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DETERMINATION OF PLASTIC DEFORMATION COEFFICIENT FOR ONE-EDGE DRILLS

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Abstract: *The plastic deformation coefficient, also called the relative plastic deformation, is related to the angle of shifting of the chip and the rake angle of the tool. Studying the nature of chip shifting and deforming layer material relative to the face and major flank of the tool is of great importance for determining both the workability of the materials and the correct choice of cutting tool characteristics.*
This article proposes a methodology based on mathematical dependencies for determining the coefficient of plastic deformation. Theoretical results are presented based on the proposed methodology, as well as results of experimental studies.

Key words: chipformation, one-edge drill, plastic deformation

1. Introduction

In the machining of metals, under the action of an external force applied by the tool on the treated metal, initially elastic deformations occur which rapidly pass into plastic. The material layer in front of the wedge in a closed elemental volume is rapidly deformed plastically, the stresses therein increasing while it shifts relative to the cut metal layer [5]. The chip is formed as a displacement of mutually interconnected elements, whereby the surface of the chip turned to the face of the tool is smooth, and the other side is notched. In this case, a displacement line or surface is distinguished, forming with the direction of movement of the tool an angle β called a shear plane angle. More in-depth studies have shown that the cutting area encompasses a considerably wider area of the metal composed of several surfaces of varying degrees of deformation on which maximum tangential stresses act and plastic movements of the machined metal are carried out [2, 4, 6, 7].

During its moving, the chip is further deformed to a certain depth as a result of friction on the face of the tool [2, 3].

This deformation is observed in the metal layer at the cutting edge and is called secondary deformation. It determines the striving of the chip to roll up. The various elements of the chip forming process are shown in fig. 1 [4, 5].

Because of the contact between the cutting tool and the workpiece arise stresses that form the deformation zone. They create conditions for shearing between the grains, such as those which are oriented at an angle of 45° to the shear plane relative to the beginning of the deformation. The aim of all grains is to re-orient that way. In front of face of the cutting tool is located first zone (above the OA line) of the plastic deformation.

At the boundary of the first zone a plastic deformation begins, in which the chip forming process starts. Above it is the area where the still undeformed grains are located. Below the OA line, the secondary deformation zone is located, the boundary of which ends with the end of the shear area [1, 3, 4].

Plastic deformation of the machined metal is fading nature, and the metal layer after the line OA undergoes less deformation. The width of the cutting zone is a variable magnitude and depends on the properties of the machined metal, the cutting conditions, but to the greatest extent on the cutting speed V (m/min) [6, 7]. At high cutting speeds, the area of plastic deformation of the metal is considerably narrowed and the greatest degree, it is carried near the line OA. Therefore, with some approximation, it can be assumed that as a result of the plastic deformations, the displacement of the metal passes into chip, it is perform along the OA line. It joins the cutting edge with the transition of the outer surface of the cut layer to the chip and closes with the direction of movement of the tool angle β (shear angle - fig.1) [3].

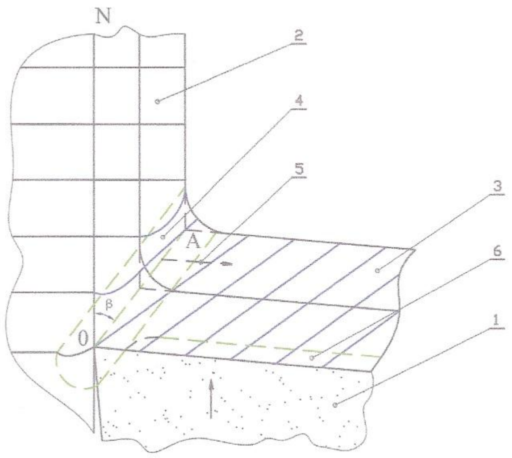

Fig.1 Chipformation at one-edge drills with disposable hard metal inserts
1 – tool; 2 – workpiece; 3 – chip; 4 – shear zone; 5 – shear plane; β – shear plane angle

2. Theoretical determination of the coefficient of plastic deformation

For the quantification of the deformation in the cutting process, the similarity in the chip forming process is used as a process of sequential displacement of an element after element with the principle of determining the coefficient of plastic deformation ε (fig.2).

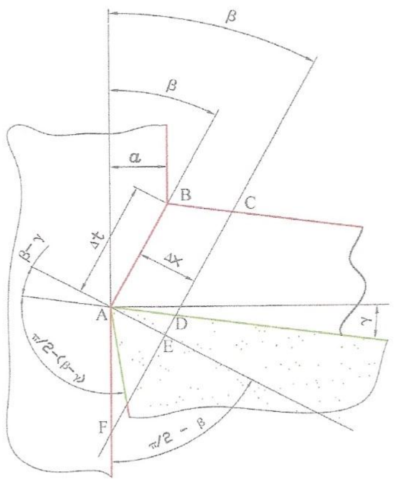

Fig.2 Principal scheme for determining the coefficient of plastic deformation

Looking at fig. 2, some conclusions can be made about the coefficient of plastic deformation ε.

$$\Delta L = AB = CD = DF;$$

$\Delta L = FE + DE$;

ΔFEA is rectangular (∢FEA=90°);

ΔAED IS RECTANGULAR (∢AED=90°).

For ΔFEA: $\cot g\beta = \frac{FE}{AE} \rightarrow \cot g\beta \frac{FE}{\Delta x} \rightarrow FE = \Delta x.\cot g\beta$

For ΔAED: $tg(\beta-\gamma) = \frac{DE}{AE} \rightarrow tg(\beta-\gamma) = \frac{DE}{\Delta x} \rightarrow DE = \Delta x.tg(\beta-\gamma)$,where γ - rake angle, °.

Then for ΔL, after substitution is obtained:

$$\Delta L = FE + DE \rightarrow \Delta L = \Delta x.\cot g\beta + \Delta x.tg(\beta-\gamma) \qquad (1)$$

but

$$\varepsilon = \frac{\Delta L}{\Delta x} \rightarrow \varepsilon = \frac{\Delta x.\cot g\beta + \Delta x.tg(\beta-\gamma)}{\Delta x} \qquad (2)$$

and for ε is obtained:

$$\varepsilon = \cot g\beta + tg(\beta-\gamma) \qquad (3)$$

but

$$tg\beta \frac{\cos\gamma}{K_a - \sin\gamma}, \varepsilon = \frac{1}{tg\beta} + \frac{tg\beta - tg\gamma}{1 + tg\beta.tg\gamma} \qquad (4)$$

where Ka- chip length compression ratio.

For ε is obtained:

$$\varepsilon = \frac{1}{\frac{\cos\gamma}{K_a - \sin\gamma}} + \frac{\frac{\cos\gamma}{K_a - \sin\gamma} - tg\gamma}{1 + \frac{\cos\gamma}{K_a - \sin\gamma}.tg\gamma}, \varepsilon = \frac{K_a^2 - 2.K_a.\sin\gamma + 1}{K_a.\cos\gamma} \qquad (5)$$

There is dependence between the coefficient of plastic deformation ε, the chip length compression ratio Ka and the rake angle of the tool γ.

The functions sinγ, cosγ are continuous and differentiable. The functions Ka, K^2a are also continuous and differentiable. Therefore, ε is a continuous and differentiable function. And hence it follows that exist $\frac{d\varepsilon}{dK_a}$ and $\frac{d\varepsilon}{d\gamma}$ at Ka>0, γ≠π, $\frac{3\pi}{2}$

And from there can be found extremum of the function ε relative to Ka:

$$\frac{d\varepsilon}{dK_a} = \frac{(2.K_a - 2.\sin\gamma).K_a.\cos\gamma - \cos\gamma.(K_a^2 - 2.K_a.\sin\gamma + 1)}{K_a^2.\cos^2\gamma}$$

$$\frac{d\varepsilon}{dK_a} = \frac{1}{\cos\gamma} - \frac{1}{K_a^2.\cos\gamma} \qquad (6)$$

$$\frac{d\varepsilon}{dK_a} = 0 \rightarrow K_a^2 = \pm 1$$

But $Ka > 0 \rightarrow Ka = 1$. Then

$$\varepsilon(K_a = 1) = \frac{2.(1-\sin\gamma)}{\cos\gamma} \quad (7)$$

Therefore, there is an extremum of the function ε and it is at Ka=1.

If the rake angle is $\gamma = 0°$. Then for the coefficient of plastic deformation ε the following extremum is obtained:

$$\varepsilon(K_a = 1) = 2 \quad (8)$$

ε(Ka) is increasing function at $\frac{d\varepsilon}{dK_a}>0$, i.e. at *1<Ka<+∞*.

ε(Ka) is decreasing function at $\frac{d\varepsilon}{dK_a}<0$, i.e. at *0<Ka<1.*

From the performed studies it can be concluded that the coefficient of plastic deformation ε has a local minimum at Ka = 1:

$$\varepsilon_{min} = \varepsilon(K_a = 1) = 2 \quad (9)$$

Therefore, when cutting the metals when there is no chip length compression, the relative plastic deformation is minimal.

It can be calculated $\frac{d^2\varepsilon}{dK_a}:\frac{d^2\varepsilon}{dK_a} = -\frac{2}{K_a^3.\cos^3\gamma} \neq 0$

Therefore, the function ε does not have an inflection point.

At $\gamma = 0°, \frac{d^2\varepsilon}{dK_a} = -\frac{2}{K_a^3};\ K_a > 0, \frac{d^2\varepsilon}{dK_a} = -\frac{2}{K_a^3} < 0$

Therefore, ε (Ka) is a convex function.

This also explains the local extremum, which is a local minimum:

$$\varepsilon_{min} = \varepsilon(K_a = 1) = 2$$

3. Experimental setup and methodology for studying the chip length compression ratio

For determining of chip breaker and studying the change in the chip length compression ratio an experimental setup is created based on an SP586 lathe with a main engine output of 15 kW, a range of revolutions - 5÷2500 (s^{-1}), longitudinal feed - 0,01÷40,9 (mm/rev) and a cooling system (consumption 30 l / min).

Scheme of the experimental setup is shown on fig.3.

For further deformation in the chip, the chip breaker needs to apply some extra load on it. For this purpose, it is placed at a certain distance from the cutting edge of the insert. This distance is exactly the difference between the radius of the chip and the critical radius. It will vary from 0.3 to 2 mm. This means that when working with different feeds, machining different materials, and using a tool with disposable hard metal inserts with different parameters of the chip forming channels, the position of the chip breaker can be determined. If working with this method, there will be obtained chips with the same length, which will be determined by the point of contact between the chip and the chip breaker.

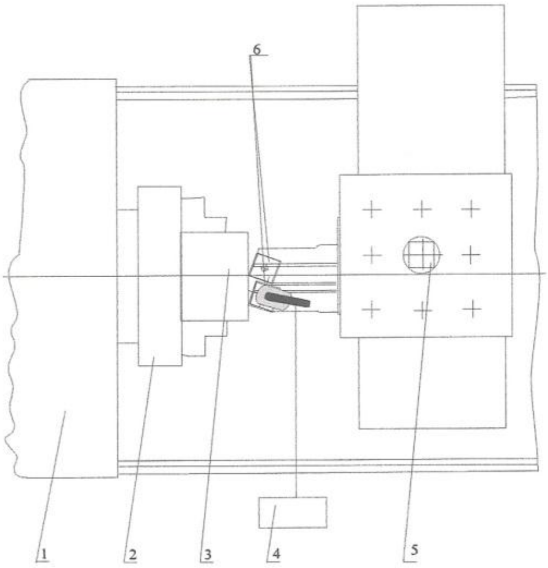

Fig.3 Scheme of experimental setup for measuring the cutting forces acting on the individual disposable hard metal inserts
1 – gearbox of lathe SP586; 2 – universal chuck Ø90; 3 – workpiece; 4 – a cooling system with 4 MPa and consumption 30 l/min; 5 – tool post; 6 – chip breaker.

When determining the chip length compression ratio – Ka it is necessary to determine the thickness of the chip. In the experiment, a micrometer with replaced spindle and anvil is used. The cylindrical are replaced by conical. The measurements are performed under the scheme $a_1 = \frac{A+B+C+D+E}{5}$, [m] shown in fig.4.

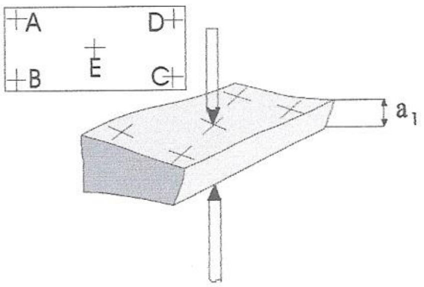

Fig.4 Scheme for measuring the chip thickness

4. Theoretical determination of the coefficient of plastic deformation

In conducting the theoretical study are used mathematical dependencies described in paragraph 2 of this article. The results of these studies are shown graphically in fig. 5 - fig.8.

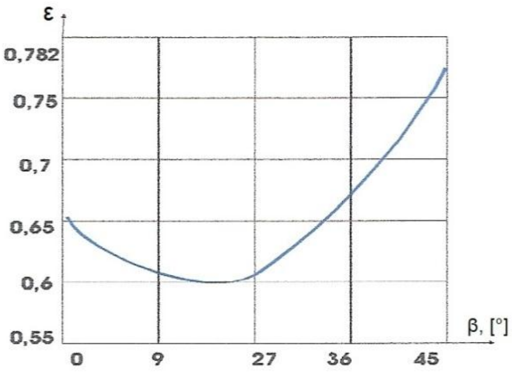

Fig.5 Changing the plastic deformation factor ε at shear angle β=0°÷45° and tool rake angle γ=0°; at chip length compression ratio Ka=2;s=0,l mm/rev; V=180 m/min during machining of steel CT80

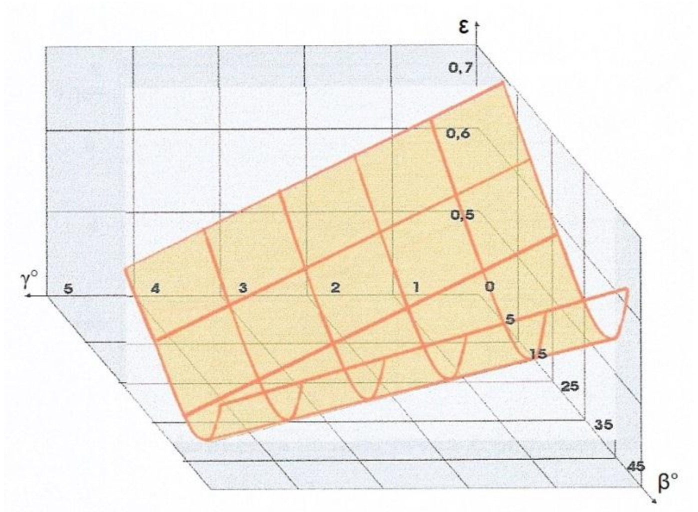

Fig.6 Changing the plastic deformation factor ε at shear angle β=0°÷45° and tool rake angle γ=5° at chip length compression ratio Ka=2; s=0,l mm/rev; V=180 m/min; during machining of steel C45

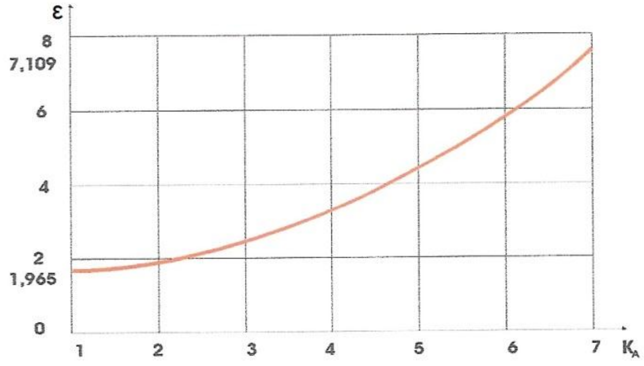

Fig.7 Changing the plastic deformation factor ε at chip length compression ratio Ka=1÷7 at tool rake angle γ=1°; s=0,08 mm/rev; V=180 m/mm; during machining of brass

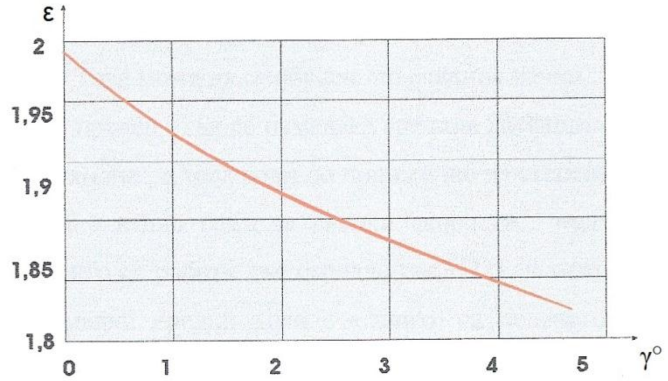

Fig. 8 Dependence between the coefficient of plastic deformation ε and tool rake angle γ=0°÷5° at chip length compression ratio Ka=1 and shear angle β= 36°; s=0,1 mm/rev; V=250m/min; during machining of steel C45

The value of the chip length compression ratio Ka and the coefficient of plastic deformation ε express the degree of plastic deformation of the cut metal layer, and there is a certain dependence between them. From the equation:

$$K_a = \frac{\cos(\beta - \gamma)}{\sin \beta} \tag{10}$$

Follows

$$tg\beta = \frac{\cos\gamma}{K_a + \sin \gamma} \tag{11}$$

By replacing in the two equations

$$\varepsilon = \frac{\Delta s}{\Delta x} = \cot g\beta + tg(\beta - \gamma) \tag{12}$$

The result is:

$$\varepsilon = \frac{K^2 - 2.K.\sin \gamma + 1}{K.\cos\gamma} \tag{13}$$

Increasing the tool rake angle γ, the coefficient of deformation ε decreases. To understand under what condition the relative plastic deformation is minimal it is necessary to differentiate and equate to 0. Dependency is solved as an equation with unknown – K.

When cutting metals when there is no chip length compression, the relative plastic deformation is minimal.

At a small rake angle γ = 2°÷4 ° in the range of high cutting speeds V=160÷280 m/min, the relative plastic deformation remains almost constant.

5. Results of experimental studies for the plastic deformation coefficient

The experiment is conducted under the following conditions: s = 0.1 mm/rev, tool cutting edge angle χ_r=85° and diameter of one-edge drill D=16 mm. The rake angle γ changes from -10° to +10°, the cutting speed – from 50 m/min to 250m/min.

Fig. 9 gives the results obtained from the study of the change of the coefficient ε during machining of holes with a one-edge drill with D=16 mm.

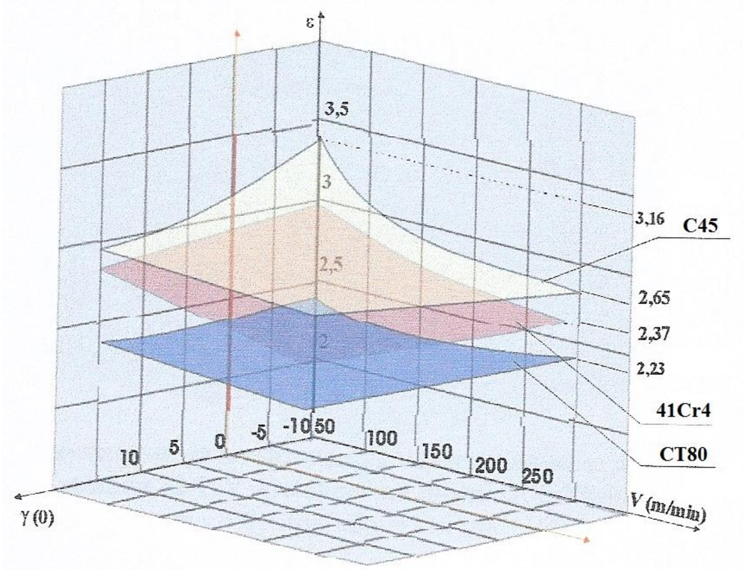

Fig.9 Changing the plastic deformation factor ε at machining of steel C45, steel 41Cr4 and steel CT80 depending on the cutting speed – V=50÷200 m/min and rake angle γ(-10° ∂o +10°), D=16 mm, s = 0,1 mm/rev, χ_r= 85°

6. Analysis and conclusions

Both in theoretical and experimental studies, the coefficient of plastic deformation is similar in value (fig.10). The conclusion that can be drawn is that with the increase of the rake angle, the coefficient of plastic deformation decreases. At small rake angles and high cutting speeds typical for tools with disposable hard metal inserts, the coefficient of plastic deformation ε varies from 2 to 4, and these values are much higher than the critical deformation for structural steels – (2÷7).10-4, which ensures reliable chip breaking.

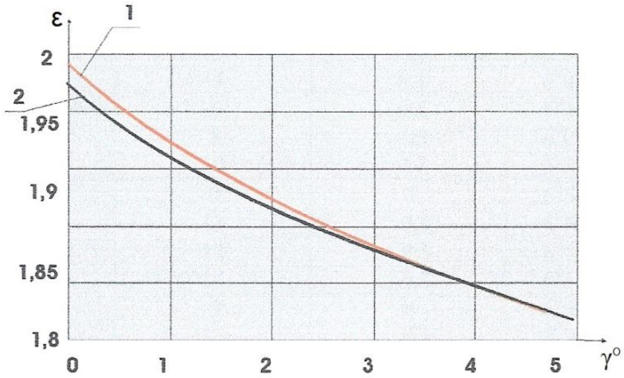

Fig.10 Dependence between the coefficient of plastic deformation ε and tool rake angle γ=0°÷5°, at chip length compression ratio Ka=1 and shear angle β=36°
1 – theoretical curve (fig.9); 2 – experimental curve (fig.10)

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