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# An Investigation into the Microstructure of Adiabatic Shear Banding in AISI 1045 Hardened Steel due to High Speed Machining

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**Abstract.** Adiabatic shear banding during high speed machining is important to understand material removal mechanisms. This paper investigates the microstructure of adiabatic shear band$_s$ (ASB$_s$) in the serrated chips produced during the high speed machining of AISI 1045 hardened steel. Optical microscope, scanning electronic microscope(SEM) and transmission electronic microscope(TEM) were used to explore the microstructural characteristics. It was found that there are two types of adiabatic shear bands. One is the deformed adiabatic shear band composed of a significantly deformed structure generated in a range of low cutting speeds, and the other is the transformed adiabatic shear band composed of very small equiaxed grains generated under high cutting speeds. The results indicated that the deformed band has a tempered martensite structure that formed through large plastic deformation and the transformed band has experienced a dynamic recrystallization process.

## Introduction

Hard high speed machining (HHSM) is a new technology to cut high hardness materials under a high cutting speed. With the development of supper-hard tool materials such as diamond, PCBN, ceramics, and TiC(N) hard alloys, hard high speed machining has had a wide range of application and has been used to replace grinding in some cases.

There are obvious differences in the material removal mechanisms between HHSM and conventional machining. Serrated chip have frequently formed during the HHSM of hardness steel, Ti alloys and Ni-Fe supper alloys, which has a significant influence on cutting forces, cutting temperature, tool wear, and quality of machined surface. Therefore, the formation mechanisms of serrated chips have received much attention. Many experiments have indicated that adiabatic shear bands form in the primary shear zone between the sawteeth in a serrated chip [1-4]. This is a ribbon structure with special microstructure that forms after the localized adiabatic shear deformation in the primary shear zone during HHSM. Adiabatic shear phenomenon has a decisive effect on the formation of serrated chip, so the microstructural observation of adiabatic shear band will be helpful for revealing the material softening mechanism during serrated chip formation. However, there has been little work reported concerning the formation and microstructure of these ASBs due to the difficulty of specimen preparation**,** particularly for transmission electron microscopy (TEM) samples. As a result, the microstructural nature of adiabatic shear band generated during HHSM of hardened steel has not been clear.

The aim of this paper is to understand the microstructure of adiabatic shear band in serrated chip produced by the HHSM of AISI 1045 hardened steel.

## Experiment

The workpiece material for this study was AISI 1045 steel. Ingots of the steel before heat treatment were machined into hollow cylindrical workpieces with the diameter of φ153mm and thickness of 2.5mm. The heat treatment process was as follows: heating the workpiece to 850℃ in vacuum and maintaining at this temperature for 70 minutes; then quenching it in salt water, followed by a tempering at 360℃ for 5 hours. The obtained hardness of the workpieces was HRC 50. The cutting tool was a carbide blade, YT15. The HHSM was a dry turning process, carried out on a lathe, CA6140. In order to keep the sharpness of the cutting tool noses, the cutting inserts were replaced as required during the experiment. The cutting conditions used were: cutting speed $v$ = 48m/min～538m/min, cutting thickness $a_c$ = 0.15mm and 0.2mm, tool rake angle $\gamma_0$ = 10°and -10°. The chips formed with different cutting parameters were set vertically into the bakelite powder. After grinding, polishing and eroding, the chip morphology and microstructure were examined under a Neuphot-Ⅱ optical microscope. The specimens for TEM characterization were prepared by electroplating metal on two sides of the chips to increase the total area prior to electropolishing and were observed by H-800 TEM operated at 200kv, L λ = 24.33 mmÅ.

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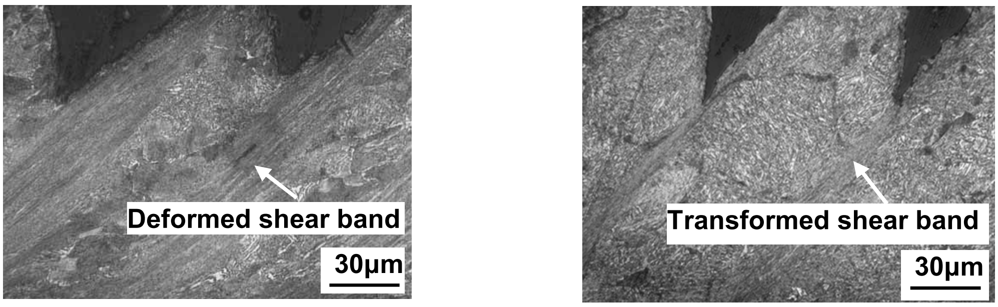
**Results and Discussion**

**Observation using Optical Microscopy and SEM.** Figure 1 shows the optical microscopic morphology of the ASBs under two different cutting conditions. It can be seen that ASBs locate in the primary shear zones between the sawteeth, and can be divided into two types. One is the shear band with highly localized strains, whose width changes in a wide range but whose material has no sign of phase transformation. The primary shear zone experienced severe plastic deformation, with intensive shear deformation and high density of slip lines. Therefore this type of ASBs are deformed bands, see Figure 1 (a). The other type of ASBs show bright, smooth and white band morphology after corrosion. There are distinct differences between white band (width = ~ 3-10 $\mu m$) and the rest of the chip material, which is a sign of microstructural transformation under the effect of adiabatic temperature. This is a transformed band, see Figure 1 (b).

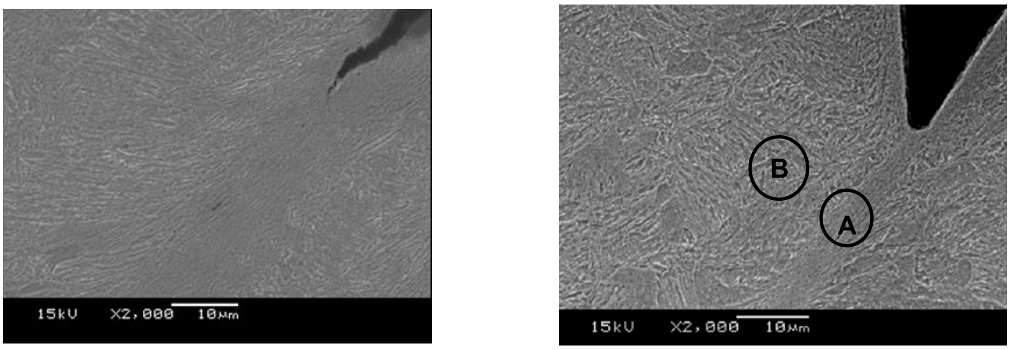



($\gamma_0$= 10°, $a_c$ =0.2mm, $v$=432.6m/min ) ($\gamma_0$= -10°, $a_c$ =0.15 mm, $v$=432.6m/min )

(a) deformed shear band (b) transformed shear band

Figure 1 Optical micrographs of adiabatic shear bands.

After the formation of the serrated chip during the high speed cutting, with the increase in cutting speed or decrease in tool rake angle, an ASB may change from a deformed band to a transformed band. Figure 2 is the SEM micrographs of a deformed and a transformed band. There is no clear boundary between the deformed band and the surrounding chip material, indicating that the material in the deformed shear band changed its geometry due to the elongation along the shear direction. No microstructural transformation occurred, see Figure 2 (a). In Figure 2 (b), the microstructure of the transformed band can be divided into two regions, A and B. Unlike the previous case, the elongated structure cannot be seen in the ASB. However, a lot of very fine non-deformed structures are present. Some researchers suggested that a phase transformation in the transformed band occurred because the adiabatic temperature rise in the shear band could be above the phase transition temperature [5,6], but some others proposed that the dynamic recrystallization in the transformed band might have taken place [7].

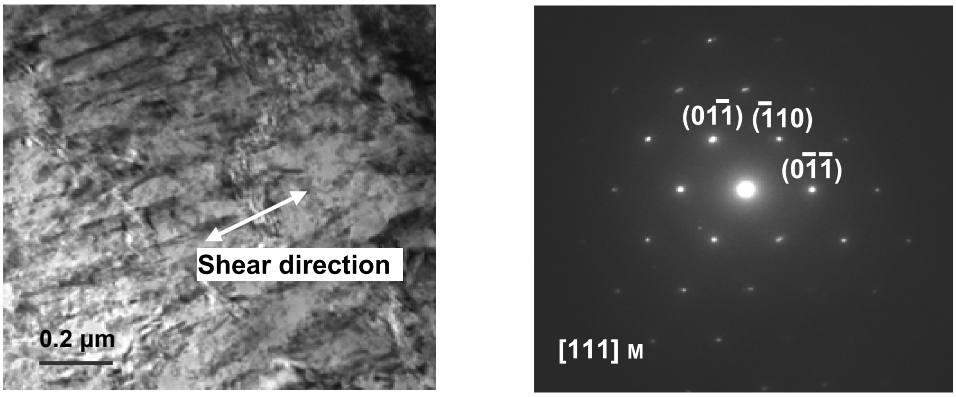



( $\gamma_0$= 10°, $a_c$ =0.2mm, $v$=432.6m/min ) ( $\gamma_0$= -10°, $a_c$ =0.15 mm, $v$=432.6m/min )

(a) deformed shear band (b) transformed shear band

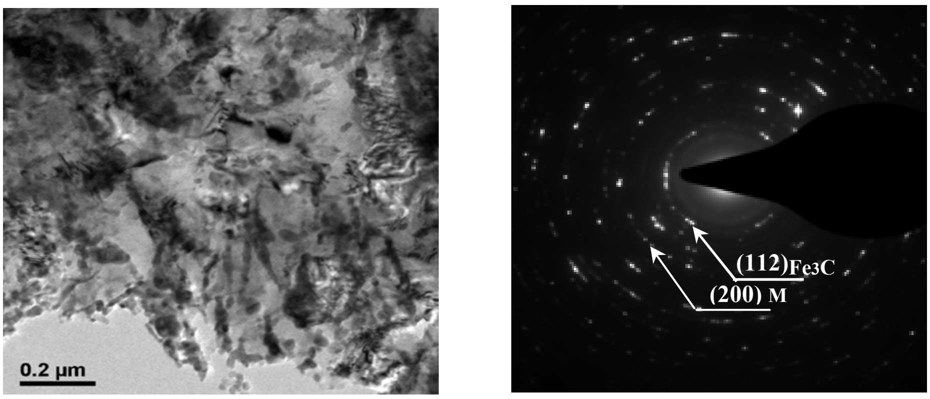
Figure 2 SEM micrographs of adiabatic shear band

**Observation Using TEM.** TEM was used to further reveal the microstructural nature of the ASBs. Figure 3(a) shows the fine microstructure in the center of a deformed band. It can be seen that the martensite laths were elongated along the shear direction and were broken. There were dense dislocations within and between the laths. The diffraction pattern in Figure 3 (b) shows that the structure is a regular martensite.




(a) BF Image (b) diffractive pattern

Figure 3 TEM micrographs of deformed shear band




(a) BF Image (b) diffractive pattern

Figure 4 TEM micrographs of transformed shear band

Figure 4 (a) is a BF image, showing that there are a large number of very fine equiaxed grains, about 100-200nm in diameter, with a low density of dislocations. However, elongated laths did not appear. The ring-like electron diffraction pattern with intermittent spots, Figure 4(b), demonstrates that these fine grains are of polycrystalline with random orientations.The indexing of polycrystalline diffraction rings shows that these equiaxed grains are composed of martensite and cementite without residual austenite, indicating that the temperature in the central area of the transformed band did not reach the austenitizing temperature during HHSM and hence martensitic transformation should not have occurred there. Meyers and Pak [8] proposed that such equiaxed grains in the center of shear band could be the result of dynamic recrystallization. Because the time of the shear localization process is very short, on the order of a few microseconds [8] based on the strain rate of the cutting tests in this study, grain boundary migration is unlikely to occur in such a short period of time. In other words, the recrystallization machnism *via* grain boundary migration based on atomic diffusion should not be the case for the formation of the fine equiaxed grains in the adiabatic shear banding here.

## Conclusions

Based on the experimental observations of the microstructures of the adiabatic shear bands within the serrated chips in high speed machining of AISI 1045 hardened steel, we can draw the the following conclusions:

(1) Two types of ASBs within the serrated chip formed, the deformed band characterized by large plastic deformation and the transformed band characterized by microstructure refinement. Although both are the manifestations of ASBs after shear localization, there are essential differences between them in their formation mechanisms.

(2) The martensite laths in the deformed band were elongated along the shear direction and were broken. There were dense dislocations within and between the laths. These confirm that during the formation of the deformed band, the microstructure had only experienced large plastic deformation. The center of the transformed band is composed of very fine equiaxed grains with a low dislocation density. However, the formation mechanism of the fine equiaxed grains in the adiabatic shear banding is still unclear and a further study is necessary.

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## References

[1] T. J.Burns and M.A.Davies, International Journal of Plasticity Vol.18 (2002), p.487
[2] A. Molinari, C. Musquar and G.Sutter, International Journal of Plasticity.Vol.18 (2002), p.443
[3]J.D. Puerta Vasqueza, B. Bolle, P. Chevrier and et.al, Materials Science and Engineering A Vol. 452-453 (2007), p.469
[4] C.E. Campbell, L.A. Bendersky, W.J. Boettinger and et.al, Materials Science and Engineering A Vol.430 (2006),p.15
[5] M.A.Meyers and C.L. Wittman, Metall.Trans.Vol. 21A(1990),p.3193.
[6] M.A.Meyers, U.R.Andrade and A.H.Chokshi, Metall.Trans.Vol.26A(1995),p.2881.
[7] M.A.Meyers,Y.B.Xu, Q.Xue and et.al, Acta Mater.Vol.51(2003),p.1307.
[8] M.A.Meyers and H.R.Pak,Acta Metall.Vol.34(1986),p.2493

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