研究論文

LOCAL SOFTENING OF HARD SHELLED SEMIPRODUCTS BY USING A PLASMA GENERATOR

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Key Words : local softening, plasma generator, softening temperature, cutting tool

Abstract

The work presents the experimental results concerning the local softening of Diesel motor cylinders with plasma using a specialized plasma generator.

1. INTRODUCTION

Cylinders for Diesel motors, are obtained through centrifugal chill casting of grey cast iron. The marginal surfaces of the cylinders have a high hardness (≥ 250 HB) shell. The roughing by cutting of the shell leads to a high consumption of cutting tools as well as to a reduced specfic discharge of chips.

In order to decrease the consumption of the cutting tool and to increase the specific discharge of chips, the marginal surfaces of the cylinder are locally heated in the transferred electric arc plasma[1,2,4].

The transferred electric arc plasma increases the temperature of the hard shell in the cutting zones and consequently, the cutting forces diminish.

Intuitively, it is not possible to have a cutting area with local plasma heating. It is necessary to correlate the plasma heating area (the power of the transferred electric arc plasma, the distance between the plasma generator and cutting tool, radius of anodic patch) and the cutting area (cutting rate, advance of cutting tool, depth of cutting) of the semiproduct, in order to obtain a good cutting regime, comparable to the usual one.

There are known the roughing technologies by cutting of hard and superhard steel semiproducts[2,3]. Roughing by cutting of semiproducts with hard shell are less well known.

In the paper there are presented the analytical temperature distribution in the cutting zone, as well as the temperature distribution on the cutting edge, at the local plasma heating for roughing of the marginal surfaces of the Diesel engine cylinders. There are evidenced the conditions necessary to attain locally the plastifying temperature of the hard shell, the temperature gradient at the cutting dege which ensure, as

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much as possible, the uniform wear of the tool, as well as the temperature area of the roughed surface which do not produce unwanted phase transformations and thermal deformations of the cylinder.

The theoretical results are compared with those obtained experimentally under semiindustrial conditions.

2. CALCULATION OF TEMPERATURE DISTRIBUTION

2.1 Description of the procedure

The limited heating with the plasma arc of the cylinder for Diesel motors which is roughed by cutting is presented in Figure 1.

The plasma generator 1, connected to the current source 2, heats the cylinder 3 along the cuttting width :

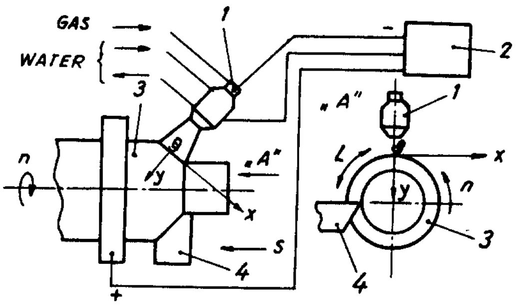

Fig. 1 Roughing by cutting of the shell on the outside surface of the cylinder for Diesel motor (schematic diagram)

where : 1-plasma generator, 2-current source, 3-cylinder, 4-cutting tool, AB-cutting width, S-cutting tool feed rate, Ox, Oy, Oz-the axes of the orthogonal coordinate system Oxyz, L-the distance between the plasma generator and the cutting tool measured on the circumference of the cylinder, n-the number of rotations of the machine tool.

thing width :

$$AB = b = \frac{t}{\sin\chi} \qquad (1)$$

where :

- b is the cutting width, m;
- t is the cutting depth, m;
- χ is the plan approach angle of the cutting tool.

The heated zone is cutby the cutting tooland then drivenaway. The roughedsurface remains at a lower temperature as compared to that of the cutting area.

The plasma generator 1, from Figure 1, is placed at a distanceL from the cutting tool 4. The roughing speed of the cylender is v.

2.2 Temperature distribution of cylinder

An orthogonal coordinatesystem Oxyz is attached tothe cutting area of thecylinder for Diesel motors, as in Figure 1.

The sense of rotation of the workpiece is chosen to ensure that the heated zone reaches on the shortest way the edge of the cutting tool. Consequently, the positive sense of the Ox axis is opposed to the velocity vector in the origin of the Oxyz coordinate system (fig. 1).

Taking into consideration that the plasma arc is a concentrated energy source having a cylindrical form the relation for the temperature in the cutting area results as follows[2,3]:

$$T(x,y,z)|_{x=-L} = \frac{0.16 \cdot P \cdot \eta}{\lambda \cdot L} \sqrt{\frac{a_o}{a_o + K_1}} \cdot$$
$$\cdot exp(-10^4 \cdot K_1 \cdot y^{2)} \cdot$$
$$\cdot exp(-\frac{10^4 \cdot a_0 \cdot K_1 \cdot z^2}{a_0 + K_1}) \qquad (2)$$

where:

- $T(x,y,z)|_{x=-L}$ is the temperature in the coordinate point $(-L,y,z)$ situated on the cutting tool edge, K;

-P is the power in the plasma arc, W;

-η is the plasma heating efficiency of the cylinder;

-L is the distance between the plasma generator and the cutting tool, measured on the circumference of the cylinder, m;

-a_0 is the confinement coefficient of the plasma arc, m^{-2}.

The confinement coefficient of the argon plasma arc is determined by means of the relation[2,3] ·

$$a_0 = \frac{3 \cdot 10^{-4}}{r^2} \tag{3}$$

where r is the anodic spot radius, m.

K_1 from the relation (2) is, expressed by means of the relation[2,3]

$$K_1 = \frac{25 \cdot 10^{-6} \cdot v}{\omega \cdot L} \tag{4}$$

where:

- v is the cutting speed, $m \cdot s^{-1}$;
- ω is the thermal diffusivity of the shell on the marginal surfaces of the cylinder, $m^2 \cdot s^{-1}$;

Taking into consideration the case in Figure 1 (x = -L and z = 0), the relation (2) becomes:

$$T(x,y)|_{x=-L} = \frac{0.16 \cdot P \cdot \eta}{\lambda \cdot L} \sqrt{\frac{a_o}{a_o + K_1}} \cdot \cdot exp(-10^4 \cdot K_1 \cdot y^{2)} \tag{5}$$

The values of radius r of the anode spot was experimantally determined. The used procedure is described in the paper[4].

For different values of P in the plasma arc of $10 \cdot 10^3$W; $16.5 \cdot 10^3$ W and $20 \cdot 10^3$W, the average value of the anode spot radius is $r = 4 \cdot 10^{-3}$ m.

The research work for the temperature distribution in the cutting area is performed by using the relation (5).

The mean experimental values of the thermophysical constants for the hard shell of the cylinders are as follows[1]:

- the softening temperature: $T_p = 873\ K \pm 10\%$,
- the mellting temperature: $T_t = 1573K \pm 10\%$,
- the thermal conductivity: $\lambda = 0,04 W\ m^{-1} \cdot K^{-1}$,
- the thermal diffusivity: $w = 25 \cdot 10^{-6}\ m^2 \cdot s^{-1}$.

2.3 Temperature distribution of cutting tool

During the roughing operation by limited heating by plasma arc the cutting tool gets warm. The temperature at a certain point on the cutting tool edge results from relation (5) multiplied by a β coefficient[2,3] i. e. :

$$T_S(x,y,z) = \beta \cdot T(x,y,z) \tag{6}$$

where :

-$T_S(x,y,z)$ is the temperature at a certain point on the cutting tool edge; K,

-$T(x,y,z)$ is the temperature at a point of the cutting edge, K.

The β coefficient takes into account the heat storages in the material. For the hard shell[1], β = 1.5.

The cutting tool wear when roughing by cutting with plasma arc limited heating is due to the non uniform distribution of the temperature along its cutting edge length[3].

To study the temperature distribution on the cutting tool edge the thermal uniformity coefficient μ is introduced. It is defined by means of the relation[1,3].

$$\mu = \frac{T_S(L,y,\frac{b}{2})}{T_S(L,y,O)} \tag{7}$$

where :

-$T_S(L,y,\frac{b}{2})$ is the temperature at a point situated at the end of the cutting tool edge, K;

-$T_S(L,y,O)$ is the temperature at a point situated in the middle of the cutting tool edge.

The relation (8) for coefficient of thermal uniformity results replacing the relation (5) in the experssion (7) and taking into account the expressions (3) and (4):

$$\mu = \exp\left[-\frac{3\,\upsilon \cdot b^2}{4(12\,\omega \cdot L + \upsilon \cdot r^2)}\right] \tag{8}$$

As the origin of the coordinate system Oxyz is chosen at a point corresponding to the half of the cutting width b, see Figure 1, there results

$$z = \pm\frac{b}{2} \tag{9}$$

Introducing the relation (9) in relation (8) there results the dependence of the thermal uniformity coefficient μ, on the z variable, i. e.:

$$\mu = exp\left(\frac{3z^2}{12\,\omega \cdot L + \upsilon \cdot r^2}\right) \tag{10}$$

3. EXPERIMENT

The experiments concerning the usual cold roughing by cutting of the shell from the marginal surfaces of the cylinder were compared to roughing by plasma arc limited heating.

The experimental installation which has been used is described in the paper[5]. A specialized plasma generator was developed in oredr to perform inside the cylinder the roughing by cutting through limited heating with plasma arc. Its description and technical characteristics are presented in paper[6]. The experimental tests are presented in Table 1.

I - the electric current intensity of the plasma arc;

U - the voltage of the plasma arc;

D - the argon flow rate;

v - the cutting speed;

S - the cutting tool feed rate;

t - the cutting depth;

L - the distance generator-cutting tool, meadured on the circumference of the Diesel motor cylinder;

d - the distance between the plasma generator nozzle and hard shell of the Diesel motor cylinder;

d_a - the diameter of the plasma generator nozzle.

The cutting tool used during the experiments has small plates, characterized by the following geometry:

-plan relief angle : $\alpha = 12^0$

-plan clearance angle : $\gamma = -6^0$

-plan approach angel : $\chi = 453^0$

-secondary approach angle : $\chi_1 = 45^0$

-inclination angle : $\chi' = -3^0$

-radius : $r' = 0.310^{-3} m$.

To avoid the heat storages inside the cylinder air should be blasted at a flow rate of 0. 2N $m^3 \cdot s^{-1}$.

The roughing by cutting of the shell from the

Table 1.

Nr. crt.	I (A)	U (V)	$10^{-3} \cdot D$ ($Nm^3 \cdot s^{-1}$)	V ($m^3 \cdot s^{-1}$)	$10^3 \cdot S$ ($m \cdot rev^{-1}$)	$10^{-3} \cdot t$ (m)	L (m)	$10^3 \cdot d$ (m)	$10^3 \cdot d_2$ (m)
1	250	60	1/3	2. 00	0. 38	4	0. 10	10-12	3. 5
2	260	60	1/3	2. 00	0. 5	4	0. 10	10-12	3. 5
3	275	60	1/3	2. 00	0. 6	4	0. 10	10-12	3. 5
4	300	60	1/3	2. 00	0. 7	4	0. 10	10-12	3. 5

marginal surfaces of the cylinder is performed when the cutting width has the value $b=6 \cdot 10^{-3} m$.

4. RESULTS AND DISCUSSION

Figure 2 shows the temperature distribution, T, in the cutting area for the depth y, in the Diesel motor cylinder wall.

For the power $P = 10 \cdot 10^3$ W in the plasma arc, the temperature on the cylinder surface (y= 0 m) is T = 1023 K, when the cutting speed is $v = 1.0 m \cdot s^{-1}$ and generator - cutting tool distance L = 0.10 m. When the cutting speed increases the temperature on the surface of the cylinder decreases. When the cutting speed is $v = 3m \cdot s^{-1}$ and the power is the same in the plasma arc $(P = 10 \cdot 10^3 W)$, (Figure 2 a), the temperature on the surface of the cylinder is T = 843 K.

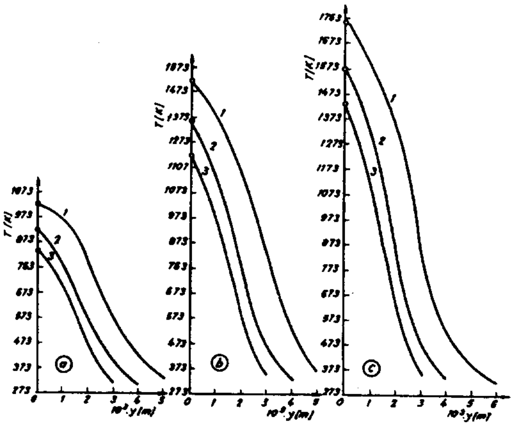

Fig. 2 The temperature distribution, T, in the cutting area for the depth, y, in Diesel motor cylinder wall

where :

-the power in the plasma arc : (a) $P = 10 \cdot 10^3 W$; (b) $P = 16.5 \cdot 10^3 W$; (c) $P = 20 \cdot 10^3 W$;

-the cutting speed : (1) $v = 1m \cdot s^{-1}$; (2) $v= 2m \cdot s^{-1}$; (3) $v = 3m \cdot s^{-1}$;

-the distance between the plasma generator and the cutting tool : L = 0.10 m;

-material : cast iron;

- o -experimental values.

The maximum temperature on the surface of the cylinder is 1773 K when the cutting speed is $v = 1m \cdot s^{-1}$ and the plasma generator-cutting tool distance is L=0.10 m as in Figure 2.

In the depth of the cylinder wall the temperature decreases exponentially to values up to 373K as in Figure 2.

The temperature in the cutting area decreases as the distance L between the plasma generator and the cutting tool increases, (see Figure 3).

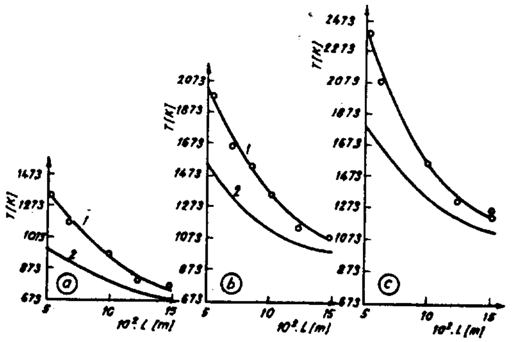

Fig. 3 The temperature distribution, T, in the cutting area, depending on the distance, L, between the plasma generator and the cutting tool

where :

the cutting speed : $v = 1 m \cdot s^{-1}$; depths in the cylinder wall : (1) y = 0 m; (2) $y = 1 \cdot 10^{-3}$ m; powers in the plasma arc : (a) $P = 10 \cdot 10^3 W$; (b) $P = 16.5 \cdot 10^3 W$; (c) $P = 20 \cdot 10^3 W$; material : the hard shell on the marginal surfaces of the Diesel motor cylinder o -experimental calues

If at the distance L = 0.05 m the temperature on the surface of the cylinder is T=1353 K for $P = 10 \cdot 10^3 W$ T=2043 K for $P = 16.5 \cdot 10^3 W$ and T=2373 K for $P = 20 \cdot 10^3 W$ then at a distance L = 0.15 m the temperature on the surface of the cylinder will become: T = 733 K for $P = 10 \cdot 10^3$ W, T = 1063 K for $P = 16.5 \cdot 10^3$ W and T=1233 K for $P = 20 \cdot 10^3$ W.

On the bases of the data from Figure 3 the temperature gradient module in the cylinder wall was calculed.

The calculed values are given in Table 2.

From Table 2 there can be observed that the temperature gradient module decreases when the distance L between the plasma generator and the cutting tool increases.

Having in view the thermophysical constants of the cylinder shell (the melting temperature T_t = $1573K \pm 10\%$; the softening the temperature T_s = $873K \pm 10\%$) there was used a cutting regime with limited heating by plasma arc corresponding to the curve 2 in Figure 2b.

The optimum area of roughing by cutting with plasma arc limited heating of the outside and respectively inside surfaces of the cylinder corresponds to the number 3 in Table 1.

When the electric current intensity is I = 275 Adc the cutting temperature, measured with an electric resistance pyrometer is T = $1273 \cdot K \pm 10\%$.

Table 2.

$10^{-3} \cdot P$ (W)	$10^{2} \cdot L$ (m)	$10^{-4} \cdot \Delta T/\Delta y$ ($K \cdot m^{-1}$)
10	5	36
	10	14
	15	4
16.5	5	50
	10	26
	15	8
20	5	60
	10	28
	15	12

where:
P - the power in plasma arc; L - the distance between the plasma generator and the cutting tool, measured on the circumference of the Diesel motor cylinder, $\Delta T/\Delta y$ - the temperature gradient module.

For electric current intensities $I > 275\ A_{dc}$, the cutting area exceeds the melting temperature of the shell and the cutting tool is thermally strongly affected.

The temperature at the roughed surfaces measured with an electric resistance pyrometer does not exceed 373 K.

The dependence of the thermal uniformity coefficient μ, along the length of the cutting tool (axis Oz, see Figure 1), is presented in Figure 4.

The temperature along the length of the cutting tool edge tends to become uniform for low values of the cutting speed, (see Figure 4A-curve 1). When the cutting speed is constant, (See Figure 4B), the temperature along the length of the cutting tool edge tends to turn uniform for high values of the distance L, between the plasma generator and the cutting tool (curve 6).

On the other hand, for the anode spot radius $\gamma = 4 \cdot 10^{-3}$ m, the temperature along the length of the cutting tool, on the cutting distance $b=4 \cdot 10^{-3}$ m is uniform (see Figure 4C-curve 8).

By increasing the value of the anode spot radius up to $r=5 \cdot 10^{-3}$ m, there results the thermal non-uniformiy of the cutting tool when the cutting width is $b=4 \cdot 10^{-3}$ m.

On the extremities of the cutting tool edge $(b=8 \cdot 10^{-3})$ m, the temperature has higher values (μ = 0.57) for the anode spot radius $r=5 \cdot 10^{-3}$ m (curve 9), as compared to the temperature in the same points of the cutting tool, but for the anode spot radius $r=4 \cdot 10^{-3}$m (curve 8).

According to the data presented in Figure 4B-curve 5, the thermal uniformity coefficient of the cutting tool is μ = 0.75. This leads to the conclusion that the wear of the cutting tool is reduced.

Table 3.

v_0 ($m \cdot s^{-1}$)	$10^3 \cdot S_0$ ($m \cdot rev^{-1}$)	$10^3 \cdot t_0$ (m)
1.33	0.22	3

where :
v_0 - the cutting speed;
S_0 - the cutting tool feed rate;
t_0 - the cutting depth.

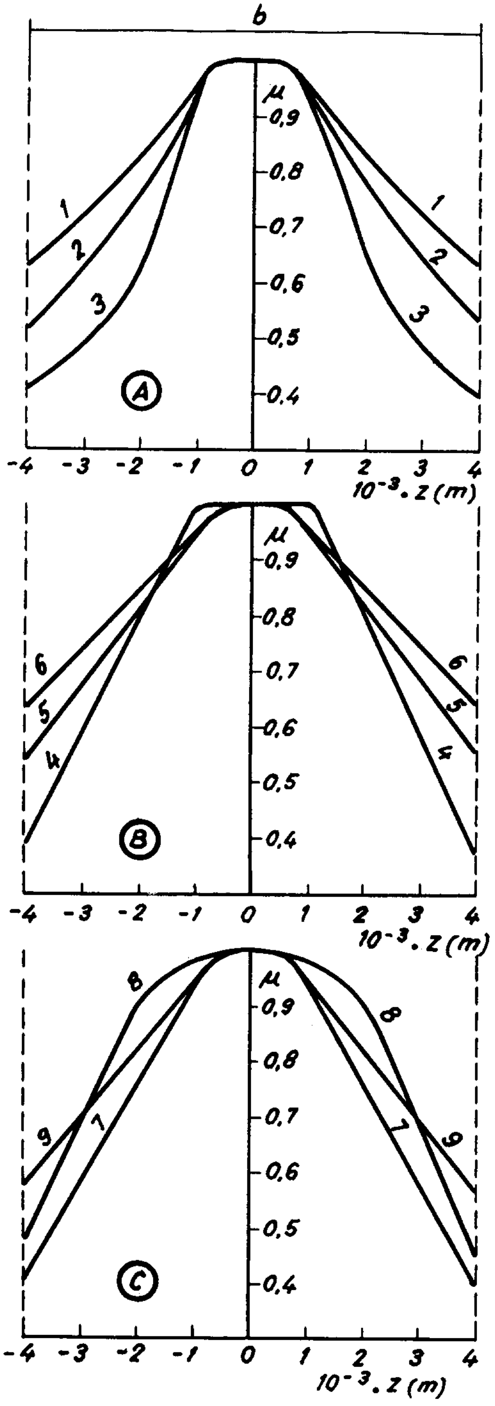

Fig. 4 The dependence of the non-dimensional magnitude μ on the z coordinate

case (A) :
-the cutting speed, (1) $v = 1m \cdot s^{-1}$; (2) $v = 2m \cdot s^{-1}$; (3) $v = 3m \cdot s^{-1}$;
-the distance between the plasma generator and the cutting tool : L= 0. 10 m
-the anode spot radius : $r = 4 \cdot 10^{-3}$ m.
case (B) :
-the cutting speed ; $v = 2m \cdot s^{-1}$
-the distance between the plasma generator and cutting tool :
(4) L= 0. 05 m; (5) L= 0. 10 m; (6) L = 0. 15 m.
-the anode spot radius $r = 4 \cdot 10^{-3}$ m.
case (C) :
-the cutting speed : $v = 2m \cdot s-1$
-the distance between the plasma generator and cutting tool : L = 0. 10 m
-the anode spot radius : (7) $r = 3 \cdot 10^{-3}m$;
(8) $r = 4 \cdot 10^{-3}m$; (9) $r = 5 \cdot 10^{-3}m$.
Observation: b is the cutting width, m.

The maximum cutting values used corresponding to roughing the cylinder without any heating are presented in Table 3.

The working life of the cutting tool having an average wear $VB_{av} = 0.8 \cdot 10^{-3}$ m is $t_0 = 15s$.

Indeed, by using the plasma limited heating cutting regime from Table 1 (number 3) it comes out that for the same average wear $VB_{av} = 0.8 \cdot 10^{-3}$ m, the working life of the cutting tool is $t = 165s$.

The Working life of the cutting tool has increased $t/t_0 = 11$ times when the plasma arc limited roughing was performed, as compared to the usual roughing of the shell from the marginal surfaces of the cylinder.

Using the roughing regime in Tabel 3 and respectively that in Table 1 (number 3) it follous that the specific discharge of chips is $\frac{v \cdot s \cdot t}{v_0 \cdot s_0 \cdot t_0} = 5.3$ times higher by roughing with plasma arc limited heating as compared to the usual roughing.

There have been noticed certain cylindricity deviations of not more than ±0. 55 10^{-3} m on the radius as a result of the plasma arc limited heating of the marginal surfaces of the Diesel motor cylinders.

As the processing by cutting for the final dimensions is commonly performed, these deviations are not significant.

5. CONCLUSIONS

1. For the cutting area, the temperature in the cutting area is of 1273 K ±10%. At depths of $y = 4 \cdot 10^{-3}$ m in the cylinder wall the temperature is up to 373 K.
2. The specific volume of chips increases 5.3 times when roughing by means of plasma arc limited heating as compared to the specific volume of chips when using the common roughing.
3. For the cutting area, the theoretical value of the ratio between the temperature at the cutting tool edge and the temperature at the half of the cutting tool is $\mu = 0.75$.
4. Correspondingly the working life of the cutting tool when roughing by means of the plasma arc limited heating increases 11 times as compared to the commonly used roughing.
5. The analytical model for roughing by cutting with limited heating with plasma arc of hard steel semiproducts gives satisfactory results also in the case of semiproducts with hard shell.

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