STUDY ON DURABILITY OF TUNGSTEN CARBIDE CUTTER HEADS

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ABSTRACT

Studies on the durability of tungsten carbide (TC) grooving and rebate cutter head and assessment of the quality of its sharpening have been conducted. The linear wear of the blade and the blunting radius when processing of massive coniferous wood and chipboard were studied. Recommendations were made regarding the preliminary preparation of the cutter heads and their effective operation.

Key words: cutter head, tool durability, tungsten carbide, linear wear, blunting radius.

INTRODUCTION

The milling processes are carried out under considerable forces and thermal loads of the tool, due to the special nature of the cutting kinematics and the inhomogeneous structure of the wood. A basic requirement for the material and geometry of the cutting tool is to obtain an edge with a small radius and retain it for a long period of operation. The cutting elements of the tool changes during wood processing. These changes are expressed in wear and dulling of edges. The working capacity of the cutting tool between two consecutive sharpenings determines its durability. This is the main criterion for evaluating the cutting properties of the material from which the teeth of the tool are made, as well as the quality of their preparation. (Gochev, 2005; Gochev, 2018; Zbieć, et al., 2008; Shuang-Xi and al. 2008; Biermann D and al. 2009; Rowe 2009).

The purpose of this article is to present some results of studies on the durability of grooving and rebate cutter head with tungsten carbide teeth. The linear wear of the cutting edges of these tools and the radius of their teeth were investigated. Basic concepts, criteria, and parameters have been formulated and a methodology for determining the durability of this type of cutter heads has been proposed. The formulated conclusions give a clear idea of the durability of these tools, and the recommendations will help to better use them in the process of their operation.

MATERIAL AND METHODS

A grooving cutter (Fig. 1A) and a rebate cutter (Fig. 1B) were used for experimental studies. The grooving cutter is used for making grooves with the grain direction in wood and various panel materials. The rebate is used cutter for rebating and grooving of solid wood and wood-based composite materials.

The basic parameters of the cutter heads manufactured by ZMM Ltd Smolyan - Bulgaria are shown in Table 1. The tool body is made of structural steel and the teeth are with brazed tungsten carbide tipped edges, type K40 and heat-treated to hardness HRC 89. (https://www.zmm-sm.com/zmmsm/english/wood.htm).

A B

Figure 1: Grooving Cutter for longitudinal cut (A); Rebate cutter (B)

Table 1: Basic parameters of the cutter heads

Catalog №	*D*, mm	*d*, mm	*B*, mm	*z*, бр	n_{max}, min^{-1}	β, ^{0}	Type
			Grooving Cutter for longitudinal cut				
WF 112-01-22	125	30	5	6	12 000	45	TCT – K20
			Rebate cutter				
WM 112-03-48	160	30	30	4	9 000	45	TCT – K20

The parameters in Table 1 correspond to:

D – Diameter of the cutter head;

d – Bore size;

B – Width of the knife;

z – Number of cutting blades;

β – Angle of sharpening;

TCT – Tungsten carbide teeth.

The TC edges type K40 (ISO grade classifications) consists of 92% tungsten carbide (WC) and 8% cobalt (Co) with a tungsten grain size of 1.0–2.0 μm (http://carbide.ultra-met.com/viewitems/iso-grades/iso-grade-classifications-tungsten-carbide).

The cutter heads are pre-sharpened with a PCD (polycrystalline diamond) abrasive wheels shape 12A2-45 (conical cup - CC) (Fig. 2, Table 2) (Gochev 2008; Gochev et al., 2019 and 2019).

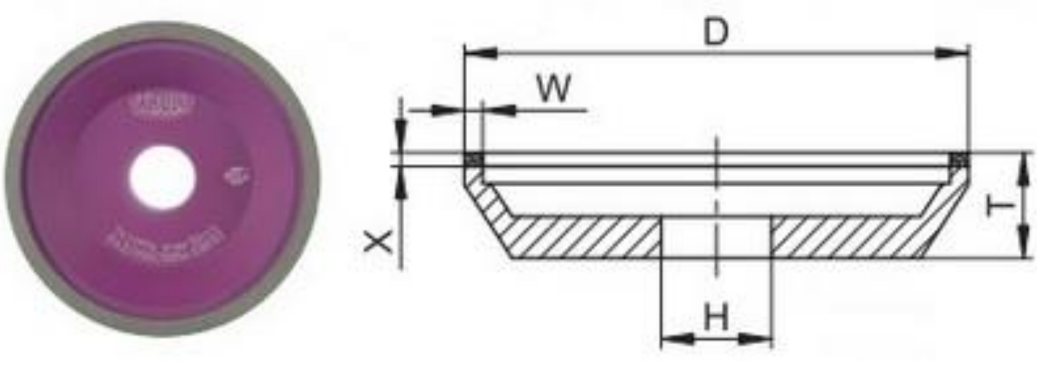

Figure 2: Abrasive grinding wheel shape 12A2-45

Table 2: Characteristics of experimental diamond abrasive wheels

Shape and dimensions	Abrasive type	Mesh Size	Bond Type	Concentration, %
12A2-45 125x5x3x32	SD (Synthetic Diamond)	125/100	B8/A	100
12A2-45 125x5x3x32	SD (Synthetic Diamond)	125/100	BM/A	100

The durability of TC tools is defined as the net wear time (T_w) and the cutting path length ($L_{c.p.}$). Teeth wear is characterized by the radius of rounding of the tooth edges (ρ), measured in three places, by the prints on the aluminum plates, after certain periods of operation – after 40; 200; 300; 500; 700 and 900 m, to a complete loss of cutting ability. The measurement was performed with a Reichert Visopan Projection Microscope - Austria.

For the purposes of the experimental studies, samples of white pine (*Pinus sylvestris*) with a density of 470 kg/m^3 and a moisture contents of 10% and particleboards with a density of 700 kg/m^3 and a moisture contents of 8% were used.

Except in hours, the durability of the tool can also be measured by the length of the cutting path ($L_{c.p.}$), passed by one tooth in the workpiece over the time between two consecutive sharpening, and is determined by the formula. (Gochev, 2018)

$$L_{c.p.} = l\ .\ n\ .\ T_{cl.t} = \frac{h.n.T_{cl.t}}{\sin\theta_{a.v.}} \qquad (1)$$

Where l is the chip length, m;

h – Cutting height, m;

n – Rotational frequency, s^{-1};

t – Milling time of one workpiece, s;

L_d – Length of workpiece, m;

$\Theta_{a.v}$ – Average value of the kinematic angle (the smaller of the angles between the vector of the cutting speed and the feed rate), ^{o};

$T_{cl.t}$ – Net milling time, s.

The total durability of the cutting tool ($T_{t.d.}$, s) is determined by the number of possible sharpening (n_{sh}) and the durability (net cut time) between two consecutive sharpening

$$T_{t.d.} = T_{cl.t.}.n_{sh.} \qquad (2)$$

Total durability can also be defined as the total length of the cutting path ($L_{t.c.p.}$)

$$L_{t.c.p} = L_{c.p}.n_{sh} \qquad (3)$$

The maximum number of sharpening (n_{sh}) is determined by the set excess (allowance) (A) and the permissible grinding width (B)

$$n_{sh} = \frac{B}{A} \qquad (4)$$

Using equations (1) to (4) for the total length of the cutting path, we obtain

$$L_{t.c.p} = \frac{h.n.T_{cl.t}B}{\mathrm{A}.\sin\theta_{a.v.}} \qquad (5)$$

RESULTS AND DISCUSSION

Chane of the blade radius

The obtained results for change of the blade radius when milling of solid wood (white pine) and particleboard are presented in Table 3, where:

ρ_{av} is the average radius of teeth blunting, µm;

t – Milling time of one workpiece, s;

L_d – Length of the workpiece, m;

T – Time of milling of all workpieces, s;

$L_{t.l}$ – Total length of the milled workpieces, m;

h – Thickness of the cut layer, m.

Based on the data in the table, charts have been drawn for the change in the average blunting radius (ρ_{av}) depending on the total length ($L_{t.l}$) of the milled workpieces (Fig. 3). Similar charts can be drawn for the milling time of all details (T). The graphs show the so-called *wear lines* determined by the criterion ρ.

The ratio between the section of the ordinate axis Δy and the section of the abscissa axis Δx for a given section of the wear line gives a value of the *intensity of wear* (J)

$$J = \frac{\Delta y}{\Delta x} = \tan\alpha \qquad (6)$$

The angle α is different at different points in the wear line, which is why formula (6) does not give a true idea of the wear intensity. More precisely if the wear intensity is defined as the wear rate by the first derivative of the wear path.

$$J = y' = \lim_{\Delta x \to 0} \frac{\Delta y}{\Delta x} \quad (7)$$

The resistance of cutting tools to wear is defined as wear resistance (Y). The relationship between J and Y is given by the dependence

$$J.Y = 1 \quad (8)$$

Table 3: Modification of ρ for solid wood milling and particleboard depending on T and $L_{t.l}$

Measurement number	ρ_{av}, µm	t, s	Workpieces, pcs.	L_d, m	T, s	$L_{t.l}$, m	h, m
Grooving cutter for longitudinal cutting of solid wood - WF 112-01-22							
1.	12	-	-	-	-	-	-
2.	22	6	50	1,16	300	58	0,012
3.	29,7	6	110	1,16	660	127	0,012
4.	35,5	6	210	1,16	1260	243	0,012
5.	43	6	300	1,16	1800	348	0,012
6.	48,5	6	500	1,16	3000	580	0,012
7.	61,5	6	705	1,16	4230	817	0,012
8.	92,5	6	912	1,16	5472	1057	0,012
Rebate cutter for rebating of solid wood - WM 112-03-48							
1.	14,5	-	-	-	-	-	-
2.	30	25	45	1,1	1125	49	0,02
3.	42,5	25	110	1,1	2750	121	0,02
4.	53,5	25	200	1,1	5000	220	0,02
5.	60,5	25	300	1,1	7500	330	0,02
6.	85,5	25	516	1,1	12900	567	0,02
Rebate cutter for rebating of Particleboard - WM 112-03-48							
1.	11,2	-	-	-	-	-	-
2.	26,2	3	110	0,5	330	55	0,012
3.	33,7	3	200	0,5	600	100	0,012
4.	46,2	3	470	0,5	1410	235	0,012
5.	53,7	3	620	0,5	1860	310	0,012
6.	62,5	3	1000	0,5	3000	500	0,012
7.	76,2	3	1800	0,5	5400	900	0,012
8.	93,7	3	2000	0,5	6000	1000	0,012

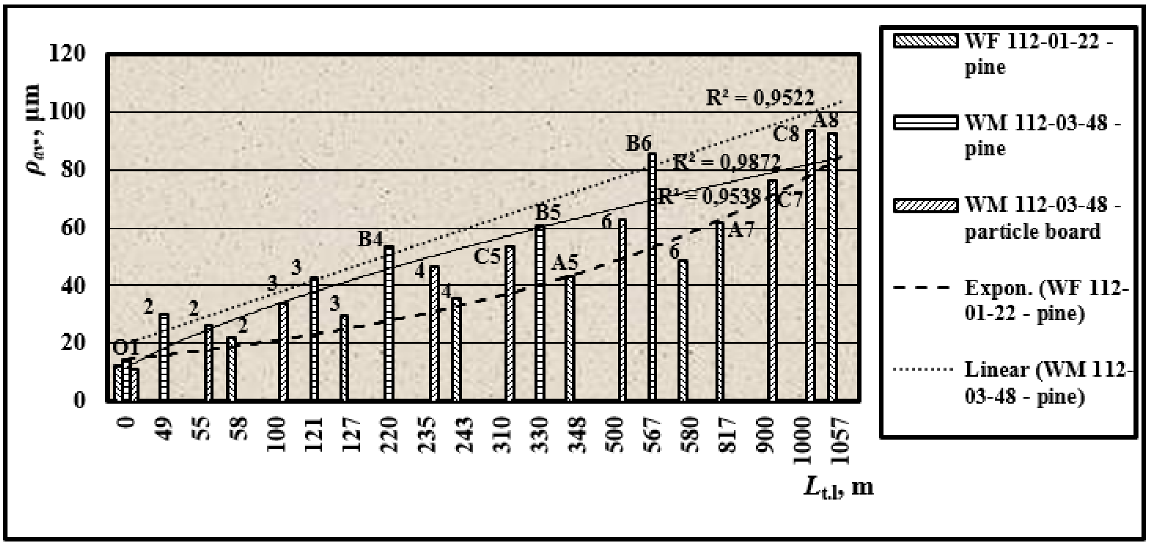

Figure 3: Change of ρ_{av} during milling of solid wood and particleboard depending on $L_{t.l}$

A. Grooving cutter for longitudinal cutting of solid wood – WF 112-01-22

Three zones can be separated from the resulting wear line (Fig. 3):

a) Initial wear zone O1-A5:

$$Y_2 = \tan\alpha_2 = \frac{22}{58} = 0{,}379;\; Y_3 = \tan\alpha_3 = \frac{29{,}7}{127} = 0{,}234;\; Y_4 = \tan\alpha_4 = \frac{35{,}5}{243} = 0{,}146$$

At the beginning of zone O1-A5, the wear intensity is high and gradually decreases towards the end. Rapid wear is the result of the extreme fragility of the sharpened at a small angle cutting edges, as well as the presence of micro-cracks from the sharpening.

b) Gradual wear zone A5-A7:

Tooth wear during this period is relatively large (43 μm) and accounts for about 47% of the limit wear. The wear intensity for points 2, 3 and 4 is:

This zone is of a monotonous and uniform character, with wear gradually increasing. It accounts for about 20% of limit wear. It is the result of complex mechanical, thermal and electrochemical processes. In this area, the blades of the cutter head are stabilized and have high resistance, which corresponds to their normal use. The wear intensity is low compared to O1-A5, gradually decreasing towards the end of the zone:

$$Y_5 = \tan\alpha_5 = \frac{43}{348} = 0{,}123;\; Y_6 = \tan\alpha_6 = \frac{48{,}5}{580} = 0{,}083;\; Y_7 = \tan\alpha_7 = \frac{61{,}5}{817} = 0{,}075$$

c) Rapid wear zone A7-A8:

Wear in this area is quite rapid, increasing suddenly, resulting in large roughing in the cutting edges of the teeth. The radius of the rounding of the teeth reaches its limit of 92,5 μm. It is not recommended to operate in this area as the teeth of the milling head are very blunt and this leads to a significant deterioration of the quality of the treated surfaces and an increase in the consumption of power consumed.

B. Rebate cutter for rebating of solid wood – WM 112-03-48

The initial radius of the cutter head teeth is 14,5 μm large. The wear line can also be divided into three zones: O1-B4 (initial zone); B4-B5 (gradual wear zone) and B5-B6 (rapid wear zone). The wear rate is accordingly for:

a) Initial zone O1-B4:

$$Y_2 = \tan\alpha_2 = \frac{30}{49} = 0{,}612;\; Y_3 = \tan\alpha_3 = \frac{42{,}5}{121} = 0{,}351;\; Y_4 = \tan\alpha_4 = \frac{53{,}5}{220} = 0{,}243$$

b) Gradual wear zone B4- B5:

$$Y_5 = \tan\alpha_5 = \frac{60{,}5}{330} = 0{,}183$$

c) Rapid wear zone B5-B6:

$$Y_6 = \tan\alpha_6 = \frac{85{,}5}{567} = 0{,}150$$

In the initial zone, wear is intense and accounts for about 50% of limit wear. In the second zone, the wear is normal and is about 23% of the limit wear. In the third zone, B5-B6 is very fast and the tool teeth reach a wear limit of 85,5 μm.

C. Rebate cutter for rebating of Particleboard – WM 112-03-48

When milling particleboards, the initial radius of the teeth of the cutter head is 11,2 μm. The wear line is separated into three zones: O1-C5 (initial zone); C5-C7 (gradual wear zone) and C7-C8 (rapid wear zone). The wear intensity is accordingly for:

a) Initial zone O1-C5:

$$Y_2 = \tan\alpha_2 = \frac{26,2}{55} = 0,476;\ Y_3 = \tan\alpha_3 = \frac{33,7}{100} = 0,337;\ Y_4 = \tan\alpha_4 = \frac{46,2}{235} = 0,196;$$

$$Y_5 = \tan\alpha_5 = \frac{53,7}{310} = 0,173$$

b) Gradual wear zone C5-C7:

$$Y_6 = \tan\alpha_6 = \frac{62,5}{500} = 0,125;\ Y_7 = \tan\alpha_7 = \frac{76,2}{900} = 0,084$$

c) Rapid wear zone C7-C8:

$$Y_8 = \tan\alpha_8 = \frac{93,7}{1000} = 0,093$$

In the third zone C7-C8, the wear is very intense, uneven along the cutting edge and reaches a limit of 83,7 μm.

Determining the length of the cutting path

Using formula (1), we can determine the length of the cutting path (*L*c.p.) when milling solid wood and particleboard (Table 4).

Table 4: Length of cutting path $L_{c.p.}$ when milling solid wood and particleboard

Measurement number	ρ_{av}, μm	T, s	n, min^{-1}	h, m	$\Theta_{a.v}$, °	$L_{c.p.}$, m
Grooving cutter for longitudinal cutting of solid wood - WF 112-01-22						
1.	12	-	-	-	-	-
2.	22	300	1600	0,012	18	310
3.	29,7	660	1600	0,012	18	681
4.	35,5	1260	1600	0,012	18	1301
5.	43	1800	1600	0,012	18	1858
6.	48,5	3000	1600	0,012	18	3097
7.	61,5	4230	1600	0,012	18	4367
8.	92,5	5472	1600	0,012	18	5649
Rebate cutter for rebating of solid wood - WM 112-03-48						
1.	14,5	-	-	-	-	-
2.	30	1125	1500	0,02	20	1644
3.	42,5	2750	1500	0,02	20	4020
4.	53,5	5000	1500	0,02	20	7310
5.	60,5	7500	1500	0,02	20	10965
6.	85,5	12900	1500	0,02	20	18860
Rebate cutter for rebating of Particleboard - WM 112-03-48						
1.	11,2	-	-	-	-	-
2.	26,2	330	1600	0,012	16	383
3.	33,7	600	1600	0,012	16	696
4.	46,2	1410	1600	0,012	16	1635
5.	53,7	1860	1600	0,012	16	2157
6.	62,5	3000	1600	0,012	16	3478
7.	76,2	5400	1600	0,012	16	6261
8.	93,7	6000	1600	0,012	16	6957

CONCLUSIONS

The following important conclusions and recommendations can be made on the basis of the studies conducted on the durability of a grooving cutter for longitudinal cutting of solid wood and rebate cutter for rebating of solid wood and particleboard:

1. The initial radius (ρ) of the teeth of the cutter heads is 12; 14.5 and 11,2 μm. These values are large. They should be within 4–6 μm, up to a maximum of 8 μm.

2. Precise sharpening is recommended, reducing the starting radius to the specified values (4–6 μm). The cutter heads will work better and have a longer working life.

3. Three zones of wear were identified in the analysis of the wear lines. In the first zone, wear is high, but it is inevitable. During the second period, wear is slow, gradual. It is appropriate to work in these two zones, i.e. use the tool until the end of the second zone and then sharpen it.

4. Based on the results of experimental research shown in Figure 3 it is recommended to work for:

- Grooving cutter for longitudinal cutting of solid wood up to 817 m milling length or 71 min pure milling time.
- Rebate cutter for rebating of solid wood up to 330 m milling length or 125 min pure milling time.
- Rebate cutter for rebating of particleboard up to 900 m milling length or 90 min pure milling time.

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