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THE EFFECT OF TOOL WEAR AND PLANNING PARAMETERS ON BIRCH WOOD SURFACE ROUGHNESS

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ABSTRACT

In this study, the surface quality of birch wood (*Betula*) test pieces planned with experimental planning tools (ET1, ET2) and influence of tool wear of quality of surface were examined. These tools were made by surfacing using a submerged arc welding (SAW) technique and a mixture of alloying elements (cromium, tungsten, fero-manganese, silicon carbide) spread on the surface under industrial flux. Surface roughness was measured along and across wood fibre. According to the results of experiments it is obviously that average roughness parameters along fibre is lower than across. Planning tool wear results revealed that 3200 m of cutting length is not significant for tools ET1 and ET2 wear. The same can be said about tool nose width change: For ET1 from 2.8 to 2.9 µm, and for ET2 from 2 to 3.4 µm – effect of negligible changes of tool edge geometry on planned surface quality is low. Feed of planning tool played more significant role – twice higher feed per insert (ET1 – 1.00 mm, ET2 – 0.5 mm) showed lower surface quality after planning. To reach necessary wood surface quality, lower feed rate and suggested experimental planning tool ET2 with higher wear resistance than commercial tool is preferable for planning of birch wood.

KEYWORDS: Wear resistance, surface roughness, planning, wood, wear.

INTRODUCTION

Studies concerned with investigation of surface roughness of wood started later than studies of surface properties of metal products in the metal industry. These studies were conducted at a number of different countries at different times. (Aslan et al. 2008).

The surface quality of solid natural wood is one of the most important properties influencing further manufacturing processes such as joining, finishing, bonding or strength of adhesive joints. Adhesives used in such applications are absorbed by the wood depending on surface roughness, thereby increase the strength of the mechanical bond between the wood and adhesive. The roughness level of the wood surface also affects the wettability of its surface thus the bond quality. Good wettability frequently ensures good bonding quality. In other words, as a result of the decrease in the surface roughness, contact angle values decrease and consequently, the bonding strength of the wood product increase. However, ultra-smooth surfaces can reduce the bonding strength of wood. Therefore, it is important to determine surface roughness of the final product in the wood machining. On the other hand, determination of the surface roughness is a complex process due to the anatomical structure of wood, the cutting processes and machining conditions (Tiryaki et al. 2014, Kilic et al. 2006).

Traditionally, in furniture wood industry, aesthetics of surfaces is primary property. Appearance of the final products, which depends on the surface quality, has a considerable influence on their aesthetics. Therefore, surface appearance of wooden products primarily concerns on final use. However, determination of surface quality is a complex process depending on the heterogeneous structure of the wood, kinematics of the cutting process, and machining conditions. Machining properties and surface roughness regarding the surface quality of woods can be determined according to the available standards. Machining properties of woods are directly related to machining defects (fuzzy grain, torn grain, raised grain, etc.) (Malkoçoğlu 2007).

Increased cutting speed results in an improved surface finish of wood products (Mithchell and Lemaster 2002). Planed surface characteristics of solid wood is a function of machining quality, which is directly related to knife marks per cm and not by cutter head speed alone (Kilic et al. 2006).

Surface quality of wooden products may be defined by topography or profile. Profiles are more widely used in evaluation of surface unevenness; also less-expensive equipment is required for profile measurement in comparison to topography (Korkut and Akgül 2007). There are several methods including visual, optical, laser, ultrasonic, electric, photographic, pneumatic technique and stylus type equipment, there is no accepted standard method to determine surface roughness of wood. Stylus type equipment was used successfully in many scientific researches to quantify surface roughness of wood (Tiryaki et al. 2014, Malkoçoğlu 2007, Aydin et al. 2006, Dundar et al. 2008). Anatomical structure of the wood and especially the constituting elements such as fibres, pores, tracheid, rays, annual ring variation, wood density, cell structure, and latewood/early wood ratio are effective in the determination of the surface roughness. Therefore, it is important to decide on the most effective and efficient method to determine the surface roughness (Kilic et al. 2006, Malkoçoğlu 2007). Stylus, optical profilometer, analyses the image using a video camera and microscope (Kilic et al. 2006, Vitosytė et al. 2015). Methods for determination of surface roughness has some disadvantages and some advantages over each other. One of the main advantages of the stylus method is to have actual profile of the surface and standard numerical roughness parameters, which can be calculated from the profile. Any kind of irregularities and magnitude of roughness on a surface can be objectively quantified by this method (Kilic et al. 2006).

The objective of this study was to evaluate effect of machining using experimental planning tools (Bendikiene et al. 2015) on the surface roughness of birch wood employing stylus type profilometer: Average roughness (R_a), mean peak-to valley height (R_z), and R_{max} roughness parameters were used to describe surface characteristics of the test pieces.

MATERIALS AND METHODS

In this study, birch wood (*Betula*) which is commonly utilized in the forest industry sector, was chosen for the roughness test. Ease of use and reasonable price, have made this tree a great craft wood, for almost any woodworking project. The wood test pieces were obtained from birch grown in Lithuania; the lumber was first air dried, after drying in the laboratory oven it reached 7 – 9 % of average moisture content, and then it was trimmed to dimensions of 1000 x 100 x 45 mm with radial surface. Special attention was paid to select test pieces free of any possible natural wood defects, however it is difficult to avoid. Test pieces were conditioned at a average ambient temperature of 20 ± 2°C and 60 ± 5 % relative humidity to the average moisture content of 8 %. Physical characteristics of birch wood are given in Tab. 1. The surface roughness values of different species of wood, which have broad annual rings, are higher (Burdurlu et al. 2005).

Tab. 1: Physical characteristics of birch (Betula)

Average moisture content ω (%)	7 – 9
Average number of annual rings per 1 cm	5.10
Average width of annual ring (mm)	1.96
Average density (kg. m^{-3})	632

The average moisture content was estimated using electronic moisture tester Gann Hydrometer H35 with an accuracy of ± 1 %. The number of annual rings per 1 cm was determined by counting the rings in the end section perpendicular to the wood fibres. In order to determine the average density of wood, the sections were cut out from each selected wood test piece; dimensions were measured with an accuracy of ± 0.01 mm using electronic sliding calliper Würth 715 76 11, and weighted on electronic scales (accuracy ± 0.01 g) for determination of density.

Average roughness (R_a), mean peak-to valley height (R_z), and maximum roughness (R_{max}) parameters were recorded and measured at intervals of cutting length 0; 50; 100; 150; 200; 400; 800; 1200; 1600; 2400 and 3200 m. Each value at every specified cutting length was an average of 5 tests. The stylus tip surface roughness tester, profilometer Mahr MarSurf PS1, was used to evaluate surface roughness parameters in radial direction (across and along the fibre). Measuring force did not put any significant damage. The main characteristics of tracing process are listed in Tab. 2.

Five sectors in the cutting lengths of each test piece were selected for roughness measurement in radial surface (across and along the fibre). All the test results were processed using Gaussian digital filter in accordance with DIN EN ISO 11562 (1998). The measurement error has not exceeded the roughness R_z by ± 10 %.

Tab. 2: Characteristics of stylus tracing process.

Tracing direction	**Radial (across and along fiber)**
Tracing length	17.5 (mm)
Stylus diamond tip radius	2 (μm)
Stylus diamond tip angle	90°
Measuring force	0.7 (mN)

The planning was conducted on the stand for wood cutting, which was made in the base of thickness planer (SR3-6), according to the scheme of longitudinal milling, with vectors of cutting speed *v* and feed speed *u* are opposite to each other. Experimental planning tools with dimensions of 60 x 30 x 3.5 mm were made by surfacing using a submerged arc welding (SAW) technique and a mixture of alloying elements spread on the surface under industrial flux. Manufacturing properties of these tools were compared with commercial cutters made of 8X6FT (GOST 6567-75) and Freud CT01M-LA2 (Bendikiene et al. 2015) steel. Both experimental planning tools showed better wear performance (from 3 to 4 times). Planning tools were sharpened – sharpness angle 40°, rake angle – 30°, clearance angle – 20°, cutting angle – 60° strait. Planning conditions were the same for each wood test piece: the test pieces were planned at 6 and 3 $m.min^{-1}$ feed speed, at 0.50 and 1.00 mm feed per one cutter, 2 mm planning depth, 45 mm planning width and using 1 cutter (diameter of cutterhead 103 mm, to avoid disbalance second insert was used but not tested) on a typical industrial thickness planer (revolution n = 5780 min^{-1}). Test pieces were processed by cutting speed 31 $m.s^{-1}$.

RESULTS AND DISCUSSION

The average values of roughness parameters of birch test pieces planned using two experimental planning tools (Bendikiene et al. 2015) measured along and across wood fibre are given in Tab. 3. Experimental planning tool ET1 was heated up to 1100°C afterwards hammered in order to examine the influence of plastic deformation on the wear performance, while chemical composition of powder used to form layer was the same. Surface roughness distribution in cutting length for both measuring directions presented in Figs. 1 and 2.

Tab. 3: Average roughness of birch test pieces across and along fibre.

Roughness parameters (µm)	ET1		ET2	
	Along fibre	Across fibre	Along fibre	Across fibre
R_a	3.95	5.15	3.34	4.94
R_z	25.16	47.36	21.99	46.23
R_{max}	38.73	56.88	35.9	55.17

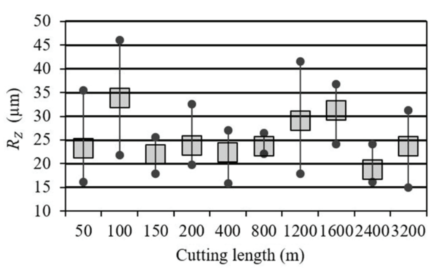

Fig. 1: Surface roughness R_z of birch test pieces along fibre planned with ET1.

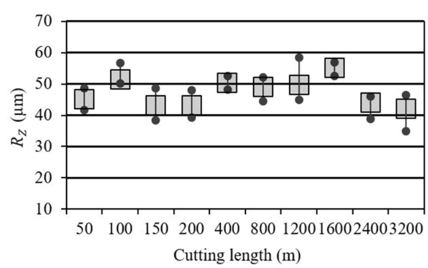

Fig. 2: Surface roughness R_z of birch test pieces across fibre planned with ET1.

Two experimental planning tools in the previous study showed better wear performance comparing with commercial tools made of high alloyed tool steel: cutting edge radius and edge recession of experimental inserts after 3200 m of cutting length was approximately 3 times lower than of standard tools. The most obvious finding from previous studies is that the relatively hard coatings (55-57 HRC) surfaced on a soft plain carbon steel can replace some commercial inserts made of high speed tool steels for relatively harder oak wood machining, reducing friction and wear of wood cutting tool.

Rake angle of experimental planning tool was γ = 25°; it was stated by Malkoçoğlu and Őzdemir 2006 that the best surface quality of the wooden products has been obtained with low rake angle. Average roughness parameters measured along fibre showed lower values.

Received results demonstrated how wear of tool edges and feed rate influence quality of planned surfaces: These factors were observed analysing quality of surfaces along and across wood fibre. It is worth to mention that micro changes of tool edge geometry were analysed until 3200 m of cutting length (Vitosytė et al. 2015).

Wear results revealed that this limit of cutting length is not significant for tools ET1 and ET2 – an increment cutting edge radius ρ did not exceed 1 µm. Analogous tendency was observed examining results of negligible nose width change: For ET1 from 2.8 to 2.9 µm, and for ET2 from 2 to 3.4 µm. Therefore, effect of negligible changes of tool edge geometry on planned surface quality is low. Slight changes of surface quality during planning along and across wood fibre were noticed on ET1 tool after 100 and 1600 m of cutting length (Fig. 3 a) and b)).

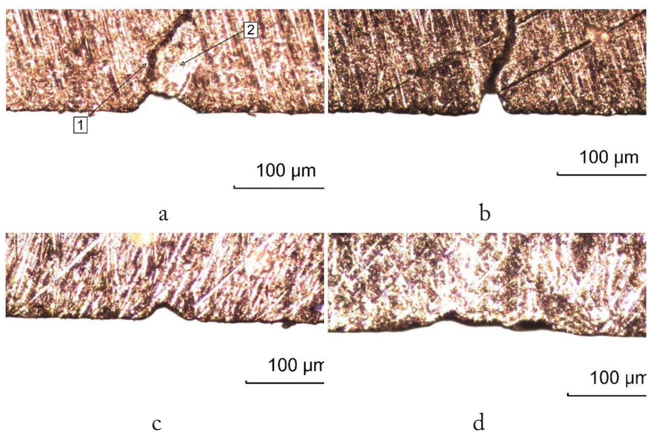

Fig. 3: Edge crumbles during planning; a) ET1 (L = 100 m); b) ET1 (L = 1600 m); c) ET2 (L = 400 m); d) ET2 (L = 2400 m).

Then resultant values of roughness parameter R_z along wood fibre were 33.8 and 31.3 µm, while planning along fibre – 51.2 and 55.2 µm (Figs. 1 and 2). For tool ET2 reduced surface quality was established after following lengths – 400 and 2400 m (Fig. 3 c) and d)). In these cases, values of roughness parameter R_z along fibre were 24.6 and 25.6 µm, and 48.9, 50.7 µm across the wood fibre Figs. 4 and 5). Reduced surface quality associates with changes of tool edge geometry, as on wear planning tools separate segments of edges crumbles away (Fig. 3).

When analysing influence of feed per insert (ET1 – 1.00 mm, ET2 – 0.5 mm), lower surface quality was observed after planning using ET1, comparing with surface shaped with ET2. Numerical values of surface roughness parameter prove this observation: Values along wood fibre were in 12.6, and across in 2.38 % higher.

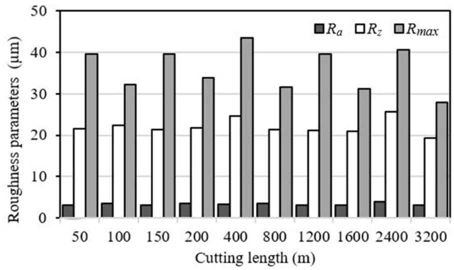

Fig. 4: Surface roughness parameters R_a, R_z and R_{max} of birch test pieces along fibre planned with ET2.

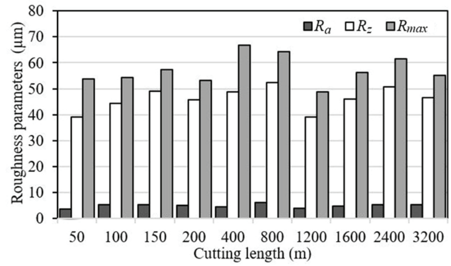

Fig. 5: Surface roughness parameters R_a, R_z and R_{max} of birch test pieces across fibre planned with ET2.

Twice higher feed rate per insert showed lower surface quality after planning. With increasing of feed rate, relative thickness of chip *a* increases as well, wherefore waviness (roughness) of surface and cutting forces grow up. Consequently, the higher cutting force is necessary to remove the wood portion, but chip formation process goes faster in that case. That generates the number of surface defects, increases waviness, downiness and shagginess of surface, portion of wood crumbles by annual ring (Magoss and Sitkei 2001, Keturakis et al. 2007).

Different values of roughness parameters R_a, R_z ir R_{max} along and across wood fibre were taken. This difference in surface quality was composed because radial surface, where high influence of annual rings presents, was analysed. Under the influence of plastic properties of wood, dissimilar behaviour of late and early wood reveals. This effect emerges because of higher density and hardness of late wood compare with early wood (Tiryaki et al. 2014).

CONCLUSIONS

Birch wood surface roughness directly depends on the anatomic characteristics of wood spieces, direction of wood grain and cutting tool characteristics. When using unhammered experimental tool ET2 (hardness after tempering 57 HRC) all surface roughness parameters in both wood grain directions were lower than using ET1 (55 HRC), while better tool wear performance in the previous work (Bendikiene et al. 2015) was achieved with later. Birch wood surface roughness parameters for both experimental tools along wood fibre were approximately 1.6 times lower than parameters in the perpendicular direction. Twice higher feed per insert showed lower surface quality after planning. Reduced surface quality associates with changes of tool edge geometry, as on wear planning tools separate segments of edges crumbles away.

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