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The differential impact of a density of Polish pine wood on cutting forces with its origin region taken into consideration

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Abstract: *The differential impact of a density of Polish pine wood on cutting forces with its origin region taken into consideration*. In the article the dependence of cutting forces in a function the density of wood with regard to the wood origin are presented. Samples used in experiment were with Scotch pine (Pinus sylvestris L.) originating from four provenances in Poland (Figure 1). Wood density was measured by two methods: stereometric method (global density) and radiometric method (local density). Stereometric method consists in measurements the volume of the sample by determination of the various dimensions (length, width, height), and weighting of the sample mass. Estimation of the local density was after experiments of cutting using a non-destructive methods of radiometric developed IVALSA \ CNR. Measurement of cutting forces made during the empirical cutting a samples of wood on the saw frame PRW15M.

Keywords: cutting force, density of wood, X-ray densitometer, wood provenance

INTRODUCTION

An accurate prediction of the power cutting is issue incredibly difficult and is the subject of research for many years. The value of the power required for sawn wood samples (cutting force) is affected by many factors related to the structural features of wood and parameters of the technological process. One of the main factors is the density of the wood. Nowadays several "easy to use" tools (i.e. internet-based) become available for determination of cutting power consumption on the basis of specific gravity of wood. However, the carried out through studies have shown that this approach can be adopted only as a very rough estimation of the cutting power [4]. Therefore appeared the objective of this paper to show the effect a density of wood on the cutting force taking into account a region of origin.

MATERIALS

Scotch pine (*Pinus sylvestris* L.) samples originating from four provenances in Poland (Figure 1) were used as experimental samples. Samples were in the form of prisms with dimensions of 60×45×600 mm (H×W×L respectively), and were conditioned to moisture content *MC* of ~12%. Eight samples from each region, obtained randomly from different representative trees, were investigated. Some more details on the sample selection, preparation and characterization can be found in the related literature [1, 2].

Density determination

Sample dimensions (width, height and length of wooden blocks) and weight were measured just before sawing. The dimensions of the cross-sectional sample (width, height) were measured with the caliper at six points, equally distributed along the prism. The length was measured with the wind-up measuring tape. The "global density" of wood was estimated by the use of the stereometrical method [3] which is based on measurements of the sample volume by measuring the various dimensions (length, width, height), and also the determination of the mass sample.

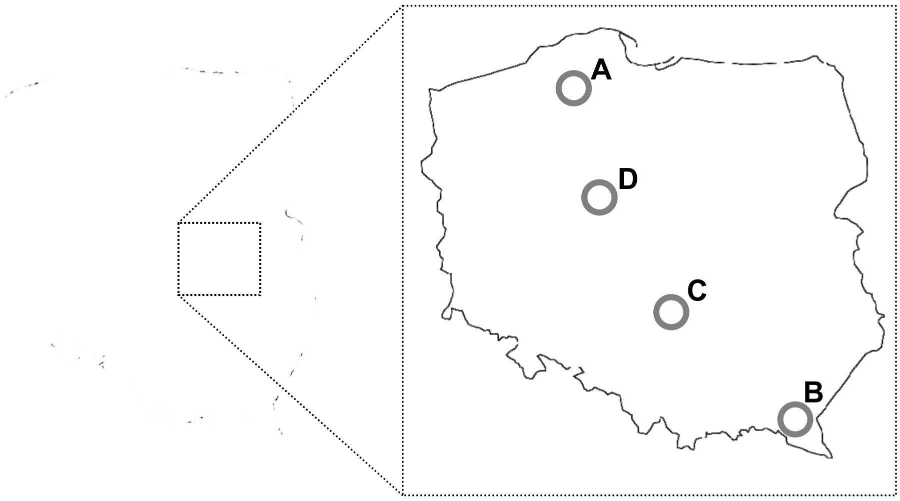

Fig. 1 Locations of Polish natural-forest regions of Scotch pine wood origins [5]

Additional measurement (estimation) of density was performed after cutting tests with a non-destructive radiometric method developed at IVALSA\CNR [7]. Six measurement points were selected along the sample length. The X-ray absorbance radiogram was scrutinized for each lamella and was saved as TIFF images for further post-processing. X-ray settings were 50kV and 40mA, the CSI scintillator (Hamamatsu) and the CMOS camera (Pixelink) for image acquisition. The custom software in the LabView (National Instruments) was developed in order to image processing and to estimate "local density" maps on the base of X-ray attenuation [5].

Estimation of cutting forces (cutting power)

Series of cutting tests to empirically determine cutting power were curried out on the frame sawing machine PRW15M with elliptical tooth trajectory and the hybrid dynamically balanced driving system [5)]. Following machine settings were applied; number of strokes of the saw frame per min $n_F = 685$ rpm, saw frame stroke $H_F = 162$ mm, number of saws in the gang $n = 5$ and average cutting speed $v_c = 3.69$ m·s^{-1}. 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 saws 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 only varying cutting parameter was feed speed applied on two levels $v_{f1} \approx 0.3$ m·min^{-1} and $v_{f2} \approx 1.1$ m·min^{-1}. It corresponded to feed per tooth f_z of ~0.04 mm and ~0.14 mm respectively. Lamellae with thickness of 5 ±0.2 mm were obtained as a result of the re-sawing process [5].

RESULTS

The relationship between the cutting force F_c and the density ρ for Scotch pine wood were analyzed independently for every location and both feeds per tooth. Regression models were developed for global (Figure 2) and local densities (Figure 3). In Figures 2 and 3 regression models for two Polish natural forest regions, for which were observed the lowest and the largest values of Pearson's r correlation coefficients between a density of wood and cutting force per one tooth, are shown. The values of the correlation coefficients (Pearson) obtained for each regression models $F_c = f(\rho)$ are presented in Table 1.

Tab. 1 Pearson's r correlation coefficients between a density of wood and cutting power per one tooth while pine sawing with their meaning and significance for level of significance α = 0.05

Region		Pearson's *r*	Correlation	Significance
		the global density of sample		
A	f_z = 0.04 [mm]	0.7485	strong	yes
	f_z = 0.14 [mm]	0.5406	medium	yes
B	f_z = 0.04 [mm]	-0.0178	no	no
	f_z = 0.14 [mm]	-0.0819	no	no
C	f_z = 0.04 [mm]	0.4926	medium	yes
	f_z = 0.14 [mm]	0.5589	medium	yes
D	f_z = 0.04 [mm]	0.8312	strong	yes
	f_z = 0.14 [mm]	0.9140	strong	yes
POLAND	f_z = 0.04 [mm]	0.6522	medium	yes
	f_z = 0.14 [mm]	0.7764	strong	yes
		the estimated local density of sample		
A	f_z = 0.04 [mm]	0.5584	medium	yes
	f_z = 0.14 [mm]	0.5518	medium	yes
B	f_z = 0.04 [mm]	0.1509	no	no
	f_z = 0.14 [mm]	0.2333	no	yes
C	f_z = 0.04 [mm]	0.3320	small	yes
	f_z = 0.14 [mm]	0.8099	strong	yes
D	f_z = 0.04 [mm]	0.9211	strong	yes
	f_z = 0.14 [mm]	0.8869	strong	yes
POLAND	f_z = 0.04 [mm]	0.5877	medium	yes
	f_z = 0.14 [mm]	0.6966	medium	yes

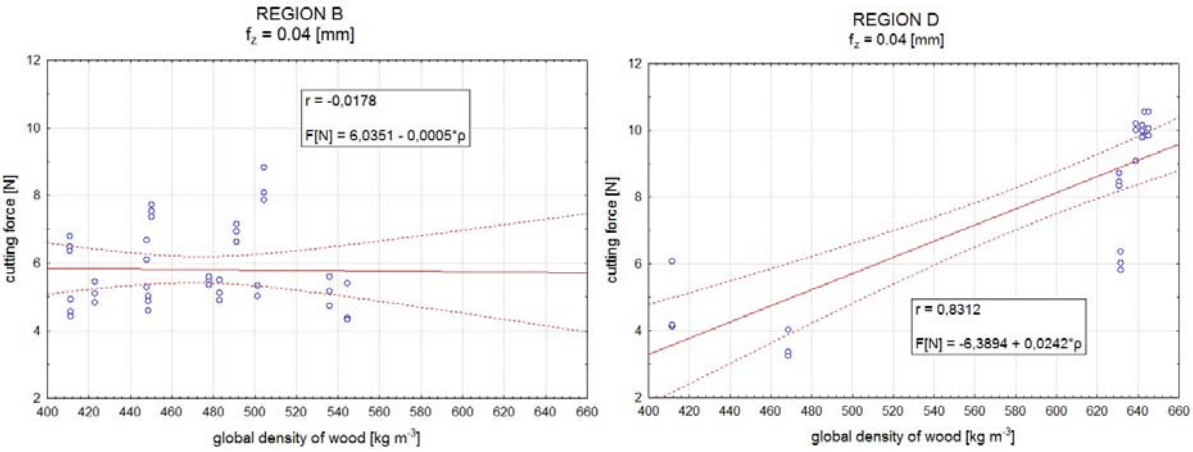

Fig. 2 The relationship between the cutting force and global density of wood for feed per tooth f_z = 0.04 mm (Regions B and D from Poland)

Correlation coefficients were slightly different for each level of feed per tooth. Very diverse relationships between the cutting force and the density of wood for different regions of origin were noticed. For Region B a values of correlation coefficient were very low r ≈ -0.02 (no any correlation) but for Region D the values of Pearson coefficient indicating very strong correlation r ≈ 0.92.

The application of the radiometric method for estimation of the wood local density caused a slight increase of Pearson's *r* in the case of region B. For other regions differences between Pearson's *r* coefficients for global and local densities of wood and cutting force per one tooth while pine sawing are rather insignificant.

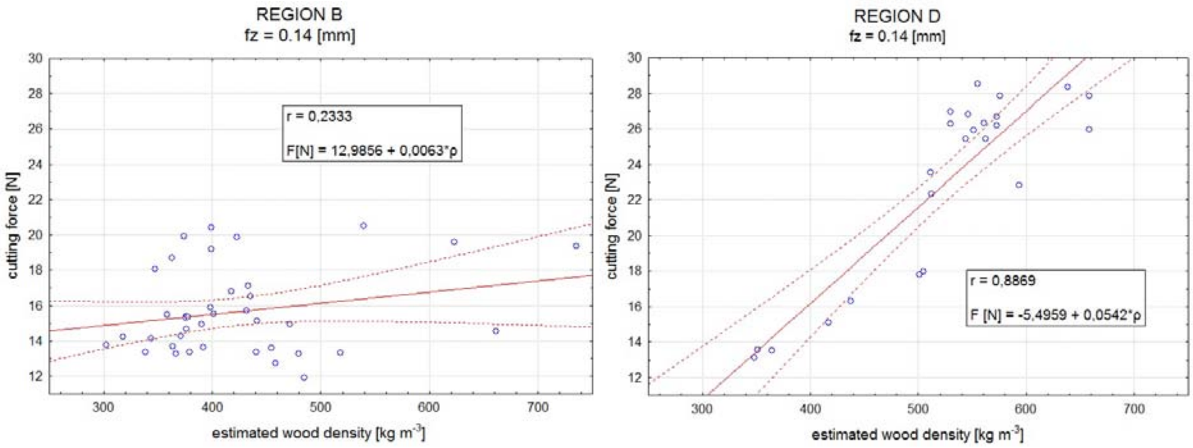

Fig. 3 The relationship between the cutting force and global density of wood for feed per tooth f_z = 0.14 mm (Regions B and D from Poland)

CONCLUSIONS

Based on the results of this study the following conclusions can be drawn:

1. Cutting forces estimated for samples of the same wood species but of different provenance change due to morphological and physical variation within wood samples.
2. The cutting forces are clearly correlated with density, even that it is not the only significant factor/variable.
3. Relationships between cutting force and density of wood are very differentiated for according on the origin of the wood.
4. Results of Pearson's r coefficients for local densities obtained with the radiometric method have not been so spectacular as it had been expected.

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Streszczenie: *Zróżnicowany wpływ gęstości polskiej sosny na siły skrawania z uwzglednieniem jej pochodzenia.* W artykule przedstawiono zależność sił skrawania od gęstości drewna z uwzględnieniem krainy pochodzenia badanego drewna. Próbki do badań były wykonane z drewna sosnowego (*Pinus sylvestris* L.) pochodzącego z czterech krain przyrodniczo-leśny Polski. Gęstość drewna mierzono dwiema metodami: metodą stereometryczną (gęstość globalna) oraz metodą radiometryczną (gęstość lokalna). Metoda stereometryczna określania gęstości polega na określeniu objętości próbki, poprzez pomiar poszczególnych wymiarów (długość, szerokość, wysokość), oraz określenie masy próbki.
Oszacowanie gęstości lokalnej dokonano po próbach przecinania za pomocą nieniszczących metod radiometrycznych opracowanych w IVALSA \ CNR. Pomiaru sił skrawania dokonano podczas prób empirycznych przecinania próbek drewna na pilarce ramowej PRW15M.

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