Mechanism of Veneer Formation at the Cellular Level

Lawrence Leney

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Mechanism of Veneer Formation at the Cellular Level

LAURENCE LENFY

Chapter I
INTRODUCTION

This research was undertaken to answer some of the fundamental questions concerning what occurs at the edge of a veneer knife. The study has purposely been broad in scope to develop a general concept of the cutting action in anticipation that the findings may lead to further research in this area.

Problem

Considerable progress has been made in applying a scientific approach to the manufacture of wood products. With this progress has come the realization that there is a lack of basic knowledge in many areas. The cutting of wood is one such area.

Because wood is easy to cut, there has been an understandable lack of incentive to learn what occurs at the edge of the cutting tool. In this respect wood has been slow to receive the technological scrutiny given to metals. The variability of wood structure and its anisotropic characteristics have understandably discouraged basic research of the cutting action.

Several fundamental studies of wood cutting in recent years have emphasized the need for further research of what happens in wood during the cutting process. Knowledge of how wood is separated by a cutting edge on the cellular level can give us a better understanding of cutting methods.

Purpose

The purpose of this study was to investigate how a knife penetrates wood and to determine what mechanical action occurs. The major objectives were to measure forces acting between the knife and the wood and to observe the deformation of the wood structure during the cutting process.
Scope

To keep the study within reasonable limits only cutting in the veneer direction was considered. Fig. 1 illustrates this veneer or orthogonal cutting with a straight cutting edge aligned parallel to the grain of the wood and moving in a direction perpendicular to the grain.

The two primary approaches to the problem were: (1) Measurement of the major force components acting between the knife and the wood. (2) Study of the deformation of the cell structure by observation through a microscope and by analysis of motion pictures taken through the microscope during the cutting operation.*

The two force components measured were: (1) The parallel force acting parallel to the direction of motion of the cutting edge. (2) The normal force acting perpendicular to the cutting plane. These components and the resultant force exerted by the knife are illustrated in Fig. 2.

A major part of the work was concentrated on the relationship of cutting geometry to chip formation. The variables concerned were species, chip (veneer) thickness, cutting angle and clearance angle. Study was also made of knife sharpness, friction of the chip on the knife face, and chip thickness variation. Observations were made to determine the type of cell failure at the cutting edge and the way in which the wood failed in the formation of cutting defects.

A nosebar was not used in the study concerned with force measurement and basic cutting action, but was introduced in later phases of the work to determine the part it played in relief of stresses at the knife edge.

The strength properties of the wood samples were not tested. It is not logical to correlate strength values obtained by a test even approaching standard, with cutting mechanics which change as the knife passes from one ring to another or from one part of the ring to another. If strength values are to be compared with cutting forces micro testing methods similar to those described by Klooft (13) should be employed.

Preliminary experiments showed that when cutting in the veneer direction the variability of the wood structure could be expected to produce considerable variation in the data. Differences within the ring and differences between rings create a problem of analysis. This research was not designed to analyze the variability to a high degree of accuracy. This would detract from the main objective of developing an over-all concept of the action which takes place at the edge of a veneer knife. A more useful approach at this time seemed to be to cover a fairly wide scope to point the way for further research, rather than dwell on the determination of fine points of variation which cannot be controlled by experimental techniques.

*A 20-minute motion picture based on this study is available on loan from Visual Education Department, 23 Jesse Hall, University of Missouri, Columbia, Mo. for a mailing and maintenance fee of $1.00.
Fig. 1—Orthogonal cutting of wood veneer.

Fig. 2—The cutting force \( R \) as resolved into the components \( F_n \) and \( F_p \) which were measured in this study. When the component \( F_n \) acts toward the workpiece it is considered positive. In this study \( F_n \) is negative in most cases. \( F_p \) is always considered positive.
Chapter II

NOMENCLATURE

Need for Standardization

Standardization is needed in the nomenclature used to designate the parts of a cutting tool. A common set of terms to designate cutting edges, angles, and surfaces will aid basic cutting research by simplifying publication and preventing confusion in the exchange of ideas.

The veneer knife and planner knife can be considered to represent cutting in its simplest form, the single cutting edge. The saw, shaper knife, and wood bit have more edges, angles, and surfaces, but any one edge is basically the same as the cutting edge of the veneer and planner knives. If this basic cutting edge and its related surfaces can first be defined, the definition of the relationship among the several edges, angles, and surfaces will more easily follow.

The following definitions and notations concerning cutting geometry are an attempt to utilize the works of others and yet introduce additions or changes where it is believed desirable.

Cutting Geometry and Notation

Figs. 1, 2, 3, and 4 illustrate the geometry of the knife edge for the following notations.

- \( \alpha \): Cutting angle, primary; (rake angle, primary)
- \( \alpha' \): Cutting angle, secondary; (rake angle, secondary)
- \( \beta \): Sharpness angle
- \( \beta' \): Grinding angle
- \( \gamma \): Clearance angle, primary
- \( \gamma' \): Clearance angle, secondary
- \( \omega_F \): Honing angle, face
- \( \omega_B \): Honing angle, back
- \( W \): Width of cut
- \( t_1 \): Depth of cut in orthogonal cutting. Theoretical chip (veneer) thickness as established by the machine setting.
- \( t_2 \): Thickness of chip: measured chip thickness after cut.
- \( K \): "Knife Angle" as known to the veneer cutter. 90° plus the clearance angle.
- \( F_P \): Parallel force (cutting force): measured force component acting parallel to the direction of motion of the cutting edge.
- \( F_N \): Normal force (thrust force): measured force component acting perpendicular to cutting plane and to \( F_P \).
- \( R \): Resultant cutting force of the two measured force components \( F_P \) and \( F_N \).
Fig. 3—Knife geometry.

Fig. 4—Simplified geometry of chip formation in veneer cutting represented as if the center of rotation of the chip is at the cutting edge.
Definitions

Chip; veneer: As there is no essential difference between the planer knife and the veneer knife, the more basic term chip will be used interchangeably with the term veneer to mean the part of the wood that is separated from the workpiece in a single cut.

Face: The side of the knife on which the surface deflects the chip away from the workpiece. Also used to designate the principal surface on the face side of the knife. (It should be noted that the term "face" and "back" of the knife are reversed from that familiar to some. The usage here is in agreement with most fundamental studies of cutting.)

Back: The opposite side of the knife from the face. Also used to designate the principal surface on the back of the knife.

Bevel: A surface, rather than an angle, produced at an angle to the principal surface or another bevel.

Ground bevel: The bevel surface ground at an angle to the principal surface on one side of the knife (usually the back) to produce a cutting edge by intersection with a surface on the opposite side of the knife (usually the face).

Face ground bevel: A ground bevel produced on the face side of the knife.

Back ground bevel: A ground bevel produced on the back side of the knife.

Honed bevel: A small bevel honed on one or both sides of the knife at such an angle as to produce a new cutting edge at a less acute angle.

Front and back bevel: Abbreviation for the front honed bevel and the back honed bevel as produced at the cutting edge on the front and/or back sides of the knife.

Cutting plane: The plane of travel of the knife as it proceeds in the cut.

Cut surface: The surface on the workpiece, produced by the cutting edge as a result of the cutting action.

Cutting edge: Theoretically, the intersection of a back plane with a face plane, usually the back bevel and the face bevel. Under the microscope, a newly sharpened cutting edge is an intersection of grooves and ridges to produce a saw-toothed edge. This thinking will be examined in greater detail in the discussion of knife sharpness effects on cutting action.

Face of veneer chip; tight side of veneer: The surface of the chip produced by the preceding cut.

Back of veneer chip; loose side of veneer: The surface of the chip produced by the present cut and which is in contact with the knife as the chip is deflected and moves across the knife.

Orthogonal cutting: A term originated by Merchant (18) to define the condition where a straight cutting edge is perpendicular to the direction of relative motion of the cutting tool (knife) and the workpiece, and generates a new plane surface parallel to the plane surface produced by the previous cut. This is essentially a two dimensional cutting system.
Chapter III

REVIEW OF LITERATURE

Metal Cutting

Much of the stimulus for this research comes from work which has been done on the cutting of metals. Motion pictures for studying chip formation and techniques for measuring force vectors in orthogonal cutting were used in metals before such work was started with wood.

Ernest and Martelloti (5, 6) determined the type of chips formed in metal cutting using a motion picture camera to record the deformation as observed through a microscope. They showed the shearing action involved in the mechanism of chip formation and described the three basic types of chips formed under different conditions.

Piispannen (23) and Ernest and Merchant (7) independently formulated a theory of formation of the continuous chip based on the shear movement of infinitesimally thin lamellas of the metal at the edge of the tool. The basic mechanics of chip formation for the three chip types were developed by Merchant (18) and Field and Merchant (8) and Merchant and Zlatin (20).

Wood Machining

Numerous studies have been made of the general performance of woodworking machines. Some of these have measured the power requirements for certain machine conditions. Fewer have measured the forces on the tool or workpiece directly, or have studied the details of chip formation.

Barkas et al. (1) assembled information on underlying principles of woodworking up to 1935 and pointed out the need for basic studies on the cutting action.

Lubkin (14) made a thorough analysis of the literature on circular sawing. His report included essentially all the basic studies of cutting which had been done before 1957. In view of this, only those references which had a part in the planning or analysis of this study will be mentioned here. For the most part this encompasses only the research papers which deal with the direct measurement of forces by use of a workpiece or tool dynamometer, or which have contributed to technique in the study of chip formation.

Kivimaa (11) did an extensive study to measure the dynamic force vectors parallel to and perpendicular to the cutting circle using a rotating cutter head in
conjunction with a workpiece dynamometer. Three directions of grain were cut, including the veneer direction, to determine the effect of the following variables: chip thickness, specific gravity, moisture content, temperature, knife angle, knife sharpness, and species of wood.

Pahlitzsch (22) measured the main cutting force parallel to the cutting circle by means of a strain gage torque-meter fixed to the shaft of a rotary planer head. By using slip rings to conduct the strain gage bridge output to an oscillograph, he was able to study the effect of the following variables on the cutting force: knife angle, knife sharpness, cutting width, cutting velocity, depth of cut, chip thickness, rate of feed, and species of wood.

Walker (27) used a "whirling arm" of special design to feed a workpiece block of wood at a chosen rate into a stationary cutting blade in a tool dynamometer. The normal and parallel force components, \( F_n \) and \( F_p \), were measured for Beech and Sycamore. The effect of variation of cutting velocity was determined when using cutting angles of 15 and 30 degrees.

Franz (10) measured the force components \( F_n \) and \( F_p \) using a tool dynamometer with an orthogonal cutting method as applied in metal cutting research. This basic work determined for wood the type of information that Ernst and Merchant (7) and Ernst and Martellotti (6) found for metal. Franz, using motion pictures to record chip formation, described three types of chips similar to those found in metal cutting. He concluded, however, that the mechanism of chip formation in wood was different from that in metal and developed a theory of a possible mechanism.

Nakamura (21) used the orthogonal cutting method similar to that of Franz to measure cutting forces on a number of wood species. The woods were cut in both the radial and transverse planes for various angles of the knife and depth of cut. The knife holder and dynamometer were based on a tension and torque principle which was quite different from the cantilever principle used by Franz.

The pendulum dynamometer first used by Reineke (24) has also been employed by McKenzie (16) and Chardin (2) to measure the force energy required to make a cut with a single saw tooth. McKenzie describes the dynamometer of the Division of Forest Products, Melbourne, as having a means of measuring the radial force \( (F_n) \) during the cut.

Veneer Cutting

From the literature available it appears that no study has been made of the forces involved in the cutting of veneer. Kivimaa (11) measured the cutting forces in the veneer direction but used relatively small cutting angles as is common in machining; so the results are not entirely representative of veneer cutting conditions.

McMillin (17) observed the checking frequency, depth of checks, variation of veneer thickness, and surface quality of 0.125 inch thick veneer cut on a small
scale using a milling machine as a feed device. The effects of both temperature and nosebar opening were determined. The strength in tension and compression perpendicular to the grain and rolling shear were tested for the four wood temperatures used. The mechanics of veneer formation were discussed with respect to the basic types of veneer, which McMillin defines. The data indicate that the thickness of the veneer increased in the process of cutting. With a machine setting of 0.125 inch thickness, a veneer of 0.128 inch or larger was produced when the nosebar pressure was zero. As the nosebar pressure was increased stepwise from zero to 15 percent of the veneer thickness, the depth of the veneer checks decreased and the frequency of the checks increased. The pattern of decrease in check depth and increase in frequency also held when the cutting temperature was increased from 80 to 200°F. Results of the strength tests are said to show that the strength is reduced more rapidly in tension than in compression as the temperature is increased. However, the curves show relatively little difference in the case of birch.

Voskresenskij (26) developed a mathematical analysis of the forces expected in veneer cutting, with the objective of showing the nosebar pressure and frictional force necessary to prevent tension failure in the wood at the edge of the knife. The nosebar illustrated was different from that being used in this country.

Lutz (15) has studied the effect of orientation of the wood structure on the smoothness of the veneer cut. He shows that a smoother cut can be made if it passes from springwood to summerwood at the ringline.

Most studies in veneer cutting have been concerned with trying various combinations of the knife angles, nosebar setting, and condition of the wood. Fleischer (9) initially inspired interest in this research. Excellent closeup photography of veneer cutting in his work showed the change in formation of veneer checks with change of nosebar pressure. This indicated the need for work at a higher magnification to determine the mechanism involved in formation of the veneer at the edge of the knife.
Chapter IV

EXPERIMENTAL METHOD

Cutting Method

A small table model milling machine, with added bracing for the support arm, was used to feed a block of wood against a stationary knife as shown in Figs. 5 and 6. A heavy aluminum knife holder was clamped to the support arm. The knife was clamped to the lower face of the holder. By loosening the support arm the knife holder could be rotated into position to give the desired cutting angle. A pointer fixed to the support arm rotated with the knife holder to show the angle by its position with respect to the stationary graduated arc behind it. The accuracy of the angle was checked with a vernier scale universal bevel protractor. A level bubble was attached to the arm of the protractor so it could be used to determine the relative angle of all surfaces involved in the cutting operation.

The desirability of having a heavier milling machine is recognized. However, for the relatively low level of forces involved, tests with dial micrometers showed less than 1 percent possible error in chip thickness due to movement of the machine. The weakest point was the deflection of the support arm. The additional brace reduced such movement to a negligible amount.

The micrometer feed screws were tested and found accurate. They proved convenient in obtaining the desired depth of cut (chip thickness) and for measuring the vertical and horizontal opening of the nosebar.

The automatic variable feed speed of the milling machine simplified the setting of a desirable rate-of-travel for moving the sample block against the knife. After tests of observational and motion picture methods, a convenient machine speed of 2.54 inches per minute was chosen as the cutting velocity for this study. In a few cases when taking motion pictures at the higher magnifications, a cutting velocity of 1.27 inches per minute was used.

Fig. 6B shows an experimental nosebar in place in the adjustable nosebar holder. The nosebars being small, ones of various design could be made and installed with little difficulty and at minimum expense.
Fig. 5—A, General view of milling machine and equipment showing the stereoscopic microscope in place. B, Close-up of dynamometer with a sample block in place.
Fig. 6—A, Close-up of knife and block in position for the cut. B, Experimental nosebar.
Measurement of Forces

Dynamometer Design

Shaw (25) discusses several approaches to the design of dynamometers for the measurement of cutting forces. Many of these have the tool attached to the transducer. As the compact tool dynamometers are essentially moment measuring devices, the force must always be applied at precisely the same point to prevent changes in the moment arm. This limits the flexibility of tool adjustment.

As easy adjustment of the knife was desirable, a work piece dynamometer was considered best for the work intended. A three-dimensional dynamometer described by Shaw (25) was redesigned to measure the smaller forces encountered in wood cutting. As shown in Fig. 5B, it consists of a steel baseplate and an aluminum top plate separated by four octagonal test rings, one of which is shown in Fig. 7A. Strain gages T-2 and C-2 measure the force F_p and gages T-1 and C-1 measure force F_n. The rings are oriented between the plates as shown by the top plan view in Fig. 7B. Rings B and D have their axes aligned parallel to the x axis, while rings A and C have their axes aligned with the y axis. For force in the x direction, F_p, rings A and C are measuring rings while rings B and D act as stiffeners. For force in the y direction, rings B and D are measuring rings while A and C act as stiffeners. (This direction was not used in this study.) All four rings are active in measuring the vertical force in the z direction, F_n.

If we designate gage T-1 of ring A as AT-1 and so forth, the bridge circuit design for F_n in the z direction and F_p in the x direction is as shown in Fig. 8. This distribution of the gages in the bridges makes the transducer independent of the point of application of the load provided all gages have matched characteristics.

The natural frequency of the dynamometer was calculated to be a little over 200 cps in the x direction and approximately twice this in the z direction. The design gave satisfactory stiffness, as the top plate moved less than 0.0005 inch in the z direction and approximately 0.001 inch in the x direction for a 25-pound load.

The disadvantage of this dynamometer design is that it is temperature sensitive. Thermal expansion or contraction of the top plate changes the balance of the bridge by distorting the test rings. As such changes are undesirable during a test, it is best if the room is maintained at constant temperature, free of rapid air changes around the test area.

1When tested for the area in which the cut was made, no measurable error was found with difference in point of application of load.
Fig. 7—Octagonal strain rings used in constructing the dynamometer. A, Position of strain gages on the octagonal ring. B, Top view of dynamometer showing orientation of rings.
Fig. 8—Design of bridge circuits for the measurement of the force components: Z, Circuit for measuring $F_a$. X, Circuit for measuring $F_p$. 
Recorder

The outputs of the dynamometer bridge circuits were amplified and simultaneously recorded on a Sanborn model 60 two-pen recorder such that the graphs were matched records of forces \( F_n \) and \( F_p \). This system supplies a 2500 cycle excitation voltage to the bridge circuit of the transducer. The record is made on a variable speed chart by a hot wire stylus attached to the galvanometer. Once the system is balanced and calibrated with a known weight on the dynamometer this calibration can be checked at any time by an internal calibration resistance.

A separate marker stylus at the side of the chart will mark events by manual or remote control switching. This marker can also be used as a timer by marking the edge of the chart at one-second intervals. The latter was used to check the chart speed.

Calibration of Dynamometer

The dynamometer was calibrated by applying a series of known weights while recording the load on the chart of the recorder. To calibrate for \( F_n \), weights were added at intervals directly on the top of the dynamometer. To determine \( F_p \), a thin flexible wire cable was attached to a block held in the vise in the center of the top dynamometer plate. The cable was extended horizontally and passed over a low friction pulley, as shown in Fig. 9. By careful orientation of the cable, a series of weights applied to the end were transmitted to the dynamometer as a horizontal force parallel to the direction of \( F_p \).

The calibration curves in Fig. 10 show the linear calibration of \( F_n \) and \( F_p \) with chart readings.

When the force \( F_p \) acts on the block at a distance above the test rings, there is a moment which tends to rotate the top plate. This increases the load \( F_n \) on two of the rings and decreases the load on the opposite pair. Any dis-

![Diagram of Dynamometer Calibration](image-url)
Fig. 10—Calibration curves for dynamometer.
crepancy in the matching of the two sets of rings will show up as an error in the force \( F_r \). For the dynamometer used in this study there was a negative error of 1 pound for the force \( F_r \) at an \( F_p \) of 70 pounds. At \( F_p \) of 35 pounds this error of \( F_r \) was reduced to less than 0.2 pound. Maximum loads were in the vicinity of 35 pounds so correction was considered unnecessary.

**Observational and Photographic Techniques**

During cuts the action of the knife was observed through a stereoscopic microscope attached to the support arm of the milling machine (Fig. 5A). Magnifications of 9X and 27X were used with satisfactory results. To facilitate observations, the cross section of the test block was first surfaced using a sliding microtome. This made possible the observation of individual cells with considerable clarity. In this surfacing procedure, care was taken to prevent change of the parallel condition of the two cross section surfaces on the test block.

**Motion Picture Methods**

Fig. 11 shows the set-up used in taking motion pictures of the cutting action. A Cine Kodak Special and a Bell and Howell 70DA were used at different times in the study. The Cine Kodak Special had the advantage of a built-in reflex finder. The Bell and Howell required a reflex finder attachment. The reflex finder was essential to the work.

The stereoscopic microscope was replaced by a monocular microscope fastened to the support arm. The microscope made no contact with the camera, the light was excluded by a light trap commonly used in photomicrography. The lens was thus suspended separate from the camera vibration. This had some advantage in reducing movement of the image.

A 48-mm. or 32-mm. microtessar objective was used without ocular lenses. An eyepiece aperture was inserted in the microscope tube to prevent the passage of light which was reflected off the interior.

A film speed of 64 frames per second was employed for most tests.

The films used were 16 mm., black and white, reversal safety film of the designation Eastman Tri-X and Cine-Kodak Super-XX. A good exposure was obtained with Tri-X film, a camera speed of 64 frames per second, and a 48 mm. tessar at an iris diaphragm opening of f/11 to f/22, depending upon whether one or two lights were used. This allowed a reasonable depth of field, which is needed in this photography.

**LIGHTING:**

The block and knife were lighted by a concentrated beam from a small American Optical Company Universal microscope illuminator which can be seen at right in Fig. 5B. This light has a transformer for varying the intensity. By concentration of a small light source, a high intensity was obtained without other parts of the equipment being subjected to excessive heat. The small size
allowed considerable flexibility in positioning the lamp for best lighting. Two such lights, one on either side of the microscope, eliminated shadows when the nosebar was in use.

**Knives**

The knives used were commercial hand plane irons 0.086 inch thick, with a 1.75-inch long cutting edge. Since they were purchased as a lot, it was assumed that their characteristics were close enough for the purpose of the study. A steel analysis was not obtained since it would shed little light on the test results. A hardness test was made and found to be between 60 and 61 Rockwell C. This is at the upper range of hardness for veneer knives.

A heavy hold-down plate was clamped on top of the knife to keep it firmly in place and give it the rigidity of a heavy blade. A knife ¾ inch thick was used for nosebar tests.

**Sharpening Methods**

A small surface grinder with a coolant system was used to grind an edge with an angle of one degree less than the final sharpness angle. The final sharp-
ness angle was then put on by hand honing, using the sharpness jig in Fig. 12. The stones used for this operation were a Norton Crystolon (silicon carbide) combination stone JB-3 and a hard Arkansas Stone.

The first step was to produce a fine finish on the face of the knife. The surface of the face was standardized at approximately 5 microinches RMS** to minimize frictional differences between knives. To produce a polished surface it is desirable to crisscross the scratches of the finer grit with those produced by the coarser grit. The scratches on the face resulting from such crisscrossing were not necessarily perpendicular to the edge but were within 30° of the perpendicular.

After the face finish was completed, a back bevel was established using the fine side of the crystolon stone. Then a final edge was produced on the Arkansas stone, finishing with alternate honing on the front and back, a few strokes at a time, until the wire edge had been completely removed, leaving a firm continuous edge. During the honing of the face, great care was taken to keep the surface flat to the stone so a face bevel angle would not be produced. The angle of the back bevel was established in the jig by using a universal bevel protractor to measure the angle between the knife and the stone.

The progress of the sharpening was controlled by periodic examination of the knife under a stereoscopic microscope at 27 X magnification.

**Classification of Sharpness**

There is no established method for determining the sharpness of a knife edge. Endersby (4) mentions that the sharpening of a cutting edge was considered satisfactory if it would cut hair on the back of the hand and showed no nicking of the edge and no contiguous scratching of the bevels when examined at a magnification of 90 X. Franz (10) and Kivimaa (11) relied on microscopic

**Root mean square roughness measured with a profilometer.**
examination to determine the condition of the edge. Commercial operators sometimes use the thumbnail or pad of the thumb to determine sharpness by the ease with which the knife catches the surface to start a cut. Another method uses the cutting of paper as an indicator. All these methods have one thing in common. They attempt to test the very edge of the knife and minimize the effect of the wedging action of the sharpness angle.

For comparison of the sharpness of the knives used in the sharpness series a test was devised to judge the sharpness of the extreme edge while minimizing the wedging effect. This test measured the force required to rupture a thin strip of plastic 0.25 inch wide and 0.005 inch thick. The strip was suspended across a slot in a block as shown in Fig. 13A. The strip was fastened in place with a measured amount of looseness so that the strip was depressed at the time of cutting. Fig. 13B shows how the block was fastened in the dynamometer and the knife edge applied to the middle of the strip with a constantly increasing force in the vertical direction until the strip ruptured. The force required to rupture the strip was dependent upon a combined effect of the reduction of the cross section area of the strip due to the penetration of the cutting edge into the plastic, and to the stress concentration on the center of the strip at the cutting edge. Both of these factors are an indication of the sharpness.

This test is still in a developmental stage but it was of help in substantiating the conclusions reached in the sharpness test series.

The quality of the edge was also determined by examination at a magnification of 27 X as previously stated. There are three main directions for viewing the cutting edge under magnification to determine the sharpness. These are listed below.

1. Sectional view, with the line of sight parallel to the cutting edge as in Figs. 3 and 6A where the sharpness angle appears as an acute angle and the edge appears as the apex of the angle. The edge may be a sharp point, rounded, or irregular, depending upon the degree of sharpness (11, 22).

2. Plane view, with the line of sight perpendicular to the edge and generally perpendicular to the knife planes. In this view the edge ranges from a straight line (which can be erroneously interpreted as being sharp) to a saw tooth or irregular jagged silhouette (4).

3. Edge view, with the line of sight perpendicular to the edge and approaching parallel to the plane bisecting the sharpness angle. This view when carefully lighted appears as a line, the width of which is indicative of the sharpness.

Methods 2 and 3 can be used without special preparation of the knife (4, 10, 11). In method 1 the knife must be sectioned at the point of interest (22). This requires special techniques.
Fig. 13—A, Relationship of the knife edge to the plastic strip in testing sharpness. B, Set-up for testing knife sharpness by use of the plastic strip.
Establishment of Zero Clearance Angle

In spite of the care taken in sharpening the knives, it was difficult to establish an exact sharpness angle in the honing process. This created a problem in the determination of a true zero clearance angle. Because a negative clearance has a pronounced effect on the force $F_n$, it was necessary to eliminate possible error by determining a true zero clearance. With the recorder set at highest sensitivity, the force $F_n$ was measured while making 0.002-inch cuts in a paraffin block. The cutting angle was increased stepwise until a definite negative clearance was shown by a high positive force $F_n$. The cutting angle was then reduced five minutes at a time until there was zero force when the knife was returned over the cut surface without changing the machine setting. This angle was checked by decreasing the cutting angle 30 minutes and again increasing it five minutes at a time until the force $F_n$ increased rapidly indicating the beginning of negative clearance. In this way the zero clearance angle is believed to be accurate within five minutes.

When at zero clearance, the cutting angle was measured as described previously and the sharpness angle was calculated.

Wood Samples

The woods tested were sugar pine, *Pinus lambertiana* Dougl.; cottonwood, *Populus deltoides* Bartr.; and silver maple, *Acer saccharinum* L. The sugar pine is representative of a soft coniferous structure. The cottonwood represents the hardwood structure with a change from soft springwood to more dense summerwood. Silver maple, being typically diffuse porous, had a minimum of change within the ring.

The cottonwood was obtained in the form of a thick slab cut parallel to the bark. The bark was peeled and the slab cut into sections approximately 14 inches long; each marked to show its relative position. In cutting the sections, the crosscut was made accurately perpendicular to the grain to establish an index surface. This surface was then positioned against a miter square and the section was ripped into strips 1 1/8 inches wide (Fig. 14A). These pieces were then turned on their side and ripped parallel to the cambium surface to produce strips 14 inches longitudinally, 1 1/8 inches radially, and 1 1/2 inches tangentially. On a smaller planner saw, blocks 1 or 1 1/2 inch along the grain were cut from these strips as needed to make up a matched test series.

As previously mentioned, when observations were made to determine the cutting action, the transverse face of the block was surfaced in the microtome. This produced slight variations between blocks for the dimension parallel to the grain. As this dimension was the width of cut, it was measured to the nearest 0.001 inch at the time of testing with a dial micrometer. The necessary corrections were made in the data so all forces were stated on the basis of a 1.000 inch width of cut.
Fig. 14—A, Method of cutting test samples from slabwood. B, Sample blocks and holder.
The block was clamped in a sample holder for cutting (Fig. 14B) and then placed in the vise which was built into the dynamometer (Fig. 5B). As a satisfactory slab of silver maple was not obtainable at the time samples were prepared, a straight grained 2-inch thick green board was chosen to match the conditions of the cottonwood slab. This board was then cut as described above to produce blocks with a minimum of grain deviation. The sugar pine sample blocks were cut in the same way from dry lumber obtained from a commercial source. A 1-inch board was carefully chosen for straightness of grain and freeness from any possible drying defects. How the board was dried was not known, but from careful microscopic examination there was no evidence of wood failure due to drying.

The samples to be tested green were submerged in water and stored in a refrigerator. Some microorganism activity was evident so all the other sample wood was carefully dried to less than 20 percent moisture content. In later tests where green material was needed these air dried samples were rewet by applying a vacuum to remove the air and replace it with distilled water. The saturated blocks then were allowed to soak for at least 24 hours before being tested.

During the cutting operation the green blocks were kept from drying on the surface by using a small brush to wet them periodically with distilled water.

As stated previously a constant room temperature was desirable for stability of the dynamometer. This was also desirable to minimize temperature effect on the properties of the wood during cutting. A constant temperature of 75°-80° F was maintained for all tests.

Interpretive Techniques

Observation of Chip Formation

A stereoscopic microscope was used to observe all the cutting operations unless motion pictures were taken. Much of the action was repetitious, allowing ample opportunity to note the way in which the cell structure was deformed. Even so, it was difficult to observe the several actions taking place simultaneously. The motion pictures were relied upon to record the changes for more detailed study. Motion pictures can be run forward and backward to observe points of interest. Individual motion picture frames were enlarged. Measurements made on these prints established angles of action or points of strain in various stages of chip development.

Oscillograph Record

The trace of the oscillograph was variable due to the change of the wood structure which the knife encountered as it advanced in the cut. This variability poses a problem in determining what part of the trace best represents the cutting action for the purpose of comparison of cutting conditions.
In the first series of force measurements, in which cottonwood was cut parallel to the ring, the maximum of the trace was arbitrarily chosen to represent both components $F_n$ and $F_p$. This method was used by Franz (10) and Nakamura (21).

During these first studies with cottonwood, the point of wood failure resulting in veneer checks was observed and marked on the chart with the marker stylus. $F_n$ was at a maximum at the time of wood failure. $F_p$ was usually but not always maximum at this point. Therefore, in the remaining studies a point of maximum $F_n$ was chosen to represent the condition when the knife was under maximum stress just prior to wood failure in the formation of a veneer check. The point on the $F_p$ trace which was directly opposite this maximum $F_n$ was considered most representative of the component $F_p$.

Fig. 15 shows a portion of a chart for each of the three species cut. Lines added to the chart (Fig. 15A) indicate how the quantities $F_n$ and $F_p$ were determined. The arrow $P_1$ points to the maximum of the $F_n$ trace and $P_2$ indicates the matching point directly opposite. $F'_n$ and $F'_p$ are the measurements made on the chart. These were converted into quantities for $F_n$ and $F_p$ by applying an appropriate conversion factor, depending upon the attenuator setting of the recorder.

In choosing point $P_1$, the beginning and the terminus of the cut were avoided. At the start of the trace a maximum often occurred before the knife was fully into the cut. This was a point of interest but was considered atypical as there was not a full development of the chip. At the end of the cut the wood was not well supported and abnormal cutting conditions resulted.

It is realized that there is considerable personal judgement needed in obtaining data from these records. An attempt was made to minimize human bias by reducing this judgement to a simple choice of the maximum in the central two-thirds of the trace.
Fig. 15—A, A portion of the oscillograph record for sugar pine showing how forces are determined. B, Cottonwood. C, Silver maple.
Sampling Methods

The depth of cut $t_1$, for most tests, was varied in sequence from 0.01 to 0.05 inch at intervals of 0.01 inch. This will be referred to as a thickness series. For the testing of sharpness, a special series of 0.02 to 0.04 inch with intervals of 0.005 inch was used. Some observational and photographic studies were done at greater depths of cut. In all cases, cuts in a thickness series were made in sequence rather than randomized. This minimized the effect of variation in chip thickness which might result from movement of the block or knife. The tendency for variation in thickness increases with increasing depth of cut; thus, there is less discrepancy when going from a 0.04- to a 0.05-inch cut in series than when going directly from a 0.01- to a 0.05-inch cut as might occur in random sampling.

Two methods of sampling were used in this study. They differed in sample size, the angle at which the cutting plane passed through the growth ring, and the clearance.

**Method A**

In the initial studies with cottonwood, end-matched blocks were tested with a zero clearance angle; the cutting plane was oriented parallel to the growth ring. Seven thickness series were cut from each of two blocks; making 14 series for each variable tested. The average included the cutting force for both springwood and summerwood. This gave considerable variation due to the differences in wood structure.

**Method B**

To gain more control over variation due to differences in wood structure and permit a reduction in sample size, subsequent tests were made with the cutting plane passing through the growth ring at an angle (Fig. 16A). In this way, the knife passes through both springwood and summerwood for every cut.

Three replications of the thickness series were cut from a single end-matched block for each variable tested. A 30-minute clearance angle was used for reasons which will be given when discussing results.

Choice of the direction in which the knife moves from springwood to summerwood at the ringline is based on experience with torn grain. Observation of cutting showed more tendency for the springwood to pull away from the summerwood at the ringline when cutting in the direction shown in Fig. 16B. Lutz (15) observed this when cutting commercial veneer.

Both a 1 and a $\frac{1}{2}$ inch width of cut, $w$, were used on the assumption that the cutting force varied directly with the width of cut (11, 22). All results of the force measurements are reported as pounds per inch width of cut.
Fig. 16—Direction of cut: A. Cutting from springwood to summerwood at the ringline. B, Cutting from summerwood to springwood at the ringline.
Chapter V

RESULTS AND ANALYSIS

Cutting Geometry and Wood Properties

This series of tests was designed to determine the effects of knife angles and chip thickness on cutting forces and deformation of the wood structure for three species of wood above the fiber saturation point.

Force Measurements

Force Components Defined

Before examining the test results, the components of the cutting force need defining. As shown in Fig. 2, the forces measured in this study were those parallel and normal to the cutting plane. Further consideration leads to the conclusion that these forces can be resolved into components which are attributed to the compression forces on the face and back of the knife, and to the frictional forces resulting therefrom. It is not intended to represent the magnitude of these forces at this time, but only to indicate the components which may occur. These are illustrated in Fig. 17 and defined in the following paragraph.

\( N_f \) — Normal force on the face of the knife.

\( F_f \) — Frictional force resulting from \( N_f \).

\( N_b \) — Normal force on the back of the knife.

\( F_b \) — Frictional force resulting from \( N_b \).

\( F_{ps} \) — Severance force; that force required for the cutting edge to penetrate the cell walls.

\( F_{pf} \) — That part of \( F_p \) which results from forces acting on the face of the knife.

\( F_{pb} \) — That part of \( F_p \) which results from forces acting on the back of the knife.

\( F_{ff} \) — That part of \( F_n \) which results from forces acting on the face of the knife.

\( F_{nb} \) — That part of \( F_n \) which results from forces acting on the back of the knife.

\( R_f \) — Resultant of the force components acting on the face of the knife.

\( R_b \) — Resultant of the force components acting on the back of the knife.

\( R \) — Total resultant of all force components acting on the knife.
Fig. 17—Relationship of force components defined in the text.
INITIAL TESTS WITH GREEN COTTONWOOD

The initial tests with green cottonwood employed Sampling Method A, with the plane of the cut parallel to the growth rings, as previously described. The sample material was not from the same source as later series. The growth rate was five rings per inch with a specific gravity of 0.45, volume when green. Using a zero clearance angle, five knives with nominal sharpness angle of 15 to 35 degrees at intervals of 5 degrees were employed with the corresponding cutting angles ranging from 75 to 55 degrees. The exact knife angles used are indicated on the graph of the results shown in Fig. 18. Table 1 shows the data from which the curves were constructed. Each value is an average of 14 cuts.

Of interest at this point are the curves for the normal cutting force, $F_n$.

### Table 1

<table>
<thead>
<tr>
<th>Sharpness angle</th>
<th>Cutting angle</th>
<th>Depth of cut, (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>$\alpha$</td>
<td>0.01</td>
</tr>
<tr>
<td>15° 45'</td>
<td>74° 15'</td>
<td>$F_n$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
</tr>
<tr>
<td>20°</td>
<td>70°</td>
<td>$F_n$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
</tr>
<tr>
<td>26°</td>
<td>64°</td>
<td>$F_n$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
</tr>
<tr>
<td>30° 30'</td>
<td>59° 30'</td>
<td>$F_n$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
</tr>
<tr>
<td>35° 20'</td>
<td>54° 40'</td>
<td>$F_n$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
</tr>
</tbody>
</table>

CLEARANCE ANGLE EFFECT

It is clear that for these large cutting angles the normal force component is negative in its direction. However, when the curves for $F_n$ are extended, as shown by the broken line, they intersect the ordinate axis somewhat above the origin. Although this broken line is not a representation of the experimental curve which would result from making continually thinner cuts below 0.01 in., the intersect indicates a positive force $F_{nb}$ which opposes $F_{nf}$ to reduce the magnitude of $F_n$. The presence of the component $F_{nb}$ was attributed to a negative clearance, possibly due to error in the setting of the zero clearance angle. The clearance angle was therefore retested by using the paraffin technique described under the discussion of experimental methods. The zero setting was believed to be correct.
Using a constant cutting angle of 60 degrees, the effects of zero, 5, and 15-degree clearance angles were tested. Results (Table 2 and Fig. 19) give evidence that a definite clearance angle eliminates the positive component \(F_{nb}\) because the curves pass through the origin. This substantiates the belief that the positive factor \(F_{nb}\) at zero depth of cut for zero clearance is due to compression under the back of the knife. The discrepancy of an apparent compressive force between the back of the knife and the workpiece with zero clearance was resolved by observation of the cutting action.

### TABLE 2

**THE EFFECT OF CLEARANCE ANGLE ON THE RELATIONSHIP OF THE NORMAL AND PARALLEL FORCE COMPONENTS TO THE DEPTH OF CUT IN COTTONWOOD ABOVE THE FIBER SATURATION POINT**

<table>
<thead>
<tr>
<th>Clearance angle</th>
<th>Sharpness angle</th>
<th>Cutting angle</th>
<th>Depth of cut, (inches)</th>
<th>Pounds per inch width of cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(\alpha)</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>0°</td>
<td>30° 30'</td>
<td>59° 30'</td>
<td>(F_n)</td>
<td>-0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(F_p)</td>
<td>10.9</td>
</tr>
<tr>
<td>4° 30'</td>
<td>25° 30'</td>
<td>60°</td>
<td>(F_n)</td>
<td>-2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(F_p)</td>
<td>9.4</td>
</tr>
<tr>
<td>14° 15'</td>
<td>15° 45'</td>
<td>60°</td>
<td>(F_n)</td>
<td>-3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(F_p)</td>
<td>9.9</td>
</tr>
</tbody>
</table>

As the depth of cut is reduced, the lack of support from above the cutting plane allows cells which are compressed at the cutting edge to be turned downward slightly. After severance occurs; these cells are held in compression under the back of the knife as shown in Fig. 20. This condition will be referred to as pseudonegative clearance.

A rounding of the cutting edge, due to wear or the method of sharpening, has the action of a microscopic back bevel which contributes to the formation of this pseudonegative clearance effect.

As shown, a large enough clearance angle with a sharp knife eliminates the pseudonegative clearance. However, this presents difficulties if a 75-degree angle is to be used. It is not easy to produce and maintain the cutting edge on a knife with a sharpness angle of less than 15 degrees. If the sharpness angle is to be kept large, it is necessary to use a clearance angle as close to zero as feasible. To satisfy these limitations and still minimize the pseudonegative clearance, a 30-minute clearance angle was used in subsequent cutting series.

### Principal Cutting Tests

The principal series of tests to determine the effect of knife angles and chip thickness were carried out using Sampling Method B. Sugar pine, cottonwood, and silver maple above the fiber saturation point were tested with the sequence of cutting angles and the series of chip thicknesses that were used in the initial testing of cottonwood. The constant clearance angle of 30 minutes was used to
Fig. 19—Effect of clearance angle on the cutting forces. Force components $F_p$ and $F_n$ plotted against depth of cut $t_1$ for three clearance angles $\gamma$ of zero, $4^\circ \ 30', \text{and} \ 14^\circ \ 15'$ with a constant cutting angle $\alpha$ of $60^\circ \pm 30'$ for cottonwood cut by sampling method A.
minimize the pseudonegative clearance effect, as discussed in the previous section.

The specific gravity and growth rate of the woods were:

<table>
<thead>
<tr>
<th>Wood</th>
<th>Specific gravity*</th>
<th>Growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar pine</td>
<td>0.39</td>
<td>20</td>
</tr>
<tr>
<td>Cottonwood</td>
<td>0.43</td>
<td>3</td>
</tr>
<tr>
<td>Silver maple</td>
<td>0.41</td>
<td>5</td>
</tr>
</tbody>
</table>

* Based on oven-dry weight and green volume.

These data on growth rates and specific gravity are to help the reader visualize the wood used. It is not intended to indicate a relationship between tests. As the amount of cell wall substance present varies within the ring and between rings, there is no attempt made to compare results by specific gravity. Such a gross average indicator as the specific gravity of the sample block is not an indicator of the cell wall thickness in any particular part of a ring. Even the specific gravity of the chip would not be adequate, since the cell wall structure differs within the chip.

Results of the principal cutting series are summarized in Table 3. The data represent the average maximum value of $F_a$ and the matching value of $F_p$ for each condition tested.
### TABLE 3

RELATIONSHIP OF KNIFE ANGLES AND DEPTH OF CUT TO THE NORMAL AND PARALLEL FORCE COMPONENTS FOR SUGAR PINE COTTONWOOD, AND SILVER MAPLE ABOVE THE FIBER SATURATION POINT, USING SAMPLING METHOD B

<table>
<thead>
<tr>
<th>Sharpness angle</th>
<th>Cutting angle</th>
<th>Vector</th>
<th>Depth of cut, (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td><strong>COTTONWOOD</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15°</td>
<td>74° 30'</td>
<td>$F_n$</td>
<td>-4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>8.9</td>
</tr>
<tr>
<td>20°</td>
<td>69° 30'</td>
<td>$F_n$</td>
<td>-3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>9.5</td>
</tr>
<tr>
<td>25°</td>
<td>64° 30'</td>
<td>$F_n$</td>
<td>-2.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>11.1</td>
</tr>
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<td>59°</td>
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<td>-3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>12.0</td>
</tr>
<tr>
<td>35° 10'</td>
<td>54° 20'</td>
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<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>15.1</td>
</tr>
<tr>
<td><strong>SILVER MAPLE</strong></td>
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<td></td>
</tr>
<tr>
<td>15°</td>
<td>74° 30'</td>
<td>$F_n$</td>
<td>-4.1</td>
</tr>
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<td></td>
<td></td>
<td>$F_p$</td>
<td>10.5</td>
</tr>
<tr>
<td>20°</td>
<td>69° 30'</td>
<td>$F_n$</td>
<td>-3.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
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</tr>
<tr>
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<td>64° 30'</td>
<td>$F_n$</td>
<td>-3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>13.5</td>
</tr>
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<td>59°</td>
<td>$F_n$</td>
<td>-2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>12.8</td>
</tr>
<tr>
<td>35° 10'</td>
<td>54° 20'</td>
<td>$F_n$</td>
<td>-2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>13.5</td>
</tr>
<tr>
<td><strong>SUGAR PINE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20°</td>
<td>69° 30'</td>
<td>$F_n$</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>9.3</td>
</tr>
<tr>
<td>25°</td>
<td>64° 30'</td>
<td>$F_n$</td>
<td>-1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>9.5</td>
</tr>
<tr>
<td>30° 30'</td>
<td>59°</td>
<td>$F_n$</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>9.2</td>
</tr>
<tr>
<td>35° 10'</td>
<td>54° 20'</td>
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<td>-0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F_p$</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Pounds per inch width of cut

1/ Results for 15° knife omitted due to error caused by defective knife.

Figs. 21, 22, and 23 show the trend for variation of cutting force with depth of cut while Figs. 24, 25, and 26 illustrate the change of cutting force with cutting angle.
Fig. 21—Relationship of parallel force component $F_p$ and normal force component $F_n$ to depth of cut at five cutting angles $\alpha$ and a 30° clearance angle for cottonwood.
Fig. 22—Relationship of parallel force component $F_p$ and normal force component $F_n$ to depth of cut at five cutting angles $\alpha$ and a $30'$ clearance angle for silver maple.
Fig. 23—Relationship of parallel force component $F_p$ and normal force component $F_n$ to depth of cut at five cutting angles $\alpha$ and a 30' clearance angle for sugar pine.
Fig. 24—Relationship of parallel force component $F_p$ and normal force component $F_n$ to cutting angle for five depth of cut in cottonwood.
Fig. 25—Relationship of parallel force component $F_p$ and normal force component $F_n$ to cutting angle for five depth of cut in silver maple.
Fig. 26—Relationship of parallel force component $F_p$ and normal force component $F_n$ to cutting angle for five depth of cut in sugar pine.
The variation of cutting force and depth of cut approximates a straight line for the smaller depth of cut. This tendency for a linear relationship is even more evident in Figs. 18 and 19 of the initial cottonwood studies. The apparent lack of curvature in the graph for the initial cottonwood studies is at least partly due to sampling method. Since sampling method A includes cuts in both springwood and summerwood, the results represent an average for the wood. In the principal cutting tests, with the cut passing through the densest part of the ring, the curves represent maximum forces.

The results for cottonwood have the greatest tendency to deviate from a straight line when the three woods for a cutting angle of 70 degrees are compared as in Fig. 27. At smaller cutting angles there is also a break in the curves for silver maple (Fig. 22). Observation of the chip formation indicates that the deviation from the linear relationship in these cases coincides with the development of wood failure at or behind the cutting edge.

When the curves for $F_p$ are extrapolated to zero depth of cut, they tend to converge on a common intercept of between 5 and 7 pounds force per inch width of cut. This may be considered to represent the fiber severance force, $F_{ps}$, necessary for the cutting edge to separate or penetrate the cells in the cutting plane.

The broken line is not intended to represent the experimental curve as the depth of cut approaches zero. As the depth of cut is reduced below 0.01 inch a point is reached when the relationship deviates from a straight line due to a change in the mechanics of chip formation partly due to pseudonegative clearance. The extrapolation to a depth of cut of zero is only a means of determining the constant factor for the straight line portion of the curves. When $F_{pb}$ is eliminated by sufficient clearance angle, this may be expressed by the formula:

$$F_n = F_{hf} + F_{ps} = k_1 t_1 + F_{ps}$$

$F_{ps}$ being the approximately constant severance force and $k_1$, the deformation factor dependent upon the cutting angle and properties of the wood being cut. This agrees with the findings of Kivimaa (11).

The variation of the cutting forces with depth of cut is compared for springwood and summerwood of cottonwood in Table 4 and Figure 28. The rise of

| TABLE 4 |
| THE EFFECT OF SPRINGWOOD AND SUMMERWOOD ON THE RELATIONSHIP OF THE NORMAL AND PARALLEL FORCE COMPONENTS TO THE DEPTH OF CUT IN COTTONWOOD, ABOVE THE FIBER SATURATION POINT |
| (cutting angle 89° 30'; clearance angle, 30') |
| Vector | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 |
| Springwood | $F_n$ | -0.3 | -2.5 | -3.3 | -4.3 | -5.0 |
| | $F_p$ | 7.7 | 10.0 | 12.7 | 15.7 | 16.7 |
| Summerwood | $F_n$ | -3.2 | -7.5 | -10.7 | -11.8 | -13.7 |
| | $F_p$ | 9.5 | 14.0 | 18.3 | 21.0 | 23.0 |
Fig. 27—Comparison of cottonwood, silver maple, and sugar pine. Parallel force component $F_p$ and normal force component $F_n$ plotted against depth of cut at cutting angle $\alpha = 69^\circ 30'$; sharpness angle $\beta = 20^\circ$, and clearance $\gamma = 30'$. 

SUGAR PINE
COTTONWOOD
SILVER MAPLE
Fig. 28—Comparison of the cutting forces in springwood and summerwood for cottonwood. Parallel force component $F_p$ and normal force component $F_n$ plotted against depth of cut with cutting angle $\alpha = 69^\circ 30'$, sharpness angle $\beta = 20^\circ$, and clearance angle $\gamma = 30^\circ$. 
the curve at 0.01-inch depth of cut in the springwood was due to the pseudo-negative clearance effect which resulted from the ease with which the springwood cells were deformed at the cutting edge. The increased resistance to severance caused by this condition will be more evident when the sharpness effect is discussed.

**Observation Study**

Previous fundamental studies of cutting action (6, 10, 17), both in metal and in wood, have defined distinct chip types according to the kind of failure which occurred at or ahead of the cutting edge. The observations made in this study show it is difficult to classify veneer by type. Any attempt to do so shows that there are not only different kinds of failure, but also a combination of these failures. Therefore, in this discussion only the basic form of the chip, to be called continuous veneer, will be defined. The types and combination of wood failure will then be considered with respect to their effect upon the veneer formation.

**Continuous Veneer Formation**

Continuous veneer will be considered a sheet of wood in which the original structure is not visibly ruptured by the cutting process. This can be accomplished for the large cutting angles without a nosebar by using a sharp knife and a small thickness of cut as in Fig. 30A. The only rupture in such a cut is the continual severance or separation of the cells at the cutting edge. This produces relatively smooth unbroken surfaces on both sides of the cut.

Fig. 29 illustrates deformation of the wood structure during formation of continuous veneer. These enlargements were made from a motion picture which recorded the start of a cut in green cottonwood. As the cells in the cutting plane are severed or separated by the cutting edge, those just above must change direction if they are to move up the face of the knife. This relative movement perpendicular to the cutting plane is resisted by wood structure above. The cells at the face of the knife are compressed (Fig. 29A). The compression increases rapidly, causing frictional resistance as these cells move up the knife and away from the cutting edge. When the distance from the cutting edge is great enough, a point of maximum pressure is reached. Further increase is relieved by the bending of the veneer. This cantilever beam action produces a maximum moment over the cutting edge (Fig. 29B to D). The rotation of the wood structure causes a visible compression strain on the top or face of the veneer and a less evident tension strain on the knife side or back of the veneer. Figs. 29A and D illustrate this point. In both pictures the numbered lines pass through the same points of the wood anatomy. The change of distance between lines for the two stages of the cut indicate the areas of tension and compression parallel to the surface of the veneer.
Fig. 29—The start of a cut in cottonwood. The lines drawn on (A) and (D) show the same points in the wood structure for the two stages of the cut; $t_1 = 0.05$ in., $\alpha = 64^\circ$, $\beta = 25^\circ$, $\gamma = 1^\circ$. 
Fig. 30—Effect of depth of cut on deformation of the wood structure; $\alpha = 65^\circ$, $\beta = 15^\circ \ 45'$, $\gamma = 9^\circ \ 15'$: 

- A, $t_1 = 0.02$ in.
- B, $t_1 = 0.04$ in.
- C, $t_1 = 0.06$ in.
DEPTH OF CUT EFFECT

Variation of depth of cut within the limits of these experiments appears to have no significant effect upon the form of the continuous veneer chip. Fig. 30 shows evidence of increase in the amount of strain as the depth of cut increases, but the general pattern of the strain is unchanged.

An increase in the resistance to deflection with an increase in the thickness of the veneer chip causes an increase of the compressive and frictional forces at the face of the knife behind the cutting edge. The point of maximum deformation due to the resultant of these forces moves further up the knife as the depth of cut increases. The localized plastic deformation of the cells appears to increase the allowable tensile strain perpendicular to the resultant cutting force. A shear plane tends to form between this localized compression and the wood structure above (Fig. 30B and C). Judging by the deformation of the cells, it is clear that for a 0.06-inch depth of cut the point of maximum compression is less than 0.05 inch from the cutting edge.

The compressive strain at the point of deflection on the face of the veneer shows little change in the amount of deformation with the variation in depth of cut. For the thin veneer chip in Fig. 30A the strain necessary to permit rotation of the wood structure is mostly in compression at the face of the veneer with the center of rotation at or near the cutting edge. As the depth of cut becomes greater, the localized densification at the deflection point on the veneer face does not appear to increase proportionally. Instead, the added stress is relieved by strain in tension or shear in the vicinity of the cutting edge. As mentioned, lines of shear strain have formed approximately parallel to the cutting plane behind the cutting edge in Figs. 30B and C.

It is evident that the localized deformation in compression, both on the face of the veneer and just behind the cutting edge, act together to relieve the tension stress at or just ahead of the cutting edge. It therefore would follow that any condition which aided the deformation of the wood structure in compression without equally reducing the tensile or shear strength, would increase the possibility of continuous veneer formation.

As the depth of cut increases, a limit is reached beyond which the stresses exceed the strength of the wood in tension or in shear and rupture occurs. This limiting depth of cut varies with the wood properties, moisture content, and cutting angle.

RUPTURE WHEN CUTTING PARAFFIN

As an auxiliary study of failure development, paraffin was photographed when using cutting angles of 55 and 75 degrees. For these conditions two different types of rupture were observed as in Fig. 31 and 32. Besides the severance of the paraffin at the cutting edge, the compression just behind the cutting edge produced a periodic shear failure for the 55-degree cutting angle shown in Fig.
The chip, when separated from the workpiece, moves in the direction shown by the arrow in the lower right hand frame of Fig. 31. This chip formation is similar to that found when cutting metal (6). A somewhat similar formation was described by Franz (10) when cutting wood parallel to the grain with small cutting angles. This failure type was not found at any time in this study.

A totally different chip type occurred for a cutting angle of 75 degrees (Fig. 32). Following rupture, the relative movement of this chip with respect to the
workpiece is opposite to that observed for the 55-degree cutting angle. This is indicated by the arrows in the lower right hand frame of Fig. 32.

There may be some question whether the latter type of failure is due to formation of a shear slip plane or to tension failure followed by a shear movement. The author believes this to be primarily a tension failure resulting from a combination of tension and shear stresses. It can be seen that the shear failure
in Fig. 31 is the complete development of a slip plane which gradually becomes more pronounced as the knife advances in the cut. In Fig. 32 the failure line develops gradually; the part close to the knife edge widens as the failure continues to elongate. There is not a pronounced widening of the rupture since the compression causing the tension stresses would be relieved by very little strain beyond the elastic limit. Paraffin, being somewhat plastic in compression, would be expected to show little recovery of compressive strain.

Close inspection of Fig. 32A shows the failure starts up from the cutting edge at an angle of approximately 45 degrees to the cutting plane for a short distance and then curves to approach a direction parallel to the cutting plane. As the knife advances (Fig. 32B) the failure reverses its curvature upward to approach a direction perpendicular to the cutting plane. This sinusoidal path of the failure is also evident in the previous check.

As the knife continues in the cut, paraffin severed from the workpiece forms a small lip between the failure and the knife. This lip closely follows the part of the chip above, but is rotated about a point close to the cutting plane, while the chip above the failure, pivots about a point closer to the top of the workpiece. This difference in the centers of rotation for the two parts of the chip accounts for the relative shear movement of the surface above and below the failure line, as the old and new section of the chip move up the knife.

The point of interest in this formation of failure in paraffin is the similarity between the development of the rupture shown in Fig. 32 and that observed during the formation of veneer.

**Rupture When Cutting Wood Veneer**

Three types of rupture development were noted in this study. These were formed individually or in combinations, depending upon the cutting geometry and the wood properties. For the purposes of discussion these rupture types have been defined as: (1) tension check, (2) shear check, and (3) compression tearing. All may contribute to the formation of what is known as “knife check” or “lathe check” in veneer cutting.

**Tension Checks**

In the typical tension check formation, a short rupture opens quickly as in Figs. 33, 34, and 35. The start of the check is at an angle to the cutting plane with the appearance of being a rupture in tension which results from a combination of tension and shear stresses, at the cutting edge.

Figs. 33 and 34 show a change in direction of the failure much like that described for paraffin in Fig. 32. The initial short rupture develops at an angle of 30 to 45 degrees to the cutting plane, and then changes direction to form a smaller angle with the cutting plane as in 33B and 34B. After this slight change in direction, the failure then turns upward until it approaches a direction per-
Fig. 33—Development of a tension check in sugar pine; $\alpha = 68^\circ$, $\beta = 21^\circ$, $\gamma = 1^\circ$, $t_1 = 0.097$ in.
Fig. 34—Development of tension check in silver maple; $t_1 = 1.25$ in., knife micro-sharpened as (D) in Fig. 63 and Table 6.
Fig. 35—Development of tension check in cottonwood; $\alpha = 65^\circ$, $\beta = 15^\circ 45'$, $\gamma = 9^\circ 15'$, $t_1 = 0.08$ in.
perpendicular to the cutting plane. This sinusoidal appearance of the rupture can also be seen in the close-up picture of veneer cutting reported by Fleischer (9).

The tension check in sugar pine differs slightly from that observed in the hardwoods. The failure changes direction suddenly with the final rupture following a ray, as seen in Figs. 33 and 39.

The change of direction of the tension check is attributed to a change in the magnitude of the components of force contributing to the tensile stress causing the failure. This will be considered further when discussing the stresses in veneer formation.

Shear Checks

It has previously been pointed out that a shear plane may develop behind the cutting edge between the point of maximum compression and the wood structure above. This was evident for cottonwood in Figs. 30B and C. It can also be seen for silver maple in Fig. 36. The shear strain does not always develop into rupture; if it does, the rupture may go undetected when there is no separation of the structure in the field of view.

This type failure was more frequent at the 55 and 60-degree cutting angles. The condition conducive to its development appeared to be the presence of a large compressive strain behind the cutting edge as in cottonwood. Shear checks were seldom observed in sugar pine.

Fig. 36—Shear failure developed behind the cutting edge in silver maple; $\alpha = 54^\circ \, 20'$, $\beta = 35^\circ \, 10'$, $\gamma = 30'$, $t_1 = 0.05$ in.
The development of rupture of the type in Fig. 37 is indefinite. The initial failure circled by the dash line in B gives the impression of being due to rupture in shear. However, the cells between it and the cutting edge are in tension in the general direction shown by the arrow in C. Shear movement is in the general direction of the half arrow or more parallel to the cutting plane at the point of rupture ahead of the knife. Whether the initial rupture is shear or tension failure, it is apparently due to combined shear and tension stresses which reach a maximum between the position of the knife in A and B.

**Compression Tearing**

In the weak springwood of cottonwood and sugar pine there is less tendency for the development of tension checks. Unless the knife is sharp, however, damage to the surface of the veneer will be caused by compression tearing as seen in Fig. 38. In sugar pine, even the sharpest knife will produce this type of failure occasionally. When cutting such flexible wood structure, the cells in front of the cutting edge are under reduced tension perpendicular to the cutting plane. This lessens the tendency for the cells to fail individually due to localized stress concentration when contacted by the cutting edge. Instead, the cells wrap around the knife edge and resist severance by distributing the stress over a larger area such that the friction reduces the stress concentration at the ultimate cutting edge. As a result, the cells are compressed ahead of the knife until sufficient force is developed for severance to take place. This resistance to the movement of the cells produces a tension above and below and slightly behind the cutting edge. If resistance to severance is great enough this tension stress causes rupture such as the ones in Fig. 35A, 41A, and 42B. As the rupture enlarges it usually follows a curved path to approach a direction parallel to the cutting plane. As a result, a group of cells are peeled out of the veneer surface. The degree of roughness of the surface depends upon the depth to which this compression tearing develops. The large failure shown in Fig. 38 would impart a very rough broken appearance to the veneer. In such cases it is difficult to classify the failure.

There is considerable intergrading between what might be considered a typical tension check and compression tearing. Some tension checks apparently start with failure which is, or closely approaches, this condition described as compression tearing. The connection can be seen between the direction of the development of rupture in compression tearing and the initial stages of some tension checks which follow a somewhat sinusoidal curvature as previously described. This is compatible with the observation that rupture appears to result from shear stresses caused in part by the cutting edge resisting the movement of the wood past the knife. In other words, the initiation of the failure is at least partly dependent upon compression at the cutting edge (resistance to severance). If so, a sharp knife could be expected to reduce the tendency for check formation. These tests show some evidence that this is the case. However, as the depths of cut were small, no general conclusions should be considered at this time.
Fig. 37—Combination of shear and tension failure in cottonwood; $\alpha = 65^\circ$, $\beta = 15^\circ$
$46'$, $\gamma = 9^\circ 15'$, $t_i = 0.08$ in.: A, Before failure. B, Initial failure circled with broken line. C and D, Opening of tension failure.
Fig. 38—Development of compression tearing in sugar pine; $\alpha = 64^\circ$, $\beta = 25^\circ$, $\gamma = 1^\circ$, $t_1 = 0.05$ in.
Fig. 39—Deformation of the wood structure of sugar pine by a cutting angle of 54° 20'; \( \beta = 35° 10', \gamma = 30', t_1 = 0.05 \) in. A, Immediately before the check starts. B, Initial failure. C, Further opening of the check accompanied by the formation of compression tearing below the knife edge.
Fig. 39 shows the typical tension check may be followed by the development of compression tearing. This is dependent upon knife sharpness and the physical properties of the wood. When a tension check has formed, the knife, in effect, starts into a very small depth of cut. If severance at the cutting edge were to continue uninterrupted, the check would close up when the cutting stresses were relieved. The cells in the cutting plane, however, are not supported by wood structure above. This lack of tension perpendicular to the cutting plane makes severance difficult. The cells offer little resistance to compression by the cutting edge. As a result, compression tearing develops concurrently with the tension check.

It can be seen that compression tearing is the major cause of rough veneer surface.

**Cutting Angle Effect**

Variation of the cutting angle has a pronounced effect upon deformation of the wood structure in chip formation. In Figs. 39 and 40, the difference appears to be one of amount rather than type of chip formation.

The obvious reduction in strain with the larger cutting angle indicates the desirability of grinding the knife to a minimum angle compatible with the sharpening procedure and the forces on the cutting edge. One limitation is the increasing tendency to overheat the cutting edge and draw the temper as the grinding angle is reduced. Another consideration is the strength of the edge necessary for the type of wood being cut.

![Image of wood structure deformation](image)

**Fig. 40—Deformation of the wood structure of sugar pine by a cutting angle of 74° 30', β = 15°, γ = 30°, t₁ = 0.05 in.**
In these tests it was difficult to maintain a satisfactory cutting edge at a 15-degree sharpness angle. The edge was easily bent over, creating a condition which produced much poorer cutting results than a knife dulled to a rounded edge by metal wearing away.

The microsharpening technique (12) was investigated to provide a sturdy cutting edge while maintaining the desirable 75-degree cutting angle. Results will be discussed in the section on sharpness.

**Nosebar Action**

There is a general belief that the nosebar reduces formation of lathe checks by direct compression of the wood between itself and the knife. This appears to be only part of the action. Fig. 42 shows a stepwise increase in compression of sugar pine by varying the veneer thickness while keeping the horizontal nosebar opening at a constant 0.05 inch. There is a pronounced compression parallel to the cutting plane in front of the nosebar. If the nosebar is properly placed, this *precompression* assists the rotation of the wood structure above the cutting edge. This lowers the neutral axis to reduce the tension stress acting parallel to
the back of the veneer. When cutting greater thicknesses, the precompression is not sufficiently effective in depth to prevent the start of lathe checks, but will reduce the depth to which the checks form.

In attempting to prevent lathe checks, increased nosebar pressure beyond a critical point will produce overcompression as shown in Fig. 42C. This permanent deformation of the wood structure reduces the thickness of the veneer, as evidenced by the crooked ray structure.

Another defect resulting from overcompression is shown in Fig. 43A. The combined force of the nosebar and the knife edge parallel to the cutting plane causes tension failure under the knife edge. The checks are formed in the face of the veneer yet to be cut.

The conventional solid nosebar allows a sudden release of pressure behind the point of maximum compression as shown in Fig. 43B. This results in a shearing action which causes failure on the face of the veneer. In some cases these checks may have been started by the compression tearing at the knife during the previous cut. The sudden release of pressure behind the nosebar tends to open such failures and enlarge them. This increases the roughness of the veneer face.

To prevent tearing due to the sudden release of compression, an experimental double-surfaced nosebar based on the work of Voskrezenskij (26) was tested (see Figs. 41 and 6B). Fig. 44 illustrates the cutting action. Initially the back surface of the nosebar was set parallel to the face of the knife. The distance between the nosebar and knife when measured perpendicular to the face of the knife was the same as the horizontal opening h. A high resistance to movement of the veneer was observed, even at relatively low nosebar compressions. This resulted in a failure below the knife edge similar to that shown in Fig. 43A. A slight evidence of this failure is present in Fig. 44. To reduce the resistance to veneer movement, without changing the horizontal or vertical opening, a clearance angle, \( \varphi \) (Fig. 41), of approximately 4 degrees was used. This allowed a gradual release of compression with very satisfactory results.

Besides controlling the release of compression, the pressure of the back surface of the double-surfaced nosebar assists the rotation of the wood structure. This, in combination with an increase of friction between the veneer and the knife face, reduces the tension strain evident on the back of the veneer. The added frictional force allows a lower percentage nosebar compression than would be needed to obtain the same effect with a nosebar of conventional design.

The main disadvantage of the double-surfaced nosebar is the precision required in its adjustment. From what has been said, it can be seen that the angle and the distance between the knife and the back surface of the bar are critical.

Although the tests with the double-surfaced nosebar were limited in scope, the results indicate it adds sufficient control of the veneer cutting process to justify additional investigation.
Fig. 42—Nosebar action when cutting sugar pine; $\alpha = 68^\circ$, $\beta = 21^\circ$, $\gamma = 1^\circ$, $v = 0.01$ in., $h = 0.05$ in., $t_1$ was varied to change nosebar compression: A, $t_1 = 0.055$ in., compression = 9 percent. B, $t_1 = 0.06$ in., compression = 17 percent. C, $t_1 = 0.07$ in., compression = 29 percent.
Fig. 43—A, Failure under the knife due to overcompression in silver maple; \( \alpha = 68^\circ, \beta = 21^\circ, \gamma = 1^\circ, v = 0.03 \text{ in.}, h = 0.05 \text{ in.}, t_1 = 0.07 \text{ in.}, \) compression = 29 percent. B, Opening of failures due to sudden release of pressure behind the conventional solid nosebar; \( \alpha = 68^\circ, \beta = 21^\circ, \gamma = 1^\circ, v = 0.02 \text{ in.}, h = 0.05 \text{ in.}, \) compression = 17 percent.
Fig. 44—Action of double surfaced nosebar; $\alpha = 68^\circ$, $\beta = 21^\circ$, $\gamma = 1^\circ$, $v = 0.01$ in., $h = 0.053$ in., $t_1 = 0.058$ in.: $A$, Sugar pine. $B$, Cottonwood.
Sharpness Effect

These tests were designed to determine the effect of knife sharpness on the severance force and the deformation of the wood structure at the edge of the knife. There were two series of tests made. The first was to establish a basis for standardizing the sharpening procedure prior to the initial testing of green cottonwood. The second, made in conjunction with the principal cutting tests, was to further determine the effect of sharpening methods or cutting edge wear on the forces and failure which occurred at the cutting edge, and to determine the type of veneer surface which results.

Force Measurements

FIRST TEST SERIES

For the first tests, three knives with a classified sharpness were used to cut series of 0.01 to 0.05 inch depths of cut in green cottonwood. The cutting plane was parallel to the growth rings as in sampling method A. The knives tested had a 25-degree sharpness angle, zero clearance angle, and 65-degree cutting angle. Based on measurements made with a profilometer, all three knives were prepared with the face polished to the same fine finish of approximately 5 micro-inches RMS. This was produced on an Arkansas stone. The back of each knife was honed with a different grade of stone such that the back bevels had scratches generally perpendicular to the cutting edge and of different coarseness. Any wire edge produced during sharpening was carefully removed by using the Arkansas stone on the face side of the knife.

Table 5 indicates the knives by number. The stone used to produce the finish on the back bevel is listed. The surface finish in microinches RMS was determined by using a profilometer with the stylus movement perpendicular to the sharpening scratches.

Each knife edge was tested by the plastic strip sharpness test described previously. The average pounds of force required to break the ¼-inch wide plastic strip are listed in the table.

Table 5 also gives the average maximum force component parallel to the cutting plane for each knife tested. Fig. 45 depicts variations of $F_p$ with depth of cut for the three sharpening conditions.

There is little difference between the cutting edges produced by these three sharpening methods. This agrees with the plastic strip test (Table 5). These tests indicated that knives carefully sharpened on an Arkansas stone will give constant sharpness effect.

Experience demonstrated the need for considerable care to avoid producing a delicate wire edge which may bend over in cutting, giving the effect of a very dull knife.
Fig. 45—Comparative sharpness of knives No. 5, 14, and 3, described in Table 5. Relationship of the parallel force component $F_p$, to depth of cut for constant knife angles with cottonwood.
### TABLE 5

**THE EFFECT OF KNIFE SHARPNESS ON THE RELATIONSHIP OF THE PARALLEL FORCE COMPONENT TO THE DEPTH OF CUT IN SUGAR PINE, COTTONWOOD, AND SILVER MAPLE ABOVE THE FIBER SATURATION POINT**

(cutting angle, $64^\circ$; clearance angle, $1^\circ$ to $10^\circ$ 30')

<table>
<thead>
<tr>
<th>Plastic Finish</th>
<th>Stone used in finishing</th>
<th>Depth of cut (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knife stri? o! face</td>
<td>Knife face</td>
<td>back</td>
</tr>
<tr>
<td>lbs.</td>
<td>Sampling method A</td>
<td>Cottonwood</td>
</tr>
<tr>
<td>5</td>
<td>3.2</td>
<td>5</td>
</tr>
<tr>
<td>14</td>
<td>3.2</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>3.1</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampling method B</th>
<th>Cottonwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>5F 3.1 5</td>
<td>Fine</td>
</tr>
<tr>
<td>6E 2.2 10</td>
<td>Medium</td>
</tr>
<tr>
<td>13B 3.5 20</td>
<td>Coarse</td>
</tr>
<tr>
<td>14C 5.6 5</td>
<td>Dulled by use</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Silver maple</th>
</tr>
</thead>
<tbody>
<tr>
<td>5F 3.1 5</td>
</tr>
<tr>
<td>6E 2.2 10</td>
</tr>
<tr>
<td>13B 3.5 20</td>
</tr>
<tr>
<td>14C 5.6 5</td>
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<tr>
<th>Sugar pine</th>
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<tbody>
<tr>
<td>5F 3.1 5</td>
</tr>
<tr>
<td>6E 2.2 10</td>
</tr>
<tr>
<td>13B 3.5 20</td>
</tr>
<tr>
<td>14C 5.6 5</td>
</tr>
</tbody>
</table>

1/ Pounds forces required to cause failure of a plastic test strip as described in the text.

2/ Root-mean-square roughness measured by moving the stylus of the profilometer perpendicular to the sharpening scratches.

3/ **Fine = Arkansas hard stone**
   Medium = Silicon Carbide stone of approximately 280 grit.
   Coarse = Silicon Carbide stone of approximately 100 grit.
   Dulled by use = Sharp knife used to cut 100 feet of sycamore and 500 feet of oak shavings when cutting air-dry wood parallel to the grain.

#### SECOND TEST SERIES

Green sugar pine, cottonwood, and silver maple were used in a second series of sharpness tests. The cutting plane was at an angle to the growth rings as in sampling method B. Three replications of a special thickness series of 0.020 to 0.040 inch at intervals of 0.005 inch were cut for each sharpness condition. Three knives were sharpened with a graduating series of grit sizes (Table
5). The front and back of any one knife was sharpened with the same grit size so the scratches intersecting at the cutting edge were of the same average size. This would produce a somewhat different ultimate cutting edge compared to the sharpening method of the first series of sharpness tests.

Also included in this test was a knife which was carefully sharpened and then dulled by cutting approximately 100 feet of sycamore shavings and 500 feet of oak shavings, planing parallel to the grain with the wood at 10 percent moisture content.

Table 5 summarizes the sharpening conditions for each knife and gives its classification by the plastic strip sharpness test.

To show the characteristics of the cutting edge, photomicrographs were taken of the knife from three different aspects: (1) a plane view of the back, (2) a plane view of the front, (3) an edge view, as previously described under the section of sharpening methods. The photomicrographs are shown in Figs. 46, 47, 48 and 49.

The relationship of the force component $F_p$ to the depth of cut for each knife is shown in Figs. 50, 51, and 52. Data from which these curves were drawn are in Table 5. Because a single maximum for the cut was erratic with the dull knives, a median of the high points for the cut was estimated and used for the comparison of sharpness. This gives slightly lower forces than in previous tests.

The roughness of the surfaces generated by the 0.020 and 0.035-inch depth of cut is illustrated in Figs. 53 and 54. These matched surfaces were photographed while illuminated by a constant low angle incident light projected through a slit to accentuate the irregularities. The technique was similar to the high-light method described by Elmendorf and Vaughn (3).

Results of the force measurements show a relatively constant slope for the different knives. This indicates there is little difference in the force required to deform the chip behind the cutting edge. The forces $F_{pf}$ and $F_{nf}$ may therefore be considered independent of the characteristics of the ultimate cutting edge.

The difference in magnitude which is relatively constant between any two curves is attributed to the variation of the severance force $F_{ss}$ acting parallel to the cutting plane.

There is an evident greater effect of dulling on severance forces in silver maple than in cottonwood or sugar pine. Of the three woods, sugar pine is most sensitive to the coarsely sharpened knife 13B.

Of particular interest is the observation that knife 6E appears to have approximately the same severance force as the supposedly sharper knife 5F. Results of the plastic strip sharpness tests in Table 5 show knife 6E to be sharper. This was at first thought to be an erroneous result. However, the force measurements mentioned above and the study of the chip surfaces in Figs. 53 and 54 indicate knife 6E to be as good or better than 5F in its severance quality.
Fig. 46—Knife 5F, face and back finished to 5 microinches RMS.: A, Edge view. B, Back side, C, Face side.
Fig. 47—Knife 6E, face and back finished to 10 microinches RMS: A, Edge view, B, Back side, C, Face side.
Fig. 48—Knife 13B, face and back finished to 20 microinches RHS: A. Edge view. B. Back side, C. Face side.
Fig. 49—Knife 14C, face and back finished to 5 microinches RMS; the edge was then dulled by use: A, Edge view. B. Back side. C. Face side.
Fig. 50—Comparative sharpness of the four knives, No. 5F, 6E, 13B, and 14C, described in Table 5. Relationship of the parallel force component $F_p$, to the depth of cut for constant knife angles with cottonwood.
Fig. 51—Comparative sharpness of the four knives, No. 5F, 6E, 13B, and 14C, described in Table 5. Relationship of the parallel force component $F_p$, to the depth of cut for constant knife angles with silver maple.
Fig. 52—Comparative sharpness of the four knives, No. 5F, 6E, 13B, and 14C, described in Table 5. Relationship of the parallel force component \( F_p \), to depth of cut for constant knife angles with sugar pine.
Fig. 53—Surfaces generated by an 0.020 in. depth of cut; (F) The surface of the chip which passed over the face of the knife. (B) The surface of the workpiece which passed under the knife.
Fig. 54—Surfaces generated by an 0.035 in. depth of cut. (F) The surface of the chip which passed over the face of the knife. (B) The surface of the workpiece which passed under the knife.
There are two possible reasons for this. One is that knife 5F may have been sharpened to such a fine edge that there was an undetected bending or loss of edge in cutting. The other possibility is that the fine points produced on the edge of knife 6E by the intersection of the scratches on the front and back, gave fine points of stress concentration against the plastic strip or the delicate cell wall of a wood such as sugar pine. Additional study is needed before drawing conclusions.

Observational Study

A study of the cutting action for the knives in the sharpness tests made it possible to see how separation of the chip from the workpiece was affected by the condition of the cutting edge. Doubling the magnification in certain cases gave a clearer view of the failure at the cutting edge. The study of motion pictures of the action and general observation during the cutting operation confirmed results of the force measurements discussed in the previous section.

Knives 5F and 6E showed no detectable difference in cutting action. Both knives severed the cells without generating significant compression of the wood structure at the cutting edge. This is evident in Fig. 55.

Knife 13B had a definite tendency to compress the cells ahead of it and show poor severance characteristics. This frequently resulted in compression tearing; particularly in sugar pine and cottonwood as shown in Figs. 56A and 56B.

Fig. 55—Sharp knife 5F cutting sugar pine.
Fig. 56—Compression tearing due to resistance to severance. A, Knife 13B in sugar pine. B, Knife 13B in cottonwood. C, Knife 14C in cottonwood.
Knife 14C showed evidence of its dull condition by developing a continual series of pronounced compression tearings as in Fig. 56C, and as previously shown in Fig. 38.

For the duller knives, the resistance to severance results in the cells wrapping themselves around the edge of the knife. This may be looked upon as a gross shear strain with the compressed cells being put in tension and then rupturing slightly behind the cutting edge. This same action on a smaller scale is evident above the cutting plane of a sharp knife in Fig. 57.

Somewhat different from this is the development of fine failure cracks (Fig. 58A) extending from the cutting edge to the upper left where they connect with the two celled pore multiple. These irregular lines of failure open up in Fig. 58C to give the appearance of a small compression tear. In this case, although the failure appeared to have originated behind the cutting edge, it was actually initiated as the fine failure cracks which developed ahead of the cutting edge in Fig. 58A.

With a sharp knife, as in Fig. 55, each cell in the cutting plane appears to be compressed individually; and before additional cells are involved, it fails. The movement of cells past the cutting edge would result in a shear action. Whether the wall of the individual cells in the cutting plane fails as a direct result of tension or shear cannot be seen at this magnification. Some insight into this is possible if we can see where the failure occurs in the cell wall. This is discussed in the next section.
Fig. 57—Sharp knife 5F cutting cottonwood, showing failure of cell walls of pores by tension over cutting edge.
Fig. 58—Sharp knife 5F in cottonwood; tension and shear forces produce small failure as start of compression tearing just behind the cutting edge.
Cell Wall Failure

To determine where the cell wall fails when the chip is separated from the workpiece, special series of blocks were prepared for the three woods. The cross section was surfaced with a microtome as in previous tests. Using knife 5F, series of chip thicknesses from 0.01 to 0.04 inch were cut. Velocities of 2.54 and 10.16 inches per minute were used in different thickness series to determine any effect of cutting velocity. The cuts were left incomplete so the chip was not entirely separated from the workpiece. In this way all cuts were kept in their proper relationship.

The cross section surfaces were examined with a stereoscopic microscope, and with a Leitz Ortholux microscope which had Ultrapak illumination. It was evident that in preparation of the block the cutting of the cross section surface by either the saw or the microtome knife had caused failure between many cells at the middle lamella. This could lead to erroneous conclusions. To eliminate this error, the blocks were embedded in paraffin and again surfaced. This was done by taking thin sections with a sharp microtome knife until a depth of 2 to 3 mm. had been removed. The paraffin was then extracted and the blocks were examined. Figs. 59, 60, 61, and 62 are samples of the observations made.

Two types of failure occurred in the cell wall due to severance by the cutting edge: (1) rupture of the cell wall perpendicular to its surface, and (2) separation of cells at the middle lamella.

A definite change occurs in the type of failure in the cell wall of sugar pine as the depth of cut is increased from 0.01 to 0.04 inch. Fig. 59A shows results of a 0.01 inch depth of cut with a sharp knife. The cells were severed cleanly in the path of the cut. Most of the cells ruptured perpendicular to the wall. When the failure occurred along the middle lamella, it was because the path of the knife coincided with it. At the 0.04 inch chip thickness (Fig. 59B) a definite tearing of the wood structure was noted with considerable separation of cell walls at the middle lamella. Both types of failures can be seen together in Fig. 60A.

Fig. 60B shows compression tearing where small groups of cells pulled out of the surface, which is above the cutting plane. The separation in such cases is along the middle lamella. A similar failure can be seen for silver maple at the upper left of Fig. 61A and in Fig. 62A.

The surface produced by the 0.04 inch depth of cut in silver maple is shown at the top of Fig. 61A. This cut is more irregular than the surface produced by the 0.01 inch depth of cut just below it.

As can be seen in Fig. 61B, cottonwood showed less difference in roughness between the thick and thin chip than sugar pine and silver maple.

The higher magnification views of cottonwood (Fig. 62B) had some points where cells were pulled out of the surface by separation of the middle lamella. For the most part, however, the cells which passed under the knife (below the cut) gave the appearance of having been sheared off.
Fig. 59—Cut with sharp knife in sugar pine showing difference in cell failure with different depth of cut. (125X): $A, t_1 = 0.01$ in. $B, t_1 = 0.03$ in.
Fig. 60—Cut with a sharp knife in sugar pine: A, Showing the two types of cell wall failure, $t_1 = 0.02$ in., (250X). B, Compression tearing with failure in middle lamella, $t_1 = 0.04$ in. (125X).
Fig. 61—Cuts with sharp knife to compare regularity of the surface for $t_1 = 0.01$ in. and 0.04 in., with cut for $t_1 = 0.04$ in. at the top of each photograph, (125X): A, Silver maple, showing a difference in the regularity of the surface for the two cuts. B,
Fig. 62—Cuts with sharp knife showing cell wall failure, (250X). A, Silver maple, $t_1 = 0.04$ in. B, Cottonwood, $t_{11} = 0.01$ in.
Microsharpening

The microsharpening method described by Kivimaa (12) allows an increase of the sharpness angle to produce a sturdier cutting edge without making it necessary to decrease the cutting angle an equal amount. Tests were made to determine the effectiveness of this method and to measure its influence on the cutting action.

Fig. 63 shows the geometry of the four test knives. Since knives C and D were changes made on Knife A, the coefficient of friction on the face can be considered constant. The micro back bevel of 0.02 mm. width was produced by lightly honing the back of the knife with a hard Arkansas stone while it was held at an exact honing angle by the sharpening jig. The light honing did not tend to produce a wire edge. To eliminate all possibility of wire edge development, the face and back were honed alternately a few light strokes at a time; the face was honed with the stone in a flat position.

Results of these tests are given in Table 6 with the resulting curves in Figs. 64 through 66. Microscopic examination of these knives showed that they had the same sharp edge as knife 5F in Fig. 46.

Note the cutting action in Fig. 67 shows practically no compression ahead of the cutting edge of the microsharpened knife. The lack of compression tearing resulted in veneer surfaces as good or better than those for knives 5F and 6E in Figs. 53 and 54. Silver maple was cut particularly smooth by the microsharpened knives.

During the cut it was noticed that a depression of cells under the micro bevel appeared to increase the tension on the cells in front of the cutting edge. This tension due to deflection by both the face and back of the knife appears to aid the severance action.

The force measurements indicated that microsharpening reduced the severance force \( F_{ps} \). To determine this, the forces on knife A were compared with those on knife C or D. The severance force for knife A can be estimated by extrapolation from the curves in Figs. 21 and 23, Then the force \( F_{pf} \) can be determined from the formula:

\[
F_p = F_{pf} + F_{ps}
\]

As component \( F_{nh} \) is zero for this knife:

\[
F_n = F_{nf}
\]

The cutting angle and coefficient of friction of the face are constant for knives A, C, and D (Fig. 63). It can therefore be assumed that \( F_{nf} \) and \( F_{nf} \) do not change between knives.

When considering the microsharpened knives, the components \( F_{pb} \) and \( F_{nb} \) must be considered. The relationship for knives C and D would be:

\[
F_p = F_{pf} + F_{pb} + F_{ps}
F_n = F_{nf} + F_{nb}
\]

If \( F_{pf} \) and \( F_{nf} \) from knife A, and \( F_p \) and \( F_n \) for knife C or D are known the quantities \( (F_{pb} + F_{ps}) \) and \( F_{nb} \) can be calculated. This is illustrated by geo-
Fig. 63—Knife geometry for microsharpening tests: A and B, Regular sharpening. C and D, Microsharpening.
TABLE 6
COMPARISON OF MICROSHARPENING TO REGULAR SHARPENING BY THEIR EFFECT ON THE RELATIONSHIP OF THE NORMAL AND PARALLEL FORCE COMPONENTS TO DEPTH OF CUT IN SATURATED SUGAR PINE, COTTONWOOD, AND SILVER MAPLE

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<th>Grinding angle</th>
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<td>( \beta' )</td>
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<td>15°</td>
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Depth of cut, (inches)

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SILVER MAPLE

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SUGAR PINE

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Fig. 64—Microsharpening compared to regular sharpening for cottonwood. Parallel force component $F_p$ and normal force component $F_n$ are plotted against depth of cut for knives A, B, C, and D described in Table 6.
Fig. 65—Microsharpening compared to regular sharpening for silver maple. Parallel force component $F_p$ and normal force component $F_n$ are plotted against depth cut for knives A, B, C, and D, described in Table 6.
Fig. 66—Microsharpening compared to regular sharpening for sugar pine. Parallel force component $F_p$ and normal force component $F_n$ are plotted against depth of cut for knives B, C, and D, described in Table 6.
Fig. 67—Microsharpened knives as described in Table 6 and shown in Fig. 63: A, Knife C in sugar pine. B, Knife D in cottonwood.
Fig. 68—Determination of the reduction of the severance force $F_{ps}$, due to micro-sharpening the knife; for green cottonwood at 0.03 in. depth of cut with a 75 degree cutting angle. Forces are in pounds per inch width of cut.

**Knife A**

$\beta' = \beta = 15^\circ$

- $F_n = F_{nf} = -11.6$
- $F_p = 16.1$
- $F_{ps} = 5$ estimated from graphs
- $F_{pf} = 11.1$

**Knife D**

$\beta' = 15^\circ \quad \beta = 25^\circ$

- $F_n = -2.3$
- $F_p = 12.8$
- $F_{pf} = 11.1$
- $F_{nf} = -11.6$
- $F_{ps} + F_{pb} = 1.7$
metric construction in Fig. 68 for an 0.03 inch depth of cut in cottonwood. If the assumed constant condition for $F_p$ and $F_n$ is correct, the severance force $F_p$ has been reduced considerably.

The microsharpening method increases the strength of the cutting edge by increasing the sharpness angle. At the same time the cutting angle can be maximum to increase the possibility of producing continuous veneer. The stresses on the knife are more balanced by $F_n$ approaching zero. The parallel force component $F_p$ is reduced such that less power is required for the cutting action. The microsharpening technique will also produce a very sharp knife with a minimum tendency for the formation of a delicate wire edge; such an edge can be very troublesome.

There is an obvious need for a more complete study of this sharpening method.

**Friction Test**

To determine if slight variations of surface toughness of the knife face could significantly affect the results of the force measurements, a special test of friction was carried out. Two silver maple blocks were prepared, as closely matched as possible longitudinally, each containing the same rings. For one, a series of 17 cuts of 0.03-inch depth were made with knife 5F (which was used in the sharpness study). The surface finish on the face of this knife was approximately 5 microinches RMS with the scratches running perpendicular to the cutting edge.

The surface finish of the knife was then changed both in roughness and direction of the sharpening scratches. Using a course stone while carefully protecting the cutting edge, a surface finish of approximately 25 microinches RMS was produced to within 0.5 mm. of the cutting edge. These rough scratches made by the course stone were aligned parallel to the cutting edge.

Using this knife, a duplicate series of 17 cuts was then made in the matched block. The results are in Table 7:

<table>
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<tr>
<th>Knife</th>
<th>Surface finish RMS 1/</th>
<th>Average pounds per inch width of cut</th>
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<td>5</td>
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</tr>
<tr>
<td>5F-X</td>
<td>25 2/</td>
<td>16.6</td>
<td>10.2</td>
</tr>
</tbody>
</table>

1/ Root-mean-square roughness measured by moving the stylus of the profilometer perpendicular to the sharpness scratches.

2/ To within 0.5 mm. of the cutting edge.
Differences of both $F_p$ and $F_n$ are significant at the 1 percent level. The amount of difference would introduce a 9 percent error in the results of $F_n$. However, such a relatively small amount of change for the large difference in surface finish indicates that the error due to slight differences in roughness of knives used in this study is small for surfaces which are 0.5 mm. or more from the cutting edge.

**Variations of Veneer Thickness**

A controlled test was made to determine the cause and amount of variation in chip thickness. A series of 0.02 to 0.04 inch cuts were made at intervals of 0.01 inch in cottonwood with a cutting angle of 65 degrees.

The relative position of the top of the workpiece (block) was indicated by a dial micrometer after each cut. In this way any variation of the depth of cut due to movement of the knife or block could be determined. The deviation from the zero position when added to the machine setting for depth of cut $t_1$ gave a corrected depth of cut $t'_1$. The difference between this and the measured thickness $t_2$ of the freshly cut chip, showed the part of the chip thickness which was due to deformation of the wood structure caused by the cutting action. This $(t_2 - t'_1)$ was between 0.001 and 0.002 inch, while the variation due to movement of the knife or workpiece $(t'_1 - t_1)$ was with few exceptions less than 0.0005 inch for these tests. Error in the data due to this source is approximately 1 percent.

The part of the chip thickness due to deformation of the wood structure is attributed to generated roughness of the surface, which has been discussed previously. There appears to be no thickness increase due to deformation in shear as described for metal cutting (5).

No study was made on the effect of the nosebar on chip thickness at this time.

**Accuracy of Measurements**

The dynamometer and recording equipment worked satisfactorily with no significant error within the range in which they were used.

The knife was an important possible source of error. Care taken in the sharpening procedure successfully minimized errors in the principal cutting tests except for the 15-degree sharpness angle in sugar pine. The result for this knife was deleted from the data because discrepancies attributed to a slight bending of the cutting edge, producing a pseudonegative clearance effect. A lack of adequate matched sample material prevented a repeat of the test.

For the initial cottonwood study (Fig. 18), the difference in the intercept gives the appearance of being due to difference in knife sharpness. When corrected for this difference, the pattern of the curves more closely approaches the results for cottonwood in the principal cutting tests (Fig. 21).
The effect of any possible variation in the surface finish on the knife face was shown to be considered negligible. Variation of depth of cut compared to the machine setting also was too small to affect the results significantly.

Main source of variation in the data was differences in the sample material. Variability due to differences both between rings and within the ring was unavoidable when cutting parallel to the rings. Use of a sample size of 14 cuts for each condition tested in the initial cottonwood study was an attempt to reduce the effect of this variability by approaching a large sample size. Further testing showed it was more practical to keep sampling small and reduce the variation by close matching of the test blocks. Having each cut pass through the ringline (Fig. 16A) greatly reduced the variability within the ring. Only differences between rings remained. This was much less than differences within the ring for cottonwood.

Variability of the data increased with an increase in depth of cut. With few exceptions, the deviation of measurements from the mean was between 0 and 2 pounds for forces of 30 to 40 pounds. For the objectives of this study it was considered that this relatively small variation indicated that special statistical treatment beyond the calculation of the mean would add little of value for the objectives of this study.

**Stresses at Knife Edge**

The results show that the mechanism of veneer formation is complex. The continually changing conditions complicate analysis. Obvious localized areas of plastic deformation in compression make any attempt at a mathematical treatment difficult. This precludes strict application of the theory of elasticity. However, the strains and failures visible in the photographs afford some conclusions concerning the general stress patterns.

Stress components acting in the vicinity of the cutting edge are expressed diagramatically in Fig. 69. As shown previously in Fig. 17 the compression \( N \), normal to the face of the knife, produces friction \( F \), which resists the movement of the veneer up the knife. Stress due to the resultant force \( R \) can be resolved into compressive stress components \( C_1 \) and \( C_2 \), acting in the direction of the \( x \) and \( y \) axes. The tension stress \( T_1 \), produced by the moment \( M \), is opposed by the compressive stress \( C_1 \). As the wood is not severed ahead of the cutting edge, compressive stress \( C_2 \) produces tension stress \( T_2 \). The compression \( C_3 \) which acts at the cutting plane immediately ahead of the cutting edge, is considered to be the severance force. The magnitude of these stress components depends upon the strength of the wood, veneer thickness, cutting angle, knife sharpness, and the frictional resistance at the face of the knife.

It is evident in Fig. 69A that a point at or just above the cutting edge is in a shear stress field due to the abrupt change of stresses. The resulting shear stresses in the \( xy \) plane are shown in Fig. 69B as acting on the sides of an elementary parallelepiped. Normal stress \( \sigma_y \) is equal to the tension \( T_2 \). As the
Fig. 69—Estimated stress patterns for a point above the cutting plane at the cutting edge as described in the text.
normal stress \( \sigma_x \) is equal to the difference between \( T_1 \) and \( C_1 \), it may represent either compression or tension depending up the conditions of the cut as they affect the relative values of \( T_1 \) and \( C_1 \). Due to \( C_3 \), \( \sigma_x \) is compressive at a point directly in front of the cutting edge.

If, for the above mentioned qualitative shear pattern, \( \sigma_x \) is less than \( \sigma_y \), the maximum tension stress can be expected to be more than 45 but less than 90 degrees to the cutting plane. This agrees with the general direction of principal stresses, as estimated from the study of the motion pictures. Maximum tension \( T \) is considered to act perpendicular to the maximum compression (minimum tension) \( C \), and 45 degrees to the maximum shear stress \( S \). This stress pattern indicates why the initial tension failure in the formation of tension checks occurred at an angle to the cutting plane rather than parallel to it.

The change of direction of the tension check as it opens is attributed to a change in the magnitude of the components of force contributing to the resultant maximum tensile stress. As the rupture develops, the decrease of compression \( C_2 \) immediately behind the cutting edge will reduce \( T_2 \). At the same time \( T_1 \) will tend to increase due to the reduction of \( C_1 \) and the increase of the lever arm producing moment \( M \). This change of stresses causes the rotation of the resultant maximum tensile stress, which acts increasingly in a direction more parallel to the cutting plane as the lathe check enlarges.

As the veneer chip passes behind the cutting edge, there is a change of stresses. The high compressive stress perpendicular to the face of the knife and the tension which results from deflection of the chip as a beam is estimated to result in a stress pattern approximately as in Fig. 70A. The direction of maximum shear stress is in line with the shear slip planes observed in Fig. 30 and 36.

At the cutting edge, just below the cutting plane, the shear stress pattern is the reverse of that above the cutting plane. With the tension \( \sigma_y \) from \( T_1 \) of Fig. 69A, the estimated stress pattern which accounts for the severance of the cells is as shown in Fig. 70B. If \( \sigma_y \) is small or if a tension stress is established in the \( x \) direction due to compression at the cutting edge, the principal stresses would be rotated counterclockwise. This is the case when compression tearing occurs. The angle of the maximum tension stress at that time would account for the tension failure just behind the cutting edge as shown in Fig. 56.
Fig. 70—Estimated stress patterns: A, At the point of maximum compression behind the cutting edge. B, Below the cutting plane at the cutting edge. Depths of cut were small, no general conclusions should be considered at this time.
SUMMARY AND CONCLUSIONS

This research was prompted by the general lack of information about the mechanism of veneer formation. The purpose of the study was to determine what happens at the edge of the knife when cutting wood by the orthogonal cutting method in the veneer direction. The specific objectives were: (1) to measure the forces on the wood, and (2) to observe the deformation of the cellular structure during the formation of the veneer chip from green wood. The forces parallel and perpendicular to the cutting plane were measured by a strain gage dynamometer while the changes in the wood structure were observed through a stereoscopic microscope. Motion pictures were taken of certain conditions of sufficient magnification to see and measure strains which occurred at or just behind the cutting edge.

The first series of tests were designed to show the effect of knife angle and chip thickness on the cutting forces and deformation of the wood structure in cottonwood, silver maple, and sugar pine. Chip thicknesses between 0.01 and 0.05 inch and nominal cutting angles between 55 and 75 degree were used.

At a zero clearance angle there was found to be a pseudonegative clearance effect which complicated the accurate measurement of the force component acting perpendicular to the cutting plane. The curves for the variation of cutting force to depth of cut are almost linear up to the point of wood failure. By extrapolation of the straight line portion of these curves the compressive force in the cutting plane directly ahead of the cutting edge (herein called severance force) was estimated as being between 5 and 7 pounds per inch of cutting edge for the woods tested when using a sharp knife.

The distinct difference between species is shown. The cutting properties of springwood and summerwood in cottonwood are compared.

Observational studies led to the conclusion that it is best to define one basic chip type produced by severance of cells by the cutting edge. Besides the basic severance action, three types of rupture which determine quality of the cut are defined. Tension check is due to tension stresses resulting from combination of cantilever beam action, compression just behind the cutting edge, and shear stresses caused by the cutting edge resisting the movement of the wood. Shear checks form behind the cutting edge when high compressive stresses combined with resulting friction resist the movement of the chip up the knife. Compression tearing was attributed to a dull knife resisting the movement of the wood past the cutting edge. These failures are all closely related and often appear in combinations. Which types of failure occur is dependant upon the balance of stresses for the particular conditions of the cut.

The shear check is indistinct and not easily detected. This type failure may not always form a complete rupture. The tension check separates the wood structure while under stress, but closes when the stresses are released. Compression tearing by itself or in combination with tension checks causes disruption of
the wood structure by peeling groups of cells out of the veneer surface. The tension and shear checks weaken the veneer in tension perpendicular to the grain. The compression tearing alone or in combination with tension check is the main cause of veneer roughness.

Depth of cut has no effect upon the basic chip type, but as the chip thickness increases, there is a shift in the center of rotation from the cutting edge toward the midpoint of the chip.

Decrease in the cutting angle increases the rate of compressive deformation behind the cutting edge, and increases the tendency to shear check formation. The resulting desirability of a large cutting angle is clear. However, the difficulty in maintaining a cutting edge on a knife of small sharpness angle was a distinct problem.

By compressing the surface of the wood in a direction parallel to the cutting plane, the solid type nosebar was seen to assist the rotation of the wood structure between the nosebar and the knife. This reduces tension stress which results from the moment caused by deflection of the chip. Defects resulting from overcompression or sudden release behind the conventional solid nosebar are illustrated. An experimental double-surfaced nosebar proved successful in reducing the latter defect by relieving the compression slowly as the chip moves up the face of the knife. The added control of the deflection of the chip by this nosebar appears to allow the formation of continuous veneer with a lower percentage compression of the wood. A more thorough study of this type solid nosebar design is needed.

The effect of knife sharpness on the force component parallel to the cutting plane was tested. The value of a sharp knife was evidenced by the difference in severance force and the observed disruption of cells on the veneer surface due to compression tearing by a dull knife. A knife sharpened to a fine edge on an Arkansas stone proved to have no better severance characteristics than one with sharpening scratches perpendicular to the cutting edge produced by a silica carbide stone of approximately 280 grit.

The difference in the appearance of the knife edges tested are shown by photomicrographs from three aspects.

At a magnification of 54X, enlargements from motion pictures of cottonwood showed tension failure of cell walls in what might be considered to result from a gross shearing action. It was also seen that ruptures which open behind the cutting edge may have been started as hairline failures when the cells were still in front of the cutting edge.

A study of the rupture of the cell walls under high magnification using Ultropak illumination showed two types of cell wall failure: (1) the separation of the cells at the middle lamella, and (2) the rupture of the wall perpendicular to its surface. There is a difference in the failure type with depth of cut. There was also evidence of rupture by shearing action.
The microsharpening technique of Kivimaa (12) was tested as a means of producing a sturdy cutting edge to be used with a large cutting angle. The brief negative clearance of the micro back bevel causes a double deflection of the wood structure to apparently assist the severance action. The measured reduction of severance force may reduce wear on the cutting edge. The need for further study of this sharpening method is clear.

In a limited test of friction, a knife face having a fine surface finish was roughened by producing course scratches parallel to the cutting edge and to within 0.05 mm. of the cutting edge. The roughening of the face surface resulted in a 9 percent increase in the cutting force parallel to the cutting plane for an 0.03 inch depth of cut. This is considered small for the difference in surface conditions tested. Observation of cutting action showed that compression of the wood structure is greatest at a distance from the cutting edge less than the chip thickness being cut. Apparently any pronounced effect of frictional properties on cutting forces will be within this area just behind the cutting edge. This is of particular concern in sharpening techniques.

A measurement of veneer thickness showed a slight variation in measured thickness from the machine setting. This difference is attributed to a minor compression tearing causing surface roughness which increases the average thickness measurement.

Because of the complexity of the changing conditions at different positions about the cutting edge, a mathematical analysis has not been attempted. By a searching study of strains visible at the cellular level in the enlargements of motion picture frames, the stress patterns about the knife edge have been estimated.
BIBLIOGRAPHY


