SOME SURFACING DEFECTS AND PROBLEMS RELATED TO WOOD MOISTURE CONTENT[1]

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ABSTRACT

The mechanical properties and dimensions of wood vary as moisture content varies, so moisture content affects wood machining processes and products. Wood machining problems associated with moisture content generally result in machining defects of the wood surface or tool wear. Chip type and machining defects are described and related to the strength properties and moisture content of wood. A method for selecting rake angle is described. Also the effects of wood moisture content upon abrasive belt loading and tool wear are briefly discussed.

Keywords: Planing, wood machining, surface quality, chip type, rake angle.

INTRODUCTION

The mechanical properties and the dimension of wood vary as moisture content varies, so moisture content affects wood machining processes and products, particularly solid wood products. Wood machining problems associated with moisture content generally result in machining defects of the wood surface or tool wear. Because most prominent machining problems are related to planing, the problems will be discussed as related to planing, but could be related to wood machining processes where a wedge-shaped tool removes a chip from a workpiece as a result of mechanical failure.

DEFECTS

The surfacing defects are described in detail in several references (Davis 1962; Koch 1964; Panshin and DeZeeuw 1964).

Raised grain is a roughened condition of the surface of wood in which part of the annual ring is raised above the surface as a result of uneven shrinkage and swelling. Distortion takes place in stock machined at a low moisture content and later exposed to air at a higher equilibrium moisture content (EMC) condition. The corrugation of the surface may also be due to the transverse (across the grain) dimensional changes in the latewood in comparison to those in the earlywood, especially in those species with abrupt transition. Variations of swelling and shrinkage between damaged and undamaged wood may cause raised grain. Machining factors that cause compression enhance raised grain. Such factors as pressure rolls, dull knives, and overjointing of the knives may increase raised grain. The high forces normal to the surface associated with these factors cause the crashing.

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Fuzzy grain is fibers or groups of fibers that have not been cleanly severed by machining and stand up above the surface. Fuzzy grain is generally associated with abnormal wood of gelatinous fibers that shrink and swell more than normal wood with changes in moisture content. Fuzzy grain is often associated with some of the same factors that cause raised grain—dull knives, low rake angles, or sanding.

Chipped or torn grain occurs when short particles of wood are broken out below the surface, usually by wood splitting ahead of the knife and then failing in bending as a cantilever beam. Chipped grain is associated with machining against sloped grain. The split follows the grain ahead of the knife and below the surface. Chipped grain is caused by knife cutting against the grain with high rake angles, large depths of cut, or machining very dry or wet wood.

Chip marks are shallow compression failures in the surface caused by chips that have been pressed into the surface. Chip marks will swell as they absorb water. Chip marks may result from an inadequate exhaust system that does not remove chips from the cutterhead. Chip marks tend to occur more frequently when low EMC conditions exist, such as in the winter.

Crushing of the subsurface has been shown to occur after knife and/or abrasive planing (Jokerst and Stewart 1976; River and Miniutti 1975). The crushing is not localized as chip prints or raised grain between dense latewood and earlywood, but is a uniform layer of crushed wood below the surface and is a permanent deformation of the wood. Machining factors such as dull cutting tools and low rake angles cause crushing.

The aforementioned wood machining defects are affected to different degrees by moisture content in different species. For example, chipped grain and fuzzy grain increase as moisture content increases. Further, chipped grain occurs more frequently at moisture contents below 5%. Raised grain may occur from machining wood at a high or low moisture content and then changing moisture content due to the uneven shrinkage and swelling of the earlywood and latewood. Loosened grain occurs when the earlywood and latewood separate. The defects often do not appear until after the product is finished and can affect the serviceability of the product. The machining defects can generally be minimized by reducing moisture content variation. Machining at an optimum wood moisture content (8–12%) and then maintaining the moisture content in service help to minimize machining defects.

CHIP FORMATION

Surface quality and machining defects are related to chip formation. With machining along the grain, three distinct chip types have been observed (Franz 1958; Koch 1964; Kivimaa 1950; and Voskresenskii 1955). The three chip types as described by Franz (1958) are:

> Type I is formed when the wood splits ahead of the tool by cleavage until failure in bending occurs as a cantilever beam.
>
> Type II is formed when wood failure in the chip is along a line extending from the cutting edge to the workpiece failure.
>
> Type III is formed when compression and shear failures occur in the work ahead of the cutting edge.

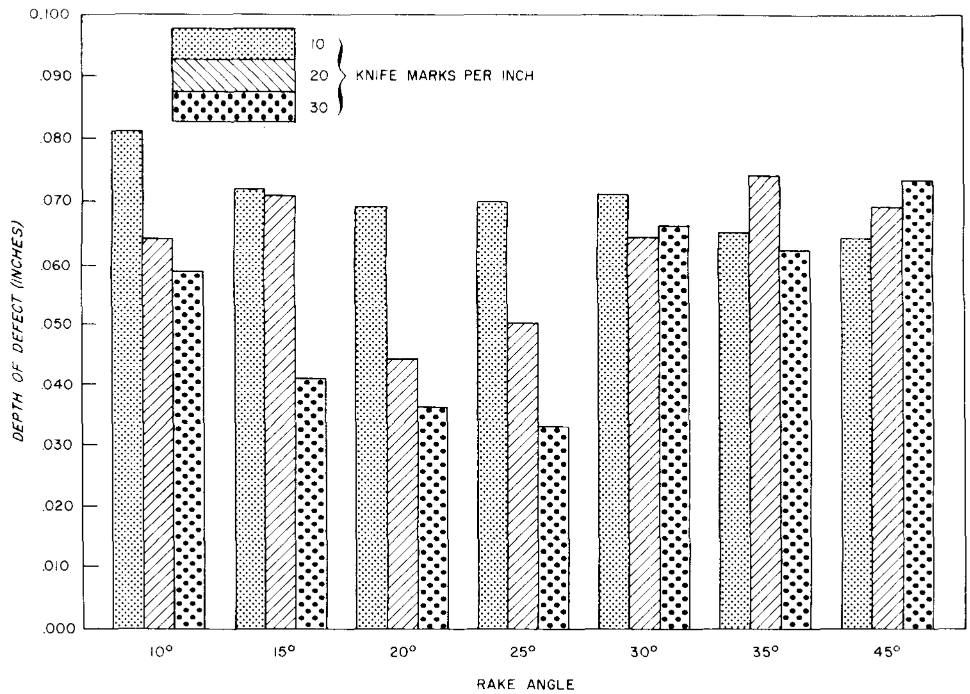

FIG. 1. Maximum depth of defect measured after knife planing hard maple at 8% moisture content, 10, 20, and 30 knife marks per inch with each rake angle. Maximum depth of chipped grain at approximately 10-degree slope of grain.

The chip types are frequently associated with a particular wood machining defect. Similarities of tool geometry, wood properties, and moisture content for wood machining processes, especially knife cutting, produce similar defects whether simple orthogonal cutting or peripheral milling.

Chipped grain and chip type I are associated with the wood properties of low cleavage or tensile strength perpendicular-to-the-grain, high compression strength parallel-to-the-grain, and high static bending strength. Very high or very low rake angles may increase the severity of chipped grain, especially when machining against slopes of grain up to 25° (Stewart 1971a, b) (Figs. 1, 2). Large depths of cut or machining conditions that increase the cut per knife also increase the severity of chipped grain.

Chip type III and defects such as raised grain, fuzzy grain, and a crushed subsurface are often associated with low or negative rake angles and dull tools, which cause excessively high cutting forces that increase crushing and do not cleanly sever the wood fibers. The situation is compounded when machining low density species or reaction wood.

A type II chip is generally associated with good surface quality. Selection of the tool geometry and cutting conditions for machining a particular species at a given moisture content can be balanced to produce a type II chip when machining along the grain. A type II chip is generally formed with moderate machining conditions.

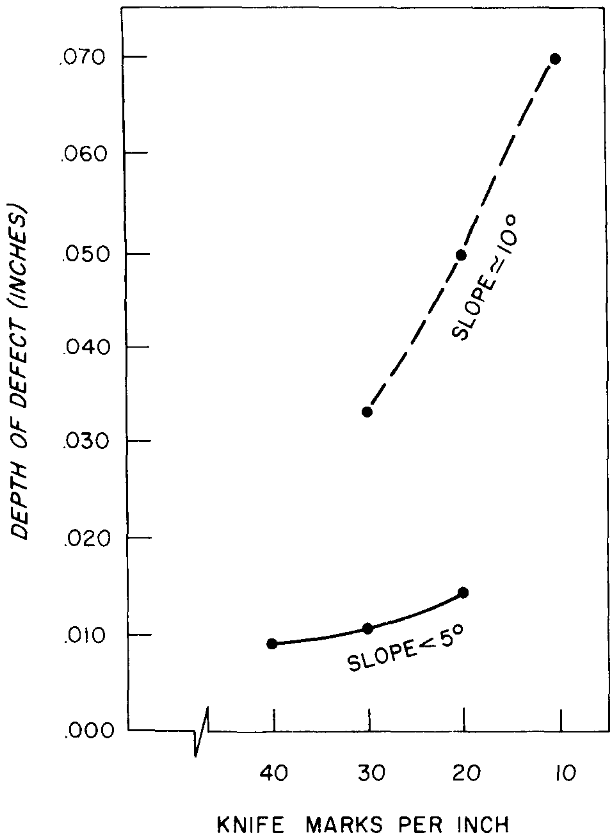

FIG. 2. A comparison of maximum depth of defect at various knife marks per inch for slope of grain less than 5 degrees and approximately 10 degrees.

RAKE ANGLE

Rake angle, the angle measured from the tool face to a perpendicular to the direction of tool travel, is the most important element of tool geometry controlling wood failure when machining. The wood failure determines formation of chip type, which is related to surface quality. Thus, selection of a rake angle to produce a satisfactory surface is paramount to efficient wood machining.

An equation was developed to approximate the optimum rake angle from the initial rake angle (Franz 1958). The technique demonstrated that an optimum rake angle for orthogonal wood cutting parallel-to-the-grain could be indirectly approximated from statistically determined mechanical properties of wood at various moisture contents and the cutting coefficient of friction.[2]

A simplified novel technique related selected strength properties directly to the rake angle by means of an expression for the coefficient of friction and has good correlation between strength properties of wood at various moisture contents and

[2] Coefficient of friction (μ) = $\tan\left(\arctan \frac{\text{Normal tool force } (F_n)}{\text{Parallel tool force } (F_p)} + \text{Rake angle } (\alpha)\right)$

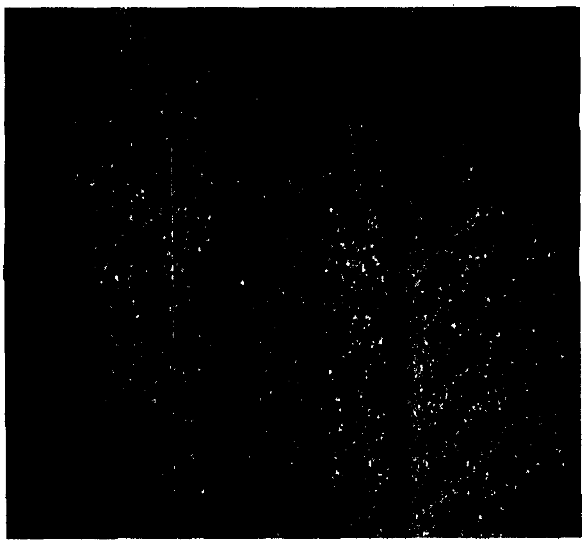

FIG. 3. Loading of Grit No. 36 aluminum oxide belt as stock removal rate increases for yellow-poplar at 90 fpm feed rate, 0.040-, 0.080-, and 0.120-inch depth of cut, and 12% moisture content.

rake angles (Stewart 1977). The cutting coefficient of friction was statistically related to the ratio of the tensile strength perpendicular-to-the-grain (T) and the modulus of rupture in static bending (R). The relations were:

MC	*Equation*
1.5 percent	$\mu = 0.25 + 5.72(T/R)$
8.0 percent	$\mu = 0.29 + 2.81(T/R)$
Saturated	$\mu = 0.95 - 6.05(T/R)$

By assuming the normal tool force to be zero, the optimum rake angle could be equated directly to the strength properties at various moisture contents. The two methods for determining rake angle for orthogonal cutting parallel to the grain compare favorably (Table 1).

TABLE 1. *Rake angles (in degrees) calculated by the Franz analysis and by correlation to selected mechanical properties for chip type II formation on sugar pine, yellow birch, and white ash at various moisture contents.*

Moisture content	Sugar pine		Yellow birch		White ash	
	Franz	Mechanical properties	Franz	Mechanical properties	Franz	Mechanical properties
1.5	18	20	22	23	24	28
8.0	17	20	19	22	22	26
Saturated	32	34	22	28	18	22

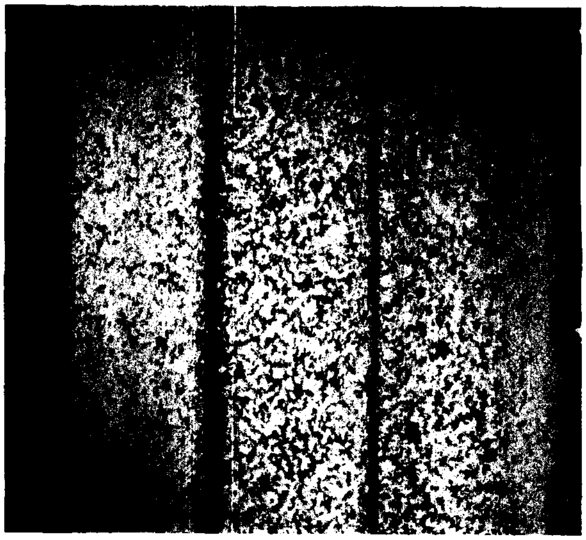

FIG. 4. Loading of Grit No. 36 aluminum oxide belt at all stock removal rates for yellow-poplar at 90 fpm feed rate, 0.040-, 0.080-, and 0.120-inch depth of cut, and saturated moisture content.

PERIPHERAL MILLING

The most severe surfacing defects occur when peripheral milling against slopes of grain of 10° to 15°. Chipped grain generally does not occur at slopes of grain more than 20°. Although some evidence exists that lower rake angles may reduce the frequency of the defect chipped grain (Davis 1962) and moderate rake angles may produce the minimum depth of defect (Stewart 1971b), a method for estimating an optimum rake angle for machining against the grain at various moisture contents has not been developed.

Considerable information relates moisture content to surface quality and cutterhead horsepower requirements for Douglas-fir (Koch 1964) and hardwoods (Davis 1962). Generally, power requirements increase as feed rate, depth of cut, specific gravity, and moisture content increase (Davis 1962; Koch 1964; Stewart 1974). The additional power to machine as moisture content increases may be due to the increase of force necessary to accelerate the heavier chip (Koch 1964). Further, wood is a viscoelastic material that absorbs more energy as it becomes wetter. The work to the proportional limit of the mechanical properties increases as moisture content increases.

GRINDING PROCESSES

Grinding processes appear to be a scraping action with a negative rake angle, but are stock removal with many single point tools with varying tool geometry, depths of cut, etc. In an attempt to avert or remove knife cutting defects, grinding processes such as abrasive planing and sanding have been applied to wood surfacing. Grinding requires substantially more power than knife cutting. Generally, power increases as feed rate, depth of cut, specific gravity of wood, and moisture content increase for abrasive planing (Stewart 1974). The higher power requirement results from higher forces associated with many single point tools, which has the effect of a negative rake angle. The forces crush the wood below the surface (River and Miniutti 1975; Jokerst and Stewart 1976). Additionally, heat is increased from the rubbing action between the coated abrasive belt and workpiece. Consequently, the defects commonly associated with grinding operations are fuzzy or raised grain and crushed, glazed, or burned surface. All of the defects except for glazing or burning occur to a greater extent as moisture content increases after machining at a lower moisture content. An increase of moisture content after a material has been crushed and/or set after machining causes the compressed fibers to swell. Often the solvent of a finish or glue will raise the grain.

Abrasive belts tend to load more readily as the moisture content of the wood increases (Stewart 1974). Belt loading is probably the result of a complex relation among the physical, mechanical, and chemical properties of the wood and the pressures and temperatures developed during abrasive planing or sanding. Some species such as yellow-poplar tend to load belts more, and abrasive planing at high moisture contents can shorten belt life.

Methods to reduce belt loading are being developed. Belt loading has been shown to increase up to a point and then decrease as stock removal rate increases for red oak and yellow-poplar abrasive planed at moisture contents of 12% and lower. However, the belt cleaning effect was not observed after abrasive planing green yellow-poplar (Figs. 3 and 4).

TOOL WEAR

Rapid staining and etching of cutters have been observed in slow linear cutting of green eucalyptus and radiata pine (Hillis and McKenzie 1964). Thus, corrosion may significantly accelerate the tool wear when cutting green wood. The wet wood provides an acidic environment for accelerating the tool wear by corrosion. Experiments with a veneer knife show a highly significant reduction of wear by applying a potential (electric) to the knife (McKenzie and McCombe 1968). Thus, the wear of knives in woodcutting is electrochemical in nature and corrosive and requires more power to machine wet wood. Generally, knife wear increases as the moisture content of the wood increases.

The selection of tool material may reduce tool wear. A variety of tool steels and carbides have been developed that may be more resistant than the types commonly selected for woodcutters. Presently, the multipurpose, inexpensive tool materials are manufactured into woodcutting tools. Research to evaluate tool material for cutting wood at various moisture contents and to develop a test for tool life may justify the increased cost of woodcutting tools.

CONCLUSIONS

Wood surfacing is one of the most important processes of forest products. Generally, wood will be machined several times from tree to finished product. Solid wood products exposed to critical view should have minimal defects and a satisfactory surface at an affordable price. However, much research remains to develop methods and tools to produce a satisfactory surface more efficiently.

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