

Original Paper

Damage Propagation of Ceramic Cutting Tools

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Abstract

Ceramic tool and CBN tool have usually been used to machine many kinds of advanced materials with their superior properties such as heat-resistance, high hardness and strength and wear-resistance. In this paper, two kinds of commercially available ceramic tips of Alumina group and Silicon-nitride group are selected and their friction and fracture properties are investigated for the cuttings of cast iron FC25 and high hard steel alloy SKS93. The wear propagation phenomena of the cutting tool edges are microscopically observed and investigated in detail under both the normal (continuous) and the discontinuous cutting condition. Through this research, the relations between brittleness of the tool material and the feature of cutting force induced are made clear.

Key words : Cutting operation, Tool wear, Ceramic cutting tip, Al_2O_3 -TiC tip, Si_3N_4 tip, Cast iron, High hard steel alloy, Discontinuous cutting

1. Introduction

Many kinds of new materials and others with their special improved properties of heat-resistance and high hardness, have been employed to be the objects of machining. It is very difficult and is required high cost to machine these materials, so ceramic or CBN tool has recently been used in the machining of such materials. However, unfortunately, these tools have the properties of low ductility (toughness) in spite of their high heat-resistance and hardness. Those are the reasons why these tips are hesitated to be employed in cutting. Therefore the detail research about the fracture mechanism and wear propagation are eagerly desired to accelerate the applicative opportunities. The ceramic cutting tips on the market have been

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developed vigorously for the ductility these ten years, but generally speaking, it seems that the high reliable directions for the proper applications of these tips are not shown yet today.

In this paper, two kinds of commercially available ceramic material tools, that is, $\text{Al}_2\text{O}_3\text{-TiC}$ and Si_3N_4 tips are selected as experimental objects and their cutting performances are investigated. The measurement of tool edge wears and observation of the phenomena of wear propagations are performed under the normal and the discontinuous cutting operations. Moreover, the differences in wear propagation mechanism between two kinds of work materials of the brittle FC25 and ductile and hard SKS93 are made clear in detail.

2. Experimental Procedure

2.1 Cutting tools

According to the material consideration, two kinds of typical ceramic cutting tips on the market are selected for investigation. Table 1 shows some mechanical properties of these materials and typical purposes recommended by the tool manufacturing company. All these tips are manufactured by Kyocera Co., Ltd. typed SNGA120408. We use the tip holder typed PSBNR2020K-12 with rake angle $\alpha = -6^\circ$ and flank angle $\varepsilon = 6^\circ$. These tips are chamfered at the cutting edges with the width of $200\text{ }\mu\text{m}$ and the height of $93\text{ }\mu\text{m}$.

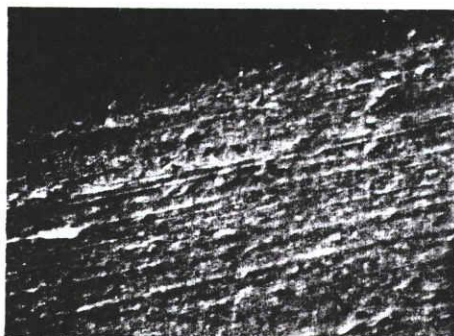
Table 1 Type of cutting tips employed and their typical properties.

Tip type	Material	Typical purposes recommended	Toughness	Hardness,HV
Alumina	$\text{Al}_2\text{O}_3\text{+TiC}$	High speed cutting for steel and cast iron Cutting for high hard materials	Low	2,100
Silicon Nitride	Si_3N_4	Heavy and high speed cutting for cast iron	High	1,600

Table 2 Roughness of virgin cutting edges.

	Alumina-type tip	Silicon Nitride-type tip
Roughness of cutting edge, μm	0.90	0.57

As shown in Table 1, Alumina-type tip is superior in hardness and wear-resistance, but Silicon Nitride tip is superior in thermal shock resistance and toughness. The initial micro chipping width measured are shown in Table 2 as the values of roughness along those tip edges. The appearances of tip edges chamfered are shown in Fig.1 (a), (b). The surface of Silicon Nitride tip cutting edge looks somewhat smoother.



(a) $\text{Al}_2\text{O}_3\text{+TiC}$ tip



(b) Si_3N_4 tip

Fig. 1 Appearances of virgin ceramic tip edges chamfered.

2.2 Work materials

Tool steel alloy SKS93 and cast iron FC25 are employed as work materials. The former is heat treated by the water-hardening process, that is, after keeping at 820 °C for five to six hours, it is thrown into cool water bath. As it is certain by the pre-inspection that the influence of hardening treatment using water bath can not be affected at the central part deeper than 10 mm from the surface as shown in Fig.2, all the cutting tests are performed in the sufficiently affected zone only. The chemical compositions are shown in Table 3 and some mechanical properties are compared with JIS standard values of the similar work materials in Table 4. The dimensions of work materials are listed in Table 5, and the feature of the work material for discontinuous cutting is also shown in Fig.3.

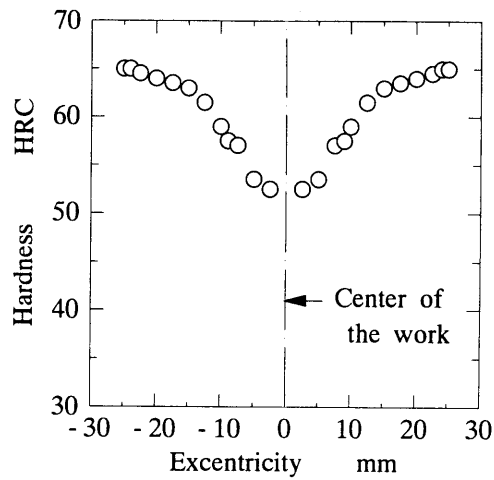


Fig.2 Example of hardness distribution along a diameter of work.

Table 3 Chemical composition of work materials in weight percentage (%).

	C	Si	Mn	P	S	Cr
Cast iron (FC25)	3.15-3.55	2.55-3.05	0.25-0.60	<0.20	0.08	—
Tool steel alloy (SKS93)	1.05	0.39	0.88	0.013	0.001	0.39

Table 4 Mechanical properties of work materials.

Work materials	Properties	JIS standard	Practical values
Cast iron (FC25)	Tensile strength MPa	215.6	245
	Hardness HRC	>10.8	16.0
	Yield strength MN/m ²	>2300	—
Tool steel alloy (SKS93)	Hardness HRC	>63 (Oil-hardening)	65 (Water-hardening)

Table 5 Dimensions of work materials.

	FC25	SKS93
Length, mm	300	370
Diameter, mm	100	57

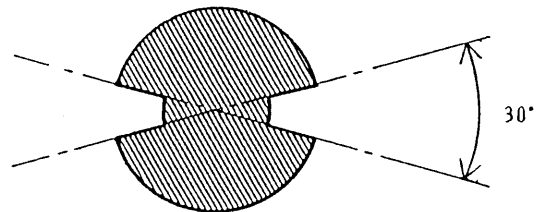


Fig.3 Sectional feature of work for discontinuous cutting.

Table 6 Cutting conditions for Al₂O₃-TiC tool.

Work material	Experimental condition			Typical recommended condition .		
	FC25		SKS93	FC20		SKD11
Cutting type	Continuous	Discontinuous	Continuous	Continuous	Discontinuous	Continuous
Cutting depth t mm	2	1, 2	0.2	2	—	1
Feed, f mm/rev	0.41	0.1, 0.41	0.2	0.8	—	0.15
Cutting speed, V m/min	100, 200 300, 350	100, 200 300	30, 50, 75, 100	200 ~ 500	150 ~ 300	≤ 150

The work materials are machined in order to keep their surface appearance same by pre-cutting under the same condition with the experiment.

2.3 Experimental conditions

The experimental conditions employed are shown in Table 6 and 7. Those cutting conditions are basically decided so as to satisfy the recommended values by the tool maker. Moreover some additional conditions are plused to make clear the influences to the tool wear. To keep the cutting speed constant in each set value, the number of revolution of the main shaft of the lathe used is controlled.

Table 7 Cutting conditions for Si₃N₄ tool.

	Experimental condition			Typical recommended condition		
Work material	FC25		SKS93	Cast iron		None
Cutting type	Continuous	Discontinuous	Continuous	Continuous	Discontinuous	——
Cutting depth t mm	2	2	0.2	——	——	——
Feed, f mm/rev	0.41	0.41	0.2	——	——	——
Cutting speed, V m/min	100, 200 300	100, 200 300	30, 50, 75, 100	200 ~ 700	200 ~ 500	——

2.4 Measurement of tool edge wears

From many variables caused on the cutting tip in cutting operation, we concentrate on the flank wear and the crater wear. Both the wears are measured by using optical-microscope and surface roughness measuring equipment with stylus tracer. Additionally in order to clear the wear propagation mechanism, the configurations of the wear and fracture at the cutting edge are observed by scanning micro scope. Therefore, to know the wear progress clearly, the measurement is done before experiment and in the initial wear progressive stage, stable stage and seriously progressive stage.

3. Experimental results

3.1 Continuous cutting for FC25.

Figures 4 shows the wear propagating curves of the Al₂O₃-TiC tip for the cutting speeds of 100, 200, 300 and 350 m/min. The flank wear seems to progress steadily for all the speeds without any sudden fracture. The wear band becomes wider in higher speed but the progressive rate seems to be very small especially in the lowest cutting speed of 100 m/min, so a very long tool life can be expected in lower

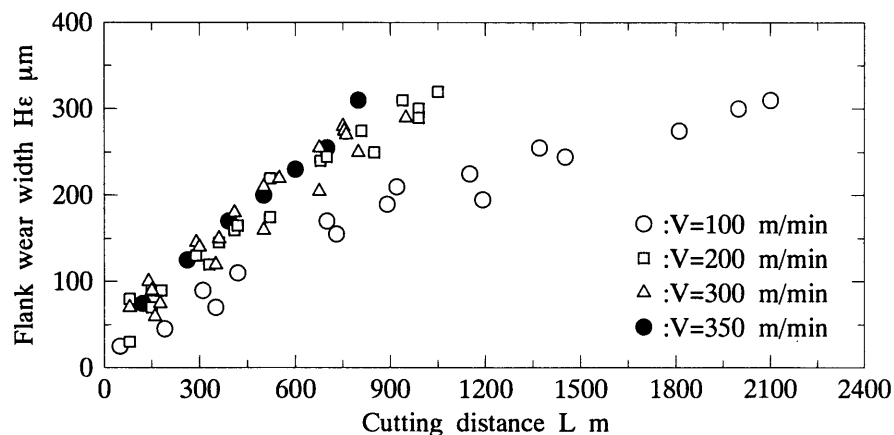
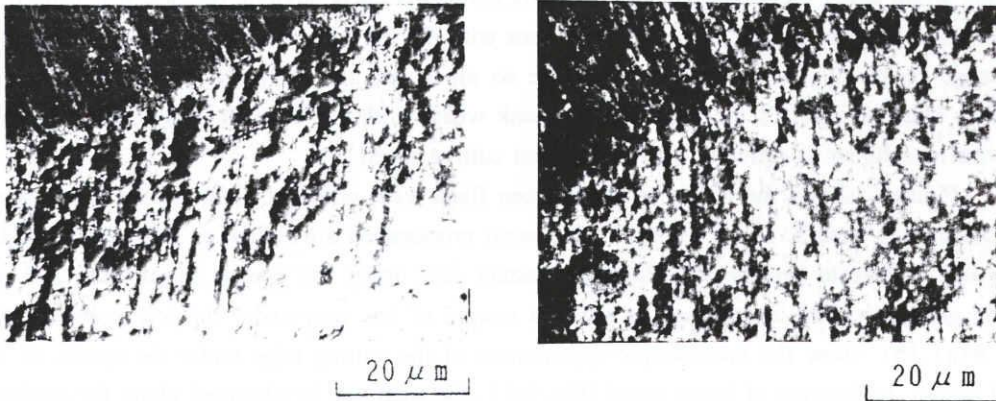


Fig.4 Relationship between flank wear and cutting distance for Al₂O₃-TiC tip.



(a) Cutting time: 1 min 51 sec

(b) Cutting time: 9 min 10 sec

Fig.5 Appearances of cutting edge of $\text{Al}_2\text{O}_3\text{-TiC}$ tip in continuous cutting of FC25 under low speed of $V=100$ m/min.

cutting speed, it is opposite to the recommendation for the case of the higher cutting speed by the tool manufacturer for this ceramic material tip. By observation of the tip edge configurations shown in Fig.5 (a), (b) and Fig.6, we can explain the above mentioned phenomena. In the case of lower speed cutting (Fig.5), at the initial stage, the wear band is very narrow yet, but the certain frictional marks appears clearly on the both faces of flank and rake, therefore the surface has already become rough. On the other hand, at the middle stable stage, the friction marks become thin. This means that the wear occurs un-uniformly on the faces. In the case of higher speed (Fig.6), the flank surface has been already worn and seems to be smooth even after the short time cutting. The wear occurs all over

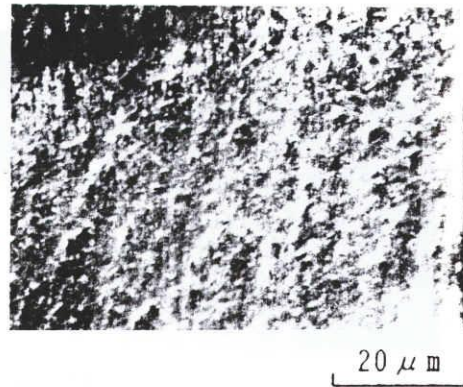
Cutting time: 33 sec, $H\epsilon = 92 \mu\text{m}$

Fig.6 Appearance of cutting edge of $\text{Al}_2\text{O}_3\text{-TiC}$ tip under high speed of $V=300$ m/min.

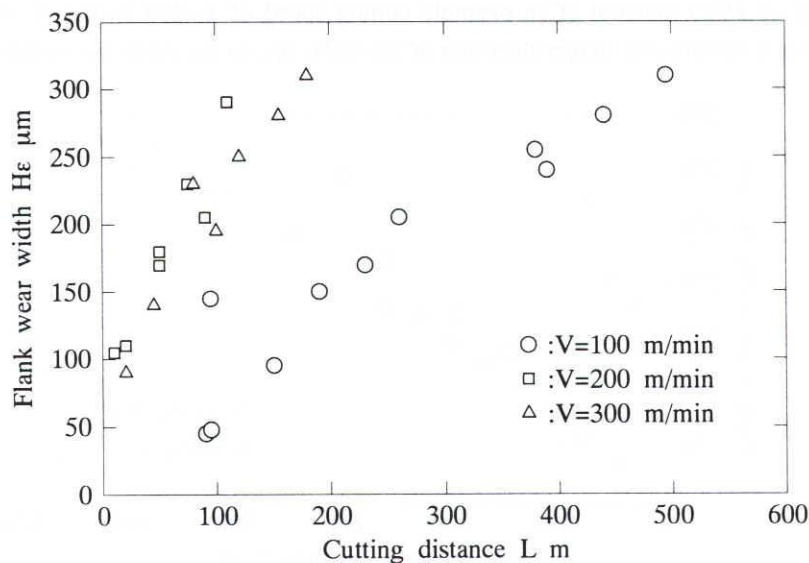
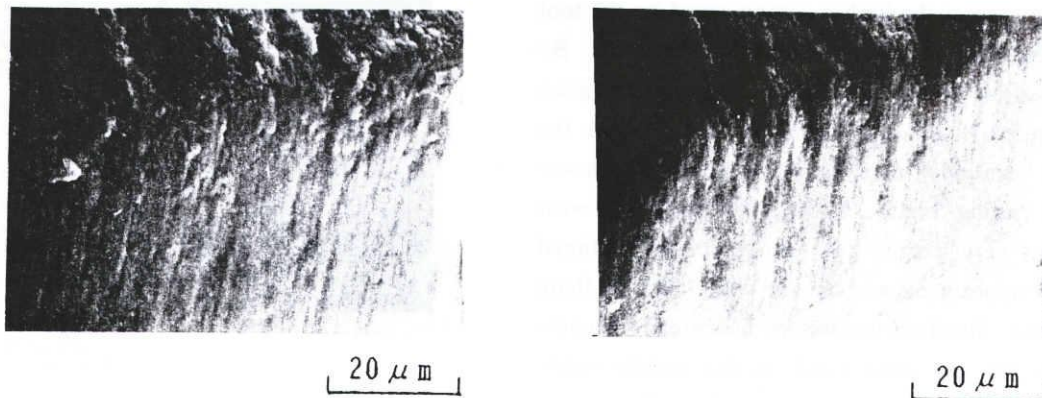


Fig.7 Relationship between flank wear and cutting distance for Si_3N_4 tip.

the cutting width along the tool edge, and the flank surface is fairly smooth, because it is caused by friction and heat. However, the cutting resistance decreases with the increase of cutting speed, so the retirement of cutting edge by the tool wear does not increase so much and the sharpness of the edge is also kept in satisfactory value in spite of the increment of flank wear width. As a result it is concluded that the wear progressive mechanism is different for the different cutting speed.

Figure 7 shows the relationships between flank wear width of Si_3N_4 tip and the cutting distance for various cutting speeds. The features of flank wear propagation are similar to those of the $\text{Al}_2\text{O}_3\text{-TiC}$ tip, that is, they propagate rapidly with almost constant rate under the speeds faster than 200 m/min and propagate gradually after initial wear of about a couple of ten μm under the low speed of 100 m/min. Figures 8(a), (b) show the microscopic appearances of the cutting edge under the speeds of 100 m/min and 200 m/min. In the case of lower speed (Fig. (a)), the wear can be observed along the cutting edge and the surface becomes somewhat smooth. But for the higher cutting speed (Fig. (b)), even after a very short cutting time of 10 sec, the cutting edge is worn out and the neighboring surface of the cutting edge becomes round and very smooth. This wear may occur under the mutual operation of mechanical and thermal effects.



Time:10sec, $H\epsilon = 93 \mu\text{m}$,
(a) Edge wear under $V=100\text{m/min}$.

Time:141sec, $H\epsilon = 168 \mu\text{m}$,
(b) Edge wear under $V=200 \text{ m/min}$

Fig.8 Appearance of cutting edge of Si_3N_4 tip for continuous cutting of FC25.

The flank wear propagations of both the Al_2O_3 and the Si_3N_4 tips are compared in Fig.9 for the continuous cutting of FC25 material at an example cutting speed of $V=200 \text{ m/min}$. It shows that the tool life of the Al_2O_3 tip is remarkably longer than that of the Si_3N_4 tip, so the Al_2O_3 tip is definitely superior for

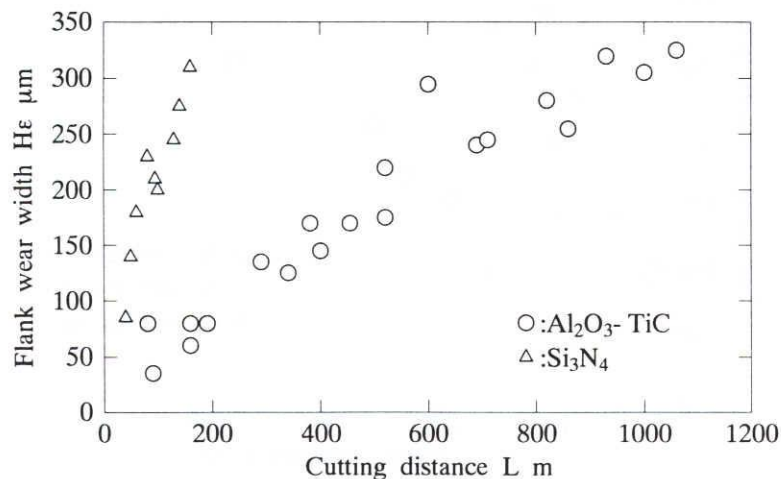


Fig.9 Comparison of wear propagations for $\text{Al}_2\text{O}_3\text{-TiC}$ and Si_3N_4 tips.

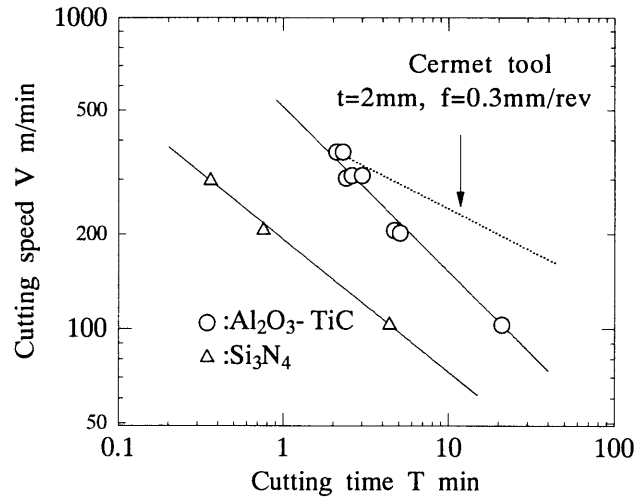


Fig.10 Tool life diagram (V-T diagram) for Al₂O₃-TiC and Si₃N₄ tips.

the continuous cutting of FC25 material under the operative conditions employed. Using these experimental results, we can draw the tool life diagram as shown in Fig.10 and can easily derive the tool life criteria as follows.

The equation from which we can derive the life time of the cutting tool can be generally given by the following equation (so called "tool life equation").

$$V T^n = C \quad (1)$$

In this equation, variable V is cutting speed (m/min), T is tool life (min) and C is constant which depends upon the combination of tool and work material and the cutting condition. The smaller is value n obtained from this equation, the longer is the tool life under the same value of C. As shown in Fig.10, every experimental result can be fitted by one line, therefore, each relationship can be expressed by the following equations.

$$V T^{0.5} = 457 \quad : \text{Al}_2\text{O}_3\text{-TiC tip} \quad (2)$$

$$V T^{0.45} = 197 \quad : \text{Si}_3\text{N}_4 \text{ tip} \quad (3)$$

Both values of power n are comparable, but that of Al₂O₃-TiC tip is somewhat bigger, so it can be concluded that the drop of cutting performance depending on the increase of cutting speed is smaller. Moreover, though the value of power n in eq. (1) for the Si₃N₄ tip, that is, the gradient of the line for Si₃N₄ tip is smaller, it may be impossible to realize the longer tool life beyond that of the Al₂O₃-TiC tip under the generally used cutting speed, because the Si₃N₄ tip has extremely short life under the same condition. The dotted line for the cermet tip shown in Fig.10 which is suggested by the tool manufacturing company is shown by the following equation.

$$V T^{0.31} = 459 \quad : \text{Cermet tip} \quad (4)$$

This equation reveals a very longer tool life under normal cutting speed, but under the higher speed the tool lives of both the ceramic tips may be longer by taking their thermo-resistances into consideration.

As a reference, an example of crater wear propagation is shown in Fig.11 under the cutting speed of 200 m/min. The depth and dimensions of the crater wear of the Al₂O₃-TiC tip is considerably smaller than that of the Si₃N₄ tip, as a result, Al₂O₃-TiC tip can be used for six times longer than the cutting distance of the Si₃N₄ tip. On observing the crater wear at any period in various cutting stages, the propagating process can be summarized as follows. First, the rake surface is rubbed by the chip ends and the shallow wear is created at the region of about 300 μm away from and parallel to the cutting edge. With the continuation of cutting, the wear becomes deeper and deeper, so irregular and very deep wear

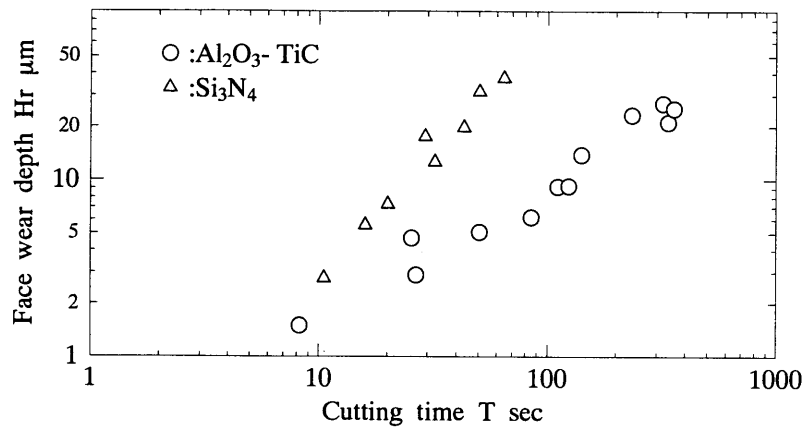


Fig.11 Comparison of crater wear depths of Al₂O₃-TiC and Si₃N₄ tips under V=200 m/min.

appears at the boundaries of the rake wear region by the unexpected sudden external force. Under the higher cutting speed, the crater wear with typical feature can be appeared.

3.2 Dis-continuous cutting for FC25.

Figure 12 shows the flank wear propagations of Si₃N₄ tips in discontinuous cutting of the FC25 work shown in Fig.3. The data for V=100 m/min has large scattering and this scattering is induced by the reason why every work used in each experiment has the different diameter, so the number of strike is also different in each work even under the same cutting speed. The higher the cutting speed is, the quicker the wear propagation is. As shown in continuous cutting, it propagates very slowly under the low speed V=100 m/min. The cutting edge is in very unstable condition, so that the tool wears not only by the gradual propagation but also by breakage, cracking and chipping those are created at the same time at the cutting edge. In this research the results for the suddenly encountered large scale breakages are not employed as the investigating objects, that is, only the gradually growing wears are investigated.

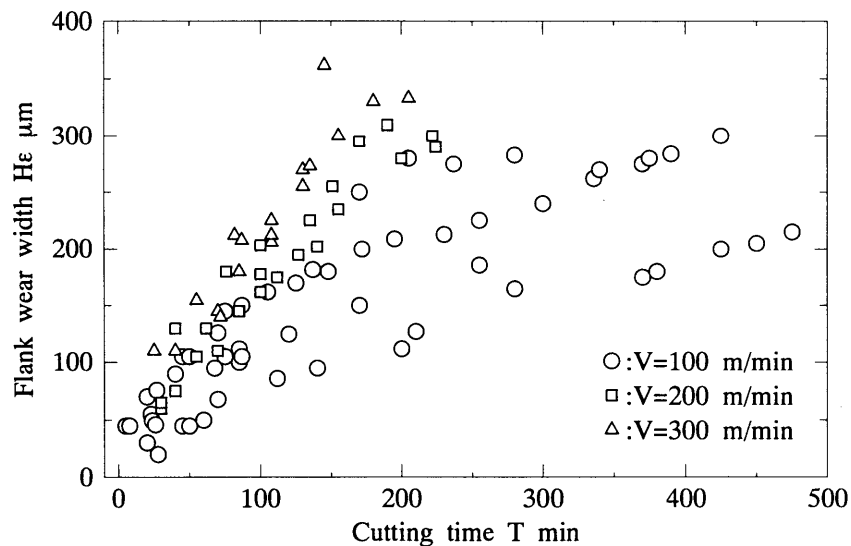
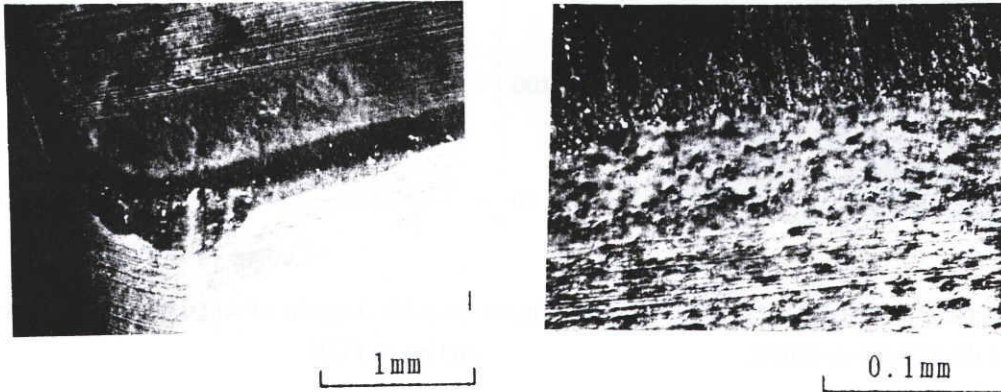


Fig.12 Flank wear propagation of Si₃N₄ tip for the discontinuous cutting of FC25.

The appearances of the worn tool edge of the Si₃N₄ tip are shown in Fig.13 (a), (b) and Fig.14 (a), (b) at the different cutting stages in discontinuous cutting of FC25 under low and high cutting speed of V=100 and 300 m/min. From Fig.13, it can be recognized that a very wide flank wear at the zone of the tip nose and small scale chippings at many points along the cutting edge are occurred after about one or

two minutes of cutting under $V=100$ m/min. Moreover irregular brakedges suddenly occur at the neighboring region of cutting zone, but the periods when such brakedges may occur can not be defined clearly. In the case of higher speed of $V=300$ m/min (Fig.14), large and deep cracks can be propagated near the cutting zone. The width of flank wear, however, uniformly appears over the cutting region.

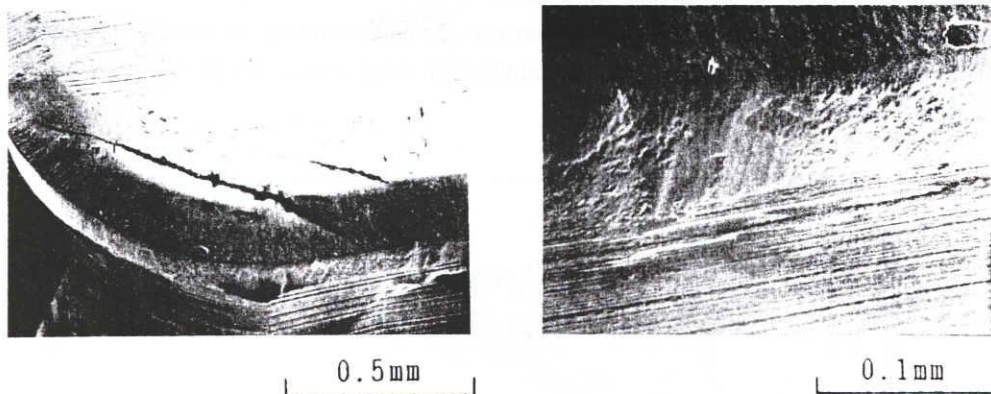


(a) Whole view of flank wear

(b) Worn region of flank

(Cutting time: $T=120$ sec, Flank wear width $H\epsilon = 155 \mu\text{m}$)

Fig.13 Appearances of flank wears of Si_3N_4 tip for discontinuous cutting of FC25 under $V=100$ m/min.



(a) Appearance of cracks induced on rake face

(b) Appearance of flank wear

(Cutting time: $T=10$ sec, Flank wear width $H\epsilon = 97 \mu\text{m}$)

Fig.14 Appearances of flank wears of Si_3N_4 tip for discontinuous cutting of FC25 under $V=300$ m/min.

It is advised that $\text{Al}_2\text{O}_3\text{-TiC}$ type tip is not suitable for the discontinuous cutting. The cutting with this material tip actually undergoes a fatal brakedge shown in Fig.15 within a very short time under the same cutting conditions those are applied for the Si_3N_4 tip. However, if the cutting condition (cutting depth and feed rate) changes to the slighter one, we can do the discontinuous cutting for a satisfactorily long time even by using the $\text{Al}_2\text{O}_3\text{-TiC}$ type tip. That is, as shown in Fig.16, the tool life elongates to about 100 sec. under the condition of $V=100$ m/min, $t=1$ mm and $f=0.1$ mm/rev. The brakedge, nevertheless, always happens and the period equals to the life limit. The dotted line shows the life limit line and gives upper limit of expecting the fatal brakedge.

All the cutting tests are performed by maintaining the cutting speed approximately constant within narrow changing smaller than 5 % through out each experiment and the revolutionary speed of the work changes depending on the work diameter. However, the number of strike of tool/work contact per unit time becomes bigger, and this reason is one of the causes of wide dispersion of the experimental

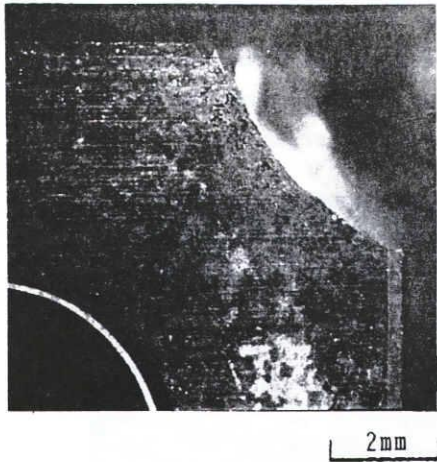


Fig.15 Typical braked edge of $\text{Al}_2\text{O}_3\text{-TiC}$ tip in discontinuous cutting.

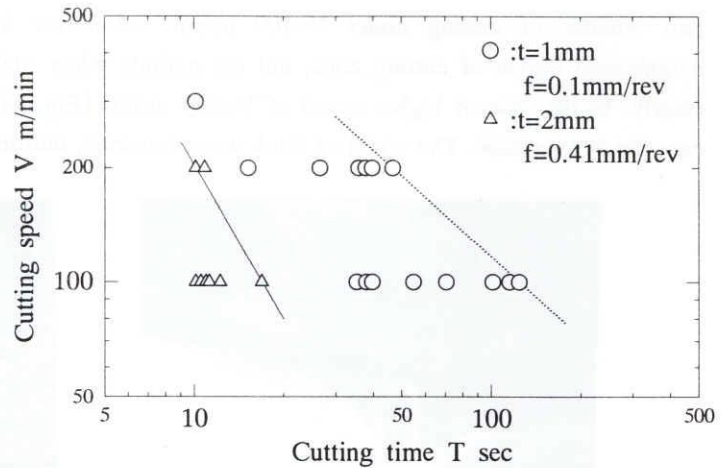


Fig.16 Tool life diagram of $\text{Al}_2\text{O}_3\text{-TiC}$ tip for discontinuous cutting of FC25.

values. Figure 17 shows the re-arranged results of flank wear propagations by the number of strikes expected from the work, corresponding to cutting speed V . The tendency of increment of the wear width is similar in each case of cutting speed, but the rate of increment is stronger depending on the increment of the cutting speed. The flank wear is very unstable in the early stage of cutting, that is, in the period of the small number of strikes, so the width of induced flank wear is widely different for each experiment especially under low speed, but the dispersion converts gradually with the increase of the number of strikes. Then finally at the period of tool life, the number of total strikes which the tool accepts so far is approximately equal.

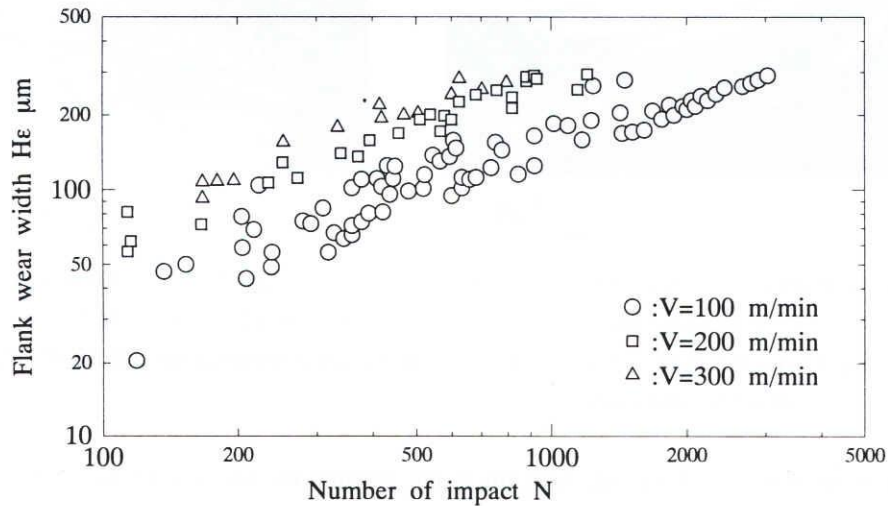


Fig.17 Relationship between flank wear width and the number of strikes for discontinuous cutting of FC25.

To summarize the experimental results for FC25, the tool life concerning to cutting distance L are compared for continuous cutting and discontinuous cutting in Fig.18 as the tool life diagram. In this figure the axis of abscissa is exceptionally noted by cutting distance L m opposite to the commonly employed values of cutting time T sec, because the cutting time can not indicate the accurate cutting distance in the discontinuous cutting. The equations for these lines are given as follows.

$$V T^{0.84} = 16900 : \text{Continuous cutting} \quad (5)$$

$$V T^{0.84} = 19700 : \text{Discontinuous cutting} \quad (6)$$

The tool lives for discontinuous cutting is always longer than those of continuous ones, but the difference is small under the high cutting speed. The main reason of such a strange result is that, as mentioned above, only the experimental values are employed, which are obtained in the case that the flank wear propagates gradually without expecting large scale brakedges in the period of early stage of short time cutting. However, these values contain the effects of dynamic periodical shocks by strikes of the contact between tool and work, so it can be stressed that the property of the Si_3N_4 tip material, that is, toughness has been developed very much.

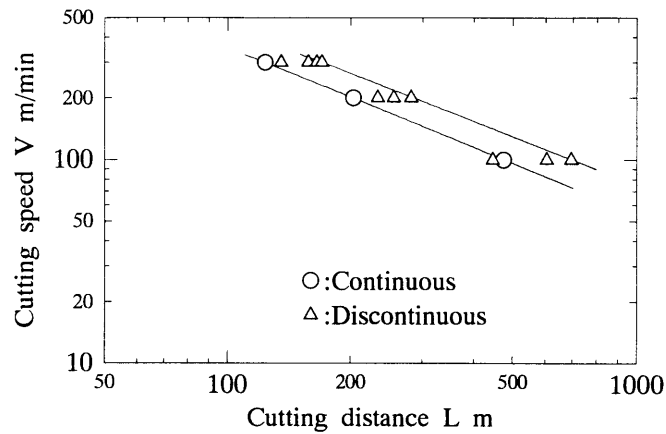


Fig.18 Tool life diagram concerning to cutting distance.

3.3 Continuous cutting for highly hardened material SKS93.

Figure 19 shows the development of the flank wear width of $\text{Al}_2\text{O}_3\text{-TiC}$ tip concerning to cutting time T min for the hardened tool steel alloy of SKS93. In the practical cutting, catastrophic brakedge or

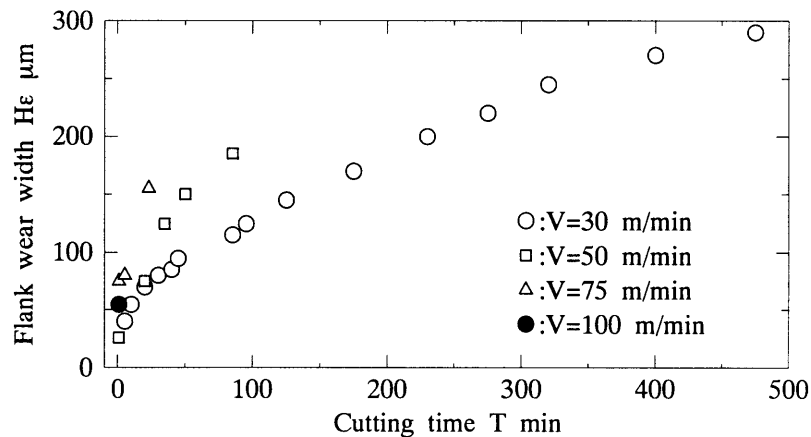


Fig.19 Propagation of flank wear against cutting time for cutting of SKS93 by $\text{Al}_2\text{O}_3\text{-TiC}$ tip.

very wide flaking occasionally happens at the cutting edge and instantaneously becomes unable to cut under the condition of the cutting speed higher than $V=50$ m/min. Therefore, the datum for the wider propagating flank wears can not be obtained for $V \geq 50$ m/min and the cutting with the long tool life can be realized in the case of expecting typical wear propagation only at the very low cutting speed of $V=30$ m/min.

Figure 20 shows the tool life diagram of the $\text{Al}_2\text{O}_3\text{-TiC}$ tip. This diagram contains all the values of tool life, whatever reasons lead the tips to their tool lives, that is, considering the gradually propagating wear and also the brakedge. As a reference, the datum for the cutting of SKD11 (HRC60) by using the same material tool tip suggested by the tool manufacturing company are shown in this figure. As it is impossible to define the period when the big scaled fatal brakedge or flaking occurs beyond the cutting speed of $V=50$ m/min, the dispersion width of the experimental results obtained depends on the period. From these experiment it may be predicted that such a fatal brakedge will occur by the period of the cutting time of 550 sec or so under the cutting speed of $V=100$ m/min and also by the period of the longer cutting time of about 30 or 95 min under the lower speed of $V=50$ or 75 m/min. Many examples with fatal

brakedges can be observed in this experiment under the somewhat higher cutting speed of $V=50$ m/min. The obtained results can be concluded to be reasonable, because even if the upper limit time is considered to be the tool life, those values are beyond the datum specified by the tool manufacturing company. The equations of tool lives can be derived as follows.

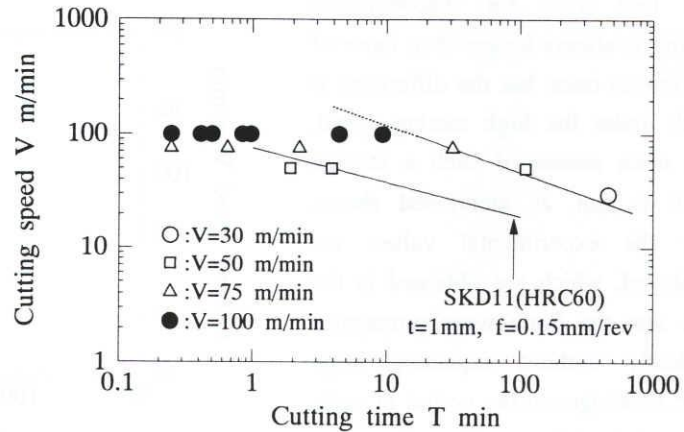
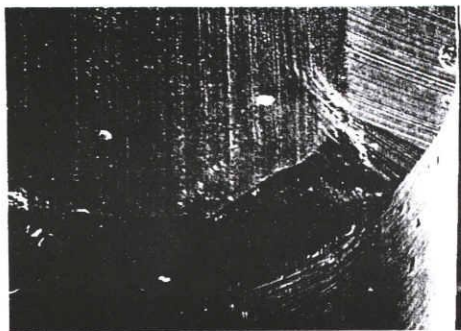


Fig.20 Tool life diagram for $\text{Al}_2\text{O}_3\text{-TiC}$ tip in cutting of SKS93.

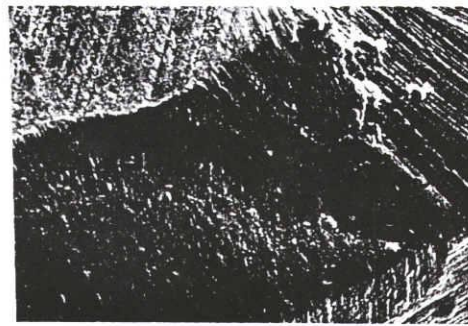
$$V T^{0.35} = 86 \quad : \text{Suggested datum by tool manufacturing company} \quad (7)$$

$$V T^{0.4} = 258 \quad : \text{Experimental results} \quad (8)$$

Figures 21 and 22 show the appearances of the tool wears and brakedges induced at the cutting edges. The former is under $V=50$ m/min, and the later is under $V=75$ m/min. From Fig.21, we can clearly observe that, at the initial period of cutting the wear is induced all over the cutting region without



0.5 mm



0.2 mm

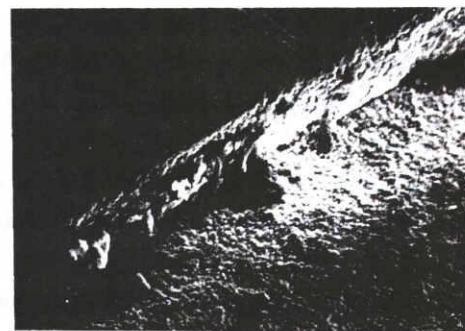
(a) Whole appearance of wear

(b) Boundary of worn region

Fig.21 Edge wear under $V=50$ m/min (Cutting time: 265 sec, $H\epsilon = 38 \mu\text{m}$).



1 mm



0.1 mm

(a) Whole appearance of damaged region

(b) Boundary of flaking region

Fig.22 Appearances of brakedge and flaking (Cutting time: 15 sec).

any brakedge at both the flank and rake face. The boundary looks very distinct and the surface of the worn out area looks rough, which may be created mainly by mechanical aggressive friction with tearing grains of the tip structure. On the other hand, the brakedge which occurs at comparatively earlier stage under $V=75$ m/min, has spreaded very wide region over both the flank and rake face as shown in the photo of Fig.22. The feature on the flank face is quite complicated and uncertain, but on the rake face it seems to be a wide flaking damage with uniformly distributing thickness. Moreover the surface appearance of the damaged region clearly reveals that it is created by the brakedge which is caused by brittle crack. This means the tool of Al_2O_3 material is more inferior in toughness.

The relationship between the flank wear propagation of the Si_3N_4 tip in cutting of hardened SKS93 and cutting distance L m is shown in Fig.23 for various cutting speed $V=30,50,75,100$ m/min. After inducing the initial stage wear of about $50 \sim 120 \mu m$, wear propagates steadily depending on the increase of the cutting distance. Moreover when the speed is higher, the propagating rate of the flank wear is larger and the tool tip reaches its tool life earlier with an exception of $V=30$ m/min. Observing the appearance of cutting edge of this material tip, we can hardly find big and fatal brakedge, crack and flaking. The wear surface is very smooth and both the flank and rake wear are continuous and have reasonable shape. Figure 24(a),(b) show some examples of the local and fine scale chipping and brakedge induced at the cutting edge. Any way, the wear for the Si_3N_4 tip is induced mainly by mechanical aggressive and rubbing mechanism at the somewhat soften region of the tool material under high temperature.

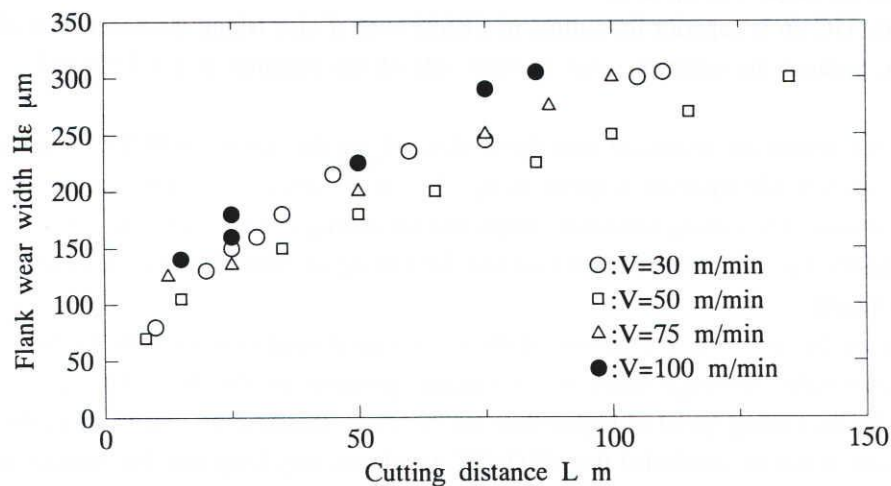
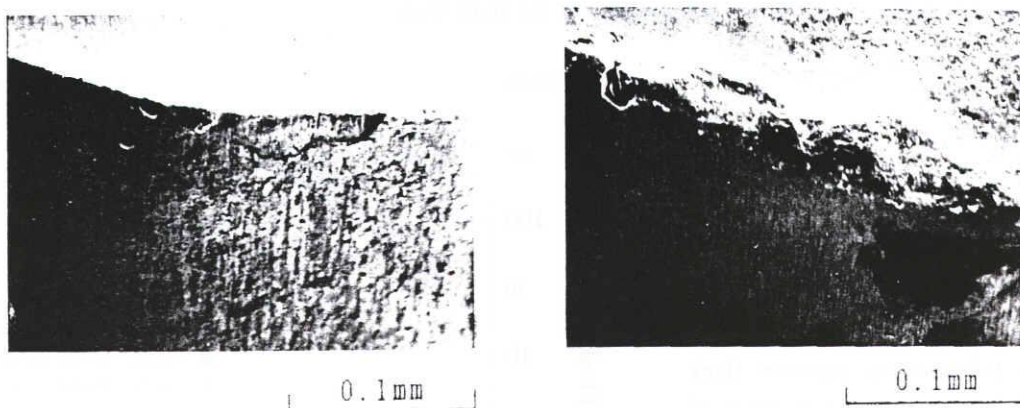


Fig.23 Relationship between flank face wear and cutting distance of Si_3N_4 tip for SKS93.



(a) Chipping and crack at cutting edge

(b) Small brakedge at cutting edge

Fig.24 Appearances of cutting edge (Cutting time: $T=213$ sec, $H\epsilon=300 \mu m$).

Similarly to the case of other work materials, the tool life diagram can be drawn as shown in Fig.25 and the equation can be derived as follows.

$$V T^{0.8} = 94 \quad (9)$$

All the results obtained are close enough to one linear line. Comparing with the results obtained for $\text{Al}_2\text{O}_3\text{-TiC}$ tip, the Si_3N_4 material tool is easily expected the brakedge under the speed higher than $V=50$ m/min and the performance of the Si_3N_4 material tip has low reliability. However, the power value in equation (8) is given as 0.4, therefore the value is just half compared with that of the Si_3N_4 tip. This means that the former tip, that is, $\text{Al}_2\text{O}_3\text{-TiC}$ tip has a smaller change of tool life than that of the Si_3N_4 tip for the corresponding cutting speed. Therefore the slower the speed is, the superior the $\text{Al}_2\text{O}_3\text{-TiC}$ tip is. In addition, $\text{Al}_2\text{O}_3\text{-TiC}$ tip is superior for cutting of SKS93 even if also taking the occurrence of brakedge into consideration, because the constant value of right side of the equation is 2.7 (258/94) times to that of Si_3N_4 tip.

If the results are compared with those obtained for the cutting of FC25 by using the same tool of Si_3N_4 tip (its tool life equation is given as eq.(3)), it is easily recognized that the tool life becomes considerably shorter. The cutting conditions employed for cutting of FC25 are very different from those for cutting of SKS93, but the extreme short tool life for cutting of SKS93 is too intolerable in the case of practical machining.

Figure 26 shows the comparison of the flank wear propagation for both the Si_3N_4 and $\text{Al}_2\text{O}_3\text{-TiC}$ tip. If the catastrophic brakedge happens, the cutting operation for the $\text{Al}_2\text{O}_3\text{-TiC}$ tip no longer can be continued under the cutting speed of higher than $V=75$ m/min, therefore no results are plotted in the figure. From this figure it can be concluded that $\text{Al}_2\text{O}_3\text{-TiC}$ tip shows very long tool life without inviting big and fatal brakedge under the lower cutting speed, but it easily invites such damages, as to become very short tool life under higher cutting speed. On the other hand, Si_3N_4 tips does not reach to the tool life by fatal brakedge and so on, but the tool life is extremely shorter than that of $\text{Al}_2\text{O}_3\text{-TiC}$ tip because of the substantial high speed rate of the propagation of the flank wear.

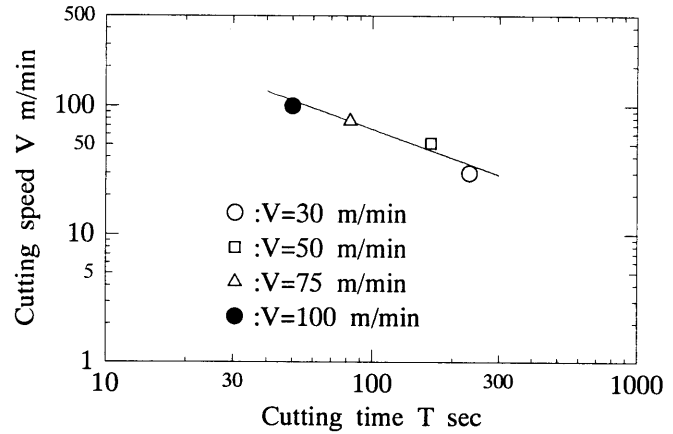


Fig.25 Tool life diagram of Si_3N_4 tip in cutting of water-hardened SKS93.

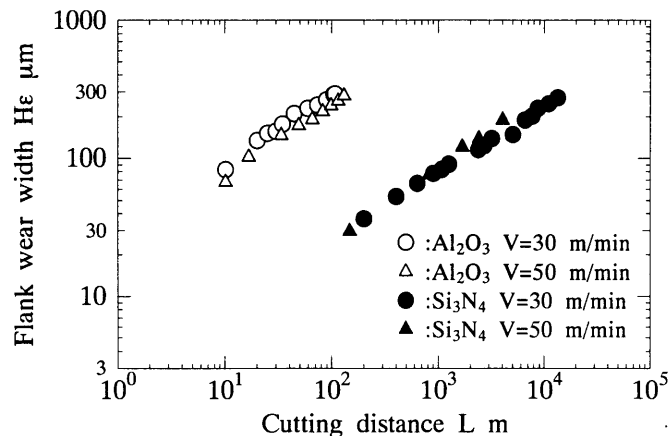


Fig.26 Relationship between flank wear width and cutting distance of $\text{Al}_2\text{O}_3\text{-TiC}$ tip compared with Si_3N_4 tip for cutting of SKS93 material.

4. Conclusions

To recognize the properties of damage propagation, and to clarify the mechanism of some ceramic cutting tools which may be useful and important to popularize various new structural materials, some kinds of cutting tests have been performed. Two typical kinds of commercially available ceramic material cutting tool tips, that is, $\text{Al}_2\text{O}_3\text{-TiC}$ tip and Si_3N_4 tip are selected. The cutting is performed on two kinds of work materials, that is, the brittle material FC25 and on the high hard material of water-hardened tool steel alloy SKS93, at dry cutting atmosphere. Cutting modes are the continuous and discontinuous for FC25 material and only continuous cutting for SKS93. The results obtained in the experiments can be summarized as follows.

(A) Concerning to the continuous cutting of FC25;

(A-1) Both the tips of $\text{Al}_2\text{O}_3\text{-TiC}$ and Si_3N_4 show the stable propagations of flank wears, and also the abnormal wears such as sudden brakedge.

(A-2) The tool life of $\text{Al}_2\text{O}_3\text{-TiC}$ tip is remarkably longer than that of the Si_3N_4 tip under the same cutting conditions.

(A-3) The tool life of the same material tip becomes longer under the slower cutting speed. However the difference is not so big for $V \geq 200$ m/min, so it is more efficient to employ the high speed cutting from the view point of machining efficiency.

(B) Concerning to the discontinuous cutting of FC25;

(B-1) In most of the cases of using $\text{Al}_2\text{O}_3\text{-TiC}$ tip, very big catastrophic brakedge is invited at the instantaneous stage after starting of cutting and it simultaneously becomes to be unable to use. Therefore it can be certain that the $\text{Al}_2\text{O}_3\text{-TiC}$ tip is not suitable for discontinuous cutting.

(B-2) Si_3N_4 tip shows high toughness and can be used effectively for the discontinuous cutting without big scale of fatal brakedge.

(B-3) Cutting performance investigation for discontinuous cutting should be performed with considering simultaneously the number of shocks accepted and the direction of dynamic striking force.

(B-4) The flank wear width and the tool life are superior in discontinuous cutting under the cutting speed lower than the middle speed. However the difference is hardly noticed under higher speed.

(C) Concerning to the cutting of SKS93;

(C-1) The catastrophic brakedge is invited in $\text{Al}_2\text{O}_3\text{-TiC}$ tip at the earlier stage of cutting, and it arrives immediately to the life limit in most of the case with the exception for low speed of $V=30$ m/min. The life limit is shorter under the higher cutting speed. Moreover, especially under the low speed, only the gradual propagation of the wear grows, so the tool life becomes longer.

(C-2) The Si_3N_4 tip does not invite such a big fatal damage found in $\text{Al}_2\text{O}_3\text{-TiC}$ tip, but the tool life is extremely short even under the very light cutting condition.

Some of the conclusions obtained, especially (A-2), (B-1) and (C-1) are very different from the suggestions and the recommended directions given by the tool manufacturing company. We should improve our research further and investigate in detail so as to propose the practically and widely useful cutting conditions for the ceramic materials cutting tips.

5. References

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