Annals of Warsaw University of Life Sciences - SGGW
Forestry and Wood Technology № 99, 2017: 75-80
(Ann. WULS - SGGW, For. and Wood Technol. 99, 2017)

Cutting power estimation of the bandsawing process of beech wood (*Fagus sylvatica* L.) dried in three operating modes

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Abstract: *Cutting power estimation of the bandsawing process of beech wood (Fagus sylvatica* L.*) dried in three operating modes.* In this paper the predicted values of cutting power for bandsawing machine (ST100R, f. Stenner), which is located at the sawmill company Complex in Dziemiany, were presented. The values of cutting power were forecasted for beech wood (*Fagus sylvatica* L.), from the northern part of Pomerania region in Poland, which was dried in three operating modes: BKP - air drying at 25°C, BKS - air-steam mixture drying at 80°C, BKW - steam drying at 110°C. The values of cutting power were determined using an innovative method of predicting the cutting power, which takes account of elements fracture mechanics.

Keywords: cutting power, beech wood, band sawing machine, drying wood

INTRODUCTION

Theoretical and experimental determination of the cutting force is basically and the most advanced parts of the mechanics of the cutting process, which is considered as the fundamental chapter of the cutting theory (Grzesik 2010). Analysis of the cutting forces can be made with the use of the classical approach, which is based on the specific cutting resistance *kc* (Grotte and Antonnsson 2008, Grzesik 2010, Kaczmarek 1970). This approach is widely used to estimate the cutting force (cutting power) for sawing operations on frame machines, circular sawing machines and band sawing machines. For each of these methods in literature are available different values the specific cutting resistances which were determined experimentally (Agapov 1983; Manzos 1974; Orlicz 1988; Scholz et al. 2009). However, their usefulness is limited because there is not any information about conditions in which these values were determined. Additionally, for narrow-kerf sawing were presented large discrepancies in the values of specific cutting resistance (Orlowski 2010).

The issue of determining the energetic effects of sawing of wood might be also analysed from the point of view of the modern fracture mechanics (Orlowski and Atkins 2007; Orlowski and Palubicki 2009; Orlowski 2010; Orlowski et al. 2013), which with success was used to describe phenomenon in separation zone during cutting of metals (Atkins 2003, 2009).

The goal of this paper is to present the effect of the drying mode of the beech wood on the estimated cutting power while sawing on the bandsawing machine. In calculations will be used Atkins's concept (Atkins 2003, 2009). This model include also the work of material separation with the friction on the rake face and plastic deformation in the shear plane.

MATERIALS AND METHODS

The values of cutting power were predicted for beech wood derived from the northern part of Pomerania region in Poland. These beech wood samples were dried in three operating modes. The first mode was consisted of drying in open air in ambient temperature approximate 25°C (BKP). The second mode was consisted of drying under accelerated conditions in experimental kiln (Fig. 1a), at 80°C (BKS), and third was consisted of drying in the experimental kiln at temperature 110°C (BKW) at the Gdansk University of Technology.

The values of material properties, which were used for the forecasting of cutting power, were determined in experimental tests (Baranski et al. 2013, 2014; Orlowski and Atkins 2007; Orlowski anf Palubicki 2009) on the frame sawing machine PRW15M with elliptical tooth trajectory and the hybrid dynamically balanced driving system (Wasielewski and Orlowski 2002).

The values of the fracture toughness and the shear yield stresses (Baranski et al. 2014) for beech wood (*Fagus sylvatica* L.) from the northern part of Pomerania region in Poland, which was dried in three operating modes are shown in Table 1.

a) b)

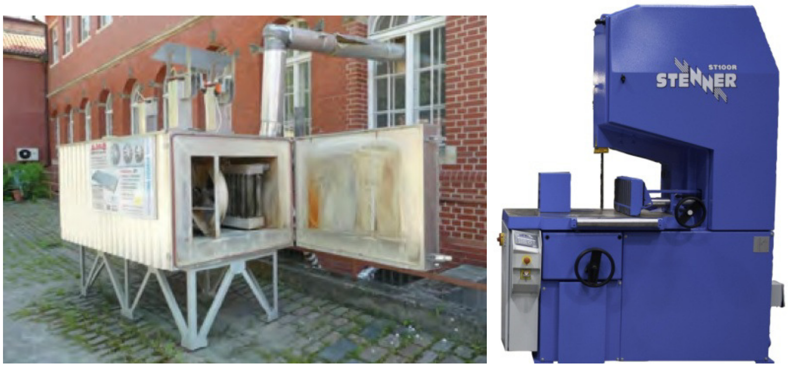

Figure 1. a) Experimental kiln at Gdansk University of Technology (Baranski et al. 2013), b) bandsawing machine ST100R f. Stenner (Stenner 2011)

Table 1. The average values of fracture toughness and shear yield stress of beech wood with dispersions

Sign	Operating mode of drying	Values of fracture toughness $R_{\perp}$ [J/m^2]	Values of shear yield stress τ_{γ} [MPa]
BKP	air drying at 25°C	4514.08 ± 1157.8	40.267 ±0.95
BKS	air-steam mixture drying at 80°C	3015.51 ± 1083.8	38.451 ± 0.82
BKW	steam drying at 110°C	3548.48 ± 1894.3	38.349 ± 1.33

The prediction of the value of cutting power during sawing of beech wood, which was dried in three operating modes, was conducted for bandsawing machine of type ST100R f. STENNER (Fig. 1b). The discussed bandsaw is located at the sawmill company Complex in Dziemiany (PL). 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.

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]	P_i [kW]	P_{cA} [kW] (P^1_{cA})
75	1	2,2	32	20	173	29	5–60 (0.083–1)	0.095–1.14	0.095–1.14	15	2.5	10 (10)

Legend: *The values used in computation of predicted cutting powers, P_{EM} – electric motor power, P_i – idling power, P_{cA}, (P^1_{cA}) – available cutting power in the cutting zone (available cutting power per one saw blade), n_{sb} – number of saw blades

The cutting power was is described by equation (1), which by proposed by Atkins and Orlowski (2007), and Orlowski et al. (2003), which allows the machine tool user to predict cutting power for a band sawing machine. This equation takes into account also, that chips, which were created, have to be accelerated to value of speed equal to the cutting speed of the tool v_c (Atkins 2009; Pantea 1999).

$$\overline{P}_{cw} = F_c v_c + P_{ac} = \left[z_a \cdot \frac{\tau_\gamma S_t \gamma}{Q_{shear}} v_c \overline{h} + z_a \cdot \frac{R S_t}{Q_{shear}} v_c \right] + P_{ac} \tag{1}$$

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), τ_γ is the shear yield stress, γ is the shear strain along the shear plane, which is given by:

$$\gamma = \frac{\cos \gamma_f}{\cos(\Phi_c - \gamma_f) \sin \Phi_c} \tag{2}$$

f_z is feed per tooth (uncut chip thickness h), S_t is a kerf (the width of orthogonal cut), β_μ – friction angle which is given by $\tan^{-1}\mu = \beta_\mu$, with μ the coefficient of friction, γ_f is the rake angle, Φ_c is the shear angle which defines the orientation of the shear plane with respect to cut surface, $R_\perp$ is specific work of surface separation/formation (fracture toughness), and Q_{shear} is the friction correction:

$$Q_{shear} = [1 - (\sin \beta_\mu \sin \Phi_c / \cos(\beta_\mu - \gamma_f) \cos(\Phi_c - \gamma_f))] \tag{3}$$

For least force F_c the shear angle Φ_c satisfies [2]:

$$\left[1 - \frac{\sin \beta_\mu \sin \Phi_c}{\cos(\beta_\mu - \gamma_f) \cdot \cos(\Phi_c - \gamma_f)} \right] \cdot \left[\frac{1}{\cos^2(\Phi_c - \gamma_f)} - \frac{1}{\sin^2 \Phi_c} \right] = \\ = -\left[\cot \Phi_c + \tan(\Phi_c - \gamma_f) + Z \right] \cdot \left[\frac{\sin \beta_\mu}{\cos(\beta_\mu - \gamma_f)} \left\{ \frac{\cos \Phi_c}{\cos(\Phi_c - \gamma_f)} + \frac{\sin \Phi_c \sin(\Phi_c - \gamma_f)}{\cos^2(\Phi_c - \gamma_f)} \right\} \right] \tag{4}$$

in which $Z = \frac{R}{\tau_\gamma \cdot f_z}$ is the parameter which makes Φ_c material dependent. Equation (4) is solved numerically.

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

$$P_{ac} = \dot{m} v_c^2 \tag{5}$$

where: $\dot{m}$ (kgs^{-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:

$$\dot{m} = H_P S_t v_f \rho \tag{6}$$

where: ρ is density of sawn wood .

RESULTS

The values of estimated cutting power of the bandsawing process of beech wood (*Fagus sylvatica* L.*)* dried in three operating modes, were presented in Figure 2.

The highest values of the cutting power are for material dried naturally in air. Lower values are for wood after drying process using air-steam mixture at 80°C and steam at 110°C, nevertheless, these values are very similar.

The figure 2 shows that the values estimated cutting power are higher than available cutting power in the cutting zone in half range of uncut chip thickness. The limit value of uncut chip thickness for beech wood dried in air (BKP) is about 0.54 mm. For beech wood dried with using the other two discussed operating modes (BKS and BKW), the limit values of uncut chip thickness are about 0.66 mm.

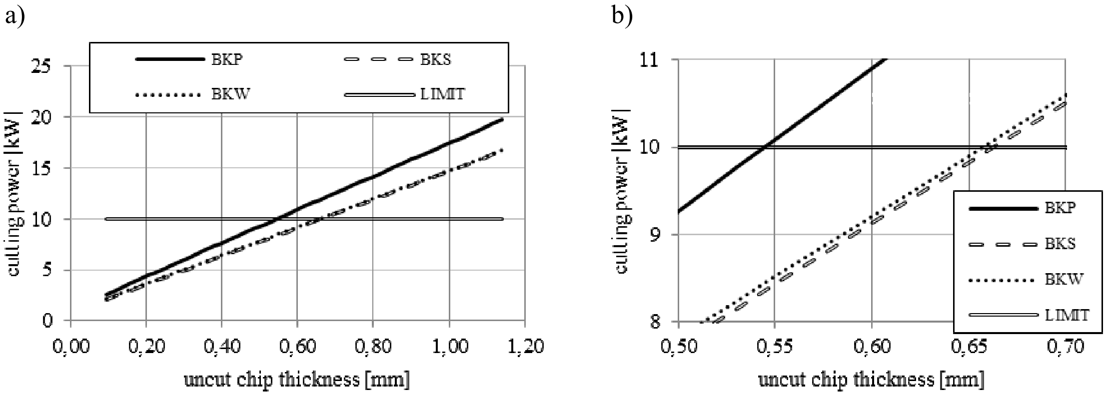

Figure 2. Predicted cutting power of the bandsawing process of beech wood (*Fagus sylvatica L.*) dried in three operating modes: a) full range of forecast, b) narrow range to make it easier to see the differences in the values

CONCLUSIONS

Predicting of cutting power with using modern model which based on elements fracture mechanics and takes account of material properties allows the sawmill management to estimate the capacity of the bandsawing machine in terms of the available power for beech wood ,which was died in different operating modes, in advance before processing. The highest values of cutting power were obtained for naturally dried wood.

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Streszczenie: *Prognozowanie mocy skrawania dla procesu przecinania na pilarce taśmowej drewna bukowego (Fagus sylvatica* L.*) po procesie suszenia w różnych warunkach.* W artykule przedstawiono prognozowane wartości mocy skrawania dla procesu przecinania na pilarce taśmowej (ST100R, f. Stenner), która zlokalizowana jest w tartaku firmy Complex w Dziamianach. Warności mocy skrawania zastały oszacowane dla drewna bukowego (*Fagus sylvatica* L.*)* uzyskanego z północnej części Pomorza w Polsce. Drewno to zostało poddane procesowi suszenia w trzech różnych warunkach: BKP - przy użyciu powietrza w temperaturze 25^{o}C, BKS - mieszaniny powietrzno-parowej w temperaturze 80^{o}C, BKW - pary wodnej w temperaturze 110^{o}C. Do określania wartości mocy skrawania zastosowano nowatorską metodę uwzględniającą elementy mechaniki pękania.

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