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Distinctive properties of Scots pine (*Pinus sylvestris* L.) originating from the Carpathian and Great Poland-Pomeranian of Nature and Forest Land

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Abstract: *Distinctive properties of Scots pine (Pinus sylvestris L.) originating from the Carpathian and Great Poland-Pomeranian of Nature and Forest Land*. In this paper values of properties of Scots pine, the fracture toughness and of shear yield stress in the shear zone are presented. Samples of Scotch pine (*Pinus sylvestris* L.) wood of two provenances from Poland were tested. These properties were determined from the values of cutting power obtained experimentally on the saw frame PRW-15M. The values of fracture toughness and shear yield stress based on the Atkins model for cutting power and using a methodology developed by Orlowski were determined. The diversity characteristic properties of Scots pine depending on the origin of wood were showed.

Keywords: Scots pine, fracture toughness, the yield strength, the origin of wood~~;~~

INTRODUCTION

In review of issues relating to cutting wood with saws (Naylor and Hackney 2013) were demonstrated that predicting energy effects of the process of cutting (cutting power and cutting force) are still mainly calculated on the basis of specific cutting resistance k_c (Manžos 1974; Orlicz 1988), the same as in the case of metal-cutting (Grzesik 2010; Olszak 2008). However, this issue arouses interest, as evidenced by the publications by Sitkei (2011) and Cristóvão et al. (2013). Sitkei (2011) has compared the similarities energetic of cutting processes on sash gang saws, circular sawing and band sawing machines. Cristóvão et al. (2013) have studied the power consumption of a circular saw during cutting of pine wood (*Pinus sylvestris* L.) under industrial conditions. The empirical results obtained by Cristóvão et al.(2013) were compared with the results of calculations of cutting power of the empirical model by Axelssson (Axelsson et al. (1993)). The mentioned model has been transformed by Porankiewicz et al. (2011) into the multi-factor equation of regression, which takes into account the following factors: the angle between the wood grain and cutting speed $\Phi_{G\text{–}vc}$, the wood density ρ, the moisture content of wood MC, the wood temperature T, radius of the cutting edge round up ρ_{CE}, the rake angle γ_f, the cutting speed v_c, and the uncut chip thickness h.

The modern approach proposed by Atkins (2003, 2005, 2009) to the cutting process shows that the cutting force (cutting power) depends on the fracture toughness of R [J/m^2] and the shear yield strength τ_y of the raw material of the workpiece and the friction conditions in the cutting zone. This model enables a simple determination the fracture toughness of R and the shear yield strength τ_y on the basis of experimental cutting tests (Atkins 2003, 2005, 2009).

MATERIALS

In experimental tests samples of Scotch pine (Pinus sylvestris L.) originating from two provenances in Poland were used (Fig. 1) (Krzosek 2009). Samples were obtained randomly from different representative trees and they were prepared as the rectangular prisms with dimensions of 60×45×600 mm (H×W×L respectively). From each region eight samples were investigated. Moisture content MC of samples was concentrated about ~12%.

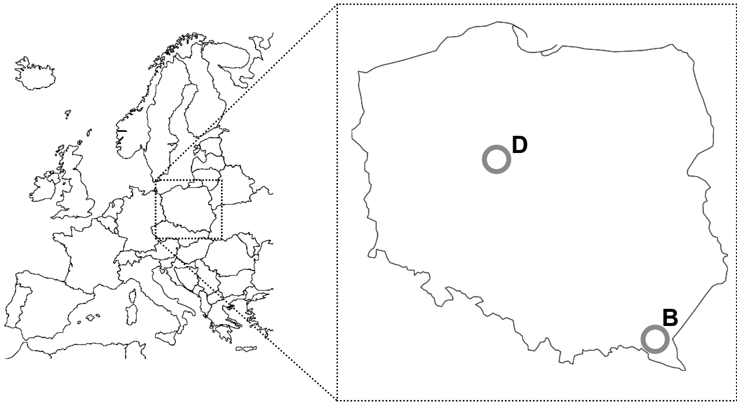

Figure 1. Locations of Polish natural-forest regions of Scotch pine wood origins

Cutting tests for empirical determination of cutting power were carried out on the frame sawing machine PRW15M with elliptical tooth trajectory and the hybrid dynamically balanced driving system (Wasielewski and Orlowski 2002). In the experimental tests following machine settings were applied; number of strokes of the saw frame per min $n_F = 685$ rpm, number of saws in the gang $m = 5$ and average cutting speed $v_c = 3.69$ m·s^{-1}, saw frame stroke $H_F = 162$ mm. Saw blades were sharp, 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, tension stresses of saw blades in the gang $\sigma_N = 300$ MPa, blade width $b = 30$ mm, tooth pitch $P = 13$ mm, tool side rake $\gamma_f = 9°$, and tool side clearance $\alpha_f = 14°$.

The feed speed v_f was established on two levels of about 0.3 and 1.1 m / min. The exact values of the feeds speed and corresponding feeds per tooth were determined on the basis of actual recorded courses of cutting power which was consumed by the engine of the main movement of the frame sawing machine.

The value of the average cutting power $\overline{P}_c$ was calculated as the difference of the mean total power the main propulsion $\overline{P}_{cT}$ and the average idle power main propulsion $\overline{P}_i$ (Orlowski 2012):

$$\overline{P}_c = \overline{P}_{cT} - \overline{P}_i \tag{1}$$

The average idle power main propulsion of frame sawing PRW15-M was determined immediately before the commencement of each cutting tests. It allowed to take into account changing the value of the average power idle, which depends on the temperature of the oil in gearboxes of the main propulsion. Values of the average cutting power in a working stroke were calculated in accordance with Fig. 2 as follows (Orlowski 2012):

$$\overline{P}_{cw} = 2\overline{P}_c \tag{2}$$

Taking into account the model of cutting forces presented by Atkins (2003, 2005), the average value of cutting power in the working stroke $\overline{P}_{cw}$ [W] (Fig. 2) for one saw blade in cutting wood on the frame sawing machine (sash gang saw) can be described (Orłowski and Ochrymiuk 2011; Orlowski et al. 2013; Orlowski and Pałubicki 2009):

$$\overline{P}_{cw} = m\left[n\frac{\tau_\gamma S_t \gamma}{Q}v_c f_z + n\frac{RS_t}{Q}v_c\right] = m\left[\frac{H_P}{P}\frac{\tau_\gamma S_t \gamma}{Q}v_c f_z + \frac{H_P}{P}\frac{RS_t}{Q}v_c\right] \tag{3}$$

where: n – is the number of teeth being in contact with the kerf (average), H_P – is workpiece height (cutting depth) [mm], f_z – is feed per tooth (uncut chip thickness h), [mm], γ – is the shear strain along the shear plane, Q – is the friction correction (Atkins 2003, 2005; Orlowski et al. 2013).

For the needs of this experiment values of the shear angle were determined with equation proposed by Merchant (Orlowski and Atkins 2007; Orlowski and Pałubicki 2009), since, it was assumed that the phenomena concern sawing for larger values of uncut chip thicknesses.

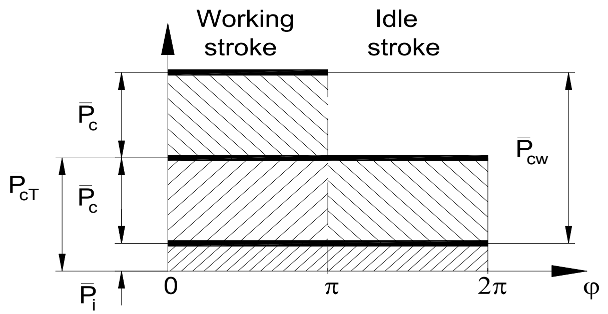

Fig. 2. Cutting powers in the saw frame machine cycle (working stoke + idle stoke) (Orłowski 2010)

Values of fracture toughness R [J/m^2] and shear yield stress τ_γ were determined from the coeeficients of the equation (3) and average values cutting power in a working stroke obtained in cutting tests. Methods of determining these properties were extensively described in the publications (Orlowski and Atkins 2007; Orlowski and Pałubicki 2009).

RESULTS

Figures 3 and 4 show changes in cutting power per one saw during cutting of Scots pine originating from two different regions of Poland (Fig.1).
For values in Figures 3 and 4 were determined respectively the regression equations, for region B:

$$P_c\,[\mathrm{W}] = 69{,}84906 + 2184{,}62531 \cdot f_z \tag{4}$$

characterized by a coefficient of determination r^2 = 0,7584 (Pearson coefficient r = 0,8709), and for region D:

$$P_c\,[\mathrm{W}] = 53{,}28331 + 3828{,}82596 \cdot f_z \tag{5}$$

characterized by a coefficient of determination r^2 = 0,7417 (Pearson coefficient r = 0,8612).

The average values of fracture toughness $R_\perp$ [J/m^2] (Tab. 1) and the average values of shear yield strength in shear zone τ_y [MPa] (Tab. 2) were determined from respective regression equations (equation 4 for region B; equation 5 for region D). These values are also illustrated in the graphs (Fig. 5 and Fig. 6). Dispersions for both parameters were determined based on dashed lines relate to an area of variation for probability 95% (significance level α = 0.05).

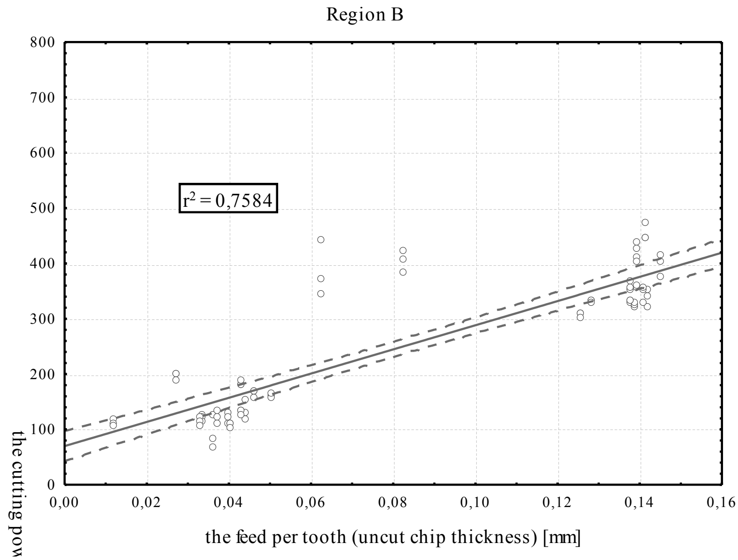

Figure 3. The cutting power per one saw blade as a function of feed per tooth (uncut chip thickness) during cutting Scots pine from the Carpathian of Nature and Forest Land (dashed lines relate to an area of variation for probability 95%)

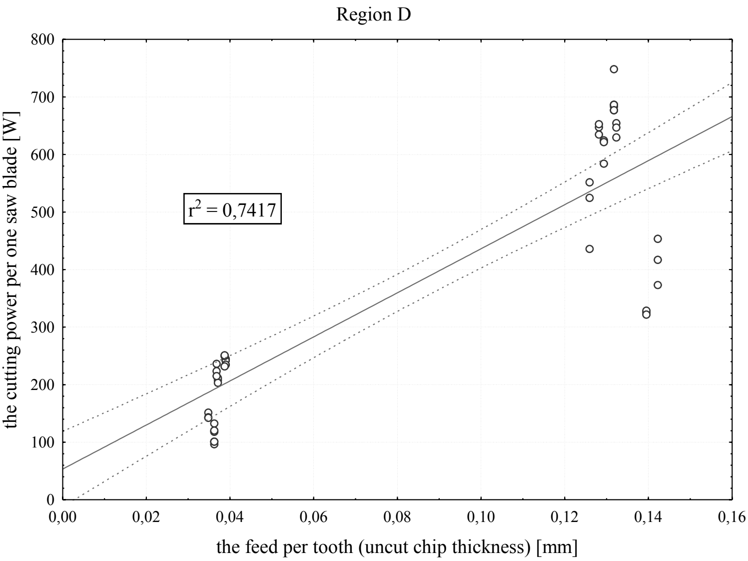

Figure 4. The cutting power per one saw blade as a function of feed per tooth (uncut chip thickness) during cutting Scots pine from the Great Poland-Pomeranian of Nature and Forest Land (dashed lines relate to an area of variation for probability 95%)

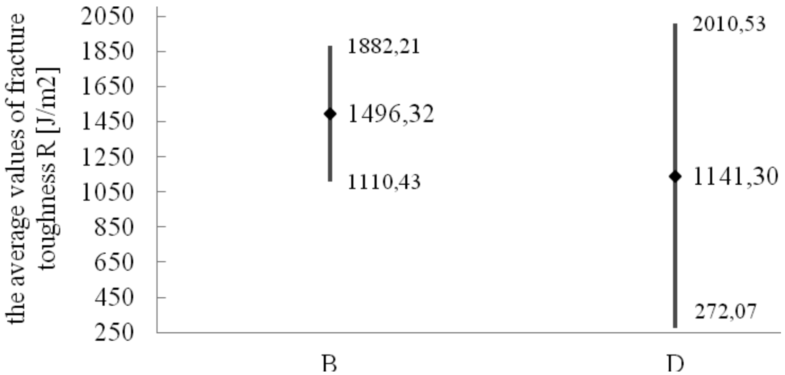

Figure 5. The average values of fracture toughness of Scots pine with dispersions

Table 1. The average values of fracture toughness of Scots pine with dispersions

Region	Location	Values of fracture toughness $R_{\perp}$ [J/m^2]
B	Carpathian Natural Forest Region	1496,32 ± 385,888
D	Great Poland-Pomeranian Natural Forest Region	1141,30 ± 869,23

Table 2. The average values of shear yield stress τ_y of Scots pine with dispersions

Region	Location	Values of shear yield stress τ_y [MPa]
B	Carpathian Natural Forest Region	16,846 ± 0,384
D	Great Poland-Pomeranian Natural Forest Region	29,521 ± 0,968

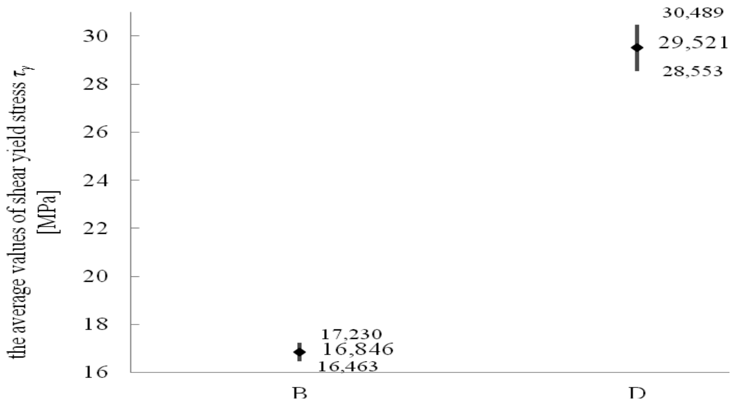

Figure 6. The average values of shear yield strength in shear zone τ_y of Scots pine with dispersions

CONCLUSIONS

The average values of fracture toughness and shear yield strength for Scots pine from two Polish regions are varied. The average values shear yield strength for Scots pine from region D (Great Poland-Pomeranian Natural Forest Region) are much higher (τ_y = 29,521 MPa) than the

values obtained for Scots pine from region B (Carpathian Natural Forest Region) (τ_γ = 16,846 MPa).
The average values of fracture toughness of Scots pine from Region B (R = 1496.32 J/m^2) are higher than the values obtained for Scots pine from region D (R = 1141.30 J/m^2), but this difference in not large.
There are differences of characteristic properties of Scots pine depending on the region of origin.

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Streszczenie: *Charakterystyczne właściwości sosny zwyczajnej pochodzącej z Karpackiej i z Wielkopolsko-Pomorskiej Krainy Przyrodniczo-Leśnej.* W niniejszym artykule zostały przedstawione wartości właściwości drewna sosnowego, takie jak: wiąskość R i naprężenia tnące τ_γ. Badane próbki drewna sosnowego pochodziły z dwóch regionów Polski. Wspomniane właściwości drewna były wyznaczane z wartości mocy skrawania uzyskanej doświadczalnie na pilarce ramowej PRW-15. Do wyznaczenie wartości wiązkości i naprężeń tnących wykorzystano model Atkins'a dla mocy skrawania oraz zastosowano metodologię opracowaną przez Orłowskiego. Wykazano zróżnicowanie wartości charakterystyczny właściwości drewna sosnowego w zależności od regionu pochodzenia.

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