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# THE EFFECT OF RAW MATERIAL SELECTION ON MATERIAL EFFICIENCY INDICATORS IN LARGE-SIZED ROUNDWOOD PROCESSING

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**ABSTRACT**

**Background.** In order to conduct the investigations pine wood (*Pinus sylvestris* L.) was used in the form of large-sized roundwood of grade WC0. This raw material is a basic material processed in the domestic sawmill production.
**Material and methods.** The aim of presented research was to evaluate the effect of roundwood dimensions on material recovery efficiency indicators. The model large-sized roundwood was processed into logs. Next, logs were sawn in order to provide edged timber with the target application as prefabricated materials.
**Results.** The results are presented starting with log manipulation and ending with timber sawing and manufacturing of final products.
**Conslusions.** On the basis of presented results it was found that both raw material selection and the applied technology were important factors affecting material recovery efficiency indicators in the large-sized roundwood sawing process. The study shows an increase in values of performance indices for the processing of logs with smaller diameters. This indicator results from prefabrication assumptions.

**Keywords:** pine, material efficiency, sawing process, diameter

## INTRODUCTION

Wood is one of the most important and currently deficit material playing a crucial role in meeting the social needs. It is widely used in various industry branches such as building, furniture and power generation. The functional characteristic of wood is related to its structure and mechanical properties.

The main supplier of raw material in the domestic market is the State Forests National Forest Holding, which is responsible for sourcing the raw material. The harvested wood is then transported to the woodworking enterprises (Przypaśniak, 2015). The State Forests is an institution established based on the following regulations: the Regulation of the President of Poland of 30 December 1924 on the State Forests organization and of 28 June 1924 on the company statute of the Polish State Forests. The purpose of introduced regulations was to reduce problems with continuing deficits of forest resources (Lasy…, 2018).

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The continuous shortage of wood resources on the global scale was accompanied by an increase in the percentage share of Polish forested areas from approx. 28.8% (GUS, 2005) to 29.6% in 2018 (Lasy…, 2014–2020). It resulted in the possibility to increase the quantity of sourced wood. Over the past 20 years the Polish State Forests noted a growth in merchantable wood volume at 1225 million $m^3$. Moreover, the total allowable harvest is about 44.2 $m^3$ (GUS, 2019) of wood each year, which means that sourcing level is lower than the annual growth of forests resources.

The increase in wood resources results from the increase in forested areas and the growing shares in particular age classes (Publikacje…, 2018).

The most common wood species occurring in Poland is pine (*Pinus sylvestris* L.). It constitutes around 58% of all forest areas, 60.2% in the Polish State Forests and 54.9% of private forests (Raporty…, 2018). It is a widely available species characterized by good technical properties and optimal market value (Adamowicz and Cierniak, 2011). Pine wood is commercially available in various quality classes (grades) and comes in various dimensions, which have an influence on adjusting the processing technology and efficiency. Because of these differences it was decided to investigate the effect of qualitative and dimensional structure on the material recovery efficiency indicators.

Pine trees are characterized by characteristically straight stems and a highly variable level of branch occurrence. The possible diversity in the structure within the native species results from the adaptation to various site conditions (Androsiuk et al., 2011; Białobok et al., 1993; Tomczak and Jelonek, 2013).

The dependence between wood selection and its technological or physical properties shows that wood obtained from trees growing in harsher conditions is characterized by better properties, which consequently results in easier technological processing (Krzosek and Grześkiewicz, 2008; Lis and Lis, 2013).

Several more significant factors showing the relevant effect on material recovery efficiency may be distinguished, of which a major role is played by dimensional selection. In order to increase production capacity, the quality of wood and its dimensions should be adjusted to reach the requirements on the maximum use of roundwood cross-sections. Moreover, attributes such as top log diameter and the size of the knotless section also determine the number of obtained semi-finished products.

Production efficiency is also dependent on the presence of wood defects. Their types, dimensions, location and frequency affect the material productivity. The native species are usually characterized by the presence of defects such as blue stain, slope of grain and taper (Mirski et al., 2019). To avoid or minimize their effect on the production capacity the defects are grouped in specific sections during log manipulation (Gawroński, 1960).

Another significant factor is connected with production technology, which includes the number of operations, machinery, saw set determining timber thickness and the organisation of work at each stage of the process (Bidzińska et al., 2007). However, the type of applied technology is mainly dependent on the type of the final product (Hruzik, 2006; Hruzik et al., 2005). The variability of products requires the use of roundwood having dimensions, which allow to include adequate material excesses in every operation. In order to obtain quality products it is necessary to properly sort both large-sized roundwood and manufactured timber in relation to their dimensional and qualitative parameters (Buchholz and Hruzik, 1981; Dzbeński et al., 2007).

All of the above-mentioned factors are determinants affecting the process efficiency and they are closely interdependent. The right relation between them and the characteristics (both qualitative and dimensional) of manufactured products have an effect on the final production capacity.

## THE PURPOSE OF RESEARCH

The aim of the presented work was to evaluate indicators of processing pine raw material depending on wood qualitative and dimensional class. The capacity structure is related to the share of both main products and by-products in the production process.

## METHODOLOGY

The investigations were conducted in a sawmill in 2019. The raw material was delivered to the enterprise from the Szczecinek Forest Inspectorate in the form of large-sized roundwood and then it was sawn into experimental logs. Five model pieces of roundwood of

**Table 1.** Dimensional characteristic of experimental large-sized roundwood
**Tabela 1.** Charakterystyka wymiarowa dłużyc badawczych

| Label<br>Numer | Length<br>Długość<br>m | Top log diameter<br>Średnica w cieńszym końcu<br>($d_{ck}$)<br>cm | Midpoint diameter<br>Średnica środkowa<br>($d_{1/2}$)<br>cm | Volume<br>Objętość<br>$m^3$ |
|---|---|---|---|---|
| D1 | 13.2 | 25.5 | 31 | 0.99 |
| D2 | 12.9 | 24.0 | 29 | 0.85 |
| D3 | 12.6 | 21.0 | 27 | 0.72 |
| D4 | 12.1 | 21.0 | 27 | 0.69 |
| D5 | 8.2 | 31.5 | 23 | 0.70 |

grade WC0 (Table 1) were distinguished. During manipulation and sawing the dimensional characteristics (taper, curvature) and anatomical defects were taken into account. The sawing process was conducted with the use of a frame saw including a block unitary sawing set. The saw kerf width was 5 mm and the thickness of green timber was 31 mm.

Unedged sawntimber produced after sawing was subsequently cut into a multiple width of 10 cm. This dimension resulted from the maximum width of the elements directed to optimise the cutting process. It was the upper limit adopted for semi-finished products. Manufactured sawn materials were subjected to the process of measurement and grading.

In order to verify the material flow, volume measurements of both large-sized roundwood and manipulated logs were carried out in accordance with the Huber formula (PN-D-95000:2002; PN-EN 1309-2:2006). The measurements were made accurate to 0.1 mm using a caliper in the case of diameters and a tape measure in the case of length. The diameters were measured at the midpoint of length in each piece. The width of individual unedged boards was measured on the narrower side (Gerszyński, 2013).

## RESULTS

Five pieces of large-sized roundwood were manipulated into a set of logs with a length from 2.3 m to 4.5 m. Every log was classified as WC0 (PN-D-95017:1992) and their specific dimensions are given in Table 2. The highest level of manipulation efficiency was noted in the case of roundwood no. 2 (124%), while it was lowest for roundwood nos. 1 and 3 (approx. 111%). Piece no. 2 reached 10% higher values of recovery efficiency than the other pieces. Presumably, the reason for such a major difference was that this piece of roundwood was processed into the log characterized by the greatest taper, which may have affected the results.

On the basis of the presented results it was found that butt logs have higher values of taper than the others. Logs nos. 1 and 2 achieved particularly high values of 2–3 cm/m, which probably resulted from the butt-end log origin. It was also found that the material recovery efficiency increased after log manipulation and it resulted from the xylometric paradox.

Table 3 presents the material recovery efficiency values in relation to log diameter. The highest values were recorded for roundwood pieces nos. 1 and 4, amounting to 81% and 82%, respectively.

The highest sawing efficiency of unedged sawn timber was observed for processing logs with small diameters. It was maximum of 80% for the diameter of 21 cm. The average log efficiency at the first stage of the sawing process was between 64 and 74%. Moreover, both the material efficiency values and log share in model roundwood volume were also investigated.

The timber manufactured in the sawing process was edged and optimised to obtain the width of the closest multiple of 10 cm (Fig. 1). The experiment eliminated shavings and slabs generated as a result of wood processing. The average material efficiency in relation to the volume of processed roundwood at this stage ranged from 46 to 63% for D1–D5. The highest

**Table 2.** Performance and dimensional characteristics of logs
**Tabela 2.** Charakterystyka wymiarowa i wydajnościowa kłód

| Large-sized roundwood Dłużyca | Log Kłoda | Length Długość m | Top log diameter Średnica w cieńszym końcu ($d_{ck}$) cm | Midpoint diameter Średnica środkowa ($d_{1/2}$) cm | Taper Zbieżystość cm/m | Log recovery efficiency from roundwood Wydajność kłody % | Log recovery efficiency Wydajność kłód % |
|---|---|---|---|---|---|---|---|
| D1 | 1 | 3.7 | 34 | 38 | 2.39 | 43.98 | 111.45 |
| | 2 | 3.8 | 31 | 32 | 0.79 | 31.63 | |
| | 3 | 2.3 | 29 | 30 | 0.87 | 16.37 | |
| | 4 | 3.3 | 25 | 27 | 1.05 | 19.48 | |
| D2 | 1 | 3.5 | 32 | 40 | 4.43 | 52.11 | 124.00 |
| | 2 | 3.2 | 30 | 21 | 0.78 | 28.81 | |
| | 3 | 3.0 | 28 | 29 | 0.67 | 23.19 | |
| | 4 | 3.2 | 24 | 26 | 1.25 | 19.91 | |
| D3 | 1 | 3.7 | 30 | 33 | 1.61 | 45.43 | 111.08 |
| | 2 | 3.1 | 27 | 28 | 1.11 | 28.25 | |
| | 3 | 2.7 | 25 | 26 | 0.73 | 20.08 | |
| | 4 | 3.0 | 21 | 23 | 1.33 | 17.31 | |
| D4 | 1 | 3.6 | 30 | 34 | 1.91 | 47.84 | 112.68 |
| | 2 | 3.8 | 26 | 28 | 1.03 | 35.59 | |
| | 3 | 4.5 | 21 | 24 | 1.20 | 29.25 | |
| D5 | 1 | 4.0 | 34 | 37 | 1.73 | 63.77 | 113.12 |
| | 2 | 4.1 | 31 | 33 | 0.61 | 49.36 | |

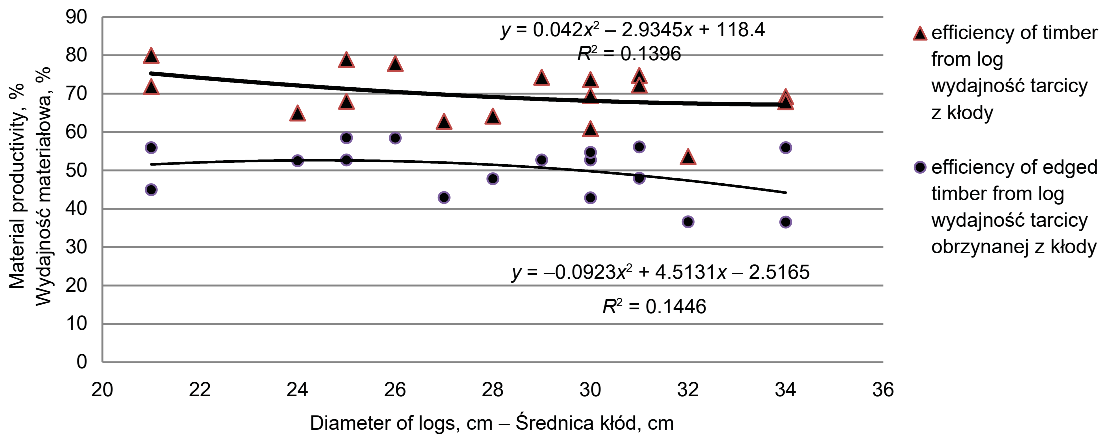


**Fig. 1.** The effect of timber diameter on sawn timber recovery efficiency
**Rys. 1.** Wpływ średnicowy surowca drzewnego na wydajność materiałów tartych

**Table 3.** Percentage characteristic following the sawing process
**Tabela 3.** Charakterystyka procentowa po przetarciu

| Large log<br>Dłużyca | Log<br>Kłoda | Top log diameter<br>Średnica<br>w cieńszym końcu<br>($d_{ck}$)<br>cm | Recovery efficiency<br>of sawn timber<br>from log<br>Wydajność tarcicy<br>z kłody<br>% | Recovery efficiency<br>of sawn timber<br>from large log<br>Wydajność tarcicy<br>z dłużycy<br>% | Recovery efficiency<br>of edged timber<br>from log<br>Wydajność tarcicy<br>obrzynanej z kłody<br>% | Recovery efficiency<br>of edged timber<br>from large log<br>Wydajność<br>tarcicy obrzynanej<br>z dłużycy<br>% |
|---|---|---|---|---|---|---|
| D1 | 1 | 34 | 69.27 | 30.43 | 55.95 | 24.58 |
| | 2 | 31 | 74.77 | 23.66 | 56.10 | 17.74 |
| | 3 | 29 | 74.32 | 12.15 | 52.72 | 8.63 |
| | 4 | 25 | 78.97 | 15.39 | 58.53 | 11.40 |
| Average efficiency | | | 74.33 | 81.63 | 55.83 | 62.35 |
| D2 | 1 | 32 | 53.63 | 27.96 | 36.57 | 19.06 |
| | 2 | 30 | 73.71 | 21.28 | 52.75 | 15.20 |
| | 3 | 28 | 64.18 | 17.60 | 47.85 | 13.11 |
| | 4 | 24 | 64.95 | 12.90 | 52.52 | 10.45 |
| Average efficiency | | | 64.12 | 79.74 | 47.42 | 57.82 |
| D3 | 1 | 30 | 60.90 | 27.23 | 42.84 | 19.17 |
| | 2 | 27 | 62.83 | 17.72 | 42.94 | 12.13 |
| | 3 | 25 | 68.06 | 13.70 | 52.72 | 10.59 |
| | 4 | 21 | 80.01 | 13.87 | 44.94 | 7.78 |
| Average efficiency | | | 67.95 | 72.52 | 45.86 | 49.67 |
| D4 | 1 | 30 | 69.52 | 33.29 | 54.68 | 26.16 |
| | 2 | 26 | 77.89 | 27.75 | 58.44 | 20.80 |
| | 3 | 21 | 71.84 | 20.98 | 55.95 | 16.37 |
| Average efficiency | | | 73.08 | 82.02 | 56.36 | 63.33 |
| D5 | 1 | 34 | 67.90 | 43.25 | 36.51 | 23.20 |
| | 2 | 31 | 72.25 | 35.71 | 47.99 | 23.69 |
| Average efficiency | | | 70.08 | 78.96 | 42.25 | 46.89 |

average indicators for the groups of logs were recorded for the pieces of large-sized roundwood nos. D1 and D4 and they were around 56%. The efficiency of the edging process was 71.4%.

The previously verified effect of processed log diameters allows to specify the function of material recovery efficiency variations in the process of obtaining unedged timber $y = 0.042x^2 – 2.9345x + 118.4$. The exponential function shows a gradual decrease despite the increase in the diameters included in the analyzed top log diameters within the range of 20–35 cm. At the same time the edging process significantly reduced the material recovery efficiency indicator values on the basis of the following exponential function: $y = 0.0923x^2 + 4.5131x - 2.5165$. The average decrease in material efficiency in relation to the top log diameter was between 17% and 25%. The obtained values for the experimental sawing processes was from 12% up to 35% (piece of large-sized roundwood D4, log no. 4).

## DISCUSSION

On the basis of the analysis of the raw material selection and the edged timber production process it was found that selection based on roundwood diameter had a major effect. The increase in diameters of large-sized roundwood processed into small-sized timber resulted in a decrease of material recovery efficiency. This was probably caused by an increased share of saw kerf and the quantity of generated slabs. It is contrary to the standard assumptions that an increase in material recovery efficiency is always related to an increased raw material diameter. The raw material volume after manipulation into logs was less influenced by the xylometric paradox. Moreover, the real volume of large-sized roundwood was decreased by the presence of the taper.

The effect of timber edging on the values of material recovery efficiency indicators was of particular importance in the case of applied prefabrication. The introduction of the assumption that the width of manufactured timber has to be a multiple of 10 cm resulted in a major decrease of material recovery efficiency. It resulted from the increasing share of generated by-products, e.g. shavings. The less restrictive assumptions on prefabrication may cause an increase in recovery efficiency as noted based on empirical observations (Hruzik, 1993; Wieruszewski and Hruzik, 2004).

Available industrial reports from processing of coniferous sawn timber into unedged sawn timber materials showed no negative productivity change. It can be concluded that the results of processing sawn timber from thicker logs do not translate into an improvement in the final yield of prefabrication.

A major reduction in manufactured timber volume in relation to the volume of logs was expected and it resulted from the taper and a considerable share of by-products. The effect of production technology was also noted. The sawing process conducted with the use of a frame saw and block sawing sets increased the share of saw kerfs in the material cross section.

A clear disproportion between the volume of material at the starting stage of the process and the volume of finished products was also pointed out. The finished products account for about 50% of the starting volume of large-sized roundwood. Moreover, material recovery efficiency decreased with every successive technological process.

## CONCLUSIONS

1. On the basis of conducted investigations it was found that large-sized roundwood of grade WC0 is characterised by a good material recovery efficiency of approx. 111–124%. It results both from the xylometric paradox and the presence of the taper.
2. A major reduction in the material volume was observed for the edging process. The efficiency for unedged materials was 64–75%.
3. The introduction of the edging process to the technology generates a decrease in material recovery efficiency at the level of 20% (in the case of experimental observations) and 17–25% (in the case of theoretical assumptions). The values of material recovery efficiency depend on prefabrication, the share of saw kerfs and the quantity of generated by-products.
4. The material recovery efficiency decreases with an increase in diameters of processed logs.

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## WPŁYW DOBORU SUROWCA SOSNOWEGO NA WSKAŹNIKI PRZETARCIA

### ABSTRAKT

**Wstęp.** Do badań wykorzystano drewno sosnowe (*Pinus sylvestris* L.) w postaci wielkowymiarowego drewna okrągłego charakteryzującego się klasą jakości WC0. To podstawowy surowiec przetwarzany w krajowej produkcji tartacznej.

**Materiał i metody.** Celem prezentowanych badań była ocena wpływu wymiarów drewna okrągłego na wskaźniki wydajności materiałowej. Modelowe drewno okrągłe wielkogabarytowe zostało przetworzone na kłody. Ponadto otrzymane kłody zostały przetarte w celu uzyskania z nich tarcicy w docelowym zastosowaniu jako materiał prefabrykowany.

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**Wyniki.** W pracy zaprezentowano wyniki począwszy od manipulowania kłodami, a skończywszy na ich piłowaniu i wytwarzaniu produktów końcowych.
**Wnioski.** Na podstawie przedstawionych wyników stwierdzono, że zarówno dobór surowca, jak i zastosowana technologia są istotnymi czynnikami wpływającymi na wskaźniki efektywności materiałowej w procesie wielkogabarytowego piłowania drewna okrągłego. Badania wykazały wzrost wskaźników wydajności przy obróbce kłód o mniejszych średnicach. Wskaźnik ten wynika z założeń prefabrykacji.

**Słowa kluczowe:** sosna, wydajność materiałowa, proces przetarcia, wymiary