Research Journal of Applied Sciences 9 (11): 767-770, 2014
ISSN: 1815-932X

Solid Carbide End Mills Tool Life Increase in Titanium Alloys Machining by Design Development and Rational Choice of Geometrical Parameters

Dmitry Leonidovich Skuratov, Alexey Nikolaevich Zhidyaev and Mikhail Borisovich Sazonov
Samara State Aerospace University (SSAU), 34 Moskovskoye Shosse, 443086 Samara, Russia

Abstract: This study describes the research of solid carbide end mills tool life which were developed in Samara State Aerospace University (SSAU) and intended to substitute the expensive end mills developed by international manufacturers. The study also reflects the research of one of the international manufacturer's basic end mill tool life and also the tool life of the prototype end mill with normal and strengthened tooth.

Key words: End mills, design, manufacturing technology, titanium alloys machining, cutting conditions, tool life

INTRODUCTION

The cutting tool plays a critical role in mechanical technology. During machining operation the contacting surfaces of the tool are under significant specific load while the temperature in the cutting area may increase to 600-1500°C depending on tool material grade and cutting parameters (Evdokimov *et al*., 2014). Under such conditions the tool wear rate is significantly higher than the wear rate of the other components involved in technological system. For this reason the durability of the technological system would primarily depend on the design and the quality of the applied tool, i.e., its manufacturing technology. The rational choice of the design, geometry and manufacturing technology becomes especially important in case of manufacturing the parts made of hardened and stainless steels, heat-resistant steels and alloys, titanium alloys (Khaimovich and Balaykin, 2014) when the metal-forming process is accompanied by significant power and temperature loads.

Solid carbide end mills, manufactured by various Russian and International companies are in general use for slots, shoulders, narrow faces and profile machining. But the customer is not always satisfied with the "price-quality" ratio of the tool. Thus, the goal was to develop solid carbide end mills for machining of titanium alloys which will ensure high performance and durability of the tool and also acceptable manufacturing cost.

The analysis of the literature connected with the research of the design and durability of end mills showed that the significant amount of the studies were devoted to design and geometric parameters of the end mills and its influence on the cutting process. Thus, Engin and Altintas (2001) and Altintas and Engin (2001) describes the generalized mathematical model of end mill, the stability of cutting process by the end mills is considered by Kivanc and Budak (2004) and Turner *et al*. (2007) reflects a comparative study of performance of variable helix and variable pitch end mills. There are also researches devoted to optimization of end mills geometry for different materials machining (Subramanian *et al*., 2013). The variety of the end mills design is represented by cutting tools manufacturers.

A lot of attention is also paid to research of the machining by carbide tool with and without coating especially in dry milling (Ginting and Nouari, 2006; Chung-Chen and Hong, 2002). Devillez *et al*. (2007), Zareena and Veldhuis (2012) and Ginting and Nouari, (2007) are devoted to tool life and tool wear mechanism.

The tool life testing results can be used to confirm the models of metal cutting tools optimal replacement time (Vagnorius *et al*., 2010).

MATERIALS AND METHODS

In accordance with the aim 2 types of solid carbide end mills were developed with normal (Fig. 1) and strengthened tooth (Fig. 2). The design and geometric parameters of these end mills were end mill's diameter 12 mm, shank diameter 12 mm, cutting length 24 mm, overall length 83 mm, corner radius 1.5 mm, number of teeth 4.

The chip groove of the end mill with normal tooth has one core and with strengthened tooth 2 cores. The 2 core chip groove forms in 2 steps. During the 1st step, the top

Corresponding Author: Dmitry Leonidovich Skuratov, Samara State Aerospace University (SSAU), 34 Moskovskoye Shosse, 443086 Samara, Russia

Fig. 1: Prototype end mill with normal tooth

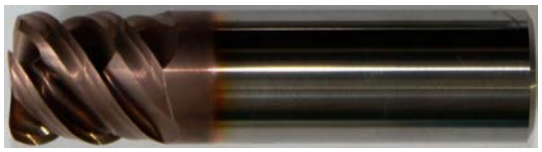

Fig. 2: Prototype end mill with strengthened tooth

part of chip grove grinds on the full cutting length of the end mill. The bottom part of the chip groove forms during the 2nd step (Fig. 2). On the one hand 2 cores enable to increase the rigidity of the end mill, on the other it strengthens tooth and increases its durability. During the end mill grinding the second core was manufactured for the length of 16 mm from end face.

End mills were manufactured on tool and cutter grinding machine with computer numerical control ВЗ-6310Ф4 using the method of creep feed grinding. The separate part program was developed for each variant of the end mill. The calculation of the temperature in the cutting area was based on analytical dependency provided in articles (Skuratov *et al*., 2007; Perez *et al*., 2008). This helped to avoid workpiece overheating during the grinding operation on chosen cutting conditions.

Below is the list of steps of grinding operation (in order of its accomplishment):

- First core of the groove machining
- Second core of the groove machining
- Rake face of the end face machining
- Cylinder first clearance machining
- Cylinder second clearance machining
- End face first clearance machining
- End face second clearance machining
- Corner radius second clearance machining
- Corner radius first clearance machining

1A1, 1V1 and 11V9 forms of diamond grinding wheels were used as a tool for carbide end mills manufacturing. These diamond grinding wheels have the following characteristics: grit size D64, concentration 100%.

End mills were manufactured of 2 submicron carbide grade. Grades properties are shown in Table 1.

Grinded carbide rods were used as the workpiece for end mills manufacturing. The length of carbide rods was 84 mm, diameter 12 mm, tolerance band h 6.

Table 1: The chemical composition and physical-mechanical properties of carbide grades

Chemical composition and physical-mechanical properties	Grade 1	Grade 2
Co (%)	9	10
$WC+Cr_3C_2+VC$ (%)	91	90
WC grain size (μm)	0.7-0.8	–
Hardness index HRA	92.0	91.9
Hardness index HV30 (kgf mm^{-2})	1710	1600
Density (g cm^{-3})	14.40	14.45
Bending strength (H mm^{-2})	3100	4100

In order to increase wear resistance the coating was applied on end mills using ННВ6.6-И1 ion-plasma machine and worked out method with process conditions. (Ti-Cr) N wear-resistant coating was applied on work surface of end mills with normal tooth, end mills with strengthened tooth were covered by (Ti-Al-Si) N wear-resistant coating.

In order to estimate the efficiency of developed and manufactured (prototype) end mills they were compared with basic end mills made by one of the world leading manufacturer of cutting tools.

The cutting conditions of milling operation cutting speed $V \approx 30$ m min^{-1}, feedrate $S_m = 250$ mm min^{-1}, depth of cut t = 5 mm, width of cut B = 3 mm. Blaser Swisslube AG® brand Blasocut 4000 emulsion was used as lubricating and cooling fluid with copper (6%) added as the additional lubricating element. All other machining conditions during end mills test were identical.

Tool life testing was performed on 6Т82Г-1 horizontal milling machine. Testing of prototype end mills with normal tooth (1st variant of end mill) and the basic end mill was performed in machining of ВТ9 titanium alloy, the same time wear resisting testing of prototype end mills with strengthened tooth (2nd variant of end mill) and the basic end mill was performed in machining of ВТ20 titanium alloy. The ultimate strength of ВТ9 titanium alloy is 1030-1226 MPa, ВТ20 titanium alloy 1120-1200 MPa.

RESULTS

The results of tool life testing are shown in Fig. 3. As can be seen in the Fig. 3, the basic end mill tool life is 435 min (7 h 15 min), the SSAU manufactured prototype end mill with normal tooth made of carbide grade 1 tool life is 177 min (2 h 57 min) which is 40.7% of basic end mill tool life. The research of end mill tool life made of carbide 2 with (Ti-Cr) N coating showed that the tool life is 175 min (2 h 55 min) which is practically equal to tool life of end mill made of carbide 1 without coating. The tool life of prototype end mill made of carbide 1 with (Ti-Cr) N coating was 265 min (4 h 25 min) which is 60.9% of basic end mill tool life.

Maximum tool life of prototype end mills with strengthen tooth is shown in Fig. 4.

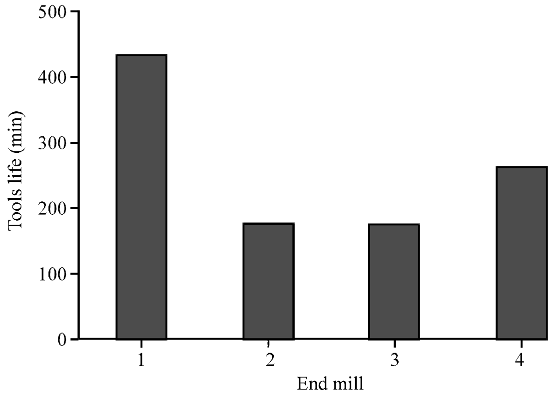

Fig. 3: The maximum tool life values of basic end mill and prototype end mills with normal tooth; 1: basic end mill with coating; 2: prototype end mill with normal tooth made of carbide 1 without coating; 3: prototype end mill with normal tooth made of carbide 2 with (Ti-Cr) N coating; 4: prototype end mill with normal tooth made of carbide 1 with (Ti-Cr) N coating

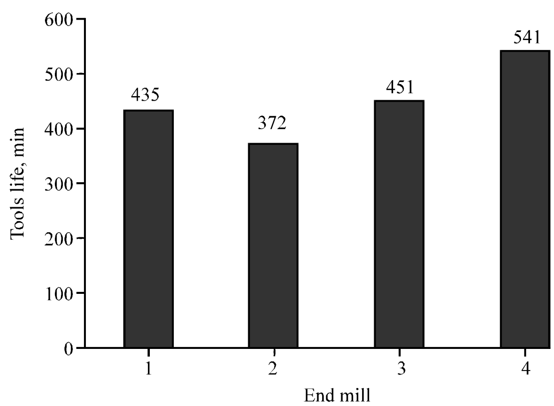

Fig. 4: The maximum tool life values of basic end mill and prototype end mills with strengthen tooth; 1: basic end mill with coating; 2: prototype end mill with strengthened tooth made of carbide 2 without coating; 3: prototype end mill with strengthened tooth made of carbide 1 without coating; 4: prototype end mill with strengthened tooth made of carbide 1 with (Ti-Al-Si) N coating

As can be seen in Fig. 4 the tool life was increased significantly through the end mill's tooth strengthening. This relates to end mills with (Ti-Al-Si) N and without coating, at the same time it also enabled to come closer and even excel the basic end mill tool life in the following machining conditions: $V \approx 30$ m min^{-1}; $S_m = 250$ mm min^{-1}; t = 5 mm; B = 3 mm.

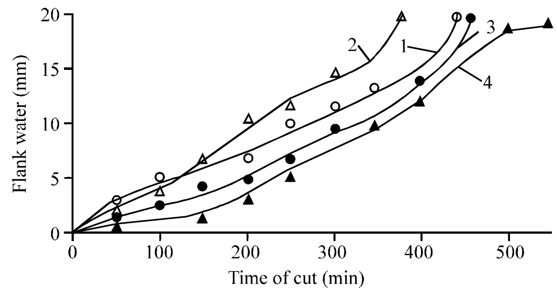

Fig. 5: Frank wear time of cut dependency diagrams; 1: basic end mill with coating; 2: prototype end mill with strengthened tooth made of carbide 2 without coating; 3: prototype end mill with strengthened tooth made of carbide 1 without coating; 4: prototype end mill with strengthened tooth made of carbide 1 with (Ti-Al-Si) N coating

The tool life of prototype end mill without coating made of carbide 2 was 372 min which is practically equal to basic end mill tool life of 435 min. The tool life of prototype end mill made of carbide 1 with (Ti-Al-Si) N and without coating exceeded significantly the basic end mill tool life and showed the result of 451 and 541 min. Moreover, the end mill with (Ti-Al-Si) N coating was suspended from test without teeth failure and technically could continue to perform machining that can be seen in the wear graphic chart, showed in Fig. 5. End mill test suspension was due to degradation of material's surface roughness.

The failure mode of end mills with strengthened tooth is equal to failure mode of end mills with normal tooth. Usually, failure occurs on cylindrical teeth near corner radius from cylindrical teeth to end face teeth. As a rule end mills with coating have less teeth failure than the end mills without it.

DISCUSSION

As it was mentioned before the teeth strengthening and two core cutting flute enabled to significantly increase end mills tool life in BT20 titanium alloy machining. Apparently, it is connected to heat removal improvement due to increase in thickness of tooth wedge and consequently its mass increase which is beneficial to intensification of heat removal from cutting area.

The calculations showed that prototype end mills manufacturing cost was ~60-70% of selling price of end mills which were made by leading tool manufacturing companies and are sold on Russian market.

Since, the end mills with mentioned earlier characteristics have fine-grained texture, it appearsil, that the usage of these end mills on more intensive modes is inappropriate. However, this supposition requires further research.

CONCLUSION

By the received results of research it is possible to draw a conclusion that:

- The design of end mill with strengthened tooth is preferable for titanium alloys machining
- The tool life of prototype end mills with strengthened tooth is higher than the tool life of end mills with normal tooth and basic end mill
- Carbide grade 1 ensures higher durability in semifinishing of titanium alloys
- The developed end mills with this design, geometry, strengthened tooth and (Ti-Al-Si) N wear-resistant coating can be used in titanium alloys machining

ACKNOWLEDGEMENTS

This research was financially supported by the Government of the Russian Federation (Ministry of Education and Science) based on the RF Government Decree No. 218 dated 09.04.2010 (topic code 2013-218-04-4777) and by the Ministry of Education and Science.

REFERENCES

Altintas, Y. and S. Engin, 2001. Generalized modeling of mechanics and dynamics of milling cutters. CIRP. Ann. Manuf. Technol., 50: 25-30.

Chung-Chen, T. and H. Hong, 2002. Comparison of the tool life of tungsten carbides coated by multi-layer TiCN and TiAlCN for end mills using the Taguchi method. J. Mater. Process. Technol., 123: 1-4.

Devillez, A., F. Schneider, S. Dominiak, D. Dudzinski and D. Larrouquere, 2007. Cutting forces and wear in dry machining of Inconel 718 with coated carbide tools. Wear, 262: 931-942.

Engin, S. and Y. Altintas, 2001. Mechanics and dynamics of general milling cutters: Part I: Helical end mills. Int. J. Mach. Tools Manuf., 41: 2195-2212.

Evdokimov, D.V., D.G. Fedorov and D.L. Skuratov, 2014. Thermal stress research of processing and formation of residual stress when end milling of a workpiece. World Applied Sci. J., 31: 51-55.

Ginting, A. and M. Nouari, 2006. Experimental and numerical studies on the performance of alloyed carbide tool in dry milling of aerospace material. Int. J. Mach. Tools Manuf., 46: 758-768.

Ginting, A. and M. Nouari, 2007. Optimal cutting conditions when dry end milling the aeroengine material Ti-6242S. J. Mater. Process. Technol., 184: 319-324.

Khaimovich, A.I. and A.V. Balaykin, 2014. Analysis of titanium alloys plastic properties under severe deformation conditions in machining. ARPN J. Eng. Applied Sci., 9: 1828-1833.

Kivanc, E.B. and E. Budak, 2004. Structural modeling of end mills for form error and stability analysis. Int. J. Mach. Tools Manuf., 44: 1151-1161.

Perez, J., S. Hoyas, D.L. Skuratov, Y.L. Ratis, I.A. Selezneva, P.F. de Cordoba and J.F. Urchueguia, 2008. Heat transfer analysis of intermittent grinding processes. Int. J. Heat Mass Transfer, 51: 4132-4138.

Skuratov, D.L., Y.L. Ratis, I.A. Selezneva, J. Perez, P.F. de Cordoba and J.F. Urchueguia, 2007. Mathematical modelling and analytical solution for workpiece temperature in grinding. Applied Math. Modell., 31: 1039-1047.

Subramanian, M., M. Sakthivel, K. Sooryaprakash and R. Sudhakaran, 2013. Optimization of end mill tool geometry parameters for Al7075-T6 machining operations based on vibration amplitude by response surface methodology. Measurement, 46: 4005-4022.

Turner, S., D. Merdol, Y. Altintas and K. Ridgway, 2007. Modelling of the stability of variable helix end mills. Int. J. Mach. Tools Manuf., 47: 1410-1416.

Vagnorius, Z., M. Rausand and K. Sorby, 2010. Determining optimal replacement time for metal cutting tools. Eur. J. Oper. Res., 206: 407-416.

Zareena, A.R. and S.C. Veldhuis, 2012. Tool wear mechanisms and tool life enhancement in ultra-precision machining of titanium. J. Mater. Process. Technol., 212: 560-570.