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Analytical and Experimental Study of Shear Localization in Chip Formation in Orthogonal Machining

J.Q. Xie, A.E. Bayoumi, and H.M. Zbib

A simplified theory of instability of plastic flow is applied to analyze the formation of shear localized chips in orthogonal machining. A flow localization parameter is expressed in terms of associated cutting conditions and properties of the workpiece material. The analysis, which indicates the important parameters in the cutting process, is used to investigate the effect of cutting conditions on the onset of shear localization and the formation of adiabatic shear banding in metal cutting. Comparisons are made between the analysis and experiments in which the flow localization parameter is obtained for several workpiece materials. The results of this investigation seem to support the analysis and its potential benefits in analyzing and/or remedying problems associated with chip formation and temperature generated in metal cutting.

Keywords

chip formation, machining, shear localization, flow localization parameter, adiabatic shear banding, metal cutting, cutting conditions

1. Introduction

THE machining process, although superficially simple, is a complex manufacturing operation. In recent years, as development and innovation in manufacturing engineering have advanced, so too has basic research on the process of chip formation. Such fundamental knowledge can help in the solution of practical problems. Many parameters in metal machining, including cutting force, temperature, tool wear, friction between tool face and chip, machining power, surface finishing, and machined surface integrity, are related to the chip formation process. Many practical problems, such as vibration, built-up edges, and chip control/breaking, also are related to this basic phenomenon.

Traditionally, most investigations of metal cutting have focused on continuous smooth flow accompanying stable chip formation. The continuous chip is ideal for analysis because it is relatively stable, allowing many conditions to be simplified. However, in actual automatic machining, a continuous chip interferes with the machining process and may cause unpredictable flaws and damage on the machined surface, cutting tool, or machine tool, or even operator injury. State-of-the-art machine tools and other improvements in metal cutting have resulted in high production efficiency. A large number of chips can be generated under a high metal-removal percentage in a unit time. Less consideration and effort, however, have been directed to the handling of chips. In some cases, production efficiency may have to be reduced in order to handle continuous chips. A segmented chip that has some shear localization (Fig. 1) is easier to break and to dispose of during automated machining. Therefore, predicting the cutting conditions that lead to a serrated chip is very useful. Machining under such cutting conditions may reduce manpower and additional requirements for cleaning and chip disposal, increase production efficiency, and thus further reduce production costs.

Theoretical or analytical analyses of the mechanisms of shear localization in chips has been limited. There is no standard parameter by which to judge the onset of shear instability in chips. Metal cutting is one process where flow localization can be observed. It is believed that most serrated chips are caused by flow (shear) localization during chip deformation. Bands of intense shear that divide the chip into segments occur in the metal cutting process (Fig. 2). These bands are very thin layers with extremely concentrated shear strain that may cause the chip to become easily separated and broken. Although in some cases the serrated chip may not be completely broken, a certain amount of damage within the chip material occurs because of the large strains inside the shear bands.

This study applies the theory of shear banding to the analysis of chip formation and chip instability. A mechanistic model is developed to predict quantitatively the critical cutting conditions that a shear localized chip may encounter. This is done by establishing a relationship between the flow localization parameter and related governing cutting conditions, that is, cutting speed and feed rate.

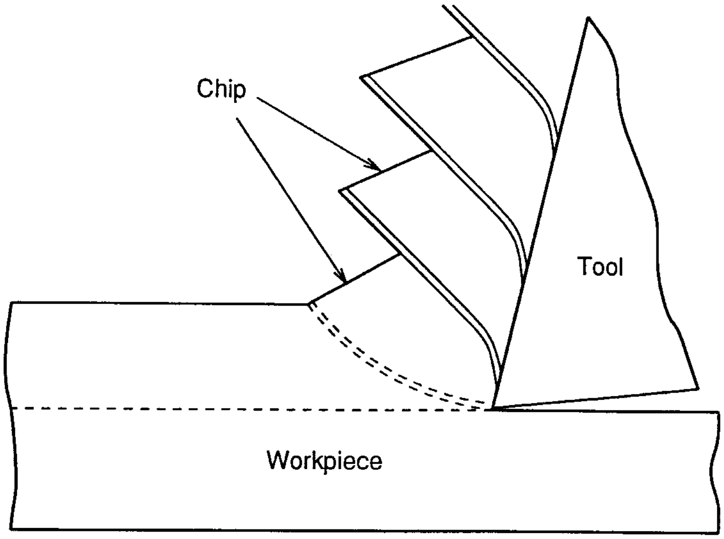

Fig. 1 Segmented chip due to shear localization

J.Q. Xie (presently at Advanced Technology Center, Valenite, Inc., Madison Heights, MI 48071, USA), **A.E. Bayoumi,** and **H.M. Zbib,** Department of Mechanical and Materials Engineering, Washington State University, Pullman, WA 99164-2920, USA.

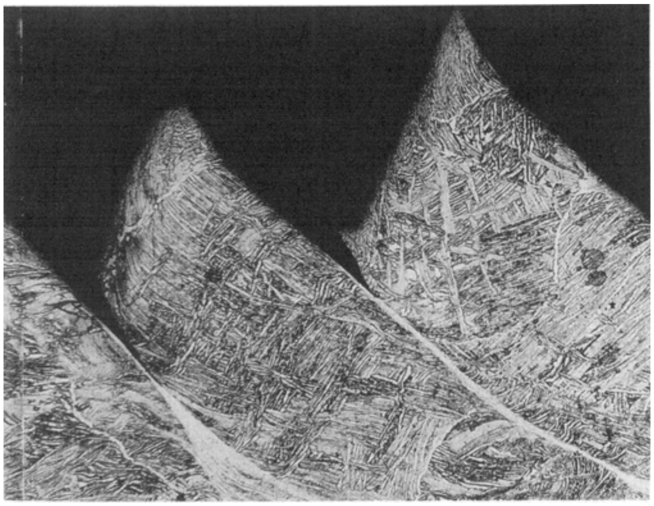

Fig. 2 Shear localized chip with shear bands in Ti-6Al-4V

2. Flow Localization Analysis of Chip Formation in Orthogonal Cutting

Adiabatic shear banding is used to describe a localization phenomenon that occurs in high-strain-rate plastic deformation processes such as metal machining. At a high strain rate and at a critical value of strain, shear bands, or narrow regions of highly localized plastic strains, may form. In this case, although the heating generated by plastic strains raises the workpiece temperature, a very small amount of heat transfer occurs between the workpiece and the tool because of the very short time of deformation. Thus, it is possible to focus the discussion of flow localization on nominally isothermal conditions for the tool and on adiabatic conditions for the workpiece.

In order to evaluate and predict the onset of instability in the chip, a relationship must be established between the flow localization parameter (see, for example, Ref 1) and the cutting conditions. The flow localization parameter, β, is defined as:

$$\beta = \frac{\partial \log \dot{\varepsilon}}{\partial \varepsilon} = \frac{1}{\dot{\varepsilon}} \frac{d\dot{\varepsilon}}{d\varepsilon} = \frac{\sqrt{3}}{\dot{\gamma}} \frac{d\dot{\gamma}}{d\gamma} \qquad \text{(Eq 1)}$$

where ε and $\dot{\varepsilon}$ are the normal strain and strain rate in tension, respectively; and γ and $\dot{\gamma}$ are the shear strain and shear strain rate in simple shear, respectively.

As shown in Fig. 3, under the plane strain conditions of orthogonal cutting, shear localization in a chip may initiate along the zero extension direction, y, which is at an angle of ϕ (shear zone angle) to the cutting speed direction. During the steady cutting process, the cross-sectional area of the shear zone does not change with position. Furthermore, the momentum equation across the band is given by:

$$\frac{d\tau}{dx} = \rho \dot{v} \qquad \text{(Eq 2)}$$

where τ is the shear stress in the y direction, x is the coordinate perpendicular to the shear plane angle direction y, ρ is the mass density, and v is the particle velocity in the y direction. This implies that the deformation across the band is approximated as a one-dimensional simple shearing. Moreover, Eq 2 implies that the state of deformation is homogeneous in the y direction. The stability of this state can be examined by considering a linear stability analysis similar to that of Clifton (Ref 2) and Zbib and Aifantis (Ref 3). This analysis leads to the conclusion that the homogeneous state of deformation becomes unstable when the shear flow stress τ reaches its maximum, leading to shear instability and shear band formation. Thus, within a one-dimensional treatment, shear instability becomes possible when

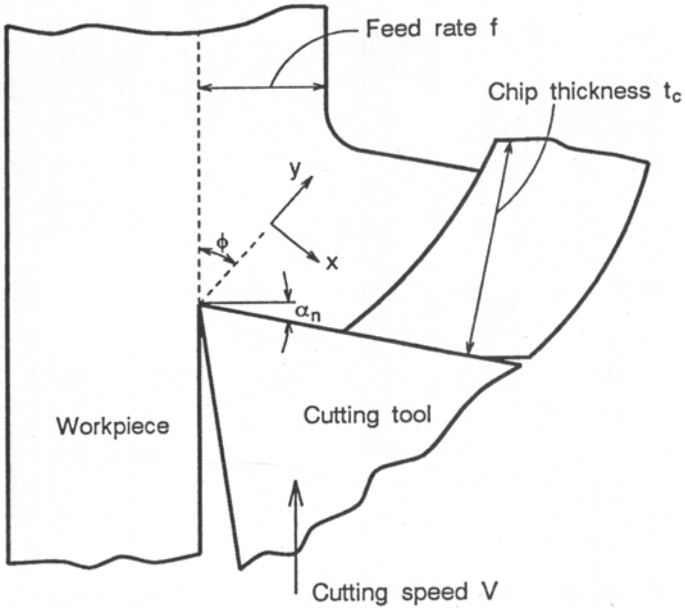

Fig. 3 Schematic of orthogonal machining

$$d\tau \leq 0 \qquad \text{(Eq 3)}$$

As mentioned in Section 1, the process of metal cutting involves high strain rates accompanied by adiabatic heating. Thus, consider a thermoviscoplastic model for τ such that

$$\tau = \tau(\gamma, \dot{\gamma}, T) \qquad \text{(Eq 4)}$$

where T is the absolute temperature. Then Eq 3 yields:

$$\left.\frac{\partial \tau}{\partial \gamma}\right|_{\dot{\gamma},T} d\gamma + \left.\frac{\partial \tau}{\partial \dot{\gamma}}\right|_{\gamma,T} d\dot{\gamma} + \left.\frac{\partial \tau}{\partial T}\right|_{\gamma,\dot{\gamma}} dT = 0 \qquad \text{(Eq 5)}$$

The strain-rate sensitivity, m, and the strain-hardening parameter, μ, are defined as:

$$m = \frac{\dot{\gamma}}{\gamma} \left.\frac{\partial \tau}{\partial \dot{\gamma}}\right|_{\gamma,T}$$

$$\mu = \frac{1}{\tau}\frac{\partial \tau}{\partial \gamma}\bigg|_{\dot{\gamma},T} \qquad \text{(Eq 6)}$$

With these definitions, Eq 5 becomes

$$\frac{1}{\dot{\gamma}}\frac{d\dot{\gamma}}{d\gamma}m + \mu + \frac{1}{\tau}\frac{\partial \tau}{\partial T}\bigg|_{\dot{\gamma},\gamma}\left(\frac{dT}{d\gamma}\right) = 0 \qquad \text{(Eq 7)}$$

Finally, the expression for the flow localization parameter, β, for orthogonal cutting can be derived from the definition given by Eq 1 and the shear banding condition given by Eq 7 as:

$$\beta = -\frac{\sqrt{3}}{m}\left[\mu + \frac{\partial \tau}{\partial T}\bigg|_{\gamma,\dot{\gamma}}\left(\frac{1}{\tau}\frac{dT}{d\gamma}\right)\right] \qquad \text{(Eq 8)}$$

The flow localization parameter, β, is useful for ranking the tendency for strain concentration within a material. Therefore, a certain critical value of β must exist which should be reached at the onset of flow localization. This postulation makes it possible to set a criterion for cutting conditions through β to predict the initiation of shear bands in the workpiece material and hence the occurrence of serrated chips. Section 3 develops a relationship between the flow localization parameter, β, and the two major governing parameters in the metal cutting process: feed rate, *f*, and cutting speed, *V*.

3. Determinations of Related Material Properties

In Eq 8, the terms *m*, μ, and $(\partial\tau/\partial T)$ are material properties that can be expressed as functions of γ, $\dot{\gamma}$, and *T*. These terms can be determined by means of conventional mechanical property tests. This apparently is an advantage of employing the flow localization parameter, β, to analyze the shear localized chips. Applying Eq 8 to the analysis of chip formation requires that several related material properties be determined.

Many experimental results have shown that cutting speed and feed rate play important roles in chip instability. In metal cutting, the cutting speed, *V*, and the feed rate, *f*, are the major governing parameters that significantly influence variables such as temperature, machined surface quality and integrity, wear and tool life, and production efficiency. It is thus practical and reasonable to include cutting speed and feed rate in the equation of the flow localization parameter, β, as governing parameters to analyze chip instability. The cutting speed and feed rate can be introduced through the term of temperature change rate during deformation in Eq 8.

The difficulty of measuring temperature in the shear zone in practice has led to many theoretical analyses of the temperature in the shear zone. The main theoretical models for temperature changes during the metal cutting process were developed in the 1950s (Ref 4-7). Loewen and Shaw's model (Ref 4) is one of the more successful and practical ones. Following their method, the rate of shear energy expended in the shear zone, E_{sh}, can be expressed as $E_{sh} = (F_{sh} \cdot V_{sh})$, where F_{sh} is the shear force along the shear zone and V_{sh} is the shear velocity. Then the energy rate expended per unit area on the shear zone for the orthogonal cutting process is given by:

$$E_s = \frac{E_{sh}}{A_{sh}} = \frac{F_{sh}V_{sh}\sin\phi}{bt} \qquad \text{(Eq 9a)}$$

where $A_{sh} = (bt/\sin\phi)$ is the shear zone, *b* is the width of the workpiece, *t* is the undeformed chip thickness, and ϕ is the shear zone angle. It can be seen from Fig. 3 that for the orthogonal machining condition, the undeformed chip thickness, *t*, is equivalent to the feed rate, *f*. Therefore, Eq 9(a) can also be written as:

$$E_s = \frac{F_{sh}V_{sh}\sin\phi}{bf} \qquad \text{(Eq 9b)}$$

Assuming that 90% of the shear deformation work, E_{sh}, is converted into heat (see also Ref 2 and 3), the total heat generated is given by:

$$Q_{sh} = 0.9\,E_s = \frac{0.9\,F_{sh}V_{sh}\sin\phi}{bf} \qquad \text{(Eq 10)}$$

A fraction of this heat, designated by R_1, is generated within the chip inside the shear zone. Then the mean temperature of the chip in the shear zone is given by:

$$T_{sh} = \frac{R_1 Q_{sh} A_{sh}}{\rho c Z_w} + T_0 = \frac{R_1 Q_{sh}}{\rho c V \sin\phi} + T_0 \qquad \text{(Eq 11a)}$$

where ρ is the density of the workpiece material, *c* is the specific heat, $Z_w = (Vbf)$ is the volume of metal removed in the unit time (metal removal rate), and T_0 is the ambient temperature. Using $V_{sh} = (\gamma V \sin\phi)$ (Ref 8) and Eq 10, T_{sh} can be derived as:

$$T_{sh} = \frac{0.9\,R_1 \gamma F_{sh}\sin\phi}{\rho c b f} + T_0 \qquad \text{(Eq 11b)}$$

According to Loewen and Shaw (Ref 4), the value of the percentage coefficient of heat transfer, R_1, in Eq 11 can be calculated from:

$$R_1 = \frac{1}{1 + 1.328\sqrt{\dfrac{K_1\gamma}{Vf}}} \qquad \text{(Eq 12)}$$

where K_1 is the thermal diffusivity of the workpiece material (at the temperature T_{sh}), γ is the shear strain in the chip, *V* is the cutting speed, and *f* is the feed rate. Thus, Eq 11(b) becomes

$$T_{sh} = \frac{1}{1 + 1.328\sqrt{\frac{K_1\gamma}{Vf}}}\,\frac{\gamma}{\rho c}\,\frac{0.9\,F_{sh}\sin\phi}{bf} + T_0 \qquad \text{(Eq 13a)}$$

On the other hand, the shear stress in the shear zone is given by:

$$\tau = \frac{F_{sh}}{A_{sh}} = \frac{F_{sh}\sin\phi}{bf} \qquad \text{(Eq 13b)}$$

where F_{sh} is the shear force. Thus, Eq 13(a) becomes

$$T_{sh} = \frac{0.9}{1 + 1.328\sqrt{\frac{K_1\gamma}{Vf}}}\,\frac{\tau\gamma}{\rho c} + T_0 \qquad \text{(Eq 14)}$$

The term $(1/\tau)(dT/d\gamma)$ in the expression for the flow localization parameter (Eq 8) can be obtained by taking the derivative of T with respect to γ in Eq 14. In this equation, the shear stress, τ, should not be considered as a constant when taking the derivative of T with respect to γ, because τ may be a function of γ. By using the power law relation,

$$\tau = \tau_0\gamma^n\left(\frac{\dot{\gamma}}{\dot{\gamma}_0}\right)^m\left(\frac{T}{T_0}\right)^\nu \qquad \text{(Eq 15)}$$

where τ_0, $\dot{\gamma}_0$, and T_0 are constant reference values, n is the strain-hardening exponent, and $\nu(<0)$ is the thermal softening parameter, along with Eq 14, we obtain:

$$\frac{1}{\tau}\frac{dT}{d\gamma} = \frac{0.9}{\rho c\left(1 + 1.328\sqrt{\frac{K_1\gamma}{Vf}}\right)}\left\{n + 1 - \frac{0.664\frac{\sqrt{K_1\gamma}}{Vf}}{1 + 1.328\sqrt{\frac{K_1\gamma}{Vf}}}\right\} \qquad \text{(Eq 16)}$$

where c is the specific heat of the workpiece material, K_1 is the thermal diffusivity, and ρ is mass density. The shear strain, γ, during cutting can be determined as $\gamma = \tan(\phi - \alpha_n) + \cot\phi$, where α_n is the rake angle and ϕ is the shear zone angle. Although $\gamma = \tan(\phi - \alpha_n) + \cot\phi$ is originally derived from a continuous chip, it is apparent that a similar result can be obtained using this equation for the chip segment that is under formation at the moment of current cutting process (Fig. 1). In Eq 16, V and f are known as cutting conditions, and ρ, c, K_1, and n are material properties that can be found in various reference sources (Ref 9-11).

Another important term in Eq 8 is the slope of the temperature dependence of shear stress, $(\partial\tau/\partial T)$, which can be determined from the relationship between the flow stress and temperature as given by Eq 15. This equation can be fitted to experimental curves that include the effect of elevated temperature on the mechanical properties of metals (e.g., Ref 10). In some previously published studies (Ref 12, 13), the slope of the temperature dependence of shear stress, $(\partial\tau/\partial T)$, as a function of the tempering temperature was obtained and used. However, it is not reasonable to consider the tempering temperature as an important factor on $(\partial\tau/\partial T)$, because many microstructural changes may take place in the material during the period of the tempering process, leading to structures different from those present in the dynamic straining operation. Thus, the materials parameters n, m, and ν can all be determined from experimental curves for a specific material. In addition, using the power law in Eq 15 and the definition given by Eq 6, it can be easily verified that

$$\mu = \frac{n}{\gamma} \qquad \text{(Eq 17)}$$

It should be noted that not all the material parameters needed to derive Eq 16 from Eq 8 are directly available or easily obtained from current material handbooks. Some material properties, such as $(\partial\tau/\partial T)$ and $(1/\tau)(\partial T/\partial\gamma)$, may have to be determined indirectly from other material parameters. One reason for the inaccessibility of these material parameters is that they have not been used significantly. However, they are not difficult to obtain from certain material property tests (Ref 14). The outcome of this study suggests that these material parameters be included in related materials handbooks along with other standard material properties. Then, the application of the flow localization parameter will become more straightforward.

4. The Flow Localization Parameter and Its Application

Combining Eq 8, 16, and 17, the final form of the flow localization parameter is given by

$$\beta = -\frac{\sqrt{3}}{m}\left[\frac{n}{\gamma} + \frac{0.9\left(\frac{\partial\tau}{\partial T}\right)}{\rho c\left(1 + 1.328\sqrt{\frac{K_1\gamma}{Vf}}\right)}\left(n + 1 - \frac{0.664\sqrt{\frac{K_1\gamma}{Vf}}}{1 + 1.328\sqrt{\frac{K_1\gamma}{Vf}}}\right)\right] \qquad \text{(Eq 18)}$$

It can be seen that the effects of the governing cutting process parameters—cutting speed, V, and feed rate, f—on the flow localization parameter, β, are complicated. Clearly, both feed rate and cutting speed have identical effects on β. However, in practice, V can be varied over a much larger range than f, and the working range of feed rate sometimes is limited by the requirements of the machined surface quality and tolerance, machine tools, cutting tools, and other factors. Realistically, therefore, cutting speed eventually has a more significant effect on β than does feed rate.

The cutting conditions (V and f) are associated with the possible onset of shear localization through Eq 18. A critical value

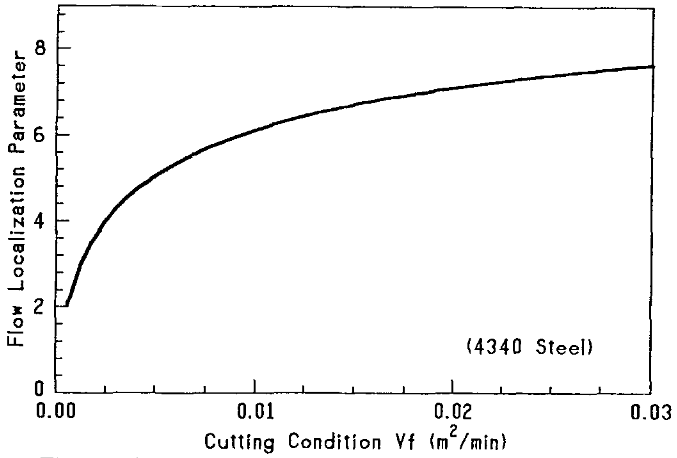

Fig. 4 Effect of cutting condition (Vf) on flow localization parameter

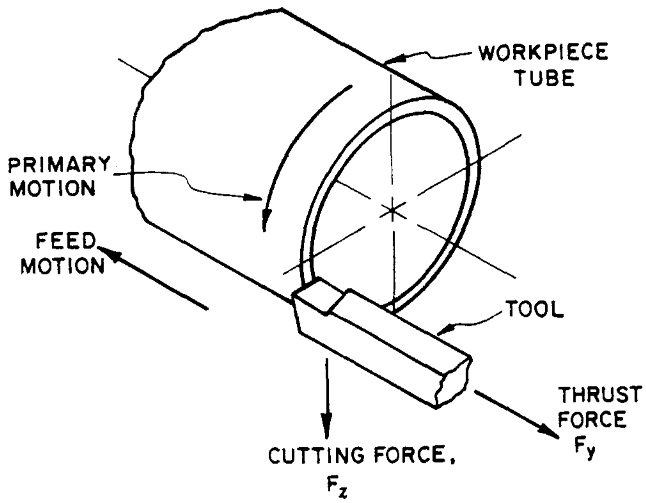

Fig. 5 Schematic diagram of the experimental setup

of the combination of V and f can be found with respect to a corresponding flow localization parameter value that may lead to the onset of shear instability in the machining process. For the purpose of simplification, the value (Vf) is called the "chip load" in this study. It should be noted that although discontinuous chips are likely to be formed at very low cutting speeds for many materials, for the sake of practicality this research concentrates on conventional and above-conventional cutting speeds.

Equation 18 can also be used to predict the flow localization parameter, β, for given cutting speed conditions and material properties without running a cutting test. The effect of (Vf) on β is shown in Fig. 4, obtained by using Eq 18. The value of the flow localization parameter increases as either cutting speed (V) increases or feed rate (f) increases. The critical value of β at which shear banding is possible is determined experimentally. For example, it has been found in metalforming research that for many materials shear instability occurs around $\beta = \beta_c = 5.0$ (Ref 12), where β_c is the critical value. Thus, β_c is taken as an experimentally measured material parameter. For a given material, β_c and τ are specified, and Eq 18 predicts the critical value of (Vf) for which shear instability during the cutting process is possible.

5. Experimental Verifications

Several orthogonal cutting experiments were carried out to verify the relationship between the flow localization parameter and the critical cutting condition at which the onset of shear localized chips takes place. Four workpiece materials—AISI 4341 steel, AISI 1020 steel, AISI 304 stainless steel, and Ti-6Al-4V titanium alloy—were tested. Preliminary cutting tests were conducted to determine the range of cutting conditions so that the machining processes were smooth, ensuring the absence of chatter or built-up edge. The cutting speed varied from 0.5 to 8.0 m/s, and the feed rate varied from 0.03 to 0.5 mm/rev. This yielded a wide range of values for the parameter (Vf). If at a given value of (Vf) serrated chips were observed, this value was then termed the critical value of (Vf), or $(Vf)_c$.

A cylindrical workpiece tube was cut on one end on a computer numerical-controlled lathe, as shown in Fig. 5. This ensured that a plane strain condition could prevail during the process of chip formation. The cutting tool was a cemented carbide cutting tip installed on a tool holder. After installation, the cutting tool had a rake angle, α_n, of 8° and a flank clearance angle, β_n, of 7°. In this investigation, a sharp tool without flank wear was assumed and used for all the cutting tests. The cutting tool edge was frequently checked under an optical microscope to ensure that the sharpness assumption was satisfied during the course of testing.

The machined chips were collected for each cutting condition to study chip formation and flow localization. The chip specimens were mounted, polished metallographically, and chemically etched. The specimens were then microscopically examined and photographed.

6. Results and Discussion

As mentioned previously, the instability in a machined chip can cause it to break easily. Therefore, in this study chip instability is considered to take place when the machined chip changes from continuous to serrated. Figure 6 shows a continuous chip and Fig. 2 shows a chip with shear localizations for the titanium alloy.

It was found that for different workpiece materials, the initial flow localized chips formed at different values of chip load (Vf). Table 1 lists the critical values of the chip load $(Vf)_c$ at which the shear localized chips were observed and the corresponding values of flow localization parameters for various materials. The flow localization parameters given in Table 1 are the critical values at which serrated chips can be formed as evaluated from Eq 18 using the critical value $(Vf)_c$.

Table 1 shows that the flow localization parameter can be realistically used to predict the critical cutting conditions at which the shear localized chips form. The critical value of the flow localization parameter varies slightly around 5.0 for different materials, which agrees with the result of Semiatin and Jonas (Ref 12). However, the critical cutting conditions to form

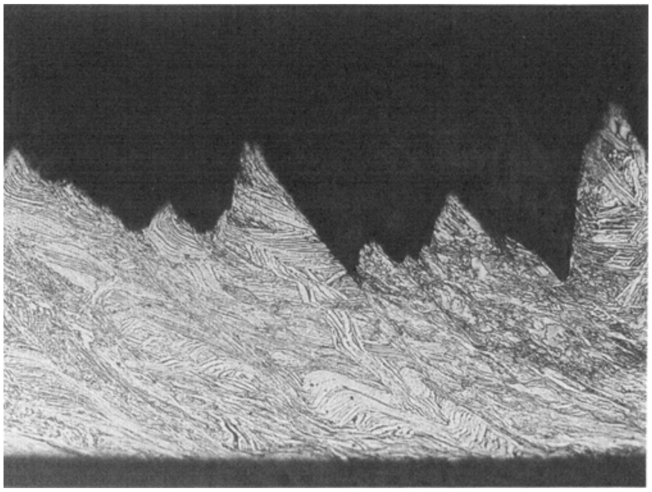

Fig. 6 Continuous chip of Ti-6Al-4V

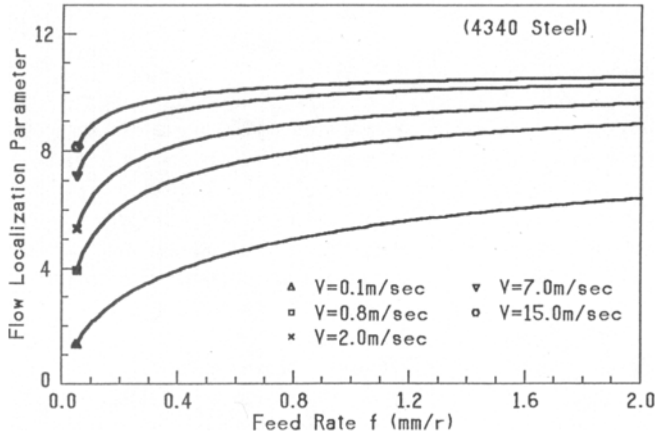

Fig. 7 Effect of feed rate, *f*, on the flow localization parameter at different cutting speeds

serrated chips vary widely for different materials. The reason for this is that the onset of shear localized chips result from the thermal softening of the material in the shear zone, and different materials have different inherent strain-hardening capacities. Therefore, different cutting conditions are needed to exceed these capacities.

Figure 7 shows the predicted effects of feed rate on the flow localization parameter at various cutting speeds according to Eq 18. Apparently, if the feed rate is lower than certain values, it is unlikely that the material will reach its instability point regardless of cutting speed. This prediction is in good agreement with the experimental observations. For all the materials tested, shear localization could not take place in the chip if the feed rate was below a certain value. In terms of cutting speed, it is more likely that the material can always reach the instability point as long as the cutting speed exceeds a certain value. In practice, a very low cutting speed is seldom employed. Therefore, increasing the cutting speed is more effective in the formation of shear localized chips.

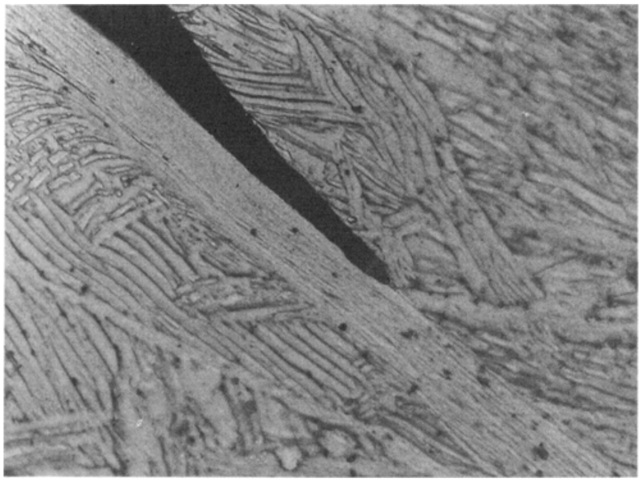

Fig. 8 Material flow and separation along a shear band in Ti-6Al-4V

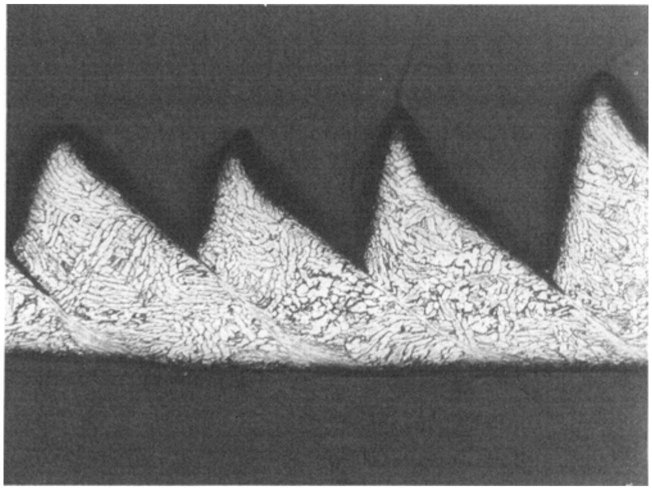

Fig. 9 Alteration of grain shape and size in a Ti-6Al-4V chip formed at a higher cutting speed

The formation of shear localized chips involves several mechanical, physical, and thermophysical material properties, including specific heat, strain-hardening exponent, density, strain-rate sensitivity, thermal diffusivity, and conductivity, and temperature dependence of flow stress. Basically, as a cutting condition (*Vf*) reaches the critical value at which serrated chips are formed, the plastic deformation becomes high and the tool/workpiece friction becomes more severe, increasing the rate of heat generation. The adiabatic or quasi-adiabatic condition may be reached due to the very high net accumulation of heat. In this case, the temperature can be very high locally in some areas of the workpiece, resulting in further thermal softening. This in turn reduces the material strain-hardening capacity so that the instability takes place in a narrow band of the chip. Figure 8 clearly shows material flow and separation along a shear band. This study has found that for some materials, such as Ti-6Al-4V, a change in grain shape and size can be caused by the high temperature. Figure 9 shows a photograph of a chip cut

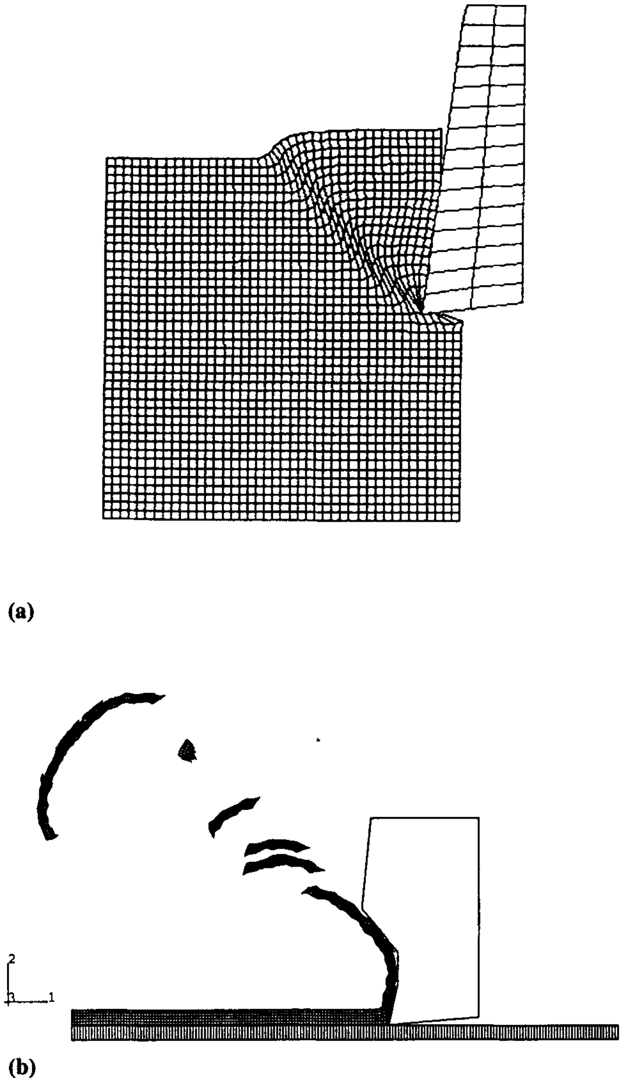

Fig. 10 Chip formation modeled by finite-element analysis. (a) Shear banding on chip. (b) Overall chip formation

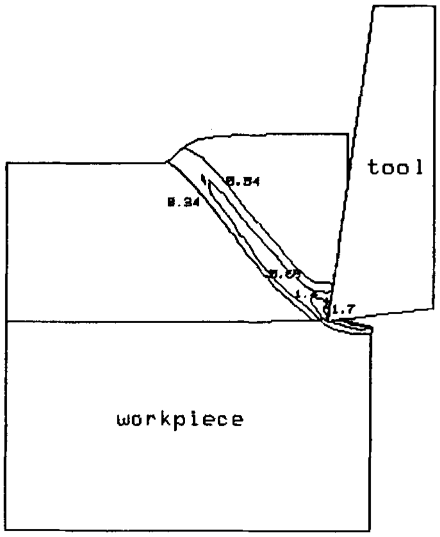

Fig. 11 Contours of effective plastic strain in the cutting process

at a relatively high cutting speed of 5 m/s. Comparison of Fig. 9 with Fig. 2, a photograph of a chip cut at a relatively low cutting speed of 1 m/s, shows that the grain shape and size of the chip have been significantly altered by the higher temperature created by a higher cutting speed.

Analysis of Eq 18 to predict the instability of chip formation reveals that only the material properties and cutting conditions (cutting speed and feed rate) are needed. These values are available in various reference sources or are given as the process governing parameters.

A database of the critical flow localization parameters, β_c, corresponding to the onset of shear localized chip formation can be established for various materials. Thus, β_c can be used as a material property to judge and predict chip breaking. This can tremendously improve control of the machining process in a computer integrated manufacturing system. The only input needed from the cutting tests is the shear zone angle (orientation), which is used to calculate the shear strain, γ, in the machining process. However, the shear zone angle usually falls into a comparatively small range and is primarily affected by the tool rake angle, which can be easily controlled. Furthermore, developments in high-speed digital computers have made it easier to predict the shear zone angle and shear strain, along with many other machining coefficients and parameters, using numerical methods such as finite-element analysis.

Figure 10 shows the chip formation process modeled by finite-element analysis, and Fig. 11 shows the contours of effective plastic strain in the cutting process. In this dynamic finite-element model, a strain-hardening and thermal-softening material model similar to Eq 15 is employed to simulate the plastic deformation behavior of the workpiece material. Figure 10(a) clearly shows the shear zone orientation and shear banding that occur during machining. Figure 11 shows the intensity of plastic strain in the shear zone. More details pertaining to this numerical analysis of the machining process are presented in Ref 15.

7. Conclusions

The flow localization parameter, β, has been developed as a function of cutting conditions and other material properties. This parameter can effectively judge and predict the onset of shear localized chip formation. The shear localized chips break easily, resulting in lower disposal costs. Use of the flow localization parameter to analyze and predict the instability of chip formation requires knowledge only of the material properties and the cutting conditions (cutting speed and feed rate).

Shear localized chip formation involves mechanical, physical, and thermophysical material properties, such as specific heat, strain-hardening exponent, density, strain-rate sensitivity, thermal diffusivity and conductivity, and temperature dependence of flow stress. Temperature plays an important role in the flow stability in machined chips. Shear localization in the chip is primarily caused by thermal softening, which may decrease the effective strain-hardening capacity of the workpiece material. For some materials, such as titanium alloys, the high cutting temperature can alter the grain shape and size.

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