing the cutting speed from 150 to 200 m/min, surface roughness value is decreased because by increasing cutting speed in defined range that this defined range depend on the material workpiece and used tool, because of the fact that the plastic deformation is easier than before and friction between chip and tool face as a result of increasing temperature is decreased.

The result of Fig. 4 shows that by increasing the cutting speed from 200 to 250 and 300 m/min surface roughness value is increased because by increasing cutting speed in this range, temperature of cutting edge is raised and with extreme increasing this temperature, wear tool is increased therefore surface roughness is increased.

Surface roughness value in feed rate about 0.08 mm/rev is less than feed rate in 0.05 and 0.11 mm/rev because in feed rate about 0.05 mm/rev, chip sticks the edge and the Built-Up-Edge is formed and cause to the surface roughness is increasing and in feed rate about 0.11 mm/rev because of the pitch in turning process is increasing, surface roughness will be decreased.

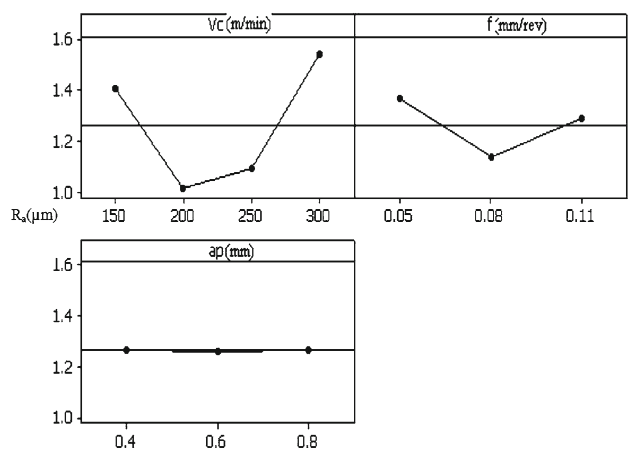

Fig. 4 Effect of different parameters on surface roughness by ceramic tool

The result of Fig. 4 shows that depth of cut has not effect on the surface roughness and the minimum surface roughness is in 0.08 mm/rev feed rate and 200 m/min cutting speed.

According to Fig. 4, only cutting speed and feed rate are affected on the surface roughness. Figure 5 shows the simultaneous influence of cutting speed and feed rate on the surface roughness.

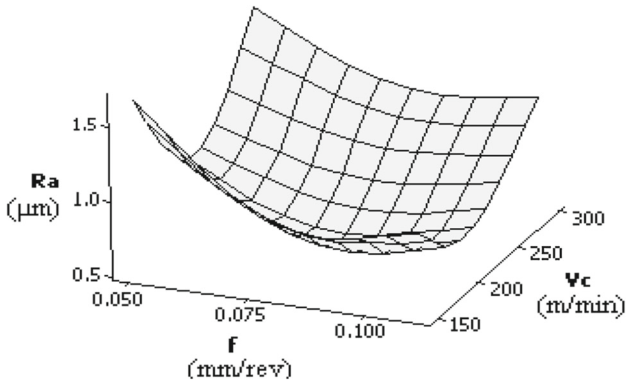

Fig. 5 Simultaneous influences of cutting speed and feed rate on the surface roughness for ceramic insert

Table 6 Regression models for cutting force

Regression models	R^2	R^2(adj)
Degree 1	0.887	0.873
Degree 2	0.946	0.917
Degree 3	0.966	0.917

According to Fig. 5, by simultaneous increasing of cutting speed and feed rate, surface roughness decreased and then increased.

Table 6 shows the value of R^2 and R^2(adj) regression models on cutting force values. It can be inferred from the Table 1 that regression model degree 3 has less error than regression model degree 2 and regression model degree 1 is not acceptable. Regression models are shown in table.

So for this experiment, regression model degree 3 is proposed for cutting force, the equation for this model is shown in Eq. (2):

$$\begin{aligned} F = & -1{,}113 + 8.91V_c + 18{,}440f + 843a_p - 94{,}270f^2 \\ & + 878a_p^2 - 0.0297V_c^2 - 47.6V_c f - 5.09V_c a_p \\ & - 18{,}962 f a_p + 0.000031V_c^3 + 0.0388V_c^2 f \\ & + 95V_c f^2 + 0.0177V_c^2 a_p - 3.09V_c a_p^2 \\ & - 4{,}243a_p^2 f + 14{,}8997a_p f^2 + 18.9V_c f a_p \end{aligned} \quad (2)$$

Figure 6 shows the effect of different parameters on cutting force by ceramic tool.

Figure 6 indicates that cutting speed a few effect on the cutting force and can ignore influence of cutting speed on the cutting force.

Also Fig. 6 indicates that with increasing feed rate and depth of cut, cutting force will be increased because of the fact that the contact of cutting edge with workpieces will become more than before.

The minimum cutting force is in 0.05 mm/rev feed rate and 0.4 mm depth of cut.

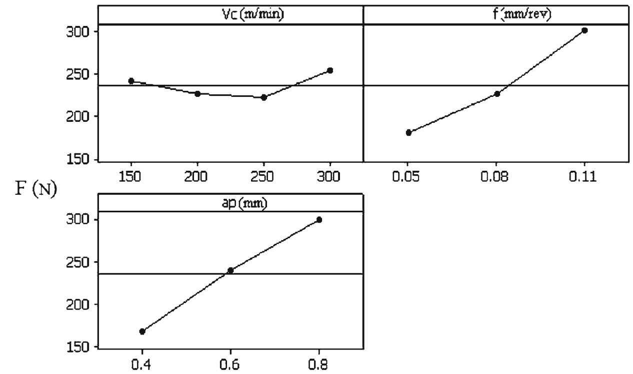

Fig. 6 Effect of different parameters on the cutting force by ceramic tool

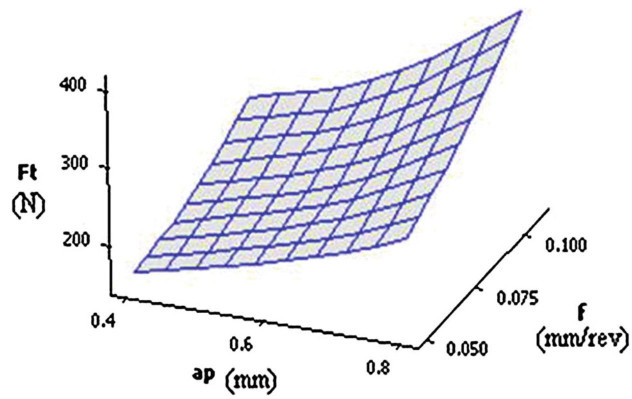

Fig. 7 Simultaneous influences of cutting speed and feed rate on the cutting force for ceramic insert

According to Fig. 6, only depth of cut and feed rate are affected on the cutting force. Figure 7 shows the simultaneous influence of depth of cut and feed rate on the cutting force.

According to Fig. 7, by simultaneous increasing of feed rate and depth of cut, cutting force increased.

4.2 Analyses the Results of Experiment by Carbide Tool

First reviews and analyzes the results for the surface roughness and then cutting force. Table 7 showed the value of R^2 and R^2(adj) regression models on R_a values. It can be inferred from the Table 1 that regression model degree 3 is suitable. Regression model degree 1 and regression model degree 2 are not acceptable. Regression models are shown in Table 7.

So for this experiment, regression model degree 3 is proposed for R_a, the equation for this model is shown in Eq. (3):

$$\begin{aligned} R_a = & \ 8.23 - 0.188V_c - 56.7f - 0.099a_p + 0.00143V_c^2 \\ & + 170f^2 + 0.060a_p^2 + 0.919V_c f + 0.00169V_c a_p \\ & - 0.43 f a_p - 0.000005V_c^3 - 0.00113V_c^2 f - 2.271V_c f^2 \\ & - 0.000005V_c^2 a_p + 0.00056V_c a_p^2 - 0.06a_p^2 f \\ & + 1.4a_p f^2 + 0.002V_c f a_p \end{aligned} \quad (3)$$

Table 7 Regression models for R_a

Regression models	R^2	R^2(adj)
Degree 1	0.922	0.918
Degree 2	0.945	0.941
Degree 3	0.989	0.987

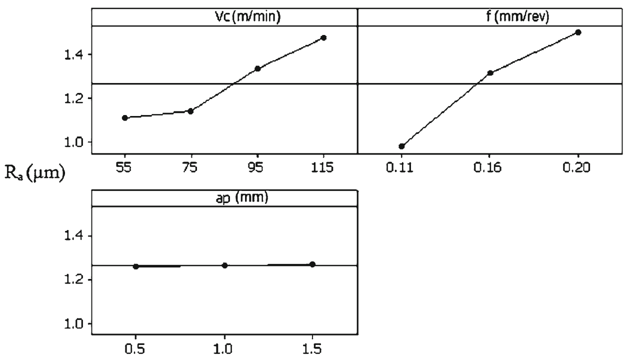

Fig. 8 Effect of different parameters on surface roughness by carbide tool

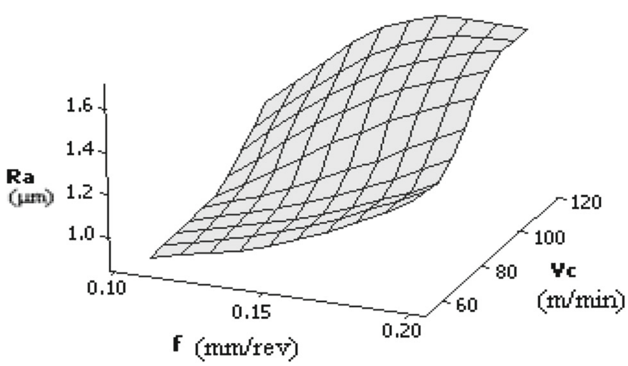

Fig. 9 Simultaneous influences of cutting speed and feed rate on the surface roughness for carbide insert

Figure 8 shows the effect of different parameters on surface roughness by carbide tool.

The result of Fig. 8 shows that the cutting speed and feed rate have higher significant influences than the depth of cut on surface roughness in turning with carbide tool. By increasing the cutting speed, tool wear is increased, therefore, surface roughness value will be increased.

Also by increasing the feed rate, tool wear is increased therefore surface roughness value will be increased and depth of cut has not effect on the surface roughness and the minimum surface roughness is in 0.11 mm/rev feed rate and 55 m/min cutting speed.

According to Fig. 8, only cutting speed and feed rate are affected on the surface roughness. Figure 9 shows the simultaneous influence of cutting speed and feed rate on the surface roughness.

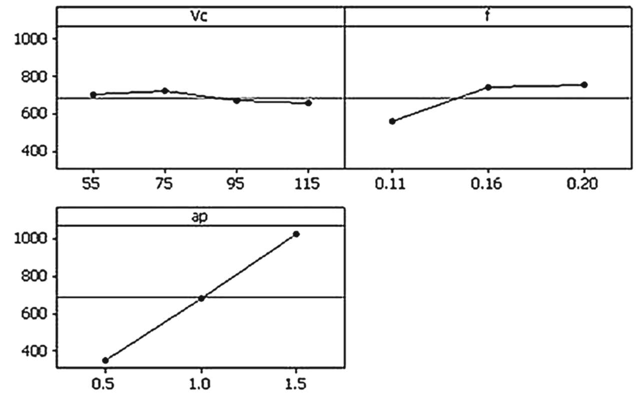

Fig. 10 Effect of different parameters on cutting force by carbide tool

Table 8 Regression models for cutting force

Regression models	R^2	R^2(adj)
Degree 1	0.939	0.931
Degree 2	0.976	0.964
Degree 3	0.984	0.969

According to Fig. 9, by simultaneous increasing of cutting speed and feed rate, surface roughness increased.

Table 8 showed the value of R^2 and R^2(adj) regression models on cutting force values. It can be inferred from the Table 1 that regression model degree 3 has less error than regression model degree 2 and regression model degree 1 is not acceptable. Regression models are shown in table.

So for this experiment, regression model degree 3 is proposed for cutting force, the equation for this model is shown in Eq. (4):

$$\begin{aligned}F = &-1{,}421 + 56.6V_c - 2,375f - 208a_p - 0.671V_c^2\\&+5{,}729f^2 - 337a_p^2 + 7V_cf - 3.6V_ca_p + 16{,}131fa_p^3\\&+0.00267V_c - 0.063V_c^2f + 29V_cf^2 - 0.0193V_c^2a_p\\&+3.72V_ca_p^2 - 45{,}298f^2a_p + 405fa_p^2 - 7.5V_cfa_p\end{aligned} \quad (4)$$

Figure 10 shows the effect of different parameters on cutting force by carbide tool.

The result of Fig. 10 shows that cutting speed has not effect on the surface roughness and with increasing feed rate and depth of cut, cutting force will be increased because cutting edge to be contact with workpiece more than pervious.

The minimum force turning is in 0.11 mm/rev feed rate and 0.5 mm depth of cut.

According to Fig. 10, only depth of cut and feed rate are affected on the cutting force. Figure 11 shows the simultaneous influence of depth of cut and feed rate on the cutting force.

According to Fig. 11, by simultaneous increasing of feed rate and depth of cut, cutting force increased.

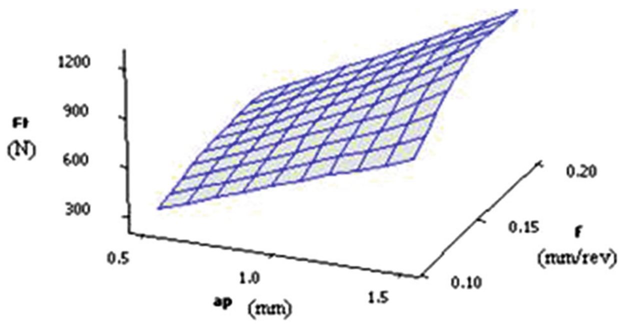

Fig. 11 Simultaneous influences of cutting speed and feed rate on the cutting force for carbide insert

5 Conclusion

In this study, the effects of turning parameters such as depth of cut, feed rate and cutting speed on surface roughness and cutting force during high speed turning Inconel 718 by ceramic and carbide cutting tools in two separate experiments were analyzed and following results were obtained:

- In high speed turning using ceramic tool indicated that cutting speed and feed rate in compared to depth of cut more effectively on surface roughness and the minimum value was 0.894 μm. The minimum surface roughness is obtained at cutting speed of 200 m/min, feed rate of 0.08 mm/rev and depth of cut 0.4 mm.
- In high speed turning using ceramic tool indicated that depth of cut and feed rate in compared to cutting speed more effectively on cutting force and the minimum value was 118.8 N. The minimum cutting force is obtained at cutting speed of 150 m/min, feed rate of 0.05 mm/rev and depth of cut 0.4 mm.
- High speed turning using carbide tool indicated that cutting speed and feed rate in compared to depth of cut more effectively on surface roughness and minimum value was 0.892 μm. The minimum surface roughness is obtained at cutting speed of 55 m/min, feed rate of 0.11 mm/rev and depth of cut 1 mm.
- cutting speed and feed rate in compared to depth of cut more effectively on cutting force and minimum value was 265.94 N. The minimum cutting force is obtained at cutting speed of 95 m/min, feed rate of 0.11 mm/rev and depth of cut 0.5 mm.
- Comparison of ceramic and carbide tools shows that force and average surface roughness in ceramic tools is lower than carbide tool. Comparison cutting speed chart shows that for the ceramic tools optimum surface roughness exists and it is the best machining conditions.

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