The force required for the creation of wood cuttings

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Abstract. Wood as a material has its own peculiar role during processing due to its characteristics which depend on a number of factors. Therefore, wood-based plate materials tend to encounter the same issues. The creation of the continuous cuttings is conditioned by the strength as it is being cut orthogonally. The cutting force is shown as the sum of the forces for plastic deformation, the force for overcoming the work of the friction force on the front and rear surface of the tool and the force for creating a new surface. Each of the forces is connected to appropriate mechanical features of wood. Examining the mechanical properties of wood, which can be used to calculate the required power to create a new surface, demonstrates the dependence of cutting power on the type of wood, cutting speed, and wood moisture.

1. Introduction
There are numerous construction materials used in the world nowadays, some of which pushed out many of the elementary materials. Wood has nevertheless stayed one of the most important materials. As such it is used in production of various products. There is the basic solid wood as well as other materials, products of solid wood with great properties. Solid wood itself and other wood-based materials, most of the time require mechanical processing. The basis for this kind of processing is in the metal processing. Wood is however anisotropic- orthotropic material, which makes its processing more complex.

Mechanical wood processing can be divided in two ways: cutting and plastic deformation. Wood processing by wood shavings separation is a series of technological, physical and economic parameters that vary as well as series of factors that affect those parameters. The simplest way of wood shavings separation processing is orthogonal cutting. This particular cutting method occurs when the tool blade goes through the item being processed, in this case wood, in a manner perpendicular to the direction of movement.

2. Wood structure
Wood is one of the natural polymers that has complex structure. In order to thoroughly observe wood structure and understand its influence on wood properties we can divide it into macroscopic and microscopic structure. It is possible to study it with naked eye or magnifying glass (macroscopic structure) or with a microscope (microscopic structure). In the field of forestry for practical purpose we need macroscopic structure knowledge while submicroscopic and microscopic structure expertise is much needed in the study of phenomena and processes such as wood cutting.
Transversal and longitude cuts provide macroscopic view of the trunk (wood). If we take a look at transversal cuts, depending on the type of wood we can see anatomical axis or core, heart, protein, bark as well as growth rings (annual rings) of early and late wood. On longitudinal cuts, radial (if the cut is along the fibers through the axis) or tangential (same cut going outside of axis) we can see same properties in the same or changed shape. Unlike deciduous trees, coniferous trees have simpler microscopic i.e. anatomic structure made of tracheid and parenchymal cells. Deciduous trees, anatomically speaking are considered to have complex structure. Here is an example to illustrate. In deciduous trees tracheid and transitional forms of vascular and vasicentral tracheid elements perform conducting. Libriform and fiber tracheids have the mechanical function while parenchymal cells take on the function of accumulation. [1]

![Simplified view of wood structure.](image)

Physical properties of wood are directed by anatomic and chemical structure as well as the nature of physical forces that have influence on it. Some of the physical properties to consider when cutting wood orthogonally are moisture, wood porosity and density, change of dimensions (shrinkage and swelling), influence of electricity and heat on wood. While being processed wood is exposed to different kinds of complex straining. Due to the complexity and very specific wood structure, it is quite hard to study them and apply classical estimation methods used with other materials. This is precisely why we need to use conventional and modern methods to study mechanical properties of wood in detail. Some of the frequently studied mechanical properties are elasticity and plasticity, static voltage in wood, (pressure, straining, shearing, chopping, bending), wood hardness, wear resistance, weather influence etc. [1]

Speaking of wood as a material we are obliged to mention other wood-based plates that bare some of the same properties as wood but at the same time have some different properties and conditions for usage, studies show. Fibrous plates, a wood-based material, has numerous advantages compared to solid wood such as more homogenous structure, lesser dimension change under the influence of moisture, possibility to manufacture specific properties, etc. Homogenous structure of these plates is great advantage in the studies and estimates of the material properties, which is in turn applicable to orthogonal cutting which is the focus of this paper. [5]

3. Orthogonal wood cutting
Cutting wood is different than cutting metal or other materials. The reason for this is the cutting resistance that changes in wood depending on the cutting planes. This difference occurs because of the
wood structure which is different in different parts of the wood as well as between early and late part of the wood. We differ three basic planes: transversal, radial and tangential plane (Figure 2).

\[\text{Figure 2. Basic wood planes. [4]}\]

Plastic deformation of wood with a tool produces wood shavings. Tool work causes complex strains. The plane where the strains are the most intense is called shear plane. Its position is determined by the angle of sheerness ($\varphi$). There are three basic methods of cutting defined by wood planes e. i. direction of movement of the tool and they are as follows: transversal (b) longitudinal (c) tangential (a) Figure 3.

\[\text{Figure 3. Scheme of basic cutting directions (a) tangential (b) longitudinal (c) transversal. [3]}\]

Orthogonal cutting starts with the blade cutting through the wood where the blade is vertically positioned in reference to the direction of the movement otherwise, we are talking about diagonal cut. The orthogonal cut has three components: the tool, the object being cut (wood) and wood shavings. The studies of the orthogonal cut are focused on the mutual influence on each other of tool, wood and wood shavings in the production process. Figure below shows system of orthogonal cut and its respective parts.[2]

\[\text{Figure 4. Schematic view of orthogonal cut. [2]}\]
Orthogonal cut can be viewed as a two-dimensional problem where there is equation between cut und uncut sawdust ($z_0 = z_1$). This process can be viewed through three different zones. First zone marked by the distance between points A and B represents length of contact of front part of the tool. Zone marked by the distance from points B to C is the zone where the cut occurs and sawdust appears. Blade point comes in the contact with the wood in point B which is shown in Figure 5.

\[ AB \] – length of contact between front side of the tool and sawdust,  
\[ BC \] – length of contact between wood and curved part of tool’s blade,  
\[ CD \] – length of contact between backside of the tool and wood  
\[ h_{BC} \] – wood compression,  
\[ h_{CD} \] – elastic return of wood  
\[ \gamma \] – front angle of the blade,  
\[ \alpha \] – rear angle of the blade,  
\[ \rho \] – radius of the blade’s curve

**Figure 5.** Schematic view of orthogonal cut in two dimensions. [2]

Dynamic of orthogonal cut is combination of tool work, wood and wood shavings. In the zone between points AB front part of the tool’s blade causes pressure on the newly formed sawdust. That pressure can be replaced by friction whose impact direction is perpendicular to the front part of the tool. The wood shaving moves in particular speed on the front part of the tool causing the friction. Vector sum of the two forces gives the resulting force on the front part of the tool. [2]

While the tool blade cuts into the wood cutting resistance occurs. When defining degree of material workability, level of weariness of tool blade, and setting the element dimensions, and machine power we need to be familiar with the resistance force. The resulting force in orthogonal cutting process (FR) is shown in the Figure 6.

**Figure 6.** Resulting force ($F_R$) in orthogonal cutting system.
- Tangential force ($F_T$) or force of friction that occurs on the front side of the tool surface and Normal force ($F_N$) that occurs in the plane perpendicular to the front part of the tool blade,
- Shear force ($F_S$) and Normal force ($F_{SN}$) that occurs in the plane perpendicular to the shear plane,
- Main force ($F_1$) and penetration force ($F_2$) that affects processed item perpendicularly. [7]

The estimated value is determined based on main cutting force which defines other components as well. This force is in turn mainly determined by material being cut and parameters of the process (cutting depth and length of tool movement). [7]

4. Power required for plastic deformation

Power required for plastic deformation of wood shavings is determined by the following equation:

$$ P_{pd} = \frac{dW}{dt} = \frac{R \varepsilon^{n+1}}{n+1} \cdot \frac{d \lambda_0}{\lambda_0} \cdot y_0 \cdot z_0 = \frac{R \varepsilon^{n+1}}{n+1} \cdot v_A \cdot y_0 \cdot z_0 $$

(1)

Formula for power (1) required for plastic deformation is derived from time formula (2) for energy required for plastic deformation.

$$ W = \int \sigma \cdot d \varepsilon = \int \bar{K} \cdot \varepsilon \cdot d \varepsilon = \frac{R \varepsilon^{n+1}}{n+1} \cdot x_0 \cdot y_0 \cdot z_0 $$

(2)

Equation (1) shows connection between power required for plastic deformation of wood shavings ($P_{pd}$) and process parameters ($v_A, y_0, z_0$), as well as mechanical properties of the material (wood) $K$ i $n$. Equivalent deformation ($\varepsilon$) depends on process parameters and mechanical properties of wood, as such it is important demonstrator of plastic deformation of wood shavings. Value of equivalent deformation is most often calculated by Von Mises yield criterion (3):

$$ \varepsilon = \frac{\sqrt{2}}{3} \sqrt{\left(\varepsilon_x - \varepsilon_y\right)^2 + \left(\varepsilon_y - \varepsilon_z\right)^2 + \left(\varepsilon_z - \varepsilon_x\right)^2} $$

(3)

Further input of main deformation values in the Mises criterion we get the equation for equivalent deformation of wood shavings (4):

$$ \varepsilon = \frac{2}{3} \cdot \sqrt{\ln^2 \xi_x - \ln \xi_x \ln \xi_y + \ln^2 \xi_y} $$

(4)

In equation (4) for calculation of power we need to express compression ratio as well as power and hardening ratio. Adding equation (4) in equation (1) we get equation (5) that links factors of compression and power spent for plastic deformation of wood shavings.

$$ P_{p1} = \frac{R \left(\frac{2}{3} \sqrt{\ln^2 \xi_x - \ln \xi_x \ln \xi_y + \ln^2 \xi_y}\right)^{n+1}}{n+1} \cdot v_A \cdot y_0 \cdot z_0 $$

(5)

Equation for equivalent value of power factor $K$ and hardening ration $n$ determined according to Hanks’ equation (Bodig and Jane, 1982):
\[
\bar{K} = \frac{K_x \cdot K_y}{K_x \cdot \sin^2 \gamma' + K_y \cdot \cos^2 \gamma'}
\]

\[
\bar{n} = \frac{n_x \cdot n_y}{n_x \cdot \sin^2 \gamma' + n_y \cdot \cos^2 \gamma'}
\]

Total cutting power can be calculated as sum of power needed for plastic deformation of wood shavings and power needed to overcome the friction force on the front and rear part of the tool blade, and power needed to create new surface. [2]

5. Conclusion
The aim of this paper is to present different kinds of wood cutting, mainly orthogonal cutting and to present the power required for plastic deformation. Besides this power, we can calculate total cutting power which is the sum of powers: the aforementioned plastic deformation power, power to overcome the force of friction on the front and rear part of the tool blade, and power required to produce new wood shavings. These powers are linked through wood shavings hardening ratio. They share some of the mechanical properties. In order to exactly determine the cutting power required it is necessary to be familiar with mechanical and physical properties of wood that depend on wood structure and conditions of the processing, and their microscopic and macroscopic structure of wood. For instance, moisture, to be exact amount of moisture in wood changes processing parameters as well as the quality of the processed object. We must mention wood-based materials such as fibrous plate compared to solid wood.

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