THEORETICAL METHOD FOR PREDICTION OF THE CUTTING EDGE RECESSION DURING MILLING WOOD AND SECONDARY WOOD PRODUCTS

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A theoretical method for prediction of cutting edge recession during milling wood and wood-based products, due to the presence of hard mineral contamination, High Temperature Tribochemical Reactions (HTTR), and frictional wearing, based on 3D random distribution of contaminant particles is presented and positively verified based on the example of three experiments from the literature, showing good correlation between the predicted and observed cutting edge recession.

Keywords: Cutting Edge Recession Theoretical Simulation, Milling, Wood, Secondary Wood Products

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INTRODUCTION

Experimental modeling of the relation between the cutting edge recession and machining parameters is a direct or indirect goal of many works. High labor and material consumption makes cutting tool-wearing experiments difficult to conduct, even with use of a numerically controlled (NC) machine. Moreover, a necessity to evaluate a long list of machining parameters, namely 75 according to the work of Porankiewicz (2003), increases the level of complication of such experiments. Unsteady properties of material machined (or in several cases not possible to evaluate using non-destructive methods) as well as the cutting edge material are additional reasons complicating the study of cutting edge wear. There are unrecognized interactions involved in the cutting edge wearing process, possible also unknown variables. Maybe in the future such a labor-consuming research can be replaced by computer simulations. The present work represents a next, small step forward on a way to reach this more distant goal. Although in earlier work by Porankiewicz (2006), using theoretical simulation of the cutting edge recession, based on random distribution of particles of hard mineral contamination inside an rectangle with two fixed dimensions (the depth of cut g_S of and the width of cut w_S) together with analytical approach of the influence of the HTTR, and the wood density D_{MC} and the porous share P_S, the predicted and observed cutting edge recession VB was successfully modelled, however, high variation of results of this calculation remained unsolved, especially for a large-size hard mineral particle contaminants. It has to be mentioned that this simplified, rectangle-based method of theoretical simulation of the cutting edge recession, was a large enough task to be solved with use of the limited personal computers memory resources that have been available in the past.

In the present study, a method of theoretical simulation of the cutting edge recession, based on 3D (in direction of the depth of cut g_S and the cutting edge width w_S and in direction of the feed speed), random distribution of the hard mineral contamination particles, was presented and analyzed for the same wearing experiments that were considered in previous work (Porankiewicz 2006).

EXPERIMENTAL

Theoretical Simulation Model of Cutting Tool Wear

In the newly developed method of the theoretical simulation, all initial assumptions made in the work Porankiewicz 2006, remained unchanged, namely:

- Each hard mineral contaminant particle is assumed to generate a defined cutting edge wearing effect, depending on the contact character and the actual cutting conditions.
- The biggest cutting edge wearing effect was assumed for central contact (Fig. 1), for which the particle center matches the cutting edge position.
- A uniform hard mineral contaminant (silica) was assumed.
- There was superposition of the wearing effects acting simultaneously, depending upon actual cutting conditions.

According to the assumptions above, the predicted cutting edge recession VB^P was defined by formula (1), being the summation of the elementary wearing effects $\Delta VB_{1E(K)}$ and $\Delta VB_{2E(K)}$, along the cutting arc and the total feed path L_{FPK}, for assumed number of fractions of the hard mineral contaminant n_{RMC}.

$$VB^P = \sum_{J=1}^{n\Phi} \sum_{K=1}^{nK} \sum_{Z=1}^{nRMC} [\Delta VB_{1E(K,Z)} + \Delta VB_{2E(K,Z)}] \quad (\mu m) \qquad (1)$$

In Eq. (1) the terms were defined as follows:

$$n_{\Phi} = \frac{\Phi_U - \Phi_L}{\Delta \Phi} \qquad (2)$$

$$n_K = \frac{L_{FPK}}{\Delta L_F} \qquad (3)$$

The cutting edge moves on, as many as n_{Φ} (2) steps $\Delta\phi$, along one single cutting arc, from the beginning ϕ_L to the final angle position ϕ_U, inside one feed step ΔL_F. The cutting edge moves on as many as n_K (3) steps ΔL_F along the total feed path L_{FPK}. The summation of the wearing effect will begin when the distance between the cutting edge and the hard mineral contaminant particle matches the following condition, given by Eq. (4).

$$0 < \Delta_{(K)} \leq 0.5 \cdot R_{PMC(K)} \qquad (4)$$

The kind of the contact that takes place between the K number of fractions of the hard mineral contaminant particles, lying on the cutting path (Fig. 1), and the cutting edge itself, depends from the distance $\Delta_{(K)}$. The elementary wearing effect $\Delta VB_{1E(K)}$ for regions where contaminant particles were not present can be defined by formula (5), and the elementary wearing effect $\Delta VB_{2E(K)}$ for the region where the contaminant particle was present, can be defined by formula (6).

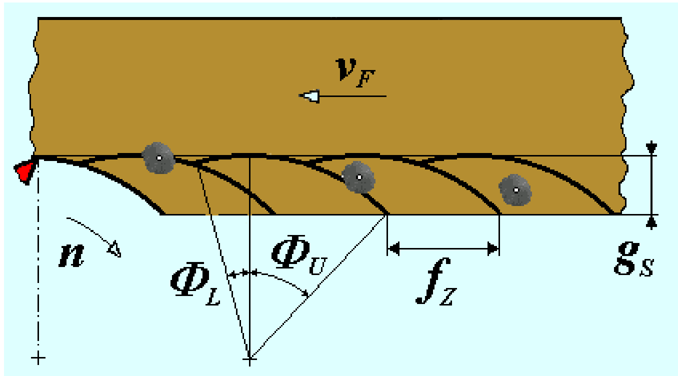

Fig. 1. Contact character between the cutting edge and the contaminant particle; n -rotational speed, ϕ_L , ϕ_U - lower and upper cutting edge angle position, v_f - feed speed, f_Z - feed per edge, g_S - cutting depth

$$\Delta VB_{1E(K)} = \Delta VB_{Lcp} + q_{VB} \cdot q_{1RM} \cdot q_{1D} \cdot q_{1PS} \cdot q_{1VC} \cdot q_{1BF} \cdot q_{1GF} \quad (\mu m) \qquad (5)$$

$$\Delta VB_{2E(K)} = R_{Pcp(K)} \cdot \Delta_{(K)} \cdot \Delta R_{(K,Z)} \cdot q_{VB} \cdot q_{2RM} \cdot q_{2D} \cdot q_{2PS} \cdot q_{2VC} \cdot q_{2BF} \cdot q_{2GF} \quad (\mu m) \qquad (6)$$

In eq. (5) and (6) the new terms were defined as follows:

q_{VB} - Quotient of enlargement of the cutting edge recession for the cutting path L_{CP} increase.
q_{1RM}, q_{2RM} - Quotients of enlargement of cutting edge recession for the HTTR, expressed by R_{MSMi} quantifier, increase.
q_{1D}, q_{2D} - Quotients of enlargement of the cutting edge recession for the wood density D increase.
q_{1P}, q_{2P} - Quotients of reduction of the cutting edge recession for the porous share P_S increase.
q_{1VC}, q_{2VC} - Quotients of enlargement of the cutting edge recession for the cutting speed v_C increase.
q_{1BF}, q_{2BF} - Quotients of reduction of the cutting edge recession for the sharpness angle β_F increase.
q_{1GF}, q_{2GF} - Quotients of change of the cutting edge recession for the rake angle γ_F increase.

The distance $\Delta_{(K)}$ between the cutting edge and the contaminant particle can be calculated from formula (7).

$$\Delta_{(K)} = [(X_{O(nK,\Phi)} - X_{Z(K)})^2 + (Y_{O(\Phi)} - Y_{Z(K)})^2]^{1/2} \qquad (7)$$

The cutting path length L_{CP} (8) was the summation of n_{PK} elementary arcs. The cutting edge was executed from the beginning of the cut, defined by the upper ϕ_U and the lower ϕ_L contacts angles, measured in the plain perpendicular to the work piece width.

$$L_{CP} = \sum_{J=1}^{nPK} R_C \cdot (\Phi_D - \Phi_U) \qquad (8)$$

In Eq. (8) the terms were defined as follows:

$$n_{PK} = \frac{L_{FP}}{f_Z} \qquad (9)$$

$$X_{O(nK,\Phi)} = L_{FO} + R_C \cdot \sin(\Phi) \qquad (10)$$

$$L_{FO} = \sum_{Jo=1}^{n\,PK} f_Z \qquad (11)$$

$$L_{FP} = \sum_{J=1}^{n\,K} \Delta L_F \qquad (12)$$

and:

$$j_O = \frac{j}{n_Z} \qquad (13)$$

$$n_Z = \frac{f_Z}{\Delta L_F} \qquad (14)$$

$$Y_{O(\Phi)} = R_C \cdot [1 - \cos(\Phi)] \quad \text{for } \phi_L < \phi < \phi_U \qquad (15)$$

$$\Phi_L = \arccos \frac{R_C - g_S}{R_C} \quad \text{(rad)} \qquad (16)$$

$$\Phi_U = \arcsin \frac{f_Z}{2 \cdot R_C} \quad \text{(rad)} \qquad (17)$$

where

L_{FP} - The feed path from the beginning of the cut (mm).
n_{PK} - The number of steps ΔL_F from the beginning of the cut (mm).
R_C - The cutting radius (mm).
n_Z - The number of steps ΔL_F in one feed per edge f_Z (mm).
ϕ - The angle position of the cutting edge (rad).
ϕ_L - Initial cutting edge angle position (rad).
ϕ_U - End cutting edge angle position (rad).

The distance $L^C_{FR(K)}$, between neighboring contaminant particles of K fraction for this case can be defined by formula (18).

$$L^C_{FR(K)} = [\frac{D_{CP} \cdot V_{Pcp(K)}}{D \cdot C_{CP(K)}}]^{1/3} \qquad (18)$$

In Eq. (18) the terms were defined as follows:

$C_{CP(K)}$ - The content of the hard mineral contamination of K fraction (mg/m^3).

D, D_{CP} - The densities of material cut and particles of the mineral contaminant (kg/m^3).

$V_{Pcp(K)}$ - The volume of K fraction, of one particle of the mineral contaminant (m^3).

The coordinates of the contaminant particle's position, as well as those of K fraction in the work piece machined, were calculated from formulas (19), (20), and (21), with use of random numbers $R_{ND} < 0; 1 >$.

$$X_{Z(K)} = L_{FR(K)} \cdot R_{ND} \tag{19}$$

$$Y_{Z(K)} = L_{FR(K)} \cdot R_{ND} \tag{20}$$

$$Z_{Z(K)} = L_{FR(K)} \cdot R_{ND} \tag{21}$$

Machining Parameters of the Experiments Modeled

The cutting edge recession observations after coated particle board milling, originated from experiments performed on an SCM milling machine, under the following conditions (Porankiewicz 1993), where the values in brackets "< >" show the minimum and maximum values of independent variables, and " .." show that many variables within a range were analyzed:

– The clearance angle α_F < 13.93 .. 15.6>°.
–Rake angle γ_F = 20.22°.
–Sharpness angle β_F < 54.18 .. 55.85 >°.
–The cutting speed v_C < 65.6 .. 73 > m/s.
–The feed rate per edge f_Z < 0.28 .. 0.44 > mm.
–The cutting edge material cemented carbide K05.
–The content of hard contamination particles C_{CP} < 299 .. 3266 > mg/kg.
–The porous share P_S < 0.0047 .. 0.0506 >.
–The density of skin of particle board D < 790 .. 962 > kg/m^3.
–The HTTR, between melamine coated particle board and cobalt, binder in the cemented carbide tool material, described by R_{MSMI} quantifier < 0.0354 .. 0.0761 > min^{-1}.
–The moisture content of particle board was of 4 – 6 %.
–Six fractions (f_1 = 0.25, f_2 = 0.63, f_3 = 0.88, f_4 = 0.15, f_5 = 0.3, f_6= 0.5 mm) of particles size R_{CP} were obtained by use meshes: 0.05, 0.075, 0.1, 0.2, 0.4, 0.6 mm.

The cutting edge recession SV observations after hard fiber board milling, were extracted from experiment done on an common milling machine (Kilinga and Back 1964), under following machining conditions:

– The clearance angle α_F = 35°.
– The rake angle γ_F = 10°.
– The sharpness angle β_F = 45°.
– The cutting speed v_C = 10 m/s.
– The feed rate per edge f_Z = 0.59 mm.

– The cutting edge material: High Speed Steel (HSS).
– The content of hard mineral contamination C_{CP} (Al_2O_3) was of 3000 mg/kg.
– The density D was of 970 kg/m^3.
– The HTTR between fiber board and iron, binder in the HSS tool material, expressed by the R_{MSMI} quantifier, assumed as 0.03 min^{-1}.

The cutting edge recession observations after a solid wood milling originated from experiments done on a Shoda Fanuc NC3 milling machine, under the following conditions (Porankiewicz et al. 2004):
– The clearance angle $\alpha_F = 5°$.
– The rake angle $\gamma_F = 30°$.
– The sharpness angle $\beta_F = 55°$.
– The cutting speed $v_C = 32$ m/s;
– The feed rate per edge $f_Z = 0.1$ mm.
– The cutting edge material HSS, SKH51 (T grade).
– The content of hard mineral contamination $C_{CP} < 4 .. 12635 >$ mg/kg.
– The wood density $D < 520 .. 1010 >$ kg/m^3.
– The HTTR between wood and iron, binder in the HSS tool material, described by R_{MW} quantifier $< 0.0017 .. 0.0165 >$ min^{-1}.
– The moisture content of wood was of 4 – 6 %.

Theoretical Simulation Implementation

The developed theoretical simulation method was implemented using the Pascal computer programming language. A general flow-chart of the program is shown in Fig. 2.

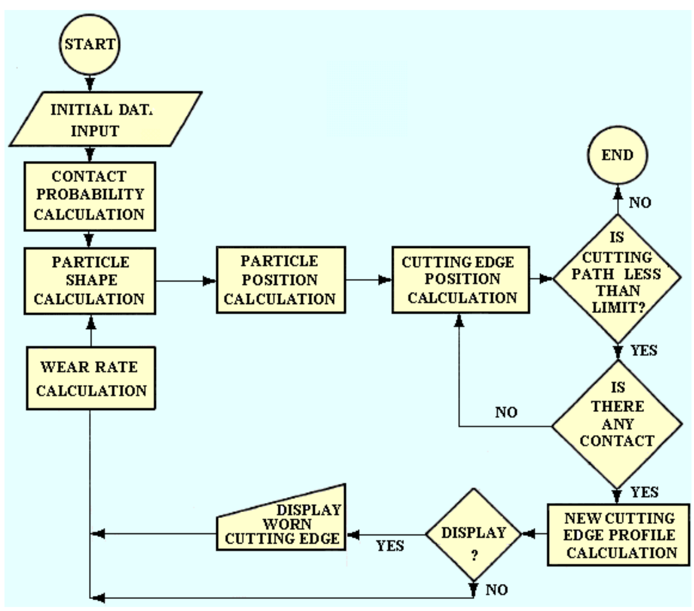

Fig. 2. The flowing chart of the cutting edge recession theoretical simulation program

Estimators of the simulation method were determined iteratively with application of an optimization program developed by the author in earlier work with further modifications (Porankiewicz 1988). The optimization program was based on a leastsquares method. Both the theoretical simulation program of the cutting edge wearing and the optimization programs were joined together and compiled using a GNU Pascal compiler (gpc) under a Unix environment. The calculations were performed using an SGI Altix 3700 computer at Poznań Networking & Supercomputing Center (PCSS). For the largest task (milling fiber board) it took 7 min to complete one loop of iteration.

For evaluation of the approximation quality, the following parameters were applied: *SK* - the summation of square of residuals. - The correlation coefficient (*R*) between observed *VB* and predicted VB^P values of the cutting edge recession. - The coefficient of agreement of algebraic differences value Q_A.

$$Q_A = 1 - \frac{\sum\left(VB - VB^P\right)}{\sum VB} \tag{22}$$

- The coefficient of agreement of absolute differences value Q_B,

$$Q_B = 1 - \frac{\sum\left|VB - VB^P\right|}{\sum VB} \tag{23}$$

RESULTS AND DISCUSSION

It has to be pointed out that number of experimental data points used for the theoretical simulation was low. Due to this reason the particular solutions presented below have to be considered as preliminary. For reliable estimation of quotients present in the theoretical model, represented by formulas (1) - (21), much more experimental data have to be analyzed in future works.

The particular solution of the cutting edge recession, based on theoretical simulation obtained for milling of the melamine coated particle boards, is presented as formulas (24) through (32).

$$\Delta VB_{WLcp} = 1.6343 \cdot L_{CP}^{0.34815} - 1.63743 \cdot (L_{CP} - \Delta L_{CP})^{0.34815} \tag{24}$$

$$q_{VB} = 20.20249 \cdot e^{-\ln(VB_{Lcp}) \cdot 0.67765 \text{ -0.00034}} \tag{25}$$

$$q_{1RM} = 1 + 4.88494 \cdot R_W^{0.80095} \quad \text{for } VB_{WL(Z)} > 8.50384 \tag{26}$$

$$q_{2RM} = 1 + C_{K+7} \cdot R_W^{1.699228} \quad \text{for } VB_{WL(Z)} > 8.50384 \tag{27}$$

$$\Delta R_{(K,Z)} = C_{K+13} \cdot S_{CPK)} \tag{28}$$

$$q_{1vbg} = 0.04092 \cdot v_C^{0.25645} \cdot B_F^{-0.40922} \cdot 0.72603^{GF} \tag{29}$$

$$q_{2vbg} = 0.04678 \cdot v_C^{0.1187} \cdot B_F^{-0.55723} \cdot 0.50816^{GF} \tag{30}$$

In Eq. (26) and (27) new terms were defined as follows:

GF - the rake angle (γ_F),
$R_W = R_{MSMI} / R_{MSMIX}$,
R_{MSMIX} - maximum value of the quantifier describing the HTTR between melamine coated particle board and cobalt, binder in cemented carbide tool material.

$$q_{1D} = 1 + 0.00091 \cdot D^{1.16254} \cdot (1 - P_S)^{0.63799} \tag{31}$$

$$q_{2D} = 1 + 0.000091 \cdot D^{2.06544} \cdot (1 - P_S)^{0.44128} \tag{32}$$

The value of estimators (C) of the cutting edge wearing theoretical simulation for contaminant particles fractions $K = 1$ up to $K = 6$ were as follows: $C_8 = 95.05265$; $C_9 = 183.076$; $C_{10} = 153.27266$; $C_{11} = 53.66562$; $C_{12} = 0.56738$; $C_{13} = 0.0196$; $C_{14} = 8.37 \cdot 10^{-6}$; $C_{15} = 5.17 \cdot 10^{-5}$; $C_{16} = 1.356 \cdot 10^{-4}$; $C_{17} = 1.951 \cdot 10^{-4}$; $C_{18} = 8.6 \cdot 10^{-5}$; $C_{19} = 1.65 \cdot 10^{-5}$.

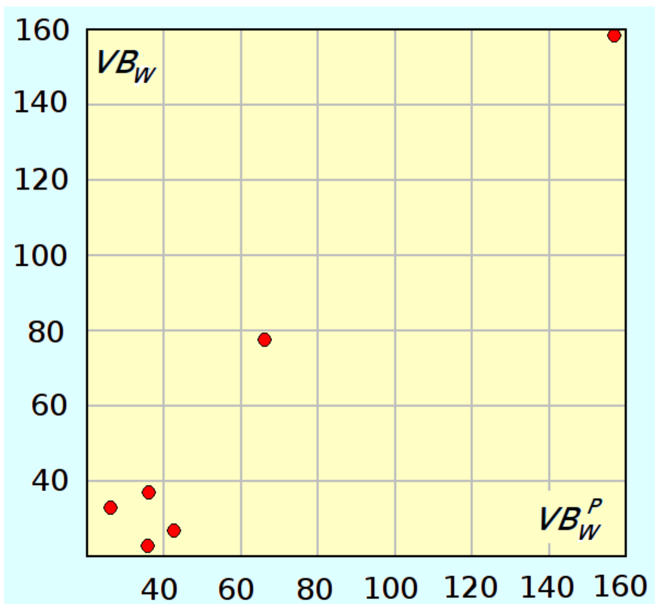

Fig. 3. Predicted VB^P_W and observed VB_W cutting edge recession for melamine coated particle board milling; SK= 585.8; R = 0.96; Q_A = 0.98; Q_B = 0.8

The particular solution of the cutting edge recession theoretical simulation, obtained, for milling of the hard fiber board is presented as formulas (33) through (39).

$$\Delta SV_{Lcp} = 0.09776 \cdot L_{CP}^{0.65396} - 0.09776 \cdot (L_{CP} - \Delta L_{CP})^{0.65396} \tag{33}$$

$$q_{SV} = 11.30879 \cdot e^{-\ln(VB_{Lcp}) \cdot 0.00045 - 0.000075} \tag{34}$$

In Eq. (33) and (34) new terms were defined as follows, where SV is the cutting edge recession:

$$q_{1RM} = 9.62571 \cdot R_{MSMI} \qquad \text{for } SV_{Lcp(Z)} > 18.94435 \tag{35}$$

$$q_{2RM} = C_{K+7} \cdot R_{MSMI} \qquad \text{for } SV_{Lcp(Z)} > 18.94435 \tag{36}$$

$$\Delta R_{(K,Z)} = C_{K+12} \cdot S_{CP(K)} \tag{37}$$

$$q_{1D} = 1 + 0.0035 \cdot D^{\ 0.0016} \tag{38}$$

$$q_{2D} = 1 + 0.00176 \cdot D^{\ 0.000091} \tag{39}$$

The value of estimators of the cutting edge recession theoretical simulation (C_8 - C_{17}), for contaminant particle fractions K = 1 up to K = 5 were as follows: $C_8 = 4.07548$; $C_9 = 2.5$; $C_{10} = 2.09871$; $C_{11} = 0.1851$; $C_{12} = 0.2298$; $C_{13} = 1.9 \cdot 10^{-3}$; $C_{14} = 2.05 \cdot 10^{-3}$; $C_{15} = 7.4 \cdot 10^{-4}$; $C_{16} = 3.25 \cdot 10^{-4}$; $C_{17} = 4.2 \cdot 10^{-4}$.

For solid wood milling the particular solution of the cutting edge recession theoretical simulation model, obtained from calculations, is shown as formulas (40) through (46).

$$\Delta VB_{FLcp} = 0.02797 \cdot L_{CP}^{0.29568} - 0.02797 \cdot (L_{CP} - \Delta L_{CP})^{0.29568} \tag{40}$$

$$q_{VB} = 1.52758 \cdot e^{-\ln(VB_{Lcp}) \cdot 0.97777 - 0.00083} \tag{41}$$

$$q_{1RM} = 1 + 160.66967 \cdot R_W^{1.1028} \qquad \text{for } VB_{FLcp(Z)} > 33.85394 \tag{42}$$

$$q_{2RM} = 1 + C_{K+7} \cdot R_W^{1.8894} \qquad \text{for } VB_{FLcp(Z)} > 33.85394 \tag{43}$$

In Eq. (42) and (43) new terms were defined as follows:

$R_W = R_{MW} / R_{MWX}$

R_{MWX} - maximum value of the quantifier describing the HTTR between wood and iron, a binder in HSS tool material.

$$\Delta R_{(K,Z)} = C_{K+19} \cdot S_{CP(K)} \tag{44}$$

$$q_{1D} = 1 + 20.8 \cdot D^{\ 0.48} \tag{45}$$

$$q_{2D} = 1 + 20.7462 \cdot D^{\ 0.49} \tag{46}$$

The value of estimators of the cutting edge wearing theoretical simulation (C_8 - C_{20}) for contaminant particles fractions K = 1 up to K = 6 were as follows: $C_8 = 3$;

C_9=0.91489; C_{10} = 0.4795; C_{11} = 4.964·10^{-2}; C_{12} = 2.745·10^{-3}; C_{13} = 3.11·10^{-4}; C_{14} = 1.4·10^{-5}; C_{15} = 5.15·10^{-4}; C_{16} = 9.9·10^{-4}; C_{17} = 1.09·10^{-4}; C_{18} = 1.5·10^{-3}; C_{19} = 9.43·10^{-5}.

Figures 4 and 5, as well as the quality of approximation quantifiers *SK*, *R*, Q_A, Q_B, show good agreement between observed *VB* and predicted VB^P cutting edge recession. In case of formula (3) the *R* and the Q_B were a bit worse.

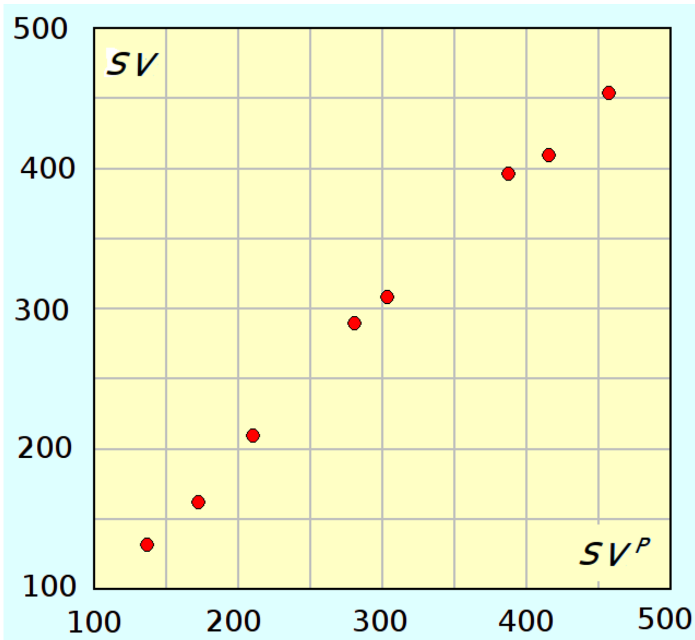

Fig. 4. Predicted SV^P and observed *SV* cutting edge recession for hard fiber boards milling; *SK* = 320.3; *R* = 0.999 ; Q_A = 0.99 ; Q_B = 0.98

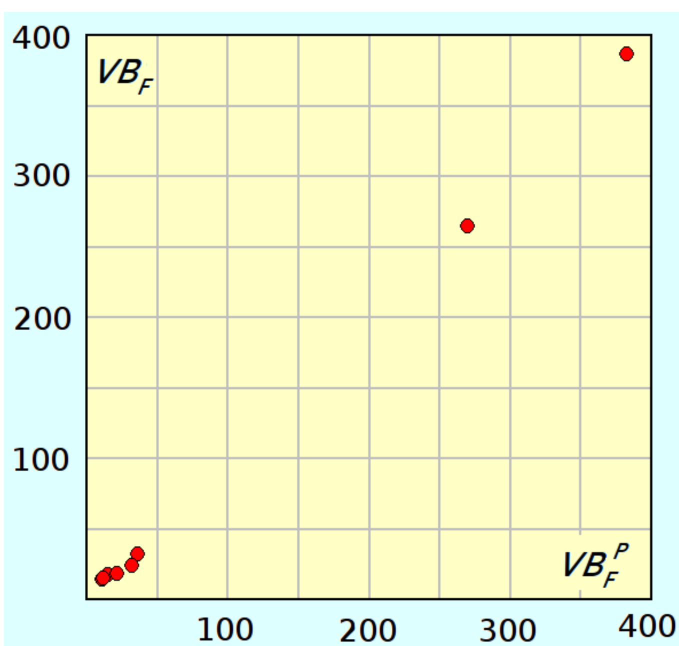

Fig. 5. Predicted VB^P_F and observed VB_F cutting edge wear rate for solid wood milling; *SK* = 147.4; *R* = 1.0 ; Q_A = 0.98 ; Q_B = 0.96

The presented method and algorithm allow for the prediction of cutting edge recession using the real size of the hard mineral contaminant particles S_{CP} and the main properties of the material machined, such the HTTR, represented by the R_{MSMI} or R_{MW} quantifiers, the density D and fractional porosity P_S for particle board. From the particular solution for coated particle board (24), (32), for hard fiber board (33), (39), and for solid wood (40), (46), it can be seen that the HTTR starts action in cutting edge wearing process, from the amount of cutting edge recession $VB^P{}_W$= 8.5 µm, SV^P= 7 µm and $VB^P{}_F$= 33.9 µm. These values are different from those obtained in the work of Porankiewicz (2006). On the actual level of knowledge in this area, it is not possible to explain such a difference.

For the newly developed method, the real, average number of contacts between contaminant particles and the cutting edge was about 0.5 % of theoretical ones, and, on average one contact took place for every 0.3 mg/kg for the smallest fraction up to about 102 mg/kg for the largest fraction. The number of theoretical contacts in actual work was on average 150 times larger in comparison to method presented in earlier work by Porankiewicz (2006), while the number of real contacts in the present study was on average 2 times smaller in comparison to the method presented in the work of Porankiewicz (2006). In the present study, the average standard deviation SD of predicted cutting edge recession (for 5 repetitions) was of 0.8 µm for the smallest fraction, up to 15.1 µm for the largest ones.

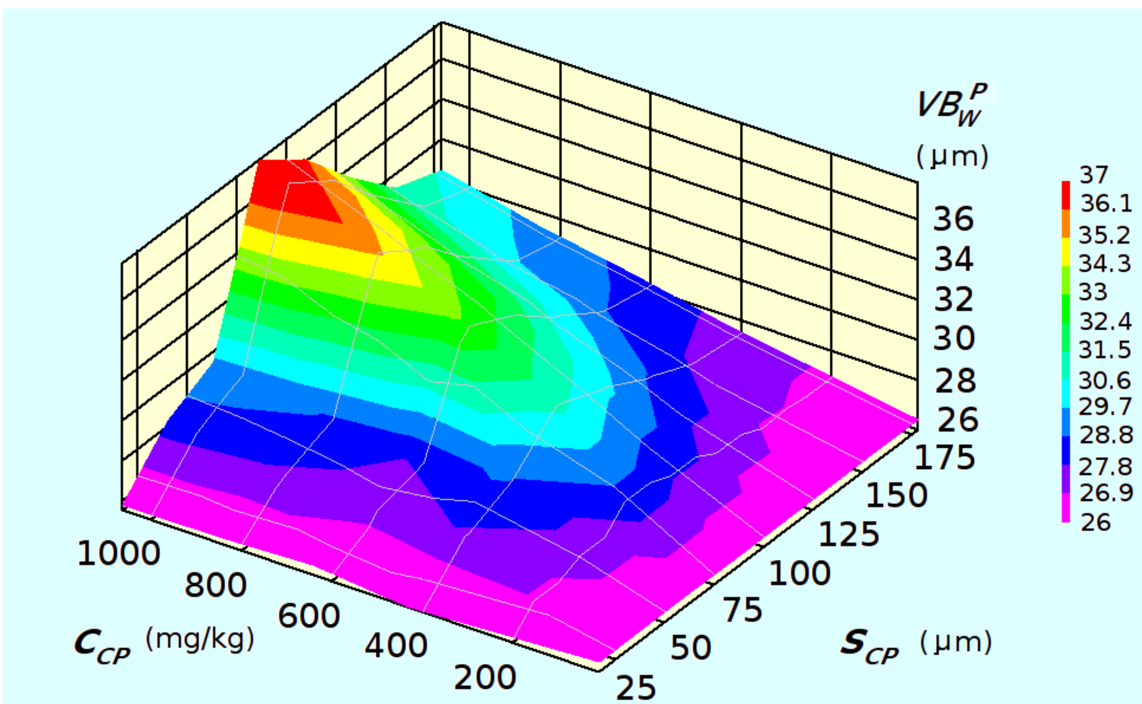

Fig. 6. The impact of content C_{CP} and size S_{CP} of the hard mineral contamination on the cutting edge recession $VB^P{}_W$, evaluated from the theoretical simulation for melamine coated particle board milling, for the R_{MSMI} = 0.0354

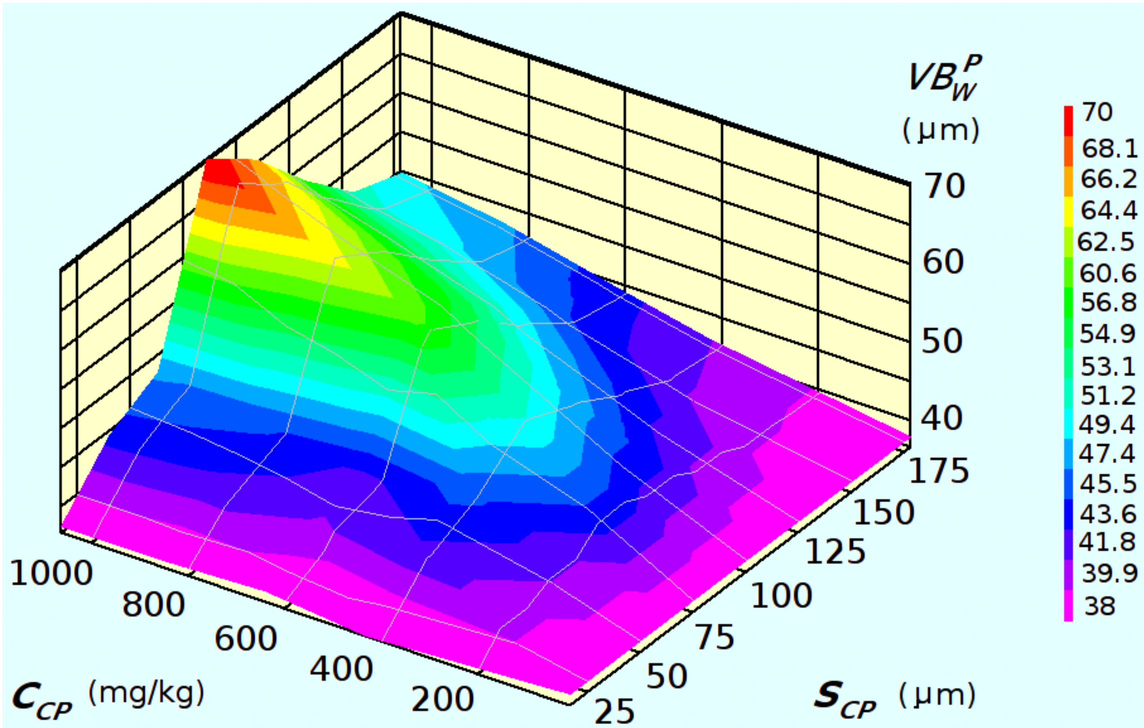

Fig. 7. The influence of content C_{CP} and size S_{CP} of hard mineral contamination on the cutting edge recession $VB^P{}_W$, evaluated from theoretical simulation for melamine coated particle board milling, for the R_{MSMI} = 0.0734

Figures 6 and 7 show that the predicted cutting edge recession $VB^P{}_W$ increased with enlargement of the size of hard contamination particles S_{CP} to a maximum laying at S_{CP}= 86 μm. The plots on Figs. 6 and 7 are different from those obtained in the work of Porankiewicz (2006), using a random distribution of contaminant particles in the feed direction, by fixed range of variation in direction of the depth g_S and the width of cut w_S, for which the maximum was for $S_{CP} > 170$ μm. The presence of a maximum in the relation $VB^P{}_W = f(S_{CP})$ can be explained by faster increase of a single-particle wearing effect with augmentation of contaminant particles size S_{CP}, in comparison to the relative increase in particle number, to the point of the maximum, and after passing it, faster decrease of big particles number than their increase in wearing effect. From Figs. 6 and 7 it can also be seen that the role of contaminant particles in the cutting edge wearing process significantly increases with enlargement of the HTTR, but to a lesser degree for the smallest and the biggest fractions.

The maximum of the predicted cutting edge recession SV^P, for hard fiber board milling (Fig. 8), was also at S_{CP}= 86 μm. For fraction f_5 = 510 μm, the predicted cutting edge recession SV^P was larger than for fraction f_4= 170 μm, which suggests that the single-particle wearing effect growth with augmentation of contamination particles size S_{CP} became larger than the effect of the decrease in the number of particles. It has also to be mentioned that the same shape of the plot of relation $SV = f(C_{CP}, S_{CP})$ for fiber board milling was obtained in the work of Porankiewicz (2006).

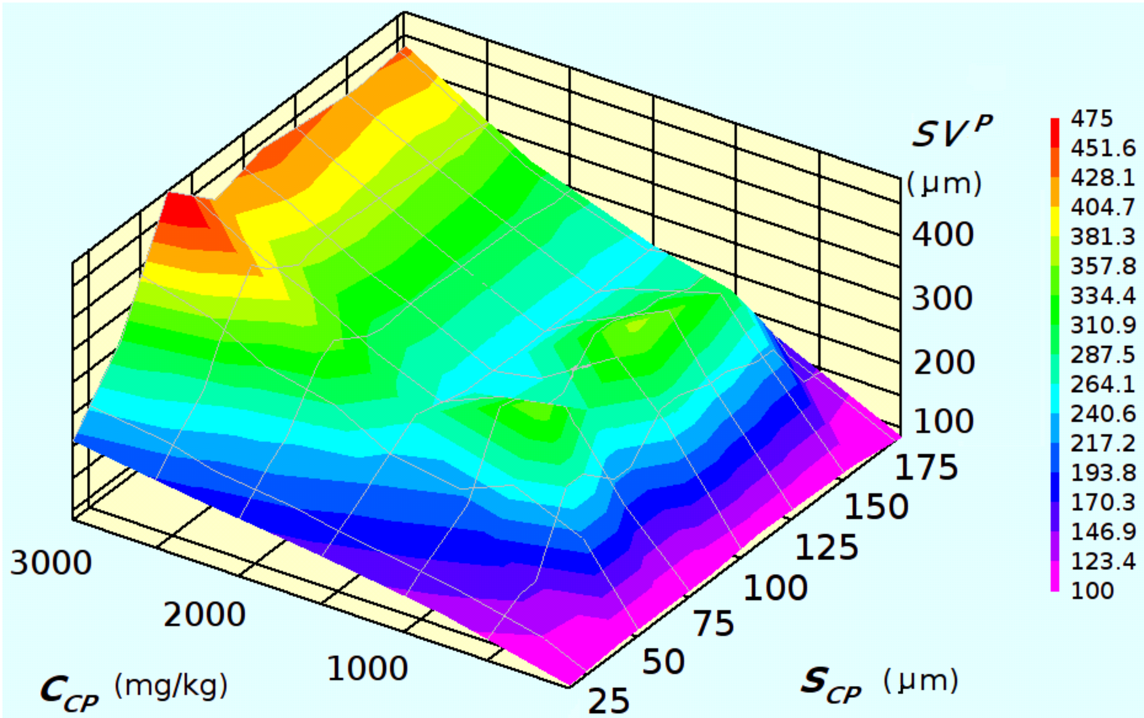

Fig. 8. The influence of content C_{CP} and size S_{CP} of hard mineral contamination on the cutting edge recession SV^P evaluated with use of theoretical simulation for hard fiber board milling

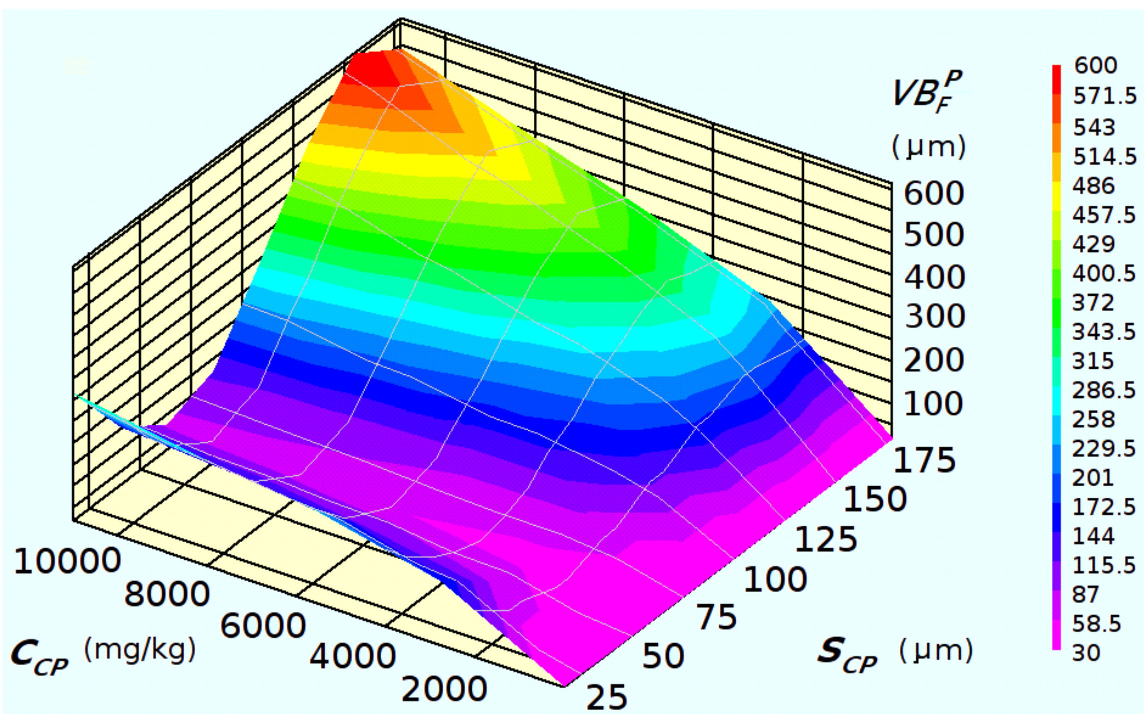

Fig. 9. The influence of content C_{CP} and size S_{CP} of hard mineral contamination on the cutting edge recession VB^P_F evaluated with use of theoretical simulation for solid wood milling, for R_{MSMI} = 0.0017

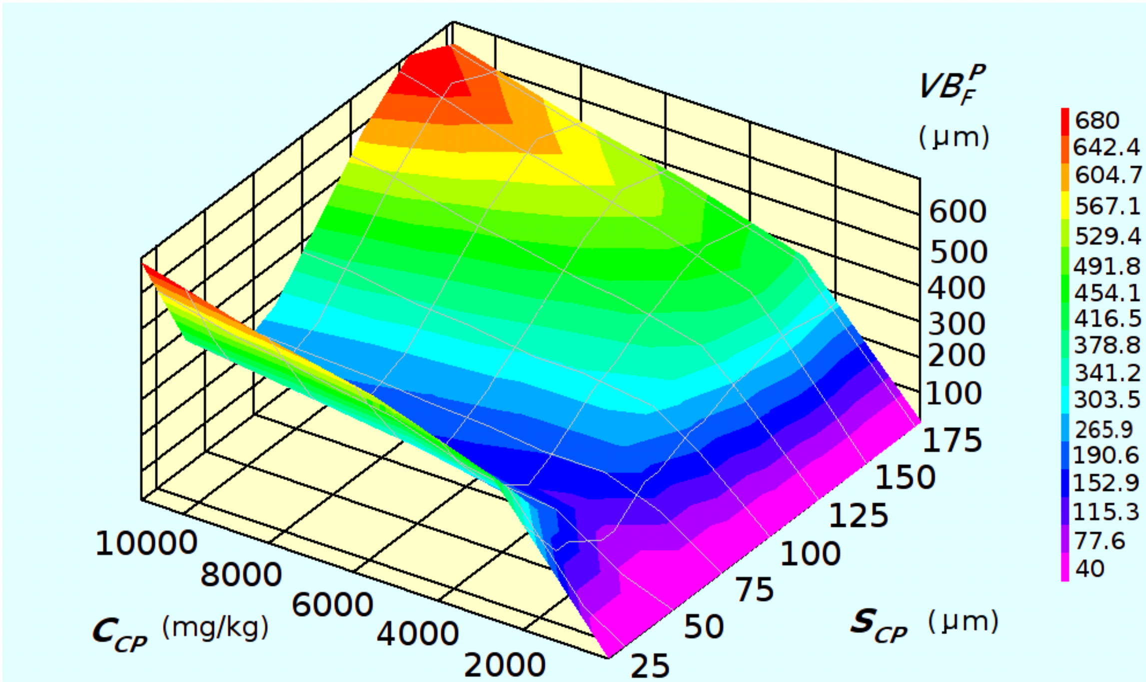

Fig. 10. The influence of content C_{CP} and size S_{CP} of hard mineral contamination on the cutting edge recession $VB^P{}_F$ evaluated with use of theoretical simulation for solid wood milling, for R_{MSMI} = 0.0165

The plots of the influence of the content and size of hard mineral contaminants on the cutting edge recession, for solid wood milling case, shown in Fig. 9 and Fig. 10, with two maximums, look very different from those shown in Figs. 6 through 8. Also in the work of Porankiewicz (2006), on the plots of the relation $VB^P{}_F = f(C_{CP}, S_{CP})$, evaluated by worse approximation (SK = 309), such two maximums cannot be seen. A possible reason for that was not the real influence of the size of contaminant particle themselves on the cutting edge recession VB_F, but rather the limited number of representation of all larger fractions of contaminant particles. In case of the solid wood milling experiment (Porankiewicz et. al. 2004) it was found that more than 90% of contaminant particles present in examined wood species were the smallest ones, due to a low representation of larger fractions. Moreover, an unknown part of the content of the bigger fractions in this case were 3D particle aggregates, not originated from the wood itself. The 3D aggregates became self-assembled due to the high content of potassium and calcium in the ash, during burning, as was required as part of the evaluation procedure for the hard mineral contaminant content. From Figs. 9 and 10 it can also be seen that the role of the smallest fraction of contaminant particles in the cutting edge wearing process significantly increases with enlargement of the HTTR.

The method of the cutting edge recession theoretical simulation, based on 3D random distribution of contaminant particles allowed for a little better approximation of the predicted cutting edge recession VB in comparison to the work of Porankiewicz (2006). The present study shows, however, that for evaluation of real impact of the content C_{CP}, and size S_{CP}, of hard mineral contamination on the cutting edge recession $VB^P{}_F = f(C_{CP}, S_{CP})$, more data has to be analyzed, especially with larger representation of big fractions of the contamination particles. It would be interesting to perform theoretical simulation on results obtained in a milling, wearing experiment including a complete experimental matrix, with laboratory-made, artificially contaminated particle boards. On the example of data extracted from work Kilinga and Back 1964, containing a large amount (3000mg/kg) of very small hard mineral contaminant particles of size 8 um, the algorithm of theoretical simulation developed in the present study, compiled in the GNU Pascal compiler did show some signs of instability. In connection with that, for such very large tasks (from the point of view of the variable matrix size) the use of C or Fortran compilers have to be checked.

CONCLUSIONS

1. A theoretical method and algorithm for prediction of the cutting edge recession, based on 3D random distribution of hard mineral contaminant particles, was positively verified on milling of three types of samples: melamine coated particle board, fiber board, and solid wood.
2. The algorithm developed in the present study allowed for more precise prediction of the cutting edge recession in comparison to method presented in the work of Porankiewicz (2006).

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