Influence of Processing Factors and Species of Wood on Granulometric Composition of Juvenile Poplar Wood Chips

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This article deals with the assessment of the influence of technical, processing, and material factors on selected mechanical properties and the granulometric composition of juvenile poplar wood chips. Individual analyses were made for two poplar species: naturally grown *Populus tremula* L. and the cultivated poplar clone *Populus* x *euramericana* “Serotina” for both juvenile and more mature wood. The main goal of this study was to evaluate the influence of the selected technical and processing parameters and of wood type (juvenile and more mature) on the chips’ granulometric composition during plane milling, its granulometric composition, and the sizes of the greatest and the smallest particles. Granulometric analysis (size test) was carried out to determine the share of the grain sizes for the individual wood fractions. While evaluating the granulometry, the influence of the milling process conditions as well as that of the wood’s physical and mechanical properties was taken into account.

Keywords: Granulometric analysis; Plane milling; Physical properties; Mechanical properties; Juvenile wood; Grain size

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INTRODUCTION

The importance of juvenile wood can be expected to grow in the future as its workability improves because of the development of saw mills and new and improved processes. Juvenile wood is generated during the first years of tree growth. This wood can be found around the medulla and in the branches. In practice, it is very important to take into account the differences in juvenile wood. An ever-growing importance of juvenile wood is expected in the future as its share in processing increases. Until recently, juvenile wood was deemed a low-quality material. However, research has found that for the manufacture of certain products, such as medium-density fiberboard (MDF), oriented strandboard (OSB), and bio-boards, juvenile wood is preferable (Sandak and Negri 2005).

Within the milling process, the size, shape, and amount of chips generated is important. These parameters depend on the wood’s physical and mechanical properties as well as on the milling process and technical conditions. No such detailed information is available in the specialized literature to characterize the properties of juvenile wood chips. Also, a comparison between juvenile and more mature wood as a function of specific conditions of the wood-cutting process is unavailable. This article deals with the issue of granulometric analysis of poplar wood chips (aspen and “Serotina”) generated from plane milling. In the wood-processing industry, the removal of chips from the point of their formation in the wood-cutting machine can be resolved by means of an air-conditioning system. As far as environmental criteria, this system can be adjusted to changes in the milled material and to changes in technical and processing conditions. Therefore, it is necessary to detail and specify the properties of the disintegrated wood mass generated under specific conditions.

Juvenile wood is defined as the wood generated during the first years of tree growth. The wood growing on a young tree or on an older tree around the medulla in the tree crown has a different annual increment structure and different shares of spring and summer woods in the given annual rings (Reinprecht and Vidholdová 2008). This fact is also reflected in the micro-, submicroscopic, and even chemical structure of the juvenile wood. Obviously, this affects the physical, mechanical, and other use-related properties of the wood (Čunderlík 2002). Generally, juvenile wood is defined by the number of annual rings around the medulla, where gradual changes in the wood's structure and properties take place. The older annual rings, or the section close to the outer margin, indicate the mature wood, or outer wood. The content of juvenile wood changes according to the wood species and also within individual trees of the same species. Its content depends on a combination of factors, the most important of which are the geographic location, soil quality, crown size, standpoint, individual position in the vegetation, and forest cultivation method. From a practical point of view, the content of juvenile wood is important within the processed wood and also in the semi-finished or final product (Požgaj *et al.* 1997).

The juvenile wood properties do not change discontinuously, but gradually, with no sharp limit between the juvenile and more mature wood. Therefore, it is not possible to determine the exact position of juvenile wood on the log's cross-section (Očkajová *et al*. 2014). The highest percentage of juvenile wood in trees can be found up to approximately the twentieth annual ring. Therefore, it comprises the essential share of the roundwood range selected from pieces with smaller diameters, cylindrical remnants of veneer manufacture, fast-growing wood plantations, and top sections of trees with age that are able to be hewn down. Juvenile wood differs from mature wood in that its cells are twice as long, with a smaller diameter and thickness, and it has a higher share of libriform fibers, lower share of ducts, and higher fibrillar angle (Pelit *et al*. 2014). The differences between juvenile and more matured wood are greater in coniferous and circular-porous wood species than in scattered-porous ones. Most of the scattered-porous species produce juvenile wood that differs slightly from more mature wood. This entails a minimum impact on production quality; therefore, the fast-growing species can also be hewn at a young age. Most deciduous wood species have reduced density at the medulla in comparison to at the bark. The reduced density of the scattered-porous wood species varies. However, the reduced density differences between the juvenile and more mature wood are very small in general terms, depending on the wood species. In addition to the reduced density, the duct size and fiber length affect juvenile wood's quality. The number of ducts per mm^2 is higher for juvenile wood than for more mature wood; the total area is smaller, and the ducts are narrower. The cell wall thickness increases from the log center toward the bark (Zobel and Sprague 1998; Čunderlík 2002).

Milling is defined as the machining process using a rotating tool (mill, milling head, *etc.*), which changes the chip's rated thickness from the minimum to the maximum value (during contrarotating milling) or *vice-versa* (during parallel milling) because of the removal depth. Also, the width or shape of the machined material changes (Prokeš 1982;

Barcík and Gašparík 2014). Because of the rotating movement of the cutting wedge and uniform straight movement of the machined piece, the cutting wedge's resulting movement is cycloidal (Lisičan 1996; Škaljić *et al.* 2009). As the cutting speed *vs.* machined piece movement ratio is significantly high, the cycloid is so prolonged that with no practical error, an assumption can be made that the cutting trajectory consists of a circle (Buda *et al.* 1983; Lisičan 1996; Kvietková *et al.* 2015).

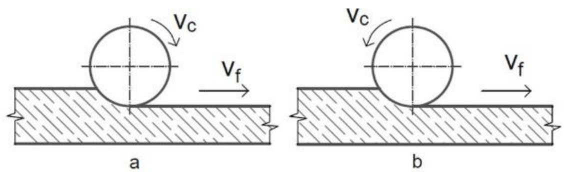

Fig. 1. Milling process by way of the feed panel: a) opposed milling; b) simultaneous milling

Grain size (granulometric composition) is a parameter featuring the share of a group of particles of a certain size in the composition of the loose mass. The most commonly used method for the determination of the granulometric composition is so-called sieving, which means by screening of sampled dust on a set of sieves (Barcík *et al.* 2005). During size analysis, the loose mass grains remain in the individual fractions, *i.e.*, the particles greater than the mesh size do not fall over the sieve and remain thereon. After sieving, fractions remain on the individual sieves. Each fraction is the result of the sieving through the previous sieve. The percentage of such fractions is determined by the fraction grain size, *i.e.*, the amount of particles from the whole sample belonging to the size ranging from the previous sieve mesh size to that of the sieve on which the fraction remained. The size analysis results are shown in the form of either a table or diagram. In practice, the size analysis is carried out either manually or mechanically. The sample sieving duration depends on the physical and mechanical properties of the loose mass and the grain and mesh sizes (Novák *et al*. 2011).

EXPERIMENTAL

Materials

Samples from two poplar species were used. The first sample set was made from the wood of Eurasian aspen (*Populus tremula* L.). According to the annual rings, the tree's age was 45 years, with a juvenile wood content of approximately 27%. The poplars were cut down at 50 cm above the ground. Two ten-meter pieces were made from the log and cut subsequently into four pieces, each 2.5 m long. The second sample set was made from the wood of Euroamerican aspen (*Populus euroamericana*) "Serotina." This is a crossbreed of Eurasian aspen (*Populus tremula* L.) and poplar I214 (*Populus italica 214*). The producer specified the juvenile wood content in the log to be 30%. Two pieces, each 5.25 m long, were cut from the log. One piece was from the lower section, and the other was from the central section. These pieces were cut to 2.5 m and subsequently sawn with a frame saw to get a sharp cut symmetric to the cortex. The pieces were then dried and conditioned to 12% moisture content. Radial boards containing the highest percentage of juvenile wood were sawn from these pieces. Subsequently, these boards were cut radially throughout the medulla, with the simultaneous separation of the section with the bark by sawing; later, the boards were cut into 1-m-long pieces. These pieces were dried and conditioned at φ = 65% and t = 20 °C to 12% moisture content. After achieving the required parameters, the pieces were roughened and leveled to 35 mm. This operation prepared the samples for the experimental procedure.

Methods

First, the density in an absolutely dry state was determined, as well as the reduced density of the test piece sets. The wood density was determined before and after testing according to ISO 13061-2 (2014). The dimensions of the samples used for the density determination were 30 mm (length in the direction of the wood fibers) by 20 mm (width) by 20 mm (thickness). In the experiment 100 test specimens were used. They were prepared in a manner that allowed the determination of the density throughout the log's entire cross-section. The test pieces were dried to 0% moisture in a drier at 103 ± 2 °C. To prevent moisture absorption and thus an increase in mass and volume, the dried pieces were inserted into glass vessels with silica gel, where they remained during the entire measurement process. The pieces were weighed and measured. The density for the absolute dry state and the reduced density were computed from these results. Determination of density was carried out according to standard STN 49 0108.

From among the wood's mechanical properties, those most affecting the process of tool contact with the machined piece during milling were monitored. These are the bending strength and impact strength. The properties were investigated on pieces conditioned to a final moisture content of 12% inside a Binder climate chamber (ED, APT Line II; Germany), at t = 20 °C and φ = 65 %. The test pieces' moisture contents were determined using the gravimetric method.

The bending strength was investigated in the tangential direction. The pieces were conditioned to 12% moisture content, and their dimensions were as follows: radial width 20 mm, tangential thickness 20 mm, and length in fiber direction 450 mm. The samples were bent in the middle-length distance (Fig. 1) using a universal testing machine (FPZ 100, TIRA, Germany) in accordance with EN 310 (1993).

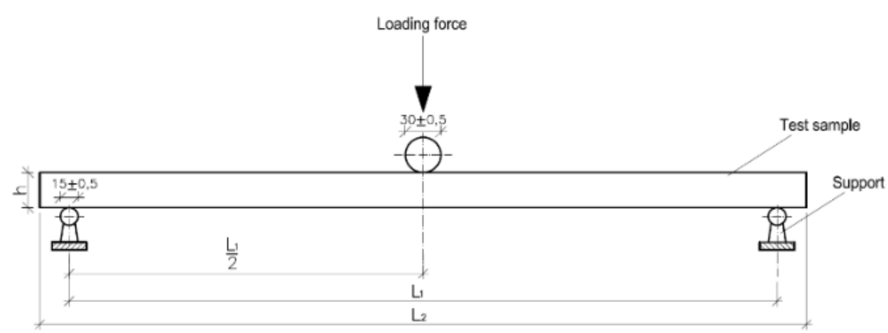

Fig. 2. Principle of the three-point bending test (EN 310 (1993))

Also, the impact strength was investigated in the tangential direction. The dimensions of the investigated pieces were the following: radial width 20 mm, tangential thickness 20 mm, and length in the fiber direction 240 mm. These pieces were also conditioned to a 12 % moisture content. The testing took place with a Charpy hammer (hammer mass 20 kg) using a universal testing machine (FPZ 100, TIRA, Germany) in accordance with EN 310 (Fig. 3).

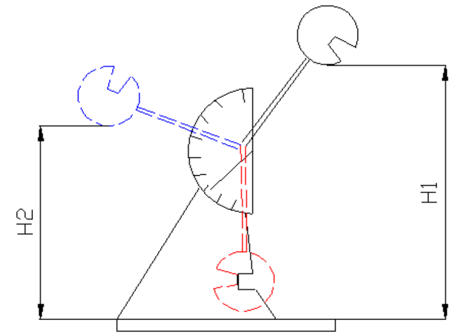

Fig. 3. Principle of the impact bending strength test (EN 310 (1993))

Milling

The milling was carried out on an experimental device (the FVS spindle shaper). The material was fed into the machine with a Frommia feeding device with gradual changes to the feed speed. See Table 1 for the technical parameters.

Table 1. Technical Parameters

FVS Spindle Shaper		Frommia Feeding Device	
Current System	360/220 (V)	Type	ZMD 252 / 137
Frequency	50 (Hz)	Feed Speed Range	2.5 / 10 / 15 / 20 / 30 ($m.min^{-1}$)
Input	4 (kW)	Engine	380 (V) /2 800 ($m.min^{-1}$)

The heads FH 45 designed for wood, with replaceable knives, made in SZT (Turany, Slovakia), were used as the cutting tool for the experimental measurements. See Table 2 for the cutting tool parameters and Table 3 for cutting parameters. See Fig. 4 for the geometry of the used mill.

Table 2. Cutting Tool Parameters

Mill body diameter	125 (mm)
Mill body diameter with open knife	130 (mm)
Mill body width	45 (mm)
Number of blades	2
Edge geometry	α = 15°, β = 45°, γ = 15°

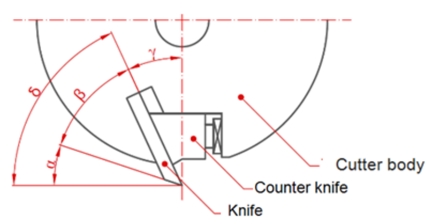

Fig. 4. Geometry of the mill

Table 3. Cutting Parameters

Feed Speed v_f ($m.min^{-1}$)	2.5
	15
Rotating Speed n (min^{-1})	4450
	6670
	8900
Cutting Speed v_c ($m.s^{-1}$)	30
	45
	60
Removal Depth a_p (mm)	1

Granulometric Analysis

The granulometric analysis (size analysis) was carried out on a Fritsch automatic vibration sieving machine (Retsch AS 200 Control, Haan, near Düsseldorf, Germany) using the set of check sieves according to STN ISO 3310 – 1 (2007). This standard does not define the sieving time, sieve mesh size, or number exactly. The sieving time was 5 min at the following mesh sizes: 8; 6, 3; 5; 4; 2, 1, and < 1. The chip fractions remained on the sieves while sieving. Their mass was determined with a lab scale with an accuracy of 0.001 g. The experimental measurements were made at 12% moisture content. The weighed chip samples (approximately 60 g) were placed on the upper sieve, which was then closed, and then the sieving started (5 min). The individual chip fractions caught on the sieves were weighed and the values were assessed. The granulometric analysis procedure was repeated three times for each sample to exclude measurement errors. The averages were then computed from the resulting values.

RESULTS AND DISCUSSION

Physical and Mechanical Properties

The average density value of Eurasian aspen in an absolutely dry state was 368 kg.m^{-3}. The lowest value of 329 kg.m^{-3} was measured in the zone of the medulla, while the highest (428 kg.m^{-3}) was measured in the cambium zone. The density increase in the direction from the medulla toward the bark was equal to as much as 26.5%. On the border between the juvenile and more mature wood (defined at the tenth annual ring), the found average density value for the juvenile wood was 349 kg.m^{-3}, and that for more mature wood was 380 kg.m^{-3}.

The highest density values for Serotina poplar were measured next to the bark, and the lowest were measured in the zone of the medulla, similar to Eurasian aspen. For Serotina poplar, the lowest density value found was 302 kg.m^{-3}, while the highest was 382 kg.m^{-3}. The density increase from the medulla toward the bark was 26%. On the border between the juvenile and more mature wood (defined at the tenth annual ring), the found average density value for the juvenile wood was 313 kg.m^{-3}, and that for more mature wood was 343 kg.m^{-3}. The overall average density value for the log was 334 kg.m^{-3}. The more mature wood was found to be 9 % denser than the juvenile wood for the given wood species.

The breaking strength values for the Eurasian aspen subject to the investigation averaged 64 MPa, and the elasticity modulus was 7519 MPa; no differentiation between the juvenile and more mature wood was evident for the investigated species. Also for this measurement, the values increased for both breaking strength and elasticity modulus in the direction from the medulla to the bark. Specifically, the breaking strength increased by 32% within the range of 56 to 74 MPa. The elasticity modulus increased by as much as 45%, with a minimum value of 6199 MPa and a maximum value of 8969 MPa. The average breaking strength for the juvenile wood was 60 MPa, and for more mature wood, it was 66 MPa, which represents an increase of 10%. For the elasticity modulus, the difference measured between the juvenile and more mature wood was 16%, with juvenile wood showing a value of 6874 MPa and more mature wood a value of 7979 MPa.

The strength parameters were influenced by the reaction wood existing in our wood species, with a slight deformation toward one side giving higher values of these parameters for one side of the log than for the other. Thus, an average value of the breaking strength on the right side of the medulla was 64 MPa, while on the left side, it was 69 MPa (7% higher).

Serotina poplar had a breaking strength equal to 50 MPa and an elasticity modulus equal to 6602 MPa. The increments also occurred from the medulla toward the perimeter, with the breaking strength ranging from 36 to 66 MPa, with a total increase of 45%. For the elasticity modulus, the minimum value was 5086 MPa and the maximum value was 8583 MPa, representing an increase of 45%. The juvenile wood's breaking strength was equal to 46.11 MPa, and for more mature wood, it was 51.8 MPa (12%). For the elasticity modulus, the juvenile wood had lower strength parameters than the more mature wood. The juvenile wood's elasticity modulus was 5648 MPa, and that of the more mature wood was 7023 MPa. The difference between the values was 24%.

The average value of the impact strength was 2.78 J.cm^{-2}, with the minimum value found in the medulla zone equal to 1.3 J.cm^{-2} and the maximum value next to the bark equal to 4.69 J.cm^{-2}. For the juvenile wood, its average value was lower by 66% (1.97 J.cm^{-2}) than for mature wood (3.28 J.cm^{-2}). Also at this measurement, the existence of the reaction wood was taken into account. This caused small deformations in the impact strength profile. For Serotina poplar, the average value of the impact strength for the whole log was 4.45 J.cm^{-2}, while the minimum value found next to the medulla was 1.37 J.cm^{-2} and the maximum value next to the bark was 7.54 J.cm^{-2}. For the juvenile wood, the average value of the impact strength was 2.81 J.cm^{-2}, while for the more mature zone, it was 5.1 J.cm^{-2}. This is an 81% increase because of the high lignin content in the juvenile wood, causing its fragility.

Table 4. Measured Values for Physical and Mechanical Properties

Properties	**Average Density Value**		**Breaking Strength Average Value**		**Elasticity Modulus Average Value**		**Average Value of Impact Strength**	
Type of wood	Eurasian Aspen	Serotina Poplar	Eurasian Aspen	Serotina Poplar	Eurasian Aspen	Serotina Poplar	Eurasian Aspen	Serotina Poplar
Juvenile wood (kg.m^{-3})	349	313	60.48	46.11	6874	5648	1.97	2.81
Matured wood (kg.m^{-3})	380	343	66.59	51.8	7979	7023	3.28	5.10
Total (kg.m^{-3})	368	334	64	50	7519	6602	2.78	4.45

Granulometric Analysis

The following diagrams use vertical bar diagrams to show the granulometric composition of the poplar chips generated during plane milling for the individual combinations of cutting conditions. The vertical bar diagrams shown below apply to both Eurasian aspen (*Populus tremula*) and Serotina poplar (*Populus euroamericana* "Serotina").

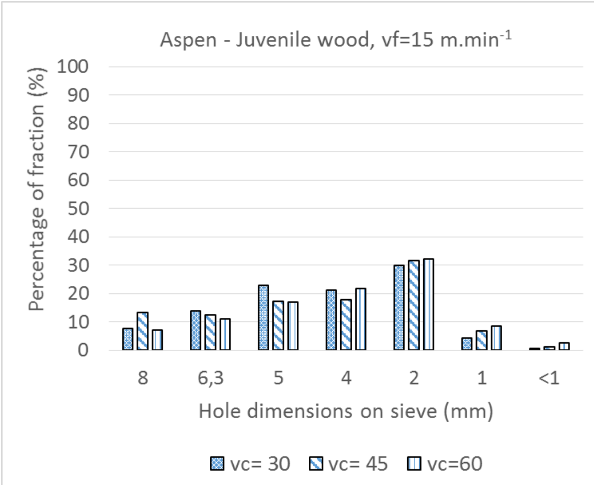

Fig. 5. Diagrams for poplar juvenile wood at feed speed vf = 15 m.min^{-1}

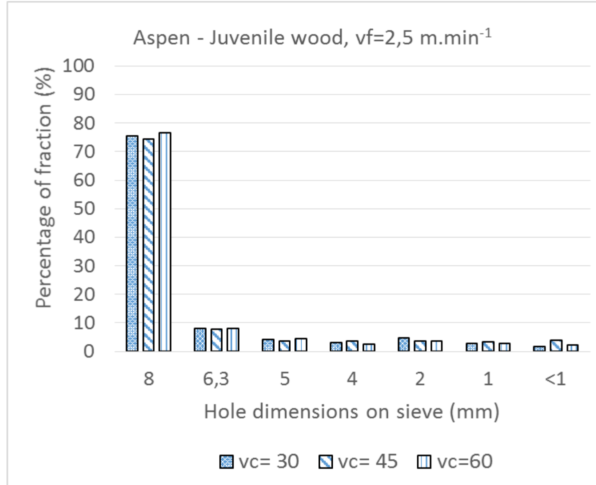

Fig. 6. Diagrams for poplar juvenile wood at feed speed vf = 2.5 m.min^{-1}

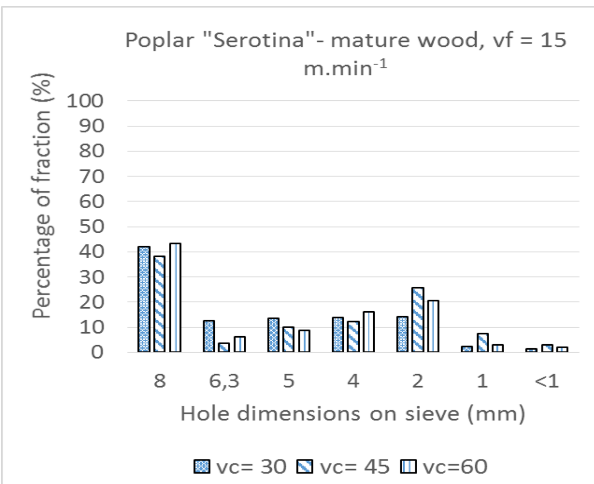

Fig. 7. Diagrams for poplar Serotina mature wood at feed speed vf = 15 m.min^{-1}

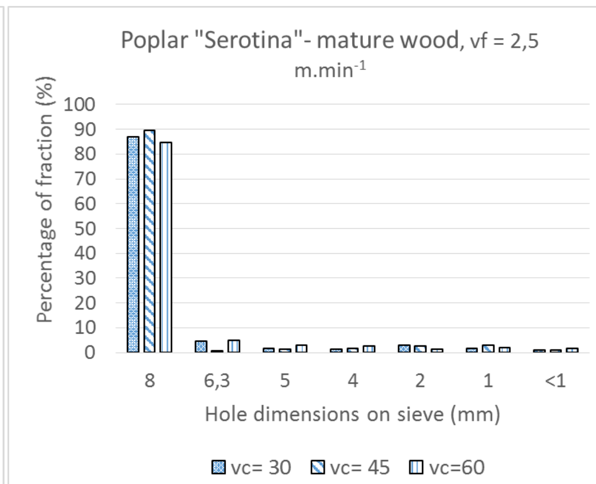

Fig. 8. Diagrams for poplar Serotina mature wood at feed speed vf = 2.5 m.min^{-1}

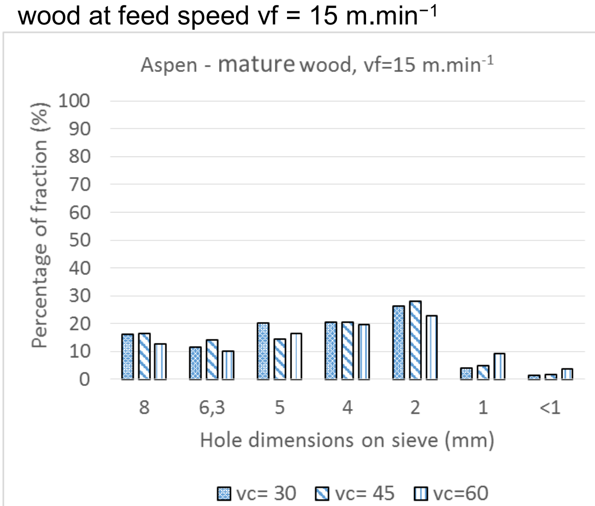

Fig. 9. Diagrams for poplar Serotina mature wood at feed speed vf = 15 m.min^{-1}

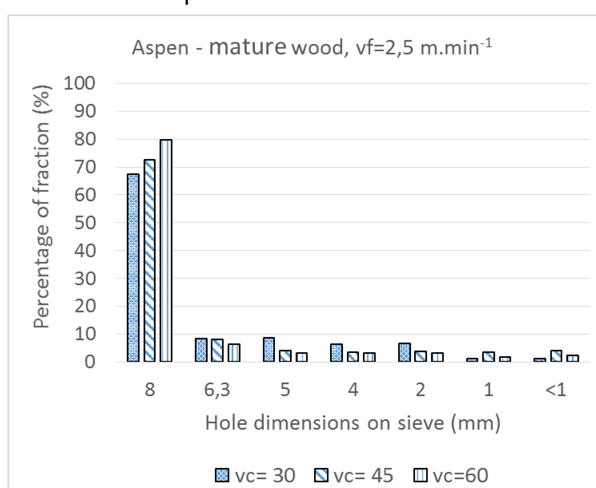

Fig. 10. Diagrams for poplar Serotina mature wood at feed speed vf = 2.5 m.min^{-1}

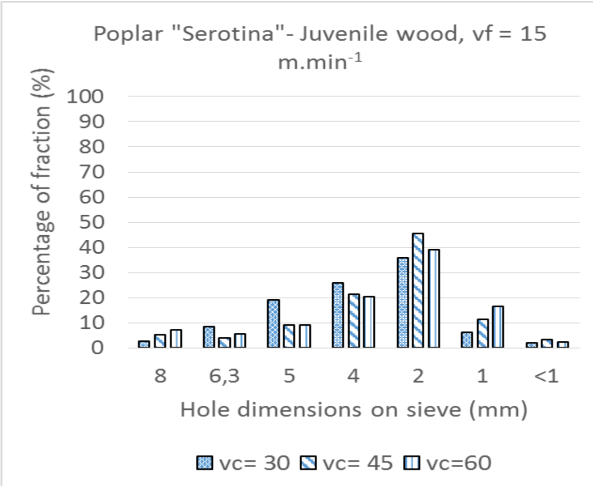

Fig. 11. Diagrams for aspen juvenile wood at feed speed vf = 15 m.min^{-1}

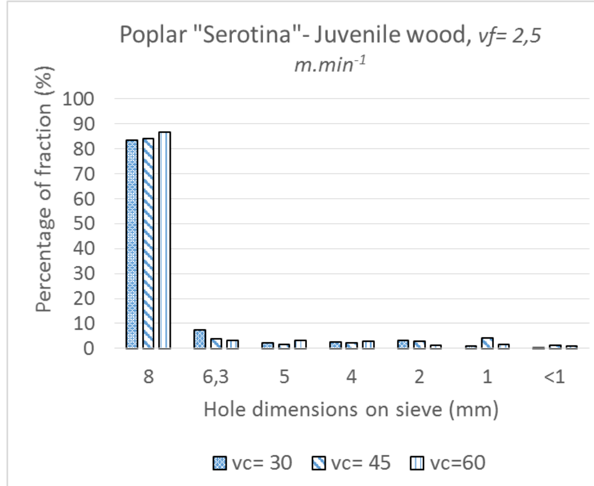

Fig. 12. Diagrams for aspen juvenile wood at feed speed vf = 2.5 m.min^{-1}

According to standard STN ISO 26 0070 (1995), the generated chips can be classified into the following fractions: A – very fine (0.07 to 0.5 mm), B – fine (0.5 to 3.5 mm), and C – fine grains (3.5 to 13 mm). According to Prokeš (1982), the chips generated by the machining can be classified from very fine waste (0.001 to 0.03 mm) to coarse waste (a > 1 mm).

Influence of feed speed and cutting speed

The influence of feed speed on the distribution within the individual fractions is important. Söğütlü (2010a) mentions similar results. The vertical bar diagrams show the change in the distribution of the individual fractions between the feed speeds of 2.5 and 15 m.min^{-1}. For the feed speed of 2.5 m.min^{-1}, the most numerous fraction was that of 8 mm. The most numerous fraction percentages ranged from 67.4% to 89.6%. Other fractions did not exceed 9% and were distributed more or less uniformly. At the feed speed of 15 m.min^{-1}, the fraction distribution was different from the feed speed of 2.5 m.min^{-1}. The most numerous fraction was that of 2 mm for all combinations of technical and processing conditions of milling. The percentages ranged from 14.3% to 45.6%. For the Eurasian aspen, other numerous fractions were those of 5 mm and 4 mm, with percentages ranging from 14.4% to 22.8%.

For Serotina poplar, the second most numerous fraction was that of 8 mm, but only for more mature wood (percentage ranging from 38.1% to 43.3%). The most numerous fraction was that of 4 mm (percentage ranging from 12.2% to 25.7%). The least numerous fraction for all combinations of feed and cutting speeds, wood species, and wood type was the fraction under 1 mm (percentage ranging from 0.2% to 4.2%). The change in feed speed from 2.5 to 15 m.min^{-1} caused a marked decrease in the most numerous fraction (8 mm). The smallest fraction (lower than 1 mm) share increase for Serotina poplar ranged from 0.3% to 1.9% after the feed speed was increased. For Eurasian aspen, no unambiguous relation of the smallest fraction percentage to the feed speed was found. At some of the combinations of technical and processing conditions, the smallest fraction percentage increased because of an increase in feed speed, while at other combinations, a decrease (percentage difference from 0.1% to 2.6%) was observed. The feed speed influence on the chips' granulometric composition can be explained by the longer removal time of the material at lower feed speeds. This generates longer chips, *i.e.*, higher amounts of larger fractions. On the other hand, the material is subject to a shorter removal time, thus generating shorter chips (higher amounts of smaller fractions).

The cutting speed influence is not very significant (Söğütlü 2010b). The distribution of the individual fractions was similar at any of the cutting speeds.

Table 5. Percentages of Fractions at Different Cutting Speeds

	8 mm	6.3 mm	5 mm	4 mm	2 mm	1 mm	< 1 mm
30 m.s^{-1} to 45 m.s^{-1}	0.4 - 5.8%	0.1 - 9.2%	0.4 - 9.9%	0.1 - 3.5%	0.2 - 11.5%	0.4 - 5.2%	0.1 - 2.9%
45 m.s^{-1} to 60 m.s^{-1}	2.0 - 7.1%	0.2 - 3.6%	0.1 - 1.9%	0.6 - 4.0%	0.2 - 6.5%	0.6 - 5.1%	0.4 - 1.9%

The feed speed influenced the distribution of the individual fractions in the chips' granulometric composition. A feed speed change from 2.5 to 15 m.min^{-1} caused a decrease in the most numerous fractions (8 mm). The smallest fraction (lower than 1 mm) percentage increased for Serotina poplar after the feed speed was increased. For Eurasian aspen, no unambiguous relation of the smallest fraction percentage to the feed speed was found. The influence of cutting speed on the granulometric composition was not found to be very important. Neither a great increase nor great decreases in the individual fractions were reported because of cutting speed, just the percentage differences for the individual fractions. No noticeable influence of the wood type for the course of the chip granulometric composition was observed, except the percentage differences between the juvenile and more matured wood within each fraction. When milling the juvenile wood, higher percentages of smaller fractions (5, 4, 2, and 1 mm) and lower percentages of greater fractions (8 and 6.3 mm) were generated. Wood species was not shown to have any evident impact on the course of the chips' granulometric condition. Similarly, just percentage variations were recorded within each fraction. When milling Serotina poplar, a higher percentage of the greatest chip and 1 mm fraction was generated than when milling Eurasian aspen. The results and conclusions are consistent with the results reported in the work (Hlaskova *et al.* 2016). On the contrary, for the remaining fractions, a higher percentage was reported for Eurasian aspen than for Serotina poplar.

CONCLUSIONS

1. The influence of the selected technical and processing parameters and of wood type (juvenile and more mature) was evaluated relative to the chips' granulometric composition during plane milling, its granulometric composition, and the sizes of the greatest and the smallest particles.
2. Granulometric analysis was used to analyze the disintegrated wood mass generated during plane milling. This analysis determined the percentages of the fraction at specific combinations of cutting conditions. As far as the physical properties of the wood species is concerned, it was shown that the juvenile wood had lower density, lower bending elasticity modulus, lower bend breaking strength, and lower impact strength than the mature wood. When comparing the wood species, it became apparent

that Serotina poplar has physical and mechanical properties inferior to those of Eurasian aspen. The generally inferior properties of the juvenile wood are caused by its anatomical structure, which is different than that of the more mature wood. These data are important for the exhaust system design, especially for the adjustment of the separation device design and type as a function of certain percentages and types of chip fractions.

3. The differences between the juvenile wood chips and more mature wood chips as well as those between the chips of Eurasian aspen and those of Serotina poplar had no noticeable influence on either the exhaust system design nor separation device type as a function of certain percentage and type of chip fractions. Therefore, for the juvenile wood milling, no type of separation device different than that used currently for the exhausting of chips generated in the milling of more mature wood is needed.

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