SYNTHESIS ON THE ASSESSMENT OF CHIPS CONTRACTION COEFFICIENT C_d

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Abstract: *The assessment of plastic deformation of chips can be done based on theoretical and experimental considerations. This paper presents the two ways of assessing the chips contraction coefficient, namely the theoretical and experimental methods. The results obtained from both methods will be used to develop a mathematical model for chips contraction coefficient. The theoretical and experimental methods have the advantage of fast assessment of deformations and the disadvantage of using intermediary elements such as correction coefficients.*

Keywords: *chips contraction coefficient, theoretical methods, experimental methods*

1. Introduction

The chips contraction coefficient represents the capacity of plastic deformation of different metals during the cutting process. The assessment of plastic deformation is based on both theoretical and experimental considerations, which are used to develop a mathematical model for C_d. In this mathematical model, C_d is dependent on the parameters of the cutting process.

2. Theoretical Considerations

An analysis of metal-cutting studies reveals that there are a few known models of this process regarding plastic deformation, chip formation or other related concepts, like stress or strain.

In his model, Timme considers the interaction between the cutting tool, the work piece and the chip. The Ernst and Merchant approach introduces the concept of the single shear plane and the angle it makes with the surface generated referred to as the shear angle. It has become a classic approach in metal cutting and has been applied in analyzing the cutting of different materials even when shearing cannot occur at all. Authors like Shaw, Cook and Finnie insist on the relationship between the shear and friction process in metal cutting. Okushima and Hitomi assume that shearing takes place within a particular flow region rather than along a single shear plane. Kececioglu studies the metal cutting mechanics assuming a uniform stress-state in the zone of plastic deformation with parallel boundaries. [Xiao, Astakhov, 2008]

Zorev suggests a model for the cutting of ductile materials in agreement with the theory of plasticity. [Astakhov, 2003]

Summarizing the ideas above, it can be said that each cutting approach or model reflects a particular aspect of metal cutting practice. No model can cover all various cutting conditions that can be found during the real process.

Historically, the chip contraction coefficient was introduced in studies on metal cutting as a measure of plastic deformation. It was shown that although C_d is not a perfect measure of plastic deformation, it directly reflects the final plastic deformation that takes place in cutting. [Astakhov, 2010]

The most frequently used theoretical model takes into consideration the dependence of the chips contraction coefficient on the shear angle and the rake angle as in Fig 2.1 and Eq. 2.1.

$$C_d = \frac{t_a}{t} = \frac{\cos(\varphi - \gamma)}{\sin\varphi}. \quad (2.1)$$

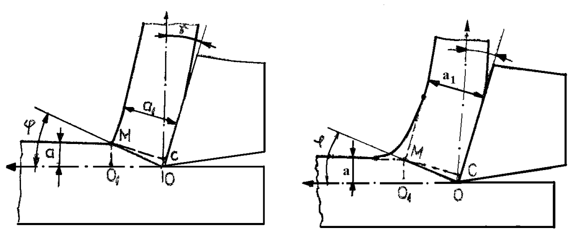

Figure 2.1: *Cutting with a single shear plane*

Most published papers take into consideration the individual influence of some cutting parameters; only few studies consider the influence of some pairs of parameters on the chips contraction coefficient (cutting speed, the nature of the cut material, feed, the angles of the cutting tool).

The results of the studies undertaken by researchers in USA and Russia show that the individual influence of the cutting speed (v), the feed (s), the inclination angle (λ) and the rake angle (γ) depends on the values of other parameters. A case in point is the influence of the cutting speed *v* on C_d, which is minimum for higher values of the rake angle and for harder and more resistant steels.

Knowing the values of the chips contraction coefficient obtained in correlation with the main influential parameters and the exact assessing requirements of the cutting forces can help in characterizing metals from the point of view of machinability. [Poenaru, 2010]

As mentioned before, both analytical and experimental methods can be used in assessing and measuring the plastic deformation in cutting.

2.1 Analytical and Experimental Methods

Analytical methods consist in the mathematical calculus of the elements that characterize the plastic deformation of the cut metal in various conditions. In order for this method to be applied it is necessary to know the yield curves, the structural characteristics of the materials and the distribution of the efforts in the deformation zone.

Experimental methods directly measure the elements of plastic deformation.

V. Astakhov [2010] suggests three experimental methods for the determination of the chip contraction coefficient. The simplest method is to measure the chip thickness and calculate C_d as in Eq. (2.2):

$$C_d = t_2 / t_1. \quad (2.2)$$

where t_2 is the chip thickness and t_1 is the uncut chip thickness. This method cannot be always used because of the chip's saw-toothed free surface or its smallness.

The second method is the weighing of the chips. After determining the length L, the width d_w and the weight G_{ch} , the chip thickness is calculated as in Eq. (2.3):

$$t_2 = \frac{G_{ch}}{d_{w1} L \rho_w g}. \quad (2.3)$$

where ρ_w is the density of the work material and $g=9{,}81 m/s^2$ is the gravity constant.

The third method proposed by Astakhov to determine chips contraction coefficient is the direct method, which can be applied in milling, turning, drilling and other processes. C_d is calculated as in Eq. (2.4):

$$C_d = \frac{L_{g1}}{L_{g2}}. \quad (2.4)$$

which can be seen in Fig. 2.2.

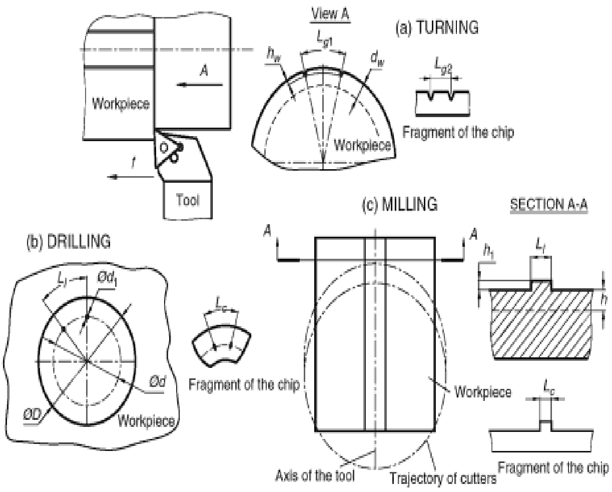

Figure 2.2 *Experimental methods to determine C_d: a. turning; b. drilling; c. milling.*

These methods, either theoretical or experimental, can lead to errors in assessing the chips contraction coefficient. To eliminate these errors, a theoretical-experimental model of assessing C_d is suggested, based on both theoretical considerations, but mostly on experimental results.

3. The Assessment of C_d

Based on the published results and experimental research, fifteen parameters which influence the plastic deformation of chips are pointed out. They have been classified into three categories according to their influence on C_d as follows: highly influential parameters (table 1), average influential parameters (table 2) and low influential parameters. The first two categories have been synthesized in tables for an easier reading.

Table 1
Highly Influential Parameters

No.	Parameter	Symbol and Field Variation	Meaning variation
1.	Cutting speed	v 0-250-500	v increases C_d decreases
2.	Feed	s 0-0.75	s increases C_d decreases
3.	Cut material	σ_r (HB) 30-100	σ_r increases C_d decreases
4.	Rake angle	γ $30^0...+40^0$	γ increases C_d decreases
5.	Inclination angle	λ $30^0...+45^0$	λ increases C_d decreases

Table 2
Average Influential Parameters

No.	Parameter	Symbol and Field Variation	Meaning variation
1.	Tool cutting edge angle	K 0^0-90^0	K increases C_d decreases
2.	Edge radius	r 0......3-4	r increases C_d decreases
3.	Radius of curvature	R_t ∞......4	R_t decreases C_d increases
4.	Edge sharpening radius	ρ 0......0,3	ρ increases C_d decreases

Low influential parameters are worth mentioning: cutting depth *t* which increases while C_d decreases; rake surface radius increases while C_d decreases; rake surface-chip contact length increases at the same time with C_d; the influence of the cutting environment and the cutting material can be seen in the decrease of the C_d; last, but not least, rake surface roughness increases while C_d decreases. These parameters tend to be neglected in assessing the chips contraction coefficient. [Segal,1993]

The importance and role of the highly influential parameters have been established by comparison with the results published in the specialized studies [Panait, 1993]

The parameters in table 2 may appear in some assessing model for C_d as correction coefficients for on the one hand the tool cutting edge angle whose values are lower than 1 and on the other hand, the three types of radius whose values are higher than 1.

Due to this classification, the assessing model for the chips contraction coefficient can take into account either all types of parameters, or only one of the mentioned categories.

3.1 The First Model of Assessing C_d

To determine C_d in the model of assessment, the following Eq. is used:

$$C_d = C\, v^x\, s^y\, HB^z\, \gamma^n\, \lambda^w\, K_k\, K_y\, K_\rho\, K_{Rt}\,. \quad (3.1)$$

in which *C, x, y, z, n, w, k* are obtained experimentally and *K* represents correction coefficients, γ is the rake angle and λ is the inclination angle.

The values of the *C* constant depend on the nature of the cut material and the cutting process and will be obtained for each type of material experimentally.

After determining the exponents and coefficients, the *C* constant is obtained as follows:

$$C = \frac{C_{d0}}{v_0{}^x s_0{}^y HB_0{}^z \gamma_0{}^u \lambda_0{}^w K}\,. \quad (3.2)$$

in which C_{d0} represents the value of the chips contraction coefficient for v_0, s_0, HB_0, λ_0, γ_0.

The *x, y, z, u, w* exponents show their level of influence and the significant interdependencies. According to experimental research, by increasing the *v, s, HB, λ, γ* parameters the chips contraction coefficient decreases and, implicitly, the exponents will become negative.

In order to take into consideration the possible interdependencies, it is suggested that the *x, y, z, u, w* exponents should have the following proposed values:

$$\begin{aligned}
x &= f_1(v,s,M,\lambda,\gamma,r,k,...)\\
y &= f_2(v,s,M,\lambda,\gamma,r,k,...)\\
z &= f_3(v,s,M,\lambda,\gamma,r,k,...)\ .\\
n &= f_4(v,s,M,\lambda,\gamma,r,k,...)\\
w &= f_5(v,s,M,\lambda,\gamma,r,k,...)
\end{aligned} \quad (3.3)$$

in which M represents the dependence of the influence level on the nature of the cut material. Since the plastic deformation capacity of different materials is different for the same cutting conditions, the level of influence of some of these factors is different from one material to another.

The correction coefficients k take into consideration the influence of the parameters with low influence on C_d. Under specific working conditions (cut material, rake angle, inclination angle, cutting speed or cutting feed), these coefficients will not appear in the assessing model for the chips contraction coefficient.

If for specific working conditions, the factors do not influence C_d, then the correction coefficients are k=1. If the factors influence C_d, then C_d increases and the values of k are higher than 1, k>1. If C_d decreases due to these factors, then k<1.

To obtain the values of the exponents, Eq. 3.4 is suggested, in which x_0, y_0, z_0, n_0, w_0 show the level of influence of these factors under standard constant working conditions according to the individual influential models (Eq. 3.5).

$$\begin{aligned}
x &= x_0 \pm a*v \pm b*s \pm c*\gamma \pm d*\lambda \pm ....\\
y &= y_0 \pm a_1*v \pm b_1*s \pm c_1*\gamma \pm d_1*\lambda \pm ...\\
z &= z_0 \pm a_2*v \pm b_2*s \pm c_2*\gamma \pm d_2*\lambda \pm ....\\
u &= u_0 \pm a_3*v \pm b_3*s \pm c_3*\gamma \pm d_3*\lambda \pm ....\\
w &= w_0 \pm a_4*v \pm b_4*s \pm c_4*\gamma \pm d_4*\lambda \pm ...
\end{aligned} \quad (3.4)$$

The *a, b, c, d* coefficients represent the interaction between the individual influence of the respective factor and the influence of the other factors of the cutting process.

$$C_d = C_1 v^{x0}$$
$$C_d = C_2 s^{y0}$$
$$C_d = C_3 HB^{z0} \quad (3.5)$$
$$C_d = C_4 \gamma^{n0}$$
$$C_d = C_5 \lambda^{w0}$$

The basic model in expressed in 3.1.1 raises problems because the γ and λ angles have the following values in reality γ=0 and λ=0. In this case, when assessing the chips contraction coefficient using the model in 3.1.1, similar values will be used but they will be higher than 1, as for example, $\gamma=1{,}5^0$ and $\lambda=1{,}5^0$.

Because the γ and λ angles get negative values, it is expected that negative values will be obtained for the C constant experimentally. This is the case when one of the γ and λ angles get negative values. In the 3.1 model, the real cutting angle(δ_r) is not used because it gets the same values for ±λ according to Eq. 3.6 and Fig. 3.1.

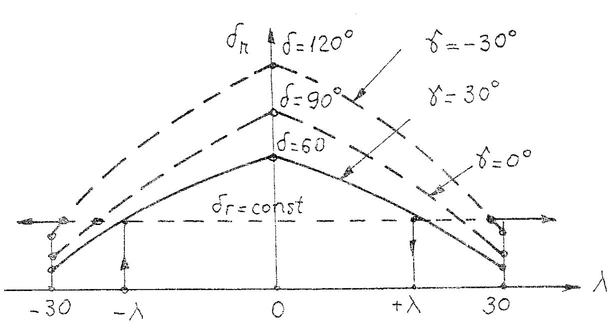

Figure 3.1 The dependence δ_r=f(γ, λ)

$$\cos\delta_r = \cos^2\lambda\cos\delta + \sin^2\lambda$$
$$\delta = 90-\gamma \quad (3.6)$$

The values of the constants, exponents and correction coefficients will be determined with the help of the conventional methodology for processing the experimental results. This model for assessing the chips contraction coefficient – after establishing the constants, exponents and correction coefficients in accordance with the cutting parameters- has the advantage of being used for predicting the plastic deformations and the cutting forces without any further experimental determinations. The experimental determination of the chips contraction coefficient is precise and is easier to do than the determination of the correction coefficients. [Shaw, 2005]

3.2 The Second Model of Assessing C_d

A group of researchers and professors from Iasi have proposed a new model for the C_d coefficient assessment [Cozminca, 2010].

Based on the fact that the known theoretical equations (Eq. 3.7) for the chips contraction coefficient do not include all the highly influential parameters, it is suggested a new model (3.8) which takes into consideration the sense and the level of influence of each considered parameter.

$$C_d = \cos(\varphi-\gamma)/\sin\varphi$$
$$\varphi = 45^o + \frac{\gamma}{2} - \frac{\rho+\rho_1}{2} \quad (3.7)$$

$$C_d = k\frac{\delta^{n_5}\omega^{n_6}}{HB^{n_1}v^{n_2}s^{n_3}K^{n_4}} \quad (3.8)$$

In order to avoid the negative and null values for the angles γ and λ in the 3.2.2 model, complementary angles are used, δ=90-γ and ω=90-λ respectively.

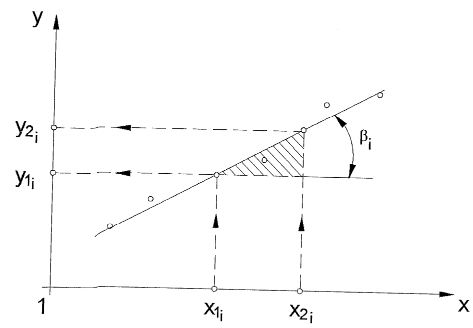

Figure 3.2 *Experimental diagram in double-logarithmic coordinates*

The influence levels of n_1….n_6 are based on the experimental diagrams in double-logarithmic coordinates of the functions y=f(x), where $y = \log C_d$ and x is in turn log HB, log v , log s, log K, log δ and log ω.

Based on the experimental values for C_d diagrams as in Fig. 3.2 are obtained

In order to determine the influence levels $n_1 \ldots n_6$, Eq. 3.9 is obtained from these diagrams.

$$n_i = tg\beta_i = \frac{y_{2_i} - y_{1_i}}{x_{2_i} - x_{1_i}} . \qquad (3.9)$$

in which i=1, 2, 3, 4, 5, 6.

After obtaining the values $n_1 \ldots n_6$, the correction coefficient k will be determined with Eq. 3.10 where v_0, s_0, K_0, δ_0, ω_0 and HB_0 are the values for the independent variables that provide the same value for C_{d0}. For this purpose, it can be used either the tables with experimental data or the diagrams in double-logarithmic coordinates.

$$k = C_{d0} \frac{HB_0^{\,n_1} \cdot v_0^{\,n_2} \cdot \delta_0^{\,n_3} \cdot K_0^{\,n_4}}{\delta_0^{\,n_5} \cdot \omega_0^{\,n_6}} . \qquad (3.10)$$

The new model proposed in Eq. (3.8) must be adjusted depending on the specific elements of each cutting process and cut material.

The values of the chips contraction coefficient for each metal are useful for establishing the deformation capacity through cutting.

The specific elements of the cutting process and of the nature of the cut material are pointed out through the values of the correction coefficient.

This second model for the assessment of C_d takes into consideration six parameters which are highly influential, namely, the cutting speed, the feed and the constructive angles of the tool γ, λ, K.

4. Concluding Remarks

Theoretical and experimental results have shown that all the parameters of the cutting process influence the plastic deformations in cutting metals.

The assessment of the influence level of the working parameters on C_d with the help of either normal coordinates or double-logarithmic coordinates diagrams has lead to the development of precise mathematical models.

The values of the chips contraction coefficient are used to assess the measure of the cutting forces much closer to the existing reality. The chips contraction coefficient enables us to take into account the interdependencies among the influences of the cutting parameters on the cutting forces.

Irrespective of the assessing method, using Cd for the assessment of some intermediary elements or even components of the cutting forces can significantly reduce the number of experimental trials and increases the accuracy of the results.

The theoretical and experimental methods have the advantage of fast assessment of deformations and the disadvantage of using intermediary elements like the correction coefficients.

In the future, based on the existent models, I will try to develop a new and more complex mathematical model which includes the existent data and the most significant parameters in assessing C_d.

5. Acknowledgements

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6. References

[1] Astakhov, Viktor, *The Tribology of Metal Cutting*, 2010 available at www.books.google.ro, Accessed: 2010-06-23

[2] Astakhov, Viktor, Shvets, S.V. , *The assessment of Plastic Deformation in Metal Cutting*, in Journal of Materials Processing Technology, Vol. 146(2), 2004 available at www.sciencedirect.com

Accessed: 2010-06-23
[3] Astakhov, Viktor, Osman, M.O. M., *Correlations amongst Process Parameters in Metal Cutting and their Use for Establishing the Optimum Cutting Speed*, in Journal of Materials Processing Technology 62, 1996, available at www.astvik.com
Accessed: 2010-08-15
[4] Astakhov, Viktor, Shvets, S.V., Osman, M.O. M., *Chip Structure Classification Based on Mechanics of its Formation*, in Journal of Materials Processing Technology, 1997, Vol. 71(2), available at www.astvik.com
Accessed: 2010-08-25
[5] Cozmîncă, I., Cozmîncă, M., Ibănescu. R., *About a new method for cutting forces evaluation,* in Buletinul Institutului Politehnic Iaşi, Tom LVI (LX) Fascicol 2a, ISSN 1011-2855, 2010, Iasi
[6] Davim, J.Paulo (ed.), *Machining. Fundamentals and Recent Advances*, Springer-Verlag London Limited, 2008, available at www.astvik.com
Accessed: 2010-08-25
[7] Panait, S., *Bazele aşchierii şi generării suprafeţelor*, Univ. Tehnice "Gh. Asachi", 1993, Iaşi
[8] Poenaru, Silviu, *Contribuţii la modelarea matematică a forţelor de aşchiere funcţie de coeficientul de deformare plastică a aşchiilor la strunjire*, Ph. Thesis, Universitatea Tehnică „Gheorghe Asachi", 2010, Iaşi
[9] Segal, R., *Contribuţii la studiul interdependenţelor dintre influenţele parametrilor de lucru asupra deformaţiilor plastice la aşchierea oţelurilor,* Phd. Thesis, Universitatea Tehnică „Gheorghe Asachi", 1999, Iaşi.
[10] Shaw, M.C., Vyas A., *The Mechanism of Chip Formation with Hard Turning Steel*, in Annals of the CIRP, vol. 47/1, p. 77-83, 1998
[11] Shaw, M. C., *Metal cutting principles*, 2nd edition, University of Oxford , New York, 2005 available at www.books.google.ro
Accessed: 2010-07-29
[12] Xiao, Xinran, Astakhov, V., *A Methodology for Practical Cutting Force Evaluation based on the Energy Spent in the Cutting System*, in Machining Science and Technology, 2008, available at www.astvik.com
Accessed: 2010-07-29