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Effect of pine impregnation and feed speed on sound level and cutting power in wood sawing

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ABSTRACT

The sound levels along with the cutting power registered during the sawing process of the impregnated and non-impregnated pine wood at two feed speeds are shown and compared in this paper. Statistically significant differences in the acoustic signals occurred at the lower feed rate. The differences became smaller with an increase in the feed speed. In contrast to the sound signal, the differences in the cutting power were statistically significant only for the higher feed rate. In addition, the average electric power of the main drive allowed for the identification of knots during the sawing process. Obtained results indicated that monitoring based on the analysis of sound signals can be used as a supplementary source of information related to the wood cutting processes. This kind of independently used monitoring could be recommended for long-running and stabilized sawing processes, due to high noise level generated during the transition states when the tool enters and exits the material - transition states.

1. Introduction

The proper monitoring of machining processes is a key issue of effective and energy efficient manufacturing. Different types of sensors can be used for reliable control of a tool or a machine tool condition, as well as for prediction of some resultant technological features like the surface finish and the machining quality in general (Gorski et al., 2019). Ribeiro Filho et al. (2019) showed that the acoustic emission signals are sensitive with the progressive increase in the surface roughness and microhardness. Recording and monitoring sound level during machining was found to be cheap and easy to use in conditions of industrial practice. Monitoring of a single-side lap grinding process with the use of electroplated diamond tools and an audible sound sensor was proposed by Deja (2014). The author presented the sound generated during grinding as waveforms at the beginning and at the end of a tool life. The audible sound generated during grinding depended on the type of tool (the thickness of the nickel plating) and on the cutting properties of the grinding tool (tool state).

Wood products are classified as eco-friendly products requiring special consideration within the life-cycle management, including manufacturing as an element of the wood products supply chain (Appelhanz et al., 2016). The wood anisotropic properties affect the cutting process characterised by complex phenomena (Kivimaa, 1950). Manufacturing is one of the global activities that has to undergo changes to significantly reduce greenhouse gas emissions, as suggested by Rao (2010). The proper approach to sustainable production in current manufacturing sectors should be based on energy-efficient machining (Wang et al., 2019). Liu et al. (2019) found the best combination of four process parameters to reduce the processing power and increase efficiency in sheet forming process. Unquestionably, the product quality required by designers is also an important factor to be considered for different manufacturing processes. Nguyen et al. (2020) considered both - the energy consumption and the product quality, in the optimization of the roller burnishing process. Iskra and Tanaka (2006) have demonstrated usefulness of the use of the RMS averaging method when applied to both sound pressure and sound intensity signals,

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although the correlation coefficient between the audio signals RMS and the obtained surface roughness while milling Japanese beech (*Fagus crenata* Blume) blocks was the highest. Noise emission was a measured signal in the empirical investigation conducted by Darmawan et al. (2011) in a design assessment of a conventional edge milling cutter and helical edge milling cutters in planing spruce wood (*Picea abies*), where it was proved that the latter cutters generate lower sound pressure level of up to 5 dB(A). In the investigation of the performance of coated carbide tools when grooving hardboards and wood-chip cement boards of various density, Darmawan et al. (2001) found out that the noise level was always lower for boards of lower density. In addition to basic researches, noise level signals were used in examinations of the high speed milling HSM of pine (*Pinus sylvestris* L.) and oak (*Quercus robur* L.) wood (Cherepanov and Luzhanskiy, 2015); planing process of Lombardy poplar (*Populus nigra Italica*), Oriental beech (*Fagus orientalis*), and medium density fiber (MDF) materials (Durcan and Burdurlu, 2018), and investigations of a tool wear while drilling of laminated chipboards (Wilkowski and Gorski, 2011). The accurate diagnostics of the real process conditions ongoing in the machining zone can reduce the energy consumption and/or noise by selecting appropriate cutting parameters depending on the actual material properties. This has been demonstrated for the machining process using rotary tools by Orlowski et al. (2017) and for the process of sawing on a circular saw by Hlaskova et al. (2018) and (2019).

Noise pollution generated during construction activities and caused by the components of manufacturing systems is an important social issue and it is harmful to human health, as pointed out by Li et al. (2016). Lu et al. (2018) considered noise pollution alongside more common energy consumption and productivity issues in a welding shop scheduling problem. The main sources of noise in the exemplary manufacturing companies were showed by Bolaji et al. (2018). Their results revealed the physiological impact of noise on the workers and the possible ways of its reduction. Sawing efficiencies of sawblades with diverse damping capacities in stone-machining were evaluated by Yılmaz (2013). For the sandwich-core blade the active power consumption and the average sound level were significantly lower in comparison with a conventional saw blade. Obtained results showed that the proper selection of a tool is a key issue for energy efficient machining which is less adverse to human health. The findings of Neri et al. (2018) clearly showed lower emissions of both vibrations and noise by Li-Ion batteries chainsaws in comparison with wired chainsaws models while cross cutting Douglas fir (*Pseudotsuga douglasii*) and Silver fir (*Picea abies* Karst.) logs. Svoreň et al. (2010) have shown that the noise level significantly depends upon the design of the saw blade body. The investigation presented by Svoreň et al. (2010) has been conducted for the sawing process with the use of circular saw blades. Dimensions, geometry of teeth and cutting parameters (feed speed, cutting speed) were the same for each investigated circular saw blade. The differences were only in the shape and arrangement of the special laser cut compensating slots on the saw blade. These small modifications in the design of the saw blade had an important effect on the noise level during sawing process. Krilek et al. (2016) revealed that while cross cutting of soft wood (spruce (*Picea abies* Karst.) and pine) circular saw blades with uniform tooth pitches generated lower noise than circular saw blades with non-uniform tooth pitches. Kvietkova et al. (2015) showed that noise levels can be affected not only by the design of the circular saw body but also, statistically, by the number of teeth. The course of machining may vary due to some material defects such as the presence of knots (Caceres et al., 2018) or differences in mechanical properties depending on the wood density (Chuchala et al., 2014), internal structure (Goli et al., 2010) and moisture content. Detailed analysis of the actual working conditions is a crucial factor for improving the energy efficiency of manufacturing processes. The measurement and analysis of the electric power of the main drive were successfully used for the estimation of the cutting forces and mechanical properties during the wood sawing process (Orlowski et al., 2017). Proposed method allowed for monitoring the sawing process in order to identify the wood defects based on the changes in the electric power. The presence of the knots caused a local increase in the power value.

Gholizadeh et al. (2015) have shown in their review that acoustic emission (AE) can be widely applied to many engineering analyses. Behnia et al. (2017) used AE parameters to distinguish different modes of fracture of multi-layer ferrocement composite slabs with partial replacement of tire rubber powder as filler. Nasir et al. (2018) used AE for testing mechanical properties of thermally modified wood and for its classification. Another application of AE, mentioned by Gholizadeh et al. (2015), was the machining process monitoring. Moreover, it was indicated that acoustic emission is suitable for monitoring the cutting process of anisotropic materials. Mohammadpanah et al. (2019) proposed modern monitoring system of circular sawing process of wood, consisting of multiple sensors located close to the cutting zone. One of the analysed sensors was the AE sensor. On the basis of studies which employed AE in process monitoring, Kishawy et al. (2018) concluded that the frequency domain spectrum analysis is better than the time domain for finding an adequate correlation between AE signals and various machining characteristics. The proper setup and location of AE sensor were pointed out as the crucial factors affecting the successful application of the monitoring technique. Nasir et al. (2019) indicated the saw guide as a suitable location for AE sensor in wood circular sawing process. They proposed AE monitoring under extreme sawing conditions to investigate the saw

Table 1
Values of wood samples properties.

Symbol and number of samples	Density, [kg·m^{-3}]	Symbol and number of samples	Density, [kg·m^{-3}]
Non-impregnated (native) pine wood		Impregnated pine wood	
SONP-2	545.43	SOIM-1	506.89
SONP-5	487.05	SOIM-2	525.05
SONP-6	625.71	SOIM-3	533.10
SONP-7	618.86	SOIM-4	598.82
SONP-9	496.45	SOIM-5	416.24
SONP-11	611.07	SOIM-6	441.35
SONP-12	534.20	SOIM-7	501.10
SONP-13	596.57	SOIM-8	590.65
SONP-14	453.23	SOIM-9	565.73
SONP-17	574.67	SOIM-12	537.73
Average moisture content, MC, [%]	10.45	Average moisture content, MC, [%]	8.09
Standard deviation, MC, [%]	1.57	Standard deviation, MC, [%]	1.49

Table 2
Machine tool and tool settings used in the conducted research.

Machine tool			
Name of parameter	Symbol	Value	Unit
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	m	5	–
average cutting speed	v_c	3.69	$m \cdot s^{-1}$
feed speed	v_{f1}	0.92	$m \cdot min^{-1}$
	v_{f2}	1.89	$m \cdot min^{-1}$
feed per tooth	f_{z1}	0.11	mm
	f_{z2}	0.22	mm
Tool			
the sharp saw blades 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
blade width	b	30	mm
tooth pitch	P	13	mm
tool side rake angle	γ_f	9	°
tool side clearance	α_f	14	°
tension stresses of saws in the gang	σ_N	300	MPa

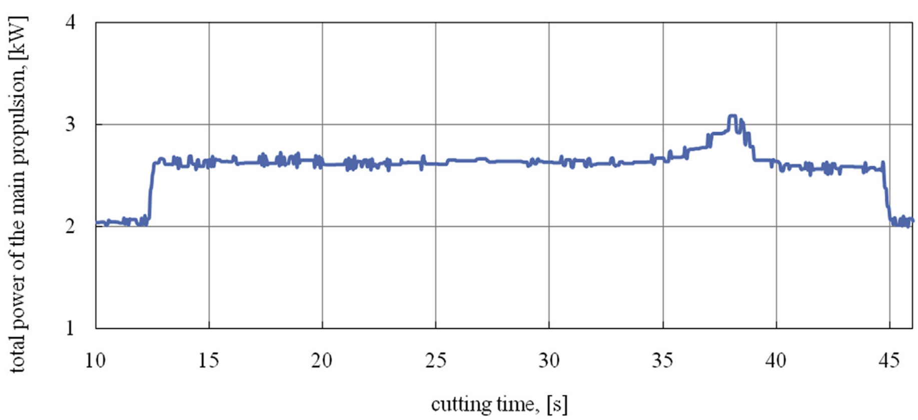

Fig. 1. Recorded changes of electrical power during the sawing process on sash gang saw PRW15M of SONP-14 sample.

blade vibrations, the interaction between the saw blade and workpiece, and the cut surface waviness. The presented methodology based on the artificial intelligence approach showed higher performance than statistical regression to correlate the AE – extracted features with the cutting power and waviness.

To sum up, many researchers have focused on the machining processes monitoring, including the wood sawing process, but the influence of the wood impregnation on the sound level and cutting power has not been demonstrated in the existing research. The purpose of this study was to investigate the impact of the pine wood impregnation process on the generated noise level when cutting wood on the sash gang saw. It should be emphasised that pine wood (*Pinus sylvestris* L.) is a very popular species in Poland and Central Europe, having many applications, also for outdoor use, e.g. in the garden program such as: benches, fences, pergolas and terraces. During the tests, apart from the noise level, the power consumption of the main driving system was recorded simultaneously. The latter data was needed for further cutting power analysis with changes of the noise during sawing.

2. Materials and methods

The wood samples were carefully prepared in the industrial company before the experimental sawing tests conducted in the research laboratory equipped with the modern measuring apparatus. This allowed the application of drying and impregnating parameters used in the real and long-term industrial practice as well as obtaining the results which can be used in the wood industry. The sound level and cutting power values were normalized by the density to eliminate the differences in the density of the tested samples. The sample preparation and test conditions are presented in detail in the following sections.

2.1. Materials

The investigation was carried out on Scots pine wood (*Pinus sylvestris* L.) harvested from Pomeranian region of Poland. The wood samples were prepared in the form of rectangular scantlings with dimensions of 50 × 50 × 500 mm (W × H × L) and in two types: impregnated and non-impregnated. The analysed wood after preliminary sawing process was subjected to a drying process in industrial conditions. The wood samples to be used in the impregnation experiments were initially dried until the relative moisture content (MC) was near, but below the fiber saturation point (FSP), within the range 26 ÷ 28%. These values, adopted in the sawmill where the tests were carried out, were considered as the most favourable for the impregnation of the selected pine wood, i.e., *Pinus sylvestris* L.

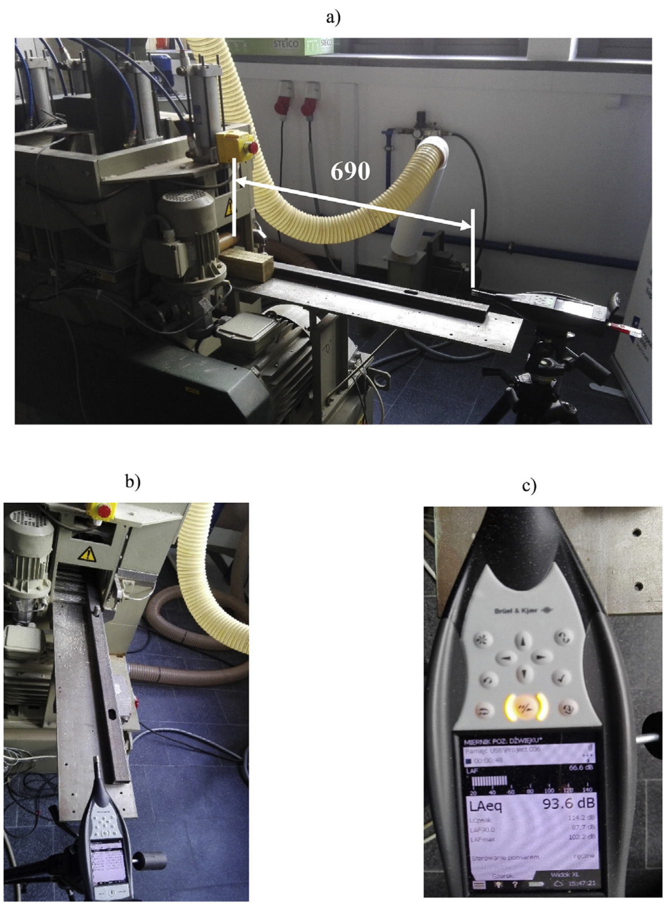

Fig. 2. The sound level measurement with a 2250 Light meter during wood cutting on a sash gang saw: a) general view, b) top view before the cutting test, c) 2250 Light sound level meter during recording of an acoustic signal.

Next, samples were full-scale impregnated in an autoclave using a water-soluble chromate and boron-free wood preservative based on copper complex compounds and a highly effective quaternary ammonium compound, Korasit® KS2, manufactured by Kurt Obermeier GmbH & Co. KG. The concentration of the impregnating substances absorbed by the processed wood was 14.2 kg m^{-3}. The conditions of the preparation of impregnated samples are described in details by Orlowski et al. (2018). After the impregnation process the samples were dried in a laboratory room where thermal-flow conditions, such as temperature and air velocity, ensured reaching the final value of the moisture content at the level of 10%. Non-impregnated samples were dried in industrial kiln to 12% and afterwards they were conditioned in a laboratory room to around 10% moisture content level. Values of wood samples properties after drying and immediately before the sawing process are shown in Table 1. The moisture content was measured with a moisture content meter type WRD 100 which uses electrical resistivity phenomenon. Measurement accuracy was in a range of ±2% (Web Source 3) for impregnated and non-impregnated pine wood. Konopka et al. (2018) demonstrated that the measurement of the moisture content, based on the resistivity method, was characterized by similar accuracy for impregnated and non-impregnated dry wood.

2.2. Machine tools and tools

Experimental cutting tests were carried out on a PRW15M sash gang saw (a prototype designed at the Gdańsk University of Technology, Poland; manufactured by REMA-Reszel, Poland) with a hybrid dynamically balanced driving system and elliptical teeth trajectory movement (Wasielewski and Orlowski, 2002). The technical data of the machine tool and saw blades is shown in Table 2. The actual value of the feed per tooth was computed on the basis of the sawing time taken from the plots of electrical power consumption vs. time (Fig. 1). The methodology for the calculation of real values of the feed per tooth was described by Orlowski et al. (2018). The average cutting power P_C was calculated on the basis of the average electrical power used for the main motion during frame sawing process, as described in the work by Chuchala and Orlowski (2016). Finally, the estimated values of the average cutting power P_C were divided by density of tested wood samples. The obtained values of the normalized cutting power $P*_C$ were used in the performed analysis.

2.3. Recording the sound signal during wood cutting

The sound level measurements were made using a first class

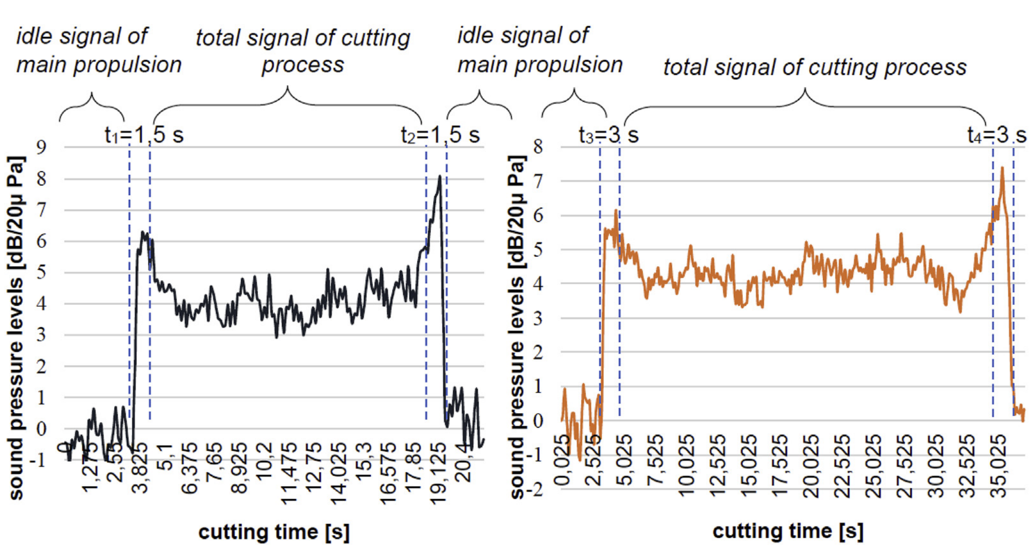

Fig. 3. The sound level during wood cutting, after the separation from the noise of a working machine tool, for the fast feed (left) and for the slow feed (right).

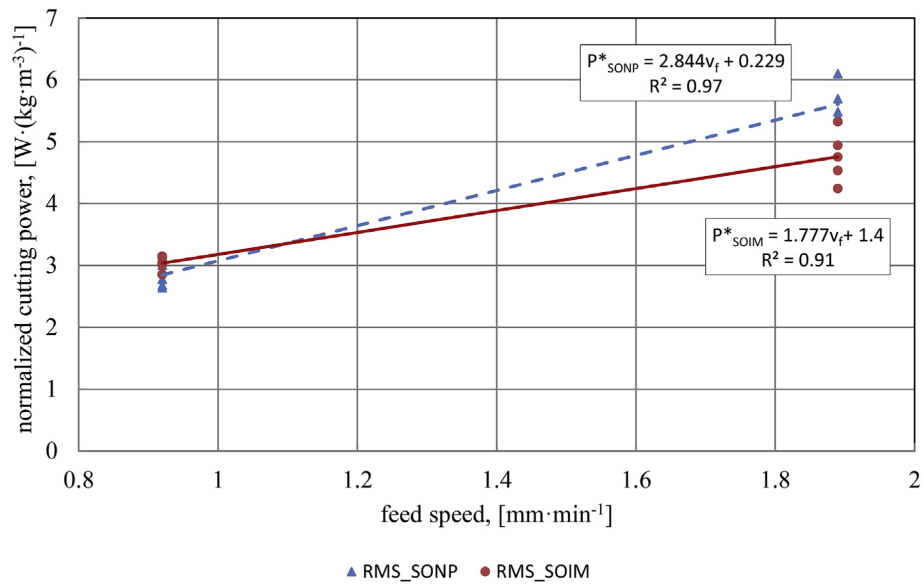

Fig. 4. The RMS value of cutting power vs. feed speed for samples of impregnated and non-impregnated pine wood, normalized by density.

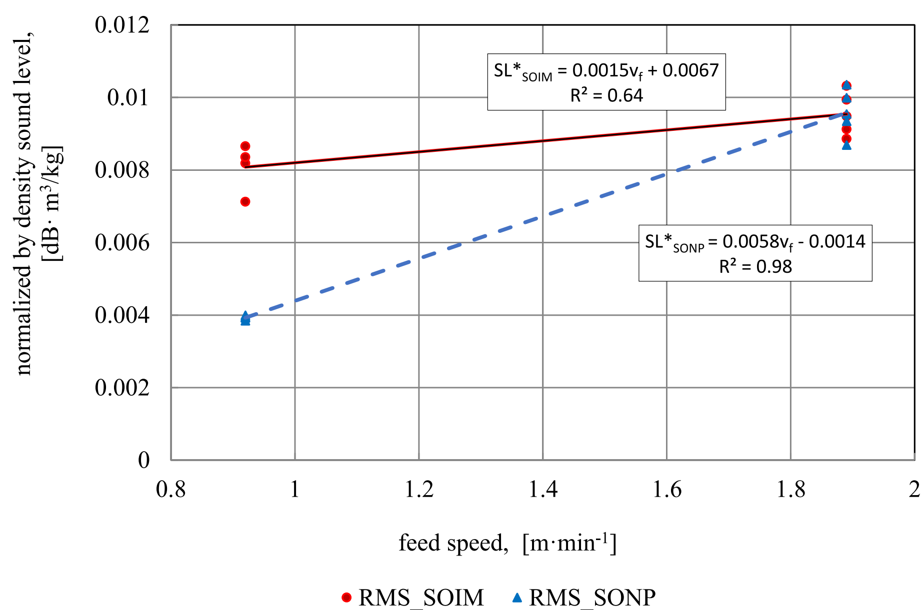

Fig. 5. The RMS value of sound level vs. feed speed for samples of impregnated (SOIM) and non-impregnated (SONP) pine wood, normalized by density.

2250 Light meter B&K (Web Source 1) by recording acoustic signals generated while cutting wood on a PRW15M sash gang saw (Fig. 2). The sensor axis was placed at the height of the workpiece (900 mm from the ground) at a distance of 690 mm from the working zone of a machine tool. The acoustic signals were simultaneously monitored and recorded during machining (Fig. 2 c). Further detailed analysis was carried out in the time domain using the dedicated Reflex Pulse 21 software (Web Source 2). The 2250 Light sound level meter recorded equivalent sound level with appropriate corrections implemented through appropriate filters called filter A and filter C, depending on the signal frequency. The frequency correction A corresponds to the characteristics of the human hearing threshold curve, i.e., it reflects low sensitivity to low frequencies and is designed to measure low sound levels. The frequency correction C corresponds to the characteristics of human hearing for higher sound levels (>80 dB) (Cempel, 1980).

2.4. Methodology for the analysis of the sound signals

The values measured were estimations in the amplitude domain given as Root Mean Square (RMS) values. RMS values contain information on the energy of the tested signal and belong to the amplitude measurements used for the description of acoustic signals. In the presented research, the process of cutting a specific wood sample under the definite cutting conditions such as cutting speed and feed speed was assumed as a single acoustic event. Its exposure sound level LAE (given in decibels, dB) was adopted for the evaluation of obtained results (Cempel, 1980; Cempel and Tomaszewski, 1992). The recorded acoustic signals were analysed in the time domain using dedicated Reflex Pulse 21 B&K software.

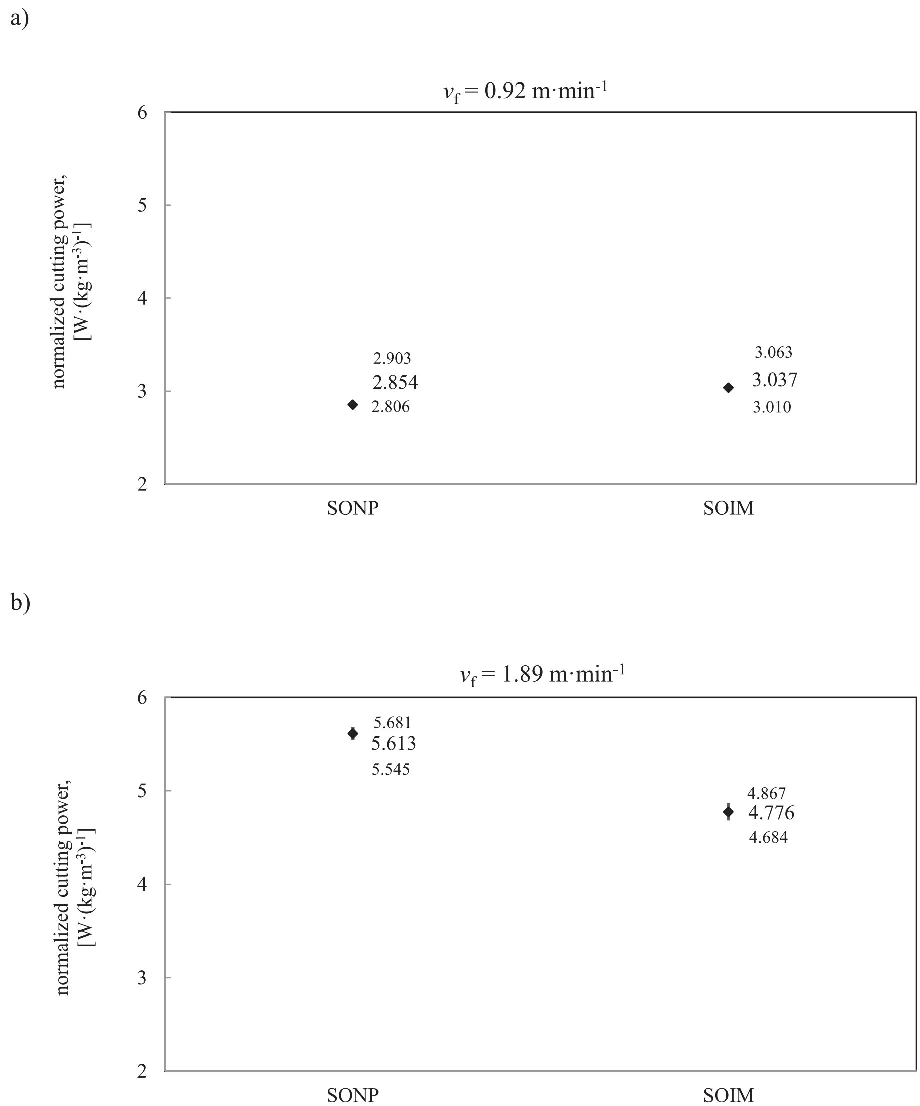

Fig. 6. The average values with spreads regarding the normalized cutting power registered during sawing process of impregnated and non-impregnated pine: a) lower feed speed value, b) higher feed speed value.

Different characteristic periods in the signal plots were detected. Idle work of a main propulsion, before and after the cutting process, was characterized by the lower values of a signal generated by the machine tool without cutting wood. The acoustic signal with the higher values was generated simultaneously by the wood cutting process as well as by the drive and elements of a machine tool. All recorded acoustic signals were separated according to the above rule, i.e., for the idle work of a main propulsion and for the cutting process. The next step was to perform a comparative analysis of the characteristics of each split acoustic signal. As a result, average RMS values were obtained for the woodworking sound level without taking into account the noise generated by the machine tool and without the acoustic background (Fig. 3). Average RMS values of the sound level were calculated for each wood sample. The sound signals after the separation from the noise of the working machine tool were used to determine the re-registration times related to the transition states occurring at the entry of the saw cutter into the material and at its exit after cutting the wood sample. The determined times were $t_1 = t_2 = 1.5$ s for a feed speed of 1.89 m min^{-1} and $t_3 = t_4 = 3$ s for a feed speed of 0.92 m min^{-1} (Fig. 3). The RMS values from the established ranges of re-registrations were not taken into account during further analysis. As a result of signal preprocessing, the final data was obtained after removing acoustic background, signals from transition states (re-registrations) and noise generated by a machine tool. Thus, the main analysis was based on the acoustic signal data related only to the process of cutting wood characterized by specific properties (Table 1). The average values of the filtered sound data related only to the wood cutting process were calculated for each sample and then Sound Level (SL*) parameter, normalized by density, was determined. SL* parameter was calculated as a ratio of the average sound level of wood processing to the wood density.

3. Results and discussion

The changes of standardised RMS values of cutting power P_C* are of a general nature. An increase in the feed speed causes an increase in the cutting power. Such a trend can be observed for both impregnated and non-impregnated pine wood. The differences in the cutting power values recorded during sawing process of impregnated and non-impregnated pine using low feed speed (0.92 m min^{-1}) were very small, almost unnoticeable. For higher

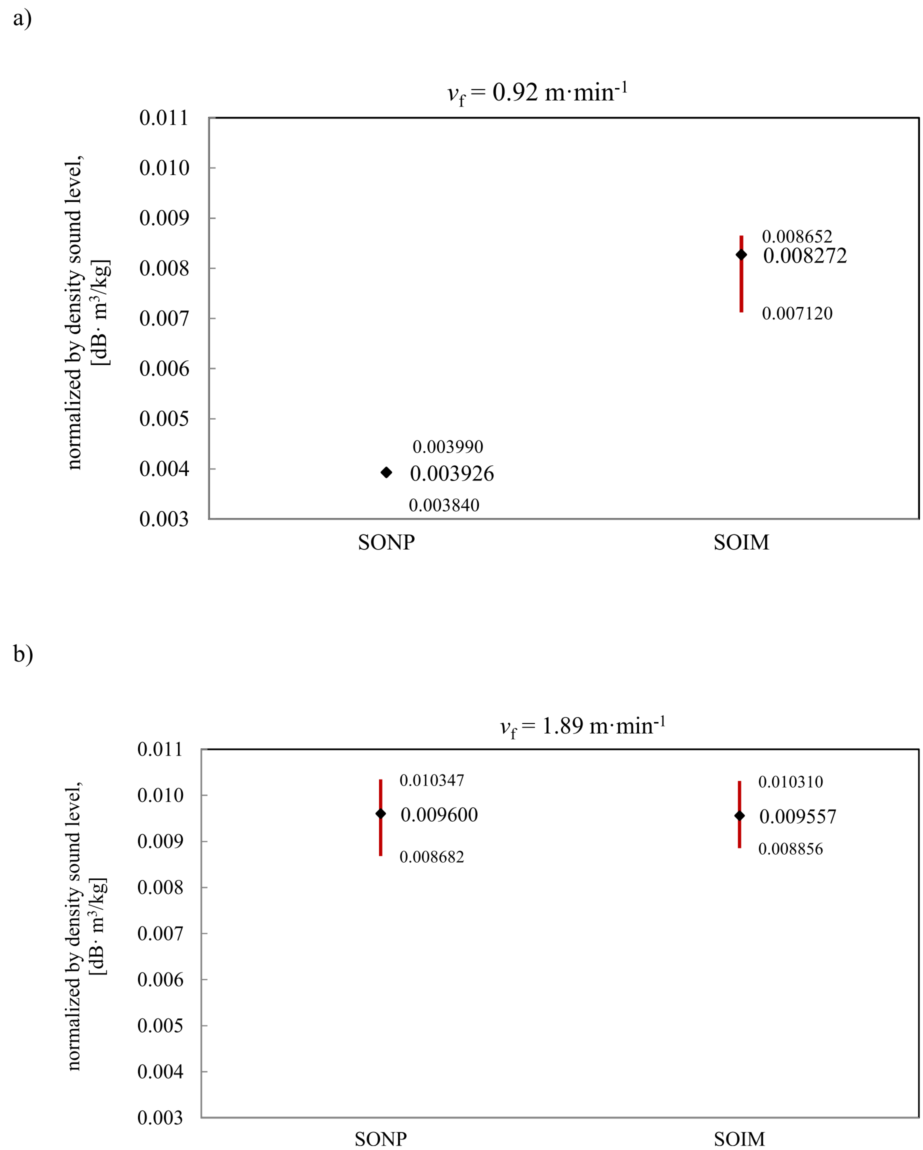

Fig. 7. The average values with spreads regarding the normalized sound level registered during sawing process of impregnated and non-impregnated pine: a) lower feed speed value, b) higher feed speed value.

Table 3
Significance of differences of normalized cutting power and sound level registered during frame sawing process of impregnated and non-impregnated pine wood.

Name of samples	Feed speed v_f [m·min^{-1}]	Average normalized cutting power P^*_C [W·m^3· kg^{-1}]	Standard deviation	Statistical value t_s	Degrees of freedom df	Critical value t_c	Significance of differences
SONP	0.92	2.854	0.217	−1.701	6	2.447	No (close)
SOIM		3.037	0.119				
SONP	1.89	5.613	0.305	3.711	7	2.365	Yes
SOIM		4.776	0.410				
Name of samples	**Feed speed v_f [m·min^{-1}]**	**Average normalized sound level SL* [dB·m^3·kg^{-1}]**	**Standard deviation**	**Statistical value t_s**	**Degrees of freedom df**	**Critical value t_c**	**Significance of differences**
SONP	0.92	0.00393	0.000055	−4.245	4	2.776	Yes
SOIM		0.00754	0.00177				
SONP	1.89	0.0096	0.00064	0.102	8	2.306	No
SOIM		0.00956	0.00059				

values of feed speed (1.89 m min^{-1}) the differences between the cutting power for impregnated and non-impregnated pine were clearly visible (Fig. 4). A different situation regarding the differences between the values of SL* can be observed in Fig. 5, although these results show an upward trend for the sound level with an increase in a feed speed. Nevertheless, at a low feed speed (0.92 m min^{-1}) the differences between the average SL* values are clearly visible for both types of the pine wood tested. The average

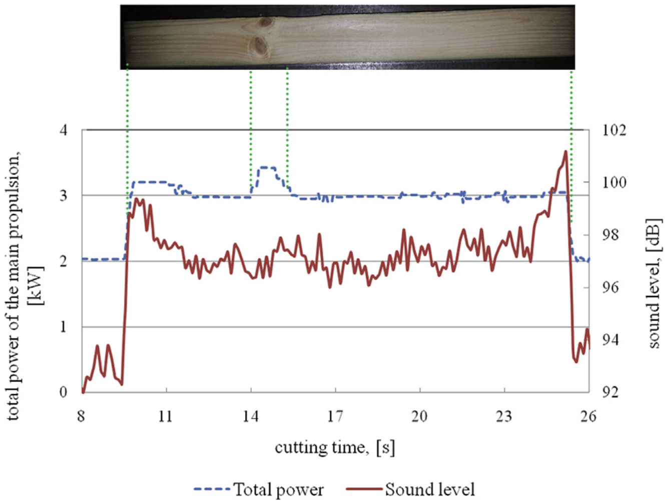

Fig. 8. Electric power of the main drive and sound level registered during sawing process of SOIM-6 sample, with the knot identification.

values of SL* for a higher feed speed (1.89 m min^{-1}) are almost the same. In addition, the average values with spreads of the cutting power and the sound level were shown in Fig. 6 and Fig. 7, respectively. As seen in Fig. 6 a, the differences in values of the cutting power obtained at a lower feed speed were relatively small, with a higher power registered for the impregnated pine wood. Reversed situation can be observed in Fig. 6 b for a faster feed speed when the disparities in the cutting power are bigger comparing to the slower feed speed. In addition, the cutting power for non-impregnated pine was higher than for impregnated pine. The differences in cutting power seem to be significant for both feed speeds, however, they are statistically significant only for the higher feed rate, as demonstrated by using a Student's *t*-test in Table 3. In the case of the lower feed rate the differences are not statistically significant (Table 3), but the value $|t_s| = 1.701$ is relatively close to the critical value $t_c = 2.447$. Similarly as for the cutting power, a lower feed rate also resulted in a higher SL* value for impregnated pine, as seen in Fig. 7 a. For a higher feed rate, the reversed similarity can be noticed, i.e., SL* and the cutting power values are lower for the impregnated pine wood. However, the observed trends were not confirmed by the analysis of statistical significance of the differences (Table 3). The differences between SL* values were statistically significant only for a lower feed rate. The minimal difference in SL* values for a higher feed speed was reflected by the estimated statistical value $t_s = 0.102$, much lower than the critical value tc = 2.306. This confirmed the lack of statistical significance of differences in SL* values when both wood types were machined.

Supposedly, the cutting power and sound level are characterised by similar trends with an increased feed speed during the sawing process of the impregnated and non-impregnated pine wood. Presented trends turned out to be the opposite, probably due to differences in wood density. However, the values of the cutting power and the sound level were normalized by the density in order to eliminate their impact on the obtained estimates. An interesting phenomenon was the difference between the average sound levels registered during the sawing process of two types of pine wood. Statistically significant differences for the impregnated and non-impregnated pine wood occurred at the lower feed speed. In the case of the higher feed speed the differences were neither observed nor confirmed by the statistical analysis. This could be due to the copper, which is one of the most important components of the impregnation liquid used to modify the tested pine samples. Copper-based impregnates reduce the mechanical properties of wood (Simsek et al., 2013). Additionally, copper itself can significantly reduce the value of a friction coefficient what was demonstrated by other authors (Hernández Battez et al., 2010; Moustafa et al., 2002). The phenomenon of lowering a friction coefficient should not cause such a visible change in the sound level, as was the case with an increase in the feed speed. On the contrary, it is known from the basic engineering knowledge that the share of friction between the tool and the material being machined decreases when the uncut chip thickness increases. This occurs with the increase in the feed speed at a constant cutting speed. It was also confirmed by Feldshtein and Maruda (2010) in their research related to finish turning. Another explanation for obtained results could be based on the damping properties of copper. Yakovlev et al. (2000) revealed that copper, as an additive, had a significant effect on reducing the vibrations by increasing the damping properties.

In addition to obtained results, sound signals registered did not identify the occurrence of knots in the cut timber. The reason for that could be placing the microphone at the distance of 690 mm from the cutting zone, although it was positioned in the direction of the feed movement of the cut samples and at the height of the cutting zone (900 mm from the ground) – Fig. 2. Nevertheless, this kind of identification is possible by the registration of the average electric power of the main drive as shown in Fig. 8.

4. Conclusions

The conducted research indicated the directions for the selection of the feed speed regarding the energy consumption and the reduction of the noise level. The cutting power and sound signals were registered during experimental sawing tests on impregnated and non-impregnated pine wood at two feed speeds. The data obtained from both sources was normalized by the density of the investigated wood samples. On the basis of the analysis, it can be stated that:

1. According to the expectations, an increase in the feed speed caused an increase in the cutting power for the impregnated and not-impregnated pine wood. The differences in the cutting power were statistically significant only for the higher feed rate of 1.89 m min^{-1}.
2. In comparison with the cutting power, statistically significant differences in the acoustic signals occurred at the lower feed rate (0.92 m min^{-1}). For the higher feed speed the differences were neither observed nor confirmed by the statistical analysis. This could justify the implementation of sound sensors for the specific machining conditions as a supplementary source of information related to the wood cutting processes, when results from other sources are not statistically significant as observed for the cutting power at the lower feed rate.
3. Monitoring based on the analysis of sound signals can be recommended for the long-running and stabilized sawing processes, due to the high noise level generated during the transition states when the tool enters and exits the material.
4. Presented methodology based on the sound signal and the cutting power could be applied in the experiments on the tool design affecting the noise level during wood sawing. As suggested by other authors, even small modifications in the tool shape can significantly reduce hazardous noise levels, tool wear and the energy consumption.

CRediT authorship contribution statement

Roksana Licow: Methodology, Formal analysis, Writing -

original draft. **Daniel Chuchala:** Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Writing - review & editing, Funding acquisition. **Mariusz Deja:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, Supervision. **Kazimierz A. Orlowski:** Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision. **Piotr Taube:** Methodology, Resources, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.122833.

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