A slip-line solution to metal machining using a cutting tool with a step-type chip-breaker

K.P. Maity *, N.S. Das

Department of Mechanical Engineering, Regional Engineering College, Rourkela, Orissa 768 008, India

Abstract

Chip-breakers play a predominant role in the effective control of chip-flow and chip-breaking, especially at high cutting speeds, for the easy and safe disposal of chips, as well as for protecting the surface-integrity of the workpiece. In the present paper, a theoretical analysis of metal machining using an orthogonal cutting tool has been carried out, using the slip-line field technique for a parallel step-type chip-breaker, assuming constant friction at the chip–tool interface. Friction at the interface of the chip and the chip-breaker is neglected. The cutting forces, radius of curvature of the chip, chip-breaking force, contact length, chip-reduction coefficient, stress-distribution at the chip–tool interface and other associated parameters are computed. Analysis predicts the condition when the effect of chip-forming starts for a chip-breaker. The conditions for under-breaking and over-breaking of the chips are determined from the analysis for mild steel. Some comparisons with experimental data, as available in the literature, are found to be satisfactory.

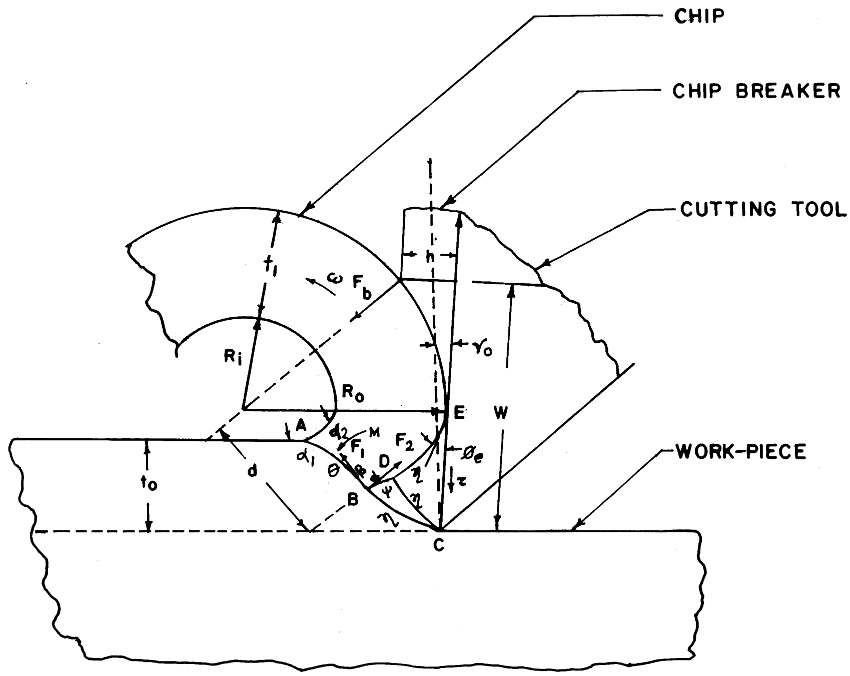
Keywords: Step-type chip breaker; Slip-line solution; Chip flow

1. Introduction

With the development of advanced manufacturing technology, metal machining operations are now being carried out at high speed to secure maximum productivity. The disposal of long and continuous chips produced at high cutting speeds has posed a problem for industry. For easy disposal of chips, the volume of the chips relative to the volume of the same material in bulk should be as low as possible. It is reported that well-broken chips have a volume ratio of between 3 and 10, whereas entirely unbroken chips have a volume ratio of 50 [1]. Long chips curl around the tool and can pose serious hazards to the workpiece surface, the operator and the machine-tool operations. The situation becomes more critical under the environment of automated machine loading and unloading and in-process inspection of the machined parameters of the workpiece. To overcome this difficulty, a number of researchers have investigated effective control of chip-flow and chip-breaking. Chip curl can be controlled by using an obstacle across the chip-flow direction, commonly known as a chip breaker or chip former.

Broadly speaking, there are two types of chip-breakers: (i) the obstruction type; and (ii) the groove type. The obstruction type chip-breaker is sub-divided into two types: (a) the step-type chip breaker; and (b) the ram-type chip-breaker. An experimental investigation of metal machining with a ram-type chip breaker has been carried out by Nakayama [2]; a good deal of work in this direction of the chip-breaking effect is due to Hendriksen [3]. The effect of the ram-type chip-breaker on the machining process has been analysed by Dewhurst [4] without flank wear and by Shi et al. [5] with flank wear, using a slip-line field solution. Some experimental observations of metal machining with a step-type chip-breaker have been reported by Trim et al. [6] and Subramanian et al. [7]. A slip-line field solution for orthogonal cutting using a single-point cutting tool with groove-like chip breaker has been analysed by Shi et al. [8].

In the present paper, a theoretical analysis is carried out for pure orthogonal cutting, using a cutting tool with a parallel step-type smooth chip breaker, assuming



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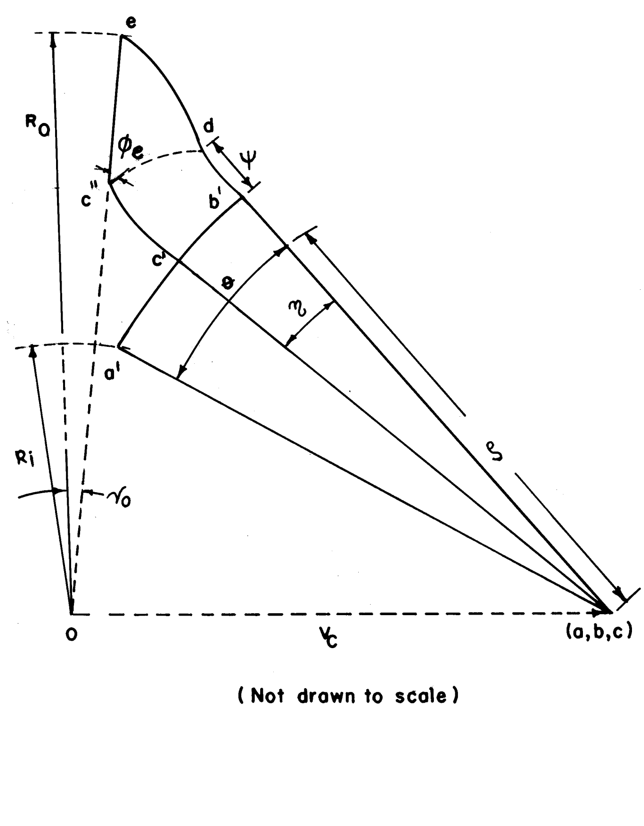

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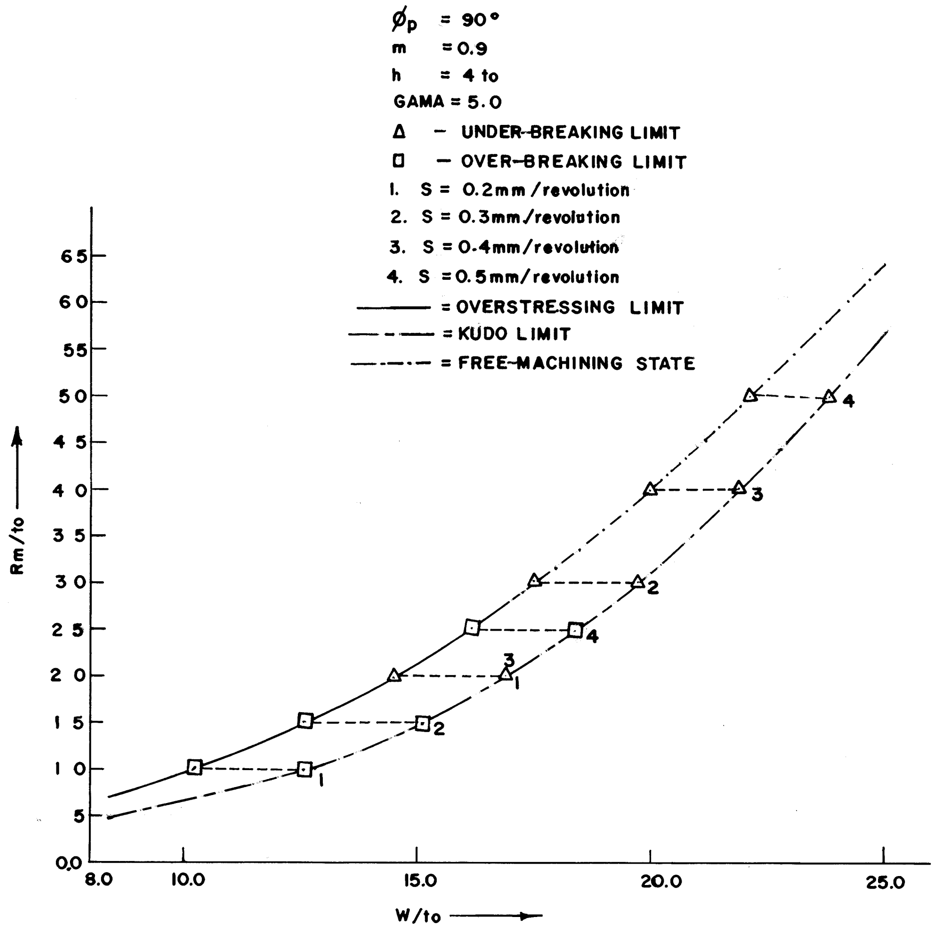

Øp = 90°
m = 0.9
h = 4 to
GAMA = 5.0
Δ — UNDER-BREAKING LIMIT
□ — OVER-BREAKING LIMIT
1. S = 0.2mm/revolution
2. S = 0.3mm/revolution
3. S = 0.4mm/revolution
4. S = 0.5mm/revolution
= OVERSTRESSING LIMIT
= KUDO LIMIT
= FREE-MACHINING STATE
Rm/to
W/to
0.0
5
10
15
20
25
30
35
40
45
50
55
60
65
8.0
10.0
15.0
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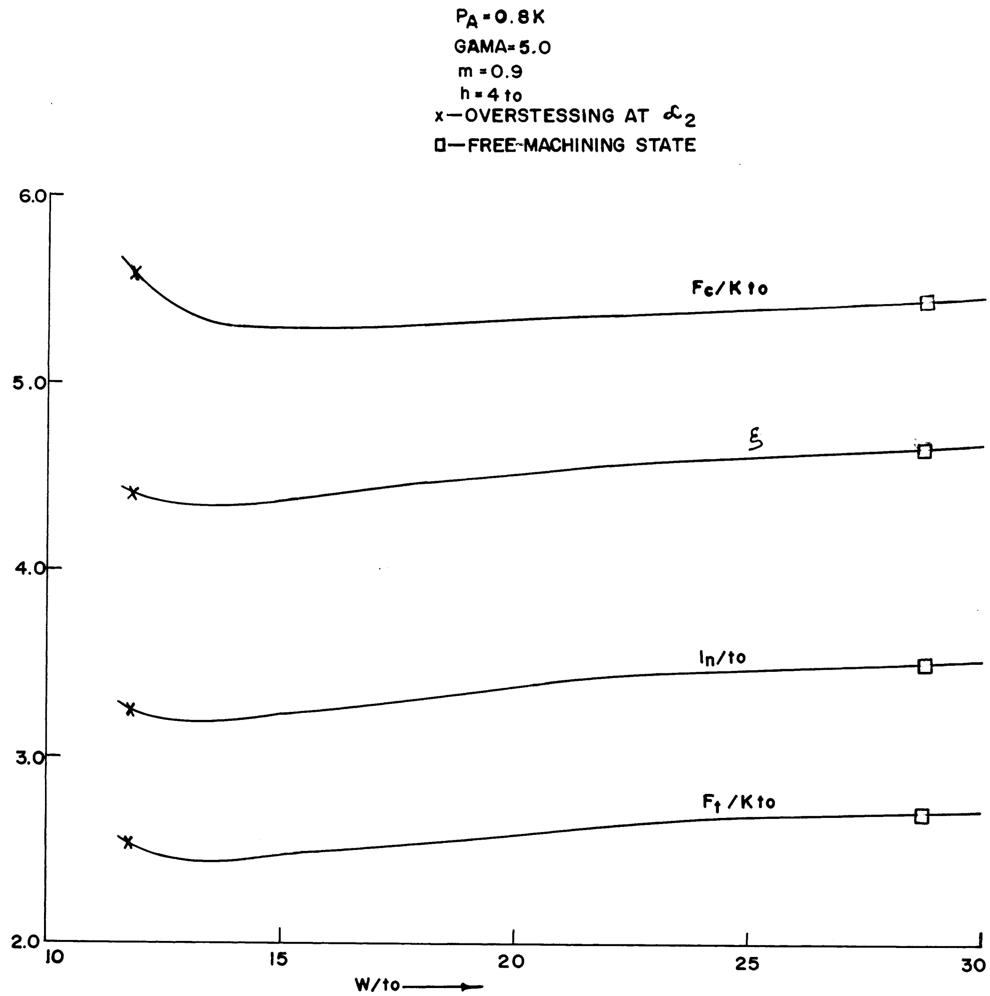
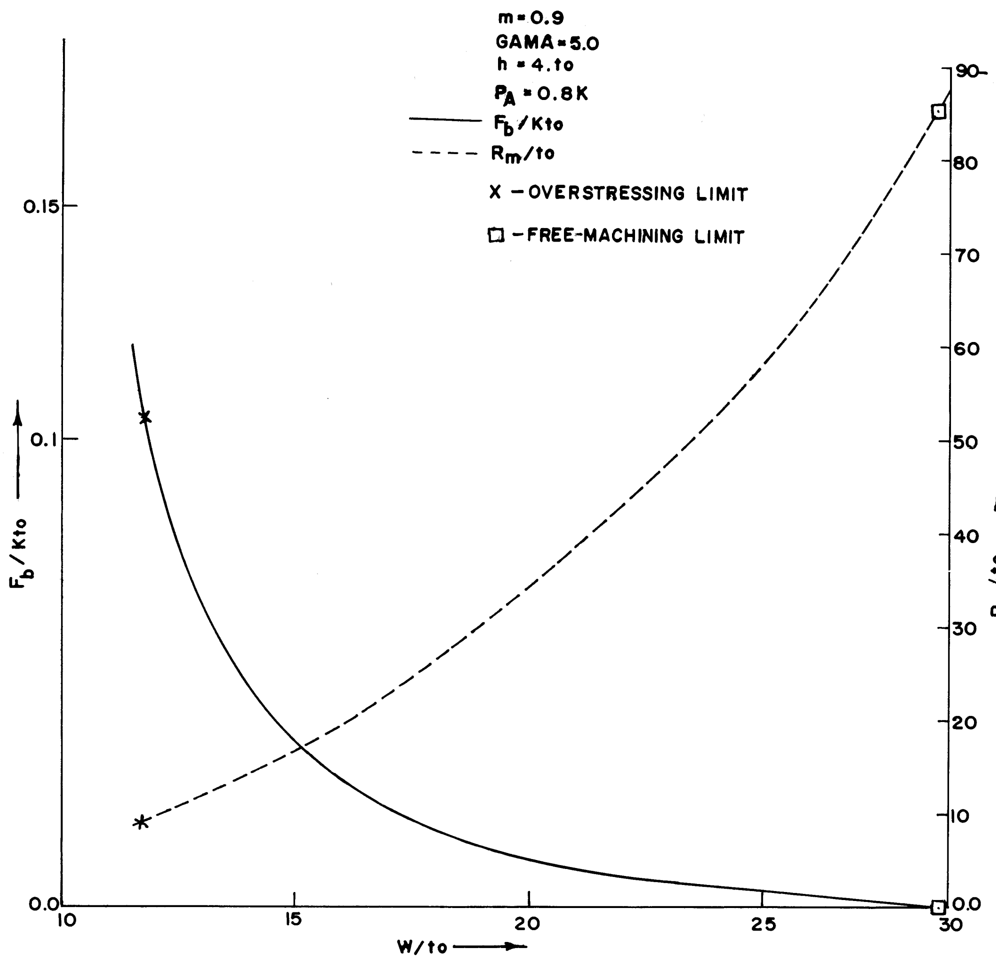


P_A = 0.8K
GAMA = 5.0
m = 0.9
h = 4 to
x—OVERSTESSING AT α_2
□—FREE-MACHINING STATE
6.0
5.0
4.0
3.0
2.0
10
15
20
25
30
W/to
Fc/K to
ξ
In/to
Ft /K to


m = 0.9
GAMA = 5.0
h = 4.to
P_A = 0.8K
F_b/Kto
R_m/to
X – OVERSTRESSING LIMIT
□ – FREE-MACHINING LIMIT
0.15
0.1
0.0
F_b / Kto
10
15
20
25
30
W/to
90
80
70
60
50
40
30
20
10
0.0
R_m/ to

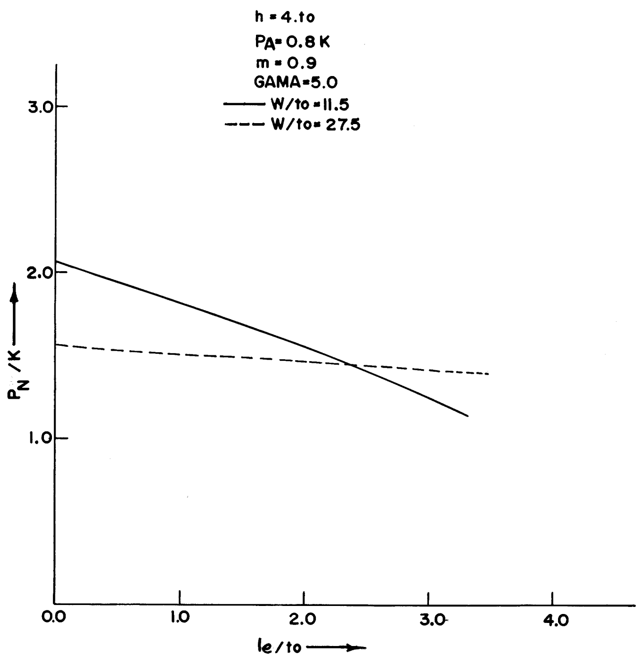


Fig. 6. Variation of normal stresses at the chip–tool interface.

Fig. 7 refers to the variation of the mean and the outer radius of curvature with chip-thickness for a parallel step-type chip-breaker with a width equal to 2.9464 mm and a height equal to 1.1938 mm with respect to chip-thickness. The outer-radius curvature predicted from the analysis agrees satisfactorily with experimental data [6]. The radii of curvature for under-breaking and over-breaking are also plotted after Okushima et al. [9] with respect to chip-thickness. The feeds for under-breaking and over-breaking are found to be 0.19 and 0.27 mm/revolution, respectively. When the feed is less than 0.09 mm/revolution, there is no chip-breaking effect, as the chip-breaking force is almost zero. The solution becomes invalid when the fed is greater than 1.2 mm/revolution, as over-stressing at the rigid vertex α_2 occurs. The variations of all other cutting parameters with respect to chip-thickness have also been computed, but are not presented in the paper. It is also observed that the feeds for under-breaking and over-breaking increase as the position of chip-breaker is shifted away from the principal cutting edge, but with the height remaining the same, which represents the actual situation.

4. Conclusions

(1) The positions of the chip-breakers are found to vary within a range for under-breaking and over-break-

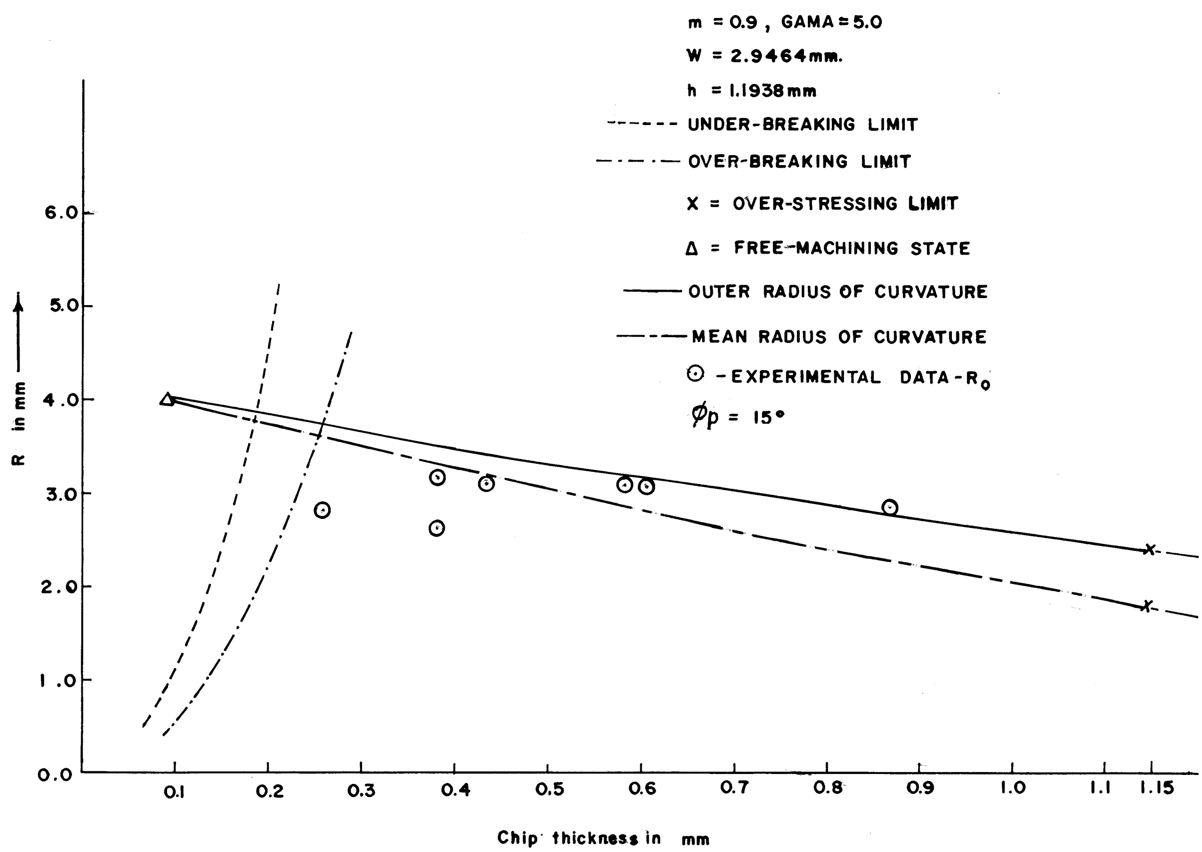


Fig. 7. Variation of the mean and the outer radius of curvature with respect to chip-thickness for a fixed position of the chip-breaker.

ing conditions for a particular feed. Increase in feed increases the positions of chip-breaker for chip breaking.

(2) The optimum positions of the chip-breaker are around 13–14 times the uncut chip-thickness, with a step-height equal to four times the uncut chip-thickness, since the cutting forces become minimum at those positions. There is no chip-breaking effect when the chip-breaker position is more than 28.8 times the uncut chip-thickness, the mode of deformation corresponding to hydrostatic pressure $P_A = 0.8\ K$. The minimum position of the chip-breaker is around 17 times the uncut chip-thickness for all possible modes of deformation at $\tau = 0.9\ K$ for a 5° orthogonal rake angle, for having chip-breaking effect.

(3) The feeds for under-breaking and over-breaking increase with increase in the chip-breaker position from the principal cutting edge with all other conditions remaining the same. The feeds for under-breaking and over-breaking are 0.19 and 0.27 mm/revolution for turning mild steel using a cutting tool with the rake and plan approach angle equal to 5° and 15° respectively, for a chip-breaker having a height and width equal to 1.1938 and 2.9464 mm, respectively.

5. Nomenclature

F_b	force exerted by the chip-breaker on the chip
F_c	tangential cutting force
F_t	thrust force
F_1, F_2, M	forces and moment acting on the chip along the boundary slip-line ABDE
h	height of the chip-breaker
K	yield-stress in shear
V_c	cutting speed
l_e	distance from the principal cutting edge
l_n	natural contact length of the chip
m	constant friction factor
P_A	hydrostatic pressure at point A in the primary slip-line
P_N	normal stress at the chip–tool interface
R_i	inner radius of curvature
R_m	mean radius of curvature
R_o	outer radius of curvature
t_0	uncut chip-thickness
t_1	chip-thickness
W	width of the chip-breaker

Greek letters

α_1, α_2	angles between the free surface and the primary slip-lines
ϕ_e	angle between slipline ED and the tool face at point E
ϕ_p	principal cutting edge angle
v_o	orthogonal rake angle
θ, ψ, η	slip-line field angles
τ	tangential stress on the tool face
ω	angular velocity of the chip
ξ	chip reduction co-efficient, t_1/t_0

References

[1] B.L. Juneja, G.S. Sekhon, Fundamentals of metal cutting and machine tools, Wiley Eastern, New Delhi, India, 1987.

[2] K. Nakayama, A study on chip breaker, Bull. JSME 5 (17) (1962) 142–150.

[3] Hendriksen, E.K., Chip breaking–a study of three-dimensional chip flow, ASME paper No. 53 s–9, 1953.

[4] P. Dewhurst, The effects of chip breaker constraints on the mechanics of the machining processes, Ann. CIRP 28 (1) (1979) 1–5.

[5] T. Shi, S. Ramalingam, Slip-line solution for orthogonal cutting with a chip breaker and flank wear, Int. J. Mech. Sci. 33 (9) (1991) 689–774.

[6] A.R. Trim, G. Boothroyd, Action of the obstruction type chip former, Int. J. Prod. Res. 6 (3) (1968) 227–240.

[7] T.L. Subramanian, A. Bhattacharyya, Mechanics of chip breaker, Int. J. Prod. Res. 4 (1) (1965) 37–49.

[8] T. Shi, S. Ramalingam, Modeling chip formation with grooved tools, Int. J. Mech. Sci. 35 (9) (1992) 741–756.

[9] K. Okushima, T. Hoshi, T. Fujinawa, On the behaviour of chip in steel cutting. The case of the parallel type chip breaker, Bull. Japan Soc. Mech. Eng. 3 (10) (1960) 109.

[10] P. Dewhurst, On the non-uniqueness of the machining process, Proc. R. Soc. Lond. A–360 (1978) 587–610.

[11] I.F. Collins, The algebraic geometry of slip-line fields with application to boundary value problems, Proc. R. Soc. Lond. A–303 (1968) 317–328.

[12] P. Dewhurst, I.F. Collins, A matrix technique for constructing slip-line field solutions to a class of plane-strain plasticity problems, Int. J. Num. Meth. Eng. 7 (1993) 357–378.

[13] L. James Kuester, Joe H. Mize, Optimisation Techniques With Fortran, McGraw-Hill, New York, 1973.

[14] R. Hill, On the limits set by plastic yielding to the intensity of singularities of stress, J. Mech. Phys. Solids 2 (1954) 278–285.

[15] H. Kudo, Some new slip-line solutions for two dimensional steady-state machining, Int. J. Mech. Sci. 7 (1965) 43–55.