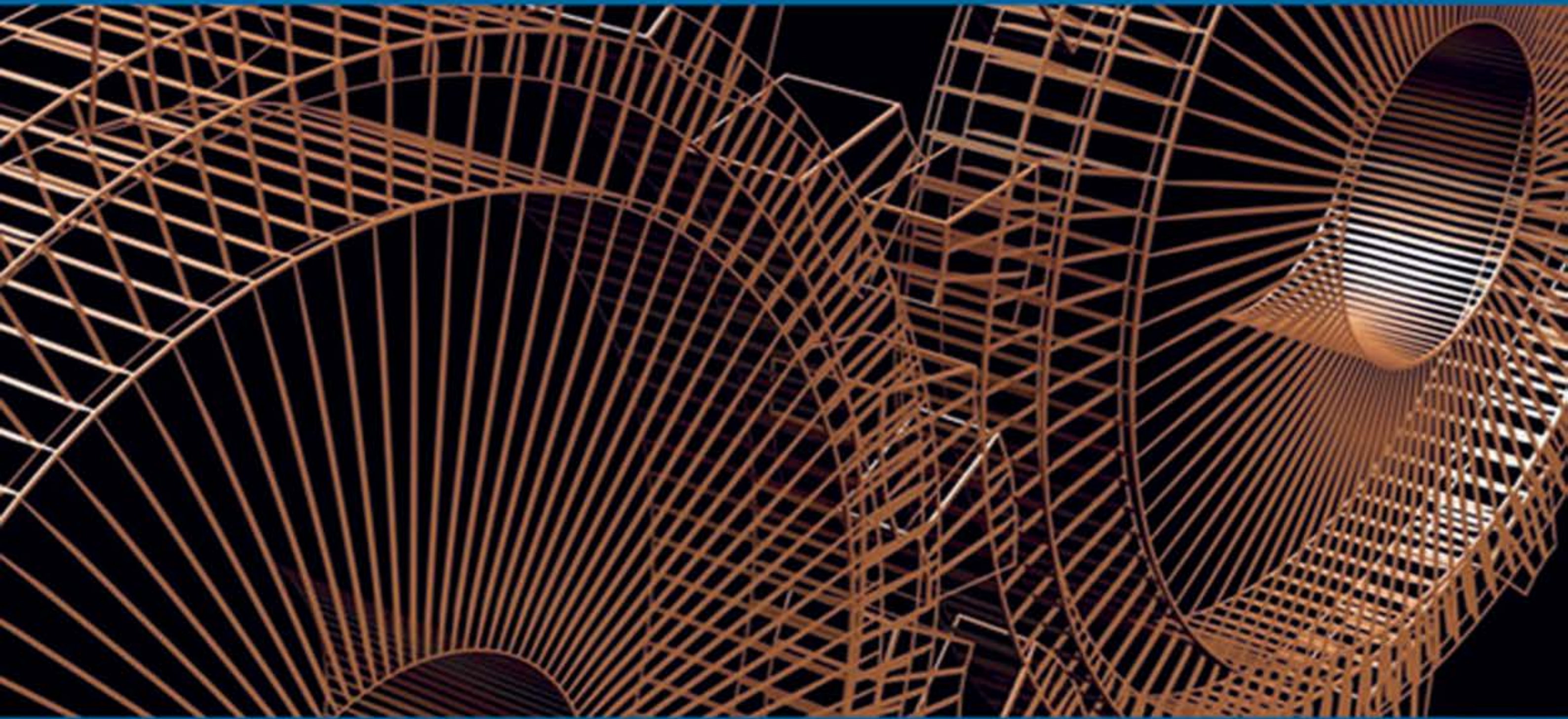

Wood Machining

Edited by
J. Paulo Davim

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Preface

In general, wood as an engineering material can be technically defined "as a hygroscopic, orthotropic, biological, and permeable material having extreme chemical diversity and physical complexity, with structures that vary extensively in their shape, size, properties and function". Therefore, using wood to its best advantage and most efficiency in engineering applications, specific characteristics or chemical, physical and mechanical properties must be considered. It is usual to divide the products into two classes, solid wood and composite wood products. Solid wood includes, for example, applications in furniture and cabinets, shipbuilding, bridges, flooring, mine timbers and posts. Composite wood products include, for example, insulation board, plywood, oriented strand board, hard-board and particle board.

In recent years the machining of wood products has acquired great importance due to the short supply of wood and increasing environmental awareness among users and manufacturers. The optimization of the machining process is around the chip formation, tool wear, workpiece surface quality, crack initiation and propagation of different types of wood. Other factors are also taken into consideration such as humidity, temperature, static preloads, and vibrations that can affect the wood during the machining process.

The purpose of this book is to present a collection of examples illustrating the state of the art and research developments in the machining of wood and wood products. Chapter 1 presents the fundamentals of machining of wood and wood composites. Chapter 2 covers wood and wood-based panels' machining quality. Chapter 3 contains information on reducing tool wear by cryogenic treatment and cooling with refrigerated air when processing medium density fiberboard. Chapter 4 is dedicated to wearing mechanisms contributing to tool life decrease by machining wood and secondary wood products. Chapter 5 covers monitoring surface quality on molding and sawing processes for solid wood and wood panels. Finally, in Chapter 6, evaluating the roughness of sanded wood surfaces is presented.

This book can be used as a research book for a final undergraduate engineering course (for example, wood, mechanical, materials, manufacturing, etc.) or as a subject on machining of wood and wood products at the postgraduate level. This book can also serve as a useful reference for academics, wood researchers, mechanical, manufacturing and materials engineers, professionals in areas related to the manufacturing of wood and wood products. The interest of this book is evident for many important research centers, laboratories and universities throughout the world. Therefore, it is hoped that this book will encourage and enthuse other research in this important field of engineering and technology.

I would like to extend my gratitude to ISTE-Wiley for this opportunity and for their professional support. Finally, I would like to thank all the chapter authors for their availability to work on this project.

J. Paulo DAVIM
University of Aveiro
Portugal
May 2011

Chapter 1

Machining of Wood and Wood Composites

1.1. Introduction

While machining of wood has been conducted for many centuries, and significant progress has been made in the cutting of wood, the shape of the tool – wedge – has not changed. With the progress of the new tool materials, more abrasion resistant and durable blades are being introduced to machining.

The rapid development of composite wood products also causes the improvement of the techniques and machines used to process such materials. New theories regarding cutting help with better utilization of raw materials. Computerized control of the machines makes it easier to achieve the assumed quality and productivity.

Chapter written by Grzegorz KOWALUK.

1.2. Wood and wood-based composites

Although wood is well known to all of us, a compact characterization of this material can be useful before starting the analysis of wood machining aspects. Chemical composition of wood, depends, among other things, on its species, it is based on cellulose (about 45-55%), lignin (about 25-30%), hemicelluloses (10-20%), resins, rubbers (4.5-9.5%) and mineral contamination (about 0.5%). Because of the significantly higher share of cellulose and lignin only those two components are described below.

Cellulose, polysaccharide with a crystalline structure, is the main component of the cell wall structure. The molecules of cellulose are bonded together in long chains creating elongated fibers – micelles. In the free spaces between the bunches of micelles the lignin and water are stored. Cellulose is not water and alcohol soluble, and can be extracted from the cell wall only in an acid environment.

Lignin is an amorphous material, which fills the frame of the cell wall, and is fixed with cellulose mechanically and chemically. The presence of lignin makes the cell walls harder and stiffer.

In the macroscopic structure of wood the following elements can be found:

– pith;

– growth rings;

– sapwood;

– heartwood;

– rays;

– resin canals.

Figure 1.1. *Cross-section of softwood (in this case Pinus Silvestris L.)*

The pith is the physiological axis of the tree and is situated in the central part of the cross-section of the stem. The shape of the pith is characteristic of the tree species: star-shaped for oak, quadrangle for ash, triangular for alder.

Growth rings are the effect of the annual accumulation of the wood layer. Two areas can be found in the structure of growth rings: earlywood and latewood. The earlywood is lighter and is created during spring. The main function of this part of the growth ring is transportation. The anatomical elements of this part have thinner walls and larger dimensions, compared to the latewood. Latewood, which is darker, is created during summer and because of the mechanical functions has thicker walls. The softwood species have a larger earlywood area, and the latewood area mostly has a constant width. Hence, when the width of the growth rings increases, the density of wood decreases. In the case of hardwood species, mostly ring-porous, the width of the latewood increases with the increase of the growth ring width.

The variation of the growth ring width gives information about the climatic conditions during creation of those rings. The width of the growth rings depends on weather, climate and soil parameters, as well as on specific biological features of the species. The width of the growth rings varies between 1 and 40 mm and depends on the temperature and vegetation period length. It means that the same species, e.g. from the mountain biotope can have narrow growth rings, whereas trees from the lowland habitat have wide growth rings.

Sapwood is a biologically active zone which transports water and nutrients along the trunk.

Heartwood does not take part in transportation, because the vessels are plugged and the walls of the vessels are impregnated with resins, rubbers and tannins. The formation of heartwood depends on the tree age (e.g. 20-30 years for pine, 60 years for ash), soil and climate.

Rays are the complex of the cells, which accumulate and transport water with mineral salts inside the trunk.

Resin canals are thin tubes, which run along and across the trunk producing resin.

The structure of wood, which consists of elongated anatomical elements, influences its anisotropy, this means that the physical and mechanical properties differ in the three principal directions relative to the trunk of the tree.

The type of wood is one of the main factors, which has a great effect upon the machining. There are two major types of wood: softwood from needle-bearing trees, and hardwood from broad-leaved trees. The descriptions “soft” and “hard” have little to do with the hardness and density of wood.

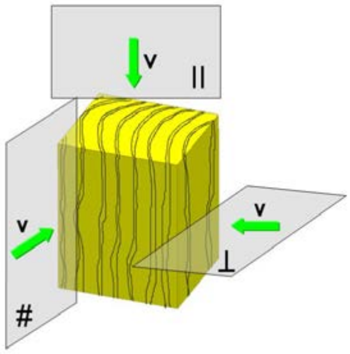

Figure 1.2. *Principal directions when cutting wood: II – longitudinal, # - tangential and ⊥ - radial*

The wood-based composite materials can be classified by the size of wood parts used to produce them. According to this, the following products can be found:

– plywood;

– OSB (oriented stradboard);

– particleboard;

– fiberboard.

Plywood is build up of thin sheets (plies) of wood (veneer), which are bonded together with glue under pressure. Plywood is produced mostly as flat panels or pre-shaped elements for furniture production. Plywood can be produced from either softwoods and hardwoods.

To achieve improved dimensional stability of plywood panels, they are usually constructed with an odd number of layers with the grain direction of adjacent layers oriented perpendicular to one another. This gives plywood fairly similar axial strength and stiffness properties in perpendicular directions within the panel plane. From the utilization point of view, two types of plywood are produced:

construction and decorative. The production of structural engineered materials, e.g. I-joists, is the other use for plywood. The main technique of plywood processing is sawing.

Oriented strandboard (OSB) is the structural-use panel produced from thin wood (most often softwood) strands bonded with resin. Because of the strands' typical aspect ratio (strand length divided by width) of about 3, and the special orientation of the strands in the panel's layers, the OSB panel has a greater bending strength in the oriented directions. OSB panels are used mostly for roof, wall, and floor sheathing in wooden and prefabricated constructions, as well as for the elements in I-beams. Utilized as flat panels elements the OSB panels are mainly machined by sawing.

Typical furniture particle panel is produced in three layers. The core layer is made of the coarser material, which improves raw material utilization. Face layers, from the fine particles, give a smooth surface for laminating, overlaying or painting. The chips are bonded together mostly with amine resins, as urea-formaldehyde resin.

Figure 1.3. *The mechanical forming head of the particleboard layer*

To improve the short-term moisture resistance of panels, paraffin or microcrystalline wax emulsion is added. Blended particles are pressed under elevated temperature and pressure. After pressing, the panel surfaces are sanded and can be finished and may also be veneered or overlaid with other materials to provide a decorative surface. The main ways of processing particleboards are circular sawing, milling (routing) and drilling.

The main difference between two types of fiberboard, hardboard and medium-density-fiberboard (MDF) is the method of mat formation: wet-method, where the fibers are moved in the water suspension and pressed with no bonding agent addition for hardboards; or the mat is formed by the pneumatic-mechanical method for MDF. The natural tendency of the lignocellulosic fibers to create larger conglomerates is utilized to produce hardboard.

During production of MDF, the fibers are blended with resin (mostly amine). The dry-formed group of panels, in addition to MDF, include high density fiberboard (HDF) and low density fiberboard (LDF). The main application of HDF panels are flooring materials, while LDF panels are used as wall facing. The furniture industry is by far the dominant MDF market, where it is frequently used in place of solid wood. The more regular structure of MDF panels across the thickness (compared to particleboards, for example) gives the opportunity for deep routing (milling) of the faces and shaping of the edges for the furniture fronts or doors. Sawing, milling, drilling, as well as deep routing are the most common ways of machining fiberboards.

1.3. Approach to cutting

Part of the tool, where the cutting is conducted, has a triangular shape. When the width of the machined material is smaller than the length of the cutting edge, free cutting is realized. In such a case only one cutting edge works. An example of free cutting is planing. If the width of the machined material is more than the length of the cutting edge, cleft cutting occurs. Apart from the main cutting edge, two side edges also work. An example of such cutting is sawing. A combination of the two abovementioned cutting methods is also possible: if the main cutting edge and one side cutting edge works. This situation often takes place during milling of wood.

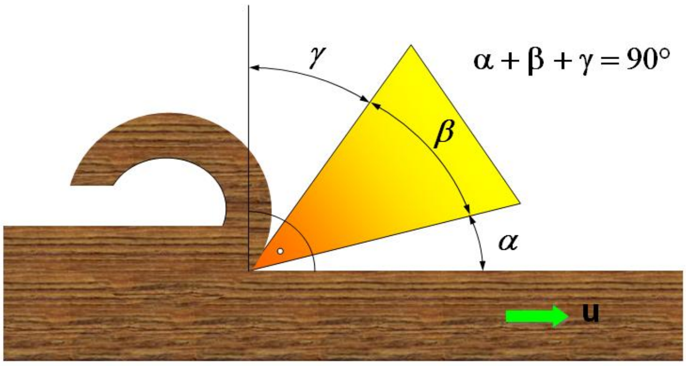

Figure 1.4. *Simplified cutting process model*

According to Huang *et al.* [HUA 00], cutting work, when cutting with an elementary knife (flat cutting), can be divided into two components: the work of new surface creation (work of fracture) and the work of chip deformation (see Figure 1.2). Cutting work can be calculated as follows:

$$E = F_C \cdot l \text{ [J]} \qquad [1.1]$$

where E is the cutting work [J], F_C is the cutting force [N], and l is the cutting path [m]. When the abovementioned cutting work is referred to the cut surface, the specific cutting work can be calculated:

$$E_A = \frac{E}{A} = \frac{F_C \cdot l}{b \cdot l} \left[\frac{J}{m^2}\right] \quad [1.2]$$

where E_A is the specific cutting work [J/m²], A is the cut surface [m²], and b is the cutting width [m].

According to Figure 1.5 the specific cutting work is the linear regression as a function of chip thickness. The equation of the specific cutting work will be as follows:

$$E_A = E_D \cdot t + E_S \left[\frac{J}{m^2}\right] \quad [1.3]$$

where E_D is the specific work of chip deformation [J/m²], t is the chip thickness [m], E_S is the work of new surface creation [J/m²]. Theoretically, if the chip thickness = 0, there is no chip deformation ($E_D \cdot t=0$), and the specific cutting work is equal to the specific work of new surface creation E_S.

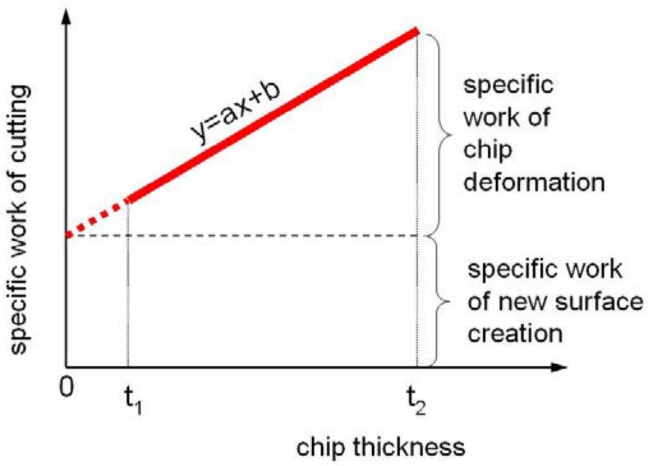

Figure 1.5. *Graphical interpretation of specific cutting work distribution [HUA 00]*

To practically calculate the specific cutting work, new surface creation and chip deformation, on the basis of regression [1.3], the set of data of the cutting forces during the processing of the material with changed chip thickness, is needed. It is relatively easy and precise to collect such data when cutting on microtome equipped with proper force measuring units.

Although, such a method is accurate and is an example of elementary (flat) cutting, the results of which can be easy applied to rotary cutting [BEE 03], the disadvantage is the low cutting speed, which is much lower than the cutting speed of conventional rotary machining.

The practical application of the abovementioned theory for rotary cutting with conventional cutting speed (e.g. 10-30 m/s) requires professional measuring equipment [KOW 07]. In such a case the chip thickness, as well as the cutting forces, change from zero to maximum in an extremely short time. However, as was proven by Sinn *et al.* [SIN 06], the thickness of the single chip changes from zero to maximum linearly.

The usefulness of the method of linear (flat) cutting on the microtome to measure the forces/cutting work was confirmed by Kowaluk *et al.* [KOW 04]. The investigation was focused on the measurement of the forces during the cutting of particleboards, with the use of tools set with gradual bluntness. It was proven that the work of surface creation depends mostly on the tool blunting stage, whereas the machined material properties influence the work of chip deformation Kowaluk *et al.* [KOW 06] also investigated the influence of the cutting speed on cutting work and the forces during the processing (milling) of particleboards. According to the research, the cutting work and the forces decrease with an increase in the cutting speed.

The other idea of the characteristic of cutting work is measurement of the electric power consumed by the machines' main motor when cutting [FUR 03]. The advantage of such a method is the relatively easy application in industrial conditions. The main disadvantages are the lack of precision of the cutting work measurement, because of the small amount of power used to cut, compared to the total consumed power, and the significant influence of the energy transmission losses (efficiency of the system).

According to Eyma *et al.* [EYM 03] – who studied the forces during cutting, with use of both a CNC router equipped with the piezoelectric sensors and a pendulum labormeter – to very accurately estimate the cutting forces involved during routing, the best solution is to measure specific gravity, elastic modulus in compression and tenacity. Also a pendulum can be useful, to provide a good estimation of cutting forces that is relatively precise.

1.4. Main techniques of machining

Cutting is an operation using cutting tools, the aim of which is to divide wood into parts, obtaining specific dimensions and shape, and smoothing the surface. The wood cutting processes can appear in two main varieties:

– where the chips are waste;

– where the chips are product.

The group of cutting processes, where the chips occur and the chips are waste, is the largest: sawing, planing, milling, drilling, turning and grinding are only some examples of machining, where the chips are waste.

The cutting processes, where the chips are desirable, are veneer production by flat slicing or peeling.

Figure 1.6. *The main ideas of wood cutting – action with a wedge – have not changed for many years*

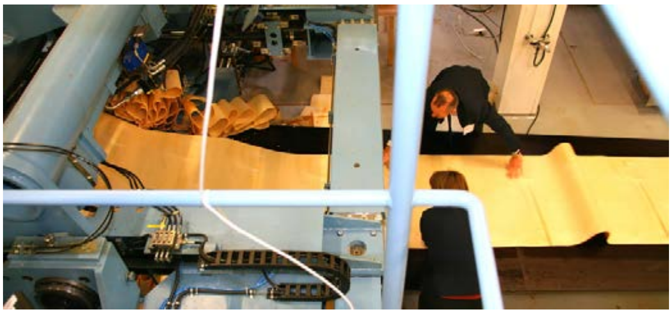

Figure 1.7. *Peeling in the laboratory*

The sawing process is conducted on various machines depend on the degree of processing. The primary processing of round softwood was recently mainly conducted on frame sawing machines when the hardwood was processed on bandsaws. The main advantage of the frame sawing machines was the comparable high capacity, especially of those with constant feed. The disadvantages were complicated installation of the machine, requiring additional levels in the building for the crank drive, and the time-consuming saw span change.

Figure 1.8. *Construction of the frame sawing machine (miniature in the Holztechnisches Museum Rosenheim, Germany)*

The cost distribution in a regular sawmill, according to Orlowski [ORL 10], is as follows: raw material 70%, labor 15%, fixed assets 10%, other costs 4% and tool costs 1%. That is the reason for the optimization of raw material processing. One of the more economic ways of processing is minimization of the kerf width, which achieves more efficient production with lower energy consumption.

Figure 1.9. *The costs of raw material presents almost ¾ of regular sawmill total costs*

Saw kerf width influences the amount of wood lost during sawing. Practically, the volume of wood lost in sawing is more than the volume removed by the tooth. Extra allowance, such as deviations or planer loss, must be added to the wood total volume loss. In the case of large kerfs, where the blades are thick, the deviation losses are comparably small. In the case of small kerf width, the deviations are bigger, but the wood loss is smaller. Only the trial-and-error method can lead to optimal kerf width and minimal wood waste.

The construction of new frame sawing machines is compact, the crank drive is replaced by special servo mechanisms and hybrid, balanced driving systems [WAS 02]. The weight of such machines is from about 800 kg to 3,500 kg. Nevertheless, the abovementioned frame sawing machines' purpose, because of a small cutting height (less than 250 mm), is to produce thin panels from wood with rectangular cross-sections, which were previously machined in other process.

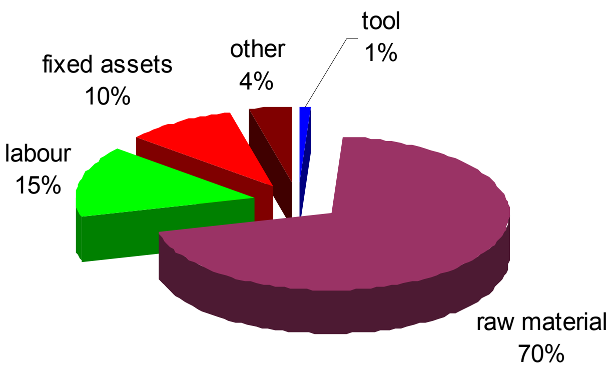

Figure 1.10. *The cost distribution in a regular sawmill [ORL 10]*

Nowadays sawing of round wood is also conducted on dedicated processing lines, where the machines' working circular saw blades are responsible for the main machining.

This type of machine is dedicated to processing logs with a diameter of 300-400 mm. Apart from the circular saw blades (with a diameter of 0.8-1 m), the machine is equipped with milling aggregates, which grind the side material.

Significant progress has been made in the construction of band saws. Many producers (e.g. Wood-Mizer) offer the frame of the machine based on a single driving rail, to avoid the machined material shape errors, connected to incorrect machine installation. Better processing results are also possible to achieve thanks to single-cantilever cutting head support. This method of fixing leads to fast and precise vertical movement of the cutting head, as well as stability during cutting.

Modular construction of the machine frame gives the opportunity for easy change of the maximal length of cutting. Screwing log leveling mechanisms helps with dexterous and exact regulation of the machined material positioning. Support of the band saw, with the smooth movement, minimizes the band saw vibration during cutting. Most contemporary band sawing machines are equipped with water band saw cooling, and some of them, also with a milling head, which extends the tool life by cutting the bark before cutting by band saw.

Contemporary planing machines for industrial application are mostly multi-head (4-8 heads). This solution enables the machining of 4 sides of the machined material simultaneously on one stand. Such machines can process elements with dimensions of about 230 x 160 mm. Depending on the size of the cutting heads (from 90 to 220 mm or more), the rotation speed of the tools varies from 8,000 to 12,000 min^{-1}. Some producers try to improve the quality of machining. One of the applied solutions is the cutting head with expansion elements inside. When the cutting head is mounted on the spindle, a hydraulic pressure is applied to the special channels inside the head. Thanks to