PUBLICATION II

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Active Wear and Failure Mechanisms of TiN-Coated High Speed Steel and TiN-Coated Cemented Carbide Tools When Machining Powder Metallurgically Made Stainless Steels

LAIZHU JIANG, HANNU HÄNNINEN, JUKKA PARO, and VEIJO KAUPPINEN

In this study, active wear and failure mechanisms of both TiN-coated high speed steel and TiN-coated cemented carbide tools when machining stainless steels made by powder metallurgy in low and high cutting speed ranges, respectively, have been investigated. Abrasive wear mechanisms, fatigue-induced failure, and adhesive and diffusion wear mechanisms mainly affected the tool life of TiN-coated high speed steel tools at cutting speeds below 35 m/min, between 35 and 45 m/min, and over 45 m/min, respectively. Additionally, fatigue-induced failure was active at cutting speeds over 45 m/min in the low cutting speed range when machining powder metallurgically made duplex stainless steel 2205 and austenitic stainless steel 316L. In the high cutting speed range, from 100 to 250 m/min, fatigue-induced failure together with diffusion wear mechanism, affected the tool life of TiN-coated cemented carbide tools when machining both 316L and 2205 stainless steels. It was noticed that the tool life of TiN-coated high speed steel tools used in the low cutting speed range when machining 2205 steel was longer than that when machining 316L steel, whereas the tool life of TiN-coated cemented carbide tools used in the high cutting speed range when machining 316L steel was longer than that when machining 2205 steel.

I. INTRODUCTION

AUSTENITIC and duplex stainless steels are normally recognized as materials difficult to machine, because of their following traits:

(1) high tensile strength and high work hardening rate and low thermal conductivity, leading to high cutting temperature and accelerated tool wear;
(2) high fracture toughness, resulting in poor chip breakability and poor surface finish; and
(3) strong bonding to the tool, especially to cemented carbide tools,[1] causing some pieces of material to be torn from the cutting tool and carried away by the chips.

Until now, the main mechanisms for tool wear when machining austenitic and duplex stainless steels are unclear, although there are some studies on them. It has been reported that the high work hardening rate, combined with low thermal conductivity, results in serrated chips when machining stainless steels.[2] The serrations of the chips cause vibration of the cutting forces and attrition wear of the cutting tool, especially the cemented carbide tool.[3] Besides vibration of the cutting forces, it has been recognized that a strong bonding between the tool and the workpiece material is also a necessary condition for attrition wear to occur. Little data concerning work hardening of stainless steels during machining have been presented until now. Also, the bonding mechanisms between stainless steel and the cutting tool, especially the cemented carbide tool, have not been investigated, although it has been generally accepted that the resulting high cutting temperature when machining both austenitic and duplex stainless steels is a very important factor causing bonding.

The machining cost of workpiece materials normally occupies at least 30 pct of the total cost of the final product. For the materials difficult to machine, such as stainless steels, it may be up to 50 pct. Powder metallurgy employing hot isostatic pressing (HIP) technology has recently been used to produce stainless steel products; this process, on one hand, reduces the machining costs because the size and shape of the products can be very close to the final product, but on the other hand, possibly causes the machinability of HIP steels to be poorer than that of the conventional steels due to considerable amounts of hard oxide particles. As the applications of HIP austenitic and duplex stainless steels are increasing due to their excellent mechanical properties and high corrosion resistance, it becomes more and more important to also know their machinability. The machinability of materials depends not only on their properties but also on the cutting tools. Although there are some new cutting tools available, both HSS and cemented carbide tools, with or without TiN coating, are still frequently used in the industry for turning. In this study, the tool lives and the cutting forces were measured in the turning tests of both HIP austenitic (PM 316L) and HIP duplex (PM 2205) stainless steels using TiN-coated HSS and TiN-coated cemented carbide tools in the low and high cutting speed ranges, respectively. Particular attention was paid to the wear and failure mechanisms of the cutting tools and the materials issues related to them.

II. EXPERIMENTAL PROCEDURE

A. *Workpiece Materials*

The workpiece materials for turning tests were HIP austenitic stainless steel PM 316L and HIP duplex stainless

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Table I. Chemical Compositions (Weight Percent) of HIP Stainless Steels: PM 316L and PM 2205

Code	C	Si	Mn	P	S	Cr	Ni	Mo	V	Al	Cu	N	O
PM 316L	0.05	0.68	1.44	0.022	0.009	16.7	11.0	2.7	0.11	0.021	0.19	0.12	0.012
PM 2205	0.03	0.66	1.42	0.022	0.008	22.1	5.3	3.0	0.07	0.016	0.13	0.21	0.014

steel PM 2205. Their chemical compositions are given in Table I.

The samples, 70 mm in diameter and 350 mm in length, were heat treated for 3 hours at 1100 °C and then water quenched. There is a considerable amount of small oxide particles distributed in both steels, mainly consisting of silicon, aluminum, and manganese, according to scanning electron microscope (SEM) observation and energy-dispersive spectroscopy (EDS) analyses. The microhardness value of austenite of PM 316L is about 240 HV, while those of ferrite and austenite phases of PM 2205 steel are about 330 and 300 HV, respectively.

B. *Tool Materials and Turning Conditions*

For turning tests of HIP stainless steels, PM 316L and PM 2205, TiN-coated HSS (T42) tools (Edgar Allen Tools Ltd., Sheffield, England) were employed in the low cutting speed range, from 15 to 55 m/min, and TiN-coated cemented carbide (P30) tools (Plansee Tizit, Austria) were employed in the high cutting speed range, from 100 to 250 m/min. The insert had the geometry of SPUN 120308 with a rake angle of 6 deg, clearance angle of 5 deg, cutting edge angle of 75 deg, cutting edge inclination of 0 deg, and nose radius of 0.8 mm. The turning tests were carried out on a center lathe with 100 kW spindle power with the cutting conditions given in Table II.

Table II. Cutting Conditions

Cutting speed, m/min	15, 35, 45, 55 (low cutting speed range) 100, 150, 200, 250 (high cutting speed range)
Feed rate, mm/revolution	0.15
Depth of cut, mm	1.00
Cutting fluid	dry

The flank wear VB of the cutting tools at every cutting speed was measured with a toolmaker's microscope. The criterion for tool life was VB = 0.3 mm or catastrophic failure of the tool edge. The principal cutting forces F_z were measured with a three-component piezoelectric force dynamometer. After turning, the wear topograph of the flank surfaces of the cutting tools was examined by an SEM together with EDS analysis. Chip root samples were obtained by means of a quick-stop device. They were mounted and cross sectioned for metallographic examinations of macrostructures and microstructures and, especially, of the possible bonding interface between the tool materials and the chips, by means of SEM and EDS analysis. The microhardness values at chip bottoms of both steels were measured with an MHT-4 microhardness tester with a load of 20 g to investigate work hardening behavior during turning.

III. EXPERIMENTAL RESULTS

A. *Tool Life*

The tool lives based on flank wear or catastrophic failure of the cutting edge when machining both PM 316L and PM 2205 steels in low and high cutting speed ranges are shown in Figure 1. It can be concluded that, according to these tests, TiN-coated HSS and TiN-coated cemented carbide tools exhibited catastrophic failure at cutting speeds over 45 and 200 m/min, respectively. The chips quickly became red hot in these cases. As can be seen from Figure 1, TiN-coated HSS tools exhibited longer tool life in the low cutting speed range when machining PM 2205 steel as compared with that when machining PM 316L steel, whereas TiN-coated cemented carbide tools presented longer tool life in the high cutting speed range when machining PM 316L steel as compared with that when machining PM 2205 steel.

B. *Cutting Force*

The principal cutting forces when machining PM 316L and PM 2205 steels in low and high cutting speed ranges are shown in Figures 2(a) and (b), respectively. It can be seen that the principal cutting forces when machining PM 2205 steel are lower than those when machining PM 316L steel in the low cutting speed range, whereas the opposite is true in the high cutting speed range.

C. *Wear Topograph and Wear Mechanisms of TiN-Coated HSS Tools*

1. *Abrasive wear at cutting speeds below 35 m/min*

The SEM observations of the worn tools revealed that the flank surfaces of HSS substrates of TiN-coated HSS tools showed abrasive grooves when machining PM 316L and PM 2205 steels at cutting speeds below 35 m/min. Some free carbides and built-up edges (BUEs) were found on the flank surfaces (Figures 3(a) and (b)), based on EDS analyses. These carbides and BUEs were believed to cause the abrasive groove wear on the flank surface of HSS substrate of the tool.[4,5] Additionally, it seems likely that the small hard oxides in these HIP stainless steels may also cause the abrasive wear on the HSS substrate of the tool, but the dimensions of the resulting groove may be too small to be resolved by an SEM.[5]

2. *Fatigue-induced failure at cutting speeds between 35 and 45 m/min*

The flank surfaces of TiN-coated HSS tools exhibited a considerable amount of fatigue-induced failure when machining both PM 316L and PM 2205 steels at cutting speeds between 35 and 45 m/min. For example, Figures 4(a) and (b) show the worn topograph of the flank surfaces of HSS substrate of TiN-coated HSS tool when machining PM 316L and PM 2205 steels at a cutting speed of 45 m/min, respectively.

It can be seen that the flank surface of HSS substrate of TiN-coated HSS tool when machining PM 2205 steel is less

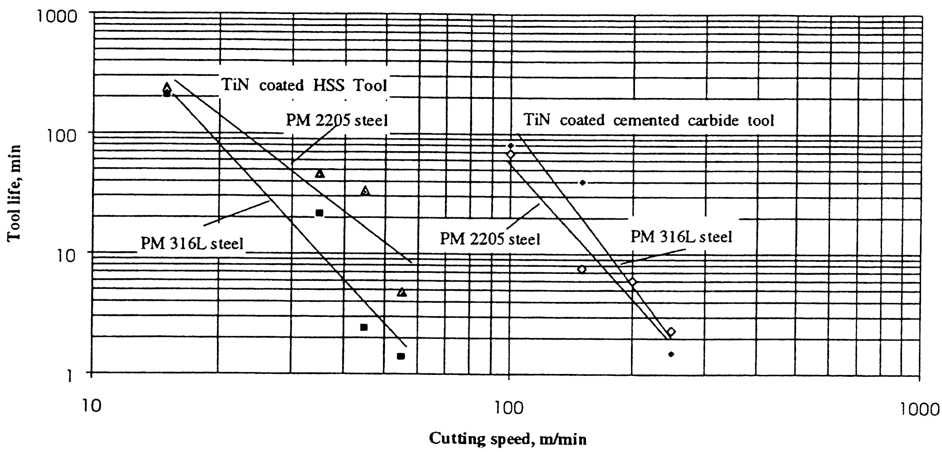
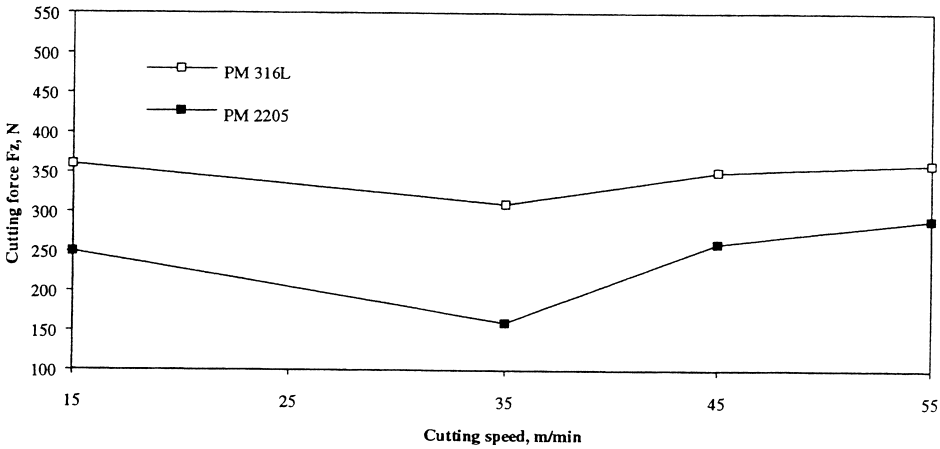
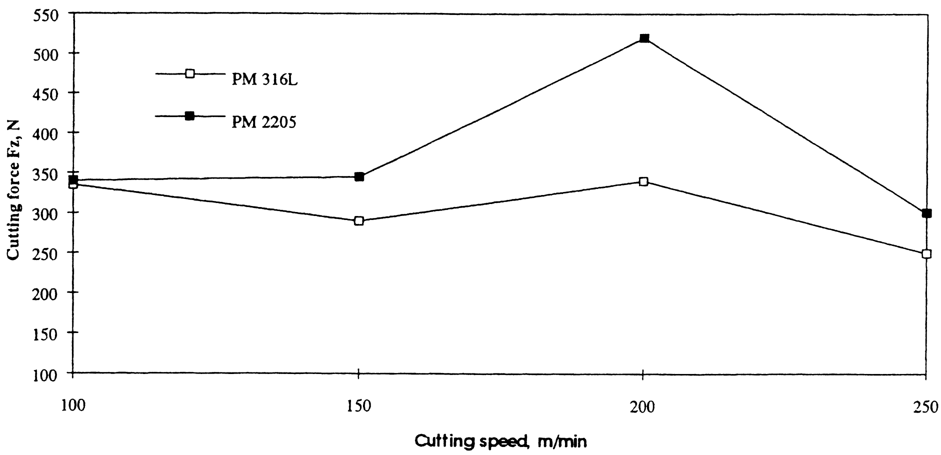


Fig. 1—Tool lives for TiN-coated HSS and TiN-coated cemented carbide tools in the low and high cutting speed ranges, respectively, when machining PM 316L and PM 2205 stainless steels.

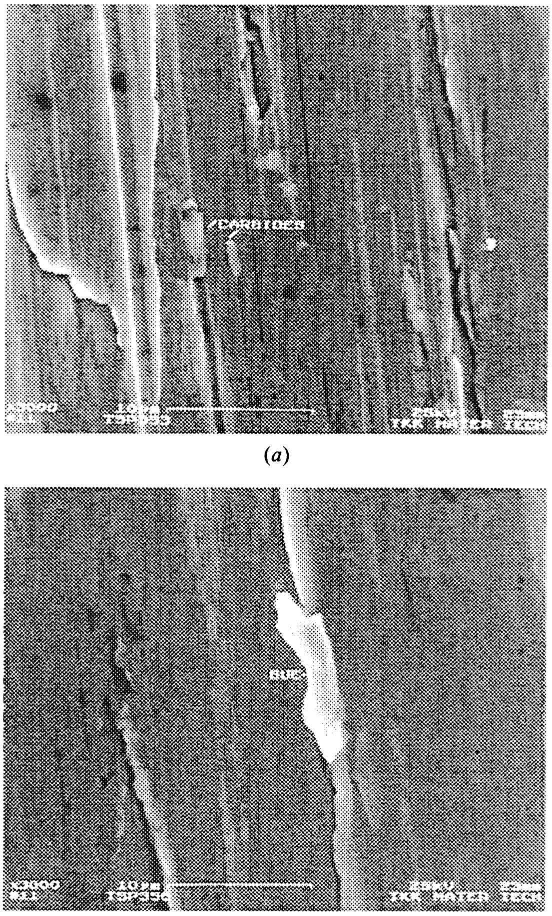


(*a*)



(*b*)

Fig. 2—Cutting forces when machining PM 316L and PM 2205 steels in low and high cutting speed ranges: (*a*) in the low cutting speed range using TiN-coated HSS tool; and (*b*) in the high cutting speed range using TiN-coated cemented carbide tool.



(*a*)

(*b*)

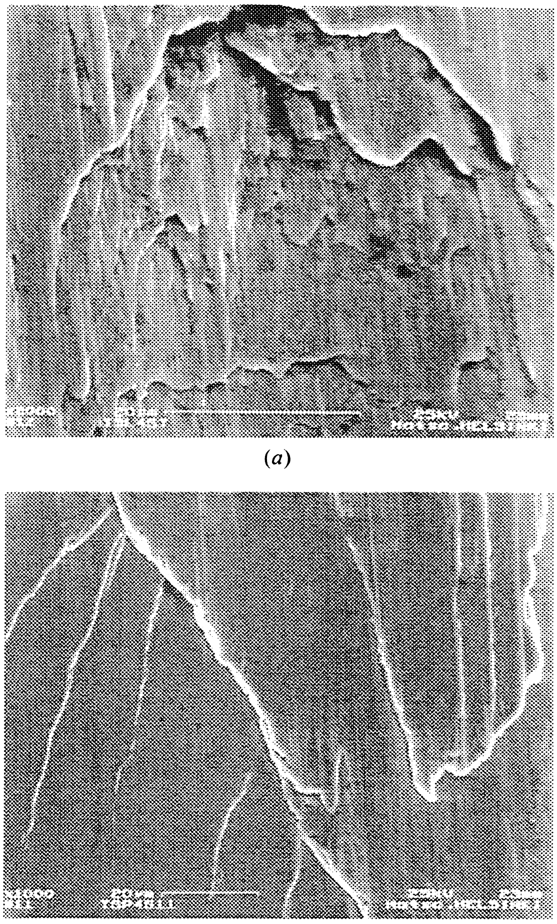
Fig. 3—(*a*) and (*b*) Abrasive groove wear on the flank surface of HSS substrate of TiN-coated HSS tool when machining PM 2205 steel at a cutting speed of 35 m/min.

rough due to fatigue cracks as compared with that when machining PM 316L steel at the same cutting speed.

3. *Adhesive wear and diffusion wear at cutting speeds over 45 m/min*

At cutting speeds over 45 m/min, bonding occurred between the HSS substrate and the workpiece when machining both PM 316L and PM 2205 steels. As an example, the bonding between the HSS substrate and PM 316L is shown in Figure 5. This bonding resulted in adhesive and diffusion wear. Some pieces of HSS substrate torn away from the tool could be seen sticking on the chips. Diffusion of the tool elements, such as W and V, across the bonding interface into the chips was detected if no TiN coating was present in the interface (Figure 6), which indicates that diffusion wear of the tool occurred in this case. On the other hand, no diffusion was detected if a TiN coating was present on the HSS substrate and on the bonding interface, which indicates that TiN coating is able to protect HSS substrate from diffusion wear.

It was observed that the fatigue-induced failure mechanism was cooperative together with adhesive and diffusion wear mechanisms for TiN-coated HSS tool at cutting speeds over 45 m/min in the low cutting speed range, especially when machining PM 316L steel, resulting in the tearing away of some pieces of HSS substrate from the cutting tool.



(*a*)

(*b*)

Fig. 4—Fatigue-induced failure on the flank surface of TiN-coated HSS when machining (*a*) PM 316L and (*b*) PM 2205 steels at a cutting speed of 45 m/min.

D. *Wear Topograph and Wear or Failure Mechanisms of TiN-Coated Cemented Carbide Tools*

Fatigue-induced failure was the dominant failure mechanism of TiN-coated cemented carbide tool when machining PM 316L and PM 2205 steels in the whole high cutting speed range between 100 and 250 m/min. The catastrophic failure of the tool due to the fatigue cracks can be seen in Figure 7.

Besides fatigue-induced failure, a diffusion wear mechanism of TiN-coated cemented carbide tools was also active when machining PM 316L and PM 2205 steels in the whole high cutting speed range. For example, the wear mor-

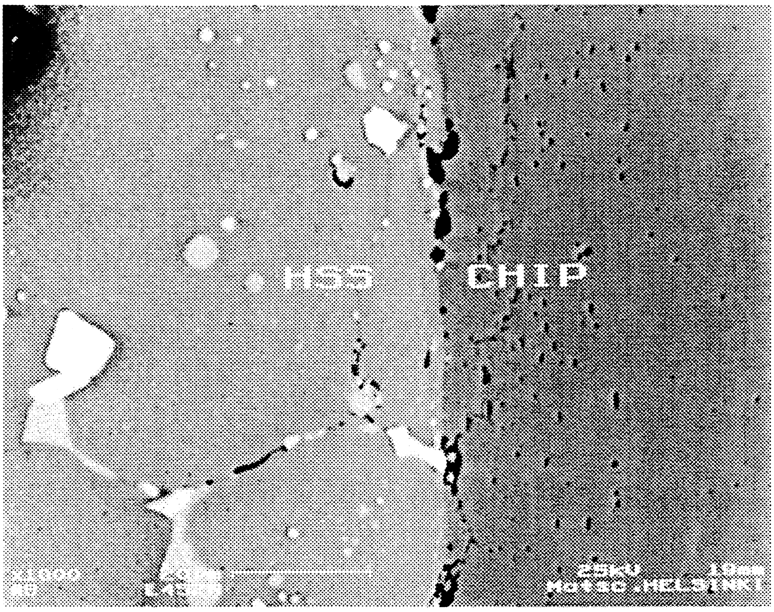


Fig. 5—Bonding between HSS substrate (left side) and the chip (right side) of PM 316L steel at a cutting speed of 45 m/min.

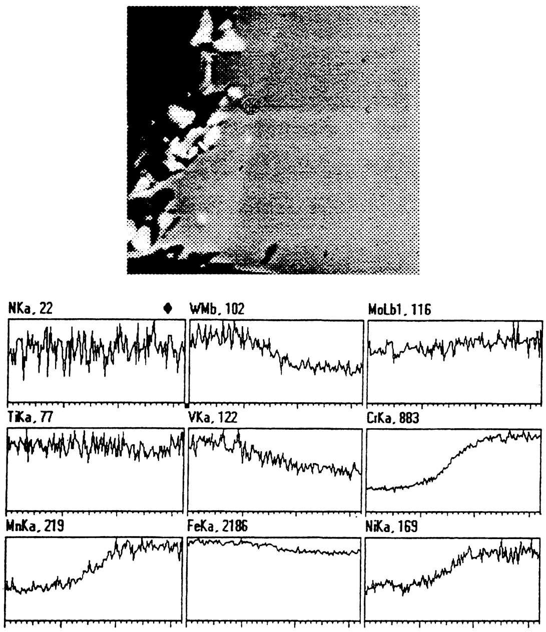


Fig. 6—Chemical composition across the bonding interface (HSS substrate on the left side and chip on the right side) without TiN coating present when machining PM 316L steel at a cutting speed of 45 m/min.

phology of the flank surface of TiN-coated cemented carbide tool when machining PM 316L steel at a cutting speed of 200 m/min, together with EDS analyses, is shown in Figure 8.

Oxide layers consisting mainly of Mn and Si can be observed bonding to TiN coating, while the workpiece layers are seen to bond to cemented carbide substrate on the flank surface. It can also be noticed that, of all the elements of the workpiece, only Ni and Mo diffused into the tool substrate, while only Co of the tool elements diffused into the workpiece. It is well known that both Ni and Co have similar crystal structure and close lattice constants at high-temperature leading to the substitutional diffusion: Ni diffuses from the workpiece into the tool substrate, while Co diffuses from the tool substrate into the workpiece. Molybdenum has the similar ability to form carbide as W, and accordingly, it is able to diffuse from the workpiece into the tool substrate, partially replacing W in the carbides.

Although the bonding of the stainless steel workpiece to the cemented carbide substrate may protect the flank surface of the cutting tool from abrasive wear, it will result in diffusion wear and also attrition wear (fatigue-induced failure) if fatigue cracks form inside the tool substrate. In general, bonding layers of stainless steel were detrimental to the performance of TiN-coated cemented carbide tool, because the main wear or failure mechanisms were the fatigue-induced failure and diffusion wear other than the abrasive wear in the high cutting speed range. No diffusion was detected within the areas of sticking oxide layers, which means that these layers can really act as protective films.

E. *Macroscopic Morphology of Chips*

1. *Low cutting speed range*

The macroscopic morphology of the chips of PM 316L and PM 2205 steels in the low cutting speed range is shown in Figures 9 and 10. It can be seen that the chips are generally continuous, showing serrations which become more and more pronounced as the cutting speed increases. The chips of PM 316L steel were thicker and more serrated as

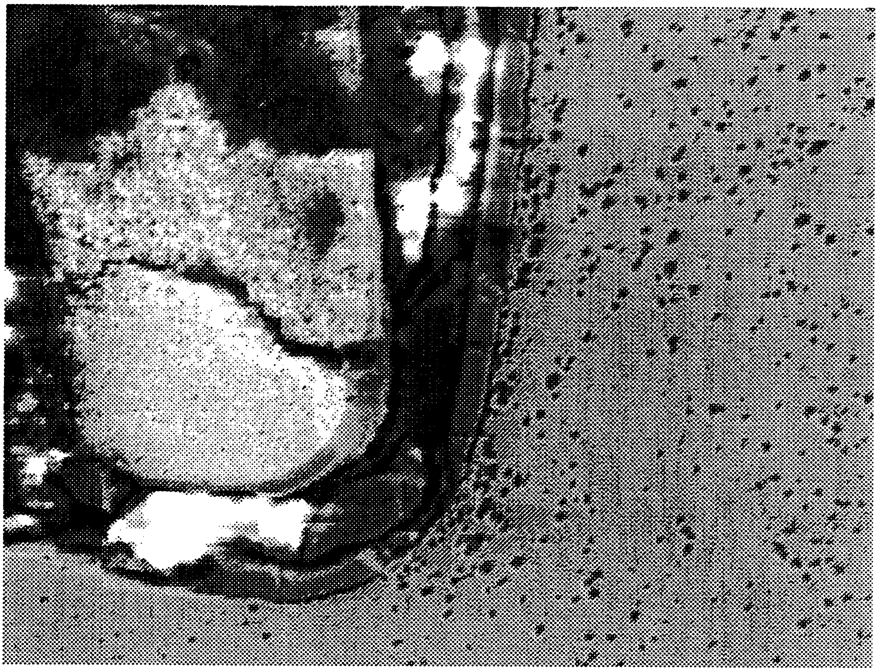


Fig. 7—Catastrophic failure of TiN-coated cemented carbide tool when machining PM 2205 steel at a cutting speed of 200 m/min.

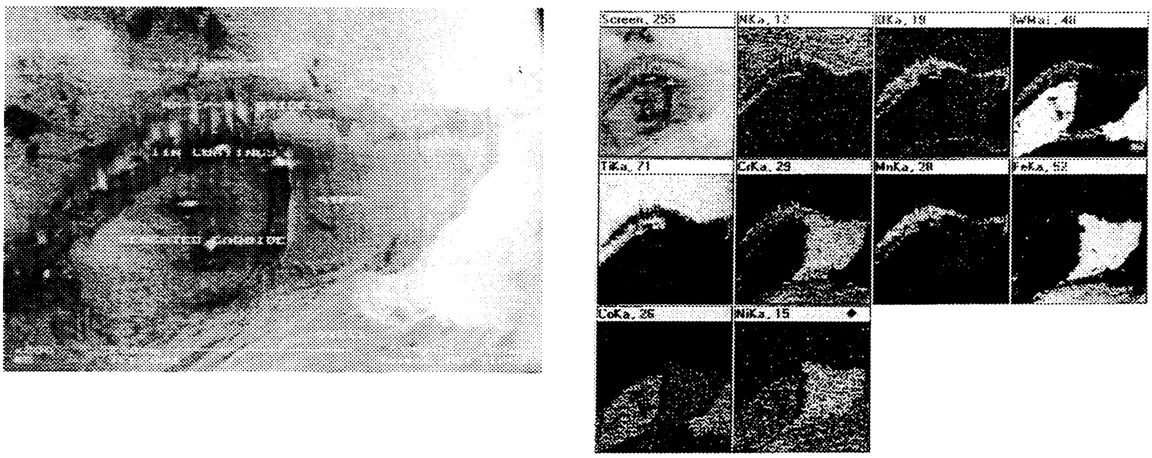


Fig. 8—Wear morphology and related EDS analyses of TiN-coated cemented carbide tool when machining PM 316L steel at a cutting speed of 45 m/min.

compared with those of PM 2205 steel at the same cutting speed. Accordingly, the cutting force when machining PM 316L steel was higher than that when machining PM 2205 steel at the same cutting speed.

2. *High cutting speed range*

The macroscopic morphology of the chips of PM 316L and PM 2205 steels in the high cutting speed range is shown in Figures 11 and 12. As compared with the chips in the low cutting speed range, the chips in the high cutting speed range are more markedly serrated. It can also be seen that the chips of PM 2205 steel are generally thicker than those of PM 316L steel at the same cutting speed. Accordingly, the principal cutting forces when machining PM 2205 steel were higher than those when machining PM 316L steel at the same cutting speed.

F. *Work Hardening of Stainless Steel during Machining*

Work hardening of stainless steel during machining can be seen from the hardness values of the chip bottom, because the chip bottom can be considered as the most markedly deformed zone inside the chips. The microhardness values of the chip bottom of PM 316L and PM 2205 steels

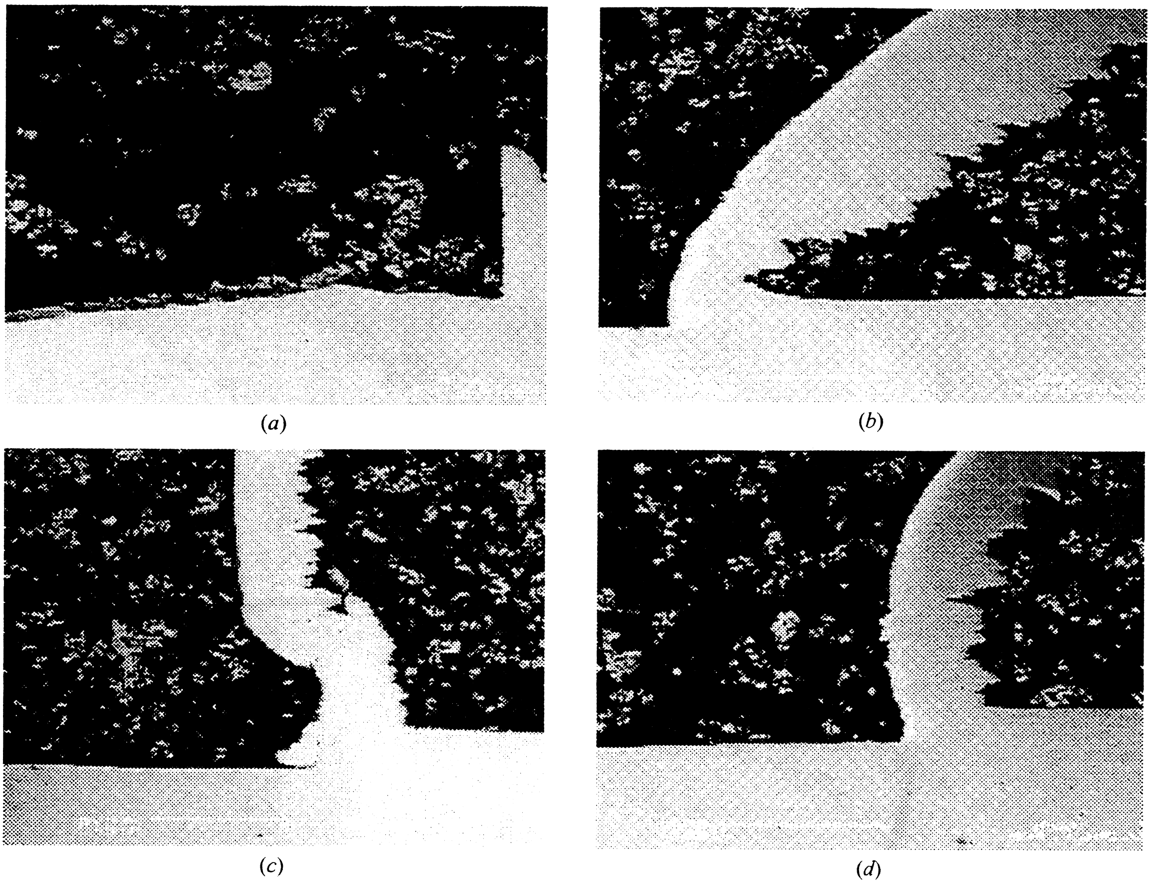


Fig. 9—(a) through (d) Macroscopic morphology of the chips of PM 316L steel in the low cutting speed range.

in the low cutting speed range, as an example, are shown in Figure 13. As compared with the original microhardness, it can be seen that the austenite phase of PM 316L steel and both the austenite and ferrite phases of PM 2205 steel undergo marked work hardening during machining. Further, it can be seen that the degree of work hardening (the change of microhardness value after turning) of PM 316L steel is much higher as compared with that of PM 2205 steel.

Similar conclusions can be drawn regarding the work hardening behavior of both steels during machining in the high cutting speed range.

IV. DISCUSSION

It was noticed in these tests that fatigue-induced failure was the dominant failure mechanism for TiN-coated HSS tools when machining PM 316L and PM 2205 steels at cutting speeds over 35 m/min in the low cutting speed range and for TiN-coated cemented carbide tools when machining these two steels in the whole high cutting speed range. It has been recognized that fatigue is induced by cyclic vibrations of the cutting forces which are related to the serrations of the chip.[3]

Based on the observations of the macroscopic morphology of the chips in the low cutting speed range, higher vibrations of the principal cutting force may be expected when machining PM 316L steel as compared with those when machining PM 2205 steel due to more serrated chips of PM 316L steel. As an example, the changes of output voltage of the piezoelectric force dynamometer when machining PM 316L and PM 2205 steels at a cutting speed of 55 m/min in the low cutting speed range are shown in Figures 14(a) and (b). There is a linear relationship between the cutting force and the output voltage, and therefore, the changes of the cutting force values can be seen from the changes of the values of the output voltage. Besides the larger amplitude, a higher vibration frequency of the principal cutting force was also recorded when machining PM 316L steel as compared with that when machining PM 2205 steel at the same cutting speed in the low cutting speed range. In the high cutting speed range, the chips were markedly serrated as compared with those in the low cutting speed range. However, little difference of the serrations of the chips of PM 316L and PM 2205 steels was observed in the high cutting speed range. Accordingly, while high frequencies and large amplitudes of the cutting force were

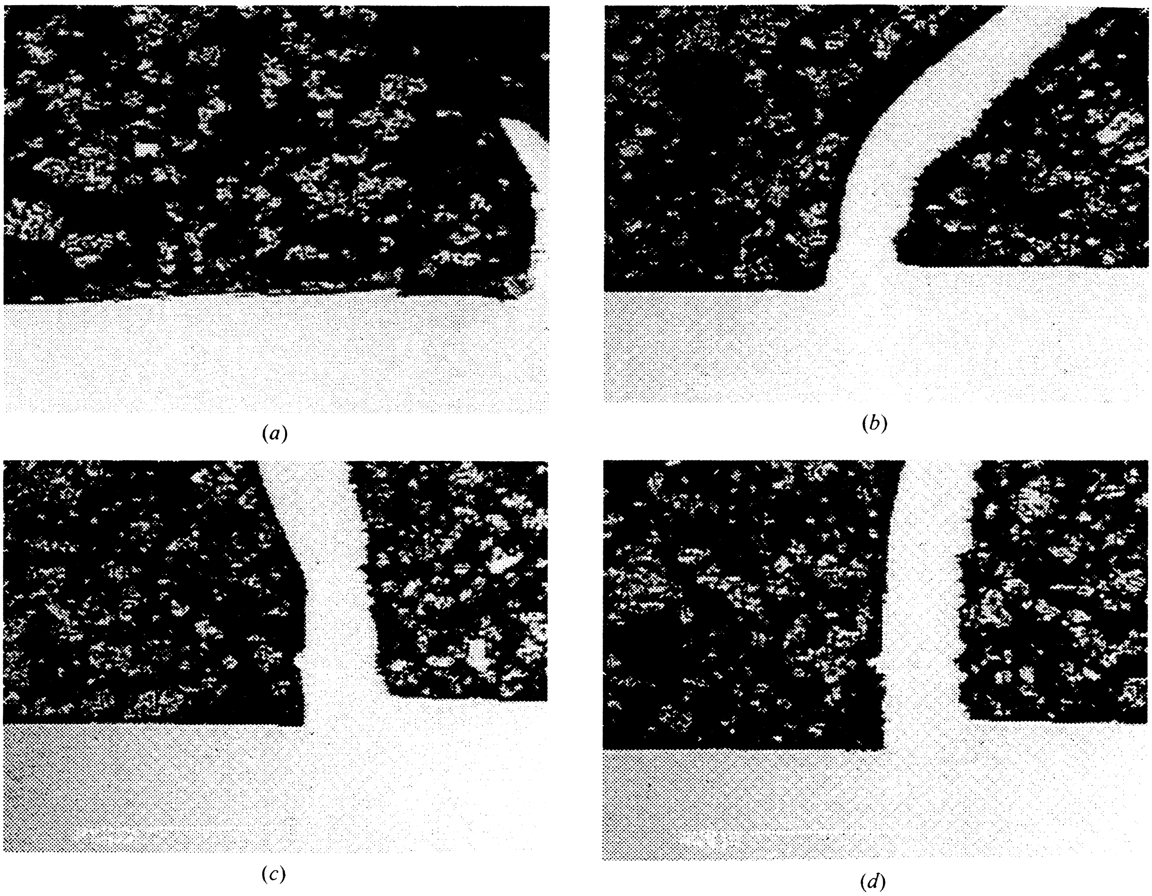


Fig. 10—(*a*) through (*d*) Macroscopic morphology of the chips of PM 2205 steel in the low cutting speed range.

recorded, there is little difference in the cutting force vibrations when machining both steels at the same cutting speed in the high cutting speed range, as shown in Figures 15(a) and (b) for PM 316L and PM 2205 steels, respectively.

It is normally accepted that deformation is concentrated to adiabatic shear bands if serrated chips are formed. As an example, the microstructure of a chip of PM 2205 steel at cutting speed of 200 m/min is shown in Figure 16. Heavy and slight deformation occur alternatively inside the chip. The heavy deformation zone seems like an adiabatic shear band. According to a previous study,[2] formation of heavily concentrated deformation zones in the chips of stainless steels was supposed to be due to high work hardening and low thermal conductivity. In addition, changes of the direction of strain in the different deformation zones (heavy and slight deformation) in the primary shear zone can also be recognized, which indicates that there have been cyclic changes of the shear angle of the stainless steel chips. The changes of shear angle may also be partially responsible for the serrations of the stainless steel chips, which agrees with an earlier study.[6]

The higher degree of work hardening would result in more concentrated deformation leading to more serrated chips. Also, the higher cutting temperature would promote the formation of serrated chips of the materials with low thermal conductivity. In the low cutting speed range, the cutting temperature when machining PM 316L and PM 2205 steels may not be very high, and only a slight difference of the cutting temperature when machining both steels may be expected. Accordingly, the work hardening degree may be the dominant factor affecting the degree of serration of the chips in the low cutting speed range. Based on the data concerning work hardening, it can be understood that the chips of PM 316L steel exhibit more marked serrations as compared with those of PM 2205 steel. In the high cutting speed range, however, the cutting temperature when machining both steels may be high and also a large temperature difference may be expected. Accordingly, the cutting temperature will, together with the high degree of work hardening, play an important role in producing serrated chips in the high cutting speed range. Due to much higher strength of PM 2205 steel, the cutting temperature when machining it is expected to be much higher than that when machining PM 316L steel in the high cutting speed range. The effect of the higher cutting temperature will

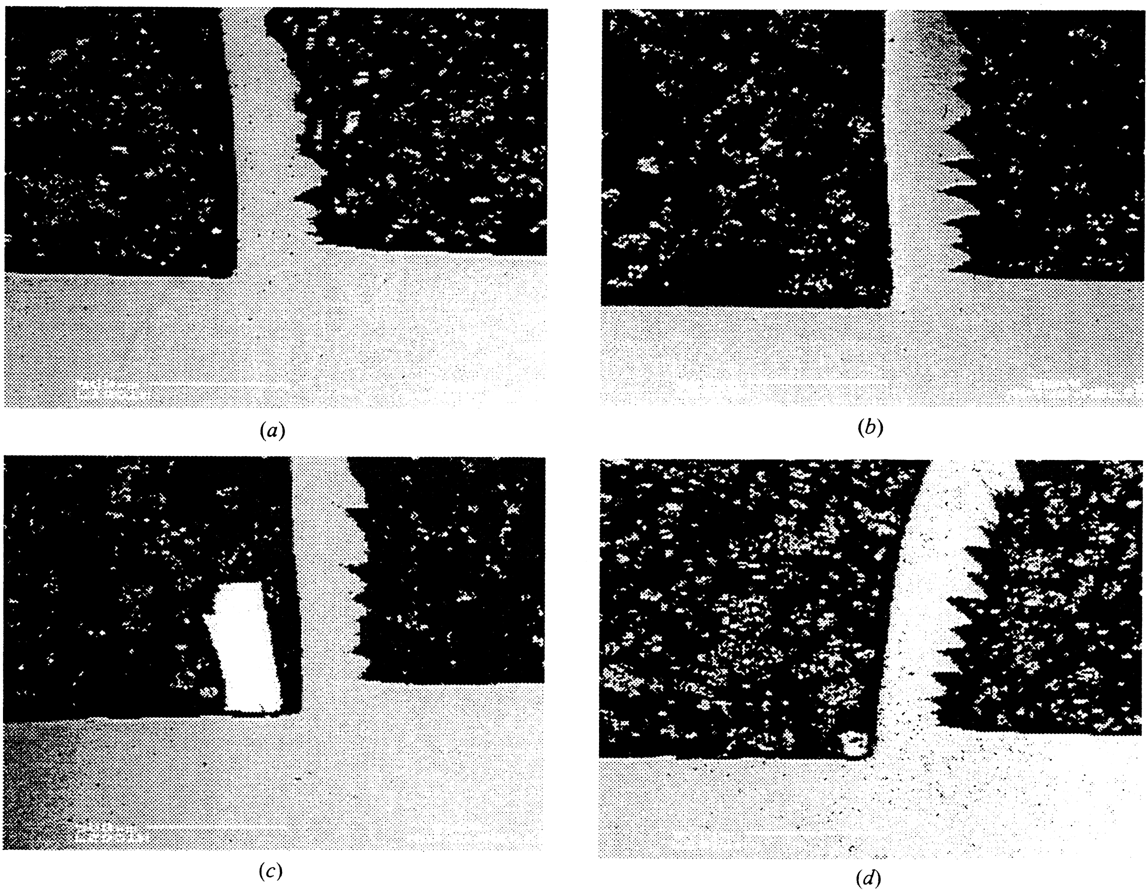


Fig. 11—(*a*) through (*d*) Macroscopic morphology of the chips of PM 316L steel in the high cutting speed range.

balance the effect of the lower degree of work hardening of PM 2205 steel on the degree of serration of the chips, resulting in chips with a degree of serration comparable to that of the chips of PM 316L steel in the high cutting speed range.

The tool life of TiN-coated HSS tool was longer when machining PM 2205 steel as compared with that when machining PM 316L steel in the low cutting speed range. At cutting speeds below 35 m/min, the abrasive wear mechanisms were dominant. Because of the higher work hardening degree of PM 316L steel, the fallen BUEs from PM 316L steel on the flank surface of the cutting tool are expected to have a slightly higher hardness and result in slightly more marked abrasive wear and, consequently, slightly shorter tool life as compared with those of PM 2205 steel. Although there were some other wear or failure mechanisms, fatigue-induced failure was the dominant and most rapid failure mechanism of TiN-coated HSS tools at cutting speeds over 35 m/min in the low cutting speed range. Based on macroscopic observations and hardness measurements of the chips of PM 316L and PM 2205 steels, it can be well understood that the chips of PM 316L steel exhibit a higher degree of serration leading to higher vibrations of the principal cutting force and therefore more marked fatigue of the cutting tools as compared with those of PM 2205 steel. Furthermore, it can be recognized that TiN-coated HSS tool has a longer tool life when machining PM 2205 steel as compared with that when machining PM 316L steel in the low cutting speed range.

In the high cutting speed range using TiN-coated cemented carbide tool, however, both fatigue-induced failure and diffusion wear mechanisms are cooperative and dominant in tool wear and failure. Based on the macroscopic observations of the chips, it can be seen that there was little difference in the serrations of the chips and accordingly little difference in the vibrations of the cutting forces when machining both PM 316L and PM 2205 steels in the high cutting speed range. Consequently, little difference of fatigue-induced failure of the tools can be expected to occur when machining both steels. The only mechanism contributing to the difference of tool lives when machining both steels is diffusion wear, which is markedly dependent on the cutting temperature. As discussed previously, the cutting temperature when machining PM 2205 steel may be expected to be much higher than that when machining PM 316L steel. Accordingly, the diffusion wear will be more

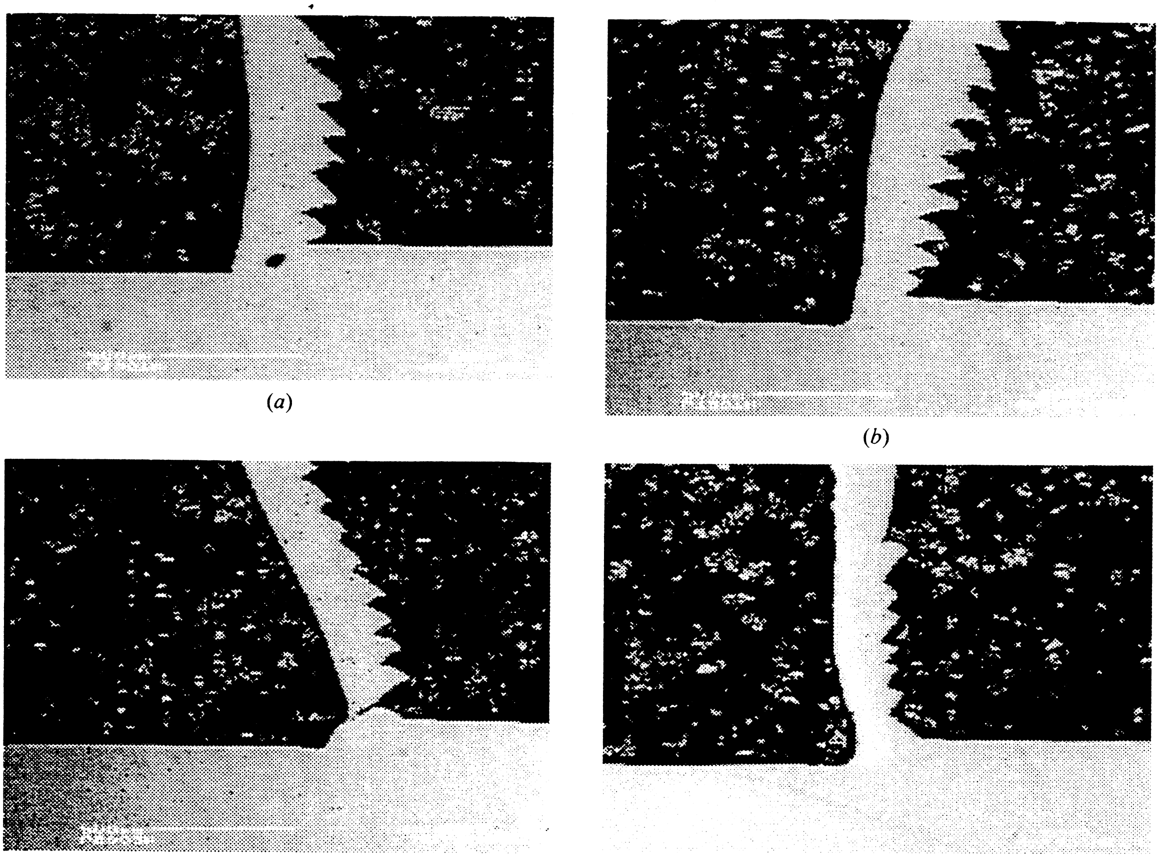


Fig. 12—(*a*) through (*d*) Macroscopic morphology of the chips of PM 2205 steel in the high cutting speed range.

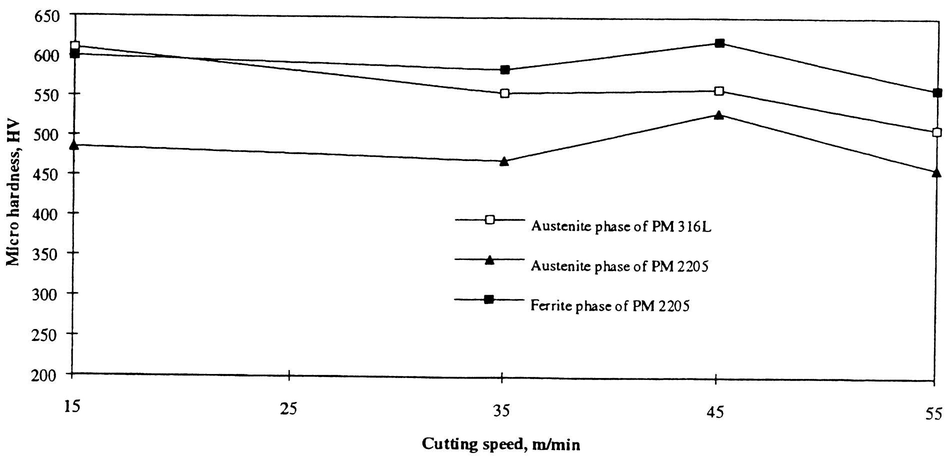


Fig. 13—Microhardness of austenite phase of PM 316L and both austenite and ferrite phases of PM 2205 steel at chip bottom in the low cutting speed range.

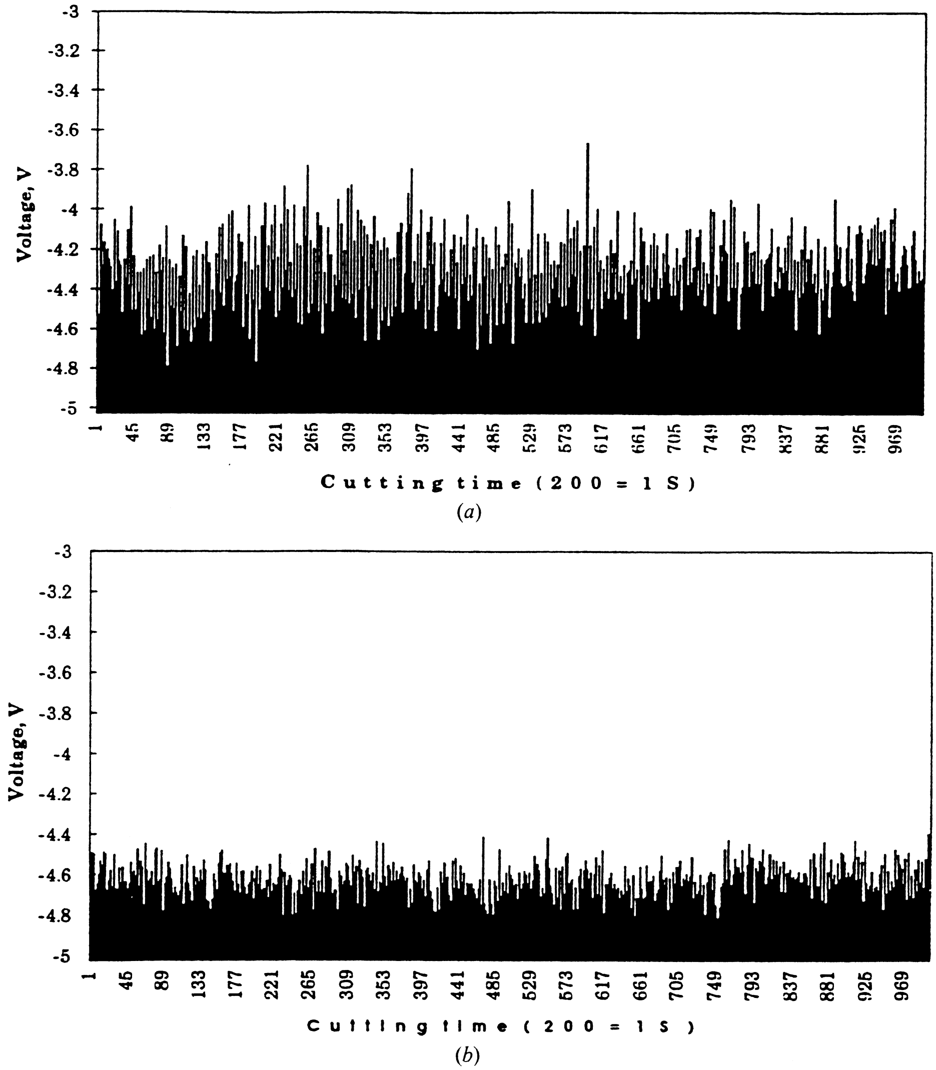


Fig. 14—Cyclic vibrations of cutting force when machining (*a*) PM 316L and (*b*) PM 2205 steels at a cutting speed of 55 m/min.

pronounced and, consequently, a shorter tool life for TiN-coated cemented carbide tool can be expected when machining PM 2205 steel as compared with those when machining PM 316L steel in the high cutting speed range.

The alloying elements of stainless steels may adversely affect the machinability and the performance of the cutting tools because of their strength-increasing role and particularly of the toughness-increasing role of Ni. Additional mechanisms contributing to the effects of the alloying elements on machinability of stainless steels or the performance of the cutting tool were investigated in this study by means of SEM and EDS analyses of TiN-coated cemented carbide tools in the high cutting speed range. It can be concluded that Ni and Mo promote diffusion wear because of the replacing diffusion of Ni from the workpiece and Co from the substrate of the tool and diffusion of Mo from the workpiece to the substrate, partially replacing W. No promotion of diffusion-induced wear of TiN-coated cemented carbide tool was caused by Cr.

V. CONCLUSIONS

TiN-coated HSS and TiN-coated cemented carbide tools were used for turning PM 316L and PM 2205 steels in the low and high cutting speed ranges, respectively. The tool lives and the cutting forces were measured, and the wear and failure mechanisms of the cutting tools were investigated. Particular attention was paid to the fatigue-induced failure. The following main conclusions can be drawn.

1. Abrasive wear, fatigue-induced failure, and diffusion

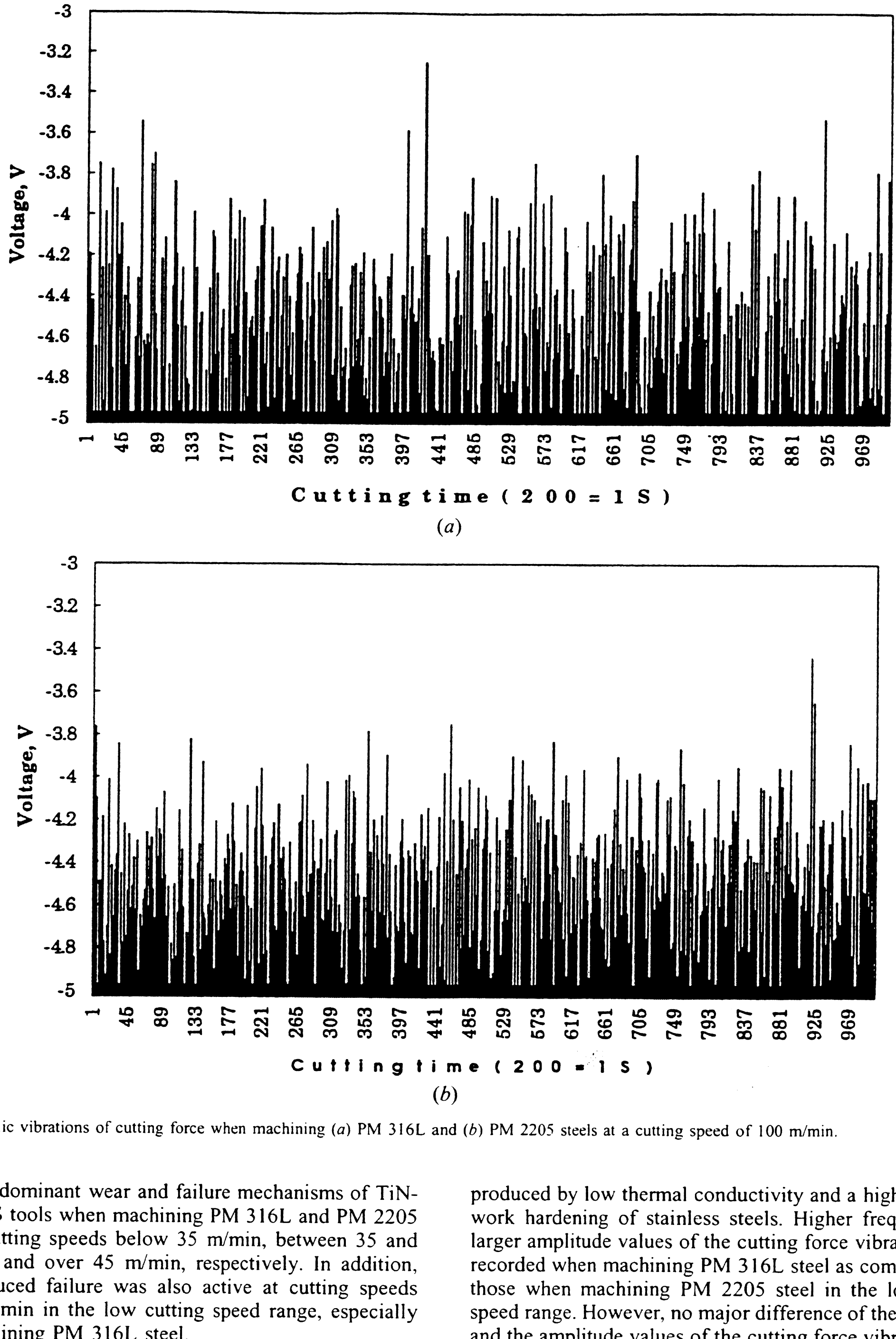


Fig. 15—Cyclic vibrations of cutting force when machining (*a*) PM 316L and (*b*) PM 2205 steels at a cutting speed of 100 m/min.

wear were dominant wear and failure mechanisms of TiN-coated HSS tools when machining PM 316L and PM 2205 steels at cutting speeds below 35 m/min, between 35 and 45 m/min, and over 45 m/min, respectively. In addition, fatigue-induced failure was also active at cutting speeds over 45 m/min in the low cutting speed range, especially when machining PM 316L steel.

2. Fatigue-induced failure, together with diffusion wear, was the dominant failure mechanism for TiN-coated cemented carbide tools in the whole high cutting speed range.

3. Fatigue affecting the cutting tool lives when machining PM 316L and PM 2205 steels was caused by serrated chips produced by low thermal conductivity and a high degree of work hardening of stainless steels. Higher frequency and larger amplitude values of the cutting force vibrations were recorded when machining PM 316L steel as compared with those when machining PM 2205 steel in the low cutting speed range. However, no major difference of the frequency and the amplitude values of the cutting force vibrations was recorded when machining both steels in the high cutting speed range.

4. TiN-coated HSS tool had longer tool life when machining PM 2205 steel as compared with that when machining PM 316L steel in the low cutting speed range, which was

Fig. 16—Cyclic deformation of a chip of PM 2205 steel at a cutting speed of 200 m/min.

attributed to the lower fatigue-induced damage when machining PM 2205 steel.
5. TiN-coated cemented carbide tool had longer tool life when machining PM 316L steel as compared with that when machining PM 2205 steel in the high cutting speed range, which was supposed to be due to the lower cutting temperature resulting in less diffusion wear when machining PM 316L steel.
6. Of the alloying elements in stainless steels, Ni and Mo promote diffusion wear of TiN-coated cemented carbide tools because of replacing diffusion of Ni from the workpiece to the tool and Co from the cemented carbide substrate to the workpiece and diffusion of Mo from the workpiece to the substrate, partially replacing W.

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