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ENHANCING KEY ELEMENTS OF THE VALUE CHAIN FOR PLANTATION GROWN WOOD IN LAO PDR

Specification on optimal machining parameters, tools and machining methods

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VALTIP2

Contents

1. Introduction

This report is one of the milestone reports within Activity 3.2 of ACIAR funded project "*Enhancing key elements of the value chains for plantation-grown wood in Lao PDR*" which objective is to enhance the competitiveness and capacity of the Lao PDR wood processing industry through the development of an industry-led value-added timber market strategy.

This report provides information on optimal machining parameters, tools and machining methods with focus being placed on appearance wood products used in indoor conditions. The report does not provide specific machining parameters for teak or eucalyptus camaldulensis but rather information on how to assess surface quality following machining since each and every machine is different with specific elements also affected by the operator. It is recommended to test each machine using different sets of parameters to optimise machining operation and achieve high quality machined surfaces.

Quality of machining is closely related to the quality of the final product. For example, well made products often fail in service due to the selection of the unsuitable coating or improper finishing method [6]. However, even the best finishing systems can't compensate for poor machining. Machining wood surface properly requires not only sound knowledge of the workpiece itself but also of the tool used to prepare the surface. Because wood is a heterogeneous and anisotropic material, it is important to understand its properties to ensure that each manufacturing step meets required quality standards. As mentioned by Ozarska [6], the final appearance of the finished item of furniture is its major selling point. However, previous manufacturing steps such as machining need to be done and understood properly to reach this objective.

Multiple studies stated that surface quality of solid wood products is one of the most important properties influencing further manufacturing process such as finishing or strength of adhesive joint [9,10]. Adhesives and finishing systems can transfer and penetrate the cell walls or surfaces of the wood material; thereby they increase the mechanical bond between the wood material and the adhesive/finishing system. The effective transfer of bond from one member to another depends on the strength of the links which can be affected by wood species and machining processes.

2. Machining wood

From a mechanical point of view, machining wood is a complex stress-failure process where, by hand or machine, force is transmitted to the wood by means of a cutting tool. The tool has pertinent geometry, and the wood has pertinent physical and mechanical properties. The orientation and direction of the force are controlled by the design of the tool and/or by the woodworker's hands, and these will determine the way stresses develop at the cutting edge and how the failure of the wood (or cutting) occurs. Two factors are important in this regard. The first one is the sharpness of the tool, in which the cutting area (A) of the tool edge is small enough so that the force (P) applied to the tool will cause a stress (P/A) greater than the strength of the wood. The second factor is the condition of the wood (i.e. moisture content, temperature, and defects) [4].

Machining can be defined as the action of a cutting tool on a piece of wood or workpiece, with the cutting action that takes place referred to as chip formation, wherein a portion of wood called the chip is separated from the workpiece [4]. Chip formation involves the geometry of the tool relative to the orientation of the structure of the wood. The aim of machining always should be the paramount consideration. The approaches used may differ drastically, depending on the objective sought. These objectives may be classified as:

Severing Two or more pieces are made from one (e.g. splitting firewood, band sawing rough parts from a plank)

Shaping A specific shape is imparted to the workpiece, in some cases a flat-planed surface, in others some specific contour. Jointing a flat surface on a cupped board is one example; milling an ogee moulding is another.

Surfacing A surface of prescribed quality is created, such as sanding a surface prior to finishing or jointing to be suitable for gluing.

In most cases, two or even all three of the above are involved concurrently. The present report covers all these approaches with more attention being paid to surfacing.

3. The Wood Surface

A piece of wood can be either produced rough or surfaced[1] depending of the end-use. For example, lumber is surfaced with the aims of attaining smoothness of surface and uniformity of size. Imperfections or blemishes, defined in multiple standards, are caused by machining and classified as manufacturing imperfections. For example, chipped and torn grain are surface irregularities in which surface fibres have been torn out by the surfacing operation. Raised grain, skip, machine burn and gouge, chip marks, and wavy surfacing are other manufacturing imperfections. Those manufacturing imperfections are further detailed in grading rules according to market or client specifications [2].

Based on a simple visual inspection, wood surface may appear to be smooth and flat. However, microscopic examination will reveal peaks, valleys, and crevices littered with loose fibres and other debris. Such surface conditions cause air pockets and blockages that prevent complete wetting by the adhesive and introduce stress concentrations when the adhesive has cured. In addition, different characteristics of wood such as grain angle, natural defects, and extractives will lead to widely different surface energies, roughness, and chemistry, all of which usually affecting the quality of finishing or gluing systems [2].

Surface properties of wood for bonding purposes

Adhesives bond by surface attachment and physico-chemical conditions of the wood's surface are extremely important to obtain satisfactory bond performance. The wood surface should be smooth, flat, and free of machine marks and other surface irregularities, including planer skips and crushed, torn, or chipped grain. The surface should be free of burnishes, exudates, oils, dirt, and other debris that form a weak boundary between the adhesive and the wood.

A smooth, knife-cut surface is usually best for bonding. Surfaces made using saws tend to be rougher than those made using planers and jointers. However, surfaces sawn with appropriate blades on properly set straight-line ripsaws can provide satisfactory results. Unless the saws and feed works are well maintained, joints made with sawed surfaces will be weaker and less uniform in strength

[1] Dressed is another common expression referring to surfaced lumber.

than those made with sharp planer or jointer knives [2]. Dull cutting edges of planer or jointer knives crush and burnish the cells on the wood surface as shown in Figure 1. Not only are these cells weaker, they also inhibit adhesive wetting and penetration, thus affecting the mechanical properties of the bonded weldline [2].

Mechanical and chemical properties of a wood surface both influence the quality of adhesive bonds. Wood whose surface is highly fractured or crushed cannot form a strong bond even if the adhesive forms a strong bond with the surface.

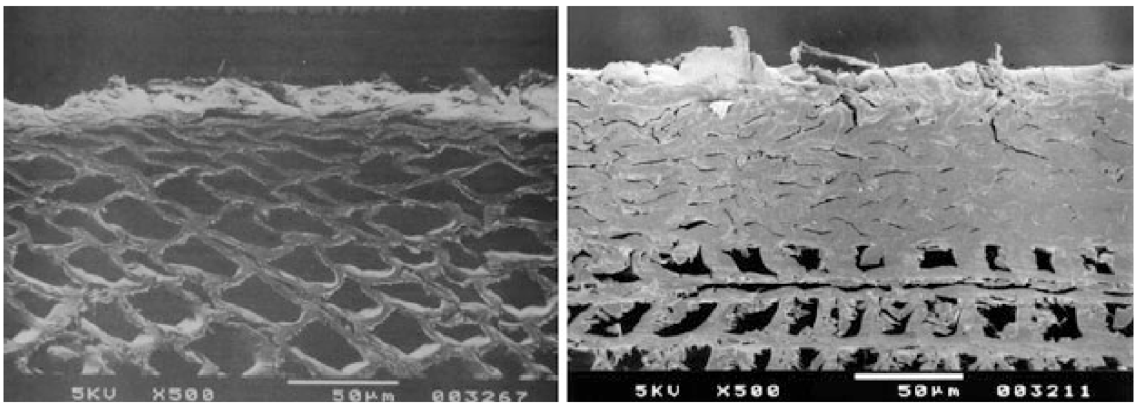

Figure 1: Crushed cells in early and late wood layers (left and right, respectively) caused by the same blunt edge [3]. Subsurface crushing of wood cells causes permanent or semi-permanent compression in wood mainly by cell deformation, void crushing, or layers of different density invading one another. These deformations take place in layers located underneath the freshly generated surface.

Abrasive (sanding) planning with grit sizes from 24 to 60 also causes surface and subsurface crushing of wood cells. The adhesive industry typically recommends 60-80-grit sanding as acceptable for wood bonding as this equates to 24 to 30 knife marks per inch when planning. Generally, anything above 200-grit fuzzes the wood surface and is not recommended for bonding. Figure 2 shows bondlines of undamaged, knife-planed lumber compared with bondlines between surfaces damaged by abrasive planning. The undamaged surfaces planned with sharp knife show open wood cells with their distinct walls (Top picture A) where the damaged surfaces abrasively planed with 36-grit sandpaper show crushed cells with their indistinct walls in and adjacent to the bondline (Bottom picture B). Such damaged surfaces are inherently weak and result in poor bond strength. If abrasive planning is to be used before bonding, sanding dust must be removed completely from the surface and belts must be kept clean and sharp when using equipment such as a wide-belt sander [6].

Damage to the surface can be revealed by wiping a very wet rag over a portion of the surface, waiting for a minute or more, removing any remaining water with a dry paper towel, and comparing the roughness of the wet and dry surfaces. If the wetted area is much rougher than the dry area, then the machining has damaged the surface. A weak joint results if the adhesive does not completely penetrate crushed cells to restore their original strength [2].

Surfacing or resurfacing the wood within 24 h before bonding removes extractives and provides a more wettable surface. Surfacing also removes any unevenness that may have occurred from changes in moisture content. Parallel and flat surfaces allow the adhesive to flow freely and form a uniformly thin layer that is essential to optimal adhesive performance [2].

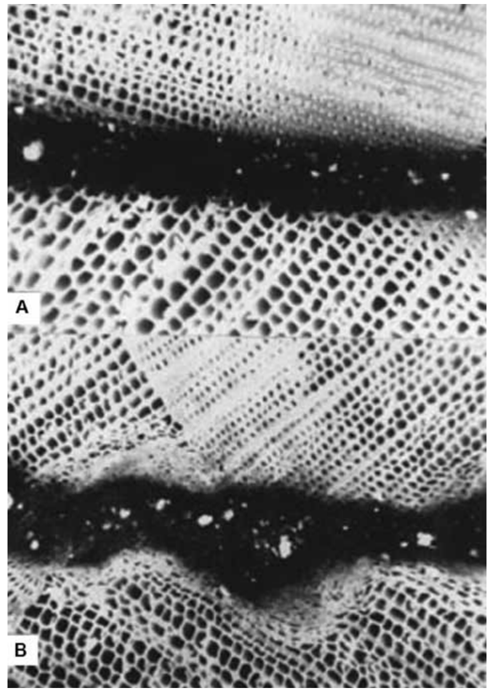

Figure 2: Cross sections of bonded joints involving undamaged and damaged surfaces. The dark area at the centre is the adhesive bondline. Top picture (A): two undamaged surfaces planned with sharp knife. Bottom picture (B): two damaged surfaces abrasively planed with 36-grit sandpaper [2]

Surface Roughness

Machined surfaces, regardless if they are made of metal, plastic or wood, are never perfectly smooth with protruding parts, valleys and peaks. These forms of surface irregularity are called ***roughness***. Surface roughness can be caused by different factors: discontinuities in the material, various forms of brittle fracture, cavities in the texture, wear of the tool edge, local deformations deriving from the free cutting mechanism (without counter blade).

Surface roughness usually has a primary influence on the visual appearance of materials but it might have other effects, too. Surface roughness may be extraordinarily detrimental for wood if the surface under the tool edge suffers permanent deformity. The stability of the damaged surface diminishes to a great extent; the durability of the processed surface will then be inferior [3].

Visual appearance and colour effects are primarily influenced by dispersion and reflection of light[2]. The original colour of wood becomes a lot more visible if the surface is bright, i.e. smooth and free of irregularities.

Surface Preparation

Wood surfaces are best prepared for maximum adhesive wetting (or any other finishing system), flow, and penetration by removing all materials that might interfere with bond formation to sound wood. Ideally, wood should be knife-planed within 24 hours of adhesive spreading. However, other surfacing methods have been used successfully for certain types of bonded joints, including sawing for furniture and millwork, knife-cutting for veneer, and abrasive-planning for panels. All methods must produce smooth, flat, parallel surfaces, free from machining irregularities, such as burnishes, skips, and crushed, torn, and chipped grain. Properly planed flat surfaces help ensure uniform adhesive spread rate [2].

[2] An example for this is transparent glass, which loses transparency following a moderate roughening process.

Origin of Surface Roughness

Roughness that evolves during machining has two major components: machining caused roughness and roughness caused by the internal wood structure. Even in the case of an ideal machining, rough surface evolves due to the inner holes cut. Moreover, in the recent practice of high-speed machining, roughness due to machining is usually much less than the structure-based roughness, especially in the case of hardwood species with large vessels. The roughness due to machining usually depends on the following factors [3]:

- Cutting speed
- Chip thickness
- Machining direction relatively to the grain
- Rake angle of the tool
- Sharpness of the tool edge (tool edge radius)
- Vibration amplitude of the work piece.

One of the primary reasons for machining-caused roughness is the brittle fracture of the wood material and its low tensile strength perpendicular to the grain. First, it is important to mention that the occurrence of brittle fracture cannot be eliminated. However, it can be limited to a lower volume. The most effective method for this is the high-speed cutting and the smallest material contact possible which is directly related to the tool edge sharpness.

The main new recognitions and conclusions on the problems of wood surface roughness can be summarized as follows [3].

- The total surface roughness can be divided into two components: the first is the component due to machining; and the second is the component due to internal or anatomical structure of wood.
- In the present days most of the roughness is originated from the roughness component due to internal structure.
- An increasing cutting speed help reducing the surface roughness but sharpness of the tool edge must be maintained.

4. The Workpiece

As mentioned above, the structural nature of wood in terms of its properties is particularly important and affects machining. The anisotropic nature of wood is the most important characteristic affecting chip formation and surface quality of a workpiece. Surface roughness of wood can be affected by various anatomical factors such as annual ring variation, wood density, cell structure, and latewood/earlywood ratio. Density variation among and within species is also of obvious importance, as is unevenness of grain, especially in ring-porous hardwoods. Heartwood extractives in some species are particularly abrasive and contribute to tool dulling. Defects such as knots create both irregularities of grain direction and variations in density. Structural irregularities such as wavy or interlocked grain cause special machining problems. Moisture content influences machining as it affects the strength of wood and so do stresses or checks developed in drying.

When machining wood, the variability between and within growth rings affects both machining forces and the surface quality resulting. These variations in physical properties not only present machining problems in themselves but, because of drying stresses that can occur in the zones of demarcation between latewood and earlywood, the problems are frequently intensified [5].

Teak

Teak (*Tectona grandis*) contains an oleo-resin which gives it a greasy feel and a distinctive odour to freshly cut material. The texture of teak can be quite uneven, being alternatively smooth and coarse because of the wood's ring-porous nature. Its grain is usually straight and is relatively easy to work but silica can be present and this will necessitate frequent sharpening of tools[3]. Teak also peels easily. Gluing sometimes present difficulties because of the oily nature of wood, and it is important to have freshly dressed surfaces [1]. Pre-treatment may be necessary to ensure good bonding of finishes and glues[4] [2]. Various adverse cutaneous reactions may occur as a result of exposure to wood dust or solid woods usually associated with manual or machine woodworking. Airborne contact dermatitis is often diagnosed as a result of exposure to wood dust [8].

Eucalyptus Camaldulensis

Eucalyptus camaldulensis, commonly named “River red gum” in Australia, is relatively fine and even. Gum veins are common and grain usually interlocked which requires adjustments of the cutting angle when dressing it [1].

5. The Tool

At the end of a cutting tool where chips are formed, the tool geometry can be described in terms of a cutting edge formed by its intersecting face and back surfaces, or planes (Figure 3). The critical geometry of the cutting edge is typically defined in terms of its direction of motion:

- Rake angle (α): Angle between the tool face and a line perpendicular to the direction of travel of the edge (also called angle of attack or cutting, hook, or chip angle). The rake angle determines the chip deformation and is between 15 and 25°. Very hard tool materials require quite a small rake angle, while veneer cutting tools are around 70° [3].
- Sharpness angle (β): Angle between the face and back of the knife (also called bevel angle). Its main function is the cutting itself, maintaining a sharp edge and conducting heat away from the edge part. Veneer cutting knives have values around 20° [3].
- Clearance angle (γ): Angle between the back of the knife and the path of travel of the edge. The clearance angle ensures that there is no friction on the bottom face of the blade. It is generally 10–15°, but veneer cutting knives have only around a 1° clearance angle [3].

[3] Average content of silica range from 0.27-0.66% depending of provenance and is known to influence the ease of processing where content of only 0.05% is considered to affect machining properties negatively [7]

[4] Chemical pre-treatments with chemical reagents are widely applied to wood surfaces in order to improve bonding ability, wettability and reactivate wood surfaces for glue–wood bonds. Mechanical pre-treatments such as sanding and planning can also be applied to get a fresh surface which eliminates bonding problems and improves glue bonding of wood [12].

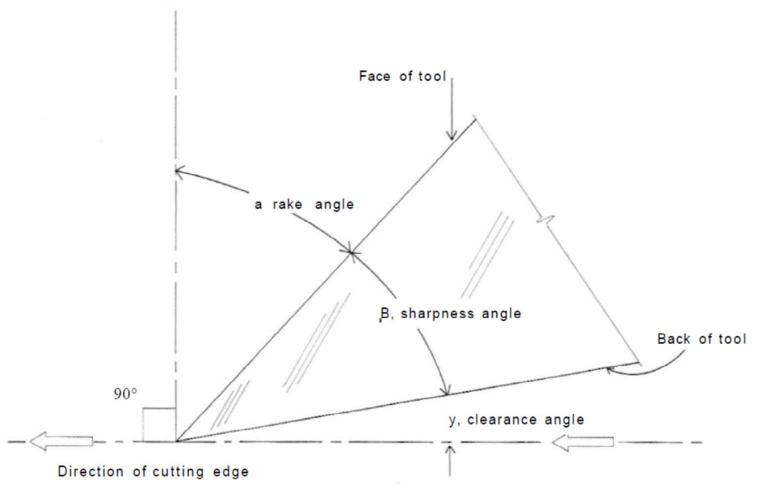

Figure 3: Characteristic angles of a woodworking tool

Oblique or slide angle decreases the normal force on the edge and the dynamic load on long knives. The main advantages of oblique cutting are: cutting forces are considerably reduced; a lower cutting noise level (which may be as high as 6–8 dB); a better surface quality.

As required by circumstance, cutting-tool geometry can be varied considerably. The sharpness angle will always be a positive value. The rake angle and clearance angle can be of negative values; a negative clearance angle indicating interference between tool and workpiece.

Common tool materials used are low alloy steel, HSS steel, satellite tipped tool, cemented tungsten carbide, boron nitride and polycrystalline diamond. Various edge treatment and coating procedures can be used for further increasing the service life of the tool. The above list of tool materials means, at the same time, the sequence of increasing hardness and tool service life. Hard materials are generally more rigid and breakable. Hard materials require a bigger sharpening angle and, as a consequence, a smaller rake angle. It is important to note that the initial sharpness (y_0) of a tooth made of hard material is always inferior to edges made of low alloy or HSS steel [3].

The edges of the tool are important in the cutting process. The cutting-edges are never absolutely sharp, but they always have a rounding off radius. The range of the radius of the main-cutting edge (ρ) is between 10-60 µm. If the radius becomes larger due to wear, the tool edge has to be sharpened [3].

The operational parameters of a tool can be summarized as follows:

- The peripheral speed of the tool which influences its productiveness, the surface quality, the wear of the edges, and to a lesser extent the cutting force. Regular values vary between 30 and 60 m/s today.
- The feed per tooth (e_z), or the chip thickness (h) influence the productiveness, the surface quality and the cutting force. If the gullet of the tooth runs full in a gap, then the chip has to fit loosely in the tooth's gullet, and that limits the maximum value of e_z. Varying chip cross sections can be obtained when using rotating tools so we should calculate the average chip thickness. Using a frame saw, the value of e_z changes as a function of the stroke, as the saw's

speed is variable, while the feed motion is constant. When cutting wood, the theoretical thickness of a chip is almost the same as the thickness of the detached chip. The reason is that the chip's plastic deformation is not significant; smaller plastic deformations occur only on the compressed side.

- The number of edges of a tool (*Z*) influences its productivity, the surface quality, and sometimes the maximum feed per tooth. The pitch of the teeth and the capacity of the tooth gullet are important in saws.

Thermal Loading in Cutting Tools

When wood is processed by machines, the chip slides on the surface of the tool and friction work transforms into heat. Most of this heat flows into the direct surroundings of the edge tool. Depending on the friction power, the area of the edge warms up and the temperature on the surface of the edge can reach a large value. The high temperature of the edge of a tool increases the wear of a tool as heat weakens and softens metals, especially above 500-600 °C.

Some notes regarding thermal loading in cutting tools

- The heat load in woodworking tools primarily originates from frictional heat;
- The high peripheral speed generates large frictional power and, as a consequence, high surface temperatures;
- The high surface temperature is an important cause of wear, as the materials soften and high temperature corrosion occurs;
- The high cyclic temperature variations of the edge surface causes cyclical heat stress that can cause pitting of the surface;
- The edge temperature of a worn tool is always larger than for a sharp tool which further increases the intensity of the wear.

Operating parameters of wood cutting tools

It is important to operate woodworking machines and tools economically and correctly. The optimal operating parameters and manufacturing costs change depending on the task. The operational parameters also have limits. Exceeding these limits may hamper the safe operation of the machine or the tool.

The most important operating parameters are the following:

- Peripheral speed of the tool;
- Feed speed;
- Feed per tooth;
- Depth of cut.

The operational parameters influence the following for a given tool:

- Kerf volume cut in the unit time;
- Cross section cut in the unit time;
- Surface roughness and waviness;
- Wear of the tool;

- Energy consumption of cutting;
- Costs of machining.

The ultimate goal of any woodworking operation should be to minimize energy consumption and manufacturing costs, and to maximize throughput and quality. The energy consumption of woodworking operations is significant part of the total production cost. Therefore, it is important to select proper tools with optimum operational parameters.

Tool wear

Woodworking tools generally operate at high speeds (up to 50–80 m/s). Their working surfaces (rake face, edge and clearance face) are subjected to large pressures due to cutting forces. The high speed motion generates high friction power turning into heat. Therefore, woodworking tools operate under heavy mechanical and thermal loads.

The cutting process is always associated with tool wear. Tool wear is actually a loss of material from the cutting edge due to mechanical, thermal and chemical effects. The wear process leads to bluntness of the cutting edge, which in turn causes an increase in power consumption, feed force and surface deterioration of the workpiece. Surface roughness and force components are especially sensitive to changes in edge profile geometry due to wear.

The appropriate tool in the woodworking industry achieve a high wood machining capacity, high dimension accuracy, good surface roughness and long service life. The costs allocated to buying and maintaining tools is significant in relation to the total production costs. Therefore, it is important to make the optimum selections of tools for different woodworking operations, and to use them rationally to ensure a long service life.

Edge Profile and Effect on Cutting Force

The initial edge profile is generally produced by grinding. Depending on the properties of the material, first of all its hardness, this profile is never smooth and has an irregular geometry. The initial profile of the tool edge is not smooth enough, and the form (concerning its stress state) is not optimal. After a tool is put into use, its edge profile undergoes a rapid change and takes on the shape of a smooth cylinder. The wear processes cause the radius of the tool edge to continuously increase and several stages of the tool wear can be distinguished. The initial edge radius (ρ), depending on the hardness of the tool material, is generally to 10–15 µm. As the initial stage of tool wear developed, the optimum edge shape extends to an approximate radius of 20 µm (Figure 4).

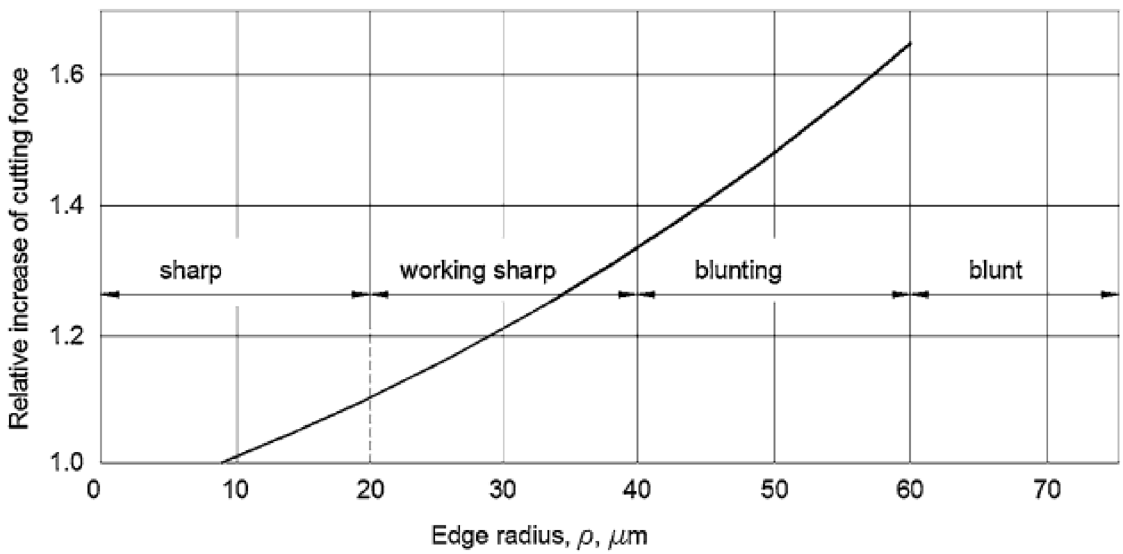

Figure 4: Stages of tool wear and the relative increase of the required cutting force [3]

The next and more important stage is the working sharp stage, which ensures the optimum cutting conditions with low energy consumption and good surface quality. Over an edge radius of 40 µm, the tool starts to become blunt, requiring increasing cutting forces and decreasing the surface quality. The tool in this stage of wear is suitable for rough woodworking operations, but it does not ensure a good surface quality. Finally, in the blunt wear stage the tool requires high cutting energy and produces low surface quality. In addition, the blunt edge compresses the upper layers of the cut surface causing severe damage and surface instability.

Quantitative measurement of tool wear is of great importance to the woodworking industry. Wear can be defined as a loss of material from the cutting edge due to mechanical, electro-chemical and high temperature effects associated with the cutting process.

The most commonly measured wear parameter is edge retraction (γ), which can easily be measured. This single wear parameter does not provide full information about the shape and geometry of a worn edge. It was also observed that the nose radius (Figure 5) may be stabilized at a particular value and does not always increase further with increasing wear.

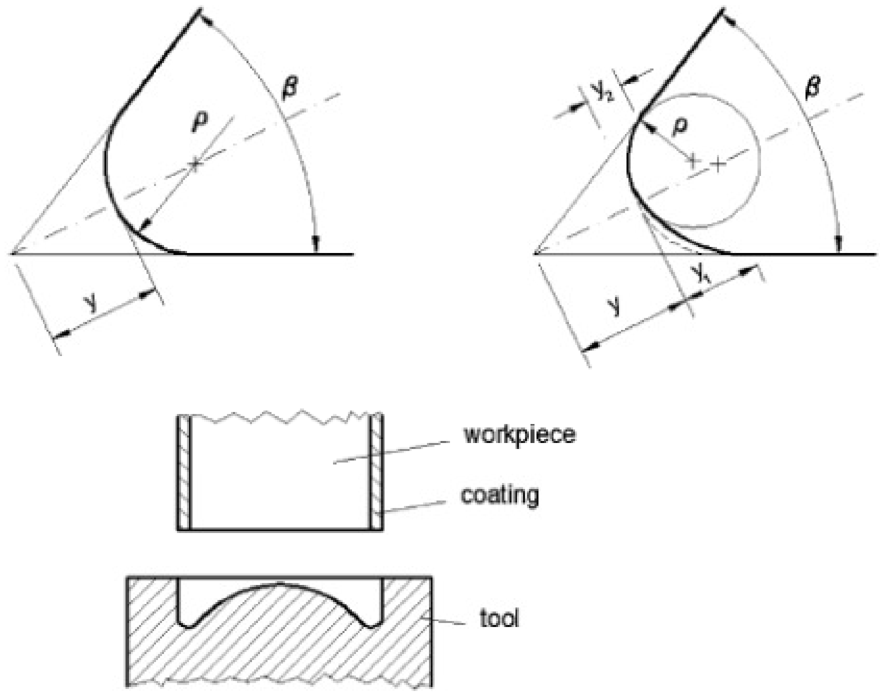

Figure 5: Different edge wear profiles: symmetric (top left), asymmetric (top right), wear due to workpiece where coating has been applied prior machining (bottom). Edge radius (ρ); Sharpening angle of the tool edge (β); Position of an ideally sharp cutting edge or edge retraction (γ) [3].

Major Tool Wear Mechanisms

Three major wear mechanisms can be distinguished in tool wear process: abrasion, electrochemical and high temperature corrosion. Generally, abrasion is always present as a mechanical wear process acting together with one of the other two, depending on the density, moisture content, and acidity of the wood and cutting parameters, especially edge surface temperature.

Abrasion occurs from the motion of hard particles between the sliding surfaces of a tool and wood. Wood species have always some mineral contaminations (which can be estimated by using a combustion method). The remaining hard mineral contaminations can be separated into fractions and measured. Their particle size is generally smaller than 50 µm. Silica is especially responsible for excessive blunting of tools. The silica content may be very different ranging from 0.1 to 10 g per kg of wood. The density of wood is also important in the process of mechanical wear. Denser wood has higher mechanical strength and exerts higher pressure on the edge face of a tool.

Electro-chemical wear is attributed to the extractives in wood, such as gums, resins, sugars, oils, starches, alkaloids and tannin in the presence of water. Most extractives are reactive compounds forming chemical reactions between the wood extractives and the metallic constituents of a tool. The acidity of wood (pH number) has great importance in this wear process.

High temperature corrosion is also a common wear mechanism due to high temperatures in the cutting zone. High temperatures around 800-900 °C may occur depending on the cutting speed and other operational parameters. This high temperature can induce oxidation, which attacks the tool material. Different wood species have different behaviour in high temperature oxidation. The intensity of high temperature corrosion also depends on tool material and wood species.

Factors Affecting Wear

To reduce tool wear, the selection of appropriate tool materials or their treatment, such as coatings, is very important. Coatings are more resistant to high temperature corrosion and provide a longer tool life. Polycrystalline diamond is highly resistant to abrasion and to chemical attack. A high coefficient of heat conduction in a tool material is of great importance in lowering the surface temperature in the cutting zone. A larger sharpening angle also lowers the maximum edge temperature.

Main factors influencing tool wear can be summarized as follows:

Tool Properties

- Tool material
- Sharpening angle
- Rake angle
- Edge treating or coating
- Accuracy of edge running circle
- Accuracy of side running

Workpiece Properties

- Strength properties
- Moisture content and pH-value
- Density
- Cutting direction
- Resin and ash content
- Adhesives and surface coating

Operational Parameters

- Cutting speed
- Tooth bite
- Cutting depth
- Vibration of the tool

The number of influencing factors is very high, the interaction of different wear mechanisms is very complicated and, therefore, the tool life for a particular case can only be determined experimentally.

Effects of Tool Wear on the Surface Roughness

Blunt tools with a bigger edge radius transmit bigger forces onto the material causing cell fractures (Figure 6). The material in front of the tool travels a longer distance going around the edge. The forces transmitted to the chip at the detachment point cause a fracture of elementary particles [3].

The cell walls get essentially damaged in the compressed layer therefore, this layer loses its stability in all aspect. It will have poor mechanical strength and low abrasion resistance, humidity will cause its swelling to various extents. Furthermore, observations have shown that the compressed layer depends also on the chip thickness: using larger chip thicknesses, the same blunt edge exerts more pressure on the bottom layers and the compressed layer increases. This further supports the advantage to use small chip thickness for surface finish. The use of oblique cutting may further decrease the damaged layer thickness.

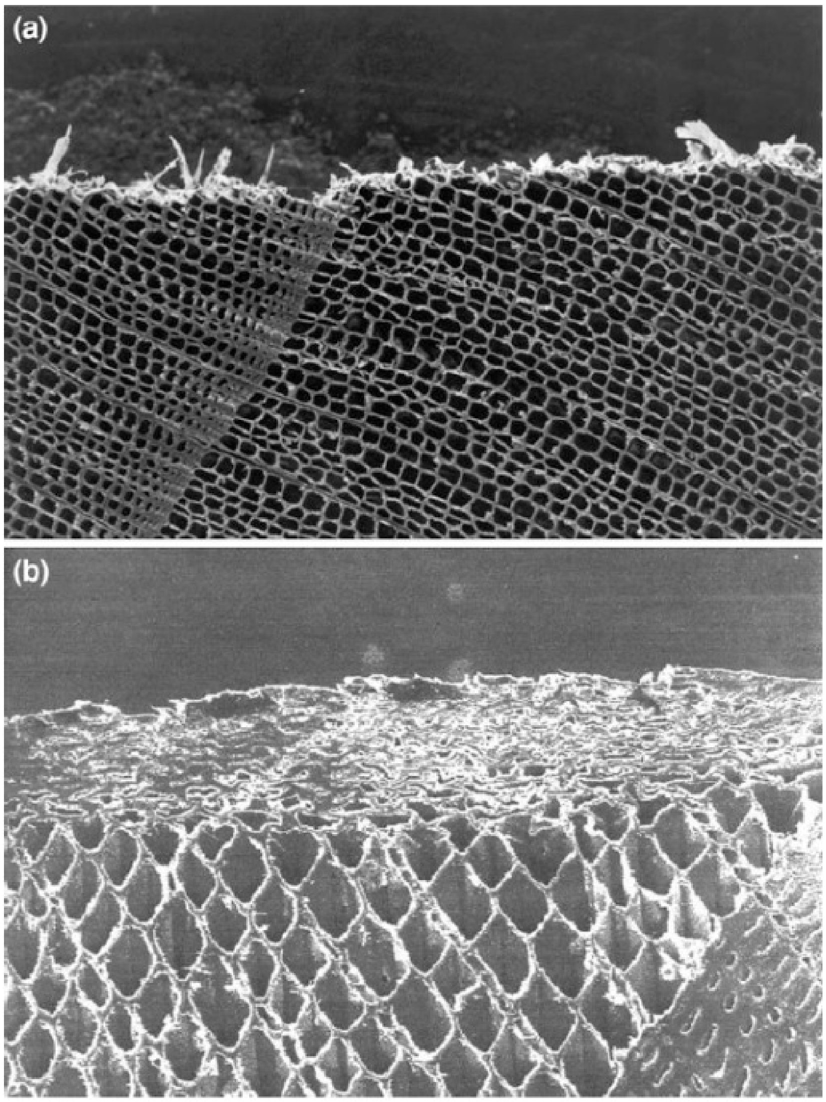

Figure 6: Clear cut of a sharp tool edge (a) and compression of the surface as a result of a blunt tool edge (b) [3].

Chip Formation

Figure 7 shows an ideal cutting action, which will vary according to the resisting grain orientation of the wood and the tool geometry. Energy is consumed in severing or separating the wood structure to form the chip, in deforming or rotating the chip, and in the frictional resistance of the tool face against the chip and the tool back against the newly formed surface of the workpiece.

When the resulting shape and surface quality of the workpiece are important, it is critical to keep chip formation close to the tool edge itself. When the chip is being formed well ahead of the tool, as in splitting wood, neither its shape nor its surface quality can be well controlled. Increasing the sharpness angle of the tool makes the edge more durable but eventually leads to excessive frictional resistance or to uncontrollable chip formation.

When cutting into wood tissue with a tool edge, two principles must be kept in mind: (1) failure occurs only when ultimate stress is reached; (2) stress is always accompanied by strain. This means that contrary to the idealized cutting action shown in Figure 7, we must imagine something where in order to develop enough stress to produce failure, the wood must first deform (Figure 8). Since stress is load divided by area, then the smaller the area of application, the higher the stress that will be produced by a given load. Therefore, concentrating cutting force on the smallest possible area should always be the focus and this is commonly called sharpness.

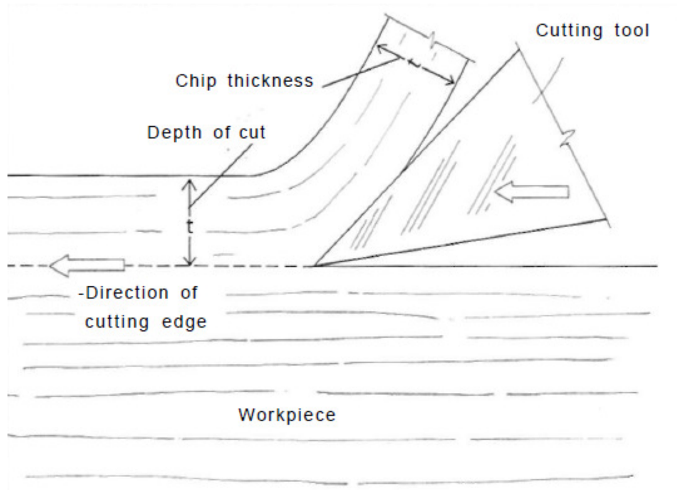

Figure 7: Idealized cutting action [4]

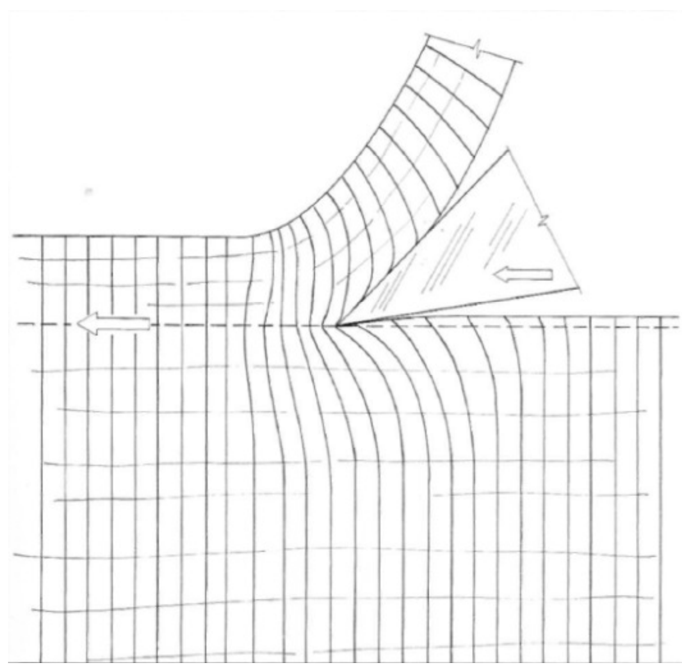

Figure 8: Real-world cutting action [4]

Types of Cutting Action

According to Hoadley [4], there are two basic types of cutting action. The first is called orthogonal cutting, in which the tool edge is more or less perpendicular to its direction of motion. The cut is in a plane parallel to the original surface of the workpiece, and the chip is continuous. An ordinary plane peeling a shaving from the edge of a board is one example.

The second type of cutting action is called peripheral milling, in which a rotary cutterhead with one or more cutting edges intermittently contacts the work surface. As the head turns, each cutter proceeds on a curved path and removes a single chip.

Orthogonal cutting is described by two numbers. The first is the angle between the cutting edge and the cellular grain direction, and the second is the angle between direction of cutting and the grain direction.

Thus there are three basic cutting directions: 90°-0° cutting, 90°-90° cutting, and 0°-90° cutting (Figure 9). Note that 0°-0° cutting does not produce a chip but rather runs down the surface of the wood.

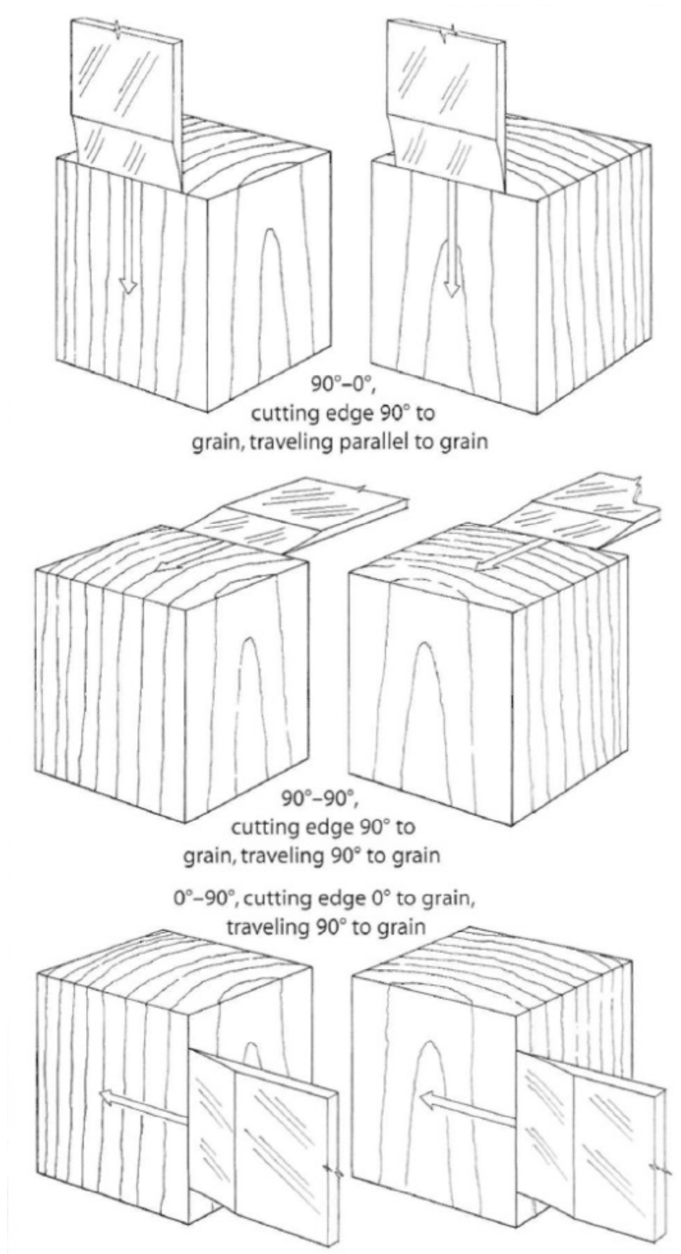

Figure 9: Three types of orthogonal cutting [4]

90°- 0° Cutting (Planning Along the Grain)

Parallel-to-grain cutting is typified by the standard handplane. The chip forms as the plane is pushed along the board. The typical cutting action involves a cyclic sequence of events (Figure 10). The blade, also called the iron, separates fibres lengthwise to begin a chip (A). As the knife advances, the separated chip slides up the iron. The chip is now a cantilever beam that resists bending. It lengthens itself by failure of the wood in tension perpendicular to the grain well ahead of the knife edge (B). Finally, the chip is so long that bending stresses equal the strength of the wood and the chip breaks (C). The cutting edge advances to the fracture point and begins to lift the next segment of chip (D) and so on. The chip, produced in a long, jointed curl [4].

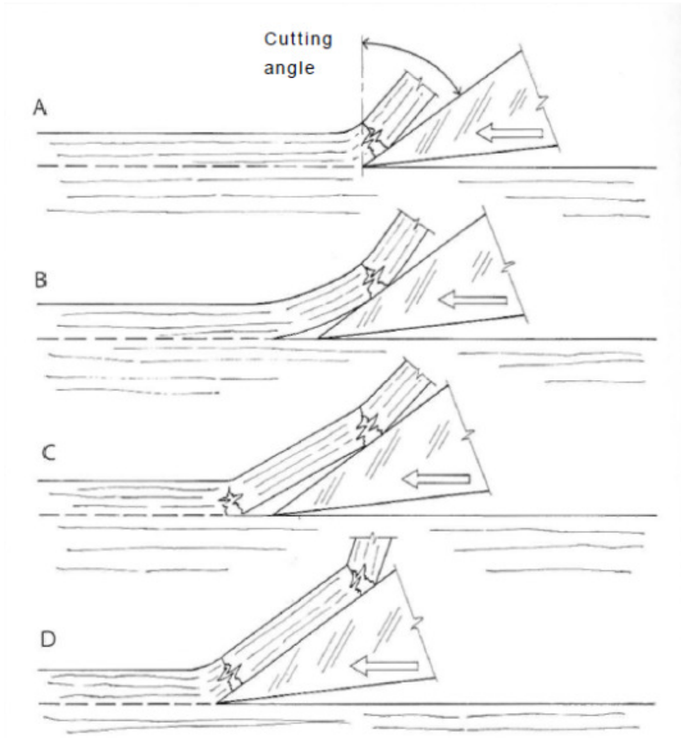

Figure 10: Cutting action: (A) the cut begins; (B) the chip bends as it slides up the knife, and the wood fails ahead of the edge due to tension perpendicular to the grain; (C) the chip breaks; (D) the next segment of the cut starts. In 90°-0° cutting, this is known as a Type 1 chip, produced by a relatively large cutting angle [4].

The typical plane blade is set at an angle of 45°. Sharpening to an angle of 30° leaves a 15° clearance angle. If the rake angle becomes too great, the friction of the chip upon the iron face would increase and the efficient bending and breaking action would be lost.

At smaller cutting angles, a greater component of forward compression and a smaller component of upward lifting are transmitted to the chip. Failure may occur as a diagonal plane of shear, bending the fibre structure, so chip formation develops as a continuously generated curl of deformed cell structure. This is classified as a Type II chip (Figure 11). The cutting edge produces the surface as it dislodges cell structure. Greater force is required because of the compression resistance. Where the tool is well controlled and a reasonably thin chip is taken, chip formation takes place quite uniformly, and an excellent surface is produced. Some handplanes with a cutting angle of only about 30° are designed to take advantage of this type of cutting action.

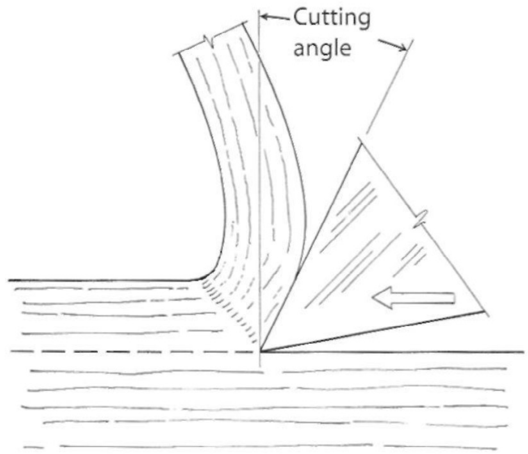

Figure 11: At small cutting angles, the face of the knife produces more forward compression than upward lifting. Failure occurs as a diagonal plane of shear right at the cutting edge. With enough force and a thin chip, the workpiece surface can be left in excellent condition. This is a Type II chip in 90°-0° cutting [4].

As small (or even negative) cutting angles are used, force is transmitted mainly as compression parallel to the grain. The cutting edge produces the surface as it shears free the cell structure. As the wood fails in compression, the damaged cell structure packs up against the cutting face and may form a wedge that transmits force and causes failure out ahead of the edge, often below the projected cutting plane. The failure is erratic and leaves an irregular surface and is accompanied by an irregular chip of mangled cell structure. This is Type III chip formation (Figure 12). With very low cutting angles, a smooth surface and uniform cutting action occur only when the chip taken is extremely thin and forms Type II chips. This is the cutting action of scrapers. The quality of cutting depends mainly on two factors: the grain direction and the mechanics of chip breakage.

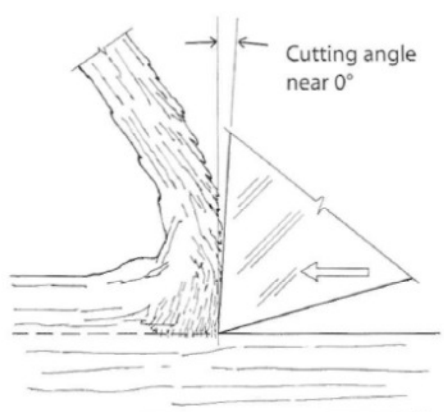

Figure 12: At very small or even negative cutting angles, force is transmitted mainly as compression parallel to the grain. The damaged cells pack up against the cutting surface, often causing erratic failure ahead of and below the edge. This is the Type III chip in 90°-0° cutting. The *snowplow* effect can only be avoided by taking a very thin chip, whereupon it becomes Type II cutting [4].

Cutting with the grain instead of cutting against the grain

Cutting with the grain should always be the preferred way since the splitting of the wood associated with chip formation projects harmlessly into the next chip segment which subsequently will be removed (see Figure 13). The cut produces a new surface generated by the continuous severing of wood at the tool edge. Cutting with the grain is very efficient because most of the chip segments fail readily due to cross grain. By contrast, cutting against the grain can result in chip formation where the splitting projects below the intended plane of cutting. The resulting surface is called chipped or torn grain. Woodworkers usually reverse either the work or the tool to cut with the grain.

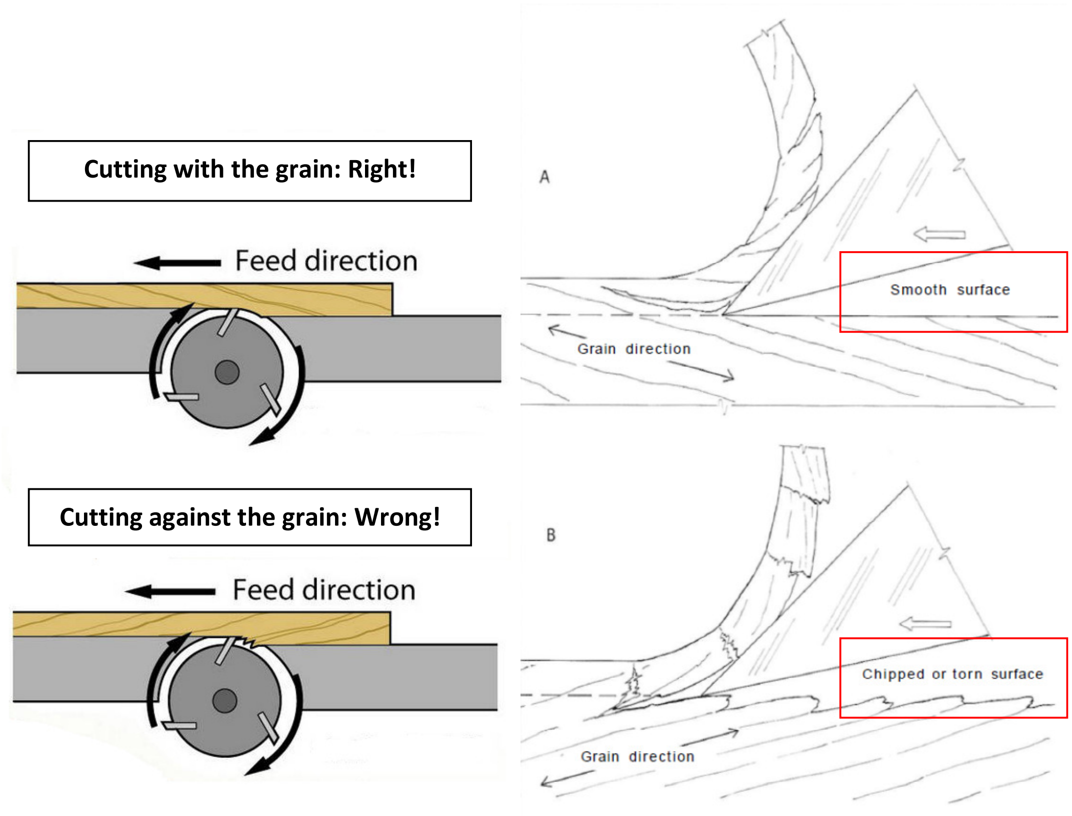

Figure 13: In the real world, the wood grain is rarely parallel to the cutting direction. (A) Typically the fibres are rising ahead of the line of the cut, and cutting with the grain leaves a very smooth surface. (B) When the fibres lead down below the line of cut, cutting against the grain leaves a chipped surface [adapted from 4].

The importance of the clearance angle in the cutting process should be appreciated. As with the springback of a wet sponge, some deflected cell structure will recover after the chip forms (Figure 15). In order for the back of the cutting edge to clear this material, frictional drag and pressure against the back of the blade must be eliminated. If the cutter were infinitely sharp, of course, little clearance would be needed, and recommended clearance angles of up to 15° may seem excessive. However, such large clearance angles are probably safeguards against less-than-perfect sharpening.

Peripherical Milling (Machine Planning)

Orthogonal cutting in the 90° - 0° mode has its counterpart in peripheral milling when a revolving cutterhead operates along an edge or face of a board as in the jointer, single surfacer, spindle shaper, and router. The cutting action is modified by the path of each cutting edge, which follows a trochoidal path due to the combined revolution of the cutterhead along the surface of the workpiece (Figure 14). Each cutting edge takes a curved chip from the workpiece. Customarily, rotation of the cutterhead is opposed to the feed, representing the upmilling condition.

In most rotary cutterhead designs, the cutting angle is decreased to between 10° and 30°. This requires more power to make the cut. but the chip type produced approaches a scraping Type II or Type III chip rather than a splitting action, as in Type I chips, since there is less uncontrolled splitting ahead of the blade. Also, the rotational speed of such cutters translates into relatively thin chips.

Knife marks

Surface generated by overlapping cutting arcs of successive edges is wavelike and these waves are known as knife marks. The best surface for finish lumber is produced with 12 to 25 knife marks per inch. When the number of knife marks per inch exceeds 30, unless the cutting edges are extremely sharp, the surface will be worse than the one made with fewer marks per inch.

The surface generated by the overlapping cutting arcs of successive edges is wavelike. These waves are often visible and are known as knife marks. The best surface for finish lumber is produced with 12 to 25 knife marks per inch. When the number of knife marks per inch exceeds 30, unless the cutting edges are extremely sharp, the surface will be worse than the one made with fewer marks per inch. With so many knife marks per inch, the chip gets so small that each cutting edge does not bite but rather rides over the surface. Frictional heat also may be produced, and the resulting surface, although apparently smooth, is simply glazed by the crushed cell structure and chemically altered by heating. Extremely slow feed rates can also scorch the surface, which is clear from the obvious discoloured band that results when a board gets stuck or pauses in a thickness planer. Such glazed surfaces on boards are not acceptable for gluing.

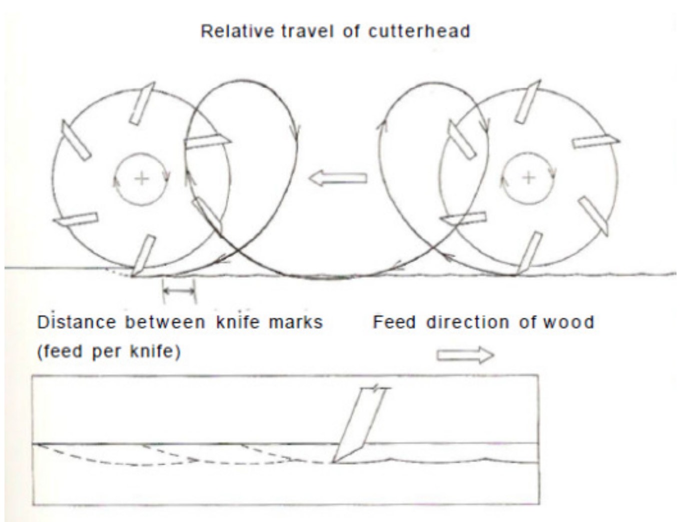

Figure 14: Peripheral milling where each cutter follows a tromoidal path relative to the workpiece, the result of cutterhead rotation plus feed [4].

Another problem with chip formation in peripheral milling is related to the practice of jointing the knives. After the knives are set, a sharpening stone is passed along the revolving cutterhead. Any high spots are ground back, ensuring that all the edges lie on the same cutting circle and that each knife takes a chip of equal depth.

Raised Grain & Faulty Surface Planning

Raised grain results when wood is unevenly compressed during cutting, with resulting uneven springback. The extreme situation occurs on the pith side of flat sawn boards of uneven grained conifers (Figures 15-17). The acutely angled layers of latewood are driven down into the weak supporting layers of early wood as they pass under the knife. Then they spring back and rise up above the machined surface. In extreme cases, the cell structure of the supporting earlywood is so badly damaged by compression that upon springback, the layers of latewood actually separate. This is referred to as loosened grain or shelled grain. When wood has MC 12% to 15%, raised grain may also occur as a result of soft earlywood, even if the knives are sharp.

Figure 15: Raised grain occurs during peripheral milling when layers of harder latewood are driven down into the soft earlywood and then spring back unevenly [4].

Figure 16: Raised grain on the pith side of a flat sawn board [4].

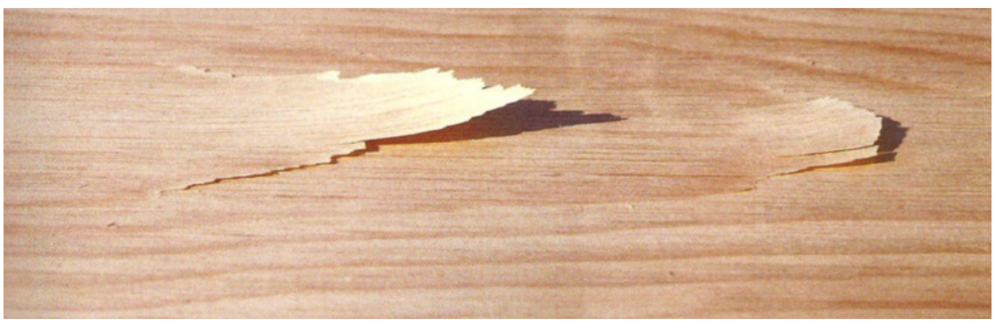

Figure 17: Raised grain where the earlywood layers actually fracture, resulting in loosened grain [4].

Raised or loosened grain is usually apparent immediately. In some cases, however, additional strain recovery or separation takes place at a slower rate. Even boards that are sanded smooth may continue to recover for years afterward. This effect is doubtless amplified by variations in moisture content. The "grain" will often show through or "telegraph" onto the surface of a painted board years later. Remember that the worst effects of raised grain in softwoods appear on the pith side, so it can be minimized by using a board so that the bark side is visible and the pith side is concealed. (This memory crutch may help: B stands for better and bark side, P stands for poor and pith side.)

Woolly or fuzzy grain (Figure 18) may result from planning material with a high moisture content, especially at low rake angles. Milling tension wood in hardwoods will also produce such a surface.

Another common defect that results from faulty surface planning is chip marks (Figure 19). This problem is machine related, not due to inherent flaws in the wood. It occurs when chips are not being cleared from the cutterhead because of insufficient air flow or static electricity. Instead, the chips are caught by the knives and then dragged through the region of chip formation, where they cause compression on the surface that has already been produced.

Figure 18: Woolly grain occurs when planning material with high moisture content or when machining tension wood in hardwoods [4].

Figure 19: Chip marks are the result when a machine's exhaust system isn't capable of clearing debris from the cutterhead [4].

90° - 90° Cutting (Planning End Grain)

Planning across the end-grain surface of a board is a common example of 90° - 90° cutting (Figure 20). Here the cutting edge must sever the chip by cutting longitudinal cell structure across the grain. The chip is displaced as much by shear deformation and failure as it is by bending, and it often moves up the face of the cutting edge as a partially connected string of rectangular chip segments [4].

Since the cutting tool must sever fibres across the grain, a dull edge (or a low rake angle) will drastically deform the wood in compression perpendicular to the grain during cutting. This may result in severely bent-over fibre ends and even splits down into the surface of the resulting cut. For this reason, high rake angles, low sharpness angles, and sharp cutting edges are essential to minimize damage on end-grain surfaces.

In sawing we are working primarily at the surface of the bottom of the kerf. Therefore, in addition to forming the chip, we must sever it along its lateral faces in order to free it from the bottom of the kerf. But since the shear strength parallel to the grain is so low compared with the stress developed by the rake angle of the cutter face, the chip is easily sheared free along its sides.

To avoid frictional contact of the saw against the sides of the cut, its teeth must have set (that is, the saw must be made wider across its cutting edges than the overall sawblade thickness) (Figure 21). This is usually accomplished either by swage-setting or spring-setting. Slightly jointing the saw teeth back as far along the sides of the teeth as the depth of the chip will clean up the sheared wood and will leave a smoother surface. However, excessive side jointing is counterproductive to set and will result in frictional heating.

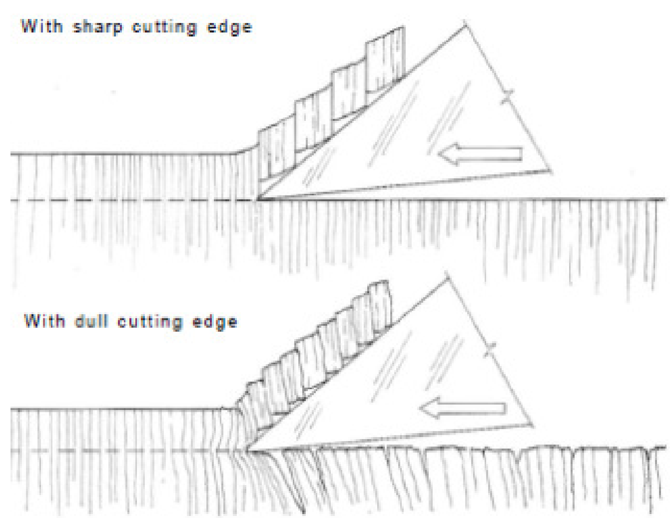

Figure 20: 90° - 90° cutting action: If the tool is dull or a thick chip is taken, damage may extend deep into the end-grain surface [4].

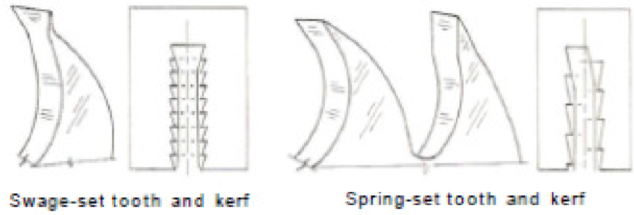

Figure 21: Setting a saw involves making the tips of the teeth slightly wider than the gauge of the saw. It prevents the saw from binding in the kerf. Swage-set teeth are spread at the tip; spring-set teeth (more common on ripsaws) are bent alternately to the sides [4].

On a table saw, the cutting action approaches 90° - 0° when the blade is raised to its fullest height (Figure 22). But when the blade is adjusted for making a shallow grooving cut, the rip teeth develop 90° - 0° cutting and shear the chips laterally from the cut. The chips removed from the bottom of the kerf tend to be more stringy.

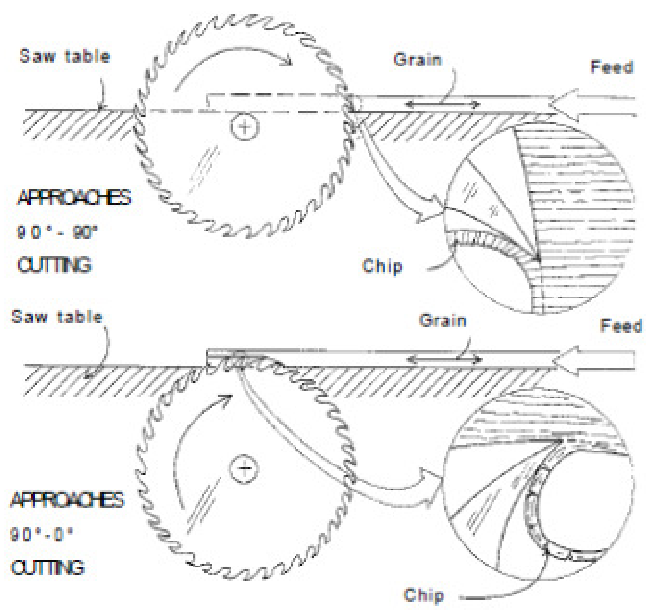

Figure 22: A table saw approaches ideal ripping action (90° - 90° cutting) when the blade is raised to its maximum height. It is also a more dangerous working situation. When the saw is lowered for safety or to make a grooving cut, 90° - 0° cutting is involved [4].

0° - 90° Cutting (Planning Across the Grain)

While 0° - 90° cutting is exemplified by using a handplane across the side-grain surface of a board, the classic case is veneer cutting. In making veneer, the chip itself is as important as the surface generated in the workpiece.

Examining the cutting action (Figure 23), we see that failures called knife checks are produced at regular intervals in the veneer. The face of the veneer having the knife checks is called the open or loose side. The opposite side is called the closed or tight side of the veneer. Knife checks are more pronounced in veneer greater than 1/8 in. thick. As veneer is cut thinner and thinner, knife checks tend to become insignificant.

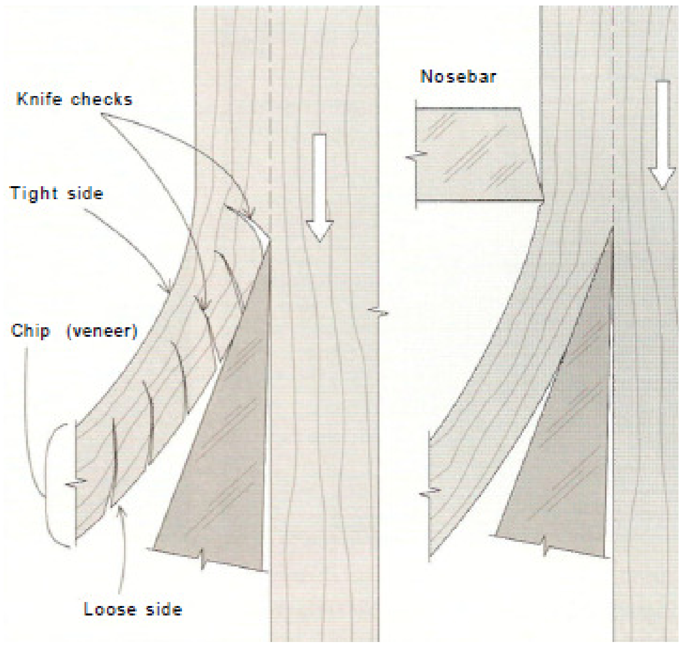

Figure 23: Veneer slicing is an example of 0° - 90° cutting. Unbalanced pressure from the knife causes checks in the loose side of the veneer. A counterbalancing nosebar and the greatest possible rake angle minimize knife checks [4].

In cutting veneer, the maximum possible rake angle minimizes knife checking. It is limited by the minimum sharpness angle that will hold up (about 21° in commercial veneer cutting) plus a clearance angle (0-2°). A rake angle of about 68° typically results. Even with properly designed and sharpened knives, checking is still a serious problem, so an auxiliary tool component, the nosebar, is introduced (Figure 24) to restrain the veneer as it is cut. By setting the nosebar to give proper pressure, knife checks can be minimized or virtually eliminated without unduly damaging the veneer by over compression.

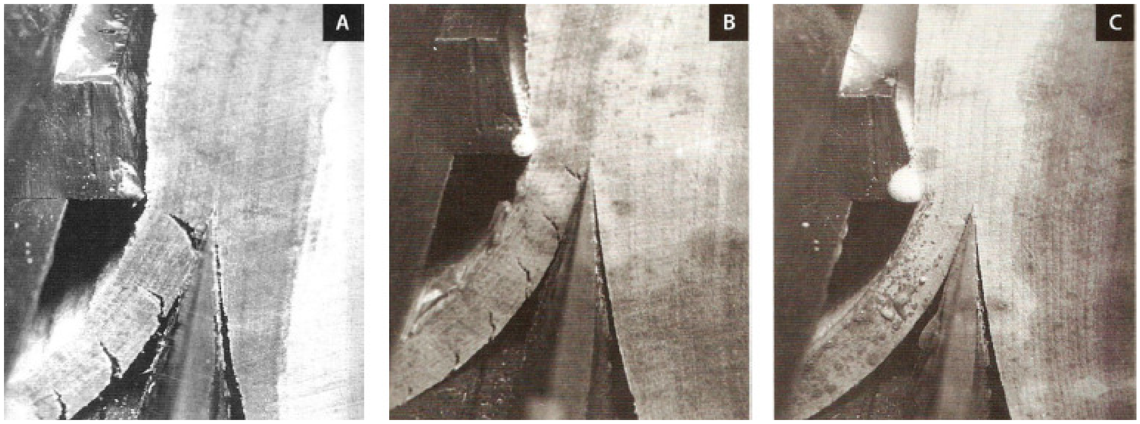

Figure 24: With the nosebar retracted (A), the veneer checks seriously as it curls over the knife. A little nosebar pressure (B) reduces the checking. When nosebar pressure is in the range of 15-20% of the veneer thickness (C), checks are nearly eliminated. In this series of photos, the veneer being cut is relatively thick, exaggerating the knife-check effect [4].

6. Conducting Machining Tests of Wood Materials

One of the significant characteristics of wood and wood-base panels is the facility with which they can be machined and fabricated. Different species and products, however, vary greatly in their behaviour under cutting tools, so that some systematic method is needed for determining their suitability for uses where the character of the machined surface is of prime importance. Such uses include cabinetwork, millwork, and other applications where favourable machining properties are essential to good finish. For such products as common boards, on the other hand, good machining properties are secondary, although still an asset [11].

The machining test procedures presented in standard test methods D1666 Standard methods for conducting machining tests of wood and wood base materials cover such common operations as planning, routing/shaping, turning, boring, mortising, and sanding. They are the result of many years of extensive research and development and include practical methods for qualitatively evaluating and interpreting the results. Because of their satisfactory use with a wide range of materials, it is believed that the methods are equally applicable to species, hardwoods and softwoods, and to wood-base panel materials, such as plywood, particleboard, fibreboard, and hardboard. Because of the importance of planning, some of the variables that affect the results of this operation are explored with a view to determining optimum conditions. In most of the other tests, however, it is necessary to limit the work to one set of fairly typical commercial conditions in which all the different woods are treated alike.

Several factors enter into any complete appraisal of the machining properties of a given wood or wood-base panel. Quality of finished surface is recommended as the basis for evaluation of machining properties. Rate of dulling of cutting tools and power consumed in cutting are also important considerations but are beyond the scope of test methods D1666.

Apparatus

To yield data that can be duplicated for comparative purposes, all machines used in these tests shall be modern commercial size machines of good make, in good mechanical condition, and operated by fully qualified persons.

While either automated or manual feed machines may be used, preference shall be given to machines with automated feed systems. To the extent possible, the feed rates used for the tests shall be chosen to correspond with the desired cutting conditions that will be employed for production. The feed rates and cutting conditions shall be kept constant throughout each test type and reported.

Insert tooling or one-piece cutters may be used for testing. Carbide-tipped knives and cutters shall be the preferred type because of the much longer sharpness life of that material. High-speed steel shall be second choice and carbon steel third. The cutting tool, material, manufacturer, and any relevant grade information shall be made part of the record. Every precaution shall be taken to keep the sharpness uniformly good in all tests by resharpening or replacing the knives and cutters when necessary.

The tests shall primarily be made on seasoned material brought to an equilibrium moisture content in a conditioned environment of 20 ± 6°C and 65 % (± 5 %) relative humidity. Lumber shall be clear[5], sound, well manufactured, and accurately identified as to species. It may be either rough or dressed.

Methods of Testing Lumber

Planning

As mentioned in test methods D1666 [11], the cutting angles and knife mark frequencies used for the testing shall be as required to satisfy the test objectives:

Optimization — If the goal of the test program is to optimize the cutting angle or knife mark frequency, or both, then make four runs with knives at cutting angles[6] of 15, 20, 25, and 30°. The feed rates and cutterhead speeds for these tests shall be adjusted to give 20 knife marks/in. (0.8/mm). An additional three runs shall then be made with a fixed 20° cutting angle, while feed rates and cutterhead speeds are adjusted to give 8, 12, and 16 knife marks/in. (0.3, 0.5, and 0.6/mm).

Representative — If the cutting angle and knife mark frequency are recommended by the tooling manufacturer or otherwise known, then make four runs using the known conditions. The cutting angle and knife mark frequency used for the test shall be recorded.

Visually examine each test specimen carefully for planning defects after each run. For each specimen, grade any planning defect that may be present according to degree and record on prepared forms. ASTM test methods D1666 [11] classify the planning characteristics of each

[5] Clear means free from all defects, including knots, stain, incipient decay, surface checks, end splits, compression wood, and tension wood.

[6] Because there are no accepted standards, the terms used in connection with planer knives vary considerably.

specimen by visual examination on the basis of five grades or groups as follows: Grade 1, excellent; Grade 2, good; Grade 3, fair; Grade 4, poor; Grade 5, very poor.

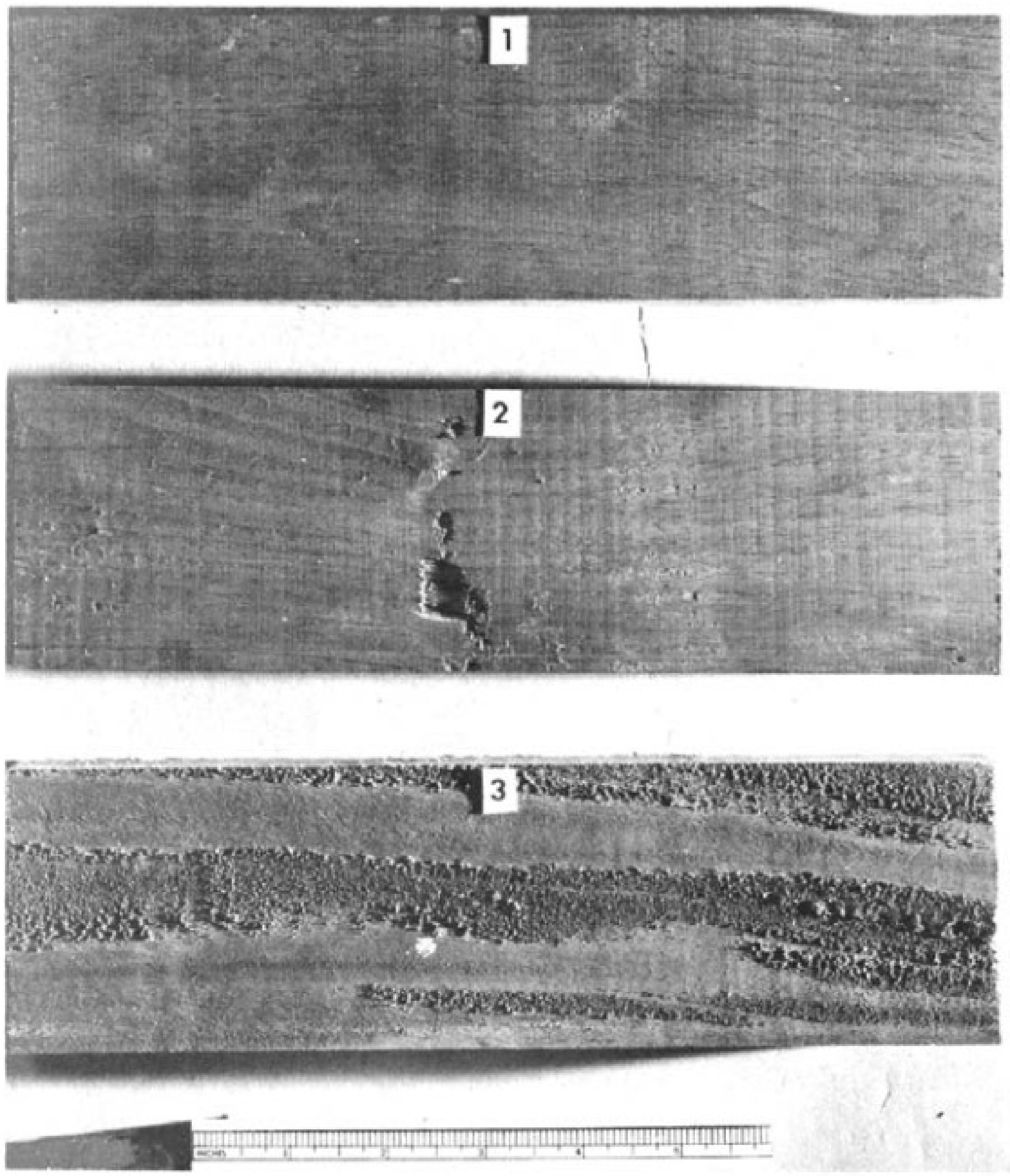

Figure 25: Planning grades Nos. 1 and 5: (1) Black Walnut Grade No. 1; (2) Black Walnut Grade No. 5 because of chipped grain; (3) Mahogany Grade No. 5 because of extreme degree of fuzzing probably due to abnormal fibres [11].

While the extreme conditions seen in the two lower specimens of Figure 25 may occur in any species, they are usually lacking or negligible in most species, except when planning under very unfavourable conditions. Figures 26-29 show the intermediate grades, Nos. 2, 3, and 4, which may be considered as slight, medium, and advanced degrees.

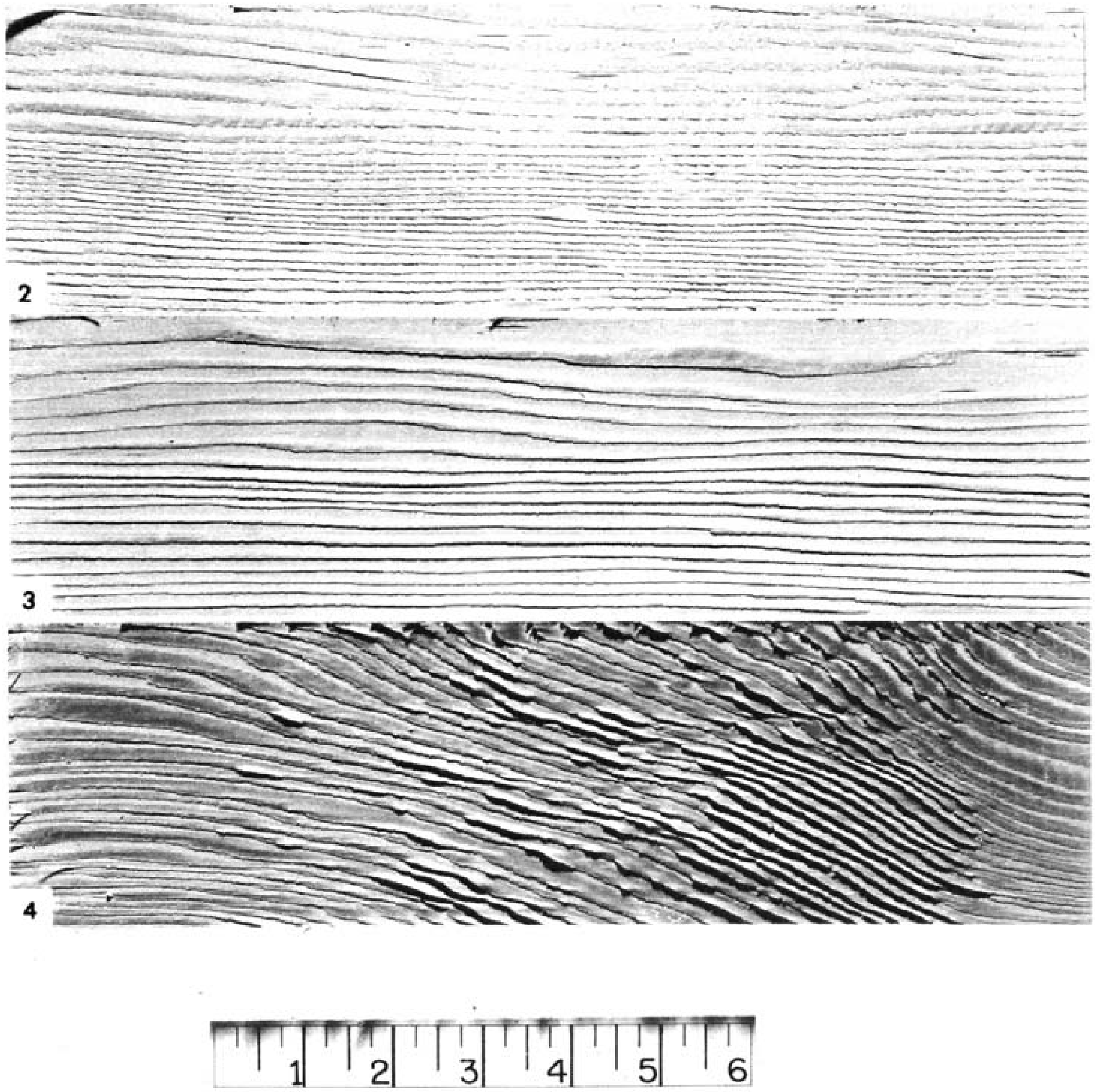

Figure 26: Raised Grain in Douglas-Fir, Grades Nos. 2, 3, and 4 [11].

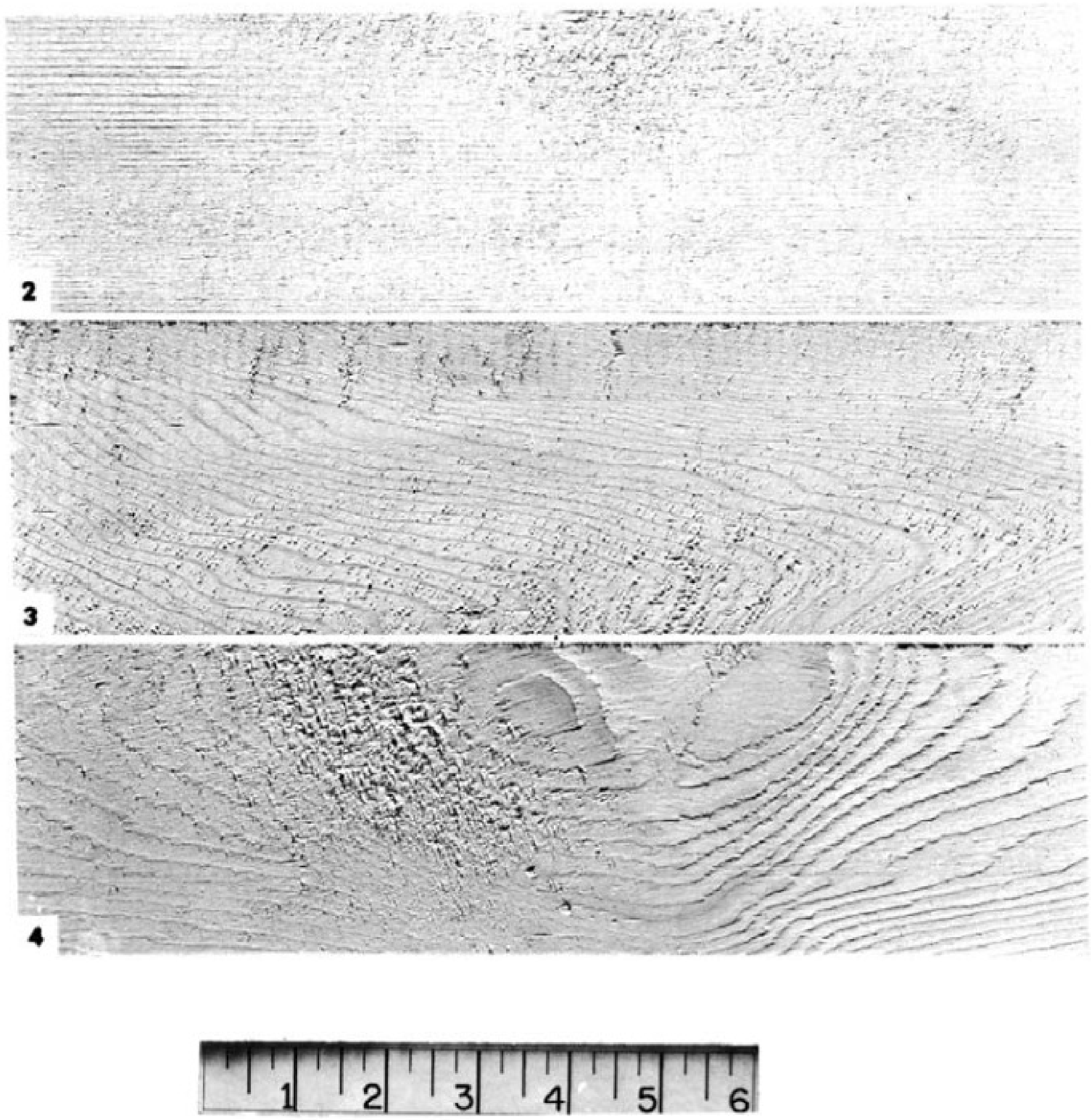

Figure 27: Fuzzy Grain (small particles or groups of fibres that did not sever clearly in machining but stand up above the general level of the surface) in Engelmann Spruce, Grades Nos. 2, 3, and 4 [11].

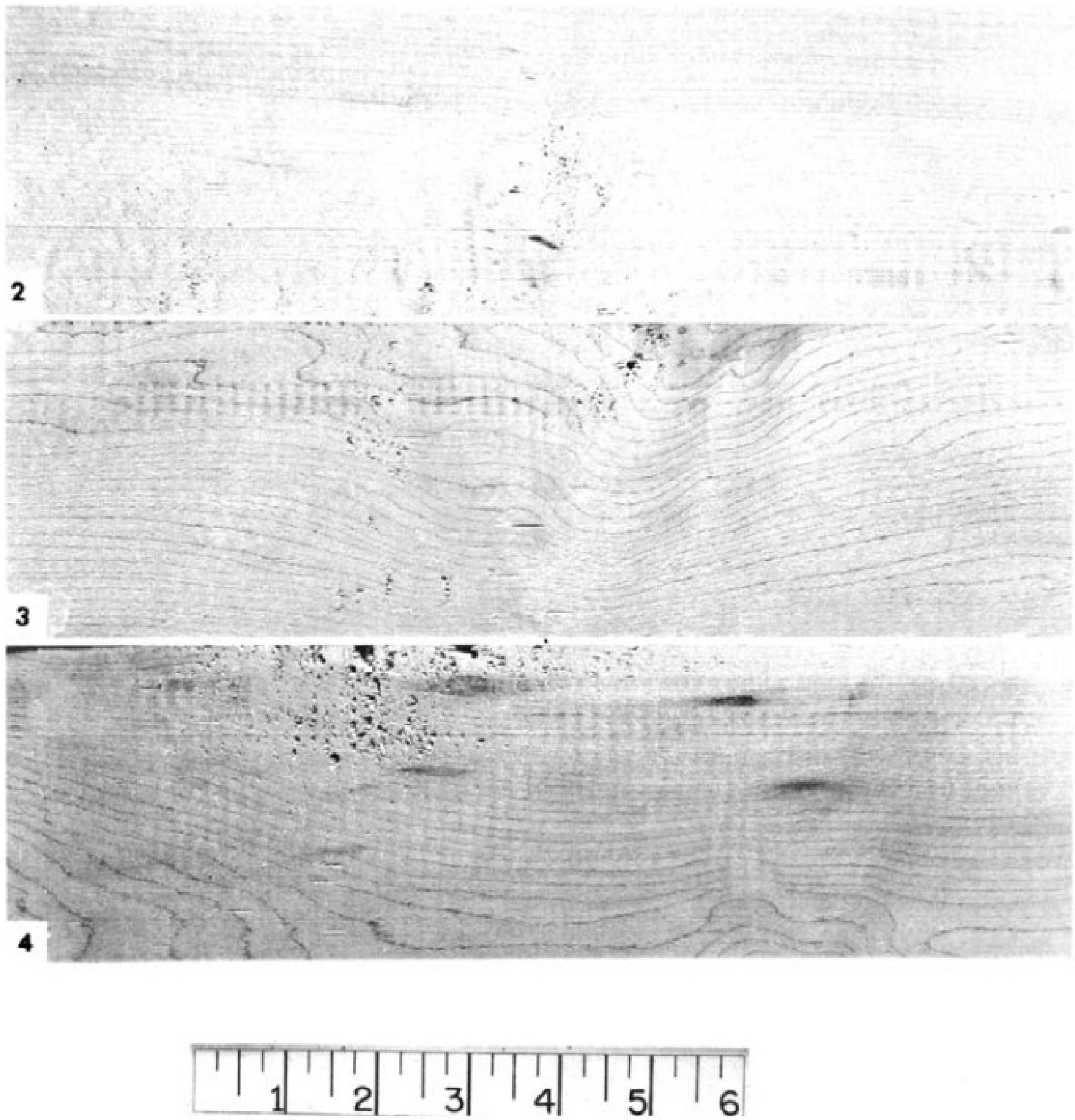

Figure 28: Torn Grain in Hard Maple, Grades Nos. 2, 3, and 4 [11].

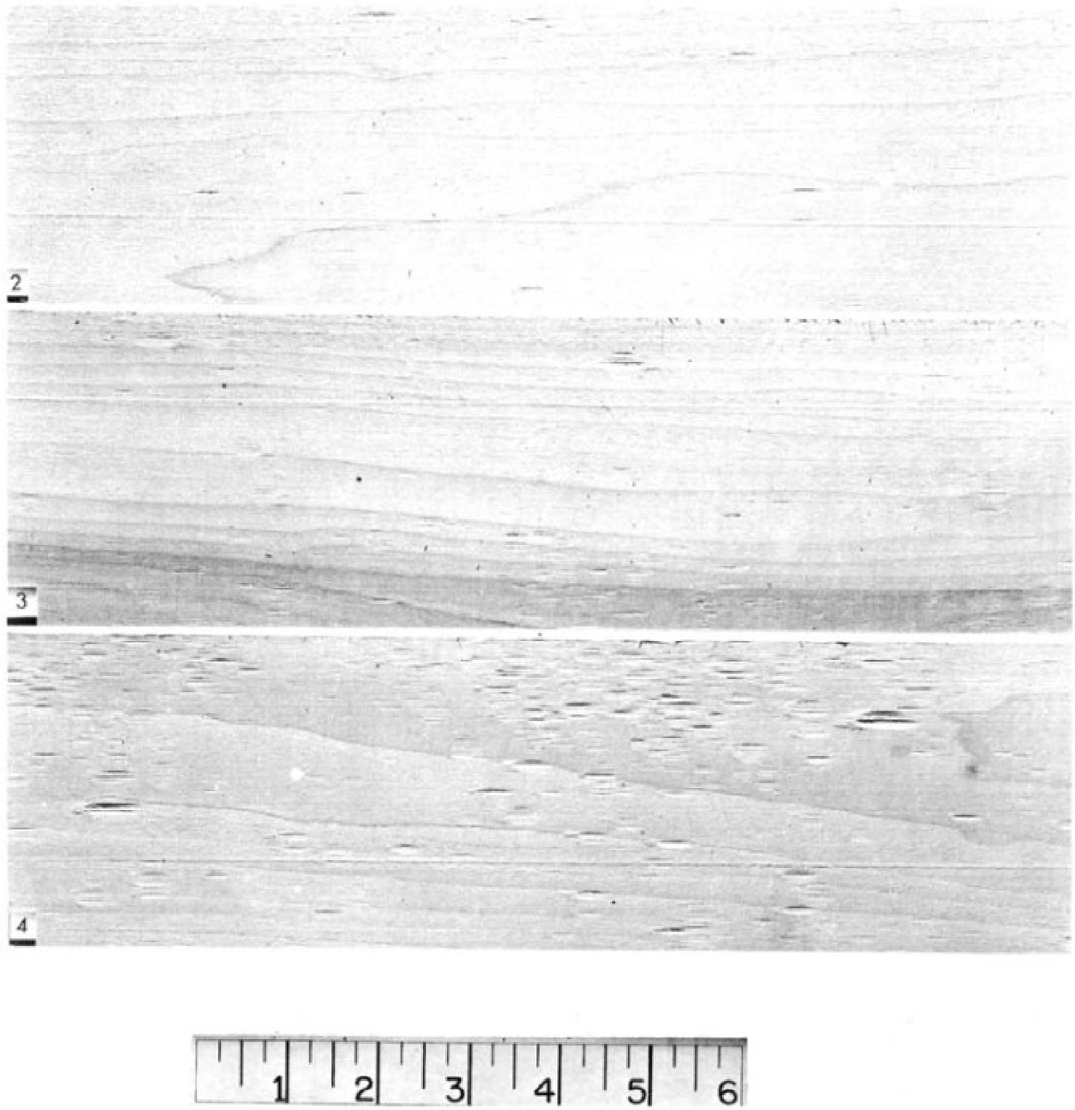

Figure 29: Chip marks in the surface (caused by shavings that have clung to the knives instead of passing off in the exhaust as intended) in Yellow-Polar, Grades Nos. 2, 3, and 4 [11].

For additional information on machining methods such as sanding, boring, routing/shaping, mortising, and turning please refer to ASTM Standards D1666.

7. Summary recommendations on machining procedures

Machining wood surface properly requires not only sound knowledge of the workpiece itself but also of the tool used to prepare the surface. Because wood is a heterogeneous and anisotropic material, it is important to understand its properties to ensure that each manufacturing step meets required quality standards.

The aim of machining always should be the paramount consideration. The approaches used may differ drastically, depending on the objective sought. These objectives may be classified as severing, shaping, and surfacing. In most cases, two or even all three of the above are involved concurrently.

The orientation and direction of the cutting force are controlled by the design of the tool and/or by the woodworker's hands, and these will determine the way stresses develop at the cutting edge and how the failure of the wood (or cutting) occurs. Two factors are important in this regard. The first one is the sharpness of the tool, in which the cutting area (A) of the tool edge is small enough so that the force (P) applied to the tool will cause a stress (P/A) greater than the strength of the wood. The second factor is the condition of the wood.

Based on a simple visual inspection, wood surface may appear to be smooth and flat. However, microscopic examination will reveal peaks, valleys, and crevices littered with loose fibres and other debris. Such surface conditions cause air pockets and blockages that prevent complete wetting by the adhesive and introduce stress concentrations when the adhesive has cured. In addition, different characteristics of wood such as grain angle, natural defects, and extractives will lead to widely different surface energies, roughness, and chemistry, all of which usually affecting the quality of gluing and/or finishing systems.

A smooth, knife-cut surface is usually best for bonding. Surfaces made using saws tend to be rougher than those made using planers and jointers. However, surfaces sawn with appropriate blades on properly set straight-line ripsaws can provide satisfactory results. Unless the saws and feed works are well maintained, however, joints made with sawed surfaces will be weaker and less uniform in strength than those made with sharp planer or jointer knives.

Mechanical and chemical properties of a wood surface both influence the quality of adhesive bonds. Wood whose surface is highly fractured or crushed cannot form a strong bond even if the adhesive forms a strong bond with the surface.

Wood surfaces are best prepared for maximum adhesive wetting (or any other finishing system), flow, and penetration by removing all materials that might interfere with bond formation to sound wood. Ideally, wood should be knife-planed within 24 hours of adhesive spreading. However, other surfacing methods have been used successfully for certain types of bonded joints, including sawing for furniture and millwork, knife-cutting for veneer, and abrasive-planning for panels. All methods must produce smooth, flat, parallel surfaces, free from machining irregularities, such as burnishes, skips, and crushed, torn, and chipped grain. Properly planed flat surfaces help ensure uniform adhesive spread rate.

Machined surfaces, regardless if they are made of metal, plastic or wood, are never perfectly smooth with protruding parts, valleys and peaks. These forms of surface irregularity are called roughness. Surface roughness can be caused by different factors: discontinuities in the material, various forms of brittle fracture, cavities in the texture, wear of the tool edge, local deformations deriving from the free cutting mechanism.

Surface roughness of wood can be affected by various anatomical factors such as annual ring variation, wood density, cell structure, and latewood/earlywood ratio. Density variation among and within species is also of obvious importance, as is unevenness of grain, especially in ring-porous hardwoods.

The peripheral speed of the tool influences productiveness, the surface quality, the wear of the edges, and to a lesser extent the cutting force. The feed per tooth or the chip thickness (h) influences the productiveness, the surface quality and the cutting force.

It is important to operate woodworking machines and tools economically and correctly. The optimal operating parameters and manufacturing costs change depending on the task. The operational parameters also have limits. Exceeding these limits may hamper the safe operation of the machine or the tool.

The ultimate goal of any woodworking operation should be to minimize energy consumption and manufacturing costs, and to maximize throughput and quality. The energy consumption of woodworking operations is significant part of the total production cost. Therefore, it is important to select proper tools with optimum operational parameters.

Several factors enter into any complete appraisal of the machining properties of a given wood or wood-base panel. Quality of finished surface is recommended as the basis for evaluation of machining properties. Rate of dulling of cutting tools and power consumed in cutting are also important considerations.

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Annex

Methods of Sawing a Log

We can differentiate two main methods of sawing a log (Figure 25):

- Plain-sawing (back-cutting, tangential cutting)
- Quarter-sawing (quarter cutting, radial cutting)

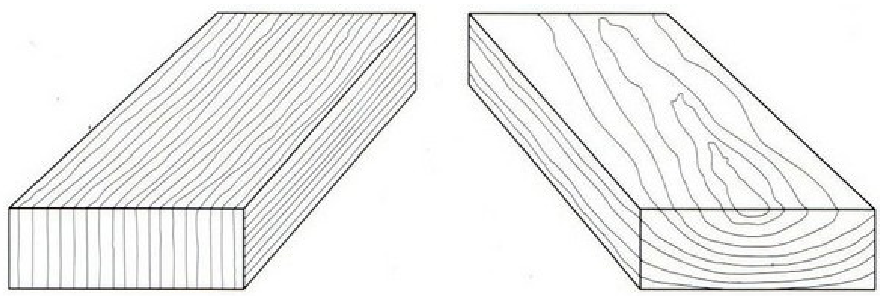

Figure 25: Quarter-cut (left) and plain-cut (right) boards

Plain-sawing is a common method and aims at the production of boards with faces roughly tangential to the annual growth and at right angles to the rays. In practice, timber is regarded as plain-sawn if the growth rings meet the face of the board at an angle less than 45° [1].

Plain-sawing is flexible and enable high-grade timber to be obtained from low-quality logs. It generally gives a higher recovery of timber than quarter-sawing, a greater speed of production, and is a simpler milling operation. Knots, if present, shown in round form, not as spike, and the proportion of wide boards will also be greater than from a similar sized log when quarter-sawn. Timber also shrinks and swells less in thickness [2].

Quarter-sawing aims at producing as many boards as possible with their faces parallel to the rays and has a number of advantages [1].

1. It may give a better appearance to the hardwood by showing prominent ray figure.
2. Because quarter-sawn boards shrink less in width there will be a less noticeable movement in service. The quarter-sawn boards of some species wear better than back-sawn boards.
3. Gum veins found in the eucalypts may show on the back-sawn boards as shallow but wide and unsightly blotches; on quarter-sawn faces the same veins may show as narrow lines, quite acceptable in appearance.
4. Quarter-sawn material is generally less prone to cupping, warping and checking.
5. Hardwoods that are prone to collapse during the seasoning process can be more successfully reconditioned if quarter-sawn, as the back-sawn material, unless carefully controlled during drying, can tend to form many surface checks.

6. It also holds paint better in some species [2].

The cross-sections produced by sawing are usually sorted, graded and processed (dried, dressed, remachined, etc.) depending upon the final product destination. Board products are usually graded visually in accordance with relevant market or company standard, which take into consideration aesthetic as well as any end-use requirements.