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OBLIK MAZIVOG SLOJA KOD DRESIRANJA TRAKE

Sažetak

Analiziran je geometrijski oblik mazivoga sloja na traci ispred valjaka kod procesa dresiranja.Daje se utjecaj te visine na visinu mazivoga sloja na ulaznome presjeku zone deformacije metala gdje je jak utjecaj upravo u malim područjima zahvatnih kuteva. Metodom Monte-Carlo rješavana je diferencijalna jednadžba koja je dala ekstremne geometrijske karakteristike mazivoga sloja ispred ulaznoga presjeka zone deformacije.Ta geometrija moguća je i dostižna u procesima dresiranja s visokokvalitetnim mazivima kada se želi postići ušteda maziva u tehnološkome procesu. Pronađena je kritična točka koja se postavlja realno u nizu navedenih dijagrama jer razgraničava optimalnu visinu mazivoga sloja od slučaja kada se mazivo dodaje u suvišku što je česta praksa u tehnološkom procesu. Za teorijska istraživanja važno je pozicioniranje kritične točke.

1.Uvod

Pri procesima plastične [1,2] deformacije (kovanje, valjanje, prešanje, izvlačenje različitih profila cijevi, itd.) koriste se tehnološka maziva [3,4] u velikim količinama zbog više razloga:

1. smanjenje kontaktnoga trenja
2. odvođenje topline i hlađenje alata da se smanji trošenje
3. smanjenje otpora deformacije i smanjenje rada deformacije
4. smanjenja naljepljivanja na alat i čiste površine proizvoda

Tehnološka maziva moraju ispuniti niz zahtjeva, počevši od visoke sposobnosti podmazivanja, tj. sposobnosti nastanka ravne, čvrste opne koja razdvaja kontaktne plohe, zatim temperaturne postojanosti, stabilnosti maziva bez utjecaja korozije na deformirani proizvod, bez štetnoga utjecaja na čovjeka, itd. Osnovne grupe maziva koje zadovoljavaju prethodne uvjete jesu:

a) tekuće emulzije
b) masti i kompaundi
c) konzistentna maziva
č) prozirna staklasta maziva
ć) praškasta maziva
d) metalna maziva

Tekuće emulzije se posebno koriste pri hladnome [5,6] valjanju. Kompaundi su smjese biljnih i mineralnih ulja a jednako se primjenjuju pri valjanju lima i trake debljina 0,3-0,4 mm.

Kod hladnoga valjanja tankih limova postoji i proces dresiranja čiji je cilj smanjenje valovitosti lima gdje se iznimno primjenjuju tekućinska maziva.

Proces podmazivanja [7-9] trake kod dresiranja može se opisati sljedećom diferencijalnom jednadžbom, prema slici 1.

$$\frac{dp}{dx} = \frac{6\mu(v_0 + v_{Rx})}{\varepsilon^2(x)} - \frac{12\mu Q}{\varepsilon^3(x)} \tag{1}$$

Specifična potrošnja maziva po opsegu trake iznosi:

$$Q(x) = \int_0^{\varepsilon(x)} u\,dy = -\frac{1}{12\mu}\frac{dp}{dx}\varepsilon^3(x) + \left(\frac{v_0 + v_{Rx}}{2}\right)\varepsilon(x) \tag{2}$$

Projekcija vektora brzine valjaka na os x za dresiranje daje se sljedećom relacijom:

$$v_{Rx} = v_R\sqrt{1 - \left(\sin\alpha - \frac{x}{R}\right)^2} \approx v_R\cos\alpha \approx v_R \tag{3}$$

Visina mazivoga sloja određena je relacijom:

$$\varepsilon(x) = \varepsilon_0 + R\left[\cos\alpha - \sqrt{1 - \left(\sin\alpha - \frac{x}{R}\right)^2}\right] \tag{4}$$

Dužina mazivoga klina [10-12] predstavljena je odnosom prema slici 1.

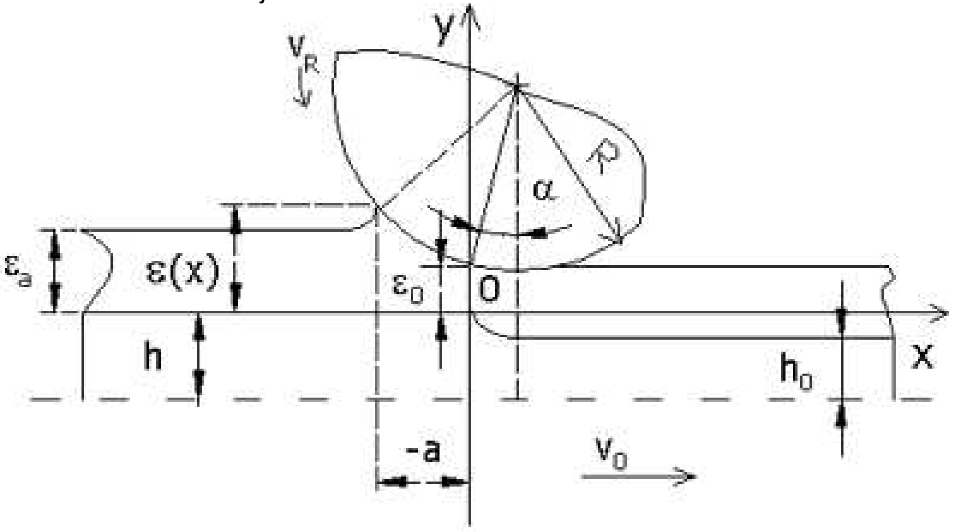
$$a = R\left[\sqrt{1-\left(\cos\alpha-\frac{\varepsilon_a}{R}+\frac{\varepsilon_0}{R}\right)^2}-\sin\alpha\right] \tag{5}$$

Za procese dresiranja izraz (4) se može razviti u red potencija:

$$\varepsilon(x)=\varepsilon_0-\alpha x+\frac{x^2}{2R}-\frac{\alpha x^3}{2R^2}+\frac{x^4}{8R^3} \tag{6}$$

U radu se promatra oblik mazivoga klina u području (-a; 0). Ova analiza nedostaje u literaturnim podacima. Interesantna je za praktičnu primjenu, pronalaženje optimalne visine mazivoga sloja i uštede visokokvalitetnih maziva u tehnološkom procesu.

Slika 1: Shema dresiranja trake s mazivima



2. Rezultati izračunavanja i diskusija

Diferencijalna jednadžba (1) rješavana je metodom Monte-Carlo. Tehnološki parametar izvučen eksplicitno glasi:

$$A=\frac{1-\exp(\gamma p)}{6\mu_0\gamma(v_0+v_R)} \tag{7}$$

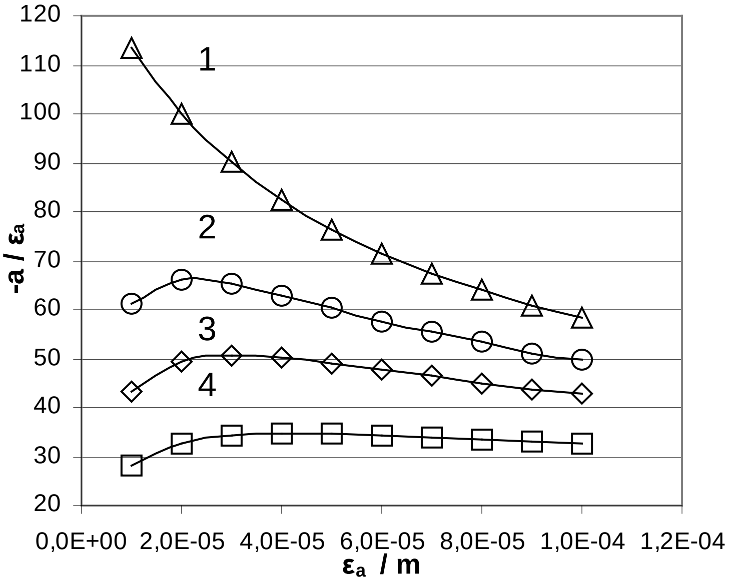
Uvjeti tehnološkoga procesa predstavljeni su u tablici 1.

Tablica1: Uobičajene vrijednosti za procese dresiranja pojedinih parametara [6,7]

Parametar	Vrijednost	Jedinica
γ-piezokoeficijent viskoznosti	2,18E-7	Pa^{-1}
p-pritisak valjanja	20E6	Pa
v_0-brzina gibanja trake	6	m/s
v_R-brzina valjanja	10	m/s
R- radijus valjaka	0,2	m
μ_0-dinamička viskoznost maziva	0,024	Pa s
α- kut zahvata	0-0,04	rad
ε_a-visina maziva na traci	0,001-0,00001	m
A-tehnološki parametar	1.965512E6	m^{-1}
Pretpostavljaju se glatke površine valjaka i trake		

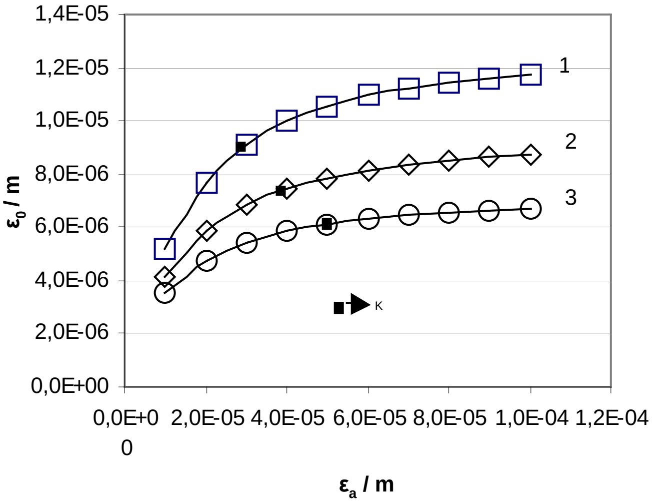
Analiza je usmjerena prema traženju kritičnoga oblika mazivoga sloja pri dresiranju za sliku 1 u području (-a : 0). Rezultati će biti predstavljeni u nizu dijagrama. Slika 2 nosi temelj analize, a otkriva da za određene vrijednosti zahvatnih kuteva postoji ekstremna vrijednost geometrijskoga oblika mazivoga klina.

Slika 2: Ekstremne vrijednosti geometrijskog oblika mazivoga klina



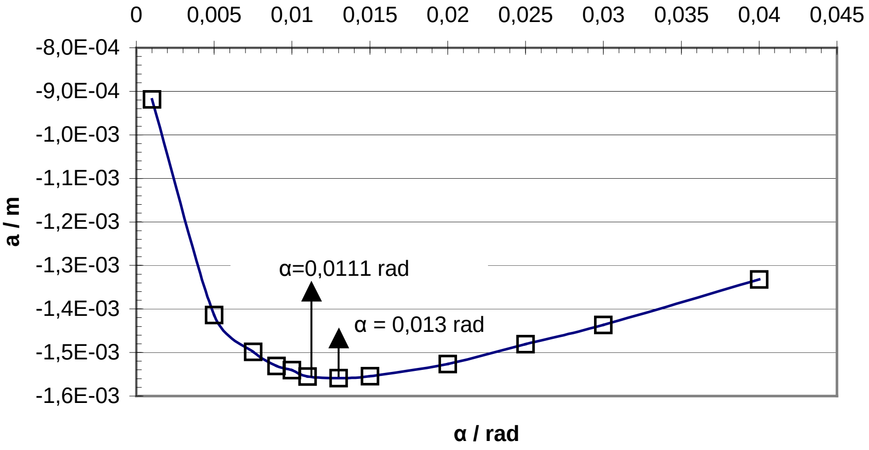
serija 1- $\alpha \to 0$ rad
serija 2- $\alpha = 0.005$ rad
serija 3 -$\alpha = 0.01$ rad
serija 4 -$\alpha = 0.02$rad

Slika 3: Utjecaj ε_a na ε_0 za različite zahvatne kuteve

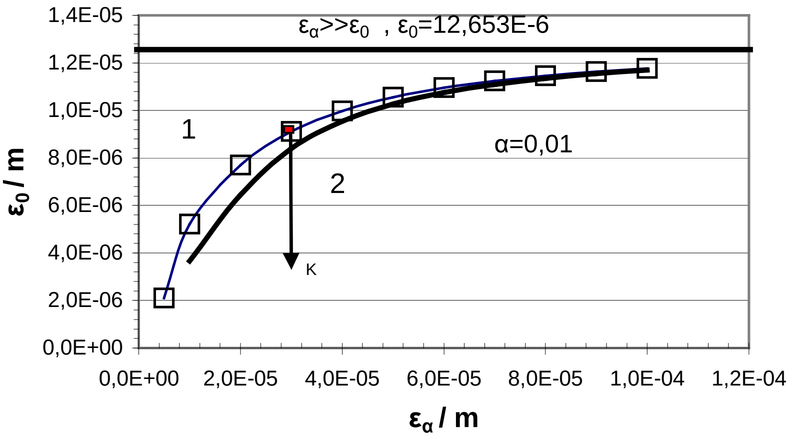


serija 1 - α =0,01 rad serija 3 - α = 0.03 rad
serija 2 -α = 0.02 rad K – marker kritične točke

Slika 4: Ekstremna vrijednost dužine mazivoga klina u funkciji kuta dresiranja



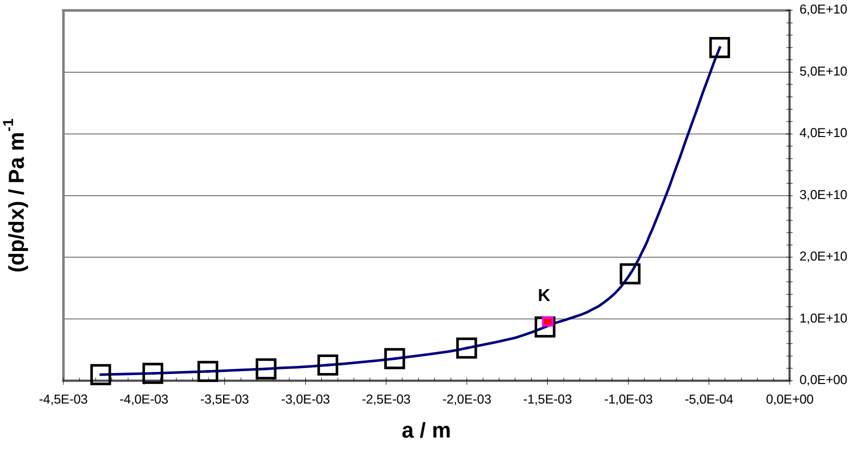
Slika 5: Ocjena kritične točke o utjecaju ε_a na ε_0



1- **Epsilon 0**

2- **Metoda pokretnih sredina (2 per. Mov.Avg. Epsilon 0)**

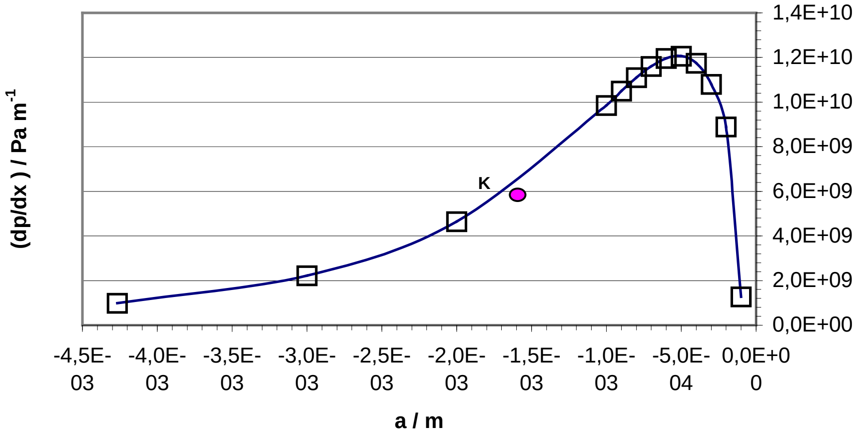
Slika 6: Centralna pozicija kritične točke kod gradijenta pritiska za zahvatni kut α=0.00131 rad.



Slika 3 daje utjecaj visine maziva na traci na visinu maziva na ulaznome presjeku zone deformacije za nekoliko različitih zahvatnih kuteva.Primjetno je da je utjecaj ε_a na ε_0 najveći za α=0,01 rad i da sa porastom kuta zahvata opada. Markerom *K* na svakome zahvatnome kutu označen je položaj kritične točke.Ona se porastom zahvatnoga kuta miče udesno na dijagramu, tj. prema većim vrijednostima ε_a. Markeri točke *K* na slici 3 su ekstremne vrijednosti funkcije $-a / \varepsilon_a$ u funkciji ε_a. Isto je vidljivo i na slici 2 gdje se taj ekstrem s porastom zahvatnoga kuta miče udesno ili prema većim vrijednostima ε_a.

Slika 4 daje kritičnu vrijednost forme mazivoga sloja za parametre tehnološkoga procesa predstavljene u tablici 1. Ucrtana vrijednost α=0,0111 rad dobiva se iz izraza (6) kada se on aproksimira parabolom. Tablica 2 donosi geometrijska izračunavanja po vrijednostima tablice 1.

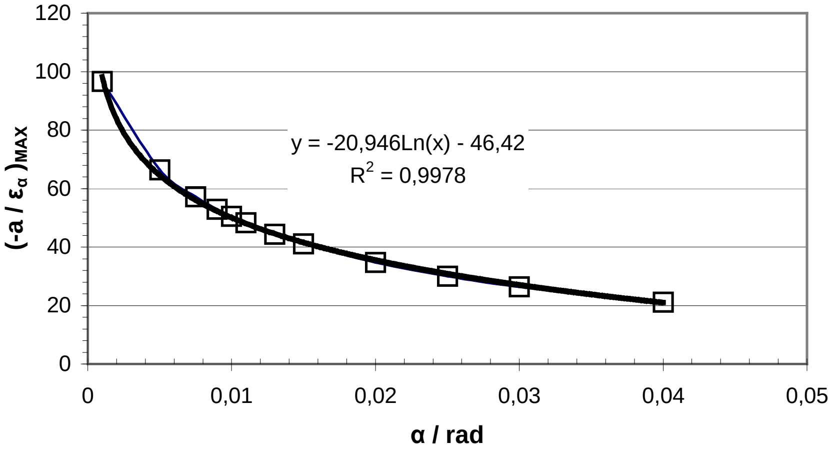
Slika 7: Pozicija kritične točke u gradijentu pritiska za α=0,02 rad



Tablica 2: Geometrijske karakteristike kritičnog oblika mazivoga sloja

Kut zahvata α / rad	Dužina klina a / m	Visina maziva na traci ε_a / m	Maks.	Visina maziva na ulaznom presjeku deformacije ε_0 / m
0,0131	-1,5591E-3	3,512E-5	44,408	8,751E-6

Slika 8: Regresijska analiza između kuta zahvata i ekstremnih vrijednosti forme mazivoga klina (Apscisa x je kut zahvata α u regresiji)



Slike od 5 do 7 daju pozicije kritične točke u nekim odabranim izračunavanjima.

Na slici 5 kritična točka razgraničava kada počinje intenzivniji utjecaj visine mazivoga sloja na traci ispred valjaka na visinu mazivoga sloja na ulaznome presjeku zone deformacije. Pri tome izračunata [12] visina od ε_0= 12,653E-6 predstavlja granični slučaj kada $a \to -\infty$.

Ovisnost $\varepsilon_0 = \varepsilon_0(\varepsilon_a)$ može se predstaviti statističkom metodom pokretnih sredina koja je i ucrtana na slici 5, a zbog malih vrijednosti koeficijenata regresije zaobilaze se uobičajene ponude u statističkim paketima.

Slika 6 i slika 7 pozicioniraju kritičnu točku tablice 2 u analizi gradijenta pritiska diferencijalne jednadžbe (1).

Na slici 6 markirana je kritična točka za ε_0=11,761E-6 m, A=1965512 m^{-1}. Vidljivo je da ona ima središnje mjesto u podnožju gradijenta pritiska. Rezultati izračunavanja u 10 točaka kretali su se za ε_a=0,00001 – 0,0001 m s porastom 0.00001.

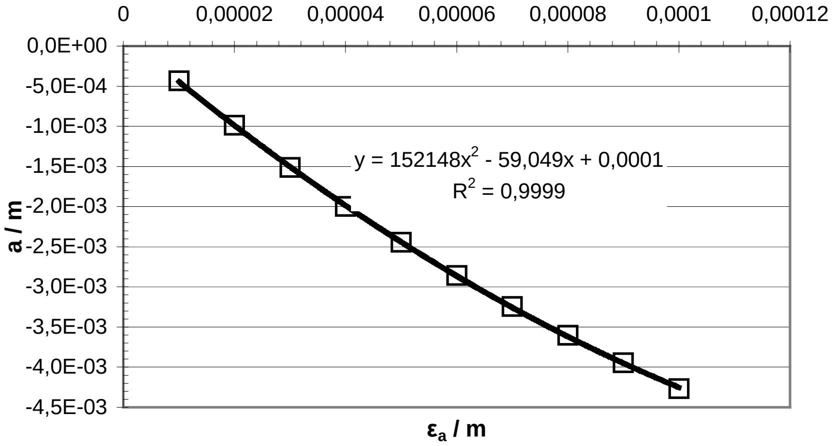
Na slici 7 daje se pozicija kritične točke za α=0,02 rad, gdje je ona malo dislocirana iz podnožja u smjeru maksimuma gradijenta pritiska.

Na slici 8 predstavljena je uspiješna regresijska analiza između geometrijske forme mazivoga klina i kuta zahvata prema tablici 1. Veza je logaritamska s visokim vrijednostima koeficijenta regresije.

Na slici 9 daje se još jedna uspješna regresijska analiza između sljedećih parametara diferencijalne jednadžbe (1) , a = a(ε_a). Rezultati izračunavanja predstavljeni su u tablici 3.

Visina mazivoga sloja na traci varirana je dok se nije postigao određeni maksimum dat u tablici 3. Jaka regresijska veza za sliku 9 predstavljena je polinomom drugoga stupnja.

Slika 9: Veza kritične forme mazivoga klina za zahvatne kuteve α=0,005-0,04 rad



Tablica 3: Rezultati izračunavanja kritičnih točaka za sliku 9, sliku 4 i sliku 3

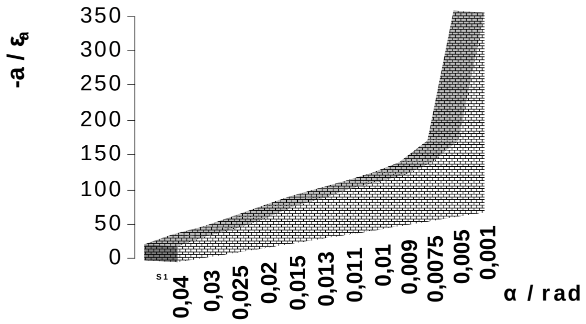
α / rad	a / m	ε_a / m	ε_0 / m	Maks.
0,001	-9,183E-4	9,420E-6	6,471E-6	96,66786
0,005	-1,414E-3	2,130E-5	9,242E-6	66,366104
0,0075	-1,498E-3	2,620E-5	9,350E-6	57,186342
0,009	-1,531E-3	2,891E-5	9,283E-6	52,96016
0,01	-1,540E-3	3,050E-5	9,161E-6	50,50616
0,011	-1,555E-3	3,210E-5	9,042E-6	48,285549
0,013	-1,559E-3	3,510E-5	8,751E-6	44,40791
0,015	-1,554E-3	3,790E-5	8,432E-6	41,12099
0,02	-1,527E-3	4,400E-5	7,631E-6	34,699001
0,025	-1,481E-3	4,930E-5	6,871E-6	29,98262
0,03	-1,437E-3	5,440E-5	6,211E-6	26,363014
0,04	-1,332E-3	6,300E-5	5,152E-6	21,175123

Slika 10 pruža rafinirani uvid u utjecaj kritične geometrijske forme mazivoga sloja kada zahvatni kutevi teže nuli. Interesantno je primijetiti da kritični geometrijski oblik mazivoga sloja postiže ekstrem za α= 0,0131 rad, dok se optimalna visina mazivoga sloja na ulaznome presijeku zone deformacije metala eksponira za $\alpha\approx$ 0,0075 rad. Ako postavimo referentnu točku ucrtanu na slici 4 da to razgraniči

$$\alpha = \sqrt[3]{\frac{8}{15RA}} = 0{,}0111 \text{ rad} \qquad (8)$$

tada se optimalna visina ε_0 postavlja ispred formule (8) dok se kritični geometrijski oblik mazivoga sloja javlja poslije formule (8).

Slika 10: 3DView-Kritična forma mazivoga sloja kada α→0



3. Zaključak

I. Prema tablici 3 vidljivo je da ε_0 postiže optimalnu vrijednost u odnosu na ε_a od oko 9,35E-6 pri ε_a= 2,62E-5 m prilikom porasta zahvatnih kuteva dresiranja. Iako se ova visina mazivoga sloja na traci ispred valjaka u praksi teže dostiže jer se mazivo u procesima dresiranja dodaje u suvišku, moguć je i obrnut zaključak, da se mazivo dodaje u suvišku upravo da se neutralizira efekt kritične točke.

II. Kako su pokazala teorijska izračunavanja prekoračenje kritične točke mazivoga sloja izaziva velike promjene na utjecaj ε_a na ε_0 u cilju snižavanja ε_0. Za te slučajeve gradijent pritiska podnosi oscilacije a s njime oscilira i utjecaj inercijskih sila maziva. Kritična geometrijska točka eksponira se oko formule (8). Smanjenjem zahvatnih kuteva dresiranja kritični oblik mazivoga sloja naglo raste preko odnosa [- *a* / ε_a]. Ovo istraživanje kada α→0 ima i teorijski interes a slikovitu ilustraciju pruža slika 10.

4. Popis oznaka

Simbol	Jedinica	Napomena
α	rad	Kut zahvata; slika 1
ε_a	m	Visina maziva na traci ispred valjaka
$\varepsilon(x)$	m	Izvedena relacija za visinu maziva u području (-a ; 0)
ε_0	m	Visina maziva na ulaznome presjeku zone deformacije
μ	Pa s	Dinamička viskoznost maziva
γ	Pa^{-1}	Piezokoeficijent viskoznosti maziva
a	m	Dužina mazivoga klina; slika 1
A	m^{-1}	Tehnološki parametar
dp/dx	Pa/m	Pritisak u mazivome sloju
h_0	m	Debljina trake na izlazu iz zone deformacije
h	m	Debljina trake prije dresiranja
K	-	Kritična točka, aproksimativno se postavlja oko formule(8); potvrđuje je metoda Monte-Carlo, slika 9
Max	-	Oznaka za maksimum
p	Pa	Pritisak u mazivome sloju
R	m	Radijus valjaka
R^2	-	Koeficijent determinacije
u	m/s	Brzina gibanja maziva uzduž osi x
v_0	m/s	Brzina gibanja trake
v_R	m/s	Brzina valjanja
x,y	-	Koordinate Decartesovog sustava
Q(x)	m^2/s	Specifična potrošnja maziva po opsegu trake – jednodimenzijski model ; za x= 0 , Q= 0.5(v_0 + v_R)
∞	-	Oznaka za beskonačno
$\rightarrow$	-	Oznaka za « teži »

LUBRICATING FILM FORMATION FOR STRIP DRESSING

Abstract

The geometrical lubricating film formation on a strip in front of the rollers at dressing process is analyzed. The effect of the initial thickness of the lubricant film on the initial section of the metal deformation zone is calculated. This effect is great for low rolls gripping angle. The differential equation for extreme geometrical properties of the lubricating layerin before the initial section of the deformation zone is solved by the Monte-Carlo method.

This geometry can be achieved in dressing processes using high quality lubricants, aimed to save lubricant in the technological process. In the series of diagrams the critical point separating the optimal thickness of the lubricant film from the excess of lubricant is established. For theoretical investigations, the positioning of this critical point is of essential importance.

1. Introduction

At processes of plastic deformation (forging, rolling, pressing, drawing of different pipe profiles, etc.), technological lubricants are used in large volumes, for several reasons:

1. reduction of contact friction,
2. heat release and tool cooling in order to reduce wear,
3. reduction of deformation resistance and operation,
4. reduction of sticking to the tools and the clean product surfaces.

Technological lubricants must meet a number of requirements, starting from high lubrication capacity of the contact surface, then temperature stability, stability of lubricants without corrosion impact on the deformed product, without harmful impact on man, etc. The basic lubricant groups meeting the above conditions are as follows:

- a) liquid emulsions
- b) greases and compounds
- c) consistent lubricants
- d) transparent glassy lubricants
- e) powder lubricants
- f) metal lubricants

Liquid emulsions are used particularly for cold rolling. Compounds are mixtures of vegetable and mineral oils, while they are also applied for sheet metal and strip rolling with the thickness of 0.3-0.4 mm.

At the cold rolling of thin metal sheets, there is a dressing process having as goal the reduction of metal sheet wavyness, where fluid lubricants are especially applied.

The process of strip lubrication at dressing may be described by the following differential equation, according to Figure 1.

$$\frac{dp}{dx} = \frac{6\mu(v_0 + v_{R\,x})}{\varepsilon^2(x)} - \frac{12\mu Q}{\varepsilon^3(x)} \tag{1}$$

Specific lubricant consumption per strip volume is as follows:

$$Q(x) = \int_0^{\varepsilon(x)} u\,dy = -\frac{1}{12\mu}\frac{dp}{dx}\varepsilon^3(x) + \left(\frac{v_0 + v_{R\,x}}{2}\right)\varepsilon(x) \tag{2}$$

Projection of roller velocity vector to the axis x for dressing is provided by the following relation:

$$v_{Rx} = v_R\sqrt{1 - \left(\sin\alpha - \frac{x}{R}\right)^2} \approx v_R\cos\alpha \approx v_R \tag{3}$$

Lubricant film height is determined by the following relation:

$$\varepsilon(x) = \varepsilon_0 + R\left[\cos\alpha - \sqrt{1 - \left(\sin\alpha - \frac{x}{R}\right)^2}\right] \tag{4}$$

Wedge film length is represented by the relation according to Fig 1.

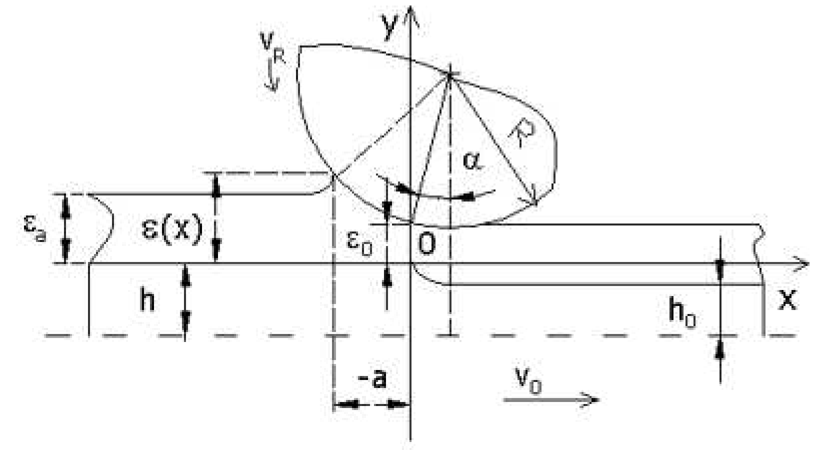
$$a = R\left[\sqrt{1 - \left(\cos\alpha - \frac{\varepsilon_a}{R} + \frac{\varepsilon_0}{R}\right)^2} - \sin\alpha\right] \tag{5}$$

For dressing processes, the expression (4) may be developed to the order of powers

$$\varepsilon(x) = \varepsilon_0 - \alpha x + \frac{x^2}{2R} - \frac{\alpha x^3}{2R^2} + \frac{x^4}{8R^3} \tag{6}$$

The paper investigates the lubricating wedge form in the area (-a; 0). This particular analysis cannot be found in the references. It is interesting for practical application in order to find an optimal lubricating film thickness and obtain savings of high quality lubricants in the technological process.

Figure 1: The layout of strip dressing by lubricants



2. Calculation Results and Discussion

Differential equation (1) was resolved using the Monte-Carlo method.Technological parameter expressed explicitly is as follows:

$$A = \frac{1 - \exp(\gamma p)}{6\mu\gamma(v_0 + v_R)} \qquad (7)$$

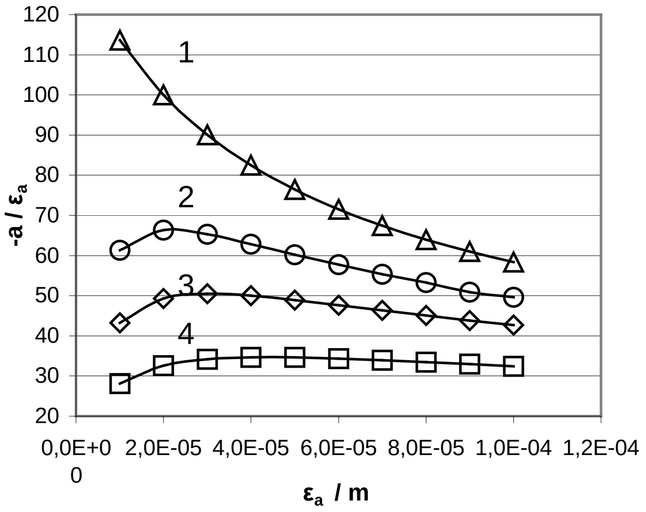
The technological process conditions are presented in Table 1.

Table 1: Common values of individual parameters for the dressing processes

Parameter	Value	Unit
γ-piezo viscosity coefficient	2,18E-6	Pa^{-1}
p-rolling stress	20E6	Pa
v_0-strip movement velocity	6	m/s
v_R-rolling velocity	10	m/s
R- roller radius	0,2	m
μ_0-dynamic viscosity of lubricants	0,024	Pa s
α- grip angle	0-0,04	rad
ε_a-lubricant thickness on strip	0,001-0,00001	m
A-technological parameter	1.965512E6	m^{-1}
Smooth roller and strip surfaces are assumed		

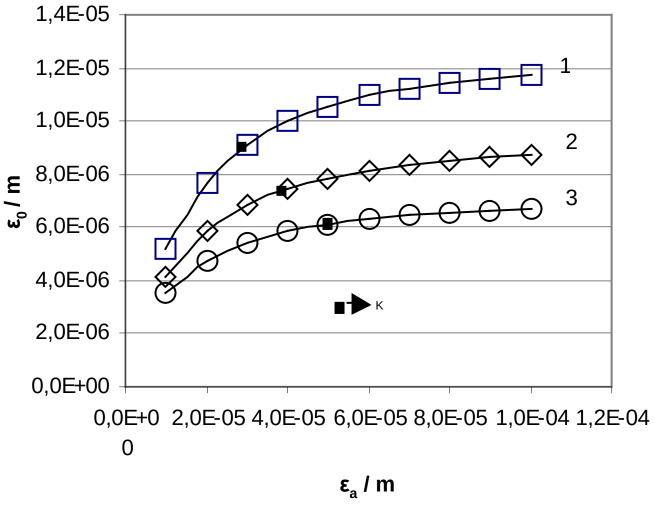
The analysis has been oriented towards finding the critical form of the lubricating film during dressing for Figure 1 in the area (-a : 0). The results will be presented in a number of diagrams. Figure 2 provides the basis of the analysis, revealing that for certain values of the grip angles there are extreme values of the geometrical lubricating wedge form.

Figure 2: Extreme values of the geometrical lubricating wedge form



series 1- $\alpha \to 0$ rad series 3 -α = 0.02 rad
series 2- α = 0.01 rad series 4 -α = 0.005 rad

Figure 3: Impact of ε_a on ε_0 for different grip angles



series 1 - α =0,01 rad series 3 - α = 0.03 rad.
series 2 -α = 0.02 rad; K – critical point marker

Figure 4: Extreme value of the lubricating film thickness as a function of dressing angle

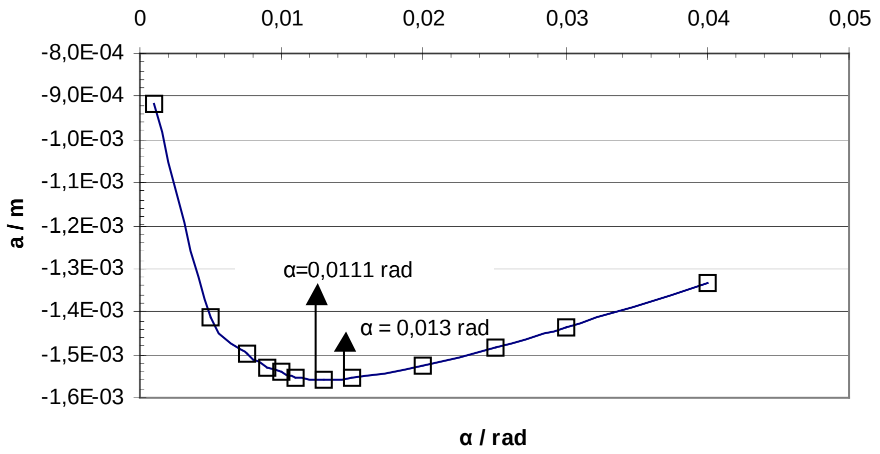


Figure 5: Critical point evaluation on the impact of ε_a to ε_0

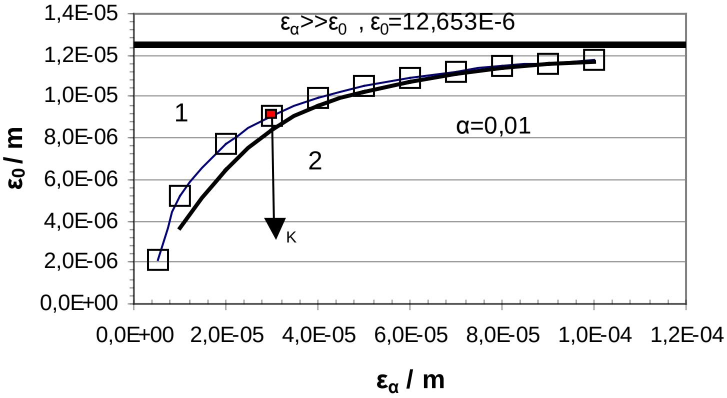


Figure 3 provides the impact of lubricant thickness of the strip on the thickness of lubricants at the input section of the deformation zone for several different grip angles. It may be observed that the impact of ε_a on ε_0 is the highest for α=0.01 rad and that with the increase of the grip angle it declines. Letter *K* on each grip angle marks the critical point position. It moves to the right in the diagram with the grip angle increase i.e. towards higher ε_a values. *K* point markers in Figure 3 are the extreme values of function $-a/\varepsilon_a$ in function ε_a. It may also be observed in Figure 2 that this extreme, with the grip angle increase, moves to the right or towards higher ε_a values.

Figure 4 provides the critical value of the lubricating film formation for the parameters of technological process presented in Table 1. The entered value α=0,0111 rad is obtained from the equation (6) when it is approximated by a parable. Table 2 provides geometrical calculations per Table 1 values.

Figure 6: The central position of the critical point at pressure gradient for grip angle α=0.00131 rad

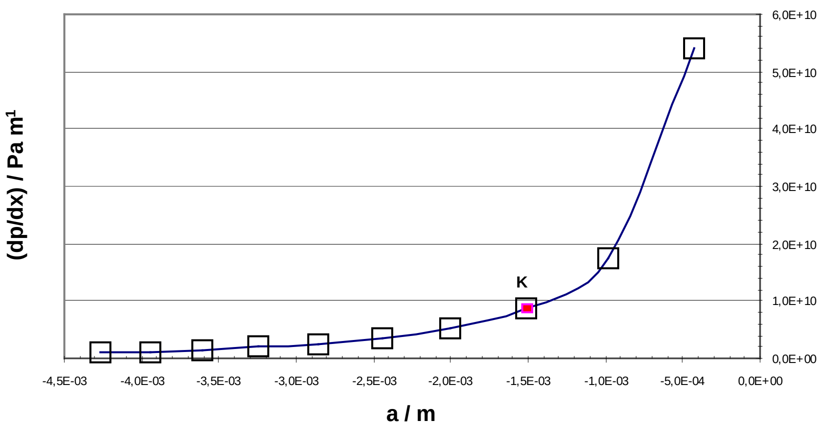


Figure 7: Position of the critical point at pressure gradient for α=0,02 rad

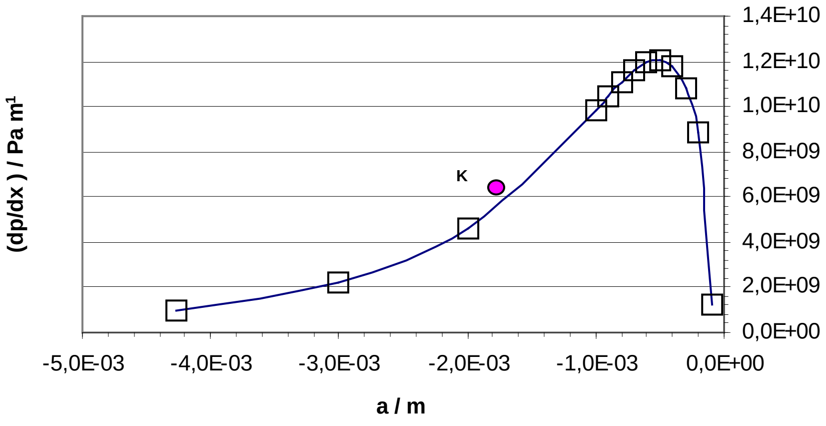
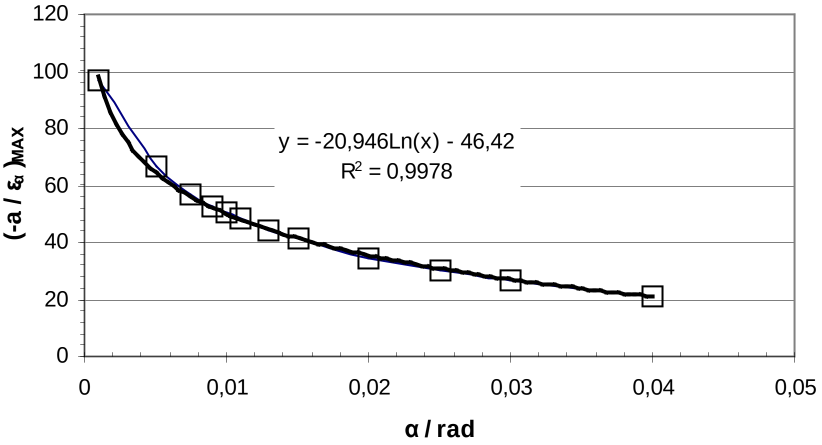


Table 2: Geometrical properties of the lubricating film critical form

Angle grip α/rad	Wedge length a/m	Lubricant height at strip ε_a/m	Max	Lubricant height at input deformation section ε_0/m
0,0131	-1,5591E-3	3,512E-5	44,408	8,751E-6

Figure 8: Regression analysis between grip angle and extreme value of lubricating wedge form



Figures 5-7 provide critical point positions in certain selected calculations. In Figure 5, the critical point becomes delimited with the beginning of a more intense impact of the lubricating film thickness on the strip in front of the rollers to the lubricating film thickness at the input section of the deformation zone. The thickness calculated in the amount of ε_0= 12,653E-6 constitutes a bordering case when $a \to -\infty$.

The dependence $\varepsilon_0=\varepsilon_0(\varepsilon_a)$ may be presented through a statistical method of mobile centres marked in Figure 5 as well. Due to low regression coefficient values, the usual offers in statistical packages are avoided.

Figures 6 and 7 position the critical point of Table 2 in the analysis of the differential equation pressure gradient (1).

Figure 6 marks the critical point for ε_0=11,761E-6 m, A=1965512 m^{-1}. It may be observed that it holds the central position in the «foot« of pressure gradient. The results of calculation in 10 points were ranging from ε_a=0,00001 – 0,0001 m, with the increment of 0.00001.

Figure 7 provides the position of the critical point for α=0,02 rad, where it is a bit dislocated from the «foot» towards maximum pressure gradient.

Figure 8 presents a successful regression analysis between the geometrical form of lubricating wedge and the grip angle according to Table 1. The bond is logarithmic, with high regression coefficient values.

Figure 9 provides another successful regression analysis between the following differential equation parameters (1), $a=a(\varepsilon_a)$. Calculation results are given in Table 3. The lubricating film thickness on the strip varied until a certain maximum was achieved, provided in Table 3. Firm regression bond for Figure 9 was presented by a second degree polynome.

Figure 9: Bond of the lubricating wedge critical form for grip angles α=0,005-0,04 rad

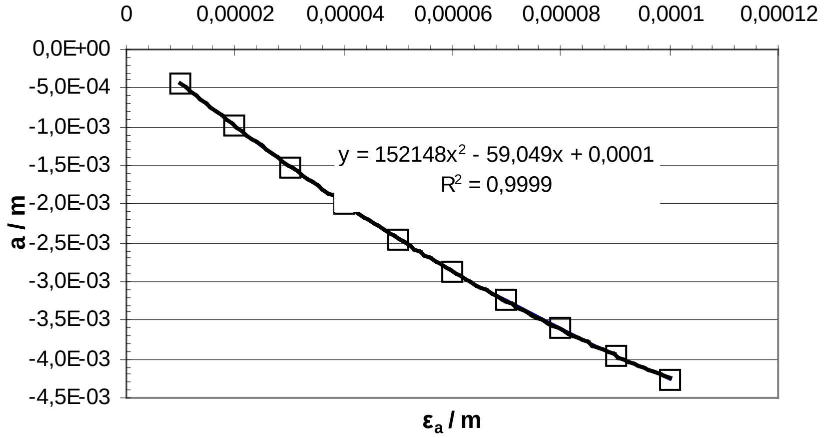


Table 3: Results of calculating critical points for figures 9, 4, 3

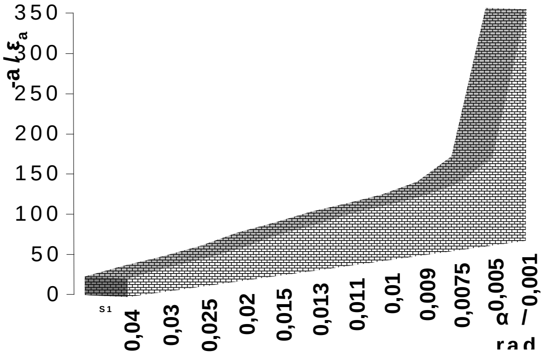
α/rad	a/m	ε_a/m	ε_0/m	max.
0,001	-9,183E-4	9,420E-6	6,471E-6	96,66786
0,005	-1,414E-3	2,130E-5	9,242E-6	66,366104
0,0075	-1,498E-3	2,620E-5	9,350E-6	57,186342
0,009	-1,531E-3	2,891E-5	9,283E-6	52,96016
0,01	-1,540E-3	3,050E-5	9,161E-6	50,50616
0,011	-1,555E-3	3,210E-5	9,042E-6	48,285549
0,013	-1,559E-3	3,510E-5	8,751E-6	44,40791
0,015	-1,554E-3	3,790E-5	8,432E-6	41,12099
0,02	-1,527E-3	4,400E-5	7,631E-6	34,699001
0,025	-1,481E-3	4,930E-5	6,871E-6	29,98262
0,03	-1,437E-3	5,440E-5	6,211E-6	26,363014
0,04	-1,332E-3	6,300E-5	5,152E-6	21,175123

Figure 10 provides a refined insight into the impact of critical geometrical form of lubricating film when the grip angles tend towards zero. It is interesting to note that the critical geometrical form of the lubricating film reaches the extreme for α= 0.0131 rad, while the optimal lubricating film thickness at the input section of metal deformation zone protrudes for α≈ 0,0075 rad. If we place a referential point entered into Figure 4 to delimit this

$$\alpha = \sqrt[3]{\frac{8}{15RA}} = 0{,}0111 \text{ rad} \qquad (8)$$

than the optimal height ε_0 is placed in front of formula (8), while the critical geometrical form of the lubricating film comes after formula (8).

Figure 10: 3D-View-Critical lubricating film formation with α→0



3. Conclusion

I. It may be seen from Table 3 that ε_0 reaches optimal value with regard to ε_a of around 9.35E-6 with ε_a= 2.62E-5 m when the dressing grip angles increase. Although this dressing lubricating film thickness on the strip in front of the rollers is harder to achieve in practice because the lubricant in dressing processes is added in surplus, the opposite conclusion is also possible: that the lubricant is added in surplus precisely to neutralize the critical point effect.

II. As shown by theoretical calculations, exceeding of the lubricating film critical point causes great changes to the impact of ε_a on ε_0 for the purpose of reducing ε_0. For such cases, the pressure gradient tolerates oscillations, while along with it oscillates also the impact of the lubricant inertial powers. Critical geometrical point is exposed in formula (8). By lowering the dressing grip angles, the critical lubricating film formation abruptly increases above the a/ε_a ratio. This particular research was performed with $\alpha \rightarrow 0$, having a theoretical interest as well, while the illustration may be found in Figure 10.

4. List of Marks

Symbol	Unit	Note
α	rad	Grip angle; Figure 1
ε_a	m	Lubricant height on strip before rollers
$\varepsilon(x)$	m	Relation performed for lubricant thickness in the area (-a; 0)
ε_0	m	Lubricant thickness at the input section of deformation zone
μ	Pa s	Lubricant dynamic viscosity
γ	Pa^{-1}	Piezo coefficient of lubricant viscosity
a	m	Lubricating wedge lenght; Figure 1
A	m^{-1}	Technological parameter
dp/dx	Pa/m	Pressure in the lubricating film
h_0	m	Strip thickness at the output of deformation zone
h	m	Strip thickness before dressing
K	-	Critical point
Max	-	Maximum
p	Pa	Pressure in the lubricating film
R	m	Roller radius
R^2	-	Determination coefficient
u	m/s	Lubricant movement velocity along the x axis
v_0	m/s	Strip movement velocity
v_R	m/s	Rolling velocity
x,y	-	Coordinates of the Decartes System
Q(x)	m^2/s	Specific lubricant consumption per strip volume – one-dimensional model
∞	-	Infinite
$\rightarrow$	-	«heavier»

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UDK	ključne riječi	key words
621.771.23	valjanje limova	plate rolling
621.771.23	dresiranje traka	strip dressing
621.891	podmazivanje	lubrication
65.012.122	optimalizacija proizvodnih troškova i količina prerade	processing cost and quantity optimization

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