Annals of Warsaw University of Life Sciences – SGGW
Forestry and Wood Technology № 122. 2023: 108-120
(Ann. WULS - SGGW, For. and Wood Technol. 122, 2023: 108-120)
Received: 11.04.23 / Accepted: 02.05.23 / Published: 30.06.23

Influence of pine wood sawing technology on material efficiency indicators

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Abstract: *Influence of pine wood sawing technology on material efficiency indicators*
Coniferous wood processing is one of the basic methods of using natural wood resources. The aim of the work was to determine the impact of the selection of wood cutting technology, which plays an important role in shaping the material indices, especially the volumetric efficiency index. In the case of pine wood processing, group and individual technologies were assessed.. The use of frame saws guarantees the achievement of repeated sorting's with a quantitative efficiency rate of 69%. The introduction of individual technology based on band saws results in an increase in quantitative sawing efficiency to 72%. The selection of processing technology and the dimensional structure of processed roundwood have a significant impact on the average sawing rate.

Keywords: scotch pine, sawing, timber, classification, productivity.

INTRODUCTION

With the increase in demand for wood products, one strives to achieve increased material efficiency. This effect is influenced by the structure of the machinery park. Research to date includes work on the processing of pine wood, which is a common forest-forming species in Poland and Europe. In the Carpathian region, pine occurs only in islands up to an altitude of about 1570 meters above sea level (Białobok and Boratyński, 1983, Jaworski 1995). In the Polish timber industry, pine wood is of particular importance for the lumber industry. Sawmilling, which is an intermediate stage between forestry and, for example, the furniture industry, construction and other economic branches, is closely linked to the rational processing of wood into final products. Scots pine is also one of the main species constituting the raw material base for construction timber in Poland (Kozakiewicz and Krzosek 2013). In Poland, the main supplier of raw material to the timber market is the State Forest Holding (State Forest Holding State Forests.), which is responsible for about 92% of the domestic timber harvested and sent for sale (Statistics Poland 2022).

The sawmilling industry is based mainly on processing large-size timber, and elemental processing of the raw material results in sawn materials (main and side lumber).

They are widely used - either directly or indirectly through their secondary processing - in other timber industries and other branches of the economy, such as construction, mining, transportation, power generation and agriculture (Collected Works 2019). Pine wood is characterized by good utility properties (Hruzik 1993). The negative effect is the accumulation of knots (Malinowski and Wieruszewski 2017, Wieruszewski and Mydlarz 2021) and dimensional desorption changes. Shrinkage of pine wood and related side effects such as cracking, warping of the material negatively affects the use of the wood (Kozakiewicz and Krzosek 2013) resulting in the need to dry to the moisture content at which the material will ultimately work. Depending on habitat conditions and ecotype, pine has different tendencies to produce wood quality. In the western part of its range, it tends to have a greater tendency toward increased convergence and increased defects. On drier and poorer soils, it produces stems that are cleaner and have higher straightness. Under good conditions, it shapes sorties with a significant proportion of straight wood and a low change in diameter over length (Jaworski 1995).

Pine wood is one of the most important construction materials, which are used in furniture, construction, wood branches and other areas. The easy availability of wood raw material, makes it possible to sort a pine wood sort that fully meets individual needs, both for industrial and individual purposes (Dzbeński et al. 2007, Milewska 2005).

Wood sawing methods

The use of a particular method of sawing wood depends on the size and type of logs, but also on the subsequent use of the lumber. One method of sawing wood is single-group sawing, known as sharp-cutting, in which uncut boards or logs are obtained. Two-fold group sawing is otherwise known as sawing with prying. The round wood is sawn in at least two passes through the sawing station, where it is the side parts of the lumber that are separated from the central part, and then the resulting beam (prism), is rotated by 90^o and sawn into the desired grades (Bajkowski 2007).

Types of machines and equipment designed for sawing wood

Sawing based on frame saws, block band saws and multi-disc saws are among the most commonly used technologies for group processing of pine wood in Polish sawmills. Depending on the solution used, specific material efficiency rates are achieved, as well as the flexibility to change the dimensions of the harvested lumber thickness and width. Vertical frame saws, can be divided according to the dimensions of sawn wood into small, medium and large. The maximum speed of sawn wood, according to manufacturers of the fastest sawmills, is 20-25 m/min. (Orłowski and Pałubicki 2009; Collected work 2019). For a frame sawmill, the most commonly used saws are bifurcated, swellable, racked, with HM blades, with chrome coating, with cutouts to aid cooling and transport sawdust out of the cutting zone. Depending on the material of the cutting blade, in practice there are both hollow saws and (average working time is about 3-4 hours), hollow saws with a chrome coating (working time about 6-8 hours), -swell saws (working time 3-4 hours), stelited saws (working time about 12-16 hours), and the preferred ones with carbide blades (working time about 16-20 hours) (Bieniek and Duchnowski 2002).

A log band saw is a machine tool that works with a tool in the form of a toothed endless band, tensioned and guided on two band wheels. Such a solution makes it possible to replace the saw (after correcting the moving setting) as well as to properly tension the saw after replacing it. The most commonly used tools in the group of band saws are single-toothed band saws. Also used are band saws with double-toothed saws for log splitting band saws. The advantage of band saws (especially for hardwoods and coniferous timber of considerable size) is the operation of a single saw, that is, an individual method of sawing. This machine makes it possible to maximize the quality zones of the sawn log and at the same time, in the case of block saws, increases the efficiency of processing (Nasir and Cool 2018, Collective work 2019). For the band sawmill, the technology of splitting with band saws makes it possible to saw through logs with large diameters and with a small throw compared to circular saws. The types of band saws available on the market are saws with stellite blade, bifurcated blade, swaged blade, carbide blade. The saw guiding quality parameter determines the value of the internal tension of the saw and the place of the tool guiding on the width of the material (Ištvanić et al. 2009; Collective work 2019).

The purpose of this study is to determine the occurrence of the effect of the selected log splitting technology on the material yield of harvesting untrimmed pine lumber. The effect of the origin of the wood raw material from the length of the logs on material yield was evaluated. The research was verified for block and individual cutting technologies. It was assumed that the technology used significantly affects sawn productivity. The scope of the work included the selection of equal quality pine raw material, the selection of specific technologies for separated pine timber, the characterization of technologies and the selection of a method for verifying lumber yield indicators.

MATERIALS AND METHODS

Timber from Scots pine (*Pinus sylvestris* L.) was used for the analysis. Six pieces of WC0 grade pine logs (sawn timber of the third quality class) with a length of 12.4 meters were selected for the study. All logs were divided into logs with lengths of respectively: O-girdle (O) - 4.15m, Middle (S) - 4.15m, and Middle second (S) - 4.10m. This division was due to the planned use of the lumber for the production of carpentry products. Half of the harvested logs were directed to be sawn on a vertical sawmill and the other half on a horizontal sawmill, and their designation is presented in Tables 1 and 2. In sawing, it was designed to obtain uncut lumber with a thickness of 26mm and a minimum uncover (width at mid-length) of 50mm.

Table 1. Parameters of logs to be sawn on a horizontal band saw machine .

Log No	Mid-length diameter	Log length	Volume
	mm		m^3
I	410	12400	1.636
II	385	12400	1.443
III	395	12400	1.519
		Sum	4,598

Table 2. Parameters of logs to be sawn on a vertical frame sawmill.

Log No	Mid-length diameter	Log length	Volume
	mm		m^3
IV	435	12400	1.842
V	385	12400	1.443
VI	375	12400	1.369
		Sum	4.654

Preparation of the material

Prior to sawing, logs are selected only for their origin from the length of the arrow, i.e.: stub, middle. In the manipulation process, logs with characteristics of top logs are not separated. After the initial selection (sorting), with the help of a wheel loader, the logs go to the chain conveyor feeder and are directed to the individual stations of the sawmill hall. The research was conducted based on selected technologies based on machine tools: group sawing (DTRA-63 vertical sawmill) and individual sawing (Wood-Mizer LT-70 horizontal sawmill). The saws used in the vertical sawmill had a thickness of 2.2 mm and a per-side opening value of 0.9 mm, while the band saws used in the horizontal sawmill had a thickness of 1.0 mm and a per-side opening value of 0.75mm, which directly affects the width of the cut and thus the amount of sawdust waste generated. In the process, the logs are moved through chain feeders to the sawmill hall where they are sawn into 26mm-thick uncut lumber. Measurements of the diameter of the logs and logs were made using a diameter gauge with an accuracy of +/-1 mm. The width and length of the lumber were measured using a tape measure with an accuracy of +/-1 mm. Meanwhile, the thickness of the lumber was measured using an electronic caliper with an accuracy of +/-0.01 mm. Measurements were made in accordance with EN 1309-1.

Material formulas were used to calculate throughput rates (Hruzik 1993) [1].

$$W_m = W_k \cdot W_t \qquad [1]$$

where:

W_m - material yield

W_k - material productivity of logs

W_t - material yield of lumber

Quantitative material yield of logs was determined according to [2]

$W_k = V_k/V_d \cdot 100\%$ [2]

$V_k > V_d$ Hence, nationally $W_k = 1.02$

where:

V_k - volume of logs

V_d - volume of logs

Quantitative efficiency of lumber [3 i 4]

$W_t = V_t/V_k \cdot 100\%$ [3]

$W_t/_d = V_t/V_d * 100\% = Vt/Vk \text{ x } Vk/Vd = Wt * Wk$ [4]

RESULTS

From the experimental logs selected in the yard, logs of the required length were mangled and cut. Half of the logs were directed to be sawn on a horizontal band sawmill (I-III) and the other half on a vertical frame sawmill (IV-VI). After the logs were harvested, roundwood volume measurements were taken (Table 3-4).

Table 3. Parameters of logs to be sawn on a horizontal bandsaw.

No logs	Longer zone	Mid-length diameter	Log length	Volume
		mm		m^3
I	1O	450	4150	0.660
	1S	410	4150	0.548
	2S	385	4100	0.477
	Sum			1.685
II	1O	415	4150	0.561
	1S	385	4150	0.483
	2S	355	4100	0.406
	Sum			1.450
III	1O	420	4150	0.575
	1S	395	4150	0.508
	2S	360	4100	0.417
	Sum			1.500
Total vol. of all logs to be sawn on a vertical sawmill				4.635

O- butt logs; S- middle logs

The yield of logs headed for individual sawing was set at an average of 101%.

The handling efficiency of logs prepared for sawing on a frame saw was 102%.

Table 4. Parameters of logs to be sawn on a vertical frame sawmill.

No logs	Longer zone	Mid-length diameter	Log length	Volume
		mm		m^3
IV	1O	535	4150	0.932
	1S	385	4150	0.483
	2S	365	4100	0.429
			Sum	1.844
V	1O	405	4150	0.534
	1S	385	4150	0.483
	2S	365	4100	0.429
			Sum	1.446
VI	1O	430	4150	0.602
	1S	375	4150	0.458
	2S	345	4100	0.383
			Sum	1.443
Total vol. of all logs to be sawn on a vertical sawmill				4.733

O- butt logs; S- middle logs

<u>Thinning efficiency</u>

As a result of the processing of logs directed to be processed on the horizontal sawmill, the indicators of volume and sawing efficiency were established (Table 5-7).

Table 5. Parameters of uncut lumber obtained from logs "I".

No logs	Width halfway down	Thickness	Length	Volume	Efficiency
I O	mm			m^3	%
Min	180	25.70		0.020	
Mean	320	26.67	4150	0.035	
Max	391	27.76		0.044	
DS.	68.98	0.66		0.0077	
Sum				0.461	69.85
I S	mm			m^3	%
Min	160	25.89	4100	0.020	
Mean	297	26.78		0.032	
Max	375	27.70	4150	0.042	
DS.	71.23	0.646		0.0077	
Sum				0.754	73.56

DS – Standard Deviation

Table 6. Parameters of uncut lumber obtained from logs "II".

No logs	Width halfway down	Thickness	Length	Volume	Efficiency
II O	mm			m^3	%
Min	200	26.08		0.022	
Mean	325	26.63	4150	0.036	
Max	387	27.10		0.043	
DS.	61.18	0.364		0.0068	
Sum				0.395	70.41
II S	mm			m^3	%
Min	126	25.89	4100	0.014	
Mean	292	26.79		0.030	
Max	375	27.70	4150	0.040	
DS.	66.01	0.57903		0.0074	
Sum				0.647	72.78

DS – Standard Deviation

Table 7. Parameters of uncut lumber obtained from logs "III".

No logs	Width halfway down	Thickness	Length	Volume	Efficiency
III O	mm			m^3	%
Min	80	25.75		0.002	
Mean	301	26.52	4150	0.033	
Max	413	29.09		0.047	
DS.	101.9	0.860		0.01398	
Sum				0.424	73.74
III S	mm			m^3	%
Min	170	25.89	4100	0.019	
Mean	295	26.71		0.031	
Max	381	27.70	4150	0.038	
DS.	68.0	0.576		0.0077	
Sum				0.683	73.84

DS – Standard Deviation

The quantitative weighted average yield of wet sawn timber obtained from sawing on a horizontal band sawing machine was on the average level of 72.6%. As a result of the processing of the logs sent for processing on the vertical frame sawing machine, the volume and sawing efficiency ratios were determined (Table 9-11).

Table 11 and 12 summarize the machining accuracy by dimensional deviations of lumber obtained by sawing individual logs. It is indicated that the dimensional deviations are higher when sawn on band saws

Table 8. Parameters of uncut lumber obtained from logs „IV”.

No logs	Width halfway down	Thickness	Length	Volume	Efficiency
IV O	mm			m^3	%
Min	379	25.94		0.041	
Mean	430	26.56	4150	0.047	
Max	471	26.80		0.052	
DS.	36.51	0.242		0.004	
Sum				0.569	61.05
IV S	mm			m^3	%
Min	119	26.05	4100	0.013	
Mean	267	26.37		0.028	
Max	345	26.76	4150	0.037	
DS.	77.09	0.227		0.0084	
Sum				0.641	70.29

DS – Standard Deviation

Table 9. Parameters of uncut lumber obtained from logs „V”.

No logs	Width halfway down	Thickness	Length	Volume	Efficiency
V O	mm			m^3	%
Min	120	26.23		0.013	
Mean	303	26.53	4150	0.033	
Max	467	26.90		0.051	
DS.	89.8576	0.236		0.00989	
Sum				0.398	74.53
V S	Mm			m^3	%
Min	118.00	26.70	4100	0.013	
Mean	271.67	26.70		0.031	
Max	350.00	27.63	4150	0.039	
DS.	66.36	0.441		0.00731	
Sum				0.63	69.08

DS – Standard Deviation

Tabela 10. Parameters of uncut lumber obtained from logs „VI”.

No logs	Width halfway down	Thickness	Length	Volume	Efficiency
VI O	mm			m^3	%
Min	197	26.22		0.021	
Mean	322	26.49	4150	0.035	
Max	390	26.84		0.043	
DS.	64.47	0.202		0.0073	
Sum				0.425	70.60
VI S	[mm]			[m^3]	
Min	110	26.16	4100	0.012	
Mean	278.19	26.32		0.029	
Max	360.00	26.65	4150	0.038	
DS.	73.54	0.139		0.0081	
Sum				0.636	75.62

DS – Standard Deviation

Table 11. Accuracy of band saw processing in relation to lumber thickness for individual logs.

No logs	I	II	III
	%		
Min	25.45	25.45	25.75
Mean	**26.74**	**26.73**	**26.57**
Max	26.74	26.73	26.57
DS.	0.61	0.60	0.39

DS – Standard Deviation

Table 12. Accuracy of frame sawing in relation to lumber thickness for individual logs.

No logs	IV	V	VI
	%		
Min	25.94	25.89	26.16
Mean	**26.43**	**26.65**	**26.39**
Max	26.85	27.63	26.84
DS.	0.37	0.71	0.28

DS – Standard Deviation

Table 12 shows the dimensions of the lumber obtained by sawing on the vertical sawmill. The quantitative yield of wet lumber obtained from sawing on the vertical sawmill was 69.7%.

Table. 13. Productivity in lumber processing by group method with band saw.

No logs	Productivity (%)			
	Zone for the length of the log			Mean
	O	S	S	
I	69.85	72.26	75.05	72.39
II	70.41	71.01	74.88	72.10
III	73.74	73.03	75.06	73.94
Mean	71.33	72.10	75.00	72.81

O- butt logs; S- middle logs

Table. 14. Productivity in processing lumber by individual method with a frame saw.

No logs	Productivity (%)			
	Zone for the length of the log			Mean
	O	S	S	
IV	61.05	72.49	72.49	68.68
V	74.53	72.49	72.49	73.17
VI	70.60	74.93	74.93	73.49
Mean	68.73	73.31	73.31	71.78

O- butt logs; S- middle logs

Table 15. Summary of performance indicators of processing of large-size pine timber.

Origins of lumber from the logging zone	O	S	Mean
	%		
Performance after individual wiping process	71.33	73.55	72.81
Performance after the group sawing process	68.73	73.31	71.78

O- butt logs; S- middle logs

Table 15 shows the volume productivity rates from the two sawing technologies. Based on their presented values, it can be seen that only slightly higher material yields were obtained on the horizontal bandsaw. The conducted ANOVA of the effect of sawing technology on the performance index reached a coefficient value in the Tukey HSD test of F =0.42788. This result is not significant at $p < 0.05$.

DISCUSSION

The analysis of the processes of processing raw wood into sawn products is based on indicators derived from the dimensions of domestic sawn wood and the directions of processing into edged and untrimmed materials (Gotych et al. 2008). The analysis has led to numerous conclusions confirming the significant impact of the choice of processing technology on expected sawn results (Turchetta et al. 2013, Dietz and Krzosek 2004). Untrimmed products are the optimal sort of higher quality wood. However, the introduction of individual processes by single sawing significantly affects process performance. Wood properties, including shape requirements, can be correlated with process performance. This research shows that such an approach, based solely on the origin of the raw material, can be considered quite approximate and imperfect in estimating the yield of roundwood processing (Krzosek and Dietz 2010). Scots pine (*Pinus sylvestris* L.) timber from different provinces of Poland harvested at different qualities depending on the habitat influence may affect its final utilization rates (Mirski et al. 2021).

Throughout the analyzed case of comparing sawmilling technologies, the production rates obtained were similar. The production of sawn materials from pine timber of the central zone was at a constant level in successive sample sawmills.

The analysis showed that the largest deviation from the throughput assumptions was characterized by the group of untrimmed lumber from girdle logs. Hence, the group technology of sawing on a vertical frame saw resulted in a decrease in material yield. Consequently, the product was utilized at a lower level than when individual technology was used. At the same time, in the total amount of roundwood processed at sawmills, the share of wood of the girdle zone had a negligible effect on the aggregate sawn productivity.

However, the higher quality did not translate into higher material yield rates. The average yield in the selected class of raw material was 72%, while the average for the middle log zone was more than 73%. Comparing log yields in other studies, it can be seen that the overall material yield of sawing is in the 65%-85% range and increases with log thickness. The impact of technology plays a greater role for wood with significant shape variation (Krzosek and Dietz 2010, Kozakiewicz and Krzosek 2013, Wieruszewski et al. 2023).

The variation in the productivity of roundwood processing into uncut grades is due to shape variation, as confirmed by numerous studies (Wieruszewski and Mydlarz 2021), and is related to the division into grades, the maturity of the raw material and the selection of sawing technologies. There is a greater demand for group technologies for homogeneous lumber from the middle zone, where the product is produced with higher productivity. However, it is individual technologies that find significant recognition due to the fact that it can be used in various wood industries (Chuchała et al. 2017).

CONCLUSIONS

Based on the results obtained, the following conclusions were determined:

- A higher material yield was obtained when sawing the raw material on a horizontal sawmill equipped with a band saw compared to a vertical sawmill by less than 1%.
- The difference in sawing efficiency is mainly due to the choice of processing technology and the origin of the sawn raw material. Stub sorts were characterized by a greater effect of shape and convergence on yield in group processing.
- Based on the observations, it was noted/recognized that sawn lumber after sawing on a vertical sawmill was characterized by greater accuracy of the rope dimensions of the extracted sorts than those sawn using a horizontal sawmill. The higher accuracy of the line dimensions of the obtained raw material obtained by cutting on the vertical sawmill is explained by the rigid way of guiding the saw.

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Streszczenie: *Wpływ technologii przetarcia drewna sosnowego na wskaźniki wydajności materiałowej*. Przeroby drewna sosnowego odgrywają zasadniczą rolę w obszarze racjonalnego wykorzystania naturalnych zasobów surowca drzewnego. Drewno sosnowe stanowi dominującą grupę surowca odnawialnego na terenie Europy Środkowej. Dobór technologii rozkroju surowca drzewnego odgrywa znaczącą rolę w kształtowaniu wskaźników materiałowych a szczególnie wskaźnika wydajności ilościowej. W przypadku przerobów drewna iglastego dominujące są technologie grupowe oraz indywidualne. Zastosowanie pilarek ramowych gwarantuje uzyskanie powtarzanych sortymentów o wskaźniku wydajności ilościowej rzędu 69% wprowadzenie technologii indywidualnej opartej na pilarkach taśmowych skutkuje zwiększeniem wydajności ilościowej przetarć do poziomu 72%. Znaczny wpływ na średni wskaźnik przetarcia posiada dobór technologii przerobu oraz struktura wymiarowa przetwarzanego drewna okrągłego.

Funding: This research was funded by the National Centre for Research and Development, BIOSTRATEG3/344303/14/NCBR/2018. under Statutory Research 506.224

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