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Capabilities of Cermets Tools for High Speed Machining of Austenitic Stainless Steel

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Abstract: Cermets tools have very high hot hardness together with a low coefficient of friction, which facilitates machining at high speeds. In the present work cermet tools coated with titanium nitride were used to turn austenitic stainless steel at speeds between 300 and 700 m min^{-1}. Feed rates were varied between 0.05 to 0.4 mm rev^{-1}. Depth of cuts were between 0.1 and 0.5 mm. After machining, tool flank wear and the cutting edges were observed using Scanning Electron Microscope (SEM). The experimental results showed that when cermet inserts were used for finishing cuts, very fine surfaces were produced. However, when used for roughing cuts, they tended to fracture unpredictably rather than having gradual flank wear. Thus, the cermet tools were found to perform satisfactorily only for finishing operations with feed rates ranging between 0.1 and 0.2 mm rev^{-1} and at the maximum depth of cut of 0.3 mm. For stable operations, the maximum cutting speed should be below 600 m min^{-1}; exceeding this limit resulted catastrophic failure of the cutting edge.

Key words: High speed machining, cermets, tool failure, tool wear

INTRODUCTION

Over the last 10-15 years high speed machining has gained popularity due to its high productivity, low cutting force and improved accuracy (Tonshuff *et al.,* 1997). Development of new cutting tool materials and availability of machine tools with high rotational speeds have made it possible to increase material removal rate. But at a high cutting speed tool wear occurs more intensively and causes the requirement of frequent tool changing. Again, tool changing time increases machine downtime and reduces the productivity of machining.

Different researchers have carried out investigations on tool wear and tool life at high cutting speeds. Kishawy and Elbestawi (2001) investigated tool wear characteristics and job surface integrity during high speed turning of hardened steel with polycrystalline cubic boron nitride tools. They found various types of surface damages and residual stress beneath the machined surface. They also investigated the modes of tool wear under different cutting conditions. Fryderyk (1998) illustrated the influence of different cutting parameters on tool life at high cutting speeds. He also suggested the approach of idealization of cutting conditions for maximum production at a minimum cost.

Toh (2003) found that not only a high cutting speed, but the tool path strategies over the workpiece also had a strong impact on tool wear. In his experiments hardened AISI HI 3 steel was machined using coated carbide inserted end mills at a cutting speed of 314 m min^{-1} and at a feed rate of 0.067 mm per tooth. It was found that tool life is higher when raster strategy is employed rather than single-direction or off-set strategy.

Trent and Wright (2000) illustrated that tool wear at a high cutting speed was greatly influenced by fluctuating stresses caused by the formation of segmented chips. Hence formation of continuous chip is a prime condition of high tool life. Much research and development work has been carried out in the areas of high speed milling of aluminum alloys, titanium alloys, steels and super alloys (Kalpakjian and Schmid, 2001).

Researchers have evaluated the high speed machining process based on types of chip produced, cutting force, tool life, surface finish, economics of machining, etc. Investigations have also been done on cutting conditions and tool optimization for high speed milling of aluminum alloys with minimum use of coolant (Lopez de Lacalle, 2001).

Cermet tools have been employed for high speed machining for a long time due to their high wear resistance and high hot hardness. Jawid *et al.* (2002) have established that the contribution of the cutting speed and feed rate to tool performance is in excess of 80%, with the cutting speed showing the greater degree of influence during machining of martensitic stainless steel. It was found that nose wear, plastic deformation and

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chipping at the cutting edge were the main failure modes of the cutting tools. In the present study, investigations were carried out to analyze the performance of cermet tools during machining of austenitic stainless steel under different cutting conditions.

MATERIALS AND METHODS

The workpiece material used in the present work was autenitic stainless steel (grade SUS 304) with an approximate composition of 0.08% C, 2% Mn, 10% Ni and 19% Cr. The diameter and length of the workpiece were 200 and 500 mm, respectively. Titanium nitride coated cermet tool inserts (SNMG 120408-HM, grade 200) were used in the present work. The cermet tools were mechanically clamped to the tool holder. Geometrical parameters of the inserts were as follows: relief angle-4°, rake angle-10°, principal cutting edge angle-85° and auxiliary cutting edge angle-5°.

The experiments were conducted on a lathe model Harrison M390. Metal cutting was performed at cutting speeds of 300, 400, 500 and 700 m min^{-1}. Feed rates were 0.05, 0.1, 0.2 and 0.4 mm rev^{-1}. Depths of cut tried were 0.1, 0.2, 0.3 and 0.5 mm. A full factorial set of experiments (64 trials) was performed with 4 different cutting speeds, 4 levels of depth of cut and 4 levels of feed rates. Cutting parameters were selected to cover roughing, finishing and fine finishing. Each insert of the cutting tool had 8 edges (4 on each side). Thus each insert was capable of performing 8 trials.

RESULTS AND DISCUSSION

Results of the experiments were analyzed with the help of the photographs taken by the SEM. The photographs were taken with high magnification in order to obtain a clear view of the worn-out cutting edges. It was not possible to machine austenitic stainless steel with high cutting parameters (cutting speed, feed and depth of cut) due to high hardness of the work material and low fracture toughness of the cermet tools. Discussions on the results have been set out in the following paragraphs.

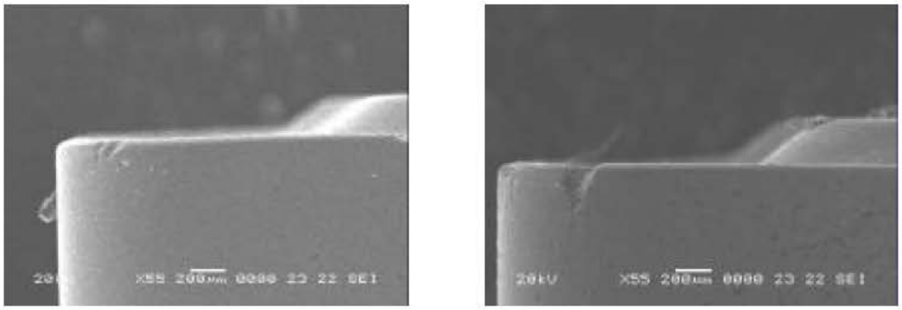
Mode of failure of ceramic tools: Figure 1 shows the behavior of cermet tools under different cutting conditions. A minifracture of a depth of 80 μm can be observed at the cutting edge (Fig. la) after 10 min of machining at a cutting speed of 300 m min^{-1}, feed rate of 0.05 mm rev^{-1} and a depth of cut of 0.1 mm.

But as the cutting condition becomes heavier (cutting speed: 400 m min^{-1}, feed rate: 0.2 mm min^{-1} and depth of cut: 0.2 mm), as in Fig. 1b, the depth of the crater becomes larger after 5 min of machining. Further heavier cutting conditions worsen the mode of tool failure. Figure ld shows catastrophic failure of the cutting edge after a machining time of only 2.5 min at a cutting speed of 700 m min^{-1}, feed rate of 0.4 mm rev^{-1} and a depth of cut of 0.5 mm. From the Fig. 1 it is obvious that cermet tools can be used efficiently only at low depths of cut and feed rates. A few factors are responsible for catastrophic failure of the cutting edges (Fig. 1d). First of all, under heavier cutting conditions the rate of heat generation at the cutting zone is high, but the thermal conductivity of the cermet tools is very low. As a result the temperature at the cutting edge rises to a very high level which ultimately causes tool failure. The second reason is obviously the low fracture toughness of the cermet tools.

Effect of cutting parameters on tool failure effect of depth of cut: Figure 2 shows the photographs of tool edges after 10 min of machining at a cutting speed of 300 m min^{-1} and a feed rate of 0.1 mm rev^{-1}. With an increase in depth of cut, the contact length of the cutting edge with the workpiece increases and wear occurs deeper along the cutting edge. It can be seen that the size and depth of the cracks on the cutting edge not only increase with an increase in feed, but they occur deeper away from the tip of the cutting edge. This is because, due to the increase in the depth of cut, chip width increases and the center of pressure of the chip on the tool face moves away from the tool nose.

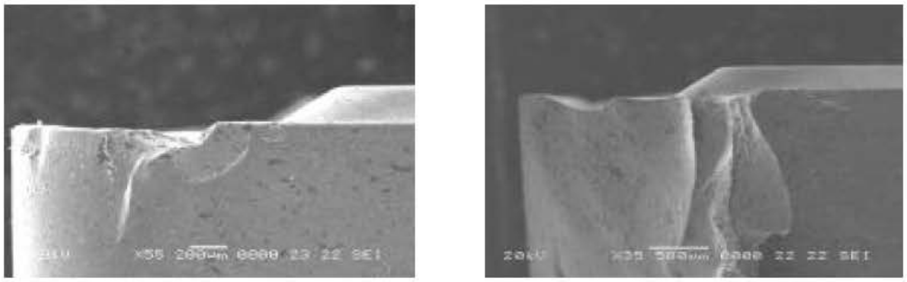
If the center of pressure moves away from the tool nose, the generated heat is dissipated easily within the body of the tool due to the wedged shape of the cutting edge. This is a positive aspect in terms of heat distribution, but the quantity of heat generated due to the increase in depth of cut is more which causes the increase in temperature at the cutting edge. It should also be noted that, as the chip width increases with the increase in depth of cut, the surface of the chip becomes rougher and the real contact area between the tool face and the chip is reduced resulting localized heat concentration at the contact areas mentioned. Moreover, the increase in depth of cut causes more compressive stress on the cutting edge resulting in rapid fracture of the tool edge.

Figure 3 shows the effect of depth of cut on flank wear after 10 min of machining at a cutting speed of 300 m min^{-1} and a feed rate of 0.2 mm rev^{-1}. It can be observed that flank wear increases almost linearly with the increase in the depth of cut within the range considered. It can also be observed that cermet tools are not suitable for machining with a depth of cut beyond 0.3 mm with a cutting speed of 300 m min^{-1} and a feed rate of 0.2 mm rev^{-1} since the maximum permissible flank wear is 0.3 mm.



(a) V = 300 m min^{-1}, f = 0.05 mm rev^{-1}, depth of cut = 0.1mm

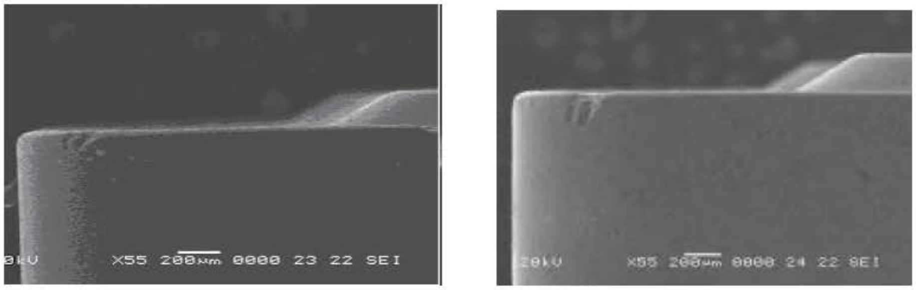
(b) V = 400 m min^{-1}, f = 0.2 mm rev^{-1}, depth of cut = 0.2 mm



(c) V = 400 m min^{-1}, f = 0.2 mm rev^{-1}, depth of cut = 0.3 mm

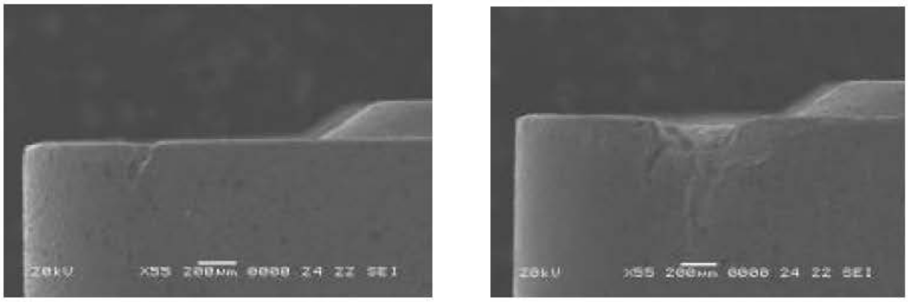
V = 700 m min^{-}, f = 0.4 mm rev^{-1}, depth of cut = 0.5 mm

Fig. 1: Failure mode of cermet tools



(a) depth of cut = 0.1 mm

(b) depth of cut = 0.2 mm



(c) depth of cut = 0.3 mm

(d) d.o.c = 0.5 mm

Fig. 2: Effect of depth of cut.(V = 300 m min^{-1}, feed rate = 0.1 mm rev^{-1}, 10 min of machining)

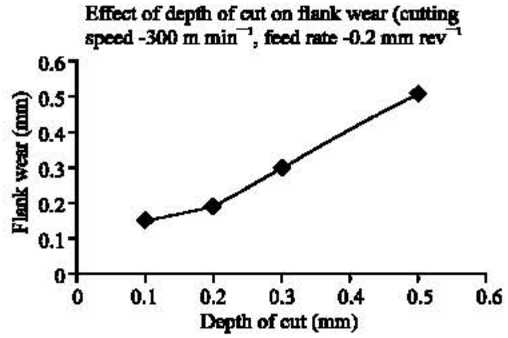


Fig. 3: Effect of depth of cut on flank wear

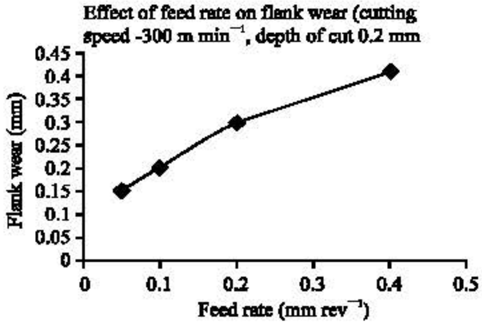
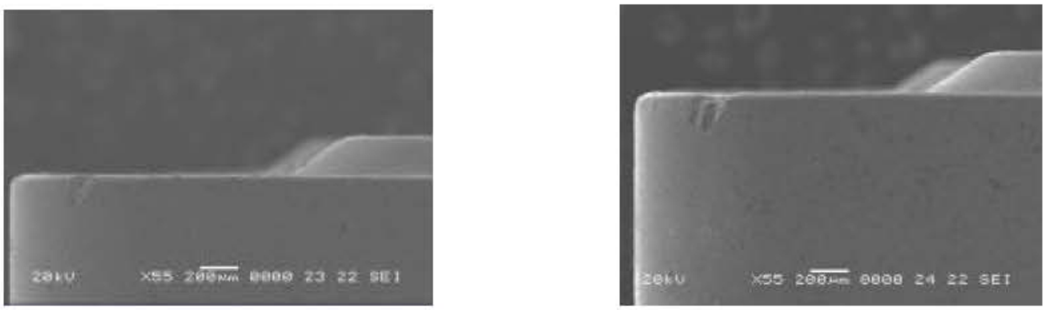


Fig. 4: Effect of feed rate on flank wear

Effect of feed rate: Similar to the change of depth of cut, increase in feed rate increases the size and depth of fracture on the cutting edges. But unlike the depth of cut, increase in feed does not shift the position of the cracks. That is, the crack always occurs near the tip of the cutting edge. Relationship of depth of crater on the tool flank and feed rate is shown in Fig. 4. As the feed rate is increased, pressure on the unit length of the cutting edge is also increased. A higher feed rate increases the chip thickness and makes the chip surface rougher that reduces the real contact between the tool face and the chip. It results on poor heat dissipation at the cutting edge. Moreover, increase in the feed rate may cause vibration in the system which results in fracture of the brittle cermet tools.

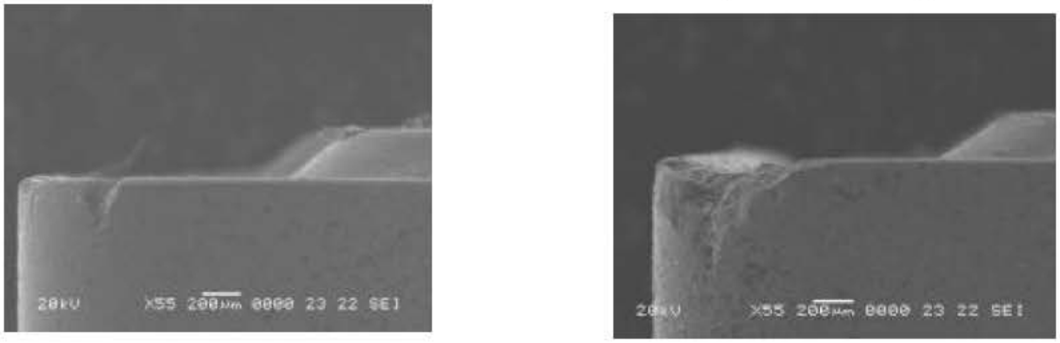
Figure 5 shows the conditions of the cutting edges after machining at a cutting speed of 300 m min^{-1}, depth of cut of 0.2 and at different feed rates. It is obvious that depth of the cracks on the flank increases with increase in the feed rate.

It can be observed from Fig. 5 that as the feed rate is increased from 0.05 to 0.1 mm rev^{-1}, the depth of crack is increased from 100 µm to 200 µm. Figure 5c and d show further deterioration of the cutting edges at higher feed rates. Catastrophic failure of the cutting edge can be observed in Fig. 5d at a feed rate of 0.4 mm rev^{-1}.



(a) feed rate = 0.05 mm rev^{-1}
(10 min of machining)

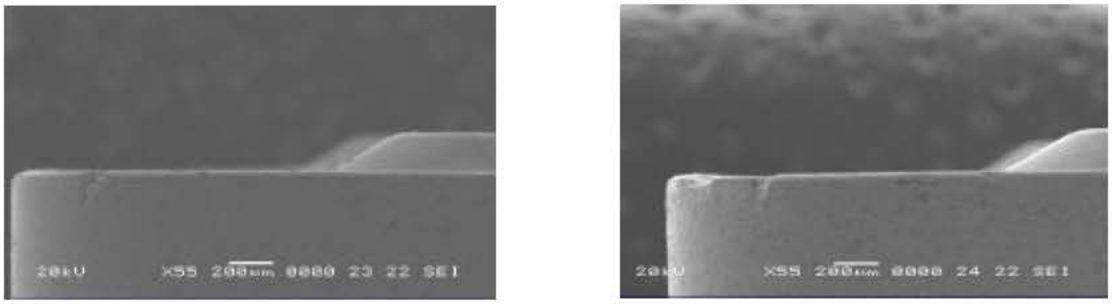
(b) feed rate = 0.1 mm rev^{-1}
(8 min of machining)



(c) feed rate = 0.2 mm rev^{-1}
(10 min of machining)

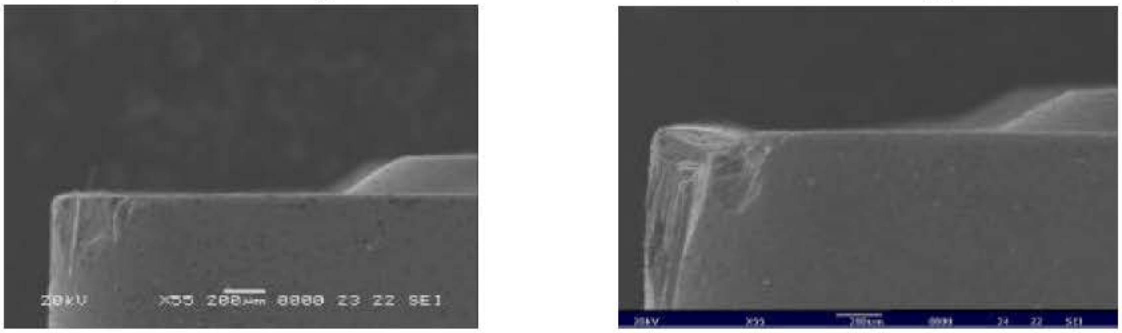
(d) feed rate = 0.4 mm rev^{-1}
(5 min of machining)

Fig. 5: Flank wear under different feed rates



(a) cutting speed V = 300 m min^{-1} (10 min of machining)

(b) cutting speed V = 400 m min^{-1} (8 min of machining)



(c) cutting speed V = 500 m min^{-1} (5 min of machining)

(d) cutting speed V = 300 m min^{-1} (2.5 min of machining)

Fig. 6: Flank wear under diffrent cutting speeds (feed tare -0.2 mm rev^{-1} and depth of cut -0.1 mm)

Effect of cutting speed: It can be observed from Fig. 6 that cermet tools are very sensitive to cutting speed. When the cutting speed is comparatively low (300 m min^{-1}), as in Fig. 6a, the size and depth of the crack on the flank is very small after a machining time of l0 min. Crack grows rapidly at higher cutting speeds. Figure 6b and 6c shows the condition of the cutting edges after a machining time of 5 min at a cutting speed of 400 and 500 m min^{-1}, respectively. Figure 6d shows the catastrophic failure of the cutting edge after a machining time of only 2.5 min at a cutting speed of 700 m min^{-1}. The cutting force on the tool edge increases as the cutting speed is increased. Though cermet tools have high hot hardness and wear resistance, they have low fracture toughness. As a result tool wear intensifies at a high cutting speed.

It was also found by Khan *et al*. (2002) that the life of cermet tools is very long while machining with low cutting parameters. At low cutting parameters a gradual flank wear is observed. But as the cutting speed is increased up to a certain limit, a brittle fracture occurs at the cutting edge rather than a gradual flank wear and the depth of the cracks on the cutting edge increases rapidly resulting in a catastrophic failure of the tool.

CONCLUSIONS

From the present analysis and discussion the following conclusions can be drawn:

1. The failure of the cutting edges of cermet tools starts with microcracks rather than a gradual wear. In course of machining, these microcracks grow in size and cause the total failure of the tools. The growth of the microcracks is rapid and unpredictable. This is due to the low fracture toughness of cermet tools.
2. At a low cutting speed, feed and depth of cut the life of cermet cutting tools is quite long and the job surface finish is quite satisfactory. But an increase in cutting parameters causes rapid failure of the tools. Among the cutting parameters, (cutting speed, feed and depth of cut) the first one has the most prominent influence on the failure of cermet tools.
3. Experimental results show that as the depth of cut is increased, chip width also increases and the center of pressure of the chip on the tool face moves away from the cutting edge. As a result, with an increase in the depth of cut, the zone of initiation of the crack

moves away from the cutting edge. It was also found that the depth of cut should be kept within 0.3 mm in order to have a satisfactory tool life under the cutting speed and feed rate considered.

4. At a low feed rate tool wear rate is low, but the maximum practical range of feed rate is 0.2 mm rev^{-1}. An increase in cutting speed causes increase in cutting force and microcracks develop rapidly on the cutting edge due to low fracture toughness of cermet tools. It can be recommended that the cutting speed should not exceed 300 m min^{-1} during machining of austenistic stainless steel.

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