HARD MILLING AND HARD DRILLING EXPERIMENT OF ABRASION RESISTANT STEEL HARDOX 500 AT DEPENDENCE OF T = f (v_c,f_z)

Jozef MAJERÍK[1] – Jaroslav JAMBOR[2]*

[1] *Ing. Jozef Majerík, PhD., Faculty of Special Technology, ADU of Trenčín, Pri Parku 19, 911 05 Trenčín*

[2] *Ing. Jaroslav Jambor, PhD., Alexander Dubček University of Trenčín, Študentská 2, 911 50, Trenčín*

*Corresponding author E-mail address: jozef.majerik@tnuni.sk

Abstract

Presented paper deal about the face milling and drilling process of the HARDOX 500 steel. Material abrasion resistance HARDOX 500 have to discharge very hard inquires against mechanical wearing. Manufacturing process of this material is result of various factors effect as are combination of high strength, stiffness and toughness. Materials that are heat-treated thermomechanical include but are not armoured plates and abrasion HARDOX. Are the product of Oxellösund SSAB (Sweden), and used for parts that are subjected to exploitation in the process of growing demand for abrasion resistance. Therefore used for the cup tablespoons loaders, excavators, parts of the stone crushers, the hull truck dumpers for conveyors, sprockets and other. HARDOX 500 are produced by hot rolling at 900 ÷ 920 º C with a reduction of 50 to 85% in the area of a stable austenite, and then to one minute sharply hardened in the water spray. They are rolled in thicknesses from 4 to 80 mm. Their chemical composition is indicative as follows: max 0.29% C, 0.70% Si, 1.60% Mn, 0.025% P, 0.010% S, 1.0% Cr, 0.50% Ni, 0.30% Mo, approximately 0.04% B. After quenching they followed by low temperature tempering at 200 to 300 º C. The structure of the material is low-temperature tempered martensite, with partial residual austenite. Achieved hardness ranges from 470 to 530 HBW, i.e. about 46 to 50 HRC. Can be classified into groups intricately hard machinable hardened steel. In the process of machining these materials operate in highly abrasive cutting tool.

Keywords: hard milling, hard drilling, abrasion resistance steel, HARDOX 500, tool wear.

1 Introduction

HARDOX 500 is the abrasion resistance steel verified the fundamental requirements for its hardness [2,4,5]. Its important facility against mechanical wear. Very important basic factors from its production process result from high hardness, stiffness and toughness combination. Termomechanical heat treatment causes improvement and increase os physical-mechanic properties. All these positive facilities predestinated HARDOX 500 for large spectrum of application. Machining of those materials with defined tool geometry, cutting wedge creates difficulties for high shear stress on the slip plane shear deformations in chips [1]. To hardness of 50 HRC can be used even tools HSS-Co, but with low productivity and low durability. In practice, the best certified cemented carbide (HW) without coating, or better with CVD and PVD coatings (HC). Fine-grained and ultra fine grain cemented carbide structure with grain size of 0.3÷0.5 μm increases the hardness and flexural strength, and thus the cutting tool properties [3,7,8,11]. Drilling can be used bits of high speed steel or cemented carbide drills [3,5,9] . Type used depends on the drilling machine tool, which is available as well as its stability [6]. Whatever type of drill is necessary to minimize vibration. Drilling can be used with HSS + Co (8%), with a large helix angle (10 º) and with the heavy heart that better withstand high torque. Experimental testing methods of HARDOX 500 face milling (Fig.4) were realized by PRAMET milling cutter with 8230 changeable inserts SNHF 1204EN-SR-M1 (Fig.6, 7) [2,10,12].

2 Experimental drilling test at T = f (v_c) dependence and results

In the process of the experiment was monitored dependence T = f (v_c) at a constant feed f = 0.03 mm = constant. Each test was conducted at five cutting speeds: n = 90 - 140 to 224 - 355 to 560 min^{-1}, v_c = 2,827 - 4.398 to 7.037 - 11.152 to 17.592 m.min^{-1}. Individual measurements were repeated 3 to 4 times what we got with the average value of life, which was used to construct a T = f (v_c) dependencies. The criterion of wear was determined as destroying a transverse cutting edge showing a screeching or whistling. Wear was measured with a magnifying glass workshop at a magnification of 10 x and the microscope MITUTOYO TM - 500 at a magnification of 30x. The size of wear on the cutting edge was measured only informative. Sharpening drill was carried out by hand in controlling the angle ε, the width of cutting edge width and transverse cutting edge. The

test results were reported in the tables and transferred to graph log T = log C_T - m. log v_c. Using the least-squares constants were calculated m and C_T.
Material: HARDOX 500 on the dimensions of 400 x 150 mm, h = 12 mm
Machine tool: tests will be performed on VR–2 radial drilling machine, P = 2, 25 kW.
Spindle speed: n = 90 – 140 – 224 – 355 – 450 – 560 – 710 – 900 – 1120 – 1800 – 2800 min^{-1}
Feed motion: f = 0,03 – 0,05 – 0,08 – 0,12 – 0,19 – 0,30 mm
Cutting tool: drill (Fig. 1) ø 10 mm HSS–HX with taper shank (STN 22 1140), Morse 1, λ_s = 10 º, 2ε = 130 º, (chemical composition analysis according to SPEKTROLAB-Jr-CCD
Workpiece clamping: in a vice, supported by washers.
Cutting fluid: drilling emulsion DASCOL 2500, 5% (ARAL) – see on Fig.3.
Drilling (see in Fig. 3) of abrasion resistant HARDOX 500 (h = 12mm), with ø10 mm drill HX (HSS+Co) by the constant feed motion f = 0,03 mm. Open drilling values are in Table 1.

Table 1 *Drilling values from test [5,9]*

No.	n	v_c	f	v_f	VB_{max}	pc	T (min)	øT
1	90	2,827	0,03	2,7	0,45	4	17,78	22,22
2					0,42	5	22,22	
3					0,5	5	22,22	
4					0,45	6	26,67	
1	140	4,398	0,03	4,2	0,5	10	28,57	28,56
2					0,45	9	25,7	
3					0,51	10	28,57	
4					0,47	11	31,4	
1	224	7,037	0,03	6,72	0,52	12	21,43	23,22
2					0,47	12	21,43	
3					0,48	15	26,8	
4					0,5	13	23,2	
1	355	11,152	0,03	10,65	0,49	7	7,9	6,76
2					0,51	5	5,63	
3					0,48	6	6,76	
1	560	17,592	0,03	16,8	0,48	3	2,14	2,14
2					0,5	4	2,86	
3					0,48	2	1,43	

Values obtained from Table 1 were processed to determine the constants C_T and "m" for the equation (see Table 2)

$$T = \frac{C_T}{v_c^m}$$

To calculate the constants C_T and exponent "m" I apply the method of least squares. Then:

$$\sum \log T_i = n.\log C_T - m.\sum \log v_{ci} \qquad (1)$$

$$\sum (\log T_i.\log v_{ci}) = \log C_T.\sum \log v_{ci} - m.\sum \log^2 v_{ci} \qquad (2)$$

solving equations, the equation for determining the "m":
Note: For the calculation we consider only the linear part of the dependency graph that is with points. ($n_{3,4,5}$) (see in Fig. 2).

Fig.1 *HSS-HX Drill ø10 mm with taper shank [5,9]*

***Table 2** Results of parameters[5,9]*

n	T_i	v_{ci}	$\log T_i$	$\log v_{ci}$	$\log T_i\ .\ \log v_{ci}$	$\log^2\ v_{ci}$
1	22,22	2,827	1,347	0,4513	0,6079	0,2037
2	28,56	4,398	1,456	0,643	0,9362	0,4134
3	23,22	7,037	1,366	0,8474	1,1575	0,718
4	6,76	11,152	0,83	1,047	0,869	1,0962
5	2,14	17,592	0,33	1,2453	0,411	1,55
$\sum$	82,9	43	5,329	4,234	3,9816	3,9813
$\sum n_{3,4,5}$	32,12	35,781	2,526	3,1397	2,4375	3,3642

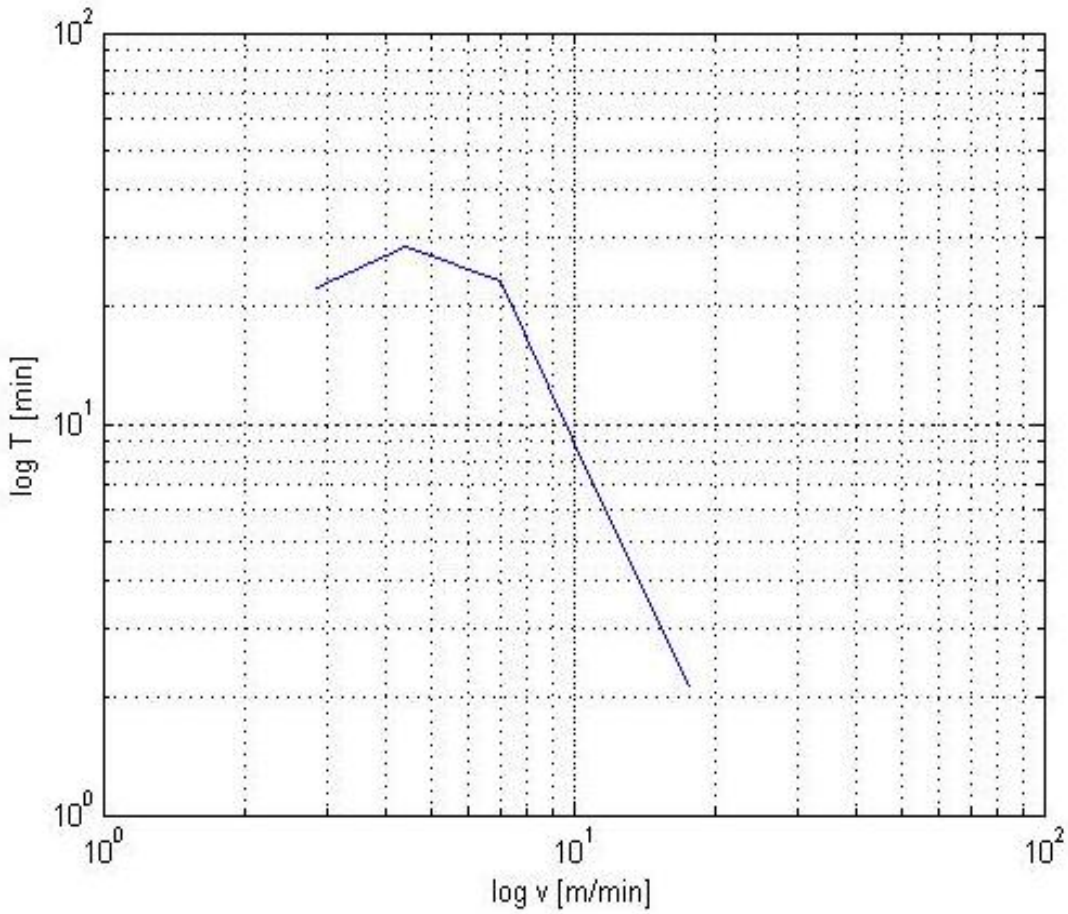


***Fig.2** Graphical dependence $T = f\,(v_c)$ at constant displacement 0.03 mm in two logarithmic coordinate system for the abrasion resistant sheet HARDOX 500 (h = 12 mm), with the drill ø10 mm HX (HSS + Co) STN 22 1140, the VR- 2 machine and cooling DASCOL 2500 (5%) [5,9]*

Note: n = 3 is the number of measurements of cutting speeds. Substituting from Table 1 into the equation for m we get:

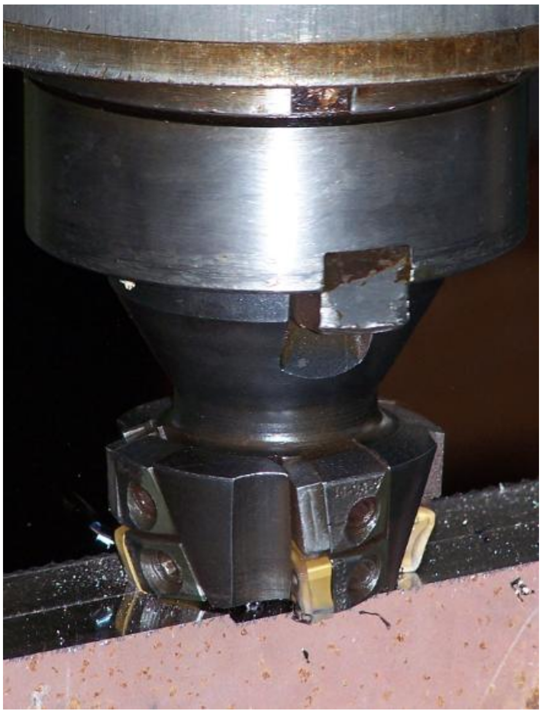
$$m = \frac{n.\sum(\log T_i . \log v_{ci}) - \sum \log T_i . \sum \log v_{ci}}{\left(\sum \log v_{ci}\right)^2 - n.\sum \log^2 . v_{ci}} \qquad (3)$$

$$m = \frac{3.2,4375 - 2,526 . 3,1397}{(3,1397)^2 - 3.3,3642} = 2,633 \qquad tg\alpha = 2,633 \Rightarrow \alpha = 69°12` \approx 70°$$

C_T constant we determine when we substitute the value "*m*" in equation (1):

$$\log C_T = \frac{\sum \log T_i + m.\sum \log v_{ci}}{3} \qquad \log C_T = \frac{2{,}526 + 2{,}633.3{,}1397}{3} = 3{,}5976 \quad C_T = 3{,}959132\ .10^3$$

***Obr. 3** Hard drilling of Hardox 500 [9]*



***Obr. 4** Hard face milling of Hardox 500 [2,10]*

3 Experimental face milling test at T = f (v_c) dependence and results

Material: HARDOX 500 abrasion resistance sheet
Dimensions: 20x150x705mm created by laser (TRUMATIC L3030 – STELLIT Ltd.Trencin)
Hardness: 46÷50 HRC
Chemical composition: 0,29% C; 0,70%Si; 1,6%Mn; 1,0%Cr; 0,5%Ni; 0,3%Mo; 0,004%B; 0,025%P; 0,010%S
Manufacturing process: hot sheeting at 900 ÷ 920 degrees, then heat treatment in stabile austenite area, rapid hardening up to 1 min at water jet, low temperature annealing
Machine tool: FA3V vertical console milling machine, P = 45 kW
Cutting tool: NAREX milling cutter with changeable inserts, D = 50 mm, PN 222460.12, z = 4, K_r = 75 deg, rake angle γ = -7 deg, cutting clearance angle α = 7 deg, λ_s angle = - 4 deg (Fig. 4).
Changeable cutting insert: SNHF 1204ENSR-M1-8230 PRAMET TOOLS (see on Fig.2a,b)
Workpiece material clamping: two pieces of sheet clamped in double grippers on machine tool support for 150 mm highness
Milling parameters: for T = f (v_c) – where T is a function of cutting speed to Taylors ratio.
Constant parameters:
Depth of cut a_p = 2,0 mm
Width of cut $a_e = B$ = 40 mm
Allowed wear estimation VB_k = 0,2 mm
Revolution feed f_o = 0,224 mm
Feed motion pre tooth f_z = 0,056 mm
Without coolant
Changeable parameters:
Cutting speed v_{c1} = 55,7 m.min^{-1}
Spindle speed n_1 = 355 min^{-1}
Translation speed v_{f1} = 80 mm/min^{-1}
Cutting speed v_{c2} = 78,5 m.min^{-1}
Spindle speed n_2 = 500 min^{-1}
Translation speed v_{f2} = 112 mm.min^{-1}
Cutting speed v_{c3} = 111 m.min^{-1}

Spindle speed $n_3 = 710$ min^{-1}
Translation speed $v_{f3} = 160$ mm.min^{-1}
Time of milling process and reached cutting durability:
$t_{AS1} = 8{,}86$ min, $t_{AS2} = 6{,}29$ min, $t_{AS3} = 4{,}40$ min
$T_1 = 223$ min, $T_2 = 135$ min, $T_3 = 39{,}6$ min
Milling time estimation: directly from formula $t_{AS} = L / n.\, f_z .z$
The graphs of wearing depending up of time you can see on (Fig.5a,b,c), where a) $v_{c1} = 55{,}7$ m.min^{-1}, b) $v_{c2} = 78{,}5$ m.min^{-1}, c) $v_{c3} = 111$ m.min^{-1}.
Sequential relation $T = f(v_c)$ acquired from graphs and processed by square method is displayed in Fig. 9 in logarithmic axis system.
This acquired relation from cutting durability to cutting speed has the final form:

$$T = \frac{2{,}4.10^4}{v_c^{2,1}}$$

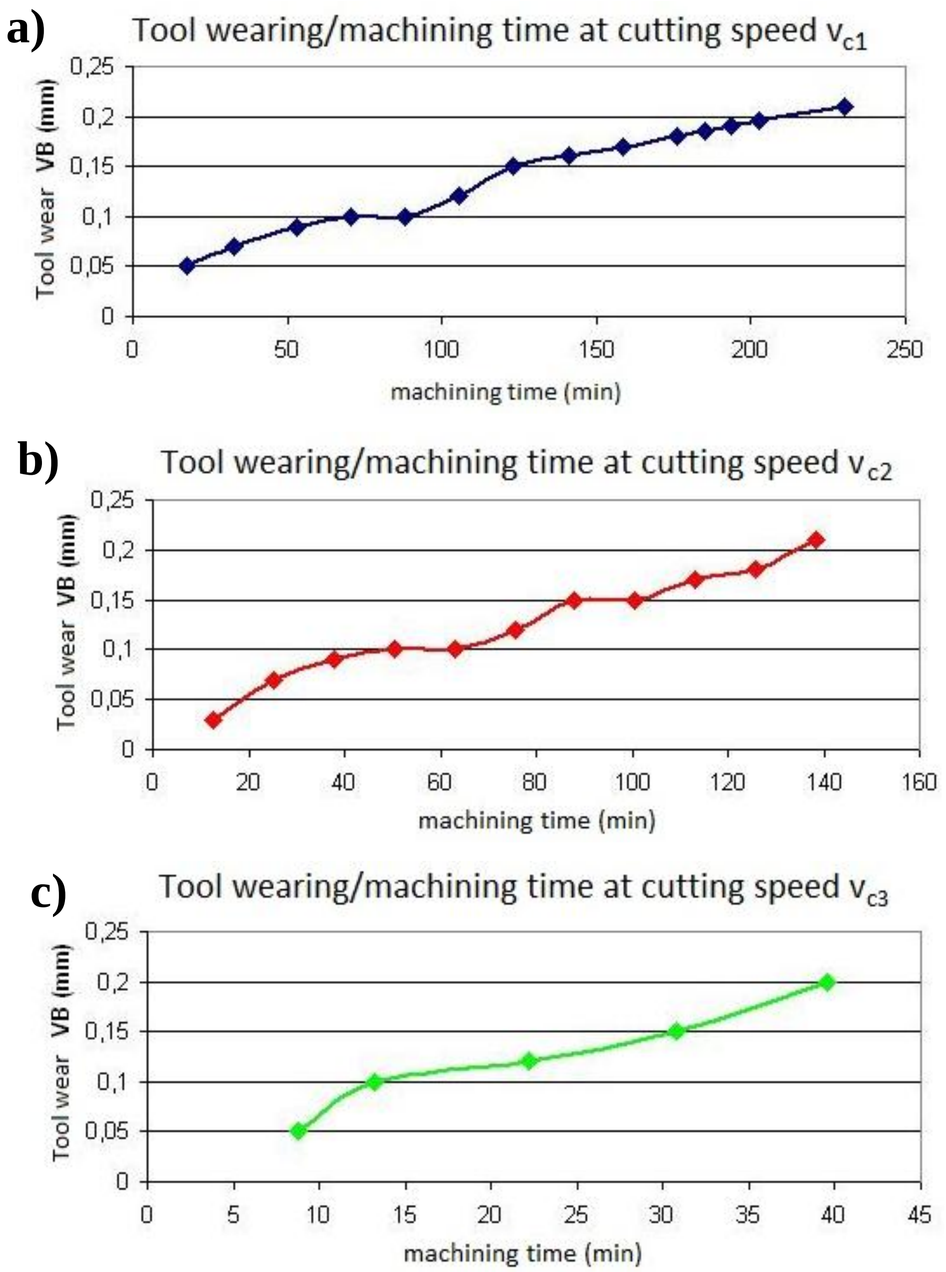
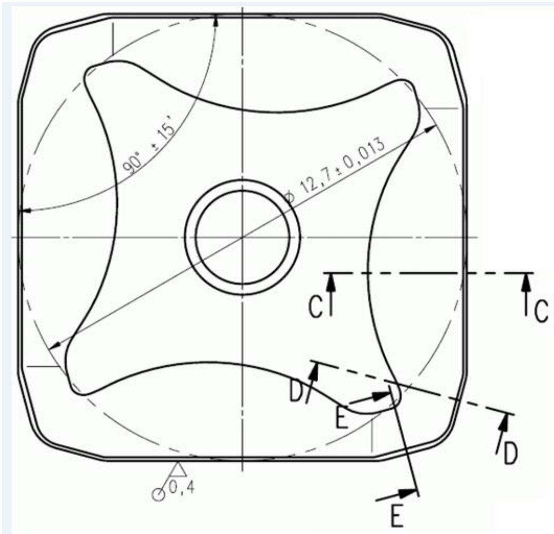


Fig.5a, b, c *Generated graphs at various cutting speed during hard face milling process[2,10]*

The face milling process with the same tool holder NAREX PN222460.12 with 4 inserts was realised by the PRAMET changeable inserts 8240 SNHF1204ENSR-M1 (Fig. 6, 7). Cutting conditions during milling were is the same as in the previous process. The overall results from measured cutting times, inserts durability but at various feed motions $f_{z1} = 0.039$ mm/tooth; $f_{z2} = 0{,}056$ mm/tooth; $f_{z3} = 0{,}078$ mm/tooth; $f_{z4} = 0{,}112$ mm/tooth; $f_{z5} =$

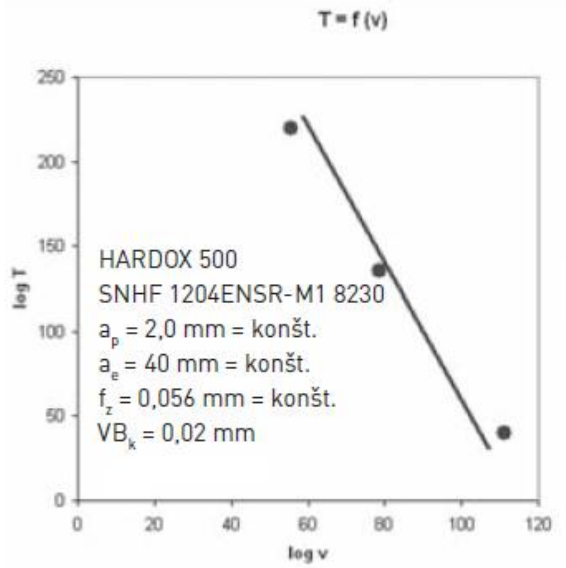
0,15 mm/tooth were graphically executed. Then from these measured values at constant revolutions n = 355/min were designated $T = f\,(f_z)$ by the square method to the final form: $T = C_T/\,f_z^{\,y}\,.T = 7{,}551/f_z^{\,0{,}99}$. Reached surface roughness was reached by the feed motion growth in the range from R_a = 0,6÷0,95 μm to R_a = 1,2÷1,6 μm. The auxiliary cutting edge was also worn to VB = 0,1 ÷ 0,12 mm. See on Fig. 8.

__Obr. 6__ An overview on carbide inserts[2,10]



__Obr. 7__ Tool carbide insert geometry of type SNHF[2,10]

__Obr. 8__ Tool carbide insert wear of SNHF[2,10]



__Obr. 9__ Graphical dependence of $T = f\,(v_c)$[2,10]

4 Conclusion

These experimental hard face milling process with PRAMET 8230 and 8240 show us that carbide insert 8230 has cutting durability T = 223 min whereas 8240 only T = 132 min, what is 68% more than with 8240. Both two types of coated cemented carbide inserts are desirable for hard machining technology application of HARDOX 500 with 46÷50 Rockwell hardness. 8240 is also desirable, but by lower cutting conditions. Face milling process is convenient without coolant in 8230 and 8240.

After realized tests to confirm the recommendations of the working drilling bit and the highest durability was achieved in the cutting speed of just under 5 m/min. With the increasing shift decreased the durability of the drill. During the process originated, as expected, a long helical cod. We also confirmed the requirement for high stiffness system Machine-Tool-Workpiece-Fixture, they were clearly significant differences in the vibrations of the machine depending on the distance from the carriage pole radial drills. After drilling approximately 50 to 70 holes there to wear a bit bevel gradually acquires a conical shape which caused considerable problems for the flow process. This problem was solved by shortening the bit about after 50 holes of about 7 mm. Other difficulties in happened a moment just before penetration of the drill bit through the material when there is an extreme wear transverse cutting edge and disturbing sound effects. This side effect was eliminated by inserting a steel plate below the drilled material. Results of drilling tests, and graphically processed by the method of least squares for the linear part of curves, confirmed the merits of using HSS+Co even if the wear resistant plate at a lower productivity than the HW drills but only to HRC = 50.

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