On the significance of equivalent chip thickness

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ON THE SIGNIFICANCE OF EQUIVALENT CHIP THICKNESS

by

C. BUS,
N.A.L. TOUKEN,
P.C. VEENSTRA,
A.C.H. VAN DER WOLF.

Eindhoven, University of Technology, the Netherlands

SUMMARY.

In this article, the technological importance of the equivalent chip thickness and equivalent chip width is shown. Both quantities are defined with the aid of the total length of engaged cutting edge and the true area of undeformed chip section.

In the laboratory of Production Engineering at the Eindhoven University of Technology computer programs have been developed in order to calculate these quantities in dependence on different geometrical conditions.

A relevant example concerning cutting forces is given.

ZUSAMMENFASSUNG.


RÉSUMÉ.

Dans cet article l'importance technologique de l'équivalent épaisseur du copeau et l'équivalent largeur du copeau est indiquée. Les deux grandeurs sont déterminées au moyen de la longueur totale de la lèvre de coupe concernante et l'aire effective de la section du copeau undéformée.

Au Laboratoire de la Technologie Mécanique à l'Université Technique d'Eindhoven, des computer-programmes sont développés pour calculer les grandeurs susdites en connexion de conditions géométriques différentes. Une exemple considérable concernant des forces de coupe est ajouté.
In common practice, both in the workshop and in metal cutting research the quantities depth of cut and width of cut or even feed are considered being primary variables independently controlling important technological phenomena like cutting force and life time of tools.

From this way of thinking, generalised cutting force relations and life time relations arise of a nature as proposed by Kronenberg (1).

Typically, the process is described by both a specific quantity which is arbitrarily chosen and the exponents of depth of cut and width of cut.

The specific quantity being specific cutting force or specific cutting speed accounts for the influence of materials properties. However, the exponents are still affected by the latter.

Obviously, in the relations mentioned the variables chosen are of a geometrical nature rather then being technological. It can be assumed that they do not act seperately in the technological process. On the contrary, depth of cut and width of cut are constituents of two basic technological quantities being the total length of engaged cutting edge or equivalent chip width $h_e$ on the one hand and the surface area $A$ of undeformed chip cross section on the other (2).

From these a third technological quantity is derived being the equivalent chip thickness

$$h_e = \frac{A}{b_e}$$

or rather

$$h'_e = \frac{A_e}{b'_e}$$

(1)

where $A_e$ represents the true area of undeformed chip section. Thus accounting for the influence of the nose radius as shown in Fig. 1.

Clearly the introduction of equivalent chip thickness allows for replacing the actual cutting geometry by an equivalent model containing all the parameters of geometry but for the rake angle.

It is remarked that by the very definition of equivalent chip
thickness a variety of different geometry renders the same value of the quantity in question.

Now, a point of major interest appears as experimental investigation shows that cutting force and tool temperature are merely controlled by equivalent chip thickness irrespective of the separate values of the geometry parameters involved.

This proves that the equivalent model of cutting geometry must not be considered being a conception of purely academic value. Actually, the model reveals the basic technological quantities governing the metal cutting process.

By this time, restricting ourselves to forces in turning operations, it appears that the reduced cutting force, being the cutting force per unit length of engaged cutting edge, is a strict linear function of the equivalent chip thickness, as shown in Figs. 2a and 2b.

The reduced feed and thrust force are linear functions of the equivalent chip thickness too.

Hence, Kronenberg's relations can be replaced by an expression of the type

$$\frac{F_v}{b_e} = \alpha + \beta h_e'$$ (2)

From this follows for the specific cutting force or the specific cutting energy

$$k_s = \frac{F_v}{A_e} = \beta + \frac{\alpha}{h_e'}$$ (3)

It is concluded that application of the equivalent model reduces the amount of data involved in transfer of information regarding cutting forces to only two, being the "material's constants" $\alpha$ and $\beta$.

With an eye to technology transfer the common geometrical data must be translated in terms of equivalent chip width and equivalent chip thickness. The relevant relation available (3) has only limited value as its application is restricted to the region of feed where the minor cutting edge is not engaged in cutting.

As shown in Fig. 3 a number of different geometrical conditions must
be distinguished in order to calculate the equivalent functions. It follows analytically:

case:

\[(1) \quad b_e = \frac{a - r_e (1 - \cos(\kappa))}{\sin(\kappa)} + \{\kappa + \arcsin \left(\frac{s}{2 r_e}\right)\} \frac{r_e}{2} + \]

\[(3) \quad b_e = \frac{a - r_e (1 - \cos(\kappa))}{\sin(\kappa)} + \{\kappa + \kappa'\} \frac{r_e}{2} + \]

\[+ \frac{r_e}{\sin(\kappa')} \left\{\cos(\kappa') - \sin \{\kappa' - \arcsin \left(\frac{s}{r_e} \sin(\kappa') - 1\right)\}\right\}\]

\[(4) \quad b_e = \frac{a - r_e (1 - \cos(\kappa))}{\sin(\kappa)} + \{\kappa + \kappa'\} \frac{r_e}{2} + \]

\[+ \frac{s \sin(\kappa) - r_e (1 - \sin \left(\frac{s}{2} - \kappa - \kappa'\right))}{\cos \left(\frac{s}{2} - \kappa - \kappa'\right)}\]

\[(1) \quad A_e = s(a - r_e) + r_e \frac{2 \arcsin \left(\frac{s}{2 r_e}\right)}{4} + \frac{s}{4} \sqrt{4 r_e^2 - s^2} - \frac{r}{2} \]

\[(2) \quad A_e = s \left(2 \left(\frac{1}{\sin(\kappa)} - \frac{s^2}{4} \left(1 - \kappa - \arcsin \left(\frac{s}{r_e} \sin(\kappa) - 1\right)\right)\right)\right)\]

\[\cdot \cot(\kappa) + \cos(\kappa - \arcsin \left(\frac{s}{r_e} \sin(\kappa) - 1\right)) \]

\[\cdot \left\{\frac{1 - \arcsin \left(\frac{s^2}{r_e} \sin(\kappa) - 1\right)}{2} + \frac{\arcsin \left(\frac{s}{r_e} \sin(\kappa) - 1\right)}{4} - \frac{r_e}{2}\right\}\]
\[ A_e = s a - r_e^2 \left\{ \frac{1}{\sin (\kappa)} - \cot \left( \frac{\kappa'}{2} \right) + \tan \left( \frac{\kappa'}{2} \right) - \frac{\pi}{4} \right\} \]

\[
\arcsin \left\{ 1 - \frac{s \sin (\kappa')}{r_e} \right\} \]

\[
+ \frac{\sin \left\{ \pi - \kappa' - \arcsin \left( 1 - \frac{s \sin (\kappa')}{r_e} \right) \right\}}{2 \sin (\kappa)} \]

\[
- \frac{s - r_e \left\{ \frac{1}{\sin (\kappa)} - \cot (\kappa) + \tan \left( \frac{\kappa'}{2} \right) \right\}^2}{2 \left\{ \cot (\kappa') + \cot (\kappa) \right\}} \]

In order to make these formulas practically useful, they have been numerically evaluated by means of an ALCOL-60 program. Table 1 shows the typical result referring to Fig. 3. The general program is available on request. To a limited extent, it is also possible to ask for numerical data connected with a particular case of chip geometry.

REFERENCES:

{1} "Machining Science and Application"
{2} "Wirtschaftlich Zerspanen"
  von W. Leyensetter, Westermann Verlag, 1953.

{3} "A wear Relationship for Turning, Milling and
  Grinding; Machining Economics"
Fig. 1. The true area of undeformed chip section $A_e$. 
Fig. 2a. Reduced cutting forces versus equivalent chip thickness for a cutting speed $v = 1 \text{ m/s}$. 

tooltip: P20 

material: C45N
Reduced cutting force $\frac{F_V}{b_e}$

Tooltip: P20

Material: C45N

Fig. 3b. Reduced cutting forces versus equivalent chip thickness for a cutting speed $v = 3$ m/s.
Fig. 3. Different geometrical conditions for a depth of cut of 1 mm and a corner radius of 0.4 mm.

feed 0.3 mm/rev

feed 0.7 mm/rev

feed 1.1 mm/rev

$K = 60^\circ$  $K' = 30^\circ$  

$K = 30^\circ$  $K' = 60^\circ$
### Equivalent Chip Thickness, Progr. A - 2403 - 9

- **a**: depth of cut [mm]
- **A_e**: area of the chip section [mm²]
- **b_e**: equivalent chip width [mm]
- **h_e**: equivalent chip thickness [mm]
- **κ**: major cutting edge angle [°]
- **κ'**: minor cutting edge angle [°]
- **r**: corner radius [mm]
- **ε**: feed per revolution [mm/r]

**Table 1. Typical result of the ALGOL-60 program referring to Fig. 3.**

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