

The forecasted values of cutting power for sawing on band sawing machines for Polish Scots pine wood (*Pinus sylvestris* L.) in a function of its provenance.

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Abstract: *The forecasted values of cutting power for sawing on band sawing machines for Polish Scots pine wood (*Pinus sylvestris* L.) in a function of its provenance.* In this paper the predicted values of cutting power for band sawing machine (EB 1800, f. EWD), which is used in the Polish sawmills, were showed. The values of cutting power were forecasted for Scots pine (*Pinus sylvestris* L.) wood of five provenances from Poland. These values were determined using an innovative method of predicting the cutting power, which takes into account of elements of fracture mechanics. The resulting predictions compared with the values of cutting power derived from predictions using the classical method, which is based on the specific cutting resistance.

Keywords: cutting power, Scots pine, band sawing machine, origin of wood

INTRODUCTION

Determining the energetic effects of the cutting process of materials allows on optimal designing of machines and processes of machining on those machines. The most widespread approach to determining the cutting power in a wood sawing process is model which based on specific cutting resistances (Manžos, 1974, Orlicz, 1988, Naylor et al., 2011). This classical cutting model takes also into account: geometry of cutting blade, cutting parameters (uncut chip thickness), strength of the material and friction between blade and workpiece (Manžos, 1974, Orlicz, 1988, Naylor et al., 2011).

Atkins in his book (2009) shows that the resistance to cracking of the workpiece is just as significant as strength and friction in determining the forces and power to cut. Basing on Atkins's theory (2003, 2009), which was successfully used by him to explain the phenomena occurring among others in metal cutting, wood (flat cutting) and composite materials (2009), Orłowski and Atkins (2007) proposed a model of cutting power forecasting. This model allows much more accurate prediction of cutting power (Orłowski et al. 2013) with included in machining tool geometry (rake angle), chip forming conditions (shear angle), and material properties of the cut material such as: fracture toughness and shear yield stress in shear zone. Krzosek (2009) revealed that strength properties of wood depend on the region of origin. The studies of sawing Scots pine wood from various parts of Poland have also shown that the properties of the workpiece depend not only on the species of wood but also on its origin (Chuchala et al., 2014, Chuchala and Orłowski 2016).

The present paper concerns a new approach to forecasting of the cutting power while wood sawing for the case of bandsawing machine.

MATERIALS AND METHODS

The values of cutting power were predicted for the process of sawing of Polish Scots pine wood. The wood was obtained from the five provenances of Poland (Figure 1). The values of material properties, which was used for the forecasting of values cutting power, were determined empirically on the frame sawing machine PRW15M with elliptical tooth

trajectory and the hybrid dynamically balanced driving system (Wasielwski and Orłowski 2002).

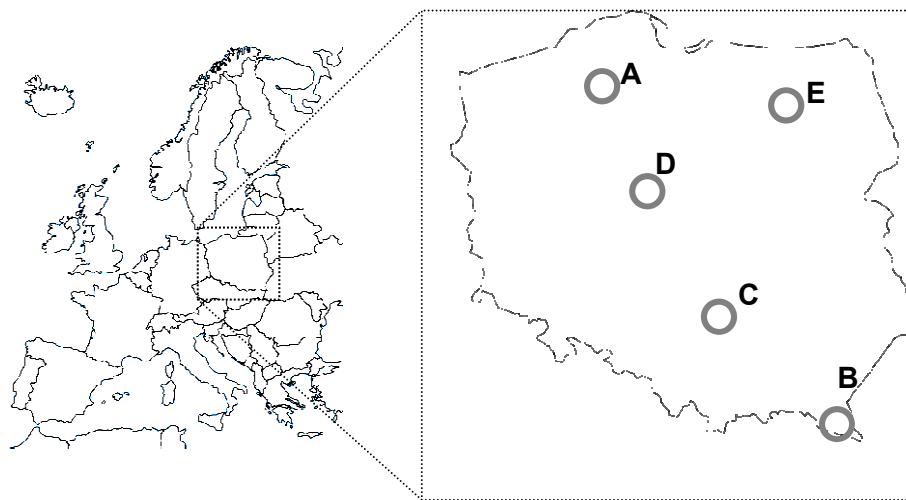


Figure 1. Locations of Polish natural-forest regions of Scotch pine wood origins, were: A - Baltic Natural Forest Region, B - Carpathian Natural Forest Region, C - Little Poland Natural Forest Region, D - Great Poland-Pomeranian Natural Forest Region, E - Masuria-Podlachian Natural Forest Region (Chuchala and Orłowski 2016)

The methodology of determining values of material properties such as fracture toughness and shear yield stresses for wood was developed by Orłowski and was described in papers (Orłowski and Atkins 2007, Orłowski and Palubicki 2009, Orłowski et al. 2013).

Table 1. The average values of fracture toughness and shear yield stress of Scots pine with dispersions

Region	Location	Values of fracture toughness R_{\perp} [J/m ²]	Values of shear yield stress τ_y [MPa]	Density ρ [kgm ⁻³]
A	Baltic Natural Forest Region	1295,33 ± 383,881	20,861±0,27	520
B	Carpathian Natural Forest Region	1496,32 ± 385,888	16,846 ± 0,384	439
C	Little Poland Natural Forest Region	1267,17±347,814	17,987±0,232	478
D	Great Poland-Pomeranian Natural Forest Region	1141,30 ± 869,23	29,521 ± 0,968	589
E	Masuria-Podlachian Natural Forest Region	1359,631±1071,429	13,87±1,419	456

The values of fracture toughness and shear yield stresses for Polish Scots pine wood were determined and were presented in the paper (Chuchala and Orłowski 2016). These values are presented in Table 1. The prediction of the value of cutting power during sawing of Polish Scots pine wood of five provenances from Poland was conducted for bandsawing machine of type EB1800 f. EWD. These type of bandsawing machines are quite popular in Polish sawmills. The characteristic data of the machine and tools used on it is shown in Table 2.

The sawing pattern for the forecasted process of bandsawing machine is presented in Fig. 2. In discussed pattern, the thickness of the main material is of $2a = 150$ mm, and on each side are additionally obtained 1 board of $c = 22.5$ mm in thickness. The dimensions of logs for forecast it: diameter d_g in thinner end about 9" (top diameter $d_g \approx 230$ mm), and length

$l = 3$ m. The workpiece thickness H_p presented in the Tab. 1 in this case is a value of kerf depth determined in the middle of the log length. In order to estimate a middle log diameter d , the taper coefficient TC (cm/m, the degree of taper) was calculated as follows (Leśnik, 2013):

$$TC = \frac{1}{10} \left[6.2 + 74l^{-3} + \left(\frac{0.48}{\sqrt{l}} - 0.12 \right) (d_g - 22 + 0.3l) \right] \quad (1)$$

where: l is the log length in m, and d_g is the top diameter without bark in cm. Thus, in this case $TC = 0.922$ cm/m, and for this data middle log diameter is $d = 24.74$ cm.

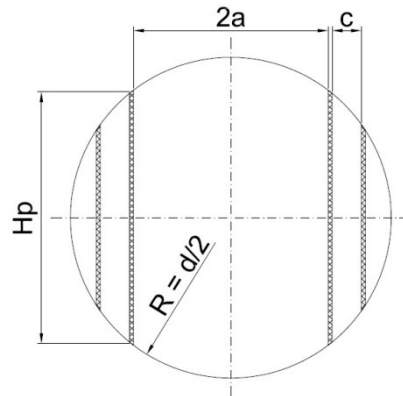


Figure 2. Applied sawing pattern

Table 2. Tool and machine tool data

H_p [mm]	n_{sb} [mm]	S_t [mm]	P [mm]	γ_f [°]	z [-]	v_c [m/s]	v_f [m/min] ([m/s])	f_z [mm]*	h [mm]*	P_{EM} [kW]
194,2	1	3,1	50	28	217	35	40–70 (0,67– 1,167)	0,95– 1,67	0,95– 1,67	110

Legend: *The values used in computation of predicted cutting powers, P_{EM} – electric motor power, n_{sb} – number of saw blades, γ_f – the rake angle, v_f – feed speed, z – number of tooth in blade

For bandsawing machines, the cutting power was is described by equation (2) (Orlowski et al. 2013).

$$\bar{P}_{cw} = F_c v_c + P_{ac} = \left[z_a \cdot \frac{\tau_\gamma S_t \gamma}{Q_{shear}} v_c \bar{h} + z_a \cdot \frac{R S_t}{Q_{shear}} v_c \right] + P_{ac} \quad (2)$$

where: $z_a = \left(\frac{H_p}{P} \right)$ is an average number of teeth being in the contact with the kerf, H_p is workpiece height (cutting depth), P is tooth pitch, τ_γ is the shear yield stress, γ is the shear strain along the shear plane, h is uncut chip thickness (feed per tooth f_z), S_t is a kerf (the width of orthogonal cut), R_\perp is specific work of surface separation/formation (fracture toughness), Φ_c is the shear angle which defines the orientation of the shear plane with respect to cut surface. The values of shear angle are solved numerically from equation which was proposed by Atkins (2003, 2009), and Q_{shear} is the friction correction (Atkins 2003).

The chip acceleration power P_{ac} variation as a function of mass flow and tool velocity is given by:

$$P_{ac} = \dot{m} v_c^2 \quad (3)$$

where: \dot{m} (kg s^{-1}) represents the mass of wood (chips) evacuated in a certain period of time at the certain cutting tool velocity v_c (cutting speed), which can be calculated as follows:

$$\dot{m} = H_p S_t v_f \rho \quad (4)$$

where: ρ is density of sawn wood .

The cutting power was also determined using a classical approach based on the specific cutting resistance k_c (k_c _Man):

$$P_c = \frac{v_f \cdot S_t \cdot H_p}{60} k_c \quad (5)$$

The values of specific cutting resistance were calculated using dependence, which was recommended by Manžos (1974) for a band sawing machine in the case of pine sawing as follows:

$$k_c = 9.91(5.3 + 0.01H_p - 0.03v_f) \quad (6)$$

where H_p is in mm and v_f is $\text{m} \cdot \text{min}^{-1}$. The obtained values from equation (6) were multiplied by factor $k_{vc} = 1.04$ (Manžos 1974, Orlicz 1988), which takes into account the cutting speed.

RESULTS

Estimated values of cutting power for band sawing process of Scots pine originating from five different regions of Poland were shown on Figure 3.

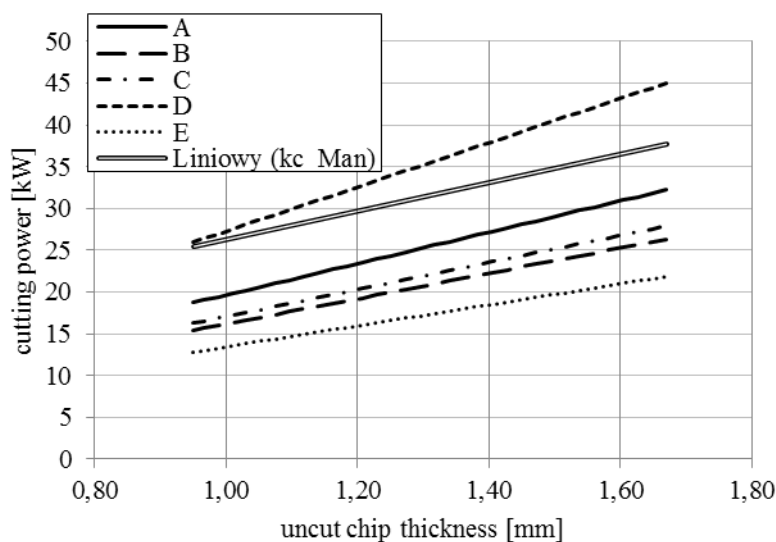


Figure 3. Forecasted values of cutting power for band sawing process of Scots pine originating from five different regions of Poland

The differences in forecasted values of cutting power are noticeable since they have taken into account the region of origin of the raw material. The highest values of cutting power are forecasted for Scots pine wood from the Great Poland-Pomeranian Natural Forest Region (Region D). The smallest values of cutting power are forecasted for Scots pine wood from the Masuria-Podlachian Natural Forest Region (Region E). The predicted values of cutting power

using classical approach (k_c _Man) are only slightly less than determined values for Scots pine wood obtained from the Region D.

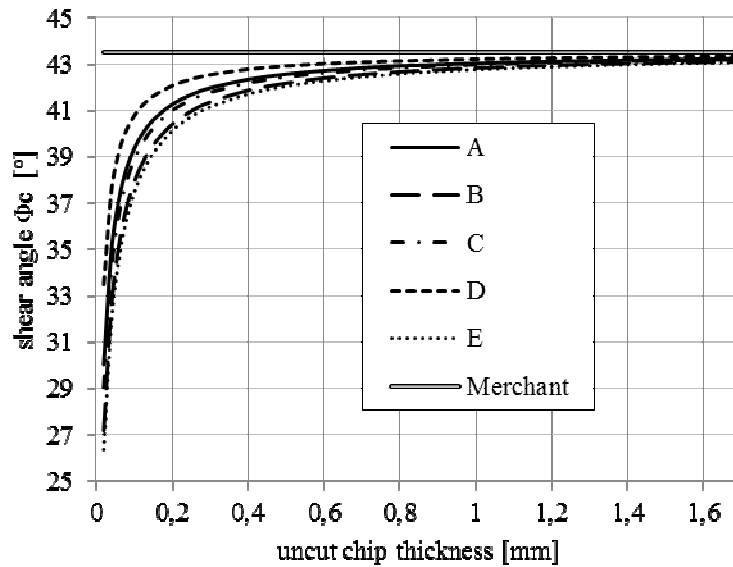


Figure 4. Determined values of shear angle for band sawing process of Scots pine originating from five different regions of Poland

In Figure 4 the values of shear angle, which were forecasted using Atkins's idea for Scots pine wood obtained from five region of Poland were shown. For comparison in the same figure the values of shear angle determined using Merchant equation were shown. The all determined values of shear angles are similar for values of uncut chip thickness larger than 1.2 mm. For smaller values of uncut chip thickness, differences of values of shear angle are noticeable.

CONCLUSIONS

The model of forecasting of energetic effects of sawing process, which based on fracture mechanics, allows more accurate prediction of cutting power and shear angle, since it takes into account the origin of Scots pine.

This kind of approach to modelling of energetic effects while wood cutting allows for differentiation of the wood sawing process depending on the region where the wood is obtained.

REFERENCES

1. ATKINS A.G., 2003: Modelling metal cutting using modern ductile fracture mechanics: quantitative explanations for some longstanding problems. *International Journal of Mechanical Sciences*, 45: 373–396.
2. ATKINS A.G., 2009: The science and engineering of cutting. The mechanics and process of separating, scratching and puncturing biomaterials, metals and non-metals, Butterworth-Heinemann is an imprint of Elsevier, Oxford.
3. CHUCHAŁA D.; ORLOWSKI K.A., 2016: Shear yield stresses and fracture toughness of Scots pine (*Pinus sylvestris* L.) according to the raw material provenance, *Chip and Chipless Woodworking Processes* 10(1): 49-55
4. CHUCHAŁA D., ORLOWSKI K., SANDAK A., SANDAK J., PAULINY D., BARANSKI J., 2014: The Effect of Wood Provenance and Density on Cutting Forces While Sawing Scots Pine (*Pinus sylvestris* L.), *BioRes.* 9(3), 5349-5361.
5. GROTHE K.H., ANTONSSON E.K. (Eds.), 2008: Machining Processes. W: Springer Handbook of Mechanical Engineering, Part B: Applications in Mechanical Engineering. Springer: 606–656.
6. KRZOSEK S., 2009: Wytrzymałościowe sortowanie polskiej sosnowej tarcicy konstrukcyjnej różnymi metodami, (In Polish: Timber strength grading of *Pinus Sylvestris* L. using a different methods), Wydawnictwo SGGW, Warszawa, 127 p.
7. Leśnik, 2013: LasyRej_20130110. Obsługa drewna kłodowanego. Podręcznik użytkownika. System Informatyczny Lasów Państwowych. Lasy Państwowe. Warszawa, styczeń. 21 p.
8. MANŽOS F.M., 1974: Derevorežušie Stanki, (In Russian: Wood cutting machine tools), Izdatel'stvo Lesnaâ Promyšlennost', Moskva.
9. NAYLOR A., HACKNEY P., PERERA N., CLAHR E., 2012: A predictive model for the cutting force in woodmachining developed using mechanical properties, *BioRes*, 7/3, 2883–2894.
10. ORLICZ T., 1988: Obróbka drewna narzędziami tnącymi, (In Polish: Wood machining with cutting tools), Skrypty SGGW-AR w Warszawie, Wydawnictwo SGGW-AR, Warszawa.
11. ORLOWSKI K.A., ATKINS A., 2007: Determination of the cutting power of the sawing process using both preliminary sawing data and modern fracture mechanics. In: Navi P., Guidoum A. (eds) Proceedings of the third international symposium on wood machining. Fracture mechanics and micromechanics of wood and wood composites with regard to wood machining, 21-23 May, Lausanne, Switzerland. Presses Polytechniques et Universitaires Romandes, Lausanne.
12. ORLOWSKI K.A., PAŁUBICKI B., 2009: Recent progress in research on the cutting process of wood. A review COST Action E35 2004-2008: wood machining-micromechanics and fracture. *Holzforschung* 63.
13. ORLOWSKI K.A., 2010: The fundamentals of narrow-kerf sawing: the mechanics and quality of cutting. Publishing house of the Technical University in Zvolen, Technical University in Zvolen.
14. ORLOWSKI K.A., OCHRYMIUK T., ATKINS A., CHUCHAŁA D., 2013: Application of fracture mechanics for energetic effects predictions while wood sawing. *Wood Sci Technol*, 47(5): 949–963 (Open access).
15. WASIELEWSKI R., ORLOWSKI K., 2002: Hybrid dynamically balanced saw frame drive. *Holz Roh- Werkst* 60.

Streszczenie: *Prognozowane wartości mocy skrawania dla przecinania na pilarcze taśmowej polskiego drewna sosnowego (*Pinus sylvestris* L.) w zależności od region pochodzenia.* W artykule przedstawiono prognozowane wartości mocy skrawania dla pilarki taśmowej (EB 1800, f. EWD), która jest popularna w polskich tartakach. Wartości mocy skrawania były prognozowane dla drewna sosnowego (*Pinus sylvestris* L.) pochodzącego z pięciu regionów Polski. Wartości te określono przy zastosowaniu innowacyjnej metody prognozowania mocy skrawania, która uwzględnia elementy mechaniki pęknięcia. Uzyskane prognozy porównano z wartościami mocy skrawania określonymi przy zastosowaniu klasycznej metody, która opiera się na właściwym oporze skrawania.

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