THE ASSESSMENT OF PLASTIC DEFORMATION IN METAL CUTTING

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1.INTRODUCTION

- The process of physical separation of a solid body into two or more

  parts is known as “Fracture” and thus machining must be treated as the purposeful fracture of the layer being removed.

- The stress in the chip formation zone should exceed the strength of the work material.

- The ultimate objective of machining is to separate a certain layer from the rest of the work piece with minimum possible plastic deformation and thus energy consumption. Therefore, the energy spent on plastic deformation in machining must be considered as wasted

COMPARISON BETWEEN MACHINING AND FORMING PROCESS ON THE GROUND OF PLASTIC DEFORMATION

- In machining, stress in chip formation zone should exceed strength of work piece.
- Objective is separate chip with minimum possible plastic deformation and thus energy consumption.
- It is desired that material exhibit the strain at fracture as small as possible

- In forming, stress should sufficiently high to achieve shear flow stress.
- High strain involve and uses plastic deformation to accomplish the process.
- Material should exhibit higher strain before fracture

CHIP COMPRESSION RATIO (CCR)

The ratio of the length of cut, *L1* to the corresponding length of the chip, *L*c or

the ratio of the chip thickness, *t*2 to the uncut chip thickness, *t*1

i.e. $\zeta = L1/Lc$

$= t2/t1$

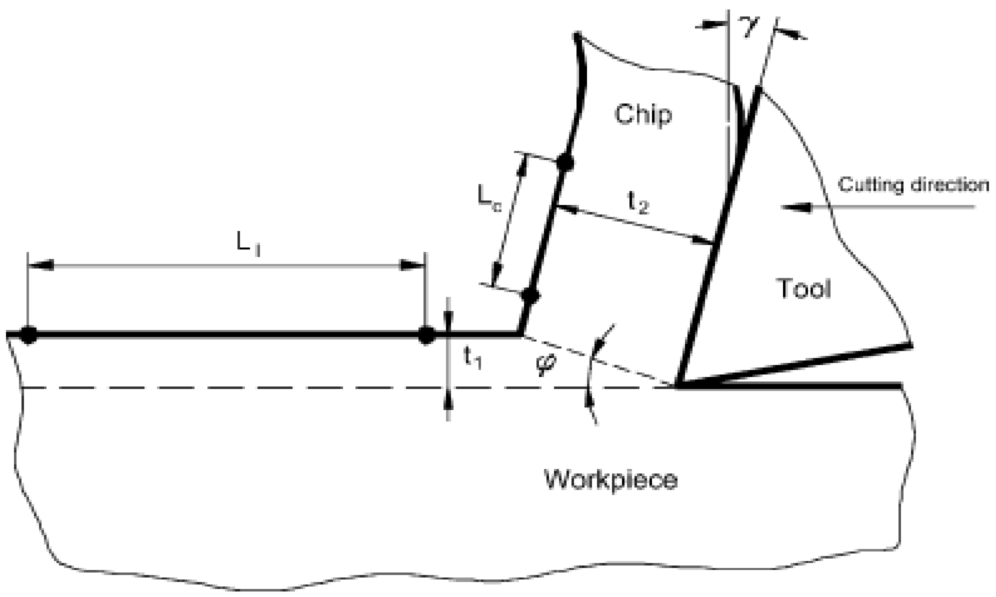

Fig. 1. Scheme of chip deformation in cutting.

CONTD….

- The chip compression ratio competes with shear strain for the role of a measure of plastic deformation encountered in metal cutting, it seems only logical to verify the justification of its usage as such a measure.

- A/t Merchant shear strain ε:

$$\varepsilon = \cos\alpha / \cos(\phi - \alpha) \sin\phi$$

$$= (\zeta^2 - 2\zeta \sin\alpha + 1) / \zeta \cos\alpha$$

where α is the cutting tool rake angle, ϕ the shear angle.

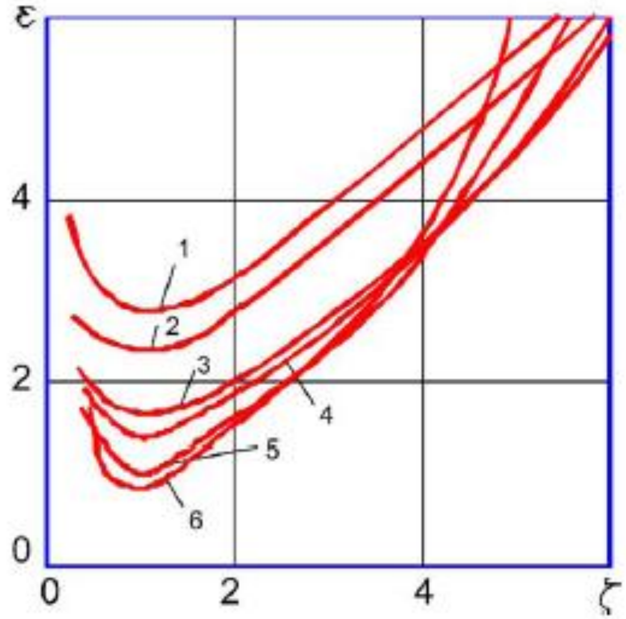

Fig. 2. Shear strain vs. the chip compression ratio for different rake angles: (1) −15°, (2) 0°, (3) 15°, (4) 30°, (5) 45°, (6) 60°.

The shear strain depends on a large extent of the rake angle and decreases rapidly when CCR tends to 1.

DRAWBACK OF MERCHANT SHEAR STRAIN RELATION

- derived using pure geometrical consideration
- It does not consider the change in internal energy of chip due to changed chip density, increased dislocation concentration or, stress imposed on the boundaries of grains.
- When $\zeta = 1$, the chip thickness is equal to the uncut chip thickness.
- This reveals a contradiction;

  as CCR, considered to be a measure of plastic deformation, indicates that no plastic deformation occurs while the final shear strain remains significant a/t Merchant shear strain relation.
- So not perfect measure of plastic deformation

OBJECTIVE:

To reveal the meaning and significance of CCR as the true measure of plastic deformation in metal cutting.

WORK OF PLASTIC DEFORMATION IN METAL CUTTING

- The applied external forces, which result in the work done over the system, are not uniformly distributed over the system's components. To define the action of an external force on the different region of a body, the notion of stress is used.
- Consider an infinitesimal element in the form of parallelepiped with its faces oriented parallel to the coordinate planes

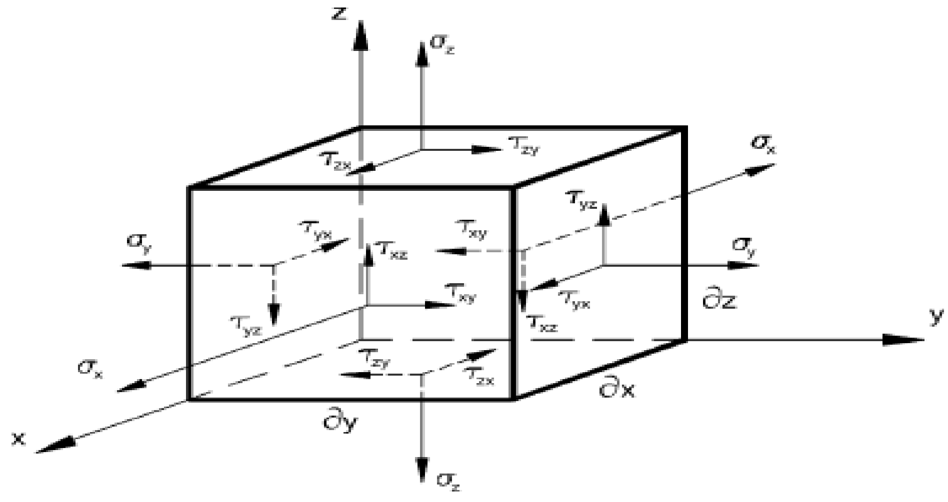

Fig. 3. Stresses acting on elemental free body.

- Stress equilibrium equation :

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} = 0$$

$$\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \sigma_y}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} = 0$$

$$\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \sigma_z}{\partial z} = 0$$

$$e_x = \frac{\partial u_x}{\partial x}, \qquad e_y = \frac{\partial u_y}{\partial y}, \qquad e_z = \frac{\partial u_z}{\partial z},$$

$$\gamma_{xy} = \frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}, \qquad \gamma_{yz} = \frac{\partial u_y}{\partial z} + \frac{\partial u_z}{\partial y},$$

$$\gamma_{zx} = \frac{\partial u_z}{\partial x} + \frac{\partial u_x}{\partial z}$$

Here, components *ex*, *ey* and *ez* are called the longitudinal strains while γ_{xy}, γ_{yz}, and γ_{zx} are known as the engineering shear strains.

A/t Hooks law :

$$e_x = \frac{1}{E}[\sigma_x - \nu(\sigma_y + \sigma_z)], \qquad e_y = \frac{1}{E}[\sigma_y - \nu(\sigma_z + \sigma_x)],$$
$$e_z = \frac{1}{E}[\sigma_z - \nu(\sigma_x + \sigma_y)], \qquad e_{xy} = \frac{2}{E}(1 + \nu)\tau_{xy},$$
$$e_{yz} = \frac{2}{E}(1 + \nu)\tau_{yz}, \qquad e_{zx} = \frac{2}{E}(1 + \nu)\tau_{zx} \qquad (7)$$

E is modulus of elasticity and v is poission’s ratio

- Unbalanced external forces causes deformation
- Leads to displacement of point so energy needed
- This energy depends on the work done in displacement of all points in body.

- Work done over volume V is

$$A = \int_V \sigma_i e_i \, \mathrm{d}V$$

The Von-Mises' stress is

$$\sigma_i = \frac{1}{\sqrt{2}}[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)]^{1/2}$$

Equivalent strain is

$$e_i = \frac{\sqrt{2}}{3}[(e_x - e_y)^2 + (e_y - e_z)^2 + (e_z - e_x)^2 + 6(e_{xy}^2 + e_{yz}^2 + e_{zx}^2)]^{1/2}$$

ESTIMATION OF PLASTIC DEFORMATION IN METAL CUTTING

- Let XYZ coordinate system is set so that

- Y-axis is directed along the chip length Lch
- X-axis is directed along chip width,b2
- Z-axis is directed along chip thickness
- True strain =ln(1+nominal strain)

$$\varepsilon_z = \ln \zeta_t, \qquad \varepsilon_x = \ln \zeta_b, \qquad \varepsilon_y = -\ln \zeta_L$$

Similarly rewriting total strain

$$\varepsilon_i = \frac{\sqrt{2}}{3}[(-\ln \zeta_L - \ln \zeta_t)^2 + (\ln \zeta_t - \ln \zeta_b)^2 + (\ln \zeta_b + \ln \zeta_L)^2]^{1/2}$$

- Plain strain condition appears because CCR along width is found 1 because width remains same before and after deformation (found).

- Therefore, $\varepsilon_i = 1.15 \ln \zeta$

  As other stress not depends on width direction

$$\sigma_x = 0.5(\sigma_z + \sigma_y)$$

Substituting these values

$$\sigma_i = \frac{1}{\sqrt{2}}\{[\sigma_z - 0.5(\sigma_z + \sigma_y)]^2 + [0.5(\sigma_z + \sigma_y) - \sigma_y]^2 + (\sigma_y - \sigma_z)^2\}^{1/2}$$

After simplification

$$\sigma_i = 0.87(\sigma_z - \sigma_y)$$

- A/t Luderick's eqn :

$$\sigma = K\varepsilon^n$$

Here n varies between 0 to 1

So stress eqn takes the forms..

$$\begin{aligned}\sigma_i &= 0.87(K\varepsilon_z^n - K\varepsilon_y^n) = 0.87K(\varepsilon_z^n - \varepsilon_y^n) \\ &= 0.87K[(\ln\zeta_t)^n - (\ln\zeta_L)^n] = 0.87K2(\ln\zeta)^n \\ &= 1.74K(\ln\zeta)^n\end{aligned}$$

As it is assumed that chip has uniform deformation so,

Work spent over plastic deformation per unit volume is –

dW = $\sigma_i\varepsilon_i = 1.74K(\ln\zeta)^n 1.15\ln\zeta = 2K(\ln\zeta)^{n+1}$

- The above relation correlates the work done in plastic deformation in cutting with CCR in simple manner.

- Total workdone
- W =dw * v*f*d*t

  d = depth of cut

  t = cutting time

  f = feed mm/rev

- So this method of estimating the work of plastic deformation in metal cutting gives new meaning of CCR

EXPERIMENTAL METHODS FOR THE DETERMINATION OF THE CHIP COMPRESSION RATIO (CCR)

- First method-

- measure chip thickness and then use CCR formula(t2/t1)
- Demerits-NOT always possible because
- - chip might have saw-toothed pattern
- - chip may be so small and 3D - curved

2ND METHOD : WEIGHTING METHOD

- \- separate small piece of straight chip from rest of chip (5-10 mm long)
- \- measure its length and width , use computer vision if necessary
- \- measure weight G(N)
-
- \- chip thickness
- $t2 = weight/(width*length*density*g)$
- Then find CCR

3RD METHOD -IN FINISHING OPERATION

- In case of finishing operation
- --depth of cut is very small
- --difficult to measure width of chip

- so CCR is determined as

- CCR = cs area of chip/cs area of uncutchip
- Chip cs area = Wt./length*ρ*g
- Uncut chip cs area = df

4^{TH} METHOD : DIRECT METHOD

- - applicable for turning, milling, drilling and other cutting operation
- - work piece is marked before cutting and then resultant mark on chip are compared with original mark
- After the test measure distance Lc on chip
- Find CCR

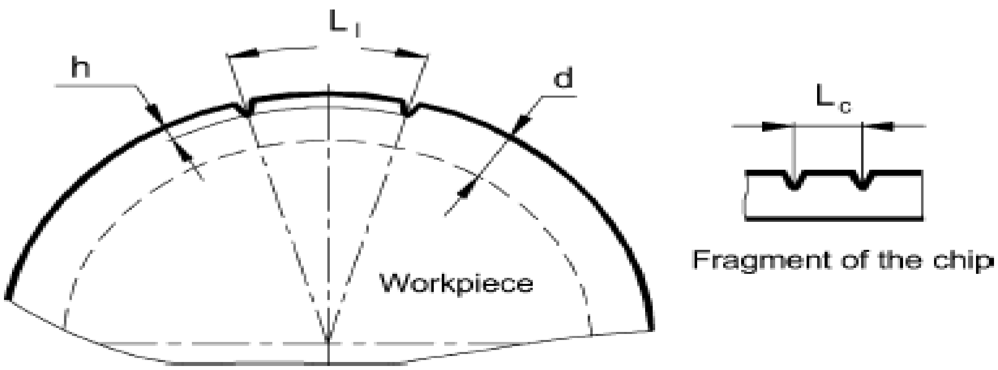

Fig. 11. Application in turning.

5TH METHOD- IN DRILLING

- Two small hole of dia d1 are drilled on trajectory of point of drill cutting edge
- Dia d is less than required hole dia
- Arc length L1 measure
- After machining measure mark length on chip Lc
- Find CCR

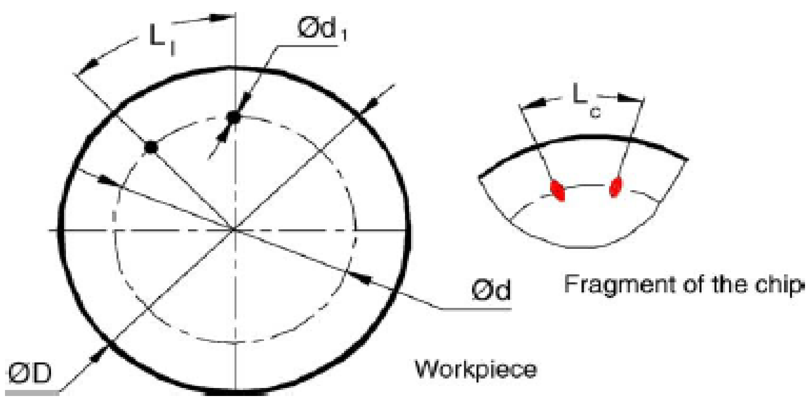

Fig. 12. Application in drilling.

6^{TH} METHOD: BY PECLET NO.

- CCR depends on f, λ ,t1 so it may have different influence at difference speed
- So it should be determine as Peclet no as
-

$$Pe = \frac{vt_1}{w_W} \qquad (30)$$

where w_W is the thermal diffusivity of workpiece material, m^2/s

Peclet no. characterize the relative influence of cutting regime v1*t w.r.t thermal properties of material

- Thermal diffusivity = thermal conductivity / volume sp. Heat

- If Pe > 10, then heat source (tool) moves over the work piece faster than heat wave propagation in the work piece, so influence of thermal energy generated in cutting of plastic deformation of work piece is only due to residual heat from the previous tool position.

- If 2< Pe < 10 then thermal energy makes strong contribution in the process of plastic deformation during cutting.

INFLUENCE OF COMBINED STRESS

- Combined stress :-
- Shearing causes chip formation in metal cutting
- But no chip produced in blanking and punching operation
- So real cause of chip formation is combined stress in deformation zone (compressive and bending stress)
- Compressive force and bending moment causes maximum combined stress at 1-1
- Chip serve as cantilever that transmits the force p to chip formation zone

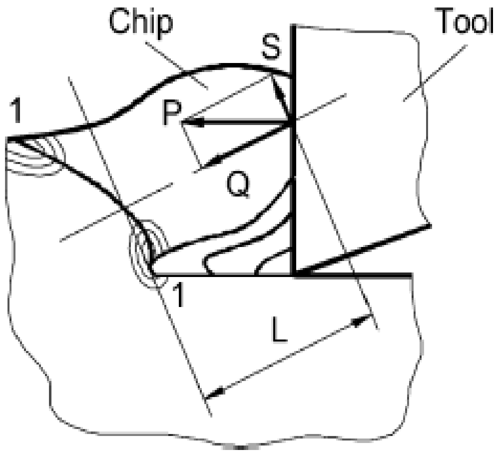

Fig. 6. Interaction between the tool rake face and the chip results in the formation of the compressive force Q and the bending force S as the components of the penetration force P.

CONCLUSION

1 As plastic deformation is nuisance in metal cutting so it should reduce in order to increase the process efficiency

so less plastic deformation ,better cutting speed

2 Merchant shear strain used to asses plastic deformation is not a relevant characteristics because it does not correlate with known properties of work material

3 CCR represents true strain in plastic deformation so it should be used to calculate work

4. cutting speed influences the energy spent on deformation of chip

5. CCR should be calculated in terms of Peclet no. This accounts combined effect of cutting zone and physical properties of work piece.

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