Influence of Technological Parameters on Tool Durability during Machining of Juvenile Wood

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This work examined differences encountered when machining juvenile wood *vs.* mature wood. Difference in the blunting of the cutting tool when processing types of juvenile and mature wood from pine (*Pinus sylvestris* L.) and poplar (*Populus tremula* L.) were studied. The experimental model process included milling at various feed (2.5 and 15 m·min^{-1}) and cutting speeds (pine 20 m·s^{-1}, poplar 30 and 60 m.s^{-1}), at various angle geometries (rake angle, cutting edge, and clearance angle). The blunting of cutting edge was measured after milling at 100, 300, and 500 meters on milling machine with the lower spindle. The results showed that milling of juvenile wood gives a longer technical lifetime for cutting instruments than milling of mature wood.

Keywords: Juvenile wood; Mature wood; Milling; Blunting of cutting edge

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INTRODUCTION

Most diffuse-porous wood produces juvenile wood that is only slightly different from mature wood. Fast-growing species may therefore be cut down in young years, even when nearly all the wood is juvenile, without significant loss of quality. Previously, juvenile wood was rarely used, but new processing technologies can exploit the diffuse-porous types of woods (Siklienka and Kminiak 2013).

Juvenile poplar wood is difficult to recognize visually. The amount of juvenile poplar wood may range between 28 and 45% (Buda *et al.* 1983). These values indicate a relatively large volume of juvenile wood.

In forestry conditions, the raw material contains a large share of juvenile wood obtained from the sorting spruce and pine monocultures. The second source of juvenile wood is the peak part of mature trees. Smaller sources of juvenile wood are residual rolls after peeling, which are further processed into sawmill intermediates, particularly sawmill goods (Thörngvist 1993; Gaff *et al*. 2015).

The action of uncut chips and workpiece on the cutting part of the tool causes blunting. The cutting material always comes into contact with a new clean metal surface. The friction of the surfaces acts at an angle as a result of the interaction between machining and cutting material, which leads to increased blunting surfaces on the tool. Linear dimensions of the wear of the cutting edge increase with time according to a regular pattern (Buda *et al*. 1983).

The use of juvenile wood is increasing due to technological developments and new and improved procedures. This work compares of results in experimental monitoring focused on the blunting of the machining tool (cutting edge) for machining juvenile woods of scots pine and aspen poplar. The study considered ranges of technological and technical parameters and parameters of the face milling tool (Lisičan 1988).

EXPERIMENTAL

Pine Processing

The Scots pine wood (*Pinus sylvestris* L.) originated from the area of Zubačková bučina, cadaster of the village Podzámčok bučina (School Forest Enterprise). The wood was grown at an altitude of 450 meter above sea level and harvested in autumn. Individual trees were limbed on the site of harvest, and cut-outs with the length of 5100 mm were created (Barcík *et al*. 2005; Čunderlík *et al*. 2006). They were subsequently transported to the laboratory in Zvolen. After cutting at the two plates with a radial cut and shortening the length to 1 m, the logs were dried and acclimatized to 12 ± 1% relative humidity (RH). All practical tests were conducted on an experimental device that was completed and installed in the development workshops and laboratories in Zvolen. The boards were milled on the milling machine with the lower spindle type FVS with a Frommia feeding device having a stepped change of feeding speed 2.5 and 15 $m \cdot min^{-1}$. The cutting speed was 20 $m \cdot s^{-1}$. The angle of the cutting edges was 55°, and the face angle - rake angle was 15°, 20°, 25°, or 30° (Fig. 1) (Javorek 1995). The blunting cutting edge of the tool was measured using a Hommel Tester T 6 (D) instrument (Slavia Tools, Detva, Slovakia). The wear of the cutting edge was examined after milling 100 m, for all conditions. The most commonly used rake angle 15° was examined on the blunting edge after milling 300 m and 500 m. The boards were milled in the area with juvenile and mature wood (Tables 2 and 3).

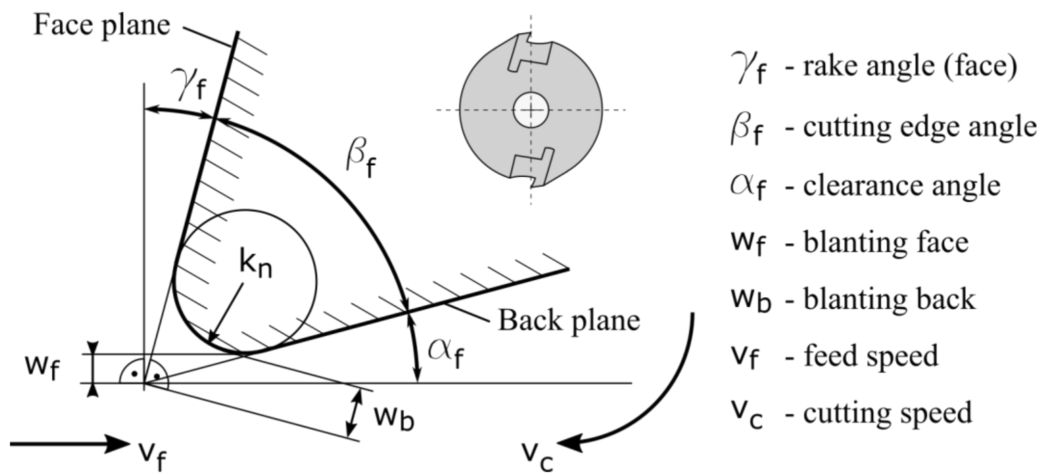


Fig. 1. Measurement blunting on the tools cutting edge

Poplar Processing

Aspen poplar (*Populus tremula* L.) logs were cut to 1 m long radial samples at 12 ± 1% RH after conditioning. Samples were milled on the milling machine with a feeder under technological parameters of v_f = 2.5 and 15 $m \cdot min^{-1}$ and v_c = 30 and 60 $m \cdot s^{-1}$ (Tables 5, 6 and 7, 8). The milling tool was a double knife disc mill with angular geometry of γ_f = 15° and β_f = 55°, with material removal of 1 mm. The parameters were chosen based on previous experiments as well as for their practical valuation (Barcík and Homola 2004).

The blunting of the cutting edge was measured using a Hommel Tester T 6 (D) instrument (in company Slavia Tools, Detva, Slovakia). The blunting of the cutting edge was examined after sharpening tools, *i.e.*, the absolute sharpest, and after milling 100 m, 300 m, and 500 m of wood. The boards were milled in the area of juvenile and mature wood.

Materials and Devices

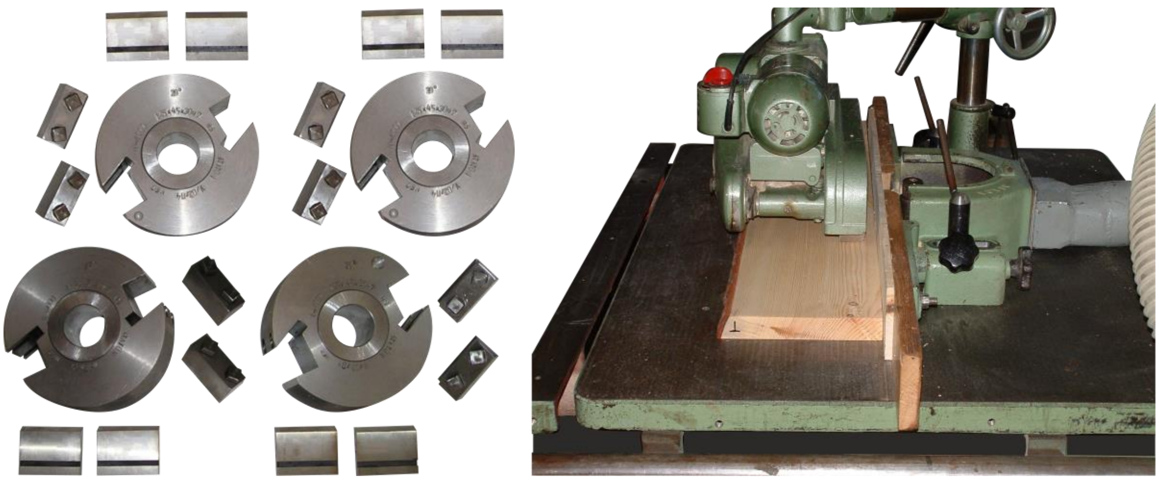
Before milling the density of pine wood and poplar wood were measured (Table 1).

Table 1. Measured Density of Pine Wood and Poplar Wood

Wood Density	**Measured values**			
Wood	Pine		Poplar	
	Juvenile	Mature	Juvenile	Mature
Density in absolutely dry state (kg·m^{-3})	460	530	349	380
Reduced density (kg·m^{-3})	403	470	313	338

Information about the used equipment

The equipment used for the study is diagrammed in Figs. 2 and 3.



(a) (b)

Fig. 2. (a) Cutter heads and blades, (b) milling machine with feeding device

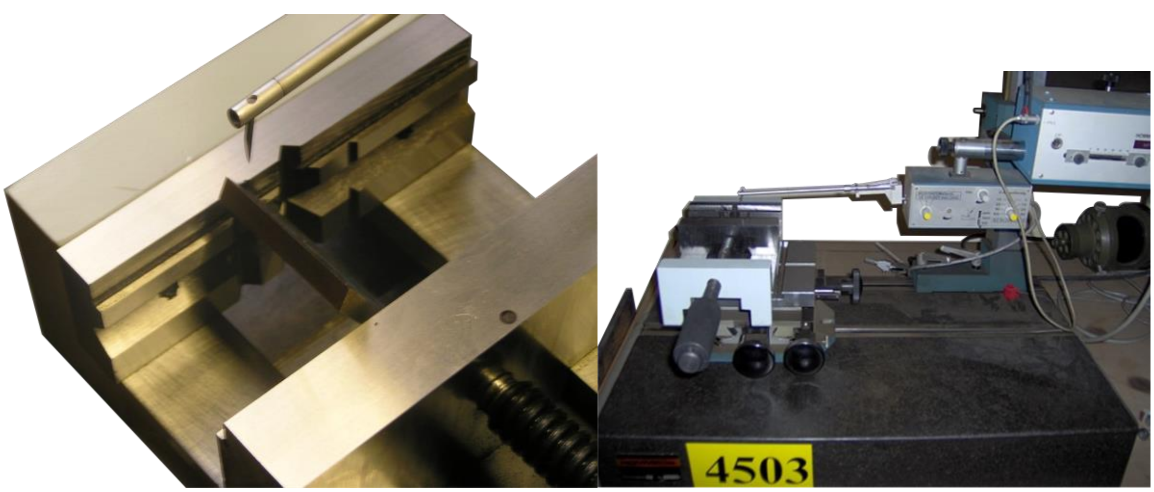


Fig. 3. Measurement blunting using a Hommel Tester T 6 (D)

The following parameters were used in the present work:

FVS machine with the lower spindle:	- cutting speed ($m \cdot s^{-1}$),	v_c = 20; 30; 40.
Feeding device Frommia:	- feed speed ($m \cdot min^{-1}$),	v_f = 2.5; 5; 15; 30.
Cutter head with tow cutting blades:	- diameter w/ blades (mm),	D = 130.
Angle geometry:	- rake angle (°),	γ_f = 15; 20; 25; 30,
	- cutting angle (°),	β_f = 55.
Tool material:	- Max. Special 55: 1985/5, hardness 64HRC.	
Measuring instrument:	- Hommel Tester T 6 (D).	

RESULTS AND DISCUSSION

Pine Wood

While maintaining the cutting edge at an angle of 55º, the increasing rake angle resulted in increased wear on the cutting edge (Tables 2 and 3). This can be due to higher friction of workpiece on the cutting tool when changing the clearance angle. During milling of the juvenile wood, there was less wear of the cutting wedge than when processing mature wood. This is due to the lower density of juvenile wood. The same volume has less wooden material, *i.e.*, there is less resistance for the same work. Another reason is the lower strength of juvenile wood. Juvenile wood exhibits lower strength in bending stress in frontal hardness and impact strength (Pugel *et al*. 2004), which impacts the cutting process. Thus, juvenile wood provides less mechanical resistance to penetration by cutting tools.

Table 2. The Size of Blunting Face, Back and Edge Radius of the Tool at the Feed Speed v_f of 2.5 $m \cdot min^{-1}$ and Cutting Speed v_c of 20 $m \cdot s^{-1}$

Pine Wood	Angle Geometry (°)	w_f (µm)	w_b (µm)	k_n (µm)
Juvenile	15/55	3.3	6	9.5
Juvenile	20/55	5	6.5	10
Juvenile	25/55	5.5	6.5	11
Juvenile	30/55	7.5	8	11
Mature	15/55	4.5	8	11
Mature	20/55	5	8.5	11
Mature	25/55	7	9	12
Mature	30/55	8	9	12

w_f, blunting face of the cutting tool; w_b, blunting back of the cutting tool; k_n, blunting edge radius of the cutting tool

Table 3. The Size of Blunting Face, Back and Edge Radius of the Tool at the Feed Speed v_f of 15 $m \cdot min^{-1}$ and Cutting Speed v_c of 20 $m \cdot s^{-1}$

Pine Wood	Angle Geometry (°)	w_f (µm)	w_b (µm)	k_n (µm)
Juvenile	15/55	3	5	6
Juvenile	20/55	4	6	7
Juvenile	25/55	5	6.5	10
Juvenile	30/55	6	7	10
Mature	15/55	3.5	6	7
Mature	20/55	4	7	7
Mature	25/55	5	7.5	11
Mature	30/55	7	7.5	12

w_f, blunting face of the cutting tool; w_b, blunting back; k_n, blunting edge radius of the cutting tool

During the process of blunting the cutting tool, the chemical composition of the workpiece can influence the extent of electrochemical corrosion (Oswald *et al*. 1997). The amount of extractives, mainly the amount of tannins, affects the electrochemical reaction of wood and tools (Makovíny *et al*. 1992). According to Solár *et al*. (2005), juvenile spruce wood contains a lower proportion of accompanying substances (1.90%) compared with mature wood (2.01%). While the accessory substances in juvenile pine wood were not measured, a similar reduction of extractives was expected. This reduced amount causes less wear of the cutting edge.

Table 4 shows the results when the cutting length was 0 m and at the designated absolute cutting edge (rake angle 15°). This result confirmed the hypothesis that the juvenile wood causes less dulling of the cutting wedge after milling 300 m and 500 m of wood. The reasons are similar to the detected blunting of the cutting edge after 100 m (Figs. 4, 5, and 6).

Table 4. The Size of Blunting Face, Back and Edge Radius of the Tool at the Feed Speed v_f of 2.5 m·min^{-1} and Cutting Speed v_c of 20 m·s^{-1}

Pine Wood	Cutting Length (m)	w_f (μm)	w_b (μm)	k_n (μm)
Juvenile	0	2	4	8
Juvenile	100	3.3	6	10
Juvenile	300	6	10	11
Juvenile	500	8	12	13
Mature	0	2	4	8
Mature	100	4.5	8	11
Mature	300	7	12	12
Mature	500	10	14	14

w_f, blunting face of the cutting tool; w_b, blunting back of the cutting tool; k_n, blunting edge radius of the cutting tool

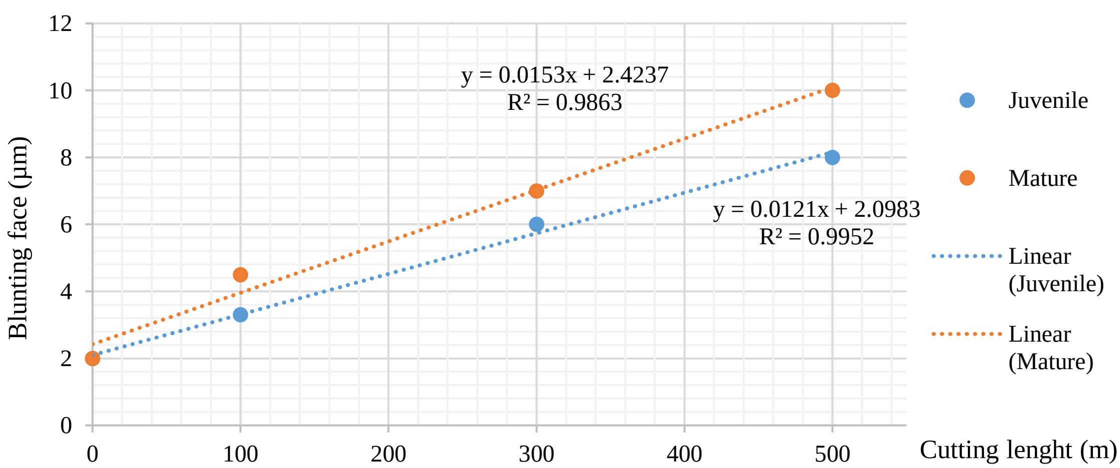


Fig. 4. Graph of blunting face of cutting tool at feed speed v_f of 2.5 m·min^{-1} and cutting speed v_c of 20 m·s^{-1}

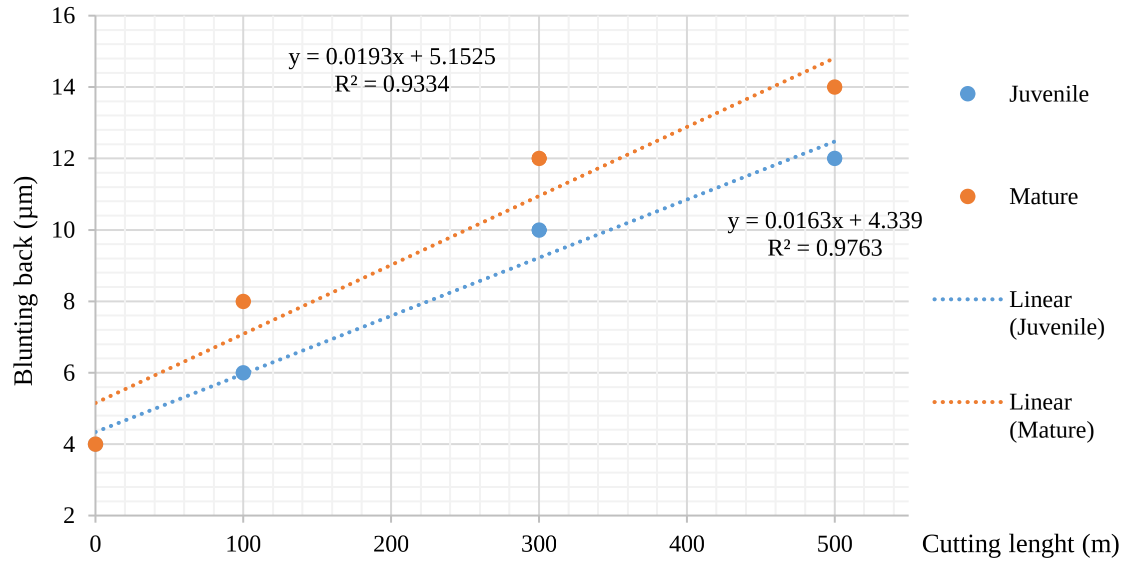


Fig. 5. Graph of blunting back of cutting tool at feed speed v_f of 2.5 m·min^{-1} and cutting speed v_c of 20 m·s^{-1}

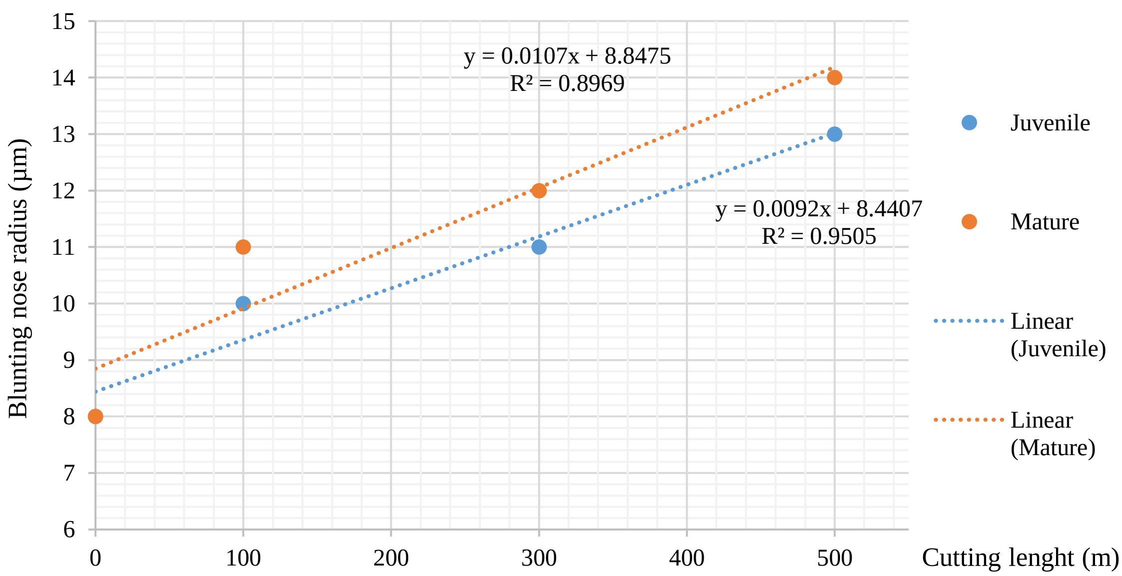


Fig. 6. Graph of blunting edge radius of cutting tool at feed speed v_f of 2.5 m·min^{-1} and cutting speed v_c of 20 m·s^{-1}

Poplar Wood

During milling of juvenile poplar wood, there was less blunting of the cutting edge than at processing of the mature wood, which was due to the lower density of juvenile wood. The same volume has less wood, *i.e.*, the softer wood demonstrates less resistance to processing. Unlike mature wood, juvenile wood has a greater proportion of spring wood and transition between spring and summer wood, and it is smoother and less noticeable. In areas of juvenile wood, summer woods are made of fibers similar to spring woods (*i.e.*, transverse fibers), which makes the juvenile wood “homogeneous” (Barcík *et al*. 2009). The smoother transition between spring and summer woods allows the tool at machining to have less stress and blunt. Other reasons can be seen in the lower strength characteristics of juvenile wood. Lower strength was demonstrated in bending stress in front hardness and impact strength, with decreases of modulus of elasticity bending strength, impact resistance, and front hardness of 24.5%, 25.9%, 54.7%, and 18.6%, respectively, for juvenile wood compared with mature wood. All these loads are part of the cutting process. Because juvenile wood shows lower mechanical properties of value, there is less resistance to penetration by the cutting tool (Zobel and Sprague 1998).

The measurement was confirmed the course of blunting, as described Buda *et al*. (1983). In the first phase of initial blunting, the rate of blunting was high in juvenile and mature wood. The causes must be sought in the peculiarities of friction during the cutting process. Cutting materials come into contact with new, clean wooden surfaces every time, while acting on each other at an angle. The interaction between workpiece and cutting materials increases the dimensions of surfaces on the tool (Buda *et al*. 1983). In the second phase, normal wear surfaces are adapted to each other. With increasing meters of milling, the progressive trend of blunting was stabilized (Table 5 - 8) (Fig. 7 - 12).

Table 5. The Size of Blunting Face, Back and Edge Radius of the Cutting Tool at the Feed Speed v_f of 2.5 m·min^{-1} and Cutting Speed v_c of 30 m·s^{-1}

Poplar Wood	Cutting Length (m)	w_f (μm)	w_b (μm)	k_n (μm)
Juvenile	0	50	55	30
Juvenile	100	52.5	70	45
Juvenile	300	55	70	45
Juvenile	500	65	80	50
Mature	0	50	55	30
Mature	100	55	70	40
Mature	300	57.5	80	45
Mature	500	70	85	57.5

w_f, blunting face of the cutting tool; w_b, blunting back of the cutting tool; k_n, blunting edge radius of the cutting tool

Table 6. The Size of Blunting Face, Back and Edge Radius of the Cutting Tool at the Feed Speed v_f of 2.5 m·min^{-1} and Cutting Speed v_c of 60 m·s^{-1}

Poplar Wood	Cutting Length (m)	w_f (μm)	w_b (μm)	k_n (μm)
Juvenile	0	50	55	30
Juvenile	100	60	70	45
Juvenile	300	62.5	75	45
Juvenile	500	70	85	50
Mature	0	50	55	30
Mature	100	65	70	45
Mature	300	70	80	50
Mature	500	80	90	50

w_f, blunting face of the cutting tool; w_b, blunting back of the cutting tool; k_n, blunting edge radius of the cutting tool

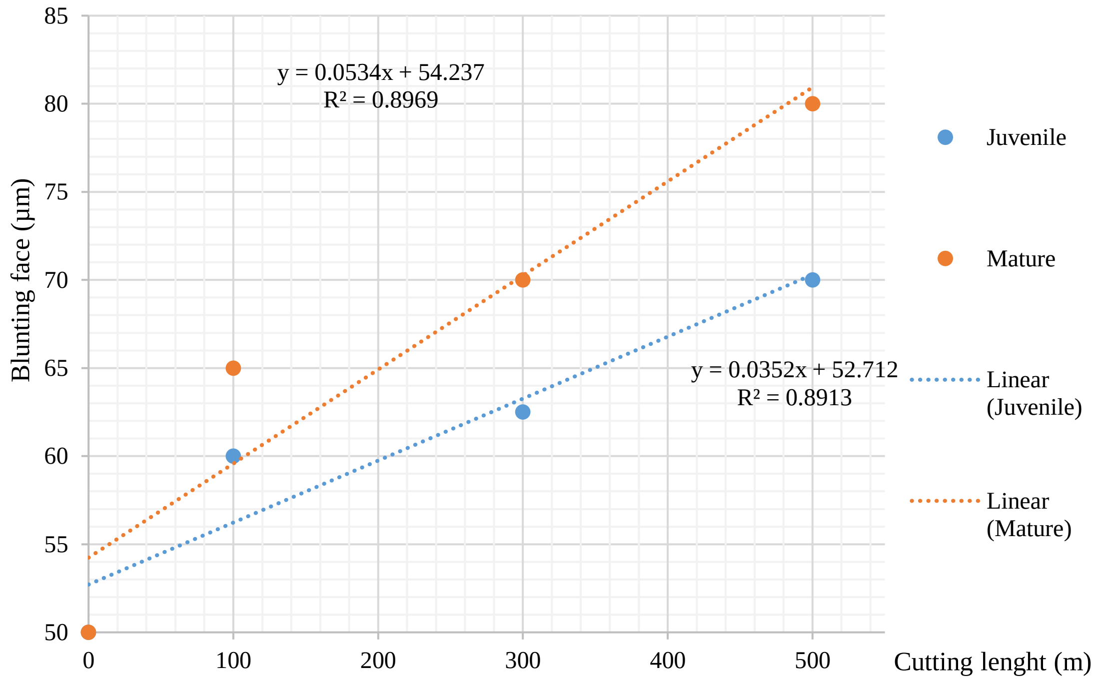


Fig. 7. Graph of blunting face of cutting tool at feed speed v_f of 2.5 m·min^{-1} and cutting speed v_c of 60 m·s^{-1}

Table 7. The Size of Blunting Face, Back and Edge Radius of the Cutting Tool at Feed Speed v_f of 15 m·min^{-1} and Cutting Speed v_c of 30 m·s^{-1}

Poplar Wood	Cutting Length (m)	w_f (µm)	w_b (µm)	k_n (µm)
Juvenile	0	50	55	30
Juvenile	100	75	100	55
Juvenile	300	80	110	65
Juvenile	500	80	130	80
Mature	0	50	55	30
Mature	100	125	160	72.5
Mature	300	160	170	75
Mature	500	145	175	80

w_f, blunting face of the cutting tool; w_b, blunting back of the cutting tool; k_n, blunting edge radius of the cutting tool

Table 8. The Size of Blunting Face, Back and Edge Radius of the Cutting Tool at Feed Speed v_f of 15 m·min^{-1} and Cutting Speed v_c of 60 m·s^{-1}

Poplar Wood	Cutting Length (m)	w_f (µm)	w_b (µm)	k_n (µm)
Juvenile	0	50	55	30
Juvenile	100	70	70	55
Juvenile	300	77.5	80	75
Juvenile	500	85	90	75
Mature	0	50	55	30
Mature	100	70	85	55
Mature	300	95	95	62.5
Mature	500	100	115	80

w_f, blunting face of the cutting tool; w_b, blunting back of the cutting tool; k_n, blunting edge radius of the cutting tool

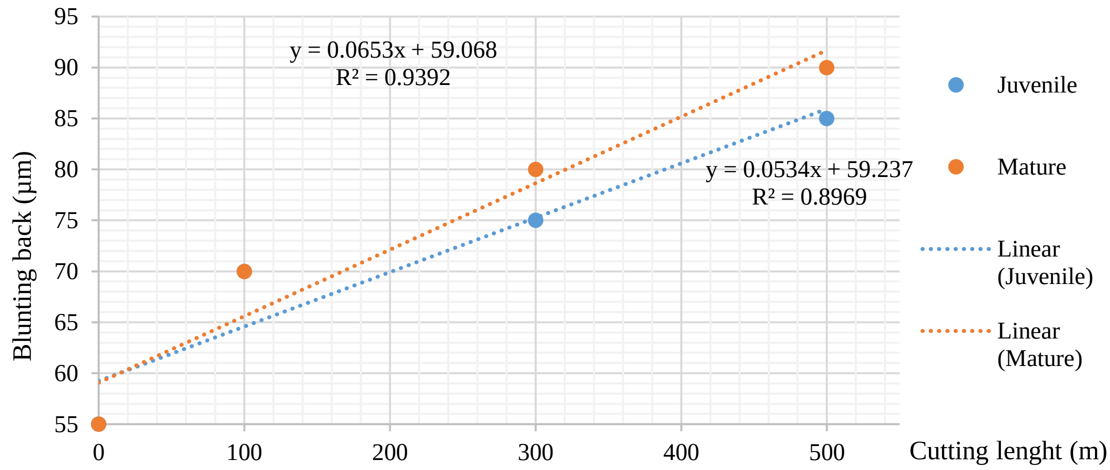


Fig. 8. Graph of blunting back of cutting tool at feed speed v_f of 2.5 m·min^{-1} and cutting speed v_c of 60 m·s^{-1}

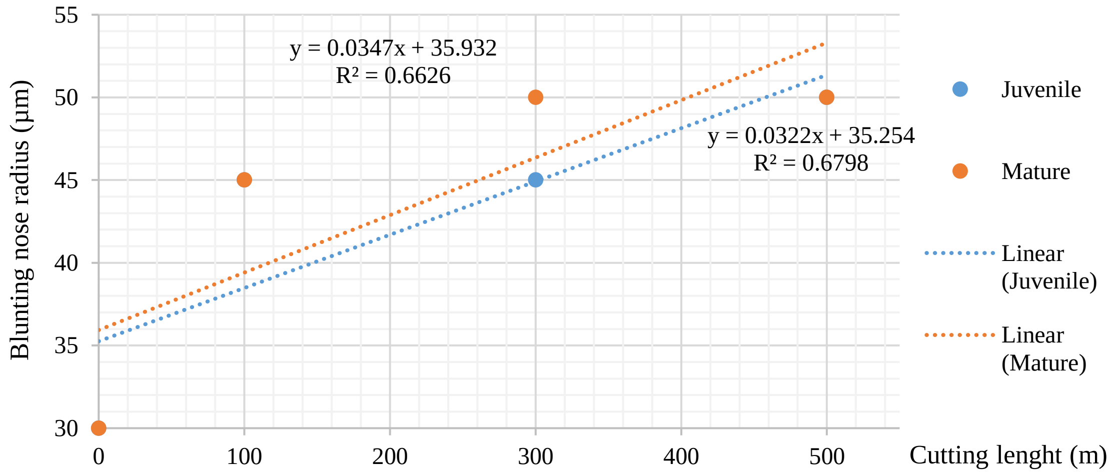


Fig. 9. Graph of blunting edge radius of cutting tool at feed speed v_f of 2.5 m·min^{-1} and cutting speed v_c of 60 m·s^{-1}

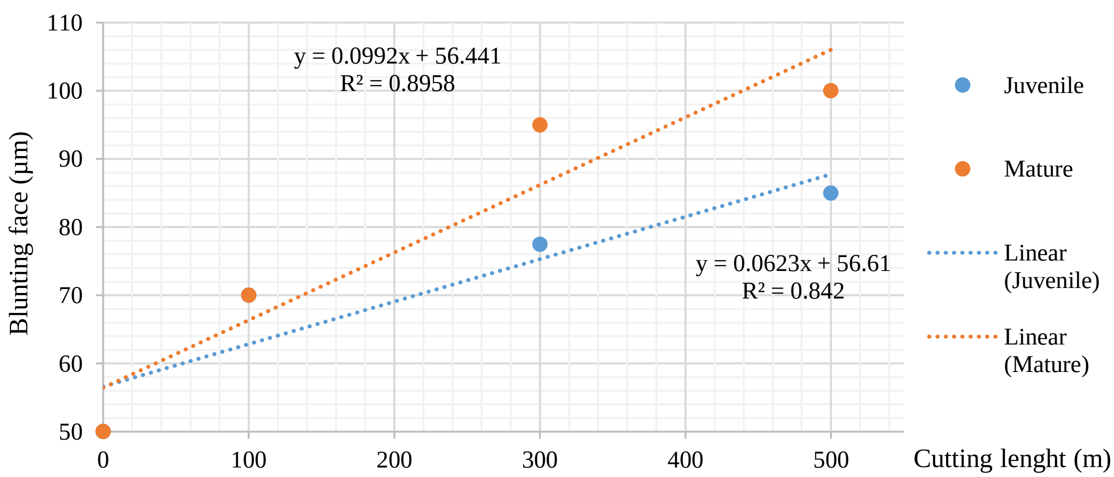


Fig. 10. Graph of blunting face of cutting tool at feed speed v_f of 15 m·min^{-1} and cutting speed v_c of 60 m·s^{-1}

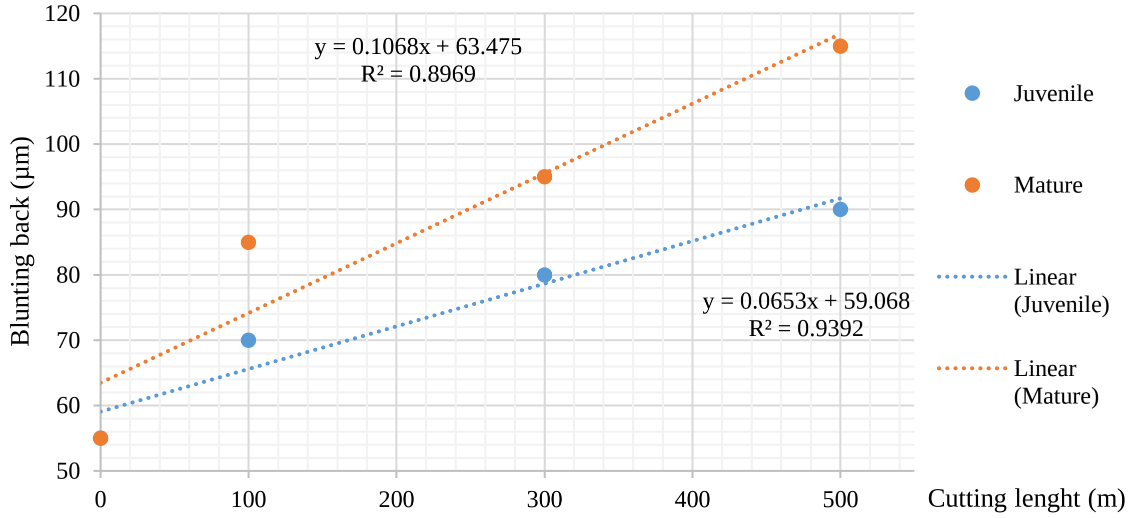


Fig. 11. Graph of blunting back of cutting tool at feed speed v_f of 15 m·min^{-1} and cutting speed v_c of 60 m·s^{-1}

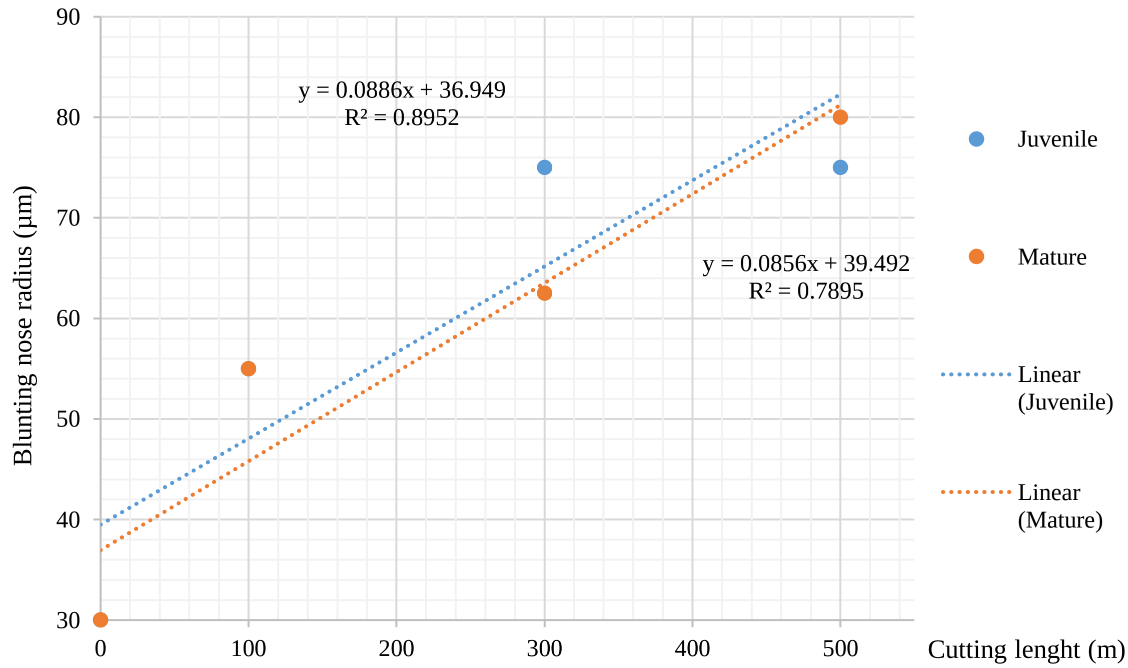


Fig. 12. Graph of blunting edge radius of cutting tool at feed speed v_f of 15 m·min^{-1} and cutting speed v_c of 60 m·s^{-1}

The measurement showed more blunting on the back than the face in juvenile wood and also in mature wood, due to the improperly chosen clearance angle. Blunting processes affected a number of factors and resulted in increasing wear on the cutting edge. One of the factors may be an impact of edge tool on a numbers of small knots, which are parts of juvenile wood. Another reason may be the direction of the wood fibers. In juvenile wood, fibers are not as parallel as in mature wood because they are remnants from when the tree was young and had a greater convergence of the strain. This created a noticeable difference in blunting for juvenile wood than mature wood.

CONCLUSIONS

1. Theoretical assumptions of less blunting of the cutting edge for face milling of juvenile wood was demonstrated across all monitored parameters. This can be attributed to different anatomical and chemical structures, as well as the lower physical- mechanical properties of juvenile wood.
2. Experimental observation was comprehensive for only part of the issue, for this does not constitute comprehensively solved issues that face milling of juvenile wood in realized conditions.
3. In general, underlying and accompanying materials available for the continuation of experiments aimed at monitoring other interaction process parameters face milling juvenile wood.

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