

Wood Machining Investigations: Parameters to Consider for Thorough Experimentation

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Investigators wanting to study aspects of wood machining face many challenges. The material under investigation is inherently different with respect to its three major axes, and it responds in various ways to local temperature, moisture, and many other variables. Researchers proposing future research projects in this area thus face a critically important task of selecting parameters to include either as variables or as quantities to hold constant. This editorial outlines key parameters and conditions of wood machining that can be considered, depending on the scope of a project.

Keywords: Wood grain orientation angles; Rake angle; Cutting edge dullness; Thickness of cutting layer; Cutting velocity; Moisture content; Wood temperature; Mechanical properties of wood; Physical properties of wood; Main force; Normal force; Tool life; Cutting edge wearing

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Introduction

Wood machining is the field of study dealing with the manufacture of wood and wood-based products using cutting tools. The wood machining process can be described by a long list of parameters and conditions. An awareness of the importance of these parameters and conditions allows the operator to conduct the machining smoothly, efficiently, and precisely. The efficiency of the wood machining process can be quantified in terms of low material and/or labor costs and by high (or expected) yield. The precision of wood machining can be determined by dimensional accuracy, deviations of shape, surface and edge roughness, as well as properties of workpiece surface layers (color, cell squeeze, rupture, chipping). The purpose of this paper is to point out important aspects for preparation and conducting of wood machining experiments.

Variables and Constant Parameters

Depending on the scope of the planned research, various dependent variables can be considered: (1) Cutting forces: main force F_C , normal force F_N , power and energy consumption; (2) Tool life indicators: cutting edge rounding ρ , cutting edge recession measured in plane of wedge bisector VB_W , cutting edge recession measured in rake face VB_S , cutting edge recession measured in clearance surface VB_F , total time of work t_C , total feed length L_F , total surface of workpiece machined A_F , total path of cutting edge L_C , total area of cutting edge wear measured in wedge bisector A_W , for saws: reduction in corner widening and other (for example SV); (3) Accuracy of the cutting process: deviation from target (nominal) dimension d_N , dispersion of obtained dimensions (standard deviation S_D), roughness of the surface of workpiece after cutting (R_a , R_z , R_{ZMX}), state of workpiece edge after machining (S_A , M_{SU}); (4) Fine dust emission and chip removal from cutting zone; (5) Acoustic emissions; (6) Working unit vibration; (7) Working unit acceleration; and (8) Change of workpiece surface layer properties.

When planning wood machining experiments, it can be important to precisely specify the constant parameters, including their acceptable range of variation, in order to

allow future comparison with results of other published experiments. Also, it is good practice to describe the tool life using several parameters, especially expressing maximum cutting edge wear, as well as a criterion of evaluation of the cutting process quality (physical or technological). For the determination of the cutting edge state, the use of total area of cutting edge wear (often without specifying the measurement plane) can be a problematic choice, because it can hide information about unacceptable blade state changes, as a basis to stop the machine and replace a tool.

Parameters and Conditions for Wood Machining Experiments

For workpiece material characterization, the best practice is to use the scientific name of the wood species. Wood density D is often specified. In cases where one wishes to relate machining outcomes to wood's characteristic properties, several mechanical properties of wood specimens such as: tensile strength along the fiber R_T , compression strength along the grain R_C , shearing strength across the grain R_S , and bending strength across the grain R_B , can be given.

Also important for the characterization of material studied are physical properties such as: moisture content m_C , temperature of wood T , and wood specimen dimensions. In the case of cutting edge wear studies, additional important parameters for characterization of material cut include: content and size of hard mineral contamination in the material cut; high temperature corrosivity of machined material towards the cutting edge material; and wet corrosivity (wood in green state before drying) of solutions present in a liquid state in wood cells towards the cutting edge material.

The wood machining experiment is performed by defining cutting parameters such as: thickness of cutting layer (chip thickness) a_p , cutting velocity v_C , width of cutting edge w_C , and cutting depth in feed direction c_D . For rotational cutting: diameter of cutting d_C , feed speed v_F , number of cutting edges z , spindle rotational speed n , and feed per edge f_z .

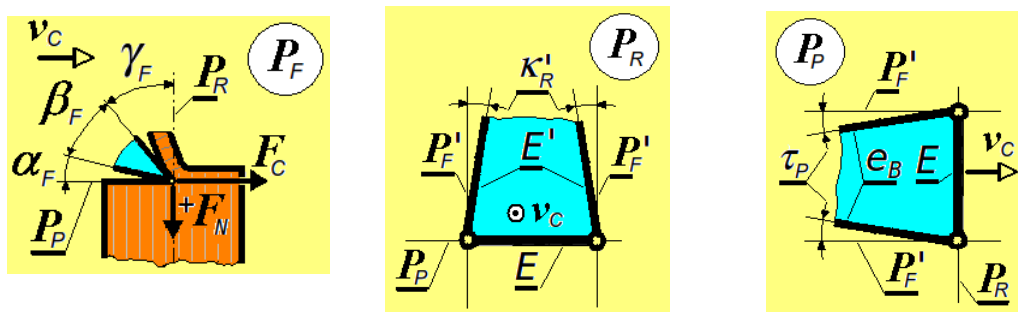


Fig. 1. Angle parameters and cutting forces; P_F - working plane, P'_F - back working plane, P_R - base plane, back plain P_P ; E - main cutting edge; E' - side edge; e_B - back edge; α_F - clearance angle; β_F - wedge angle; γ_F - rake angle; κ'_R - side edge angle; τ'_P - back edge angle; cutting velocity v_C ; F_C - main force; F_N - normal force

The machining experiment is also conducted by defining angle parameters of the cutting edge(s) such as contour (Fig. 1): cutting angle δ_F ($\delta_F=90-\gamma_F$), rake angle γ_F , clearance angle α_F ; main cutting edge E inclination angles λ_P and ψ_R , measured in the back plane P_P and in the working plane P_R , respectively (the ψ_R angle for other than sawing and sanding cases characterize tool and workpiece profile); back edge e_B angle (Fig. 1) in tangential (transversal) direction τ_P and side edge E' angle in radial

(longitudinal) direction κ'_R , for slotted cutting [sawing, milling (one side or two sides), drilling, chiseling]; orientation angles (Fig. 2): φ_E between wood grains (wg) and the E ; φ_V , between wg and the vector of cutting velocity v_C ; φ_C between wg and the cutting plane A_C ; growth rings orientation angle φ_{RT} (Fig. 2); and deviations of the angle parameters for multi-tooth tools.

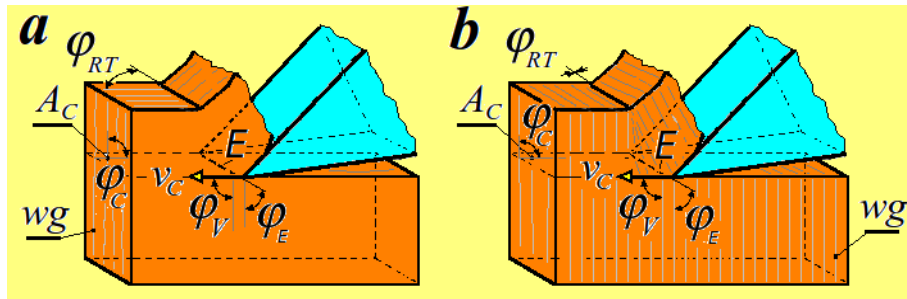


Fig. 2. Cutting orientation angles between wood grains (wg) and: φ_E - cutting edge; φ_V - vector of cutting velocity v_C ; φ_C - cutting plane A_C (Orlicz 1982)

The cutting edge also has important properties and parameters such as: material from which it is made and material of the tool body (for circular saws); contour wedge angle β_F (Fig. 1); cutting edge dullness (round up ρ , recession VB); roughness of rake R_{ar} ; and clearance surfaces R_{aa} ; deviations of the position of the corners in axial (transversal) and deviations of position in radial (longitudinal) for multi-tooth tools (run out); as well as left- and/or right-side clearance of the cutting edge corners.

It is good practice to report properties and conditions of a woodworking machine, defined for the wood machining experiment, such as: stiffness of a cutting tool fixed in a working unit (cutting tool) of the machine ε_{WU} ; stiffness of a workpiece fixed or moved relative tool ε_{WP} ; vibration and acceleration of the tool relative workpiece; radial and axial (longitudinal and transversal) play for multi-tooth tools of the arbor; stability of cutting and feeding velocity, electrostatic voltage between the working piece and tool; and chip and dust removal from working area.

Remarks on the Conducting of Machining Experiments

In ideal cases, machining experiments can be performed in three main cutting directions, for which wood grains orientation angles are as follows: for perpendicular (\perp) ($\varphi_E=90^\circ$, $\varphi_V=90^\circ$, $\varphi_S=90^\circ$), for parallel (\parallel) ($\varphi_E=90^\circ$, $\varphi_V=0^\circ$, $\varphi_S=0^\circ$), for transverse ($\#$) ($\varphi_E=0^\circ$, $\varphi_V=90^\circ$, $\varphi_S=0^\circ$). All cutting cases can be radial (Fig. 2a) and tangential (Fig. 2b). However, there are intermediate cases due to natural deviations of wood grain or use of other machining angles. Orlicz (1982) has presented formulas for dealing with such cases. When employing the notation: (90-90), (90-0), (0-90), with modes I and II, first mentioned by Kivimaa (1952), only the main cutting directions and ideal grain orientations can be described and analyzed.

With respect to the wood grain orientation angles, an important aspect involves cutting 'with the grains' (W_G) vs. cutting 'against the grains' (A_G). The A_G is the difficult case for smooth cutting. It has to be mentioned that for rotational cutting, together with the cutting depth c_D , as well as with changing position of the wood specimen, the cutting orientation angles also change. The wood specimens in the dry

(kiln drying) and fresh (green) state may not have the same moisture content m_C in the cross section. In a fresh cut state, only a sapwood and wood without heartwood has very high uniform (100% to 200%) water content, while the m_C of the heartwood may not be much above the saturation point (40% to 50%). This implies the need for long enough (depending from workpiece dimensions) moisture content m_C stabilization of wood specimens in order to obtain reproducible results.

The woodworking machine and the cutting tool have to be checked from the following points of the view: (a) unbalance of the arbor and tool, (b) excessive play in bearings or bad mounting bearings (too large clamping pressure) causing vibration and acceleration working units, (c) tangential (transversal) and radial (longitudinal) play and runout, (d) symmetry of back and side angles and clearance (for slotted cutting), (e) symmetry of left and right cutting edge corners state (for slotted cutting), and (f) deviations from cutting v_C and feed speed v_F , caused by insufficient power of motors used. Insufficient stiffness of the working unit and/or workpiece can be a cause of worsening of all dependent variables.

Analysis and Interpretation of Results

It is good practice to report not only relative values of dependent variables but also absolute ones, with full description for the default condition. The analysis of dependent variables (for example cutting edge wear) in relation of feed length L_F or area of wood cut A_C , seems not to be a good choice, especially for multi-edge cutting tools.

In the statistical analysis, one needs to show a strong relationship between dependent variables and independent variables. The mathematical formula employed ought to achieve a good fit to the experimental data (high R^2 , small summation of residuals square S_K and standard deviation of residuals S_D). In the evaluation process, elimination of unimportant independent variables or estimators has to be taken into account. The significance of estimators and statistics (correlation coefficient R , standard deviation S_D) ought to be evaluated and presented.

For presentation of the estimators evaluated, the number of decimal digits left ought to cause negligible deterioration in the quality of approximation. A comparison of results obtained for similar experiments from the literature is a good practice.

Summary

To sum up, the study of wood machining involves a large number of variables, many of which can be expected to interact with each other. Future comprehensive studies of wood machining can benefit from a careful selection of which variables to control and which to hold constant. By paying detailed attention to multiple aspects of the problem, not only is there potential to achieve more precise results, but it can also be easier for subsequent researchers to make potential use of the study findings.

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