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CHIP CONTROL

An important practical problem concerns the form of chips produced in machining since this has important implications relative to:

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1. Personal safety.
2. Possible damage to equipment and product.
3. Handling and disposal of swarf after machining.
4. Cutting forces, temperatures, and tool life.

Naturally brittle materials such as gray cast iron tend to form chips that range from small segments to particles. On the other hand, ductile metals tend to form long, continuous, ribbon-shaped chips that are dangerous and difficult to handle. When machining at high speed, hot chips with sharp, jagged edges represent a hazard to the operator. Such long continuous chips tend to form tangled 'nests' that may interfere with the proper functioning of the machine. Under such conditions, it is necessary for the operator to stop the machine periodically to remove the snarled chip 'nests' with a hook. This represents a decrease in productivity. If an attempt is made to remove snarled chips while the machine is running, this represents a hazard to the operator.

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둥지, 보금자리

A 'nest' of continuous chips has a very low apparent density making disposal difficult. Lang (1974) has introduced a chip packing ratio (R) where

$$R = \frac{\text{volume of chips}}{\text{equivalent volume of uncut metal}}.$$

In practice, R may range from 3 to 10 (or more) but satisfactory chip control calls for a value of R of about 4. To achieve this, chips must break periodically.

Chip curvature plays an important role relative to chip breaking as does the brittleness of the work material and the thickness of the chip (t_C). As chip thickness decreases, chips are more ductile and chip breaking becomes more difficult. A given work material that has been substantially strained during chip formation will have a critical strain at fracture (ϵ_f) which varies as the ratio t_C/R_C where t_C is the deformed chip thickness and R_C is the radius of curvature of the chip. If the natural chip curvature is not sufficiently small to cause fracture for a given feed rate t it becomes necessary to increase either t_C or chip curl to provide periodic chip fracture.

Chip curl may be increased by use of a so-called 'chip breaker' which is really a chip curler. There are two general types of chip breakers—an inclined

[illegible] coil

chip breaker

obstruction clamped to the tool face (Fig. 18.1a) or a groove ground or molded into the tool face parallel to the major cutting edge (Fig. 18.1b). If a BUE is present at the tip of a tool this will cause the chip to curl away from the tool face. Nakayama (1963) has shown that the secondary shear zone which usually develops along the tool face in the absence of a BUE can also cause the chip to curl. The material in the secondary shear zone gradually increases in speed as it travels along the tool face and as a consequence of flow continuity becomes thinner. This action is equivalent to a stationary nose of decreasing thickness that plays the same role as a BUE in causing chip curl. Figure 18.2 shows a deformed set of grid lines that are rectangular before reaching the shear 'plane'. Horizontal lines become circular arcs with a common center. By continuity, the deformed, initially horizontal lines have a closer spacing as the tool face is approached and this gives a shear 'plane' that is curved slightly convex upward. Vertical lines are also convex upward. The chip surface nearest the tool face will thus be a circular arc according to Nakayama (1963). The region labelled N (for nose) will be either a BUE or the aforementioned equivalent secondary shear zone. Thus, for volume continuity, the chip will be 'born curled' since the shear plane will be slightly curved if a BUE or equivalent secondary shear zone is present at the tip of the tool which is practically always the case. The idea that chips are formed curved has also been suggested by several others (Ernst and Merchant 1941; Henriksen 1951; Hahn 1951; and Spaans 1971) and this appears to be the case except for the rare situation where the shear plane and tool face are perpendicular and there is no secondary shear zone or BUE.

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Texture Lines

When a two-phase material is cut such as a hypoeutectoid steel having patches of pearlite which are normally approximately spherical, these patches deform into ellipsoids on crossing the shear zone. The direction of maximum deformation in the chip will thus be readily evident and make an angle ψ with the shear

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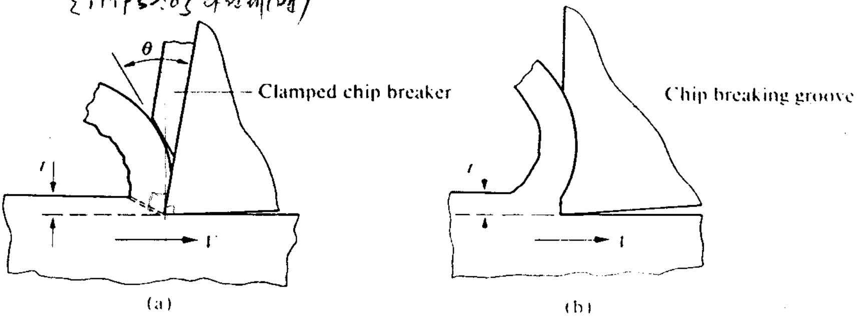


(a) (b)

FIG. 18.1. (a) Clamped chip breaker. (b) Chip-breaking groove.

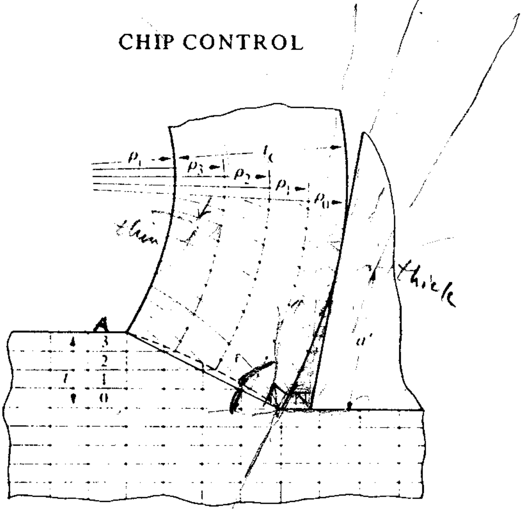


FIG. 18.2. Deformation of rectangular grid during chip formation. (After Nakayama 1963.)

'plane' (Fig. 18.3). Merchant (1945) has presented a relationship between ψ, ϕ, and α; and Towend (1947) has corrected a minor error in Merchant's analysis. However, while ψ represents a readily observable piece of data, it does not appear to lead to information concerning the cutting process that cannot be just as easily obtained via another route. The fact that the curvature of texture lines should be substantially greater than that of the shear plane does however offer a useful qualitative check on the presence of a curved shear plane.

Chip Flow Direction

In pure orthogonal cutting the chip moves across the tool face in a direction perpendicular to the cutting edge. However, there are two important situations which cause the chip flow direction to be directed otherwise. When the end of a small-diameter tube is turned (Fig. 18.4a), the cutting velocity will be substantially smaller at the inside diameter than at the outside diameter. Since the cutting ratio along the cutting edge will be approximately constant, this will cause the chip to curl to the side as shown in Fig. 18.4a. If, on the other hand, the cutting velocity is essentially constant for all points along the cutting edge but there is an inclination angle i, then the chip will also flow to the side, the direction and magnitude of the side flow being given very approximately by Stabler's rule (Chapter 16). Figure 18.4b is an example of cutting with an inclination angle. P. ~~344~~ 431

The two sources of side flow mentioned above together with the tendency for the chip to curl away from the tool face give rise to a number of different chip types (Fig. 18.5). The chip type of Fig. 18.5c (also Fig. 18.4a) is periodically broken when the chip encounters the freshly machined surface. This may

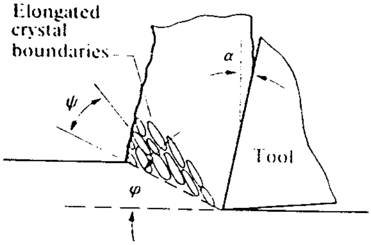
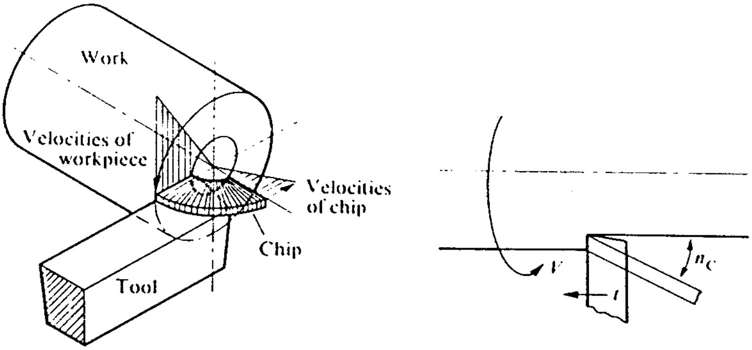


FIG. 18.3. Texture line directions in chip.

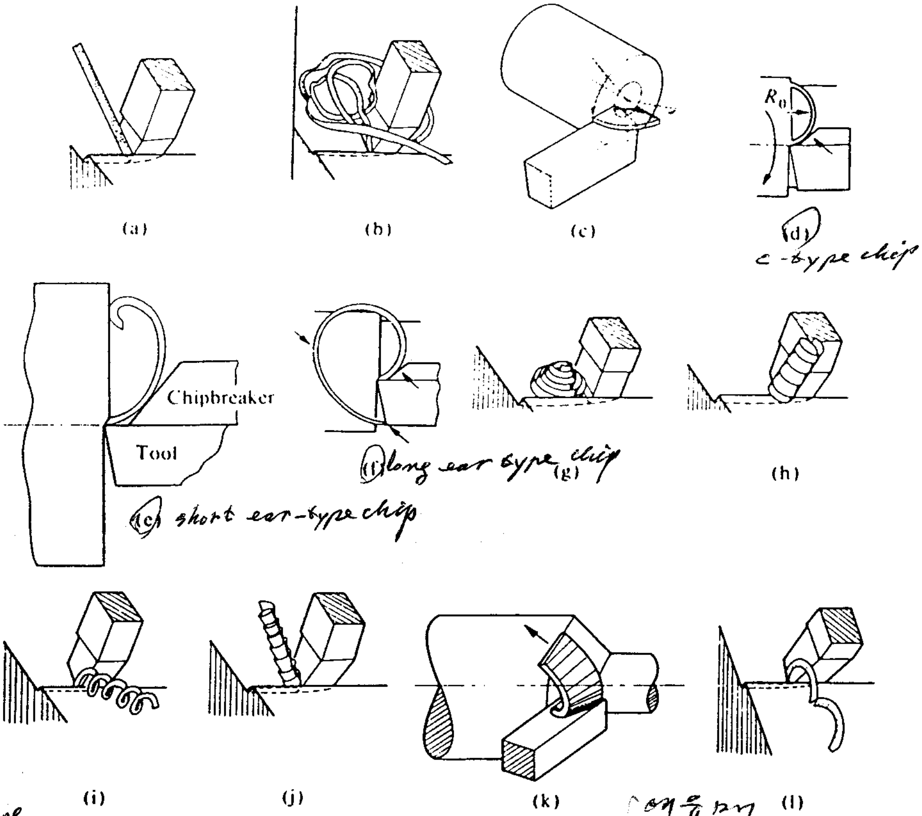


(a) (b)

FIG. 18.4. (a) Curling of chip to side due to variation of cutting speed V along cutting edge. (After Spaans 1971.) (b) Plan view of turning operation showing alteration in chip flow direction (n_C) due to inclination angle i (zero side rake angle, positive back rake angle $\alpha_b = i$).

cause undesirable surface damage in finish machining operations. Chip types 18.5d and 18.5e are broken when an up-curling chip strikes the surface about to be machined. If side flow is sufficient, the up-curling chip may miss the old surface but encounter the clearance face of the tool giving rise to chips of the Fig. 18.5f type. If there is still greater side flow, chips of the Fig. 18.5h, i, or j type may be formed.

In addition to these types, several others are observed that represent combinations of those shown in Fig. 18.5a–j. For example, types (d), (e), (f), and (g) may form under conditions where the inclination angle i is not zero or where V is not constant across the cutting edge or both. Figure 18.5k is such an example which represents a combination of the actions of types (c) and (d). Also, chips may break periodically but every fracture may not be complete. This gives rise to connected chip segments such as the connected C-type segments shown in Fig. 18.5l. The most desirable chip types from all points of



ar-type

FIG. 18.5. Representative chip types (based on Spaans 1971). (a) Straight continuous ribbon ($i = 0, n_C = 0$). (b) Wandering continuous ribbon ($i = 0, n_C$ variable). (c) Washer-type chip ($i = 0$, V = variable along cutting edge—no upward curl). (d) C-type chip ($i \cong 0$, encounters as-yet-uncut surface). (e) Short 'ear' type chip ($i \cong 0$, encounters as-yet-uncut surface). (f) Long 'ear' type chip ($i \cong 0$, encounters ~~as-yet-uncut surface~~). (g) Coil-type chip ($i = 0$, V = variable along cutting edge plus upward curl). (h) Tubular helix (i positive plus curl, large depth of cut b). (i) Spring-type chip (i positive plus curl, small depth of cut b). (j) Conical helix (combination of (c) and (h)—common for drill). (k) Combination of (c) and (d) types ($i \neq 0$) (l) Connected C-type chips.

view are individual (unconnected) C- or ear-type chips: types (d), (e), (f), or (k). While type (g) chips may yield a satisfactory density ratio R, this type with two or more turns per coil will give rise to tool forces that are higher than necessary due to over curling.

Chip Breaker Performance

If chips do not break naturally then a chip curler (Fig. 18.1) must be used or the feed must be increased or the work made more brittle. Most operating other than: We have no alternative to follow the sense of our own experience,

~~variables~~(~~other than feed~~) have a small or negligible influence on chip-breaking tendency (other than) through their influence on deformed chip thickness t_C. The most effective way of changing t_C of course is to change the undeformed chip thickness (t = feed). For example since cutting speed V has a relatively small influence on cutting ratio (in the absence of a BUE) and hence on t_C for constant feed, this variable (V) is relatively unimportant relative to chip breaking.

An increase of side cutting edge angle (C_s) gives a lower value of t_C for the same feed and hence the tendency for chips to break decreases with increase in C_s. If the side cutting edge angle is too high there is an increased tendency to form helical chips instead of the more desirable C- or ear-types. The depth of cut and work diameter have little influence on cutting ratio (t_C/t) and hence negligible influence on chip breaking. The only exception involves the turning of small-diameter work at large depths of cut where a washer-type action will tend to enter the picture (Fig. 18.5c). Use of an effective cutting fluid will normally decrease contact length between chip and tool (decrease chip curl radius) and this will have a positive effect on chip breaking. Variation of rake angle (α) has a small effect on chip breaking. The deformed chip thickness (t_C) will increase with decrease in α and this will promote chip breaking (a small effect).

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Work material of the same nominal chemistry may be made more brittle by heat treatment (hardening) or by cold-working the material. Nakayama (1962) has shown that the carbon content of plain carbon steels has a negligible influence on chip breaking. Addition of very small amounts of free-machining additives (MnS, Pb, Te, Bi, graphite, etc.) will usually improve a material's tendency to form broken chips.

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steel:
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by 이재철
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Nakayama (1962) has determined the influence of a limited range of work-material chemistry on chip-breaking tendency using a clamped-type chip breaker (Fig. 18.1a) with $\theta = 45°$. The order of decreasing ease of chip breaking was found to be as follows:

1. Cr–Mo steel.
2. Carbon steel (all carbon contents).
3. Stainless steel.

Rational Approach to Chip Control

One approach to chip-breaker design is the data bank approach where a predetermined chart gives empirical chip-breaking results for a given work material. The first charts of this sort were proposed by Henriksen (1951). Nakayama (1962) has suggested a chart of the type shown in Fig. 18.6. This gives combinations of speed (V) and feed (t) that will give ear-type chips for a given work material (AISI 1045 steel) for points that plot above the curve and continuous (unbroken) chips for combinations of V and (t) that plot below the curve. Kaldor,

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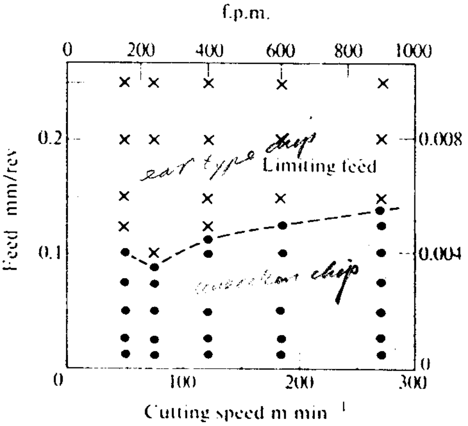

FIG. 18.6. Effects of speed and feed on chip breaking of AISI 1045 steel using clamped carbide chip breaker. $\theta = 45°$; carbide tool geometry: 0, 0, 7, 7, 8, 0, 0.5 mm; depth of cut, 2.0 mm (0.08 in); cutting fluid, none; x = broken chip, ● = continuous chip. (After Nakayama 1962.)

Ber, and Lenz (1979) have suggested a map indicating different chip-types when depth of cut (b) is plotted against feed (t) for a given machining system. A number of additional chip-breaking studies are available in the literature (Henriksen 1954a, 1954b; TenHorn and Schürmann 1954; Reinhold 1959, 1962; Okushima, Hoshi and Fujinawa 1960; Trim and Boothroyd 1968; Jones 1973; Reinhart and Boothroyd 1973; Kahng and Koegler 1977; Gertler 1978, to mention but a few).

While empirical charts are useful, it often occurs that results for a given work material are not available and some experimentation is required. Both Nakayama (1962) and Spaans (1971) have suggested rational procedures to be followed in such situations.

Nakayama (1962) has suggested the following procedure for a clamped-type chip-breaker. A trial cut is first made under the desired machining conditions and the value of deformed chip thickness (t_C) determined. The limiting value of chip curl radius R_C is then obtained from the appropriate empirical curve of Fig. 18.7. This value is reduced by 20 percent to ensure chip breaking. To limit shock on contact, angle θ on the front face of the chip-breaker should not be too steep; and $\theta = 45°$ is recommended. The value of offset distance b may be estimated from the following equation which comes from Fig. 18.8:

$\tan\frac{\theta}{2} = \frac{b}{R_c}$

$$b = \frac{R_C}{\cot \theta/2}. \qquad (18.1)$$

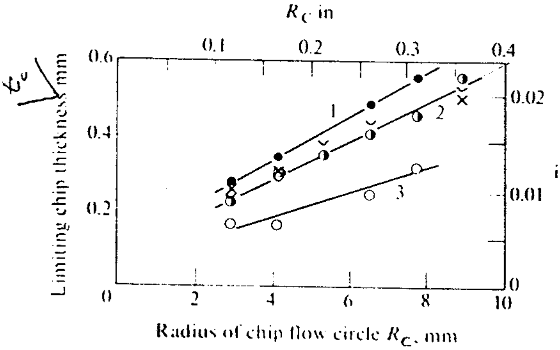

FIG. 18.7. Relation between chip flow radius (R_C) and limiting value of chip thickness (t_C) for different work materials. Curve 1 = Cr–Mo steel, 2 = plain carbon steels of all C contents, 3 = stainless steel. Machining conditions same as for Fig. 18.5. (After Nakayama 1962.)

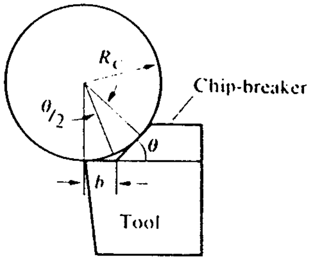

FIG. 18.8. Relation between chip flow radius (R_C) and off-set (b) of clamped chip-breaker.

For a value of θ of 45°, and R_C from Fig. 18.7, the required offset distance b is found to be (∵ 20% 작게 취함)

$b = \frac{0.8\times R_c}{\cot\frac{\theta}{2}} = \frac{0.8\times R_c}{\cot 22.5°}$

$$b = \frac{0.8R_C}{\cot(22.5°)} = 0.33R_C.$$

If the work material of interest is not given in Fig. 18.7 as will usually be the case, an estimate may be had by comparing the properties of the new material with the few that are given and interpolating, if necessary.

Spaans (1971) has suggested a useful means of rating the 'breakability' of a work material. He reasoned that values of the strain at fracture (ϵ_f) required to produce desirable ear-type chips for several materials would correlate with the ease of chip fracture. The resulting ordering of materials based on the strain at fracture (ϵ_f) he calls 'breakability'. After the chip breaker has been adjusted to give the desired 'ear' type chip, the following quantities are measured on a representative chip:

1. Chip thickness (t_C).
2. Chip curl radius (R_C).
3. Distance AB (see insert Fig. 18.9).

A nondimensional value of AB (AB*) is then found as follows:

$$AB^* = AB/R_C \quad \longrightarrow \underline{AB}^* \cdot R_c \tag{18.2}$$

and the corresponding value of ϵ_f^* is read from Fig. 18.9 where

$$\epsilon_f^* = \epsilon_f \Big/ \frac{t_c}{2} \cdot \frac{1}{R_c} \qquad \epsilon_f^* = \frac{2R_C}{t_C}\,\epsilon_f. \qquad \epsilon_f = \frac{t_c}{2R_c} \qquad \epsilon_f = \frac{t_c}{2R_c} \cdot \epsilon_f^* \tag{18.3}$$

From this latter equation ϵ_f may be estimated.

Chip Breaking Grooves

As already mentioned, chip breaking may be induced by use of chip-curling grooves. Originally these were ground into the surface of brazed carbide tools. Chip-curling grooves are now being molded into the rake surfaces of carbide inserts before sintering. This makes it possible to use grooves that would be difficult to grind. An example of this type is shown in Fig. 18.10. The grooves in this triangular insert are of variable chordal width. This is to extend the range of feed over which chip breaking occurs. The proportions of the groove were chosen to give a low increase in tool forces due to chip breaking. This turned out to be a groove of circular shape so proportioned that the depth of the groove was about 10 percent of the chordal width.

The insert shown in Fig. 18.10 produces a chip of variable cross section (Fig. 18.11) since metal is forced into the groove parallel to the secondary cutting edge. This is important in preventing partially broken chips held together along the edge farthest from the workpiece axis. Due to the complex state of stress at the nose radius, chips tend to fracture on this edge first. This relieves the stress in the chip and prevents rupture from occurring all the way across the chip. Chip segments are thus joined together by unbroken material on the edge farthest from the nose of the tool (Fig. 18.12). This limits the range of feed over which a chip breaker will give completely broken chips. By thickening the edge of the chip adjacent to the nose of the tool, fracture is postponed and more energy is stored in the chip to cause complete chip fracture once a crack does appear. Thus, the groove segment parallel to the minor cutting edge is important as well as that parallel to the major cutting edge. The role of the latter is to promote upward-chip-curl while that of the former is to prevent premature chip-fracture leading to connected chip segments.

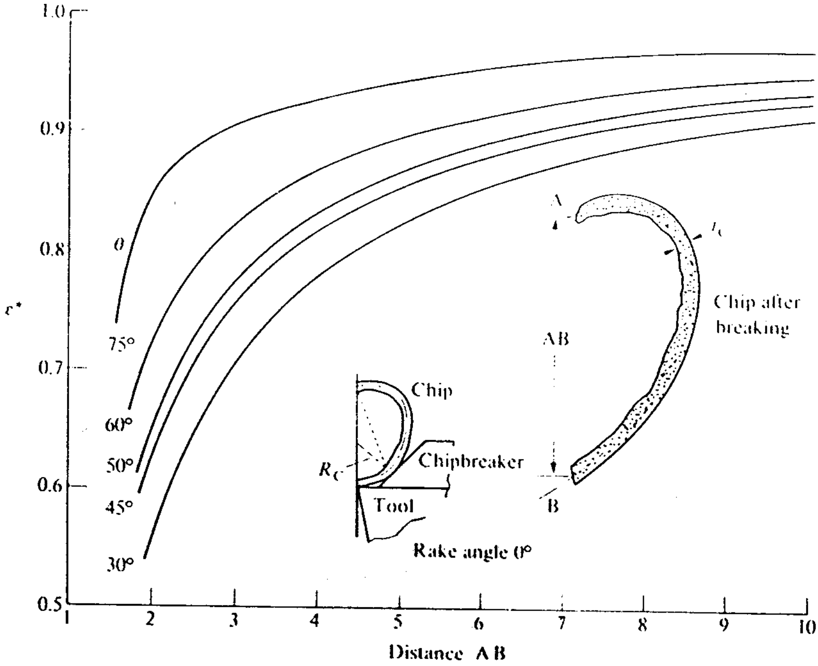

FIG. 18.9. Variation of nondimensional strain in 'ear' type chip at fracture (ϵ_f^*) with nondimensional chip size AB*. (After Spaans 1971.)

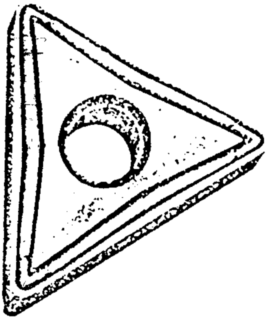

FIG. 18.10. Triangular carbide tool insert with chip-breaking grooves molded into the rake face. (After Kaldor, Ber, and Lenz 1979.) ← page No. 10

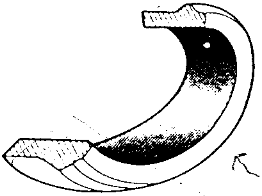

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FIG. 18.11. Cross section of chips produced by tool of Fig. 18.10. (After Kaldor, Ber, and Lenz 1979.)

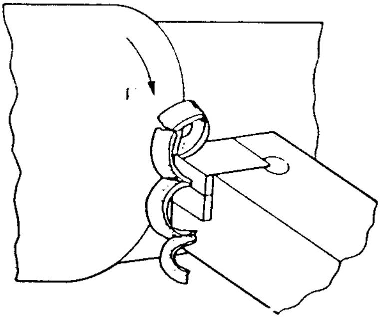

FIG. 18.12. Formation of connected chip segments due to relief of stress due to critical fracture on edge of chip nearest nose of tool. (After Kaldor, Ber, and Lenz 1979.)

Variable Feed

Since the magnitude of t_C and hence of undeformed chip thickness (t = feed rate) plays such an important role in chip-breaking, it is not surprising that chip control may be improved by use of a periodically varying feed rate. When this is done, the chip will tend to break when the feed is high even though it may not break when cutting at the mean feed rate. This method of chip control will of course lead to a visible pattern on the surface of the work that is far greater than the change in surface roughness would suggest. However, since the appearance of a machined surface is often equated to surface quality in the mind, the variable feed solution to chip control is often not acceptable even though the resulting finished surface may be equal or even superior functionally to one produced at a constant feed rate.

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