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THE EFFECT OF WOOD DRYING METHOD ON THE GRANULARITY OF SAWDUST OBTAINED DURING THE SAWING PROCESS USING THE FRAME SAWING MACHINE

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ABSTRACT

The experimental results of the study focused on the effect of drying processes of warm air drying at the temperature of 65–80°C and warm air-steam mixture drying at the temperature of 105°C of pine and beech wood to the size of sawdust grains created by cutting using RPW 15M frame saw is presented in the paper. Particle size analysis of dry sawdust was performed using two methods - screening method and optical method based on image analysis obtained from a microscope. The results showed that the drying mode did not affect the particle size distribution of the pine sawdust, but sawdust from beech wood dried with steam mixture at 105°C was characterized by finer particles.

Key words: pine wood, beech wood, warm air drying, warm air-steam mixture drying, frame sawing machine, granulometric sawdust analyses.

INTRODUCTION

The increasing interest in sawdust, as a secondary raw material, in the last years, requires a proper specification of its physical properties as follows: granularity, geometric shapes and size of sawdust chips. The shape, dimensions and amount of chips depend on the form, physical and mechanical properties of the sawed wood (BELJO LUČIČ *et al.* 2009, DZURENDA *et al.* 2009, DZURENDA *et al.* 2010, DZURENDA and ORLOWSKI 2010, 2011, 2011a, FUJIMOTO *et al.* 2011), as well as on the shape, dimensions, and sharpness of the cutting blade, technical and technological conditions of the sawing process (DZURENDA *et al.* 2006, HLÁSKOVÁ *et al.* 2016, PAŁUBICKI and ROGOZIŃSKI 2016).

Sawdust is characterized as poly-dispersion bulk material consisting of coarse and medium- coarse fractions (HEJMA *et al.* 1981, DZURENDA 2009), i.e. bulk material with dimensions of grain over 0.3 mm, while the share of fine fractions with smaller dimensions of chips is not excluded. This fraction is fully covered by dust properties, including the specifics: dust explosion, low drop speed, slow sedimentation, long residence time in the air and filtration conditions (HLÁSKOVA *et al.* 2015, OČKAJOVA *et al.* 2016, RATNASINGAM *et al.* 2010, MARKOVA *et al.* 2018, KMINIAK 2018, KUČERKA and OČKAJOVÁ 2018).

Detailed results of particle-size analysis of sawdust described by OCKAJOVA *et al.* (2006) have shown the influence of different parameters of a saw blade used for cutting on dimensions of particles created during sawing various types of wood. Comparison of the results of particle-size analysis of sawdust created in the sawing process using a universal circular saw with triangular asymmetric spring set of teeth with the results of analysis of sawdust from sawing using a saw blade with tipped swaged anti-kickback teeth, with chip breaker and optimal chip clearance shown that smaller chips were formed during the use of the universal saw blade. This applies especially to the finest particles potentially hazardous to health.

There are many parameters affecting the characteristics of wood sawdust already analyzed. However, the influence of drying method of wood on the size of dust particles generated during processing is not yet analyzed. Thus, the objective of this work was to examine the effect of the drying method on the sawdust cerated during sawing on the frame sawing machine PRW15-15.

MATERIALS AND METHODS

Materials

The material used in the experiments was pine wood (*Pinus sylvestris* L.) and beech wood (*Fagus sylvativca* L.) which were dried with different technics in industial and labolatory conditions. The wood to be used in sawing experiments were blocks in dimensions b = 50 mm × H_p = 50 mm × L_p = 500 mm.

Drying process

The drying process was conducted in the experimental facility of semi-industrial kiln, which is located at the Gdansk University of Technology (GUT). The experiments of drying process were described in details by Baranski (BARANSKI 2018). Drying modes for warm air drying as well as high temperature air-steam mixture drying take into account the ecommendations for drying the beech and pine timber listed in works (BASILICO at al. 1990; SEHLSTED-PERSSON 1995; PERVAN 2000; KLEMENT and SMILEK 2010; DZURENDA and DELIISKI 2012, 2012a; KLEMENT and DETVAJ 2013; BARAŃSKI and WIERZBOWSKI 2013; PINCHEVSKA et al. 2016).They were organized by the control system in two-stage drying, with modification in the first phase by increasing the drying medium temperature in the drying kiln to 65°C and in the second step to 80°C, while the high-temperature drying process was organized by the warm air-steam mixture was carried out at 105°C (Fig. 1).

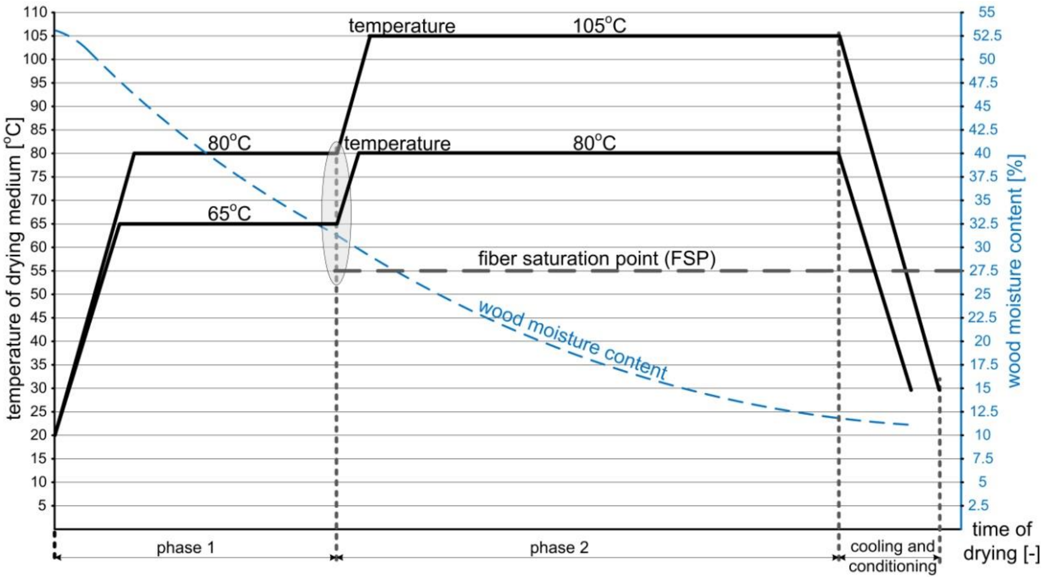

Fig. 1 Variation of temperature and moisture content for different phases of drying processes (BARANSKI 2018).

The wood moisture content during the drying processes was measured inside material in eight positions of drying kiln. The sensors (eight pieces) were placed in the material so that it was possible to measure it in several characteristic points of the kiln's volume, e.g., at the middle and at the outer layers of the wood stack. The moisture content of samples was measured using sensors operating on resistance of drying material, while temperature inside samples was measured using T type thermocouples (copper-constantan). They were put appropriately at the center of the sample, in which measured was the water content, while thermocouples were put into drilled holes from the top side of the sample to the depth about 40-50 mm according to the recommendations by (KLEMENT and DETVAJ 2013).

The moisture content of each sample was measured, before and after sawing, using the TANEL Co. (TANEL) moisture content meter type WRD 100 that has a measurement accuracy of ±2%.

Machine tool and tools

Cutting tests were performed on the frame sawing machine PRW15M (Fig. 2) with a hybrid dynamically balanced driving system and elliptical teeth trajectory movement (WASIELEWSKI and ORLOWSKI 2002) at the Department of Manufacturing Engineering and Automation (GUT, PL).

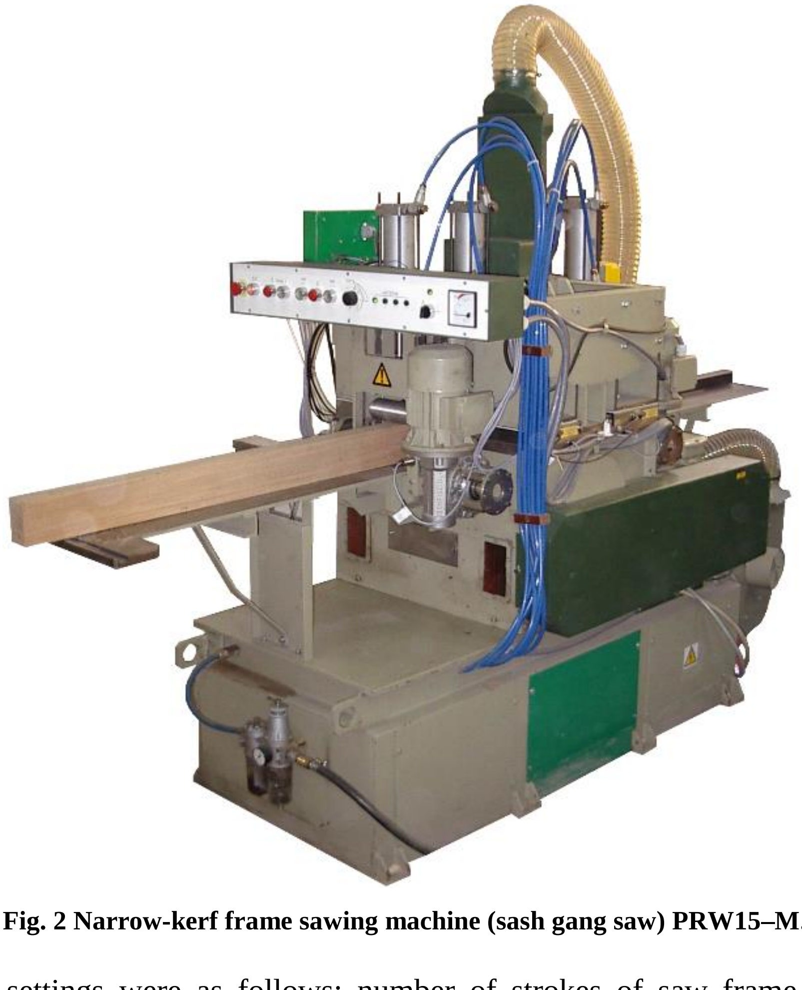

Fig. 2 Narrow-kerf frame sawing machine (sash gang saw) PRW15–M.

The machine settings were as follows: number of strokes of saw frame per min (n_F), 685 spm; saw frame stroke (H_F), 162 mm; number of saws in the gang (n), 5; and average cutting speed (v_c), 3.69 m·s^{-1}. The saw blades were sharp, with stellite tipped teeth: overall set (kerf width) (S_t), 2 mm; saw blade thickness (s), 0.9 mm; free length of the saw blade (L_0), 318 mm; tension stresses of saws in the gang (σ_N), 300 MPa; blade width (b), 30 mm; tooth pitch (P), 13 mm; tool side rake (γ_f), 9°; and tool side clearance

(α_f), 14°. The only varying cutting parameter was feed speed, which was applied at two levels: $v_{f1} \approx 0.9$ m·min^{-1} and $v_{f2} \approx 1.72$ m·min^{-1}. This corresponds to a feed per tooth (f_z) of ~0.105 mm and ~0.2 mm, respectively. Lamellae with thicknesses of 5 ± 0.2 mm were obtained as a result of the re-sawing process. The actual value of the feed per tooth were computed on the basis of the sawing time taken from the plots of time changes of electrical power consumption (Fig. 2). The mean value of feed per tooth for a sash gang saw is calculated as:

$$f_z = \frac{1000 \cdot v_f \cdot P}{n_{RP} \cdot H_{RP}} \tag{1}$$

where: strokes number of the frame n_{RP} = 685 1/min, stroke of the frame H_{RP} = 162 mm P = 13 mm is a tooth pitch, and v_f in m·min^{-1} is calculated as:

$$v_f = \frac{L_p}{60 \cdot t_c} \tag{2}$$

where: L_p is length of the sample in m, and t_c is the real cutting time taken from the plot, e.g. Fig. 3.

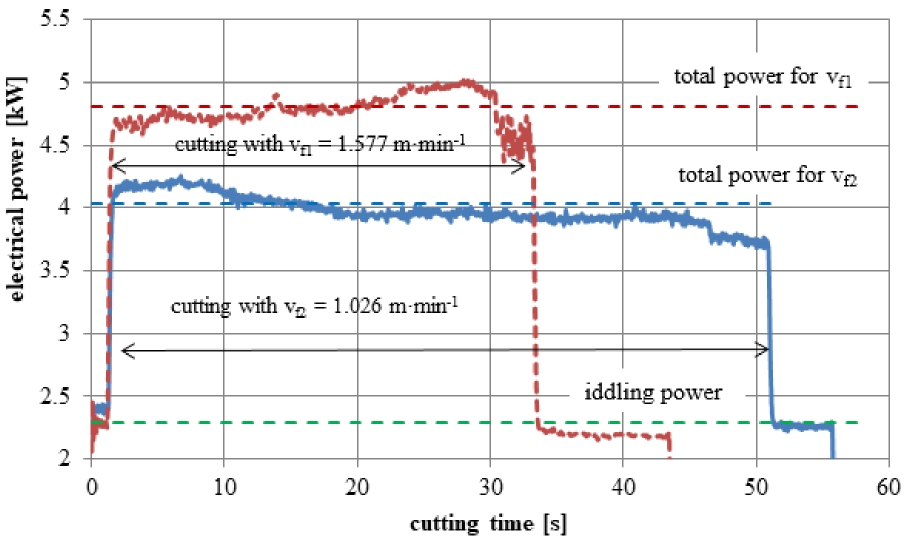

Fig. 3 Time changes of electrical power consumption while sawing at two levels of feed speed v_{f1} and v_{f2} of beech samples BKS43 and BKS50, which were dried in the experimental kiln at the GUT.

Sawdust collection and sieve analyses

For granulometric analyses, samples of pine sawdust and beech sawdust from samples dried with different technics were taken isokinetically from the exhaust pipe of a frame sawing machine PRW-15 in accordance with a standard ISO 9096.

The moisture content of both types of dust samples was $MC \approx 10\%$, and was determined by the weight method.

Sieve analysis was carried out at the Department of Woodworking of the Technical University in Zvolen on an automated vibratory screening machine Retsch AS 200 control; a set of control stainless steel sieves, diameter of sieve 200 mm, height 50 mm, diameter of sieve mesh 2 mm, 1 mm, 0.50 mm, 0.25 mm, 0.125 mm, 0.080 mm, 0.063 mm, and 0.032 mm. The residues on each sieves and bottom were weighed on a digital laboratory balance EP 200 (f. BOSCH) to an accuracy of 0.001 g. The sieving parameters were an amplitude 2 mm/(g), with an interval of 10 s, and a time of 20 min.

With the purpose of specifying of information about size of the smallest particles of fine fraction of dry sawdust a microscopic analysis of granules of fraction of dry sawdust with the size lower than 125 μm was realised. The proposed analysis of dry sawdust was carried out by an optical method – analysis of the picture obtained from the microscope Nikon Optiphot–2 with the objective Nikon 4×. Granules of sawdust were scanned by three low-cost television CCD cameras HITACHI HV-C20 (RGB 752 × 582 pixel), with horizontal resolution 700 TV lines and evaluated by a software LUCIA-G 4.0 (Laboratory Universal Computer Image Analysis), installed on a PC with the processor Pentium 90 (RAM 32 MB) with the graphic card VGA Matrox Magic under the operation system Windows NT 4.0 Workstation. The program of analysis of picture LUCIA-G enables to identify the individual particles of disintegrated wood material, quantitative determination of individual particles situated in the analysed picture and basic information such as: width and length of particles, circularity expressing the measure of deviation of projection of a given chip shape from the projection of the shape of a circle according to the scheme:

$$\psi = \frac{4 \cdot \pi \cdot S}{O^2} \tag{3}$$

where: S – surface of particle in m^2, O – perimeter of particle in m.

RESULTS AND DISCUSSION

In Table 1 the symbols of samples, methods of drying, values of feed speeds v_f and feed per teeth f_z, which were used in the tests, are presented.

Tab. 1 Symbols of samples, types of raw materials, feeding parameters and methods of drying.

Symbol	Wood species	feed speed v_f	feed per tooth f_z	operating methods of drying
		$m \cdot min^{-1}$	mm	
BKP-32	Beech (*Fagus sylvatica* L.)	0.906	0.1064	warm air drying
BKP-33	Beech (*Fagus sylvatica* L.)	1.788	0.2099	warm air drying
BKS-43	Beech (*Fagus sylvatica* L.)	1.023	0.1202	warm air-steam mixture kiln drying at 105°C
BKS-50	Beech (*Fagus sylvatica* L.)	1.580	0.1855	warm air-steam mixture kiln drying at 105°C
SOP-37	Pine (*Pinus sylvestris* L.)	1.756	0.2062	warm air drying
SOP-38	Pine (*Pinus sylvestris* L.)	0.860	0.1009	warm air drying
SOS-50	Pine (*Pinus sylvestris* L.)	0.977	0.1147	warm air-steam mixture kiln drying at 105°C
SOS-52	Pine (*Pinus sylvestris* L.)	1.580	0.1856	warm air-steam mixture kiln drying at 105°C

The results of the sieve analysis - size distribution of the dry chips of pine sawdust dried in different operating methods are given in Table 2. On the other hand, Table 3 shows the results of the sieve analysis - size distribution of the dry chips of beech sawdust dried in different operating methods.

Figure 4 presents the cumulative histogram residue granularity plots of sawdust obtained during the sawing process of pine wood dried in two different operating methods. Furthermore, Figure 5 presents the cumulative histogram residue granularity plots of sawdust obtained during the sawing process of beech wood, which was dried in two different operating methods.

Tab. 2 Granulometric analysis of pine sawdust dried in two operating methods.

Measure of sieve mesh [mm]	Mark of fraction	Representation of fractions of dry pine wood [%]			
		Operating drying methods of pine wood			
		warm air drying		warm air-steam mixture kiln drying at 105°C	
		SOP-37	SOP-38	SOS-50	SOS-52
2.000	coarse	1.92	2.58	1.67	2.53
1.000		18.06	4.53	18.09	21.59
0.500	medium coarse	53.51	43.58	54.88	48.48
0.250		19.80	35.18	18.76	20.45
0,125		5.33	11.54	4.74	5.26
0.063	fine	1.38	2.11	1.49	1.48
0.032		0.01	0.48	0.38	0.21
< 0.032		0.00	0.00	0.00	0.00

Tab. 3 Granulometric analysis of beech sawdust dried in two operating methods.

Measure of sieve mesh [mm]	Mark of fraction	Representation of fractions in dry beech wood [%]			
		Operating drying methods of beech wood			
		warm air drying		warm air-steam mixture kiln drying at 105°C	
		BKP-32	BKP-33	BKS-43	BKS-50
2.000	coarse	2.28	2.24	1.75	5.05
1.000		25.72	17.04	3.17	22.01
0.500	medium coarse	29.48	40.16	30.61	26.12
0.250		25.93	32.56	42.91	28.50
0,125		13.84	6.21	17.91	12.08
0.063	fine	2.19	1.37	2.96	5.61
0.032		0.57	0.42	0.69	0.63
< 0.032		0.00	0.00	0.00	0.00

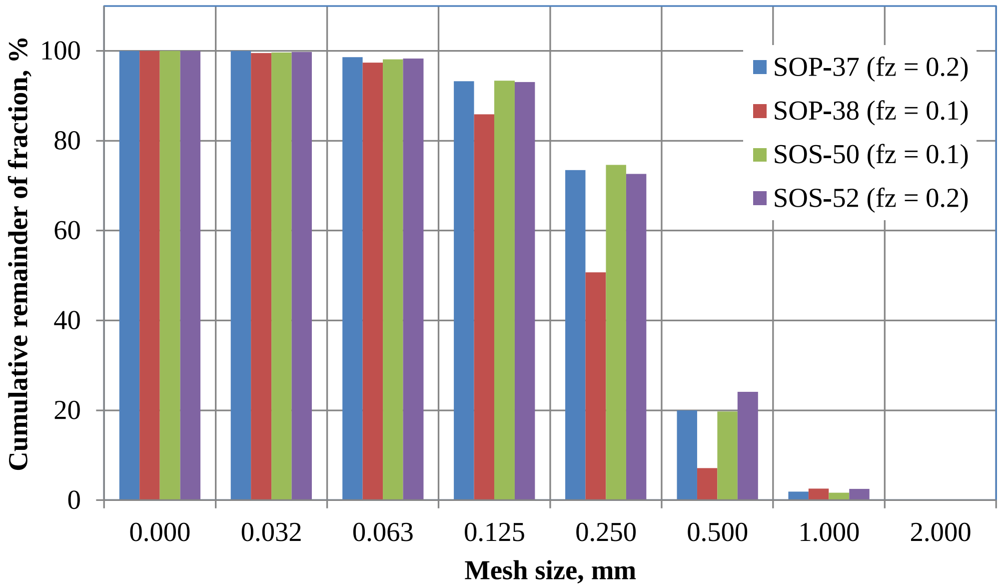

Fig. 4 Histograms of residue of pine sawdust while sawing on the sash gang saw PRW15M. Legend: close to the samples symbols in parentheses values of feed per tooth are provided; SOP - pine wood samples dried in the warm air; SOS - pine wood samples dried in kiln with warm air-stream mixture at 105°C.

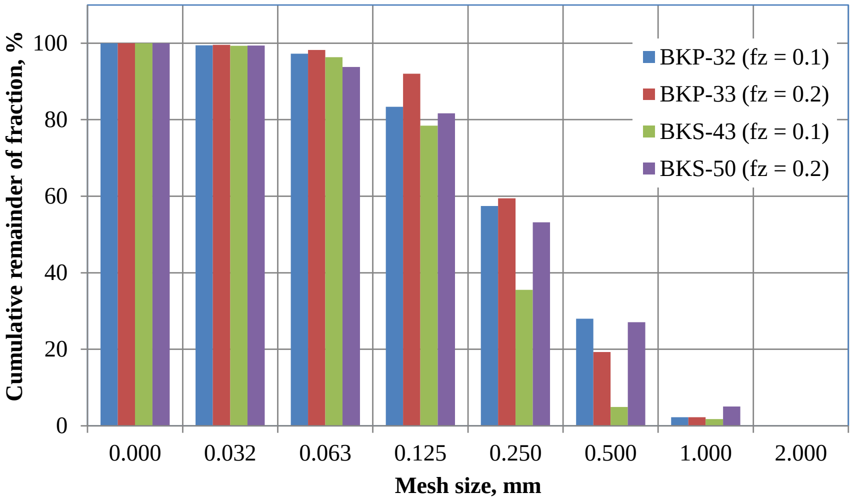

Fig. 5 Histograms of residue of beech sawdust while sawing on the sash gang saw PRW15M. Legend: close to the samples symbols in parentheses values of feed per tooth are provided; BKP - beech wood samples dried in the warm air; BKS - beech wood samples dried in kiln with warm air-stream mixture at 105°C.

The largest of about 80% of the production of chips from pinewood and beech sawdust from the PRW 15 M saw blade process, regardless of the way the drying methods are being analyzed, are chips with dimensions above 0.5 mm. Image analyses of shapes and dimensions of sawdust particles of coarse and medium coarse fractions have shown that the preponderance of sawdust granules of these fractions created in the process of longitudinal feeding while sawing of wood belong to the group of polydisperse fibrous materials, which have stick shapes with considerable elongation in one of their dimensions. Microscopic analyses of sizes and shapes of fine fraction particles of dry sawdust have revealed that particles of this fraction with their shape belong to the group of isometric particles, what means particles with the same values in all 3 dimensions. This statement is consistent with the analysis of the shape of sawdust presented in the paper by (DZURENDA *et al*. 2006).

No chips with dimensions less than 32 μm were measured, which results in a sawing process of pine and beech wood to PRW 15 m, and respirable fractions less than 10 μm are not detected. The finnest particles propably are created during sawing, but methods used in this work are not suitable to detect them. The results described by (HLÁSKOVA *et al*. 2015) shown the content of such particles in sawdust. It is therefore necessary to carry out further research using the laser diffraction method for determination of the finnest particles content in sawdust.

Drying with warm air-steam mixture at 105°C has the effect on increasing the production of dust fraction in beech sawdust, as can be explained by the higher brittleness of beechwood at the higher feed rate of workpiece on the frame sawing machine.

CONCLUSIONS

Based on the carried out analyses, it can be concluded that:

- In the sawing process of pine and beech wood on a PWR 15 M frame, regardless of the method of drying, a chip with a predominantly medium and coarse fraction over 0.5 mm is formed.
- The fraction of the dust fraction with a grain size below 125 μm does not exceed 6.5% for both analyzed types of wood.

- A dust fraction below the 32 μm grain size was not demonstrated for both pine and beech wood.
- Drying of beech wood with warm air-steam mixture at 105° C resulted in a higher production of a finer (dust fraction) compared with air dry drying. In the case of pine wood, this phenomenon has not been observed.

Based on granulometric analyzes of sawdust from pine and beech wood, it can be stated that the influence of air drying or with warm air-steam mixture drying at 80°C does not affect the change in grain size that would limit the existing processes of sawdust processing in the production of agglomerated materials or biofuel in the form of briquettes and pellets.

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