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SHEAR YIELD STRESSES AND FRACTURE TOUGHNESS OF SCOTS PINE (PINUS SYLVESTRIS L.) ACCORDING TO THE RAW MATERIAL PROVENANCE

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Abstract

In this paper values of the fracture toughness and of shear yield stress in the shear zone of Scots pine are presented. Tests of cutting were carried on samples of Scotch pine (Pinus sylvestris L.*) wood of five provenances from Poland. These experimentally cutting tests were carried on the sash gang saw PRW-15M and the values of cutting power were obtained. The values of fracture toughness and shear yield stress based on Atkins's model for cutting power and using a methodology developed by Orlowski were determined from the values of cutting power. The diversity characteristic properties of Scots pine according to the raw material provenance are shown. The obtained values of fracture toughness and shear yield stresses of Polish pine wood could be used in computations of energetic effects of sawing on sash gang saws, and bandsaw machines with higher accuracy because raw material provenance is taken into account.*

Key words: *Scots pine, fracture toughness, shear yield stress, origin of wood*

INTRODUCTION

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 stress τ_γ 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 stress τ_γ on the basis of experimental cutting tests (Atkins 2003, 2005, 2009).

MATERIALS

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

The values of cutting power were determinated from experimental tests, which were carried out on the frame sawing machine PRW15M with elliptical tooth trajectory and the hybrid dynamically balanced driving system (Wasielewski and Orlowski 2002).

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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. It was assumed that 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 σ_N = 300 MPa, blade width b = 30 mm, tooth pitch P = 13 mm, tool side rake γ_f = 9°, and tool side clearance α_f = 14°.

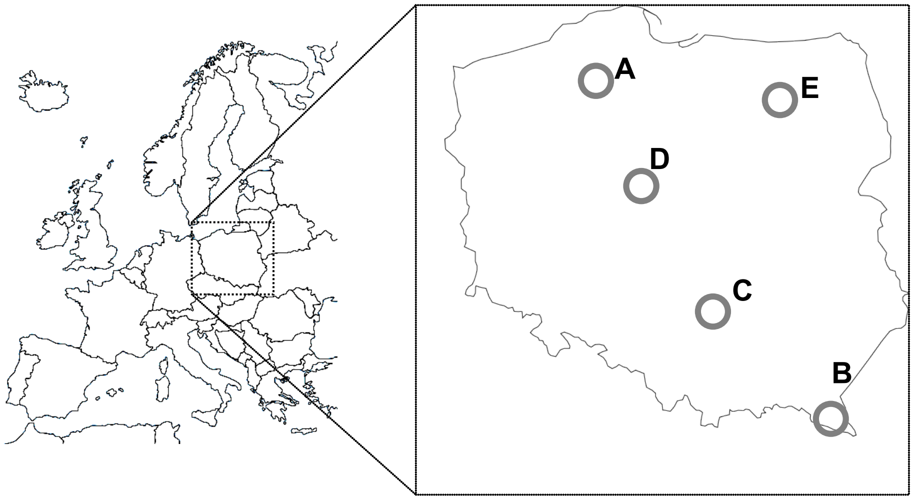

Figure 1. Locations of Polish natural-forest regions of Scotch pine wood origins, were: A - Baltic Natural Forest Region, B - Carpathian Natural Forest Region, C - Little Poland Natural Forest Region, D - Great Poland-Pomeranian Natural Forest Region, E - Masuria-Podlachian Natural Forest Region

The feed speed v_f was set 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 a difference of the mean total power the main propulsion $\overline{P}_{cT}$ and the average idle power main propulsion $\overline{P}_i$ (Orlowski 2012):

$$\overline{P}_c = \overline{P}_{cT} - \overline{P}_i \quad (1)$$

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 as follows (Orlowski 2012):

$$\overline{P}_{cw} = 2\overline{P}_c \quad (2)$$

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] 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):

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

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). The values of the shear angle for this experiment 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.

Values of fracture toughness R [J/m^2] and shear yield stress τ_γ were determined from the coefficients of the equation (3) and average values cutting power in a working stroke obtained in cutting tests. Methods of determining these properties on the basis of cutting data were minutely described in the papers (Orlowski and Atkins 2007; Orlowski and Pałubicki 2009, Hlásková et al. 2015). The goal of this paper was to present fracture toughness and shear yield stresses of Polish pine wood versus its provenance.

RESULTS

In figures 2 - 6 changes in cutting power per one saw during cutting of Scots pine originating from five different regions of Poland (Figure 1) are shown. For values in figures 2 - 6 were determined respectively the regression equations, which were presented also in these graphs. In the figures 2 – 6 additionally coefficients of determination r^2 for each equation were shown .In every plot dashed lines relate to an area of variation for probability 95%.

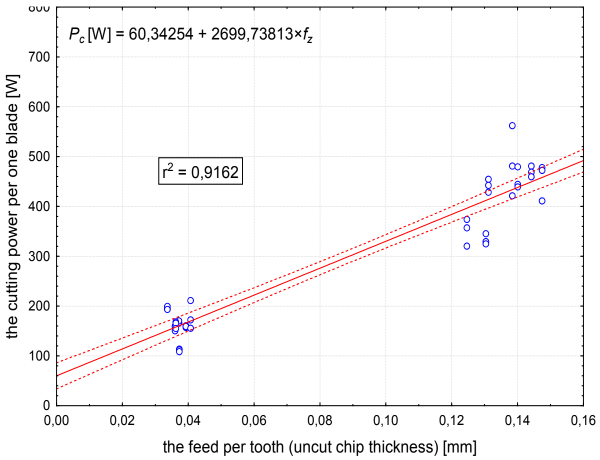

Figure 2. The cutting power per one saw blade as a function of feed per tooth (uncut chip thickness) during cutting Scots pine from the Region A

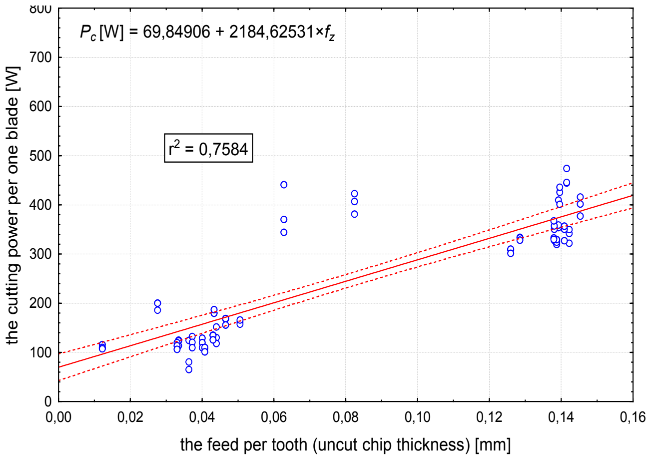

Figure 3. The cutting power per one saw blade as a function of feed per tooth (uncut chip thickness) during cutting Scots pine from the Region B

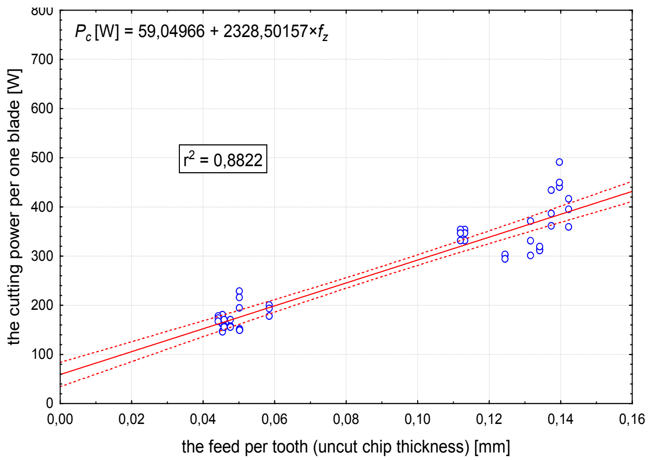

Figure 4. The cutting power per one saw blade as a function of feed per tooth (uncut chip thickness) during cutting Scots pine from the Region C

The average values of fracture toughness $R_{\perp}$ [J/m^2] (Table 1) and the average values of shear yield stress in shear zone τ_y [MPa] (Table 2) were determined from the obtained regression equations (Figures 2 – 6). Dispersions for both parameters were determined based on dashed lines related to an area of variation for probability 95% (significance level $\alpha = 0.05$).

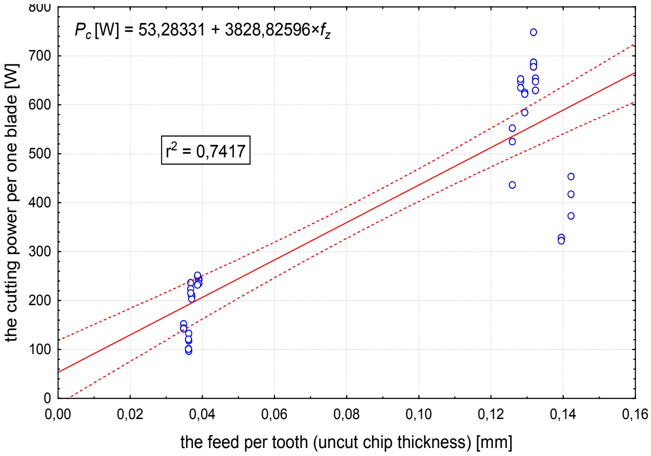

Figure 5. The cutting power per one saw blade as a function of feed per tooth (uncut chip thickness) during cutting Scots pine from the Region D

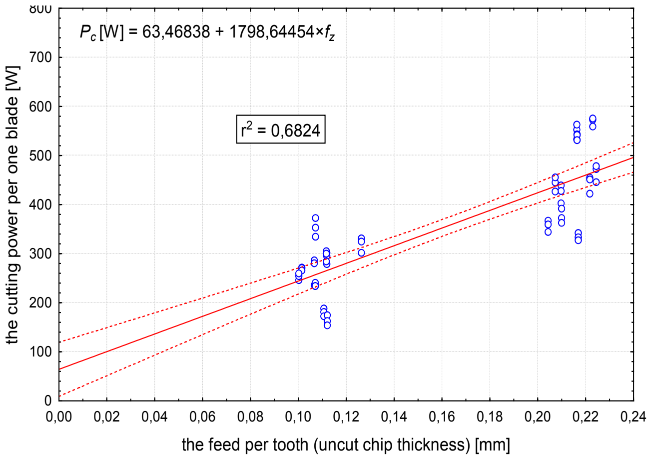

Figure 6. The cutting power per one saw blade as a function of feed per tooth (uncut chip thickness) during cutting Scots pine from the Region E

The obtained values of fracture toughness and shear yield stresses of Polish pine wood could be used in computations of energetic effects of sawing on sash gang saws (Orlowski and Ochrymiuk 2013), and bandsaw machines (Orlowski et al. 2013) with higher accuracy than with traditional approaches (we do not know a palce of raw material origin) because it takes wood provenance into account.

CONCLUSIONS

The average values of shear yield stresses for Scots pine from Region D (Great Poland-Pomeranian Natural Forest Region) are much higher (τ_γ = 29,521 MPa) than the values obtained for Scots pine from other regions. On the contrary, the average values of shear yield stresses for Scots pine from Region E (Masuria-Podlachian Natural Forest Region) are lowest among the five examined regions (τ_γ = 13,87 MPa).

The average values of fracture toughness of Scots pine from Region B (R = 1496.32 J/m^2) are highest among the five examined regions. The lowest average values of fracture toughness of Scots pine has been observed for Region D (R = 1141.30 J/m^2). Differences between average values of fracture toughness of Scots pine from five region are not large.

The average values of fracture toughness and shear yield stress for Scots pine from five Polish regions are varied. Larger differentiation in the average values is for shear yield stresses for Scots pine and less differentiation average value is for fracture toughness.

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

Region	Location	Values of fracture toughness $R_\perp$ [J/m^2]
A	Baltic Natural Forest Region	1295,33 ± 383,881
B	Carpathian Natural Forest Region	1496,32 ± 385,888
C	Little Poland Natural Forest Region	1267,17±347,814
D	Great Poland-Pomeranian Natural Forest Region	1141,30 ± 869,23
E	Masuria-Podlachian Natural Forest Region	1359,631±1071,429

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

Region	Location	Values of shear yield stress τ_γ [MPa]
A	Baltic Natural Forest Region	20,861±0,27
B	Carpathian Natural Forest Region	16,846 ± 0,384
C	Little Poland Natural Forest Region	17,987±0,232
D	Great Poland-Pomeranian Natural Forest Region	29,521 ± 0,968
E	Masuria-Podlachian Natural Forest Region	13,87±1,419

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