PREDICTION MODEL FOR BURR FORMATION

Prof. Dr.-Ing. habil. Hans-Michael Beier
FHTW Berlin
Berlin, Germany
dr.beier@beier-entgrattechnik.de

Dipl.-Ing. Reinhard Nothnagel
Dr. Beier-Entgrattechnik
Altlandsberg, Brandenburg, Germany
r.nothnagel@beier-entgrattechnik.de

ABSTRACT

A model for the prediction of burr formation will be presented. Basically the process of burr formation can be regarded as a forming process. Relations of material science and production engineering can be used by means of this assumption.
The burr formation depends mainly on the material stress and strain behavior and the occurring cutting forces. The materials elastic and plastic behavior can be derived from the results of a tensile test. The cutting forces are determined using relations of machining and forming. The combination of both focal points is leading to the model which is focused to give a fast prediction of burr formation for production and construction designers.

INTRODUCTION

The approaches developed in [1], to consider the burr formation process as a reshaping run, make up the fundamentals. The development is made using the metal-cutting procedure “drilling”. A transfer to other metal-cutting procedures is possible after an adjustment of the approach. The derivatives for the tool’s exit are made in empirical manner based on laws of mechanics and the strength of materials theory as well as material science.
The derivatives are made for the initial state of wear (tool sharpened for working). Notes on the final state of wear are made if required.

THE BASIC MODEL

Theoretic Approach

Figure 1 and figure 2 show the actual and the idealized course of the deformation zone. It is striking that the prominences show likenesses with the elastic curve of a medium fixed at one end (figure 3).

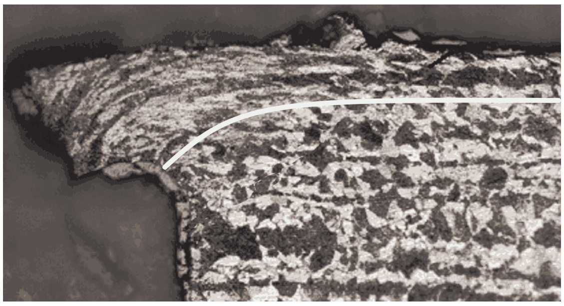
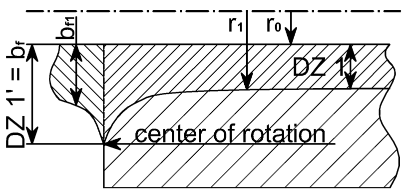


FIGURE 1. DEFORMATION ZONE.



DZ 1:	*deformation zone 1 (drill)*
b_f:	*burr base width*
DZ 1':	*deformation zone drill exit (b_f=b_{f2})*
r_0:	*radius drill / bore*
r_1:	*radius drill / bore incl. DZ 1*

FIGURE 2. IDEALIZED DEFORMATION ZONE AND BURR BASE WIDTH.

In [2] such deformation states are characterized as “plastic deformation states with yield constraint” and extreme deformations are qualified as full plastic limit stresses. Thus the transfer of an elastic problem to a plastic problem is given in consideration of special border conditions.

Derivative of the Principle

The deflection of a beam is adopted as a similar model curve for the deformation zone. Replacing f (deflection) in the equation for the elastic curve by the burr base width b_f and consider the burr formation as the initiation of a moment, then:

$$b_f = \frac{M \cdot l^2}{2\,EJ} \tag{1}$$

In the equation (1) M is the elastic moment, E is the elastic modulus, J is the moment of inertia and l is the length of the medium. These influencing factors have to be transferred to the plastic state.

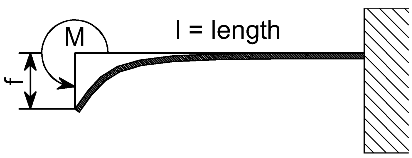


FIGURE 3. THEORETICAL APPROACH FOR THE MODEL.

The Transfer to the Plastic State

According to [2], [3] and [5] the changes as compared to the elastic state represented below result from that.

$$M = M_{pl} = 1.5\,M_{el} = \sigma_{act.} \cdot W \tag{2}$$

where the factor 1.5 is the maximum value for rectangular cross sections. The actual material tension $\sigma_{act.}$ is described by k_f – the resistance to deformation (at initial state of wear $\sigma_{act.} \approx k_f$). Replacing the ratio of J/W (W=section modulus) by the distance between center of gravity and outer edge e and setting e=2/3 b_f leads to:

$$b_f = \sqrt{3\,a\,\sigma_{act.}\,l^2/4E} \tag{3}$$

where a=1 at initial state of wear.

The Verification of the Elastic Modulus

For yield processes it is not allowed to use the elastic modulus from the tensile test [2]. Therefore the tangent modulus E_T is introduced.

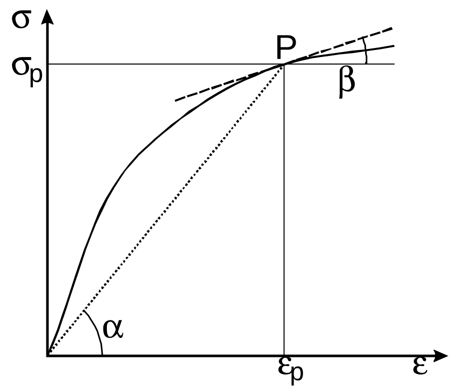


FIGURE 4. DEFINITION OF THE SECANT MODULUS S AND THE TANGENT MODULUS T IN POINT P.

From figure 4 results:

$$E_S = \left[\frac{\sigma_{max}}{\varepsilon_{max}}\right]_p = \tan\alpha$$ Secant modulus

$$E_T = \left[\frac{d\sigma}{d\varepsilon}\right]_p = \tan\beta$$ Tangent modulus

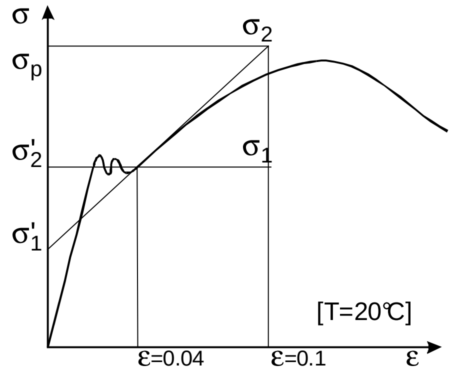


FIGURE 5. DETERMINATION OF THE TANGENT MODULUS FOR MATERIALS WITH A PRONOUNCED TENSILE YIELD POINT.

The figure 5 is explained using a material with a pronounced tensile yield point. From figure 5 results:

$$E_{T1} = \frac{\sigma_2 - \sigma_1}{\varepsilon_{0.1} - \varepsilon_{0.04}} \text{ or } E_{T2} = \frac{\sigma_2' - \sigma_1'}{\varepsilon_{0.04}}, \; E_{T1} \approx E_{T2} \quad (4)$$

According to [2] the elastic modulus depends on the temperature and the degree of deformation φ. For this purpose, coefficients of correction are introduced and determined.

Influence of Temperature: $K_T = 0.9 \dots 1.0$

Influence of degree of deformation: $K_\varphi = 0.85 \dots 0.9$

Overall Modell

From the equations (1) to (4) results the following equation for the initial state of wear with parameters a=1; K_φ=1; K_T=0.9:

$$b_f, \text{initial} \geq \sqrt{\frac{3\,a\,\sigma_{act.}\,l^2}{4\,E_T\,K_\varphi\,K_T}} \quad (5)$$

SPECIFICATION OF THE MODEL

The aim of the specification is the association of deformation, material and metal-cutting parameters for important procedures of the metal-cutting technology. The tension $\sigma_{act.}$ corresponds to the frictionless state of the ideal deformation. However, the causes for the yield are the cutting forces. They are real tensions with all acting influencing factors as for example the friction or the geometry of the tool. The initial situation was described in equation (5).

Introduction of the Specific Cutting Force

The actual tension in the material is directly coupled to the cutting force. According to its dimension k_c is a tension (cutting tension).

$$\sigma_{act.} = k_c = k_{c1.1}\,h^{-m_c} \quad (6)$$

Replacement of the Product l²

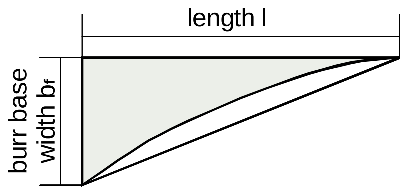


FIGURE 6. GEOMETRIC RELATION BURR BASE WIDTH / BEGINNING OF TILTING OF THE DEFORMATION ZONE.

The approximation takes place through a triangle consideration (fig. 5).

$$\sigma_{BF} = \frac{2\,F_{cut.}}{b_f\,l} \quad (7)$$

It applies: As long as the tension σ_{BF} for the burr formation is lower then the tensile yield point ($R_e/R_{p0.2}$), there will be no (residual) deformation. For this reason for the burr formation can set: the cutting force $F_{cut.}$ is equal or greater than a counterforce F_c. In the following equation f_{pc} describes the feed per cutting edge and a_p the cutting depth.

$$F_{cut.} = a_p\,f_{pc}\,k_c\,, \;\; k_c = k_{c1.1} h^{-m_c} \quad (8)$$

$$F_c = \frac{R_e\,b_f\,l}{2} \quad (9)$$

Equate (8) and (9), reduce to l² and transpose:

$$l^2 = \left(\frac{2\,a_p\,f_p c\,k_{c1.1}\,h^{-m_c}}{R_e\,b_f}\right)^2 \quad (10)$$

Equation (5) and (10) lead to the equation (11) for b_f:

$$b_f \geq \sqrt[4]{\frac{3k_{c1.1}^3\,h^{-3m_c}\,a_{p,eff.}^2\,f_{pc}^2}{R_e^2\,E_T\,K_\varphi\,K_T}} \quad (11)$$

In equation (11) the cutting depth a_p was replaced by an effective value $a_{p,eff.}$ at the exit of the cutting edge which must be established for each procedure. The specific cutting force $k_{c1.1}$ is to be corrected through the coefficients of correction K_{vc} (for the cutting speed) and K_γ (for the rake angle).

SPECIFICATION OF THE MODEL FOR CONTOUR MILLING

Establishment of the effective cutting depth for the milling

The maximum of chip thickness h_{max} is equal to the feed f_{pc} at a angle of 90 degrees. This relation can be extended to angles between 75° to 90°: $h_{max} \approx f_{pc}$.
More precise would be: $h = f_{pc} \sin(\kappa)$.
$a_{p,eff.} = r_\beta$, with r_β = radius between face and flank

Explanation:
As long as $a_p > r_\beta$ the tilting point (center of rotation) lies in the workpiece, the vector of force points into the workpiece. If a_p becomes lower or equal r_β, the center of rotation lies outside the workpiece. (The corner radius r_ε has no influence.) The burr formation begins below the center line. (Figure 7)

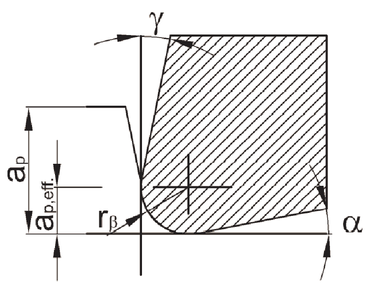


FIGURE 7. EFFECTIVE CUTTING DEPTH $A_{P,EFF.}$ UPON EXIT OF MILLING CUTTER.

Taking the additional information for contour milling into account equation (11) can be written as (12):

$$b_f \geq \sqrt[4]{\frac{3k_{c1.1}^3\, r_\beta^2\, f_{pc}^{2-3m_c}}{R_e^2\, E_T\, K_\varphi\, K_T}} \qquad (12)$$

With $K_T = 1$ and $K\varphi \approx 0.9$ at initial state of wear the coefficients of correction for temperature and degree of deformation become nearly one due to the root-function and can be furthermore neglected.

$$b_f \geq \sqrt[4]{\frac{3k_{c1.1}^3\, r_\beta^2\, f_{pc}^{2-3m_c}}{R_e^2\, E_T}} \qquad (13)$$

Tests revealed that using the value of the tensile strength R_m instead of the tensile yield point R_e allows a more precise prediction in the case of contour milling. The value R_m contains a significant part of deformation and in addition makes up the limit of the uniform elongation.

$$b_f \geq \sqrt[4]{\frac{3k_{c1.1}^3\, r_\beta^2\, f_{pc}^{2-3m_c}}{R_m^2\, E_T}} \qquad (13)$$

Explanation:

Main values of the specific cutting force $k_{c1.1}$ and for m_c according are shown in [6]. The cutting edge radius r_β either may be measured it or taken it from standard (manufacturers standard). The modulus E_T is measured in tensile test at 20°C or in yield test at 200…300°C.

Variations for a mathematical prediction are given due to variation of the parameters:

- R_e (R_{emin}, R_{emax}), E_T
- $k_{c1.1}$ – in general the values are about 10 – 15% below the tabular value, but they may scatter by up to 40% (90% of all measured values are of the order of ± 12%).

SUMMARY

A new approach for the modeling of burr formation for steel and non-iron materials was presented. The model was developed on the basis of laws of materials and production engineering regarding the burr formation as a process of plastic deformation.
The approach can be summarized into a single expression for the prediction of the burr base width which is the characteristic for the burr formation. The parameters of the model can be derived from tension tests and from specifications for machining, in some cases from plastic deformation.

REFERENCES

[1] Beier, H.-M.: Gratentstehung – ein umformtechnischer Ansatz, wt – online 12 (2001) s. 765 – 772.

[2] Issler, Ruoß, Häfele: Festigkeitslehre – Grundlagen, Springer – Verlag Berlin, Heidelberg 1997, 2. Auflage.

[3] Beitz, Dubbel, Küttner: Taschenbuch für den Maschinenbau, Springer – Verlag Berlin, Heidelberg 1987, 16. Auflage.

[4] Schwark, A.: Experimentelle Untersuchung zu einer Theorie der Gratentstehung, Diplomarbeit FHTW Berlin, 2003.

[5] Beier, H.-M.: Modell zur Gratentstehung, Arbeitskreis Gratminimierung/Gratmessung Vortrag 10. 03 2004, München.

[6] König, W. u.a.: Spezifische Schnittkraftwerte für die Zerspanung metallischer Eisenwerk-stoffe, Verlag Stahl Eisen mbH, Düsseldorf 1982.

ABBREVIATION

a	Specific coefficient of correction for plastic states
a_p	Cutting depth
$a_{p,eff.}$	Effective cutting depth
b_f	Burr base width
e	Distance between center of gravity and outside edge
E	Elastic modulus
E_T	Tangent modulus
f	Elastic deflection
$F_{cut.}$	Cutting force
F_c	Counterforce
f_{pc}	Feed per tooth or per cutting edge
h	Cutting thickness
h_{max}	Maximum chip thickness
J	Momentum of inertia
k_c	Specific cutting force
$k_{c1.1}$	Main value of the specific cutting force at b and f=1 mm
k_f	Resistance to deformation (at initial state of wear $\sigma_{act.} \approx k_f$)
K_T	Coefficient of correction for the temperature
K_{VC}	Coefficient of correction for the cutting speed
K_γ	Coefficient of correction for the rake angle
K_φ	Coefficient of correction for the degree of deformation
l	Tipping length or else deformation length of the burr base
M	Momentum – general
m_c	Tangent of the lead angle of the specific cutting force
M_{pl}	Moment in the plastic range
R_e	Tensile yield point
R_m	Tensile strength
$R_{p0.2}$	Practical elastic limit
r_β	Radius between face and flank (cutting edge radius)
W	Section modulus
α	Clearance angle
γ	Rake angle
κ	Cutting edge angle
σ_{BF}	Tension leading to burr formation (burr formation tension)
$\sigma_{act.}$	Actual tension