DOI: 10.3901/CJME.2015.0316.031, available online at www.springerlink.com; www.cjmenet.com; www.cjme.com.cn

Machinability of Hastelloy C-276 Using Hot-pressed Sintered Ti(C_7N_3)-based Cermet Cutting Tools

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Received July 30, 2014; revised March 13, 2015; accepted March 16, 2015

Abstract: C-276 nickel-based alloy is a difficult-to-cut material. In high-speed machining of Hastelloy C-276, notching is a prominent failure mode due to high mechanical properties of work piece, which results in the short tool life and low productivity. In this paper, a newly developed Ti(C_7N_3)-based cermet insert manufactured by a hot-pressing method is used to machine the C-276 nickel-based alloy, and its cutting performances are studied. Based on orthogonal experiment method, the influence of cutting parameters on tool life, material removal rates and surface roughness are investigated. Experimental research results indicate that the optimal cutting condition is a cutting speed of 50 m/min, depth of cut of 0.4 mm and feed rate of 0.15 mm/r if the tool life and material removal rates are considered comprehensively. In this case, the tool life is 32 min and material removal rates are 3000 mm^3/min, which is appropriate to the rough machining. If the tool life and surface roughness are considered, the better cutting condition is a cutting speed of 75 m/min, depth of cut of 0.6 mm and feed rate of 0.1 mm/r. In this case, the surface roughness is 0.59 μm. Notch wear, flank wear, chipping at the tool nose, built-up edge(BUE) and micro-cracks are found when Ti(C_7N_3)-based cermet insert turned Hastelloy C-276. Oxidation, adhesive, abrasive and diffusion are the wear mechanisms, which can be investigated by the observations of scanning electron microscope and energy-dispersive spectroscopy. This research will help to guide studies on the evaluation of machining parameters to further advance the productivity of nickel based alloy Hastelloy C-276 machining.

Keywords: machinability, Ti(C_7N_3) cutting insert, tool life, surface roughness, Hastelloy C-276

1 Introduction

In the machining industries, turning is one of the most common methods for cutting and especially for the finishing of components. However, it is facing a great challenge to achieve high material removal rates and good surface finish with a long tool life in machining. Nickel-based alloy is one of the extremely difficult-to-cut materials. The requirements for tool material for machining nickel-based alloys are regarded as high strength and toughness at high temperatures. Generally, CBN, coated cemented carbide and ceramic tools have been carried out to machine nickel-based alloys. The CBN cutting tool is not widely used because of its high cost. The coated carbide tool is usually used to machine the nickel-based alloys at relatively low cutting speed. Whereas, the coats are subject to peeling off at the high cutting speed, which reduces the tool life and surface quality of parts. However, the ceramic tool exhibits better advantages to machine the nickel-based alloy due to their chemical stability and red-hardness. HUANG, et al[1], used the SiC-whisker-reinforced Al_2O_3 ceramic inserts to machine the nickel-based alloys. It was considered that SiCw and SiCp toughening effect prevented catastrophic failures and reduced the wear; ALTIN, et al[2], observed that Sialon ceramic tools with round types in turning of nickel-based alloy was seen minimum flank wear at high cutting speed; At the cutting speed of 200 m/min and depth of cut of 1 mm, Sialon ceramic tool exhibited an excellent performance in high-speed machining of Inconel 718[3]. Ti(C, N)-based ceramic are normally made of Ti(C, N) solid solution and hard carbides such as WC and TaC[4–5]. Ti(C_7N_3)-based cermet cutting inserts were manufactured by the hot-pressing method and the cutting performance was investigated. The results showed that the wear width of the flank face was only 0.3 mm after 85 minutes of high-speed turning 17-4PH martensitic stainless steel at a cutting speed of 350 m/min, a feed rate of 0.1 mm/r and a depth of cut of 0.3 mm[6].

Hastelloy C-276 is a nickel-based alloy containing a high content of Cr and Mo elements. It is widely used in the chemical, aerospace and nuclear industries because of its high corrosion resistance and high strength at elevated

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Supported by Program for New Century Excellent Talents in University of China (Grant No. NCET-13-0357), Shandong Provincial Natural Science Foundation of China (Grant No. ZR2014EEM026), and Tai Shan Scholar Foundation of China

temperature[7]. But some peculiar characteristics make it difficult to machine, such as low thermal diffusive property, work hardening, and affinity to react with tool material. Thus, it is classified as difficult-to-cut material. Furthermore, some researches available about machinability of Hastelloy C-276 are very absent. The tool life and wear mechanisms in machining of Inconel 718 were investigated widely[8–10]. ZHOU, et al[11], found that the life of whisker reinforced ceramic tool was only 4 min at cutting speed of 250 m/min, depth of cut of 0.3 mm and feed rate of 0.2 mm/r; CANTERO, et al[12], investigated the tool wear mechanisms in finishing-turning of Inconel 718, and found that the tool life (VB_N=0.4 mm) did not reach 5 min due to notch wear which induced cutting edge breakage, chipping and BUE at the cutting speed of 50 m/min; KADIRGAMA, et al[13], evaluated the performance of $TiN/TiCN/Al_2O_3$ coated cemented carbide inserts in machining of Hastelloy C-22HS and found that tool failure were predominated by flank wear, chipping, notching, catastrophic and wear at nose. The tool life of KC930M which was coated with $TiN/TiCN/Al_2O_3$ through CVD multilayer process was only 20 s at cutting speed of 100 m/min, depth of cut of 2 mm and feed rate of 0.1 mm/tooth in this literature. However, it is not available in industry. KHIDHIR, et al[14], analyzed the effects of cutting parameters on surface roughness and ceramic tool wear in machining of Hastelloy C-276 nickel-based alloys. The results showed that the most significant parameters influencing the surface roughness was the cutting speed. An increase of depth of cut improved the surface roughness while a changing of feed rate took no effects on the surface roughness. However, the tool life was very short because of chipping and flank wear and the relationships and mechanisms among the material removal rates, surface roughness and tool life were not investigated in details in this literature.

In this study, $Ti(C_7N_3)$-based ceramic cutting inserts were manufactured by the hot-pressing method, which was used to machine Hastelloy C-276. Based on orthogonal experiment method, the best cutting parameter had been obtained, considering their effects on the tool life, material removal rates and surface roughness. The failure mechanisms of cutting inserts were discussed in terms of the microstructure, mechanical and chemical properties and thermal shock resistance of tool materials.

2 Experiment

The work-piece was a Hastelloy C-276 nickel-based alloy by a solid-solution heat treatment. The compositions and mechanical properties of Hastelloy C-276 were given in Table 1. The work-piece was a bar (Φ110 mm×400 mm). The used tools were $Ti(C_7N_3)$-15(WC+TaC) cermet cutting inserts which were manufactured by the hot-pressing method. The mechanical properties of cutting inserts were shown in Table 2.

Table 1. Compositions and mechanical properties of Harstelloy C-276 work-piece by a solid-solution heat treatment

	Cr	Mo	Fe	W	Mn	V
Chemical composition wt/%	15.65	15.6	5.15	3.27	0.5	0.04
	Si	Co	C	S	P	Ni
	0.04	0.01	0.007 3	0.004 7	0.003 8	Balance
Mechanical properties	Yield strength E/MPa	Tensile strength σ_b/MPa	Elongation δ/%	Hardness HBS/MPa	Thermal conductivity λ/(W • m^{-1} • K^{-1})	—
	368	762	46	232	10.2	—

Table 2. Mechanical properties and density of hot-pressed sintered $Ti(C_7N_3)$-15(WC+TaC) cermets cutting inserts

Flexural strength σ/MPa	Vickers' hardness HV20/GPa	Fracture toughness KIC/(MPa • $m^{1/2}$)	Relative density d/%
1759	18.55	6.07	99.4

The cutting experiments were performed under a cooling condition on the PUMA 200MA turning center (DAEWOO, Korea). The maximum of spindle rotational speed can reach 6000 r/min. The cutting tools were ground and polished into 16 mm×16 mm×6 mm. The edges of the cutting tool were also chamfered to avoid tipping, and their chamfer angle and width were −15° and 0.1 mm, respectively. The tool noses were rounded into a radius of 0.3 mm to enhance the impact resistance and avoid a sudden collapse at the beginning of machining. The other effective geometries of tools after rigid clamping in the tool post were: a rake angle of −5°, a relief angle of 5°, an inclination angle of −5°, an edge angle of 45°. A cutting insert had to be rejected and then a further machining was stopped based on one or a combination of the following rejection criteria in relation to ISO Standard 3685 for tool life testing: 1) Average flank wear P0.3 mm, 2) Maximum flank wear P0.4 mm, 3) Nose wear P0.5 mm, 4) Notching at the depth of cutline P0.6 mm, 5) Excessive chipping (flaking) or catastrophic fracture of the cutting edge. In this study, tool life was measured by number of cuts taken by the inserts to reach average flank wear criterion of 0.3 mm. Experiment trial will be stopped when the criteria was reached. The widths of cutting tools were measured by a laser scanning microscope (LSM, VK-X200K, Keyence, Japan). The results have been recorded after certain time. Scanning electron microscopy and energy-dispersive spectroscopy (SEM and EDS, SUPRA55, Germany) were used to examine the morphologies of wear and fracture surfaces.

The idea of experimental methods in our work is an orthogonal experiment including nine cutting experiments in Table 3. An L_9 standard orthogonal array[15] as shown in Table 4 was employed for the present investigation. The experiment results were shown in Table 5. Based on the range analysis, main effects of the cutting parameters on tool life, material removal rates and surface roughness were analyzed. The range analysis of test result was shown in Table 6. Analysis of variance (ANOVA) was also performed to study the relative significance of the cutting parameters and evaluate the effects of experimental errors. Based on these analyze, the optimum cutting conditions were given. The wear morphologies of Ti (C_7N_3)-15(WC+TaC) were investigated by scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS).

Table 3. Turning parameters and their levels

Parameter	Factors	Level 1	Level 2	Level 3
Cutting speed $v/(\mathrm{m \cdot s^{-1}})$	A	50	75	100
Depth of cut a_p/mm	B	0.2	0.4	0.6
Feed $f/(\mathrm{mm \cdot r^{-1}})$	C	0.1	0.15	0.2

Table 4. L_9 standard orthogonal array

Experiment No.	Factor A	Factor B	Factor C	Factor D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	1
9	3	3	2	3

Table 5. Experimental results for the surface roughness, tool life and material removal rates

Experiment No.	Surface roughness $R_a/\mu\mathrm{m}$	Tool life T/min	Material removal rates $Q/(\mathrm{mm^3 \cdot min^{-1}})$
1	1.17	86	1000
2	2.63	32	3000
3	3.02	11	6000
4	2.87	13	2250
5	2.82	5	6000
6	0.59	11	4500
7	2.83	6	4000
8	0.95	7	4000
9	1.77	3	9000

3 Results and Discussion

During machining nickel-based alloys, the high forces and temperature created a very harsh environment for the cutting tools[16]. Therefore, tool life is an important factor to evaluate the machinability of work-piece in a turning operation. Derived from Table 5, the analysis of range was given in Table 6 and the analysis of variance (ANOVA) was given in Table 7. Range analysis and analysis of variance (ANOVA) showed that cutting speed had the greatest effect on tool life and was followed by the feed rate and depth of cut in order. Fig. 5 showed the effects of cutting parameters on the tool life. It was seen that the first level of cutting speed (A1), first level of depth of cut (B1) and first level of feed rate (C1) resulted in the maximum value of tool life.

Table 6. Analysis of range of test results

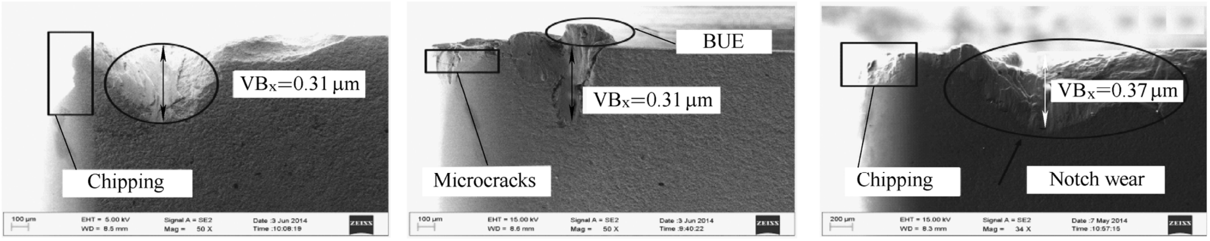
Indicator	Range analysis	Factor A	Factor B	Factor C	Error D
Tool life T/min	K1	129	105	104	94
	K2	29	44	48	49
	K3	16	25	22	31
	k1	43	35	35	31
	k2	10	15	15	16
	k3	5	8	8	10
	R	38	27	27	21
Surface roughness $R_a/\mu\mathrm{m}$	K1	6.82	6.87	2.71	5.76
	K2	6.28	6.40	7.27	6.05
	K3	5.54	5.38	8.66	6.83
	k1	2.27	2.29	0.90	1.92
	k2	2.09	2.13	2.42	2.02
	k3	1.85	1.79	2.89	2.28
	R	0.42	0.5	1.99	0.36
Material removal rates $Q/(\mathrm{mm^3 \cdot min^{-1}})$	K1	10 000	7250	9500	16 000
	K2	12 750	13 000	14 520	11 500
	K3	17 000	19 500	16 000	12 250
	k1	3333	2417	3167	5333
	k2	4250	4333	4750	3833
	k3	5667	6500	5333	4083
	R	2334	4083	2166	1500

Table 7. Analysis of variance (ANOVA) for tool life

Factor	Degrees of freedom	Sum of square	Mean square	$F_{0.05}(2, 2)$	Contribution $C/\%$
A	2	2548	1274	3.631	45.63
B	2	1164	582	1.659	20.85
C	2	1170	585	1.668	20.95
Error	2	702	—	—	12.57
Total	8	5584	—	—	—

It was seen from Fig. 1 that notching at the tool edge was a common failure mode in machining of Hastelloy C-276. The flank wear, chipping at the tool nose, BUE and micro cracks were also found. The slow tool wear, such as adhesive and chipping at tool nose were the mechanisms of Ti(C_7N_3)-15(WC+TaC) at the lower cutting speed. However, with increasing the cutting speed, the notch wear was the dominant failure mode, and the catastrophic fracture of the edge occurred to decrease the too life.

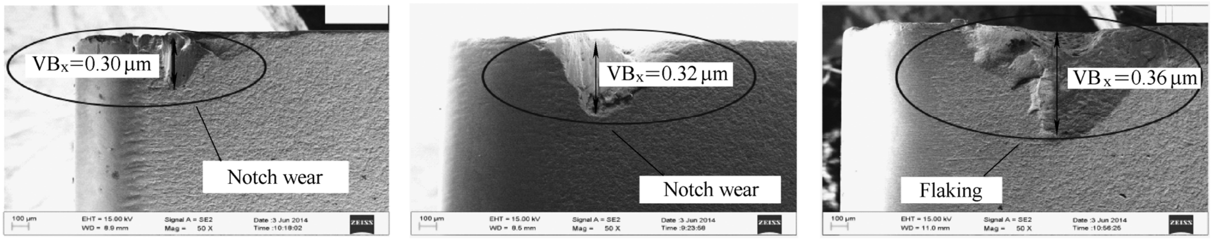
Fig. 2 showed the SEM and EDS of wear mechanisms at the different cutting parameters in machining of Hastellloy C-276.



(a) Tool life : 86 min
$v=50$ m/s, $a_p=0.2$ mm, $f=0.1$ mm/r

(b) Tool life : 32 min
$v=50$ m/s, $a_p=0.4$ mm, $f=0.15$ mm/r

(c) Tool life : 11 min
$v=50$ m/s, $a_p=0.6$ mm, $f=0.2$ mm/r

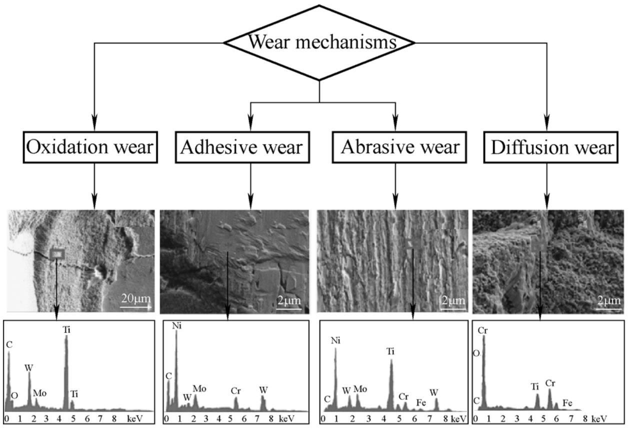


(d) Tool life : 5 min
$v=75$ m/s, $a_p=0.4$ mm, $f=0.2$ mm/r

(e) Tool life : 7 min
$v=100$ m/s, $a_p=0.4$ mm, $f=0.1$ mm/r

(f) Tool life : 3 min
$v=100$ m/s, $a_p=0.6$ mm, $f=0.15$ mm/r

Fig. 1. Flank wear of Ti(C_7N_3)-15(WC+TaC) tool machining Hastelloy C-276 at different cutting parameters



(a) $v=50$ m/min, $a_p=0.4$ mm, $f=0.15$ mm/r
(b) $v=100$ m/min, $a_p=0.4$ mm, $f=0.1$ mm/r
(c) $v=100$ m/min, $a_p=0.6$ mm, $f=0.15$ mm/r
(d) $v=100$ m/min, $a_p=0.6$ mm, $f=0.15$ mm/r

Fig. 2. SEM of flank wear of Ti(C_7N_3)-15(WC+TaC) tool at different cutting parameters

At the cutting speed of 50 m/min, feed rate of 0.15 mm/r and depth of cut of 0.4 mm, many micro-cracks were generated on the worn tool face (see Fig. 2(a)), which could produce severer influence on tool life during machining of Hastelloy C-276. A high content of oxygen was identified by the EDS though no oxygen existed in both the tool and work-piece materials. KHIDHI, et al[17], confirmed that the highest temperature reached 980°C at the contact area between tool nose and chips in machining of Hastelloy C-276 by using the finite element simulation. Thus, the oxidation wear resulted from the reaction of the Ti(C_7N_3)-15(WC+TaC) cutting tool material with oxygen in air at the high cutting temperature. At the cutting speed of 100 m/min, feed rate of 0.4 mm and depth of cut of 0.1 mm. The tool flank was worn out and some materials adhered to the worn tool (see Fig. 2(b)). The EDS identified the presence of Ni and Cr on the tool face, which indicated that there was a strong chemical affinity of HastelloyC-276 with Ti(C_7N_3)-based cutting inserts during machining process. A cold welding phenomenon was usually generated by the plastic deformation under the sufficient pressure and temperature, and it was a result of adhesive force among atoms by the plastic deformation occurred in the actual contact area of friction surface[18]. At the cutting speed of 100 m/min, feed rate of 0.15 mm/r and depth of cut of 0.6 mm, the tool wear were predominated by the abrasive wear and diffusion wear as shown in Figs. 2(c) and (d). Fig. 2(c) showed some scratches at the tool flank due to the motion relative to the surface of either harder asperities or perhaps hard inclusions trapped at the interface. Ni, Cr, Mo were also found on the worn flank where the abrasive wear occurred. Due to the high cutting temperature in machining of Hastelloy C-276, the close contact between the too-chip and tool-work piece provided an ideal environment for the atoms in the tool material with external diffusion through the too-chip interface. The EDS in Fig. 2(d) reveal that the worn flank contained many Ni, Cr, Ti, C and Fe, indicating that the work-piece material bonded to the tool surface. Also the Co element was not found at the wear area of tool flank. ZHU, et al[18], considered Co element was easy to the loss of diffusion, thus the content of Co in the tool material can determine the occurrence of diffusion wear. Diffusion seriously accelerated the tool wear and limited the cutting performance of Ti(C_7N_3)-based cermet cutting inserts. The tool life was only 2 min at the cutting speed of 100 m/min, depth of cut of 0.6 mm and feed rate of 0.15 mm/r (see Table 5).

The tool wear was a complex process in machining of difficult-cut-material. In general, several different wear forms caused the tool failure. Fig. 3 shows the SEM and EDS of tool wear at the cutting speed of 50 m/min, feed rate of 0.1 mm/r and depth of cut of 0.2 mm. The tool materials were bound to become soft at the high temperature in machining of Hastelloy C-276. When chips flowed out from the front flank, plowing effects were produced because the tool material was taken away from the rake face of inserts. The wear depth of rake face was about 0.28 mm measured by the 3D laser microscope. The Ni, Cr, Mo and Fe had been found from the tool flank wear by EDS as the adhesive wear happened. ZOU, et al[19], observed the cracks in the adhesive layer of the worn tool in machining of NiCr20TiAl nickel-based alloy. If the tool continued to be used to machine the work-piece, the adhesive layer would be detached from tool and accelerated the tool failure. The Ti(C_7N_3)-based cutting tool material reacted with the oxygen in air and resulted in the oxidation wear at the high temperature. The performance of the cermet tools had been changed because of the oxidation. These several wear mechanisms had influenced on the tool life. After working 86 min the Ti(C_7N_3)-based cermet inserts failed at that cutting condition.

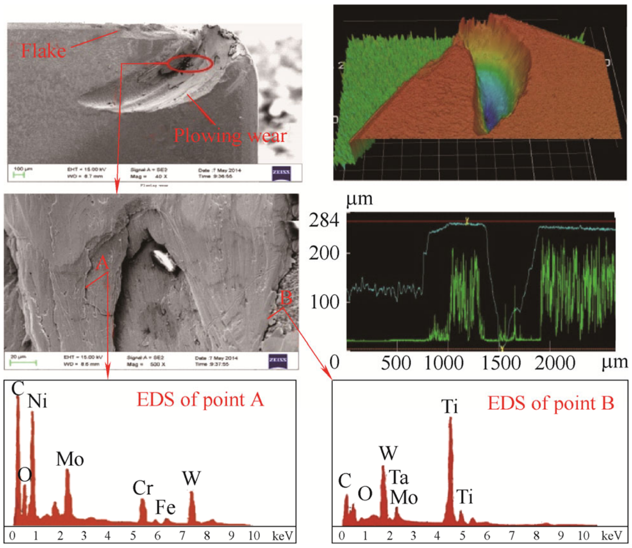


Fig. 3. SEM micrographs and EDS of rake face wear of Ti(C_7N_3)-15(WC+TaC) cutting inserts at the cutting speed of 50 m/min, feed of 0.1 mm/r and depth of cut of 0.2 mm

For rough machining, tool lifeand material removal rates were also considered. Fig. 4 was the results of the tool life at all the cutting parameters in machining of Hastelloy C-276. It can be seen from the Fig. 4 that the tool life of five groups (group 1, group 2, group 3, group 4 and group 6) was more than 10 min. Fig. 5 showed the effects of cutting parameters on the tool life. It was seen that the first level of cutting speed (A1), first level of depth of cut (B1) and first level of feed rate (C1) resulted in the maximum value of tool life.The cutting efficiency will be increased for inserts when the more material is removed at the same time. The material removal rates are expressed as

$$Q=\frac{\sum_{i=1}^{i=m} m\pi a_p D_i t_i n_i f}{60\times\sum_{i=1}^{i=m} t_i},$$

where m is the number of cutting; a_p is the depth of cut; D_i is the diameter of work pieces; f is the feed rate; n_i is the speed of work pieces; t_i is cutting time. The formula can be simplified: Q=1000va_pf. The material removal rates are closely related to the cutting parameters from this formula. Range analysis was given in Table 6 and analysis of variance (ANOVA) was given in Table 8. Range analysis showed that the depth of cut had the greatest effect on the material removal rates and was followed by cutting speed, feed rate in order. Results of analysis of variance (ANOVA) showed that depth of cut, cutting speed and feed rate affected the material removal rates by 55.96%, 18.53% and 16.85%. Fig. 6 showed the trend of effects of cutting parameters on the material removal rates in machining of Hastelloy C-276. The last level of cutting speed (A3), last level of depth of cut (B3) and last level of feed rate (C3) resulted in the maximum value of the material removal rates. For the rough turning of Hastelloy C-276 in practice, the tool life and material removal rates had to be considered. Thus, considering the tool life and material removal rates, the best cutting conditions were at the cutting speed of 50 m/min, the depth of cut of 0.4 mm and the feed rate of 0.15 mm/r. In that case, the material removal rates and tool life reached 3000 mm^3/min and 32 min, respectively.

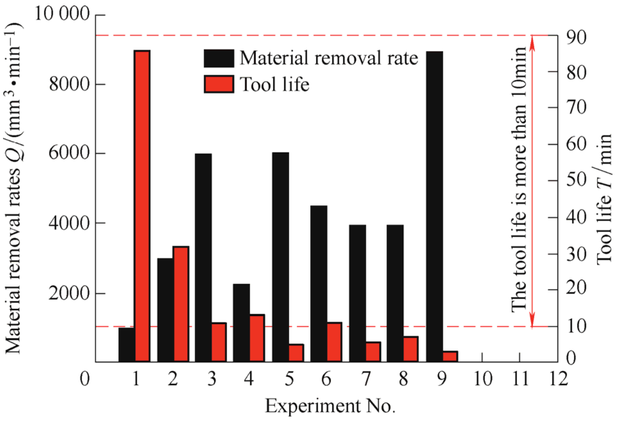
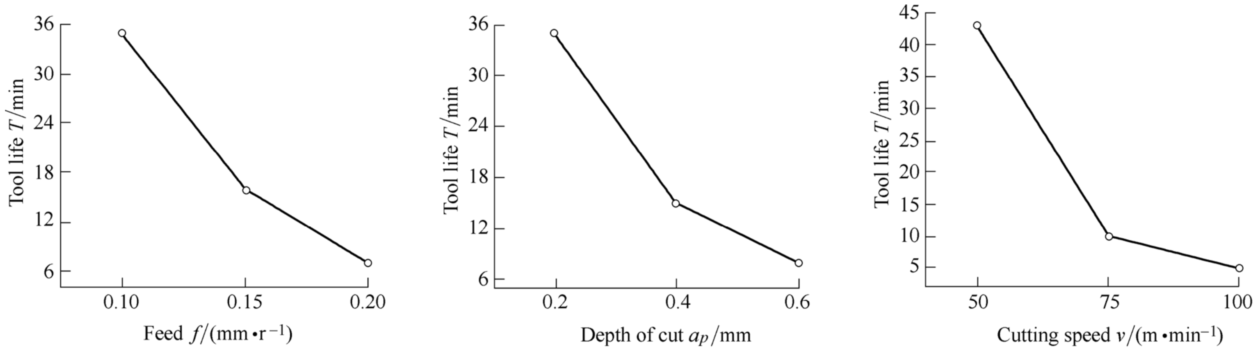


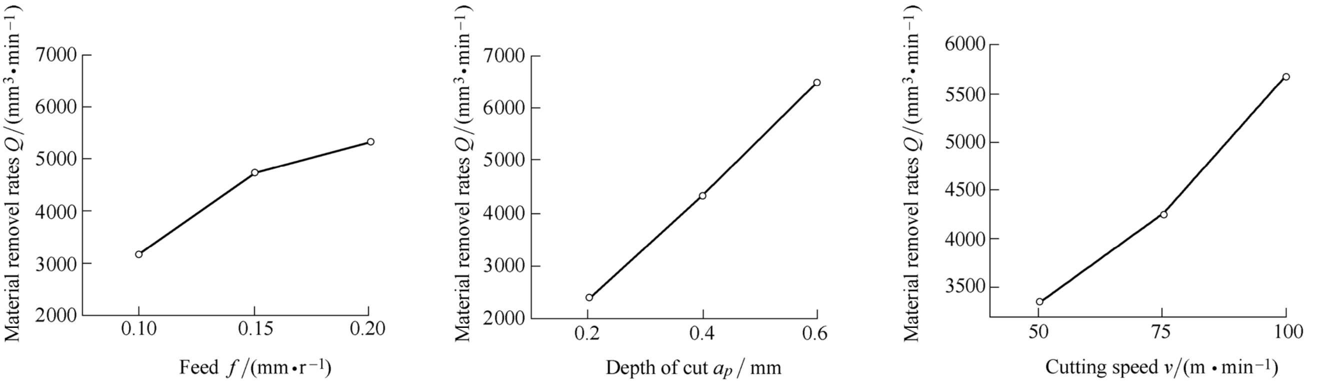
Fig. 4. Experiment results of material removal rates and tool life

For finish-machining, the important optimal goal was the surface roughness. R_a should be kept in 0.8 μm in finish-turning of Hastellory C-276[20]. During machining process, Ni and Cr in nickel-based alloy had a strong chemical affinity with tools, resulting in an adhesive layer generated. The adhesive effect had influence on the surface roughness. Therefore, the surface roughness was closely related with not only materials but also cutting parameters. The range analyses (Table 6) had shown that the feed rate had the greatest effect on the surface roughness and was followed by the depth of cut, cutting speed in order. Results of analysis of variance (ANOVA) (Table 9) showed that feed rate, depth of cut and cutting speed affect the surface roughness by 88.21%, 5.27% and 3.68%. Fig. 7 showed the effect of cutting parameters on the surface roughness of work pieces. It was seen from Fig. 7 that the last level of cutting speed (A3), last level of depth of cut (B3) and first level of feed rate (C1) resulted in the minimum value of surface roughness. Fig. 8 showed the results of tool life and surface roughness at all the cutting conditions. It was seen that the optimum cutting parameters were at cutting speed of 75 m/min, depth of cut of 0.6 mm and feed rate of 0.1 mm/r. The surface roughness and tool life were 0.59 μm and 11 min respectively at the cutting conditions, which adapted to the finish-machining. During machining Hastelloy C-276, the higher roughness was found with increasing of the feed rate. Within a certain range from cutting speed, the increase of cutting speed could improve the surface finish, the depth of cut as the same to effect on the surface roughness. Considered with the tool life and surface roughness, the best cutting parameters were a cutting speed of 75 m/min, depth of cut 0.6 mm and feed rate of 0.1 mm/r.



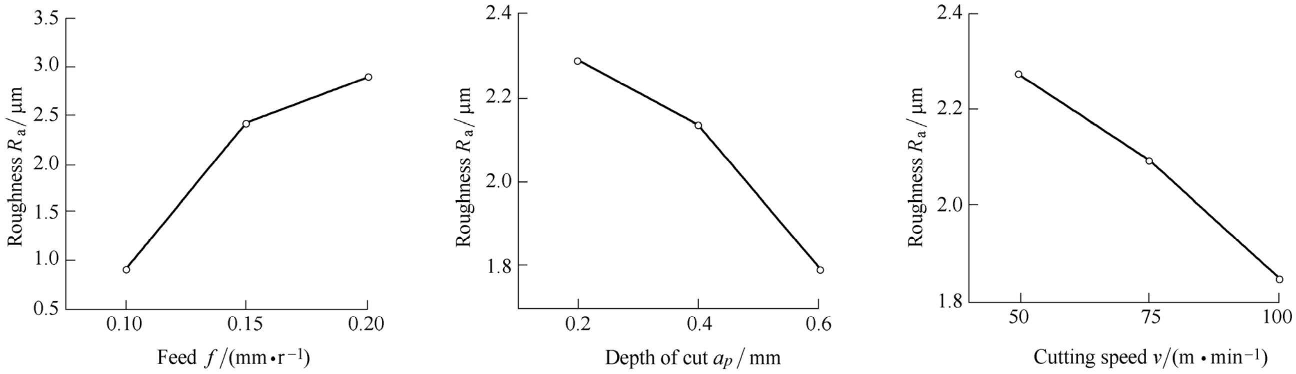
(a) Effect of feed on tool life　(b) Effect of depth of cut on tool life　(c) Effect of cutting speed on tool life

Fig. 5.　Trend of effects of the feed, depth of cut and cutting speed on tool life



(a) Effect of feed on material removal rates　(b) Effect of depth of cut on material removal rates　(c) Effect of cutting speed on material remoral rates

Fig. 6.　Trend of effects of the feed, depth of cut and cutting speed on material removal rates



(a) Effect of feed on roughness　(b) Effect of depth of cut on roughness　(c) Effect of cutting speed on roughness

Fig. 7.　Trend of effects of the feed, depth of cut and cutting speed on surface roughness

Table 8.　Analysis of variance (ANOVA) for material removal rates

Factor	Degrees of freedom	Sum of square	Mean square	$F_{0.05(2,2)}$	Contribution C/%
A	2	8 292 350	4 146 175	2.140	18.53
B	2	25 043 316	12 524 658	6.462	55.96
C	2	7 542 350	3 771 175	1.946	16.85
Error	2	3 875 416	—	—	8.66
Total	8	44 753 432	—	—	—

Table 9.　Analysis of variance (ANOVA) for roughness

Factor	Degrees of freedom	Sum of square	Mean square	$F_{0.05(2,2)}$	Contribution C/%
A	2	0.27	0.14	1.30	3.68
B	2	0.39	0.20	1.86	5.27
C	2	6.48	3.24	31.13	88.21
Error	2	0.21	—	—	2.84
Total	8	7.35	—	—	—

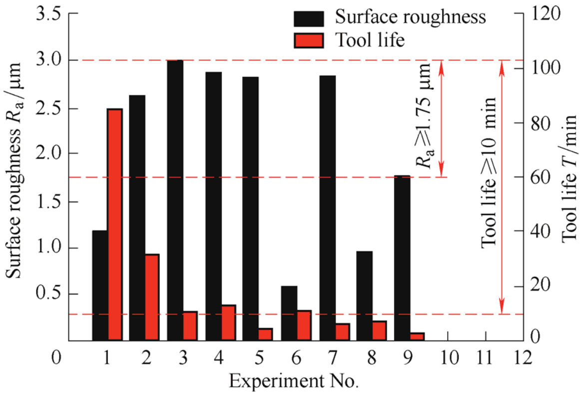


Fig. 8. Experiment results of the surface roughness and tool life

4 Conclusions

(1) Based on the ANOVA results, the first contributing factor to tool life of this newly developed tool was the cutting speed which had almost 45.63% contribution; Second, the depth of cut and feed had almost 20.85% and 20.95% contribution, respectively. Based on range analysis, the best optimal cutting condition was a cutting speed of 50 m/min, depth of cut of 0.2 mm and feed rate of 0.1 mm/r. The longest tool life reached 86 min.

(2) The depth of cut was the greatest effect on the material removal rates when the $Ti(C_7N_3)$-based cutting inserts were used for rough-turning of Hastelloy C-276. If the tool life and material removal rates were considered comprehensively, the cutting speed of 50 m/min, depth of cut of 0.4 mm and feed rate of 0.15 mm/r was the optimum cutting parameter. The feed rate was the greatest influence on the surface roughness. In view of surface roughness and tool life, the optimally used cutting parameter was a cutting speed of 75 m/min, depth of cut of 0.6 mm and feed rate of 0.1 mm/r.

(3) Flank wear, chipping and cracking were the dominant tool failure modes when machining Hastelloy C-276 with $Ti(C_7N_3)$-15(WC+TaC) cermet tools at the lower cutting speed. With increasing the cutting speed, the notch and catastrophic fracture of the edge occurred to reduce the tool life. The adhesion/attrition, abrasive, oxidation and diffusion were the main wear mechanisms of $Ti(C_7N_3)$-based cermet tools.

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