Effects of tool coatings on cutting performance of pure iron material under finish turning

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Abstract: Under the same process parameters, there are five kinds of coated tools used for finish cutting pure iron material. The effects of tool coating performance on tool life and wear models, cutting force and surface roughness of workpiece were studied. The results show that the wear resistance of the tool coatings plays an important role on the great difference performance of the tool life and the cutting force in finish turning pure iron. The best tool life and minimum cutting force was induced by the tungsten carbide tool KC5010 coated with TiAlN material. The five kinds of coated tools have the same wear models, such as nose wear and major and minor notch wear on flank surface. At the lower cutting speed, the surface roughness of the machined surface was increased firstly and then decreased. At higher cutting speed, the surface roughnesses machined by the KC5010 and KCU25 tools with TiAlN coating was the lowest. Compared with the other four cutting tools, the KC5010 coated tool was more suitable used for the finish turning pure iron components.

Introduction

The effect of tool coating is an important factor on the tool life, and it further affects the cutting performance of materials. Especially, in the difficult processing of materials, the rapid tool wear will cause the reduction of manufacturing precision and the deterioration of the surface quality [1-3]. Therefore, choosing the suitable tool coating to improve the cutting performance of the material is the key factor to the efficiency and quality of the products. The factors of cutting forces, cutting heat and tool wear are usually used to evaluate cutting performance of materials under different technological conditions [4-5]. Gu et al. [6] reports the tool durability and wear mechanism during cutting 4140 steel by tools with uncoated and coated TiN, TiAlN and ZrN. The results showed that TiAlN and TiN coatings were higher hardness and lower adhesion properties, and they had better tool durability than that of uncoating and ZrN coating tool. Chinchanikar et al. [7] studied the difference cutting performance of 4340 high strength steel with CVD multi-coated and PVD single-layer coated tool. The results showed that the cutting force and surface roughness were smallest with the PVD single coating tool, but the CVD multi-coating tool had a higher tool life, and the material hardness had a great influence on the cutting speed of the tool. Obviously, theselected suitable tool coatings for specific materials would improve the cutting performance, and the machining quality and processing efficiency. In order to select the suitable coating tool during the finishing pure iron material, the five different kinds of coating tools were used in this paper. The cutting performance of pure iron material, such as the cutting force, surface roughness and tool durability, are compared and analyzed under the conditions of minimal quality lubrication (MQL). This paper will provide technical support for high-precision machining of pure iron workpiece.

Experimental procedures

Workpiece material. The commercial pure iron material was used in the this work. The composition of pure iron material is listed in Table 1. The original material was forged at high temperature of 1000-1250 °C to form a bar with 120-mm-diameter and 250-mm-length, then cooled down to the room temperature in air.

Table 1 Composition of pure iron material (in wt%)

Elements	Fe	C	Si	Mn	Ni	S	Cr	Cu	P	Al
Content	>99.8	0.013	0.028	0.029	0.035	0.02	0.02	0.034	0.0072	0.0023

Cutting Parameters. The cutting parameters were as follows: depth of cut ap=0.15mm, feed rate f=0.1mm/r, and cutting speed v= 100 and 300m/min. The machining experiments were carried out under MQL cooling/lubrication condition. The MQL system was OoW129AC-2 (made in China), which had two nozzles. MQL media was synthetic ester and the flow rate was 80ml/h per nozzle. MQL fluid was delivered to the cutting area through two nozzles at a pressure of 0.6MPa and the distance from nozzle to cutting nose was 20mm.

All the tests were investgated on MJ520 CNC lathe (made in China). The five different cemented carbides (Kennametal DCGT11T302 HP) inserts with nose radius of 0.2mm and without chip breaker, such as KC5010 and KCU25 tools coated with TiAlN, KC5410 coated with TiB2, K313 uncoated tools and K313 coated with soft coating WS_2, as shown in Talbel.2.

Table 2 Cutting tool types and coated materials for finish machining pure iron material

types	KC5010	KCU25	KC5410	K313	K313 with soft coating
coatings	TiAlN	TiAlN	TiB_2	uncoating	WS_2

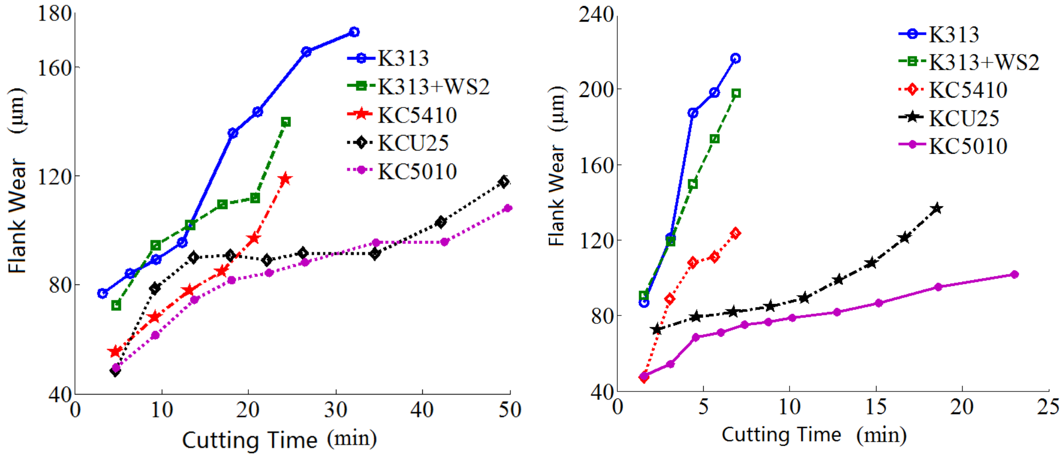
Measuring instruments. The cutting force was measured by Kistler9257B three component piezoelectric dynamometer. Surface roughness of machined samples were measured with handheld surface roughness meter TR210. The flank tool wear was measured by Leica 2500 optical microscope.

Results and Discussion

Tool life. The flank wear curves of the five different kinds of coating tools at the cutting speeds of 100m/min and 300m/min are shown in Fig.1. From Fig.1, it can be concluded that the slope of the K313 uncoated tool wear curveis the maximum and the tool life is the smallest. The WS_2 soft coating material can reduce the friction coefficient between the tool and chips, which can reduce tool wear and improving cutting performance [8]. As shown in the Fig.1, compared to uncoated K313, the tool life of K313 coated with WS_2 is slightly improved. With the process of cutting, the WS_2 soft coating material would quickly wear out or fall off, and then would lose the lubrication effect. Especially in high cutting speed, the wear degree of the two tools is the same. Obviously, the soft coating could not effectively improve the tool life during the finish turning pure iron material.

The hardness of KC5410 tool with TiB_2 coating material is higher than that of the TiN and TiAlN coating materials. It has good cutting performance in the processing of aluminum alloys, magnesium alloys, etc. In finish turning pure iron material, the tool life of KC5410 is slightly improved than that of K313 and K313 coated with WS_2 soft coating material. However, there are serious V-shaped notch wears at the major and minor cutting edges, which reduce the tool life, as shown in Fig.2.

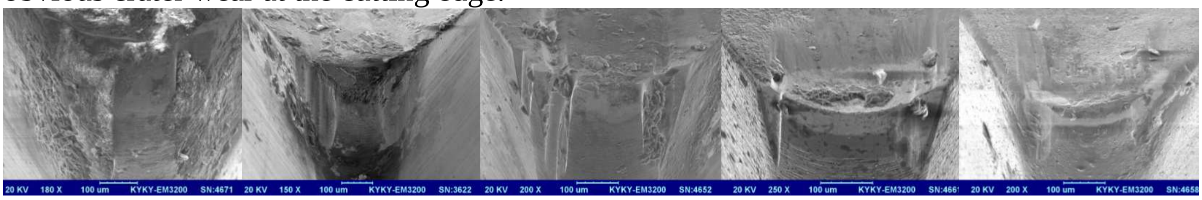
The TiAlN coating material on KC5010 and KCU25 tools has high hardness and low friction coefficient. As shown in Fig.1, compared with other tools, TiAlN coating material is beneficial to improve the tool life and KC5010 tool is more suitable for the finish process of pure iron material, especially at the high cutting speed of 300m/min.



(a) v=100m/min (b) v=300m/min

Fig.1 Evaluation of tool life with different cutting speeds

Tool wear models. The morphologies of the five different kinds of worn tools at the cutting speed of 300m/min are shown in Fig.2. From Fig.2, it can be seen that pure iron material are bonded on the surface of worn cutting tools. The surface of K313 uncoated tool, K313 coated with WS_2 soft coating material and KC5410 bonded much more pure iron material, as shown in Fig.2 (a), (b) and (c). The bonded material on rake face forms built-up edge and built-up layer, which could avoide the direct contact between the rake face and the cutting chip and is beneficial to protect the rake face. There are obvious scratches on the major and minor cutting edge of the rake face, which form serious notch wears. Comparing with other cutting tools, the notch wear degree on the rake face of KC5410 tool is most serious. The rake face wear models of KC5010 and KCU25 with TiAlN coating material not only has notch wear, but also has obvious crater wear at the cutting edge.



(a) K313+WS_2 (b) K313 (c)KC5410 (d) KC5010 (e) KCU25

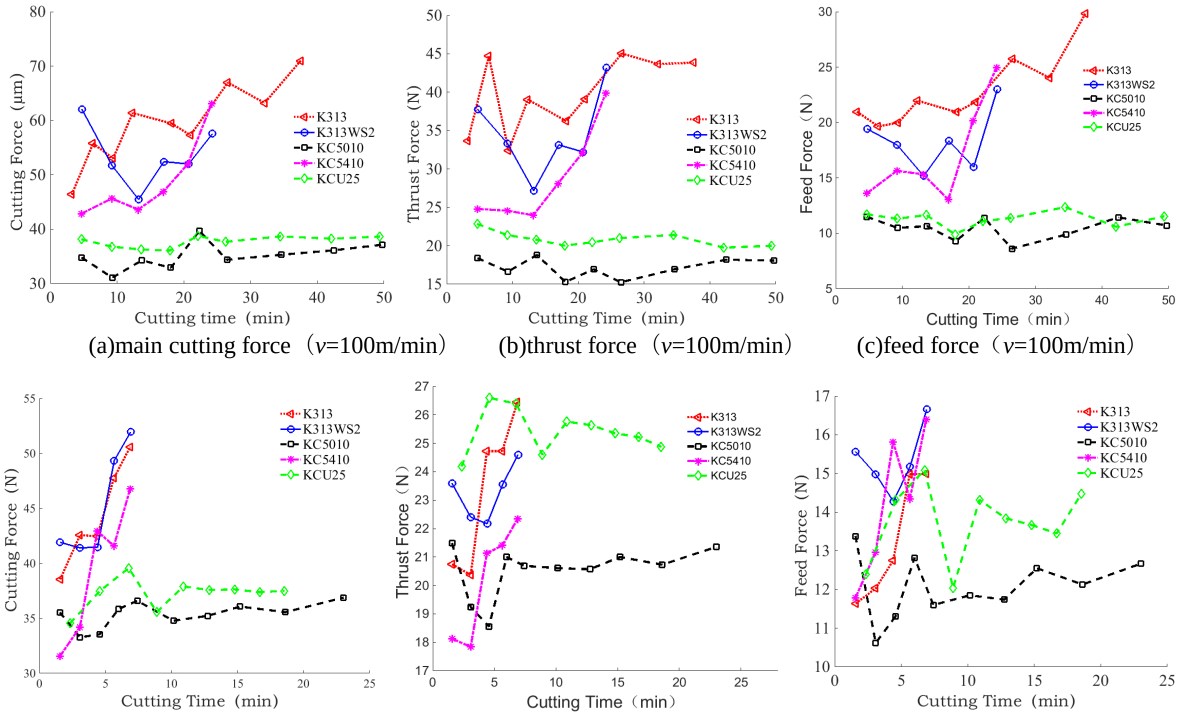
Fig.2 Morphology of tool wear for five different coated tool（v=300m/min）

As shown in Fig.2, there are two obvious long and narrow V-shaped notch wears on flank face observed on major and minor cutting edge. The uniform wear zone in middle of the two notch wears is the tip wear. Comparing with the notch wear of the five tools, it can be seen that the notch wear degree of K313, K313 coated with WS_2 and KC5410 is significantly larger than that of KC5010 and KCU25 tools.

Cutting force. The curves of cutting forces with cutting time at the cutting speed of 100m/min and 300m/min are shown in the Fig.3. From Fig.1 and Fig.3, it can be seen that the main cutting force, thrust force and feed force rapidly increase with the increasing of the flank wear for the K313 uncoated tool and KC5410 tool at the cutting speed of 100m/min. Especially for the KC5410 tool, the main cutting force rapidly increases from 46N to 63N when the flank wear increases from 80μm to 120μm. The degree of increasing the KC5410 tool is obviously greater than that of K313 uncoated tool, while the cutting force of K313 coated with WS2 show a tendency of decreasing first and then increasing. Comparing with the above three cutting tools, the flank wear of KC5010 and KCU25 coated with TiAlN coating is minimal during the finishing process. The three-direction cutting forces of these two kinds of cutting tools are smaller and basically unchanged. For example, when cutting with KC5010 tool, the main cutting force changes between 31N and 39.2N, the thrust force changes between 15.2N and 18.4N, and the feed force changes between 8.2N and 11.5N.

On the same way, at the cutting speed of 300m/min, the three direction cutting forces of the five kinds of different cutting tools have the same variation tendency at the cutting speed of 100m/min during the finishing turning pure iron.

According to the results of the cutting force and tool life during the finishing process of pure iron material with five different kinds of coated tools at the cutting speed of 100m/min and 300m/min, it can be concluded that the KC5010 coated with TiAlN material has smallest cutting force and longest tool life and it is more suitable for finish turning pure iron material.



(a)main cutting force（*v*=100m/min） (b)thrust force（*v*=100m/min） (c)feed force（*v*=100m/min）

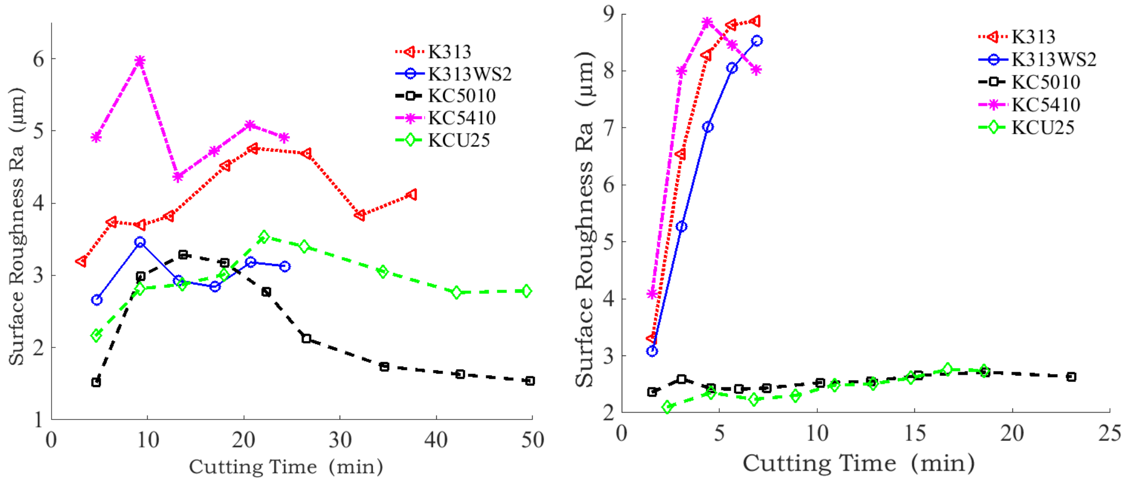
(d) main cutting force（*v*=300m/min） (e) thrust force（*v*=300m/min） (f) feed force（*v*=300m/min）

Fig.3 Evaluation curves of cutting forces with cutting time

Surface roughness. Curves of surface roughness with cutting time at the cutting speed of 100m/min and 300m/min are shown in Fig.4. As shown in Fig.4 (a), it can be seen that the surface roughness Ra during finish turning pure iron with five different kinds of tools at cutting speed of 100m/min increases firstly and then decreases. Compared with the other four cutting tools, the surface roughness is smallest during finish turning pure iron material with KC5010 coated tool. The surface roughness machined with KC5410 coated tool is largest, following with K313 uncoated and K313 coated with WS_2 tool.

As shown in Fig.1(b) and Fig.6(b), the surface roughness machined with K313, K313 coated WS_2 and KC5410 tools increases rapidly and the surface morphology deteriorates seriously due to the fast tool wear. The surface roughness machined with KC5010 and KCU25 tools is smallest and keeps stable. For example, the surface roughness Ra value machined with KC5010 changes between 2.3μm and 2.7μm.

According to the above experimental results, it can be seen that the tool surface coating material not only affects the tool life, but also has an important influence on surface roughness of the workpiece. The surface roughness is smallest during finish turning pure iron material with KC5010 tool at two cutting speeds. The KC5010 tool is more suitable in finish turning pure iron material.



(a) v=100m/min (b) v=300m/min

Fig.4 Evaluation curves of surface roughness with cutting time

Conclusions

(1) Under the same cutting parameters, the tool coating has an important impact on the tool life. Compared with the other four tools, the KC5010 tool coated with TiAlN has the best tool life.
(2) During finish turning pure iron material, the five kinds of different coated tools have the same wear morphology. The main wear models are tool nose wear and notch wear on main cutting edge and minor cutting edge.
(3) With the increasing of tool wear, the cutting force machined with K313, K313+WS_2 and KC5410 tools increased rapidly, while the cutting force of the cutting tool of KC5010 and KCU25 coated with TiAlN was smaller.
(4) The surface roughness machined by the five different kinds of coating tools increased firstly and then decreased. At the high cutting speed, the surface roughness of workpiece cutting by KC5010 and KCU25 tools in TiAlN coating was the smallest, but it increased rapidly with the increasing of the tool wear by the other three kinds of coating tools.
(5) At the processing of finish turning pure iron material, the KC5010 coating tool has the best tool life, minimum cutting force and surface roughness. It has the best cutting performance and is more suitable for finish turning pure iron material.

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