DETERMINATION OF CHIP LENGTH COMPRESSION RATIO AT ONE-EDGE DRILLS

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Abstract: *Increasing the volume of chips, taken per unit of time under conditions of high speeds and temperatures of the cutting, makes the problem of reliably shredding the chips and their effective removal from the cutting zone, particularly topical. The present scientific development examines the determination of the chip length compression ratio according to the proposed methodology. Presented are the results of the theoretical and experimental studies made according to the methodology.*

Key words: chip length compression, drilling, one-edge drill

1. Introduction

The process of formation of the chip during drilling with drills with disposable hard metal inserts (DHI) is largely similar to the mechanism of formation of the chip during turning [5, 6, 7]. This similarity is most pronounced at the moment of incision the tool in the metal and the accompanying deformation processes that occur as a result of the interaction of the tool with the workpiece material [3]. However, it is necessary to take into account the specific features of the cutting process that characterize the drilling. These are the typical working conditions in which the forces act on the formation of the chip, its movement on the face of the tool, the need to obtain such a shape of the chip which is best suited for its removal, pursuant with the design of the drill, hence the way and type of chip breaking and chip removal [2, 6].

In the most common case, the mechanism of chip formation when operating a drilling machine with disposable hard metal inserts can distinguish three main stages [2, 3, 6]:

- chip formation in the displacement zone;
- free shifting of the chip;
- chip breaking.

It is necessary to show the influence of the main factors contributing to the chip formation at the different stages. Main factors influencing are:

- For the machined part – material (critical deformation values, strength parameters and deformation properties) and dimensions, depth, diameter of the machined hole);
- For the tool – the geometry of the angles (γ, λ; χ; r); the geometric parameters of the chip breaker; tool material (friction, wear); mode of operation (speed, feed);
- For the machine – the dynamic characteristic.

The conversion of the cut metal layer into the chip during the cutting process is one of the varieties of the plastic deformation. The main sign of this is the occurred irreversible changes in the geometric form of the material as a result of external forces [1, 4].

Deformation passes through three main stages when looking at small-volume bodies (fig. 1) (when the volume of the deformed metal layer is considerably smaller than that of the workpiece) [1]:

- tension – where in one of the three main axes is observed elongation, and in the other two compressional stress;
- compression – in one of the main axes compressional stresses are observed, and in the other two axes elongation;
- shear – in this zone on one of the main axes there is no deformation. In absolute shearing, uniform crushing is observed on both axes, which are mutually perpendicular.

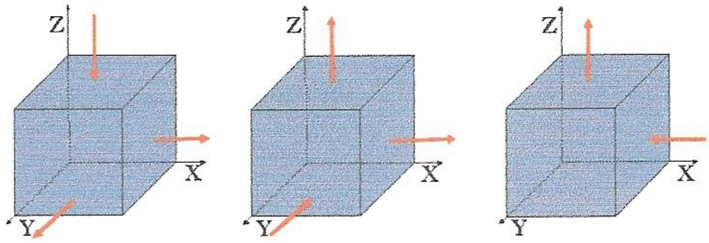

Fig.1 Type of the loads

2. Theoretical determination of the chip length compression ratio

The chip length compression is the ratio of the chip thickness a_1 to the thickness of the cut metal layer a, or the ratio of the distance passed by the cutting edge l to the length of the chip l_c.

The width of the chip is almost equal to the width of the cut metal layer. The chip length compression ratio (K_a) is determined by using the rule for the equal volume or mass of the chip and the cut metal layer. Its determination may be performed by:

- the ratio of the length of the path passed by the insert to the length of the chip measured for that time;
- the ratio of the chip thickness measured by microscope and the thickness of the cut metal layer, set by the feed;
- the ratio of mass G - measured for one chip and the multiplication of the specific mass of the treated metal (ρ), the chip length (l_c) and the width of the cut metal layer (b) and its thickness (a).

In order to determine the chip length compression ratio it is necessary to consider fig.2.

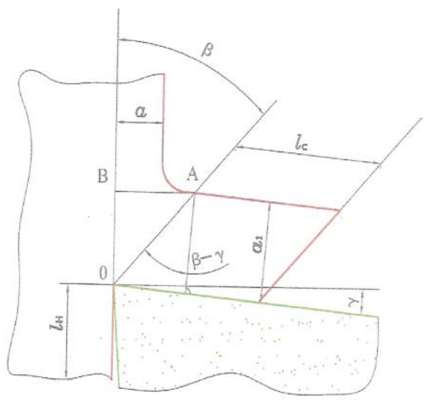

Fig.2 Scheme for determining of chip length compression ratio

From fig.2:
ΔOAB is rectangular (∢OBA=90°);
ΔOAC is rectangular (∢OCA=90°);
OA is a common hypotenuse of the rectangular triangles ΔOAB и ΔOAC.

For ΔOAB: $\sin\beta = \frac{AB}{OA} \rightarrow \sin\beta = \frac{a}{OA} \rightarrow a = OA.\sin\beta$

For ΔOAC: $\cos(\beta-\gamma) = \frac{AC}{OA} \rightarrow \cos(\beta-\gamma) = \frac{a_1}{OA} \rightarrow a_1 = OA.\cos(\beta-\gamma)$

The chip length compression ratio is expressed with the following dependence:

$$K_a = \frac{a_1}{a} \qquad (1)$$

By replacing a and a_1 in the last equality and is obtained:

$$K_a = \frac{\cos(\beta-\gamma)}{\sin\beta} = \frac{\cos\beta.\cos\gamma - \sin\beta.\sin\gamma}{\sin\beta} = \frac{\cos\gamma}{tg\beta} - \sin\gamma\,, \qquad (2)$$

i.e.

$$K_a = \frac{\sin\gamma}{tg\beta} - \sin\gamma \qquad (3)$$

Then for the displacement angle β the following dependence is obtained:

$$tg\beta = \frac{\cos\gamma}{K_a - \sin\gamma} \qquad (4)$$

It can be seen from the dependence (4) that the displacement angle β is influenced by the change of the chip length compression ratio K_a and the tool rake angle γ, i.e. increasing the chip length compression ratio reduces the displacement angle.

Let the chip length compression ratio is fixed, $K_a=K_1$. Then, the following relation between the displacement angle β and the tool rake angle γ is obtained:

$$tg\beta = \frac{\cos\gamma}{K_1 - \sin\gamma} \qquad (5)$$

Let the tool rake angle be fixed $\gamma=\gamma_0$. Then the following dependence between β and K_a is obtained:

$$tg\beta = \frac{\cos\gamma_0}{K_a - \sin\gamma_0} \qquad (6)$$

When changing the chip length compression ratio at *a* constant tool rake angle, the magnitude of the displacement angle also changes.

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.

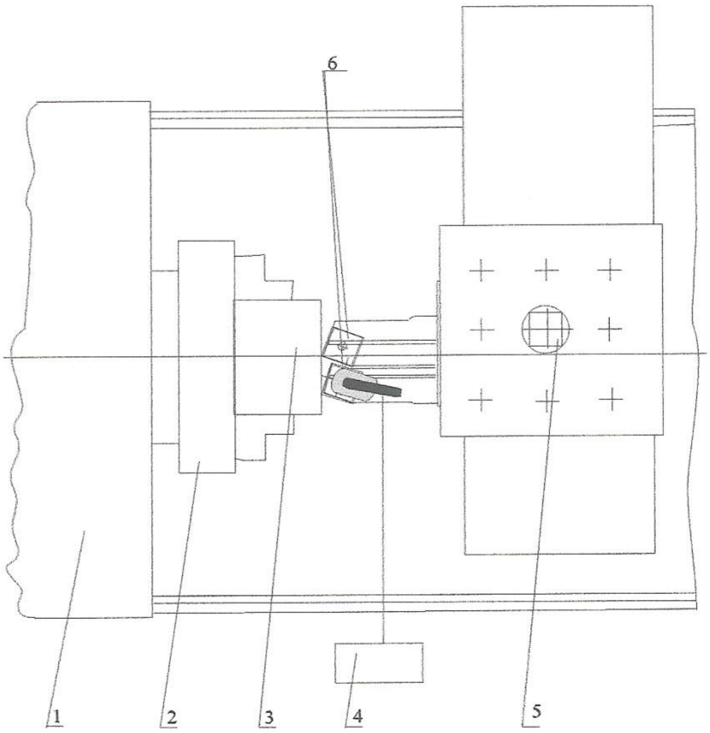

Fig.3 Scheme of experimental setup for measuring the cutting forces acting on the individual disposable hard metal inserts
1 – gearbox of lathe SP586; 2 – universal chuck Ø90; 3 – workpiece; 4 – a cooling system with 4 MPa and consumption 30 l/min; 5 – tool post; 6 – chip breaker

When determining the chip length compression ratio – K_a 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.

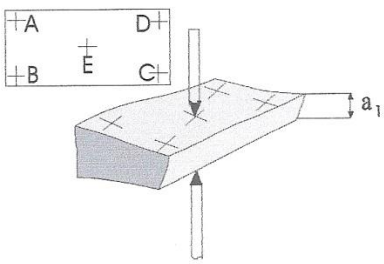

Fig.4 Scheme for measuring the chip thickness

4. Results of the theoretical studies for determining the chip length compression ratio

On the basis of the developed theoretical model and the mathematical dependencies in point 3 of the present article, for the chip length compression ratio are obtained results, which are shown graphically in fig. 5 ÷ fig. 8. The calculations are based on: permanent feed s = 0.1 mm/rev, rake angle γ (°), varying in the range 0°÷5° and 10 values of the displacement angle β in the range 0°÷45°.

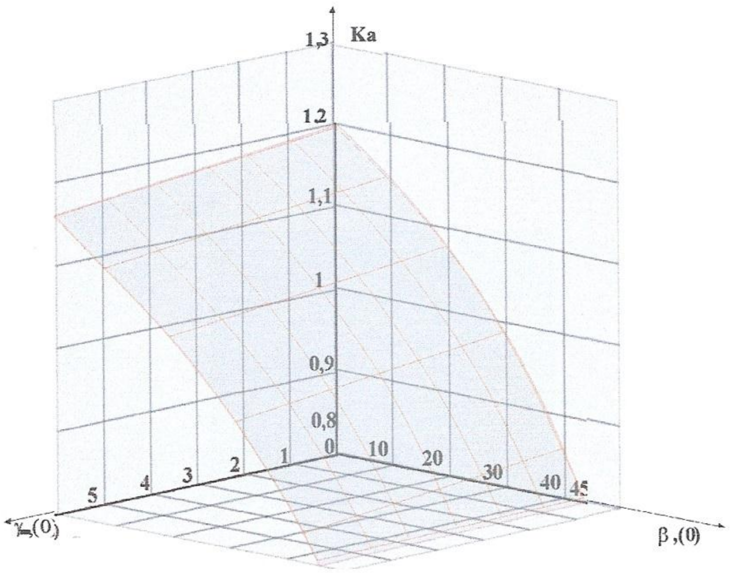

Fig.5 Dependence between the chip length compression ratio K_a, the displacement angle β and the tool rake angle γ, V = 180 m/mm; during machining steel X210Cr12

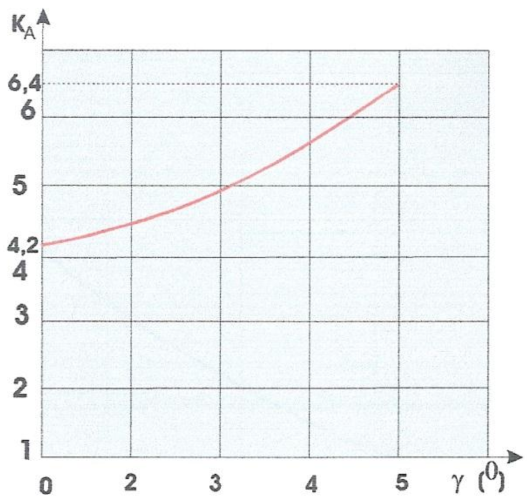

Fig.6 Dependence between the chip length compression ratio K_a, the displacement angle β=36° and the tool rake angle γ, V = 150 m/mm; during machining aluminum alloy AlCu4Mg1

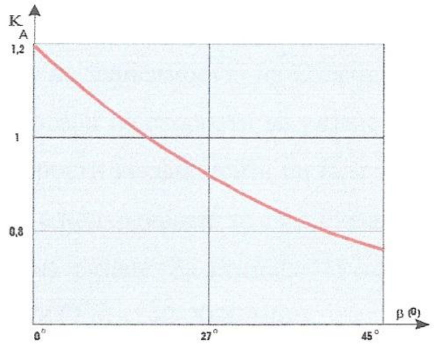

Fig.7 Dependence between the chip length compression ratio K_a, the displacement angle β and the tool rake angle γ=36°, V = 180 m/mm; during machining steel C45

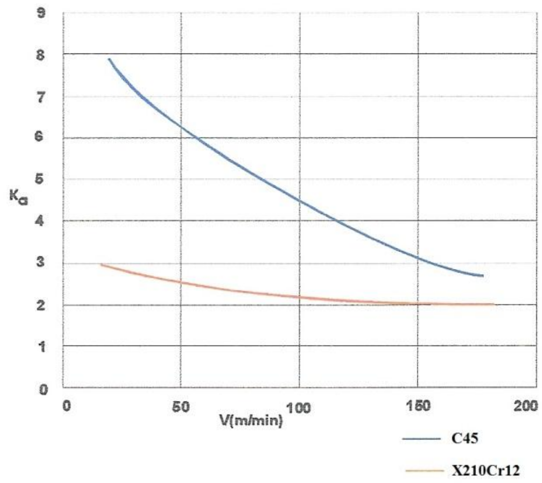

Fig.8 Dependence between the chip length compression ratio K_a, the cutting speed V(mm/min); β=36°; during machining steel X210Cr12 and C45

From the graph (fig. 8) it can be seen that the dependence of the chip length compression ratio on a wide range of cutting speeds is a curve elliptic line. At considerable speeds, the chip length compression ratio is almost stabilized. This is the range of cutting speed variations suitable for drilling with disposable hard metal inserts. For steel C45 this is the range of (160-200 m/min); for steel X210Cr12 from (140-200 m/min).

The chip length compression ratio depends on the plasticity of the machined metal:

1. For more plastic metals, chip length compression ratio is higher. - Ka reaches up to 9 at high speeds of cutting (over 180 m/min) of aluminum alloy - AlCu4Mg1 and takes values of 4-6 at low cutting speeds (from 50 - 150m/min) (fig.6)

2. For more plastic metals, chip length compression ratio is a variable magnitude for a larger range of speeds (fig. 8).

These dependencies can be explained using the theory of interatomic bonds. For more plastic metals, the atomic bonds are weaker, the position of the atoms is more easily disturbed, so the plastic deformation in the cutting is greater. At a constant rake angle of the tool the chip length compression ratio does not depend on the size of the cut layer, but the chip length compression ratio K_a reaches a maximum value at different cutting speeds.

The using of a coolant fluid reduces the chip length compression ratio, and hence the smaller plastic deformation of the material immediately above the cutting edge.

Cutting speed, chip parameters, and geometric parameters of the tool affect chip length compression only to the extent that they cause an increase in the temperature that determines the friction coefficient.

5. Results of experimental studies of the chip length compression ratio - K_a

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

Fig. 9 ÷ fig.11 shows the results obtained from studying the change of the K_a ratio at the machining of holes with a one-edge drill with D=16mm.

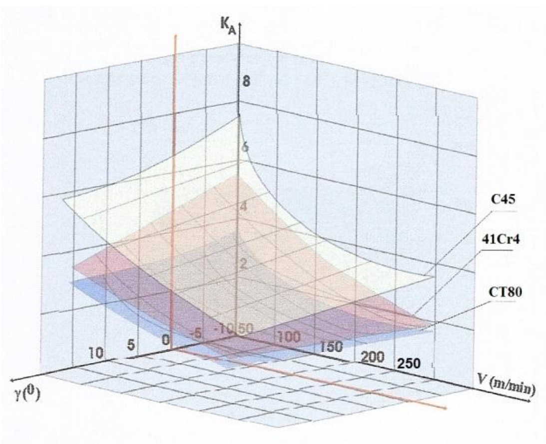

Fig.9 Change of the chip length compression ratio K_a during machining steel C45, steel 41Cr4 and steel CT80 depending on rake angle γ(-10° ∂o +10°) and the cutting speed - V (50-200) m/min, D=16mm, s = 0,1 mm/rev, χ_r= 85°

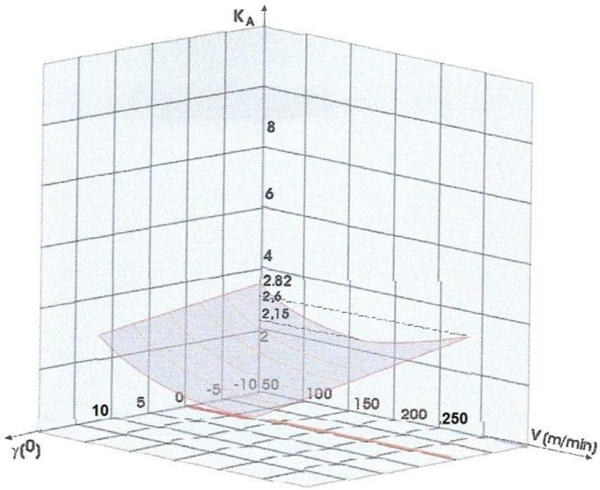

Fig.10 Change of the chip length compression ratio K_a during machining steel X210Cr12, V=50-250 m/min, D =16mm, s = 0,1 mm/rev, γ = -10° ÷ +10°, χ_r= 85°

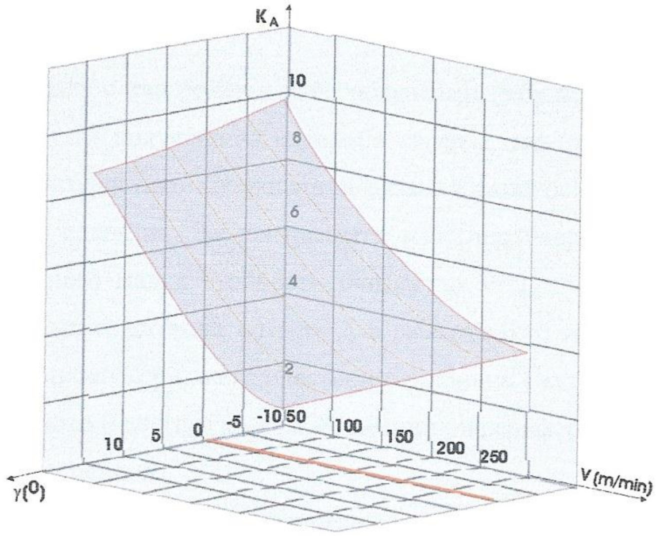

Fig.11 Change of the chip length compression ratio K_a during machining aluminum alloy AlCu4Mg1, V = 50-250 m/min, D =16 mm, s = 0,1 mm/rev, γ = -10°÷+10°, χ_r=85°

6. Analysis and conclusions

The results of the experimental studies confirm the results of the theoretical studies. The difference in the data obtained is not more than 3%. The chip length compression ratio increases with the increase of the rake angle γ (fig. 12). The chip length compression ratio K_a depends on the plasticity of the machined metal. For more plastic metals, the chip length compression ratio K_a is greater and is a variable magnitude for a larger range of cutting speeds, during machining aluminum alloy AlCu4Mg1 K_a reaches up to 9,8.

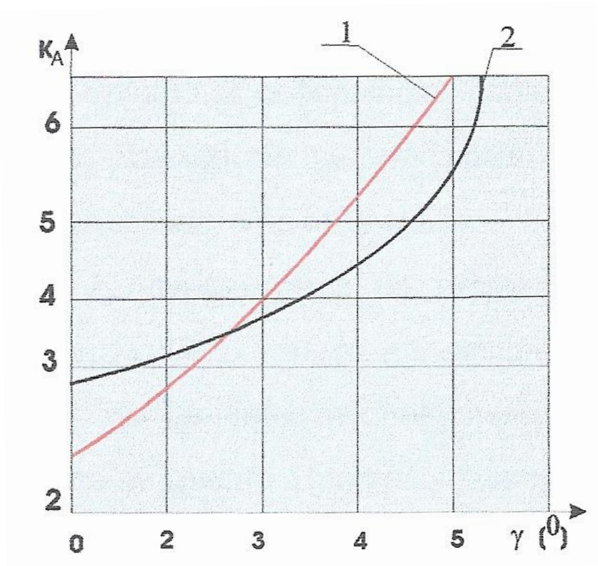

Fig.12 Dependence between the chip length compression ratio K_a and displacement angle β = 0°÷45° at tool rake angle γ = 3°
1 – Obtained in theoretical way; 2 – obtained experimentally for C45

At high cutting speeds V (over 250 m/min), the values of the chip length compression ratio are slightly different for each other for the same cutting speed intervals. The uneven change in chip length compression at different rake angles indicates that there is no direct connection between the chip length compression and the cutting speed.

Cutting speed V, chip parameters, and geometric parameters of the tool affect chip length compression only to the extent that they cause an increase in the temperature that determines the friction coefficient. At high cutting speeds, when the temperature is close to the contact metal layer temperature, the change in temperature reflects poorly on the change in the coefficient of friction, as a result of which the chip length compression ratio changes slightly. Chip length compression is an important parameter that determines the course of the cutting process, since its variation changes the cutting forces, the heat removal and the quality of the machined surface. By increasing the chip length compression ratio K_a decreases the displacement angle β.

From the results obtained it can be concluded that the displacement angle β is influenced most by the type of the machined material and the rake angle γ. By increasing the rake angle γ, the displacement angle β increases.

From the parameters of the cutting conditions, the most significant influence on displacement angle β has the cutting speed V when its value is up to 120 m/min, after this speed K_a and β almost do not change.

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