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RESEARCH ON DURABILITY OF HOBBING MILL MADE OF STEEL COVERED WITH TITANIUM NITRIDE DURING TEETH PROCESSING OF 32Cr10 GEARWHEELS

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Abstract *The complex tools made of alloy steel covered with hard layers are rarely used, mainly due to a lack of certain data for use. The instructions for use, given by the manufacturers of coating tools, are presented in the form of increased percentages of the durability of covered tools in comparison with those not covered, without indicating the cutting regimes values and areas of variation of process parameters which are valid for these increases in percentage of durability. These minuses make designers don't have certain data to enable them to establish the values of the cutting regimes parameters consistent with achieving the objectives. Lack of data often determine use of these tools to be avoided. The research carried out, presented in this article, have sought to establish data to help designers to use the covered mills in optimal conditions, in accordance with the proposed objectives.*

Keywords: durability, covered tools, covered mills

INTRODUCTION

Cutting tools with steel alloy covered with nitride titanium (TIN) is frequently used to complex tools, as is the case of mills creeper and more rarely simple tools, built, the carbide metal. Cover with layers tougher than steel base expected to increase the durability of mill covered over the bare, to processing. Research on coverage, as detached from the study bibliography, covered various aspects: thick layer of the best lodging, technology and means of filing; adherence layers, the coefficients of friction on surfaces with filing etc. On the use of tools such covered with layers and especially for complex tools, indications are, relatively, vague expressed in the form of increases in the percentage covered durability tools to those not covered, not to indicate what values are these parameters of chips and any areas for variation of process parameters that are valid for these increases in percentage of durability. These minuses make designers do not have certain data to enable them to establish the values of the parameters of splintering consistent with achieving the objectives. Lack of data makes often use these tools to be avoided.

The research carried out, presented in the article have sought to establish data to help designers to use mills covered in optimal conditions, in line with objectives.

PARTS PROCESSED

The experiments were done on pieces made of alloyed steel (32Cr10 STAS 11500/2-89), commonly used for manufacturing gearwheels for cars. The chemical analysis of the material part offered the values presented in Table 1.

Table 1. The chemical analysis of the material part

Elements		C	Si	Mn	Cr	Ni	S	P
The average values obtained from measurements, %		0,322	0,286	0,714	0,732	0,176	0,030	0,018
Values imposed by the standard	Min	0,29	0,15	0,60	0,05	-	0,02	-
	Max	0,35	0,40	0,90	1,15	0,30	0,04	0,03

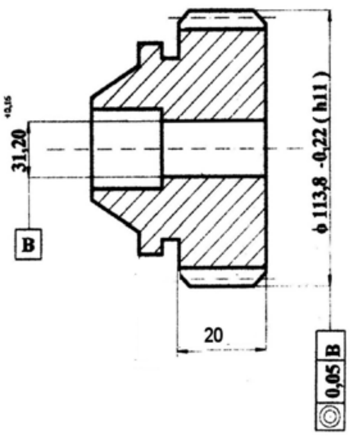

Fig. 1. The gearwheel

Table 2. The teeth parameters

No.	Parameter	Value
1	Number of teeth	42
2	Normal module	2,5
3	Normal pressure angle	22º
4	Nominal angle propeller on the division diameter	20º
5	Propeller direction	Left
6	Base diameter	104,196
7	Nominal division diameter	111,739
8	Propeller angle on the diameter base	18º44'50"
9	Interior diameter	$101^{+0,2}$
10	Exterior diameter	$113,8_{-0,22}$

The average values of the component are within the limits of the standard. The mean average is the result of five determinations. The experiments were done on the gearwheel presented in fig. 1 and the teeth parameters are presented in table 2. The hardness of the processed parts, obtained by five measurements on samples of each batch of parts are in range of 179 HB to187 HB. The average hardness is around the 183 HB.

HUBBING MILLS USED IN EXPERIMENTS

The experiments were done both with hubbing mills uncovered and covered with TIN. The uncovered hubbing mills used in experiments have been made from Rp3 steel (STAS 7382-88). The mills parameters are presented in Table 3.

Table 3. The mills parameters

1	Normal module	m_n	2,5
2	Number of teeth	z	16
3	Number of threads	n	3
4	Normal angle of the reference profile	α_{on}	22º
5	Inclination angle of the screw propeller	ω	6º16'4"
6	Propeller direction	-	Right
7	Mill teeth step in the normal section	p_n	23,4619
8	Mill teeth step in the axial direction	p_a	23,601
9	Departure angle at the top	γ	0°
10	Settlement angle at the top	α	10°
11	Exterior diameter	D	100
12	Mill's length	L	120

The mills were covered with nitride titanium (TiN), in an industrial process using vacuum of $5x10^5$ mbar, by a physical deposing process in computer-controlled atmosphere at 500°C. The deposing cycle consisted of: heating-one hour, maintaining at 500°C-one hour, cooling in the oven-one hour.
The processing were done on the FD 250-10 gearwheel milling machine, using the PIC (STAS 2800-85) sulphide oil for cooling and the advance in the opposite speed cutting for the milling process. There were performed measurements of the teeth roughness, both on clearance and settlement faces of the teeth, on a number of 30 teeth for all the mills used in the experiments. The results of the roughness on the settlement face data processing are presented in Table 4, and on the clearance face in Table 5.

Table 4. The roughness on the settlement face

Mill	Roughness average, Ra, (μm)	Squared average deviation, s, (μm)
Uncovered	0,2650	0,0120
Covered	0,1945	0,0083

Table 5. The roughness on the clearance face

Mill	Roughness average, Ra, (μm)	Squared average deviation, s, (μm)
Uncovered	0,3851	0,0189
Covered, unsharpened	0,2426	0,0064

It could be observed that the deposition roughness of the covered mills is 26% less compared to the uncovered mills. Also, the squared average deviation is 30% lower for covered mills compared to the uncovered mills. So, the coverage improved the roughness of the mills. Mills hardness was measured on the settlement faces of teeth in the top area of the teeth. The data processing offered the parameters presented in Table 6.

Table 6. The hardness mills on the settlement faces

Mill	The average hardness, HRC	The average squared deviation, sHRC
Uncovered	63,08	0,76
Covered	69,62	0,57

It notes a large increase of the hardness of the covered mill compared with the uncovered one, with approx. 6 HRC units, on the surface where occurs the mill wear. The thickness of the coverage layer was measured on several teeth on the left flank, top tooth and right flank. Data results from the measurements are presented in Table 7.

Table 7. The thickness of the coverage

Tooth	Layer thickness (μm)		
	Left flank	Top tooth	Right flank
1	2,5	2,6	2,4
2	3,2	3,4	3,0
3	2,9	3,0	2,8
4	3,3	3,5	3,2
Average	2,97	3,12	2,85

It found that the thickness of the coverage layer is slightly larger on the peaks teeth than those carried out on the side of the teeth. The thickness performed on the mill teeth is very close to those recommended for such layers, about 3 μm.

THE MODEL USED. THE EXPERIMENTS PLAN

For modeling the process, it was chosen as the output figure the mill durability for 0.15 mm wear on the settlement face. The input figures that varies during the cutting process were two figures that characterize the process: the advance expressed in mm/one rotation of the part and the cutting speed v expressed in m/min. The processing was done with successive movement of the mill after every two packages of processed parts. The parts were processed in packages of two, and the axial motion of the mill was of 1.58 mm. So, it has been made a relatively uniform wear throughout the mill length. In this way, the durability obtained for normal wear of 0.15 mm corresponds to the time the hobbing mill as a whole cuts the chip. This way of taking into consideration mill's durability is closer to mills' practical usage, when the interest is on the time the mill must be sharpened. The mill's axial movement was done on 50.5 mm length. The wear was measured on 20 teeth of mill to determine the average wear and the field values of the wear. In this way, the wear and durability determination offers more accurate results.

To determine the dependence of output figure, the mill's durability depending on the input parameters, it was chosen the following equation:

$$T = C.v^a.s^b \quad (1)$$

The equation can be made linear using logarithm, which allows to use an experiment plan on two levels. The plan used in experiments was a full factorial of 2^2 type, with the v speed and s advance as input figures, with repeat experiences for the core values, Table 8.

Table 8. The experiment plan

Experience no.	Speed v, m/min	Advance s, mm/rot
1	40,21	0,89
2	62,83	0,89
3	40,21	1,4
4	62,83	1,4
5	50,26	1,12
6	50,26	1,12

The variation areas for the two process parameters have been chosen in order to fulfill desiderates: in the field to be covered the values currently used in the gearwheel manufacture; at the maximum values of the process parameters to be achieved durability with significant value.

THE RESULTS OBTAINED IN EXPERIMENTS

The values of T durability, in minutes, obtained for mills used, corresponding to the plan implemented, are presented in Table 9 for the uncovered mill and in Table 10 for the covered mill.

Table 9. The values of T durability for the uncovered mill

Exp. No.	Variable Z1	Variable Z2	Durability T for the uncovered mill, in minutes, with VB of 0.15 mm	Yi=LGT, uncovered mill
1	-1	-1	598	2,7767
2	+1	-1	206	2,31386
3	-1	+1	214	2,33041
4	+1	+1	59	1,77035
5	0	0	168	2,2253
6	0	0	161	2,20682

Table 10. The values of T durability for the covered mill

Exp. No.	Variable Z1	Variable Z2	Durability T for the uncovered mill, in minutes, with VB of 0.15 mm	Yi=LGT, uncovered mill
1	-1	-1	1005	3,00217
2	+1	-1	422	2,62531
3	-1	+1	444	2,64738
4	+1	+1	129	2,11058
5	0	0	345	2,53781
6	0	0	355	2,55022

The wear obtained on the mill's teeth has relatively closed values, as presented in Table 11, which shows the wear for the uncovered mill on 15 teeth, the average and the squared average deviation of the wear.

Table 11. The wear on the mill's teeth

Tooth	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average	s
VB, mm	0,153	0,149	0,141	0,139	0,145	0,153	0,161	0,162	0,159	0,157	0,158	0,163	0,169	0,157	0,159	0,1562	0,01274

For a confidence level of 0.67, the wear is in the field of 0143 ... 0.169 mm.

DETERMINATION OF MILLS DURABILITY EQUATIONS

The linear form of equation (1) shall be obtained by logarithm process and its expression is:

$$\lg T = \lg C + a \lg v + b \lg s \qquad (2)$$

Using the following replacements: $\lg T = Y$; $\lg C = A_o$; $a = A_1$; $\lg v = X_1$; $b = A_2$; $\lg s = X_2$, it results:

$$Y = A_0 + A_1X_1 + A_2X \qquad (3)$$

The input variables, for each experience, have the values presented in Table 12.

Table 12. The input variables

Variable	Experience no.					
	1	2	3	4	5	6
$X_1 = \lg v$	1,604	1,798	1,604	1,798	1,701	1,701
$X_2 = \lg s$	-0,051	-0,051	0,146	0,146	0,049	0,049

The equation corresponding to normal variable is:

$$Y = B_o + B_1Z_1 + B_2Z_2 \qquad (4)$$

The relations between normal variables X and Z are:

$$Z_1 = \frac{2X_1 - (X_{1\max} + X_{1\min})}{X_{1\max} - X_{1\min}} = 10{,}31X_1 - 17{,}536 \qquad (5)$$

$$Z_2 = \frac{2X_2 - (X_{2\max} + X_{2\min})}{X_{2\max} - X_{2\min}} = 10{,}15X_2 - 0{,}482 \qquad (6)$$

THE UNCOVERED HOBBING MILL

The system of equations that offers the Bi coefficients, taking into account the six experiments done, is like:

$$\begin{bmatrix} 6 & 0 & 0 \\ 0 & \sum Z_{1i}^2 & 0 \\ 0 & 0 & \sum Z_{2i}^2 \end{bmatrix} \begin{bmatrix} B_0 \\ B_1 \\ B_2 \end{bmatrix} = \begin{bmatrix} \sum Y_i \\ \sum Z_{1i}Y_i \\ \sum Z_{2i}Y_i \end{bmatrix} = \begin{bmatrix} 6 & 0 & 0 \\ 0 & 4 & 0 \\ 0 & 0 & 4 \end{bmatrix} \begin{bmatrix} B_0 \\ B_1 \\ B_2 \end{bmatrix} = \begin{bmatrix} 5{,}427703 \\ -0{,}847277 \\ -0{,}813665 \end{bmatrix} \qquad (7)$$

Solving the system it results:

$$B_0 = 2{,}27063;\ B_1 = -0{,}2557;\ B_2 = -0{,}24857 \qquad (8)$$

The equation in the normalized variable is:

$$\lg T = Y = 2{,}2706 - 0{,}2557Z_1 - 0{,}24857Z_2 \qquad (9)$$

Replacing the expressions of Z1 and Z2 (equations (5) and (6)) in equation (9), we obtained the equation in natural variables:

$$Y= 6{,}87435 – 2{,}636\ X_1 – 2{,}522X_2 \quad (10)$$

Taking into account the substitutions made, it can be written:

$$lgT = 6{,}87435 – 2{,}636 \lg v – 2{,}522 \lg s$$
$$T = 10^{6{,}874} .V^{-2{,}636} .S^{-2{,}522} \quad (11)$$

Table 13 shows the values of the durability measured and calculated with the equation (11), and also the differences between these values.

Table 13. The values of the durability measured and calculated for the uncovered mill

Parameter	Experiment no.					
	1	2	3	4	5	6
Tmeasured	598	206	214	59	168	161
$T_{calculated}$	592	183	189	58,3	184	184
T_{max}- T_{calc}	+6	-23	-25	-0,7	+16	+23
T_{max}- T_{calc} %	1	11	11,7	1,2	9,5	14,3

As could be observed, the differences between the values measured and calculated with the equation (11) are in the limits of 1...14%.

The dispersion S_D^2 of the two experiments in center of variation field for the input parameters can be calculated with the following equation:

$$S_D^2 = \frac{SR_D}{V_D} = \frac{\sum_{i=1}^{n}(Y_{oi} - \overline{Y_o})^2}{n_c - 1} \quad (12)$$

with:

Yoi – the measured values for the experiments 5 and 6;

$\overline{Y_o}$ – the average of the two central values.

Replacing the data in equation (12), it results:

$$S_D^2 = 0{,}000175032 \quad (13)$$

THE COVERED HOBBING MILL

The equation of durability T of the covered mill is obtained by data processing following the same methodology as for the uncovered mill. The result is:

$$Y = 2{,}5788 – 0{,}22975Z_1 – 0{,}2174Z_2 \quad (14)$$
$$Y = 6{,}711– 2{,}367X_1 – 2{,}206X_2 \quad (15)$$
$$T = 10^{6{,}711} .V^{-2{,}367} .S^{-2{,}206} \quad (16)$$

Table 14 presents the values of the durability measured and calculated with equation (16), and the differences between these values.

Table 14. The values of the durability measured and calculated for the covered mill

Parameter	Experiment no.					
	1	2	3	4	5	6
Tmeasured	1005	422	444	129	345	355
Tcalculated	1056,9	371	389	135,5	376	376
T_{max}- T_{calc}	+51,9	-51	-55	+65	+31	+21
T_{max}- T_{calc} %	+5	-12	-12	+50	+9	+6

The dispersion of the core values is less than of the uncovered mill: S^2_D = 0,00002572.

CONCLUSIONS

Important conclusions can be obtained from the analysis of the equations in normal variables:

$Y = 2,5788 – 0,22975Z_1 – 0,2174Z_2$, for covered mill
$Y = 2,2706 – 0,2557Z_1 – 0,24857Z_2$, for uncovered mill

For the core values of the input parameters, the durability of the two mills are offered by the values of the constant coefficients of the two equations. Thus, for a covered mill, the resulting durability is 379 min, and for the uncovered mill bare is 187 min. So, the durability of the covered mill is two times greater than that of the uncovered mill. The proportion of increased durability rules also the values of the other input parameters, for the whole interval used in the experiments. The two input parameters influence in almost equal measure the mill durability. This remark is valid for both mills. The fact that the two coefficients of the variables for uncovered mill are greater than those of the covered mill shows that the faster the speed and advance, the durability falls earlier for the uncovered mill.
Figure 2a presents the variations of Y depending on Z2, considering Z1 with the central value and Figure 2b presents the variations of Y depending on Z1, considering Z2 with the central value. It could be noted on the graphics that the slopes for the covered mills are lower than those of the uncovered mills, this indicating a lower decrease of the durability for the covered mills during the increase of the two input parameters against the uncovered mills.
The linear equations in natural variables, obtained by data processing, are:

- for the covered mill:

$$Y= 6,711 – 2,367X_1 – 2,206X_2$$

or

$$lgT = 6,711 - 2,367 \lg v – 2,206\lg s$$

- for the uncovered mill:

$$Y= 6,87435 – 2,636 X_1 - 2,522X_2$$

or

$$lgT =6,87435 - 2,636 \lg v – 2,522\lg s$$

If it is considered that the uncovered mill works with v and s at the core values of 50.26 m/min, respectively 1.12 mm/rotation and the covered mill works with the same advance of 1.12 mm/rotation and that aim is to obtain the same durability at both mills, it results that for the covered mill the speed may be increased from 50.26 m/min to 68 m/min. The increase of the speed for the covered mill is about 36% over the uncovered mill.
If it is considered that the uncovered mill works with v and s at the core values of 50.26 m/min, respectively 1.12 mm/rotation and the covered mill works with the same advance of 1.12 mm/rotation and that aim is to obtain the same durability at both mills, it results that for the covered mill the advance may be increased from 1.12 mm/rotation to 1.36 mm/rotation. The increase of the advance for the covered mill is about 21% over the uncovered mill.
The obtained data show that for the covered mills is advantageous to pursue the preservation of the values of durability as for the uncovered mills. In this case, it could be obtained durability worth double for the covered mills compared with the uncovered mills.
If the aim is to obtain the same durability for both mills, it is more advantageous to increase speed and then advance.
The results obtained show that covering the hobbing mills is a solution that allow important increases of durability or, where appropriate, increase of the productivity of processing the gearwheels.

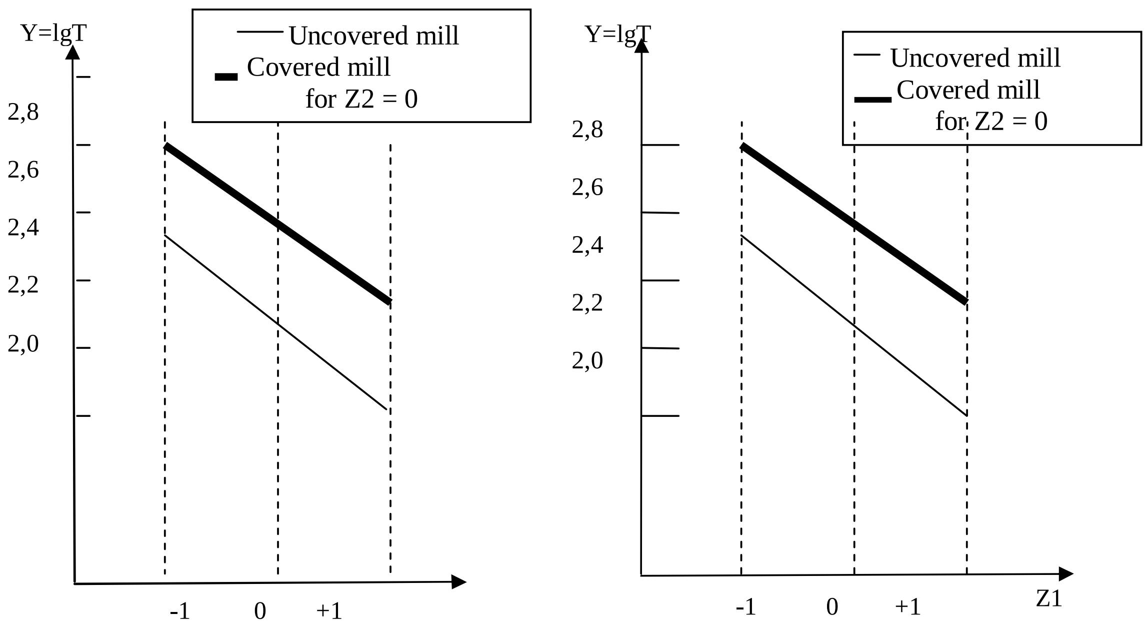

Fig. 2. The variations of Y depending on Z1 and Z2

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