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Specific cutting coefficients for the most common engineered wood products

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ABSTRACT

The aim of the present work is to investigate the specific cutting coefficients for the assessment of cutting forces when peripheral milling different types of engineered wood products (EWPs). The approach comes from previous work aiming to investigate the specific cutting coefficients when cutting solid wood with different grain orientations. The model inputs are the uncut chip thickness and width, the machining configuration i.e. up- or down-milling, the type of EWP, and the tool helix angle. Thereby, different EWPs were round shaped (peripheral milling) machined after being fixed on a dynamometric platform in order to measure the cutting forces when up- or down-milling with different chip thicknesses and tool helical angles. The acquired forces were analysed and plotted against the respective chip thicknesses to calculate the specific cutting coefficients as well as the intercepts to serve as input to the model. The EWPs assessed were: particleboard, MDF (Medium Density Fiberboard), OSB (Oriented Strand Board), and plywood. While particleboard and MDF has shown a perfectly isotropic behaviour, plywood has shown to be moderately directional. OSB has exhibited very large and unpredictable variations associated to its very heterogeneous structure that makes the cutting forces of this material very difficult to be effectively modelled.

Keywords: Engineered wood products, cutting forces, specific cutting coefficients.

INTRODUCTION

An accurate model for predicting cutting forces and cutting powers in wood machining could be of great help for manufacturers for a correct machining set-up. The research on wood machining has seen different approaches to cutting forces and cutting power predictions on massive wood and Engineered Wood Products (EWPs). The strong anisotropy of massive wood results in a very complex interaction between the tool and the material, depending on the cutting direction compared to the grain orientation, and in very different cutting conditions. The relations between the grain orientation and the cutting forces have been explored by different authors and the principal works are gathered together by some review works published by Marchal et al. [1], Naylor and Hackney [2], and Nasir and Cool [3].

More recently the attention of the authors of this work went back to investigate how the cutting forces varies when milling at intermediate grain orientations. A new method for the assessment of wood machinability and cutting tool performance when machining solid wood at different grain orientations was proposed by Goli and Sandak [4], where a massive piece of wood was machined at round shape. The same principle was applied in order to develop a method to measure the cutting forces when peripheral milling massive wood at different grain orientations (see Figure 1), this first approach being described by Goli et.

al. [5] and presented during the previous (24th) International Wood Machining seminar [6]. This last has shown to work very effectively and a generalized model for solid wood was hereby developed by Curti at. al. [7].

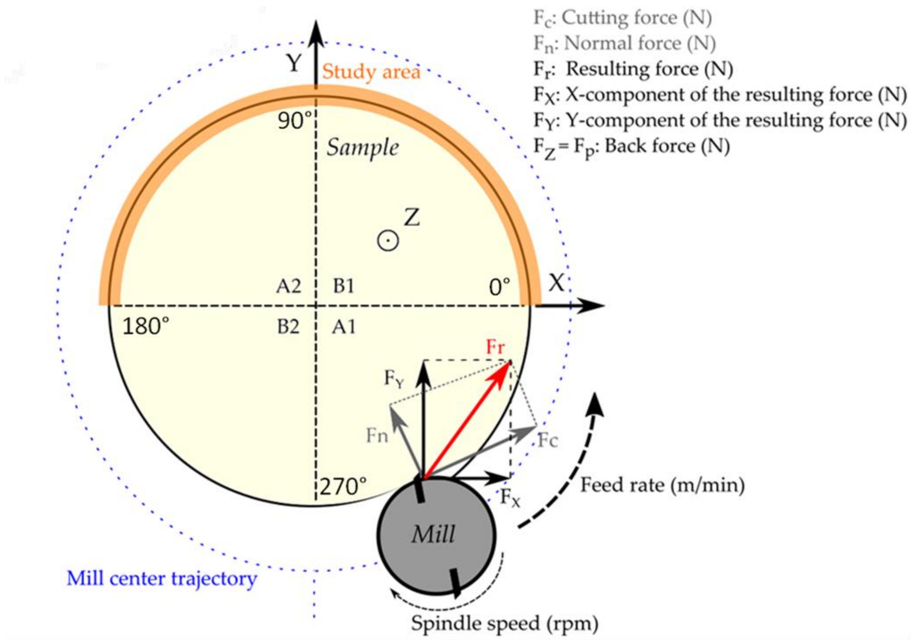

F_c: Cutting force (N)
F_n: Normal force (N)
F_r: Resulting force (N)
F_X: X-component of the resulting force (N)
F_Y: Y-component of the resulting force (N)
$F_Z = F_p$: Back force (N)
Y
Study area
90°
Sample
Z
A2
B1
0°
X
180°
B2
A1
Fr
F_Y
Fn
Fc
270°
F_X
Feed rate (m/min)
Mill
Mill center trajectory
Spindle speed (rpm)

Figure 1. Milling operation schematized with the definition of the reference system and the cutting forces. The forces were measured on the thickened half disk both for up- and down-milling processes. The up-milling was used as reference and the down milling forces vector order was reversed in order to be the same of the up-milling one.

Curti et al. work is here extended, with the same approach, to determine the specific cutting coefficients when machining EWPs such as particleboard, Medium Density Fiberboard (MDF), Oriented Strand Board (OSB), and plywood. Those EWPs are widely machined, and thus representative, for the secondary transformation sector, and for this reason, they are of interest to optimize the machining processes and eventually reducing the postprocessing interventions such as sanding to reach the desired final surface quality. Being MDF and particleboard isotropic materials, they are compared to plywood and OSB that are supposed to have two anisotropic orthotropic models superposed because produced by superposing layers with perpendicular grain orientations.

MATERIALS AND METHODS

For massive wood, the method was conceived to machine a wood specimen into a round shape in order to cut, with a single operation, with every possible grain orientation compared to the cutting edge. The specimen is fixed on top of a dynamometric platform (Kistler, type 9255A) that allows to measure directly the global cutting forces, and the platform itself is clamped on the machine worktable, see Figure 2. The specimens are machined by peripheral milling. The method is deeply described in the research work [7], and the data analysis is detailed in [5].

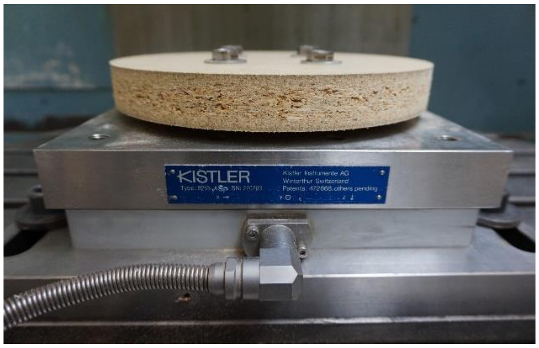


Figure 2. Peripheral milling setup used for the measurement of the cutting forces.

Four different EWPs are studied for their major importance in the furniture sector: particleboard, Medium Density Fiberboard, Oriented Strand Board, and plywood, referenced here respectively as PB, MDF, OSB, and PW. Their characteristics are summarized in Table 1. The axial depth of cut (a_p) used for the experiments is always equal to the whole thickness of the specimen and the routing bit during machining crossed over both panel's surfaces.

Table 1. Main physical properties of the machined EWPs.

Type of EWP	*Particle board (PB)*	*Medium Density Fiberboard (MDF)*	*Oriented Strand Board (OSB)*	*Plywood (PW)*
Wood specie of the EWP	NA	NA	NA	Poplar
Density (kg.m^{-3})	737.8	720.0	585.7	430.0
Moisture content (%)	11.2	9.7	8.8	8.7

Two uncoated, freshly sharpened, tungsten carbide massive tools, 20 mm of diameter, 2 cutting edges, specially designed for the purpose of the experiment provided by G3 Fantacci Corp. (located at Poggibonsi, Italy) are tested, with a special interest in the effect of the helix angle (λ), as summarized in Table 2 and shown in Figures 2-5. Indeed, this parameter is commonly used to virtually increase the sharpness of the tool and to improve the cutting quality as well as to reduce the cutting forces on the machine XY plane.

Table 2. Geometrical characteristics of the 2 cutting tools. Rake, wedge and clearing angles are referred to the normal plane. WC is tungsten carbide.

Blade type	*Diameter (mm)*	*Number of teeth -z*	*Rake angle (°)*	*Wedge angle (°)*	*Clearance angle (°)*	*Material*
Straight blade (λ = 0°)	20	2	25	55	10	Uncoated WC
Helical cutter (λ = 30°)	20	2	25	55	10	Uncoated WC

Five depths of cut are tested: 0.5, 1.0, 1.5, 2.0, and 2.5 mm to machine with five different uncut chip thicknesses (h). This results in an average uncut chip thicknesses varying from 40 μm (for the smallest depth of cut) to 100 μm (for the largest depth of cut). The data are analysed according to the method described in

Goli et. al. [5] to compute the specific cutting coefficients (K_s) and the intercepts (Int) as in the following equation:

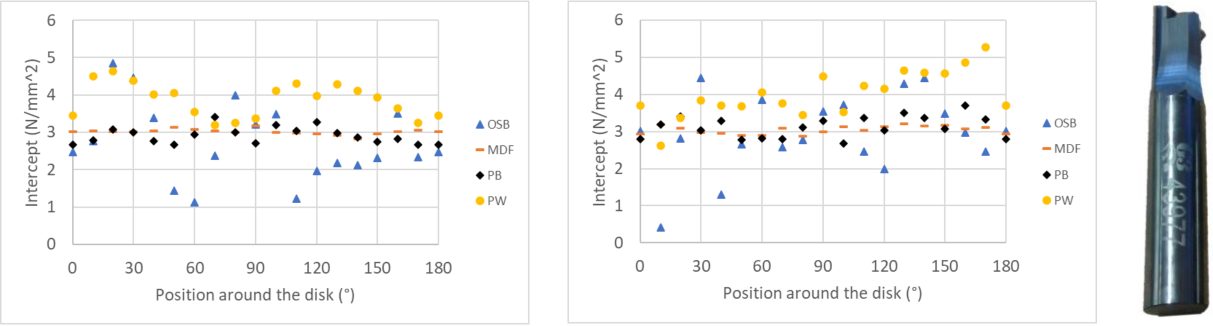
$$F_C(\theta) = \big(K_s(\theta) \times h + Int(\theta)\big) \times a_p$$

These two regression coefficients for each grain orientation (θ) will allow to estimate the cutting forces prior to machining EWPs in similar conditions (helix angle, cutting speed) whatever the machining direction.

The machining has been performed on a milling center designed for metal cutting produced by the Gambin Corp. type 120CR with a very stiff worktable than usual machining centers for wood; as a direct consequence, the forces signals are less polluted by dynamical effects due to the oscillation of the whole system. The machining conditions were all the same for every material: spindle speed 3,000 rpm; feed rate 2,000 mm/min; axial depth of cut (the force value was normalized by sample thickness); radial depth of cut: 0.5, 1.0, 1.5, 2.0, and 2.5 mm.

RESULTS AND DISCUSSION

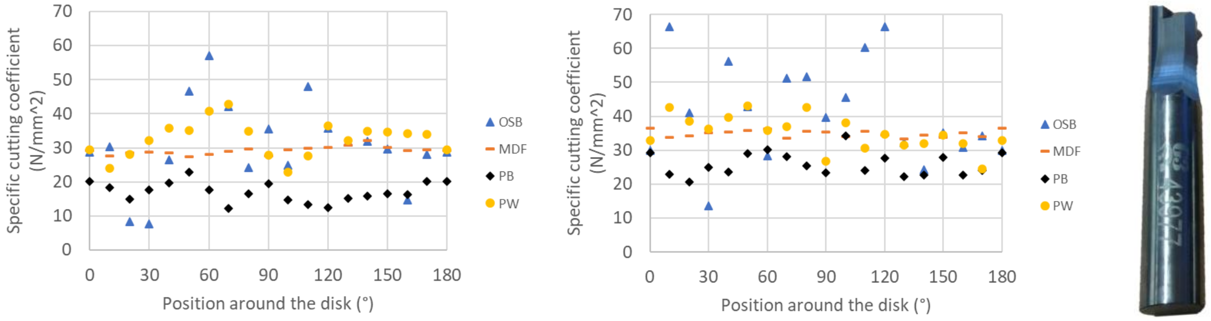
The forces are acquired and normalised over the chip width (board thickness) in order to get the forces per millimeter of blade length engaged in the cut. These normalized forces are plotted against chip thickness and the best linear regression is computed in order to determine both cutting forces model parameters: the intercept (*Int.*), and the specific cutting coefficient (*Ks*). The values of *Int.* and *Ks* are determined for the different EWPs with a span of 10° over the angular position over the half disk. In Figure 3 and 4 are reported the *Int.* and the *Ks* when up-milling or down-milling the different boards with a straight blade tool (λ = 0°).



(a) (b) (c)

Figure 3. Intercept (*Int.*) for a straight blade tool in up-milling condition (a) and in down-milling condition (b) when machining OSB, MDF, particleboard (PC), Plywood (PW) with (c) the straight blade tool (λ = 0°)

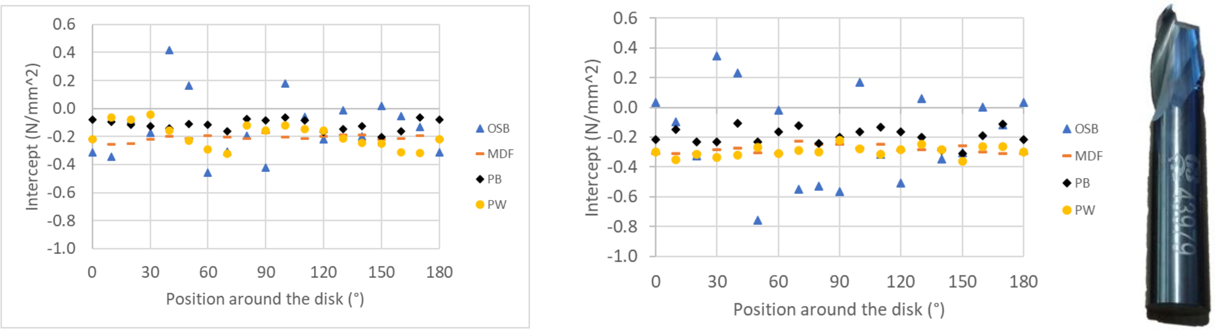
As it can be observed the values of *Int.* are not negligible when machining with a straight blade tool and must be taken into account, while when machining with a 30° of axial angle becomes almost negligible. It can also be observed how machining semi anisotropic materials such as plywood or OSB, results in much more scattered values compared to quasi isotropic material such as MDF or particle boards. As a general rule the behaviour of *Int.* does not seem to be very influenced by the machining strategy (up- or down-milling).



(a) (b) (c)

Figure 4. Specific cutting coefficient (*Ks*) for a straight blade tool in up-milling condition (a) and in down-milling condition (b) when machining OSB, MDF, particleboard (PC), Plywood (PW) with (c) the straight blade tool (λ=0°)

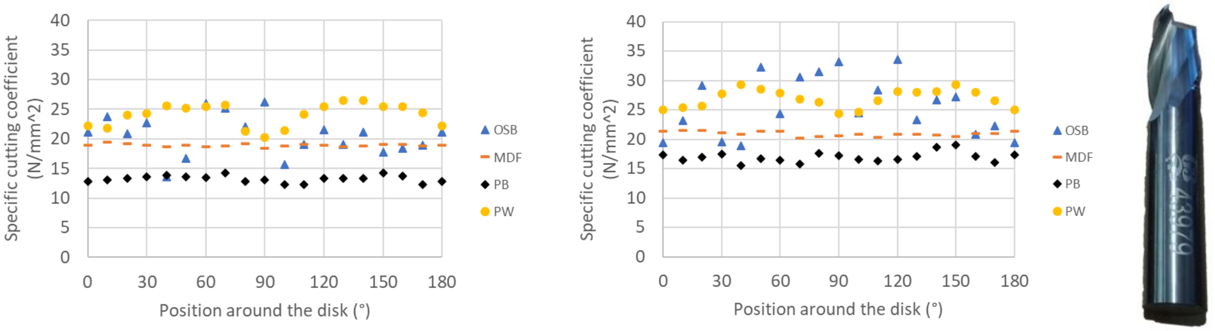
By comparing *Int*. at λ = 0° and at λ = 30°, Figure 3 and 5, it is clear how these values are much lower and less scattered for λ = 30°. As a general behaviour, the machining with λ = 30°, compared to the λ = 0°, results in a much lower *Ks* (that means lower cutting forces when machining); and in a rather negligible *Int*. (Figures 3 and 5).



(a) (b) (c)

Figure 5. Intercept (*Int.*) for a straight blade tool in up-milling condition (a) and in down-milling condition (b) when machining OSB, MDF, particleboard (PC), Plywood (PW) with (c) the 30° helical angle tool (λ = 30°)

Looking at *Ks* (Figure 4 and 6), it can be observed how up-milling generally results in lower values compared to down-milling, how MDF results perfectly isotropic, how PB result non perfectly isotropic, how OSB generally produces a very scattered behavior on the angular position. and how plywood results in a mirrored behaviour between 0 to 90° and 90 to 180° (especially for λ = 30) showing a repeated pattern depending on its moderately anisotropic structure.



(a) (b) (c)

Figure 6. Specific cutting coefficient (*Ks*) for a straight blade tool in up-milling condition (a) and in down-milling condition (b) when machining OSB, MDF, particleboard (PC), Plywood (PW) with (c) the 30° helical angle tool (λ = 30°)

CONCLUSIONS

The work allowed to identify the regression coefficients able to calculate the cutting forces when machining the principal engineered wood products. Intercepts and specific cutting coefficients were calculated for up-milling and down-milling cutting conditions as well as for two different helical angles being 0 and 30°. Isotropic materials have shown the same behaviour over the whole semi circumference machined while plywood, because of its compensated structure has shown a semi anisotropic behaviour. Conversely, OSB has shown a highly scattered behaviour over the semi circumference possibly because of its higher localized variability in density compared to the other products due to the presence of empty parts. Down-milling has generally shown higher *Ks* compared to up-milling. A higher helical angle allows a much lower *Ks* (less power is needed to cut the material) and almost negligible *Int.* (less energy is needed to create the chip) and a much less scattered signal for all the machined EWPs as expected.

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