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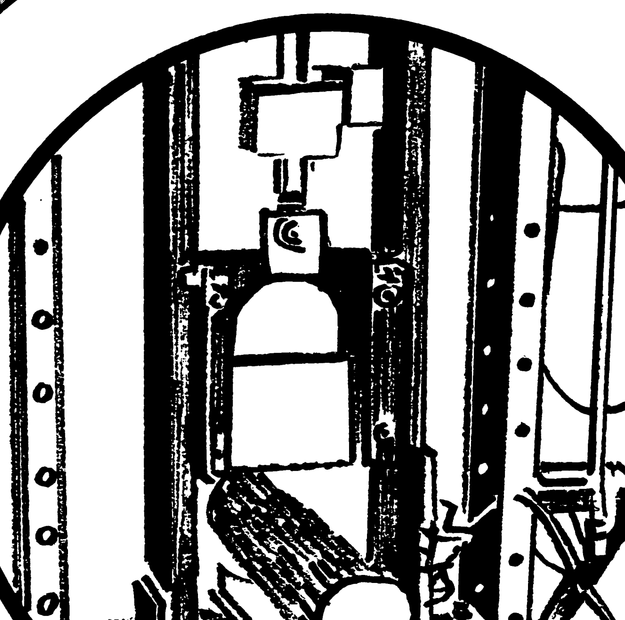
CROSSCUT SHEARING OF ROUNDWOOD BOLTS



NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE · U.S. DEPARTMENT OF AGRICULTURE

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CROSSCUT SHEARING OF ROUNDWOOD BOLTS

RODGER A. AROLA

SUMMARY

The objective of the study was to evaluate the variation in force requirements and splitting damage when shearing roundwood bolts up to approximately 10 inches in diameter. The species investigated were basswood, aspen, white spruce, yellow birch, and hard maple. Using a single-acting, ½-inch thick shear blade, three basic anvil designs were tested: (1) a deformable pad providing sample support immediately opposite the shear blade and permitting blade penetration, (2) the same deformable pad with additional exterior supports that restrained bending of the sample, and (3) a rigid anvil that conformed closely to the shape of the roundwood bolts, with an adjustable gap permitting blade side clearance. Twelve plain shear blades of varying thickness and bevel angle were tested in addition to tapered, guillotine, coated, very thin, and dull blades. The effects of wood temperature, specific gravity, and cutting speed were also investigated.

Anvil Design. — No discernible trends were noted in force required to shear unfrozen aspen or spruce with a single-acting shear blade against either a deformable anvil or contoured anvil with adjustable gap. However, with frozen wood (particularly aspen), the contoured anvil appeared to require less shearing force. Maximum splitting penetration in unfrozen aspen was approximately the same (slightly less than 2 inches) with both deformable anvils tested; therefore, restraining sample bending apparently was not beneficial. The rigid anvil resulted in slightly greater splitting damage in unfrozen aspen for all gaps tested whereas the least splitting penetration in frozen aspen was observed with the contoured anvil adjusted to a 1¼-inch blade side clearance. Splitting penetration in unfrozen spruce did not vary appreciably with the different anvils, and was erratic in frozen spruce. The deformable, flat, padded anvil frequently resulted in complete tearout of the spruce samples near the last one-quarter of the shear cut, as did the larger gap settings tested with the contoured anvil. When bending of the spruce samples was restrained by using exterior pads, more crushing of the fibers on the cut face, or "mushrooming," resulted. This was attributed to a greater normal pressure on the sides of the shear blade (also causing a slight increase in shearing force).

Blade Bevel (Plain Shear Blade Design). — Significant differences in shear force requirements were observed among individual blade bevels within the range of 20° to 50°, but consistent trends were not apparent. In the dense species (yellow birch and hard maple), the smaller blade bevel angles (20° and 30°) *appeared* to produce more gross splitting damage than the greater bevel angles (40° and 50°), but no trends defining the magnitude of maximum splitting penetration with bevel angle could be established. Predicted maximum splitting penetration occurred at a depth of cut to diameter ratio of approximately 0.75 for a single shear blade acting against an anvil.

Blade Thickness (Plain Shear Blade Design). — Blade thickness had a nonlinear effect on shear force requirements for the five species tested. The force required to shear hard maple increased 57 percent when blade thickness increased from ⅛ inch to ¼ inch, and 46 percent when blade thickness increased from ¼ inch to ½ inch. With basswood, the same increases in blade thickness increased shearing force 73 and 41 percent respectively. Percentage increases for species having densities intermediate to hard maple and basswood can be predicted. Splitting damage generally increased with increasing blade thickness; hard maple was the most sensitive. Maximum split length in hard maple was estimated at 2.5 inches per ⅛ inch of blade thickness. Spruce showed the least change in splitting damage with varying blade thickness.

Guillotine Shear Blades. — Guillotine shear blades, with the cutting edge obliquely inclined to the direction of cut, required less force to shear unfrozen aspen, spruce, and hard maple than a plain, straight-edged shear blade of equal thickness and bevel angle with the cutting edge orthogonal to the direction of cut. However, splitting damage in spruce and aspen increased with increasing guillotine angle.

Tapered Shear Blades. — Tapering the shear blade (—1° to +3° taper angles) did not greatly affect the force required to shear unfrozen aspen, spruce, or hard maple. (Shear blades were of equal thickness

across the bevel and bevel angle.) The shear blade that tapered positively at 3° from ½ inch across the bevel to ¾ inch in thickness resulted in greater splitting damage in aspen and spruce than the ½-inch untapered shear blade. The negatively tapered blade did not reduce splitting damage. Splitting penetration in hard maple sheared with either the negatively or positively tapered blade was severe, but comparable to that in maple sheared with the blade of constant thickness.

Coated Shear Blades. — Low-friction coatings applied to the shear blade surface resulted in significant reductions in shear force requirements for the five species tested, but did not reduce splitting damage. Force reductions in excess of 40 percent were recorded with some species. For all species and the two blade coatings investigated, the average force reduction was approximately 30 percent. Coating durability was a problem in the area of the blade bevel.

Thin Shear Blades. — The advantages of thin shear blades (⅛ and 3/16 inch) for reducing cutting force and splitting damage have already been summarized under blade thickness; however, the following items are also pertinent: very thin shear blades are extremely sensitive to lateral buckling due to the presence of compressive stresses within the plane of the blade. Attempts to improve the elastic stability of the blade by prestressing were only partially successful, due to the presence of compressive stresses in the chosen methods of prestressing and slight misalignment in the assembly containing the thin blades. A uniform tensioning prestress distribution would appear to be more desirable to avoid compressive stresses. With dense species, the cutting edge of very thin shear blades has a tendency to follow the path of least resistance (along the fiber lines), once the cutting edge deviates even slightly from orthogonal cutting of the fibers.

Physical Properties. — For a given blade thickness, specific gravity was found by an analysis of covariance to be the best single physical-property indicator of shear force requirements when the maximum shear force is put on a normalized pounds per maximum width of cut basis. Variations in shear force requirements within a species can also be expected due to natural variation in specific gravity. From linear regressions provided, the 95-percent upper confidence limits on a single estimate are recommended for estimating maximum shear force requirements for a given blade thickness. Specific gravity, moisture content, and bolt diameter, either treated singly or combined in an analysis of covariance, were generally not good predictors of splitting damage, except in the case of hard maple.

Dulling. — With unfrozen aspen, spruce, and yellow birch, dulling of plain and guillotine blades with flats up to 1/32 inch did not greatly increase shearing force. The largest increases in force, 20 and 30 percent, were observed when shearing aspen with dull plain and guillotine blades, respectively. Splitting damage in aspen and birch was generally greater with dull blades, and in spruce, extreme fracturing to the sheared face resulted.

Temperature. — Shearing force increased significantly with decreasing temperature. Compared with unfrozen wood (60° to 70° F.), wood frozen at about 0° F. required the following increases in shearing force with five different shear blades: aspen, 51 to 80 percent; spruce, 56 to 72 percent; and maple, 13 to 37 percent. As an approximate pooled estimate of the increase in force required to shear wood over any base value due to decreasing temperature, a unit value of 20 pounds per inch width of cut per °F. drop in temperature is recommended. Splitting also increased considerably with decreasing temperature.

Cutting Speed. — Cutting speeds varying between 2 inches per second and 12 inches per second did not affect shear force requirements with either coated or uncoated shear blades; however, power is a function of cutting speed. No relationships could be established between splitting damage and cutting speed.

INTRODUCTION

Numerous pulpwood harvesters employing shear blades were designed in the 1960's to fell, delimb, and buck trees. Many of the early prototypes were designed despite a lack of basic engineering information relating force and power requirements to shear blade design and other parameters. The "seat-of-the-pants" approach in prototype design adds to the final equipment cost necessary to recover total development costs, including second and third generation prototypes. Equipment manufacturers are still in need of reliable engineering data on crosscut shearing. In addition to force and energy, shear blade-induced damage is of vital concern. Pulpmills complain of crushed fibers on the sheared face (hindering penetration of pulping liquors) and excessive penetration of splits into the bole (causing too many oversize pulp chips). Shear blades are seldom used for felling sawtimber due to splitting damage.

To learn more about crosscut shearing of wood, a preliminary study was conducted by Erickson (1967, 1968a,b) in 1965. The study reported here was designed to extend and corroborate the results of this preliminary investigation. The primary objective was to evaluate and provide basic engineering data on the variation in force requirements and resultant splitting damage to roundwood bolts when sheared under different prescribed cutting conditions. The test species selected and their specific gravities are summarized below (table 1).

Table 1. — *Specific gravities*[1] *of the test species*

Species	Number of samples	Specific gravity Low	Specific gravity Mean	Specific gravity High	Standard deviation
Basswood (Tilia americana)	108	0.27	0.32	0.42	0.06
Aspen (Populus tremuloides)	312	.27	.38	.50	.04
White spruce (Picea mariana)	282	.27	.35	.43	.04
Yellow birch (Betula alleghaniensis)	156	.48	.55	.67	.03
Hard maple (Acer saccharum)	240	.53	.61	.68	.03

1/ Based on oven-dry weight, green volume.

The following basic anvil and shear blade designs were tested:

- Anvil design (fig. 1).
  - Deformable — flat pad support permitting shear blade penetration (anvils A and B).
  - Rigid — contoured support with adjustable gap permitting shear blade side-clearance (anvil C).
- Shear blade design (fig. 2).
  - Plain — constant thickness with double bevel and cutting edge at right angles to direction of cut (three thicknesses x four bevel angles).
  - Guillotine — constant thickness with double bevel and cutting edge obliquely inclined to direction of cut.
  - Tapered — variable thickness (increasing and decreasing) with double bevel and cutting edge at right angles to direction of cut.
  - Thin — same basic design as plain shear blade but very thin and sensitive to structural buckling (⅛- and 3/16-inch thickness.)
  - Coated — same basic design as plain shear blade but coated with low-friction material.

Various conditions and physical properties of the roundwood samples were also evaluated. These included specific gravity, moisture content, internal sample temperature at the time of shearing, cutting speed, and blade dulling. Except in tests designed to evaluate the effects of cutting speed and anvil design, a no-load cutting speed of 4.7 inches per second and a rigid anvil (fig. 1) with a 1.5-inch gap were used.

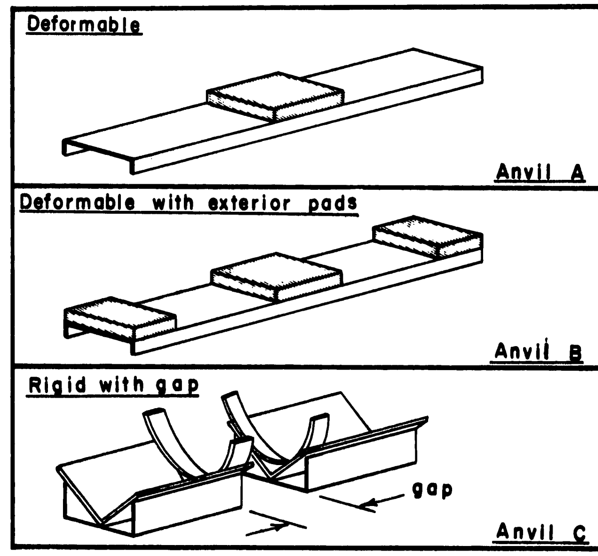

Figure 1. — *Anvil designs.*

EQUIPMENT

Shear Assembly. — The structural frame from a 25-ton hydraulic press was modified to suit the needs of this study (fig. 3). The original power package was replaced with a heavy-duty hydraulic cylinder having a 4-inch bore and 12-inch stroke. The shear blades were rigidly mounted in a U-shaped, roller-guided carriage. A load transducer was placed between the carriage and cylinder rod to measure shearing force. Axial loads were insured by providing a pin and spherical alignment bearing connection between the transducer and blade carriage.

Power Package. — A 45 g.p.m. hydraulic pump (@ 1,800 r.p.m.) driven by a 25 horsepower electric motor supplied power for cutting speeds between 2 and 12 inches per second (fig. 4). The system was designed to operate at a maximum pressure of 3,000 p.s.i.; thus, with the 4-inch bore on the hydraulic cylinder the maximum available cutting force was approximately 38,000 pounds.

Instrumentation. — The system designed was capable of continuously monitoring and graphically displaying the crosscut shearing force along with a measure of the area under the force-time curve (fig. 5a). The ring transducer, made from high-strength aluminum, was designed to measure shearing forces up to 40,000 pounds. Four 120-ohm, ¼-inch foil strain gages were mounted on the inside surface of the ring and arranged in a Wheatstone bridge (fig. 5b) to maximize the output. The maximum shearing force was extracted directly from one channel of a

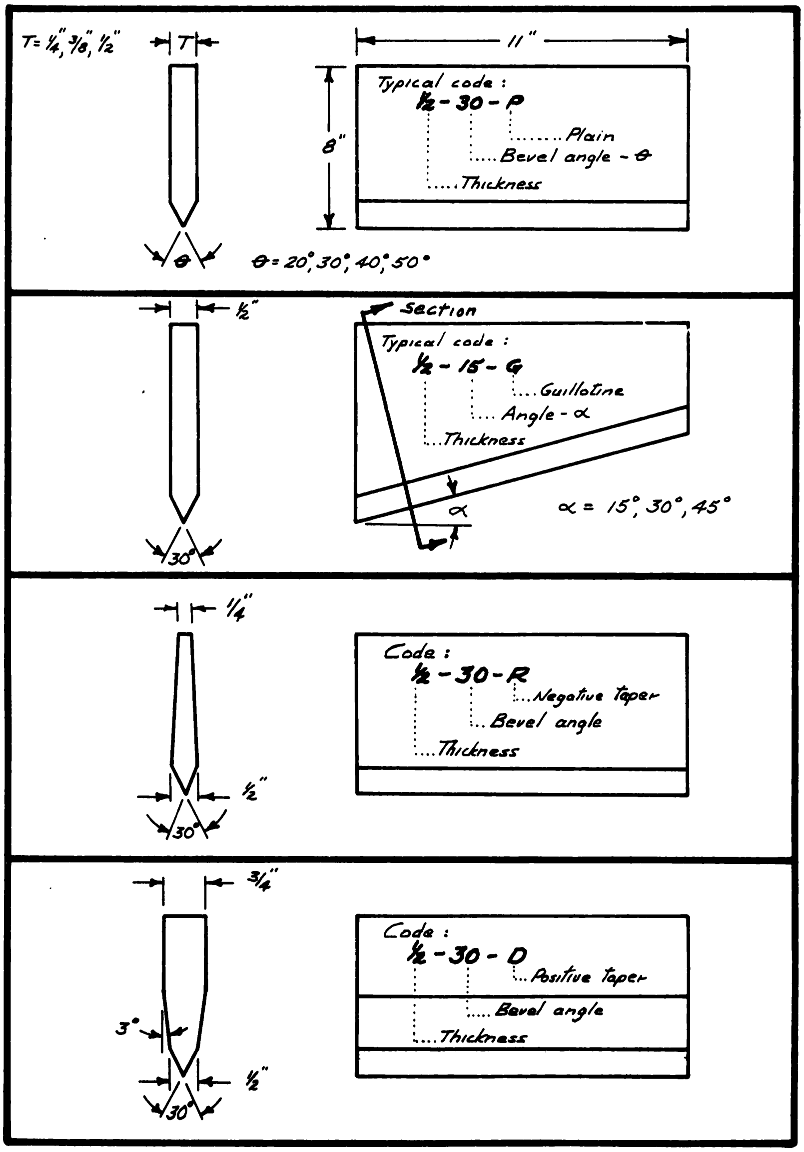

Figure 2. —*Shear blades and coding.*

dual channel strip chart oscillograph recorder. An analog computer circuit automatically determined the area under the force-time curve and this measure was displayed on the second channel of the recorder (fig. 5c). This area measure of the average power expended during the entire cut and was used to calculate the average force.

DATA COLLECTION

Data for this study included initial test conditions, sample measurements made before and after cutting, moisture content, specific gravity, wood temperature, and measurements extracted from the strip-chart recordings. All moisture content and specific gravity determinations were made on disks taken from near the sheared face and were in accordance with TAPPI Standard T18m-53. Data-reduction formulas were derived to coincide with the data extracted from the strip-chart recordings (fig. 6). Because of the cross-sectional irregularity of "roundwood" samples, three outside bark measurements were made: diameter (with diameter tape), maximum width of cut, and depth of cut. The internal sample temperature was determined immediately after cutting with a thermistor probe. Six shear cuts were made at each test level.

Maximum shearing force is reported in pounds per inch width of cut. This normalized value was de-

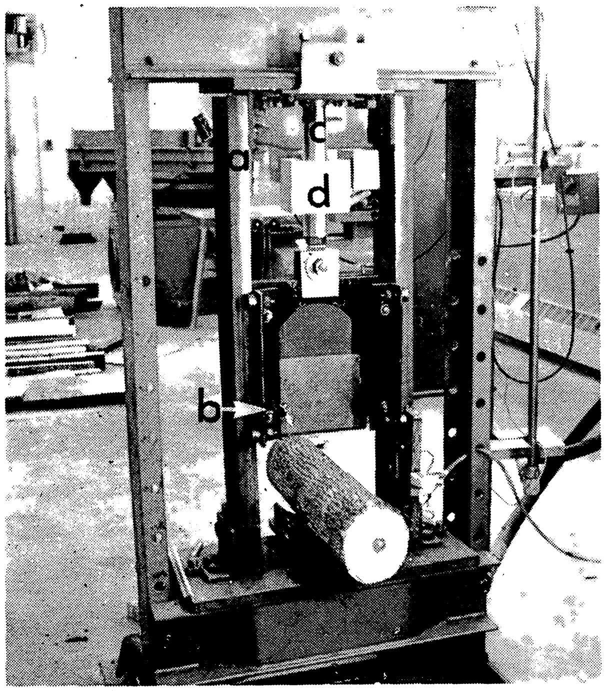

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Figure 3. — *Crosscut shearing assembly; (a) carriage guides, (b) knife carriage, (c) hydraulic cylinder, (d) ring transducer.*

rived by dividing the actual maximum shearing force, as calculated from the strip-chart recording, by the maximum width of cut in inches (outside bark) (fig. 6). For estimating or applied design purposes, the total force requirements for a given log size can be determined by multiplying the appropriate normalized value by the maximum width of cut (or sample diameter).

All sheared bolts were analyzed for splitting damage. This consisted of a measurement of the maximum split length and an "observed" average. The maximum split length is the longest crack penetrating into the bolt from the sheared face. The average split length is the measurement from the cut face to the point where the majority of splitting damage appeared to be concentrated.

Also, for several random samples of yellow birch and hard maple, the length and location of each split were recorded. The objective was to find out if characteristic splitting patterns could be detected due to variations in shear blade thickness and blade bevel. Each roundwood sample was sawed longitudinally through the center and at right angles to the laminar splits, sanded, stained, and the splits were measured.

The roundwood bolts were not all from clear logs. Because of cost and large sample requirements, it was necessary to utilize as much of the merchantable bole as possible. Subsequently, bolts having limbs removed could not be avoided. To lessen the effect of knots on splitting damage, the clearest section within the middle third of each sample was sheared, and the clearest half of the sheared bolt then analyzed for splitting damage. The effect of knots on shear force was not evaluated in this study. For most species, other than those characterized by large limbs, such as dense hardwoods, a power-package design for a felling shear based on the diameter at the root collar should generally be sufficient to effect bucking cuts at limb junctures.

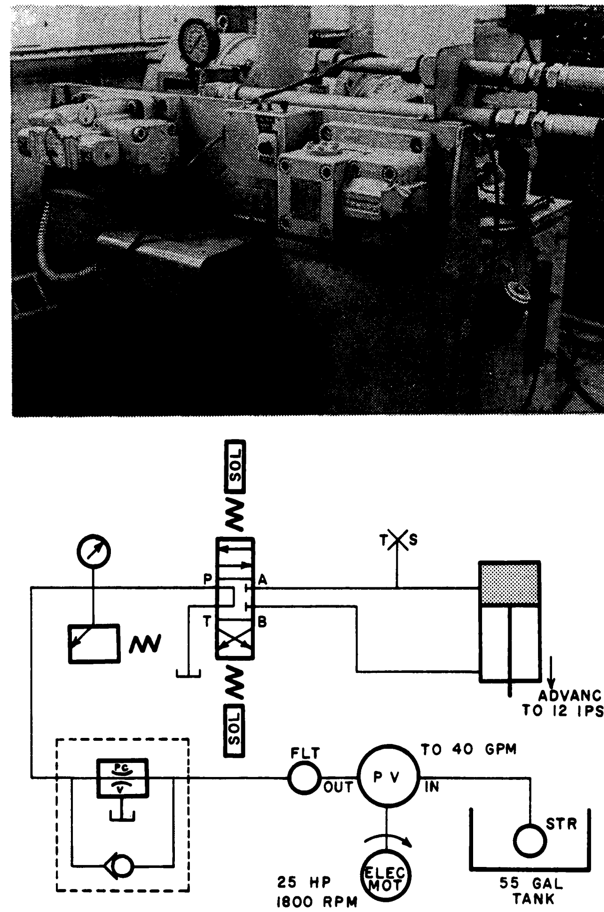

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Figure 4. — *Hydraulic power package and hydraulic circuit schematic.*

RESULTS

Anvil Design

The effects of three different anvil designs on the maximum crosscut shearing force and splitting damage for both unfrozen and frozen (23° to 32° F. internal wood temperature) aspen and spruce were

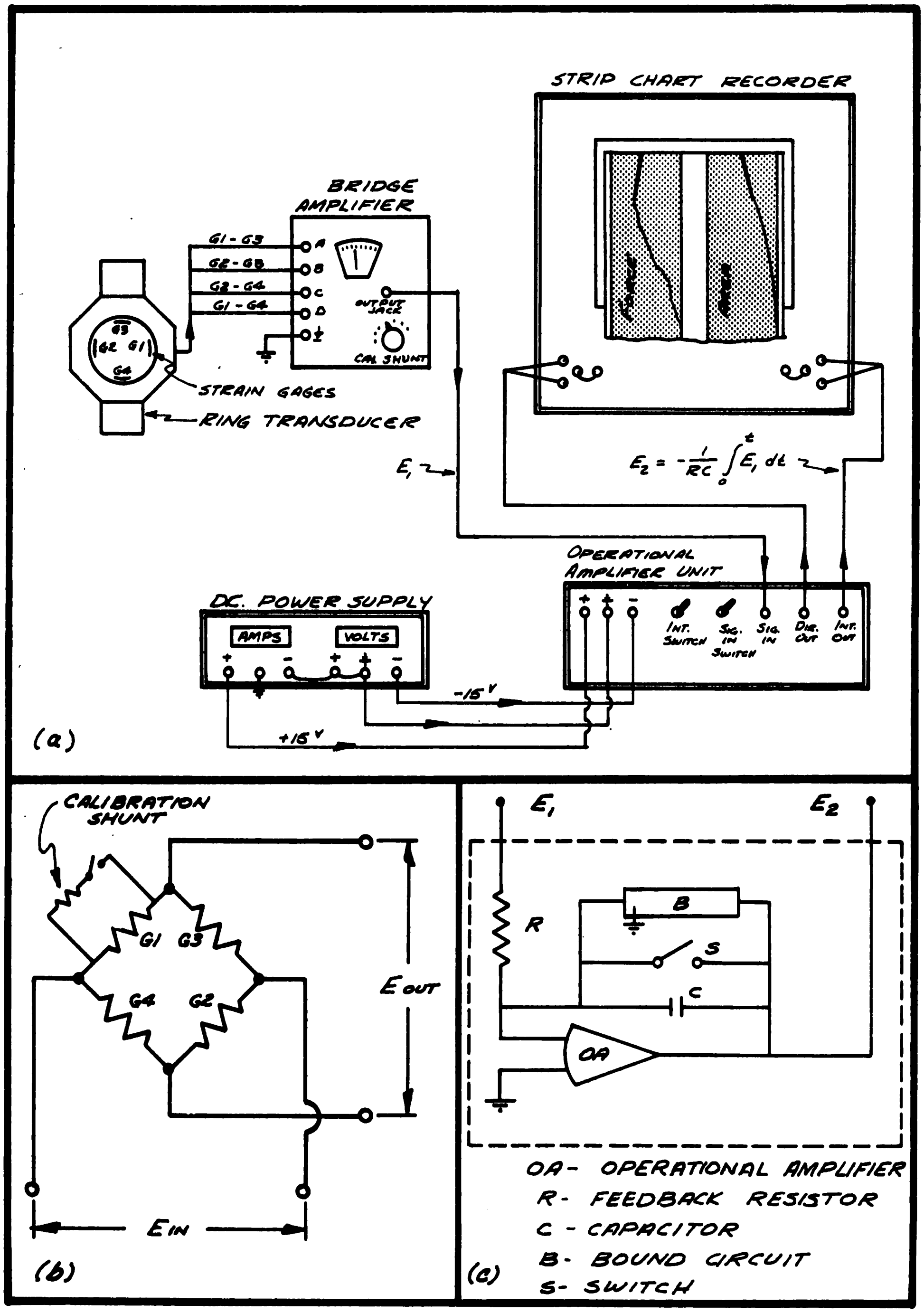
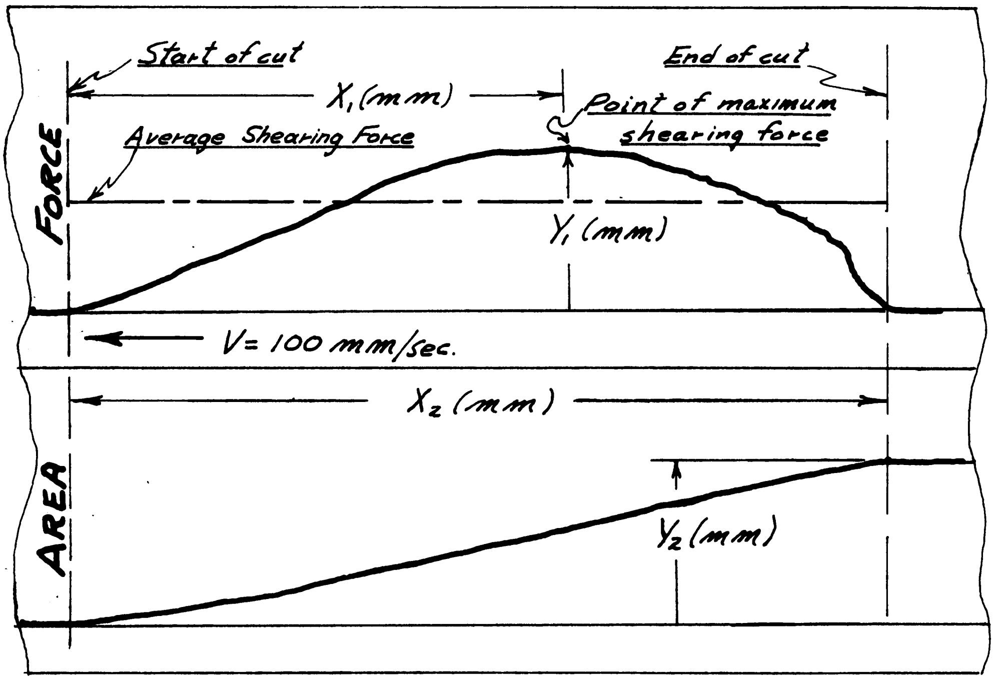


Figure 5. — *Instrumentation schematic (a), Wheatstone bridge arrangement of strain gages (b), and signal integrating circuit (c).*

evaluated when shearing with a single-acting, ½-inch thick shear blade at a no-load cutting speed of 4.7 inches per second (fig. 7). Anvil A had a deformable pad that provided sample support immediately opposite the shear blade and permitted penetration of the blade after completion of the cut. Anvil B had the same deformable pad used with anvil A, in addition to exterior deformable pads that provided restraint against bending of the sample due to the wedging action of the shear blade. The third basic anvil design consisted of a rigid, contoured sample support permitting passage of the shear blade between the



Maximum shearing force (pounds):

$$F_{max} = CY_1$$

Maximum shearing force per inch width cut:

$$Fpiwc = \frac{F_{max}}{\text{Max. Width Cut}}$$

Average shearing force (pounds):

$$Favg = \frac{CY_2V}{X_2}$$

Average speed of cut (inches per second):

$$Savg = \frac{(\text{Max. Depth Cut})\ V}{X_2}$$

where:

C = Calibration constant for ring transducer
X_2 = Length of trace on force channel from start of cut to end of cut
Y_1 = Maximum vertical deflection on force channel
Y_2 = Maximum vertical deflection on area channel at end of cut
V = Strip chart recording speed

Figure 6. — *Typical strip-chart recordings with pertinent data-reduction formulas.*

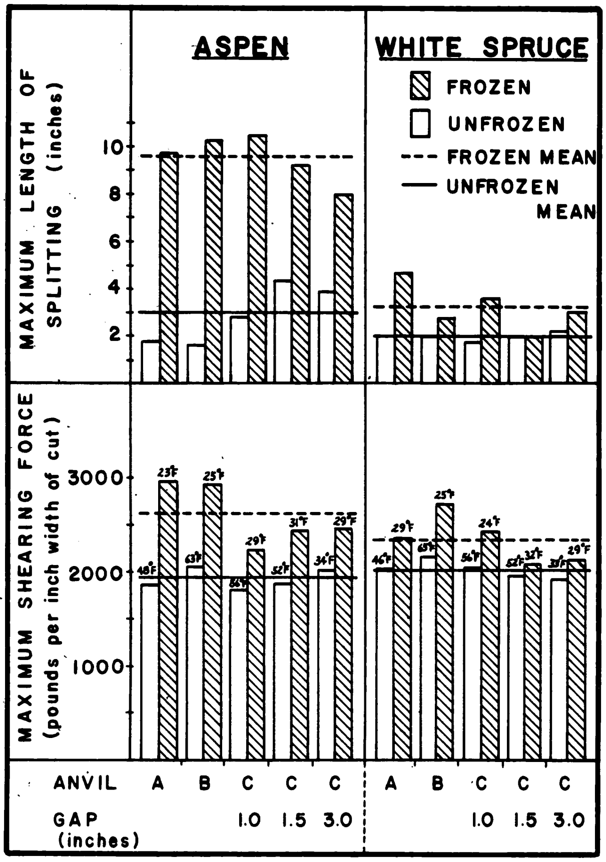


Figure 7.—*Effect of anvil design on shearing force and splitting damage for spruce and aspen (shear blade: ½ inch, 30°, plain).*

two halves of anvil C; thus, this anvil did not provide sample support immediately opposite the shear blade. This contoured, rigid anvil was tested at three nominal gap settings of 1 inch, 1½ inch, and 3 inches. Since a ½-inch thick shear blade was used, the respective side clearances between the blade and anvil were ¼ inch, ½ inch, and 1¼ inches.

In comparing the shear force requirements for unfrozen aspen and spruce, gross differences with the five possible anvil designs were not recorded (fig. 7). For frozen aspen the two deformable padded anvils required larger shear forces than the rigid, contoured anvils. This difference in shear force requirement was not as apparent with frozen spruce. An uncontrolled variability in wood temperatures (noted above each test level in fig. 7) may have had an influential effect on force.

Restraint against bending of the sample caused by the wedging action of the shear blade did not appear to reduce splitting damage. In unfrozen aspen both deformable anvils resulted in mean maximum splitting penetration of less than 2 inches, and with frozen aspen approximately 10-inch splits were recorded. Shearing unfrozen aspen against the contoured anvil yielded maximum splits of 3 to 4 inches, appearing to increase with increasing blade side clearance. With frozen aspen, 8- to 10-inch splits were recorded, with the least penetration being at a 1¼-inch blade side clearance. Splitting penetration in unfrozen spruce was approximately the same for all anvils tested, and was erratic in frozen spruce. However, the sheared face of most frozen spruce samples had "macro-tearouts" of the fibers and some "complete tearout" of wood chunks near the end of the shear cut—particularly when the contoured anvil was set with the two larger blade side clearances. (See figure 8 for descriptions and photographs of typical sheared faces.) In addition, the sheared faces of several frozen spruce samples were severely crushed or "mushroomed" when anvil B was used. This was attributed to a greater pressure normal to the sides of the shear caused by restraining the bending of the sheared bolt. This greater pressure also caused a slight increase in shearing force due to an increased frictional force.

The characteristic splitting damage to aspen can generally be described as laminar splitting occurring at right angles to the direction of cut. The splitting damage to spruce was characterized by the presence of numerous concentric ring separations and very little laminar splitting.

Although the test results do not conclusively show which anvil design is best for use with a single-acting shear blade, my personal preference would be a rigid, contoured anvil with adjustable gap to permit a close shear blade side clearance. If the gap were fixed, a blade side clearance of approximately ½ inch would appear to be a reasonable compromise.

Plain Shear Blade Designs

Unfrozen samples of all five test species were cut with all combinations of three nominal shear blade thicknesses (¼, ⅜, and ½ inch) and four blade bevels (20°, 30° 40°, and 50°). However, to extend the test range of shear blade thicknesses, the experiment was supplemented with crosscut shearing tests on basswood and hard maple with blades having nominal thicknesses of ⅛ and 3/16 inches, and a 30° bevel. The rigid, conformative anvil design was used at a 1½-inch gap setting and a no-load cutting speed of 4.7 inches per second.

White Spruce

Concentric ring-type failures and minor splitting

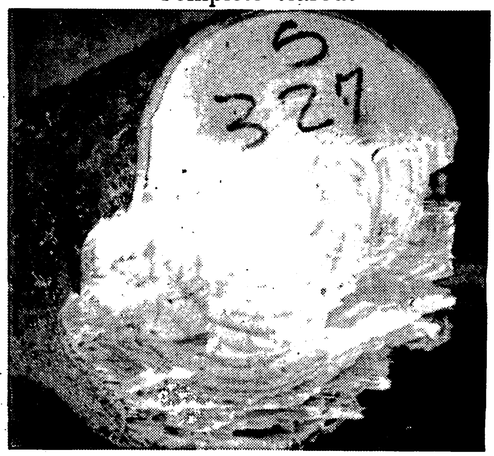
Material condition unfrozen; shear blade ½ inch, 30°, plain; anvil C; gap 1½ inches; temperature 52° F.

Concentric ring-type failures and macro-tearout

Material condition frozen; shear blade ½ inch, 30°, plain; anvil C; gap 3 inches; temperature 29° F.

White Spruce

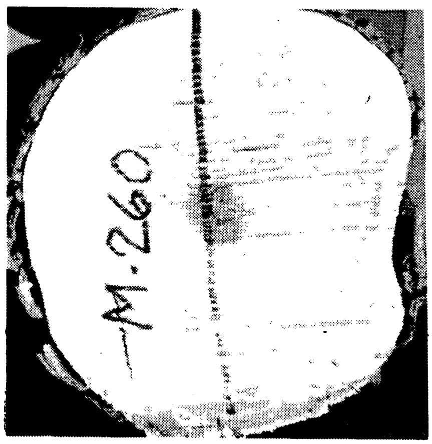
Complete tearout



Material condition frozen; shear blade ½ inch, 30°; plain; anvil C; gap 1½ inches; temperature 5° F.

Hard Maple

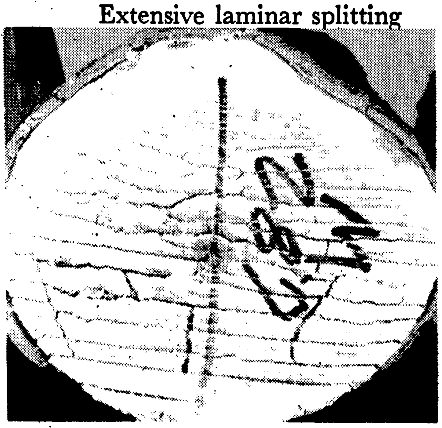
Minor laminar splitting



Material condition unfrozen; shear blade ½ inch, 50°, plain; anvil C; gap 1½ inches; temperature 51° F.

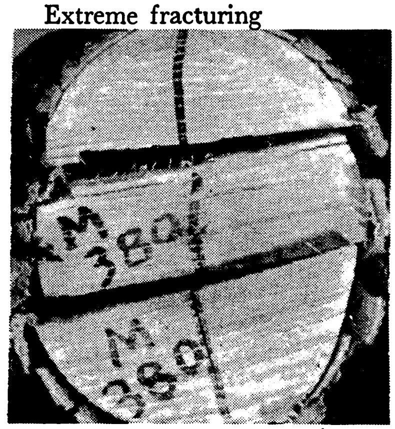
Hard Maple

Extensive laminar splitting



Material condition unfrozen; shear blade ½ inch, 30°, plain; anvil C; gap 1 inch; temperature 60° F.

Extreme fracturing



Material condition frozen; shear blade ½ inch, 30°, + 3° taper; anvil C; gap 1½ inches; temperature 6° F.

Figure 8. — *Typical sheared faces.*

SHEAR BLADE BEVEL

Past investigators have reported that blade bevel has little or no influence on shear force requirements (Johnston 1968d, Wiklund 1967). Exceptions noted were white spruce and eastern hemlock, where Erickson (1967) reported a 15- to 20-percent reduction in maximum shearing force when going from a 20° to a 40° bevel angle with a ½-inch-thick blade. In this study significant differences were recorded between individual bevel angles; however, it is concluded that bevel angle has *no consistent effect* on the magnitude of shearing force (fig. 9). An analysis of covariance to adjust for uncontrolled natural variations in specific gravity, moisture content, and bolt diameter did not yield adjusted treatment means that would change the above conclusions.

In a detailed analysis of all splits produced in individual bolts from yellow birch and hard maple, it appeared that the smaller blade bevel angles (20° and 30°) produced thicker laminar beam failures and more gross splitting damage than the greater bevel angles (40° and 50°); however, no consistent trend could be established in terms of the actual maximum depth of splitting penetration. Or, to put it in other terms, the larger bevel angles appeared to produce a greater number of laminar splits throughout the depth of cut, but they were more concentrated about the average length of split. This is best illustrated in the computer plots of the scatter diagrams of split length versus depth of cut along with a least-squares best-fit curve based on a fourth-order polynomial for each combination of blade thickness and bevel angle (fig. 10). The maximum predicted split lengths generally "peaked out" at a depth of cut to diameter ratio of approximately 0.75. The regression equations were used mainly to illustrate what appeared to be characteristic splitting patterns due to changes in blade bevel; they are not recommended for quantitative use. Thus, the equations have not been included in figure 10.

BLADE THICKNESS

Because blade bevel had no consistent effect on shearing force, the data for all bevel angles were pooled and averaged for each blade thickness. This gave a mean value of maximum cutting force for each blade thickness (excluding the ⅛- and 3/16-inch) based on 24 shear cuts instead of six.

The results revealed that as blade thickness increased, the shearing force increased nonlinearly (fig. 11). For hard maple, doubling the blade thickness from ⅛ to ¼ inch resulted in a 57-percent increase in shearing force. When blade thickness was increased from ¼ inch to ½ inch the shearing force increased 46 percent. For basswood, the same order

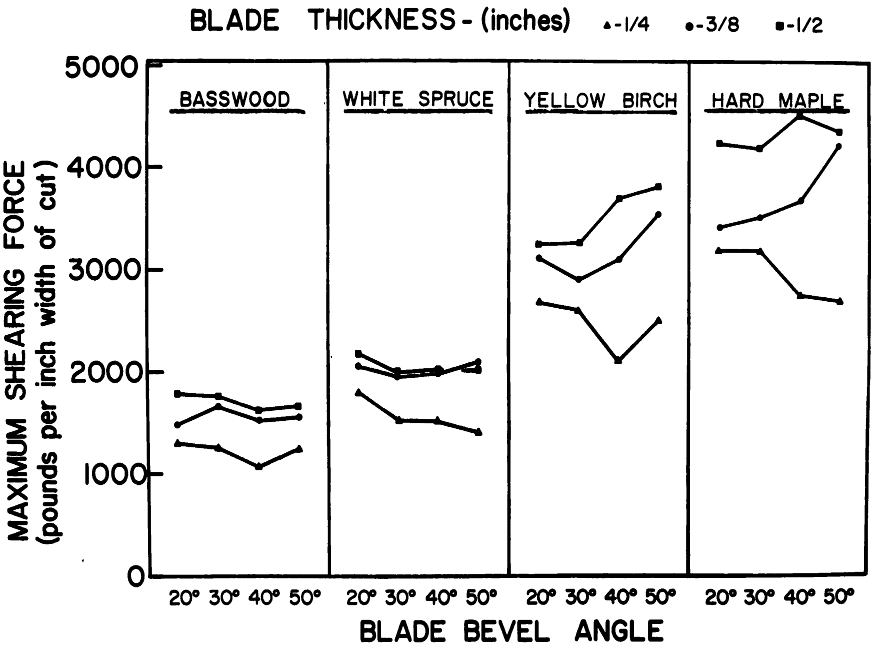


Figure 9.—*Effect of blade bevel on shearing force (anvil C, 1.5-inch gap).*

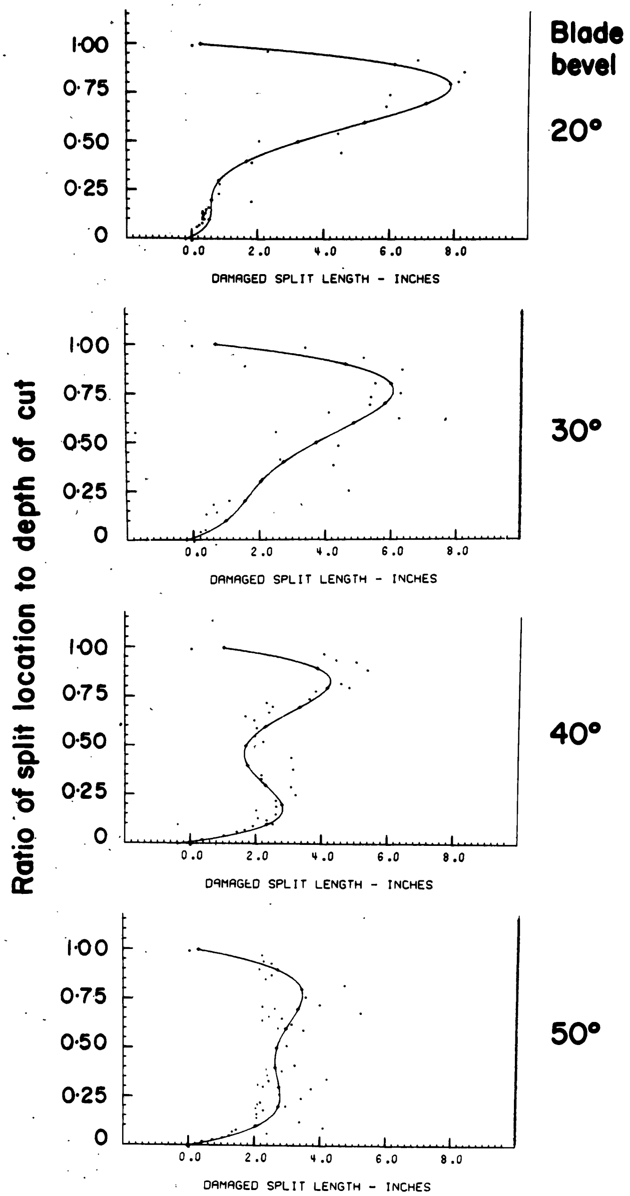


Figure 10. — *Splitting damage in yellow birch roundwood bolts sheared with ⅜-inch shear blades with varying blade bevel (anvil C, 1.5-inch gap, 4.7 inches/second cutting speed).*

of increases in blade thickness increased the shearing force 73 and 41 percent. By extrapolating the upper and lower bounds through the origin (fig. 11), a smooth envelope results for the given test conditions. It is expected that all species with densities between basswood and hard maple would be included within this envelope under similar cutting conditions. If this curve is used for estimating purposes, the user should remember that the plotted values are treatment level means, and the 95-percent upper confidence limits are recommended for design (see discussion concerning physical properties).

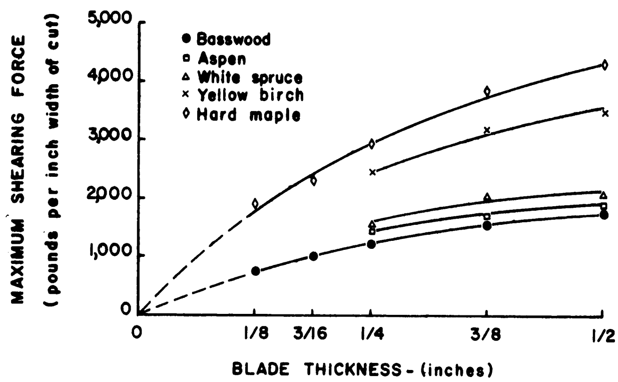


Figure 11. — *Effect of blade thickness on shearing force.*

My impression of the sheared roundwood bolts was that shear blades having 40° or 50° bevel angle generally produced a higher quality cut — the laminar splitting was not as distinct. Perhaps this is analagous to the carpenter's trick of minimizing splitting by blunting the point of a nail before driving near the end of a board, thus causing the nail to act more as a punch than a wedge.

The conclusions on the effect of blade thickness agree closely with those of other investigators. Johnston (1968d) and Kempe (1964) reported a 50-percent increase in shear force when doubling blade thickness between the range of 0.2 to 0.5 inches. Erickson (1967) reported a range of 35 to 64 percent increase in force, depending on species.

Splitting damage in unfrozen hard maple bolts was found to be the most sensitive to changes in blade thickness (fig. 12). Assuming an approximate linear relationship for mean values of maximum split length in hard maple within the range of blade thicknesses tested, an average slope of 2.5 inches of split per ⅛ inch of blade thickness is recommended for estimating purposes. The splitting damage in unfrozen spruce appeared to be the least sensitive to changes in blade thickness, with maximum splits concentrating around a depth of penetration of approximately 2 inches.

Physical Properties

Based on an analysis of covariance for each species sheared with the plain shear blades, specific gravity and shear force were found to be highly correlated, accounting for most of the variation among bolts within a treatment. Because specific gravity was the

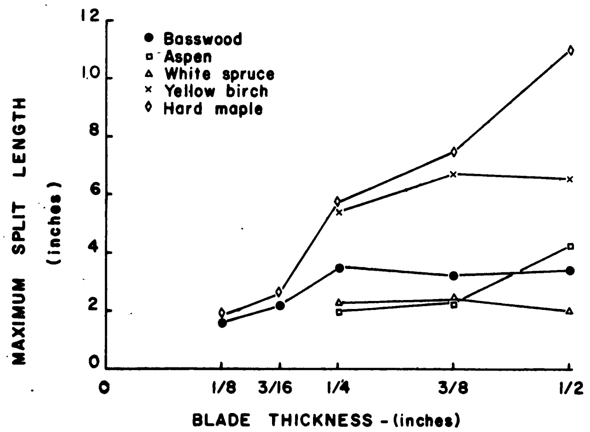


Figure 12.—*Effect of blade thickness on splitting damage.*

best single physical property indicator of crosscut shear force requirements, three separate linear regression analyses relating force to specific gravity were run for the ¼-, ⅜-, and ½-inch blade thicknesses and all blade bevel angles tested. For estimating purposes, the resulting linear regression lines, 95-percent upper and lower confidence limits on both the mean and a single estimate, and the scatter diagrams were computer-plotted for each of the three blade thicknesses (fig. 13). The 95-percent upper confidence limits on a single estimate are recommended for establishing design limits (do not include effects of dulling or shearing frozen wood). In an analysis of covariance, moisture content, specific gravity, and diameter, either treated singly or combined, were not highly correlated with splitting damage in aspen, spruce, basswood, or yellow birch. The coefficients of determination for these species ranged from 0.07 for yellow birch to 0.40 for spruce. However, with hard maple the combined coefficient was approximately 0.78, with diameter accounting for most of the variation.

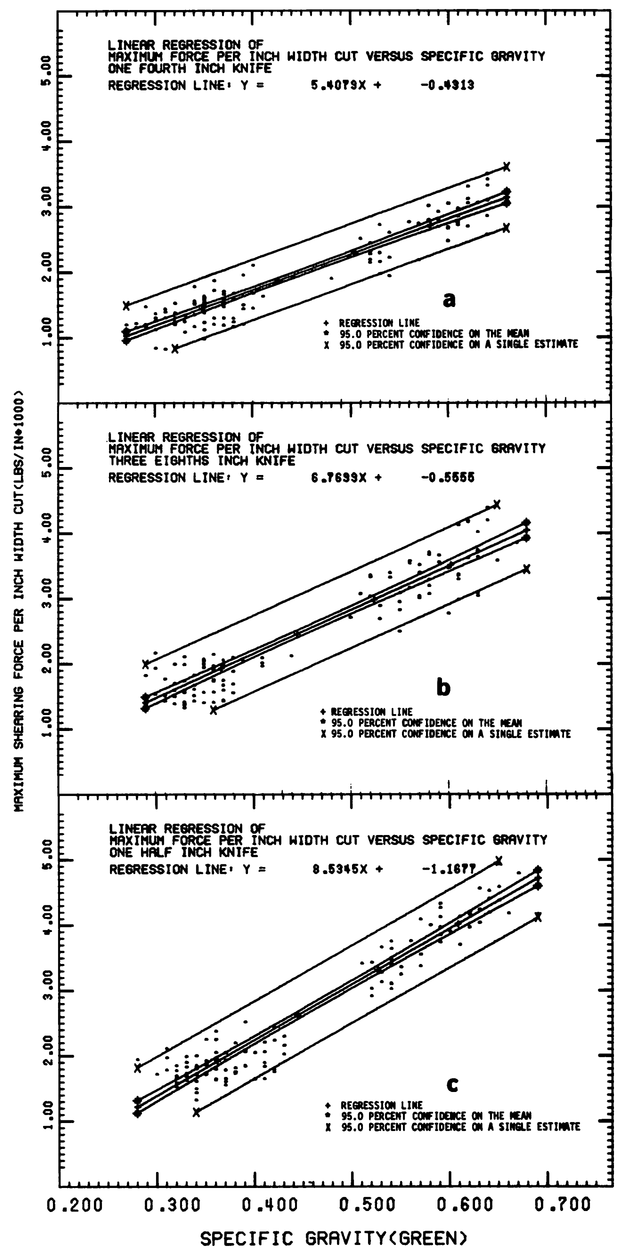


Figure 13.—*Effect of specific gravity on shearing force: (a) ¼-inch blade thickness, (b) ⅜-inch blade thickness, (c) ½-inch blade thickness.*

Guillotine Shear Blades

The purpose of testing the guillotine shear blades was to determine if a cutting edge inclined at an oblique angle to the direction of cut would induce a slicing action, thereby reducing the force requirements and splitting damage.

It has been hypothesized by previous investigators that during orthogonal cutting of the fibers (where the cutting edge is at right angles to the direction of cut), the failure is not by fiber severance but rather by tensile failures slightly ahead of the cutting edge.

In other words, beam failures (laminar splits) would occur, but at the same time, tensile failures of the fibers would result on the tension side of the beams as they are formed. If this hypothesis is true, the maximum benefit of a keen cutting edge is not being recognized. Therefore, an induced slicing action creating fiber severance appeared to be worthy of investigation.

The mean values of maximum shearing force for all guillotine blade angles (15°, 30°, and 45°) were less than for a plain shear blade of equal thickness (fig. 14). The shearing force requirements for hard maple decreased linearly with increasing guillotine angle. With maple, the 45° guillotine blade reduced shearing force about 25 percent compared with the plain shear blade (0° guillotine angle). For spruce

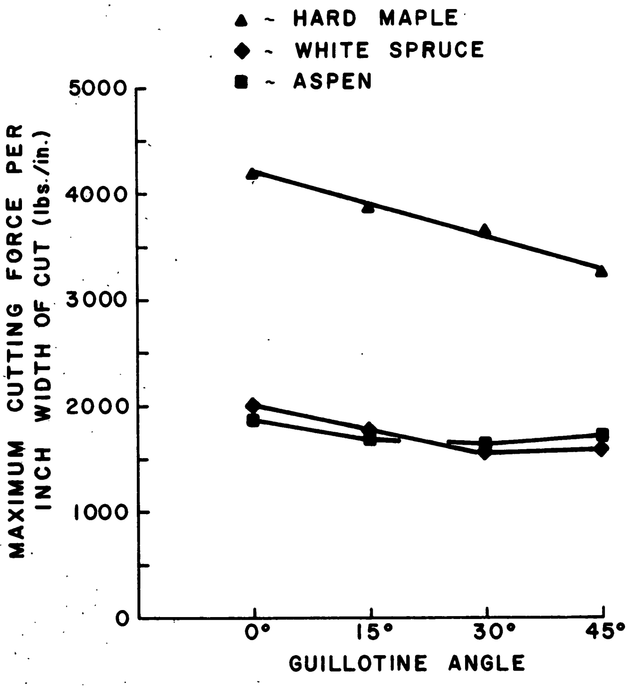


Figure 14. — *Effect of guillotine angle on shearing force (½-inch blade thickness).*

and aspen, shearing force requirements also decreased with increasing guillotine angle, with the exception of the 45° guillotine angle. However, this is attributed to the above-average specific gravities for each species at this 45° treatment level.

Surprisingly, splitting damage appeared to increase with guillotine angle for aspen and spruce, but no trend was observed for maple (table 2). Frozen wood was not tested in this phase of the study.

Table 2. — *Mean[1] splitting damage by guillotine blade angle[2] and species*

Guillotine angle and species	Splitting damage (inches) Maximum: Mean	Maximum: Range	Average: Mean	Average: Range
0°:				
Aspen	4.3	1.4- 5.6	1.7	1.1- 2.5
Spruce	2.0	1.1- 2.5	1.0	.6- 1.3
Maple	11.0	7.0-15.6	--	--
15°:				
Aspen	4.7	2.8- 7.9	1.8	.8- 2.7
Spruce	--	--	--	--
Maple	14.0	11.4-18.5	8.8	6.4-10.2
30°:				
Aspen	6.1	4.0- 8.4	2.7	1.1- 5.0
Spruce	4.3	2.5- 7.3	[3]1.5	.5- 3.2
Maple	10.8	6.8-14.3	[3]8.8	5.5-11.2
45°:				
Aspen	7.5	4.3-10.6	3.1	1.5- 4.9
Spruce	4.7	3.2- 7.0	1.1	.6- 1.8
Maple	9.9	3.3-12.7	5.8	1.2- 9.2

1/ Average of six bolts sheared at each treatment level.

2/ The four shear blades listed were 1/2 inch in thickness.

3/ Average based on only four bolts.

Tapered Shear Blades

Two basic shear blades of variable thickness were tested to evaluate the effect of blade taper on shear force and splitting damage. Both of these shear blades were fabricated with a 30° bevel angle to a ½-inch thickness, at which point they tapered either positively to a thickness of ¾ inch, or negatively to ¼ inch. The respective taper angles were approximately +3° and —1°.

Within this limited range of shear blade taper angles there was little difference in shear force requirements (fig. 15). The mean values and ranges of maximum split length in spruce and aspen for the positively tapered shear blade were distinctly greater than for the untapered shear blade (table 3). It was anticipated that splitting damage would be less with the negatively tapered shear blade than with the untapered blade; however, slight increases in the mean value of maximum split length were recorded. Splitting damage in hard maple for all three shear blades was extensive, with the mean values of maximum splits about 10 inches. For a ½-inch-thick shear blade, this maximum split length agrees with the previously given estimate of 2.5 inches of split per ⅛ inch of blade thickness.

Thin Shear Blades

Two experiments were conducted with thin shear blades. The first was to conduct an experimental photoelastic analysis of a thin shear blade by bonding a photoelastic coating to the blade surface and then subjecting the blade to compressive edge loadings (approximating crosscut shear loads), to pretensioning loads as investigated under the first phase, and

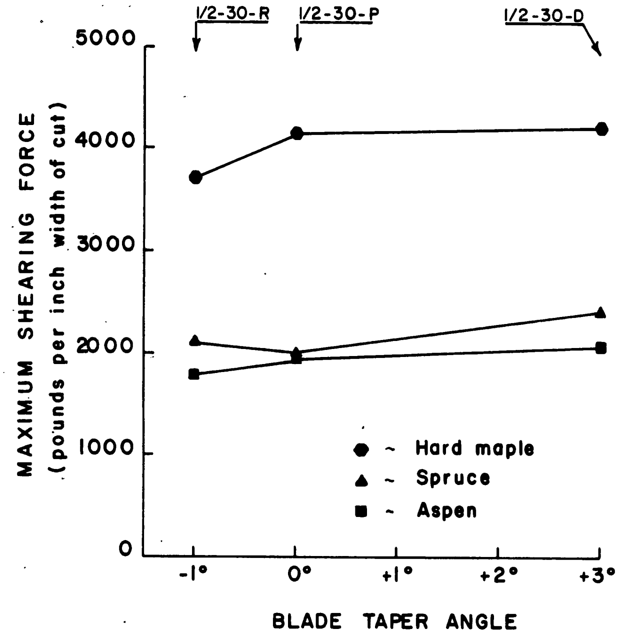


Figure 15. — *Effect of blade taper on shear-force requirements (anvil C, 1.5-inch gap).*

Table 3. — *Mean[1] splitting damage by shear blade taper and species*

Shear blade taper and species	Splitting damage (inches)			
	Maximum		Average	
	Mean	Range	Mean	Range
No taper:				
Aspen	4.3	1.4- 5.6	1.7	1.1- 2.5
Spruce	2.0	1.1- 2.5	1.0	.6- 1.3
Maple	11.0	7.0-15.6	--	--
Positive taper = 3°:				
Aspen	6.6	2.6-14.9	2.1	.8- 3.2
Spruce	4.6	2.1-10.0	1.0	.6- 2.4
Maple	9.7	3.6-13.8	6.0	1.2- 8.0
Negative taper = 1°:				
Aspen	4.7	2.7- 7.9	1.8	1.3- 2.6
Spruce	2.3	1.7- 3.4	1.0	.6- 1.5
Maple	11.7	8.5-13.0	7.8	6.2-10.7

1/ Average of six bolts sheared at each treatment level.

to a combination of approximated shearing and pretensioning loads. The second was to permit an evaluation of the performance of thin blades under actual shearing operations, during which pretensioning methods were employed to increase the elastic stability of the blade.

For both experiments the shear blades were rigidly contained in loading arms and pretensioned by means of a hydraulic cylinder (figs. 16, 17). Both phases also included an investigation of two alternative pretensioning pin connection locations (A and B) on the loading arms. Under prestressing loads, these pin locations were assumed to produce stress distributions similar to those that would be produced in thick, deep beams subjected to the same loadings (fig. 18). It must be emphasized that the thin plates

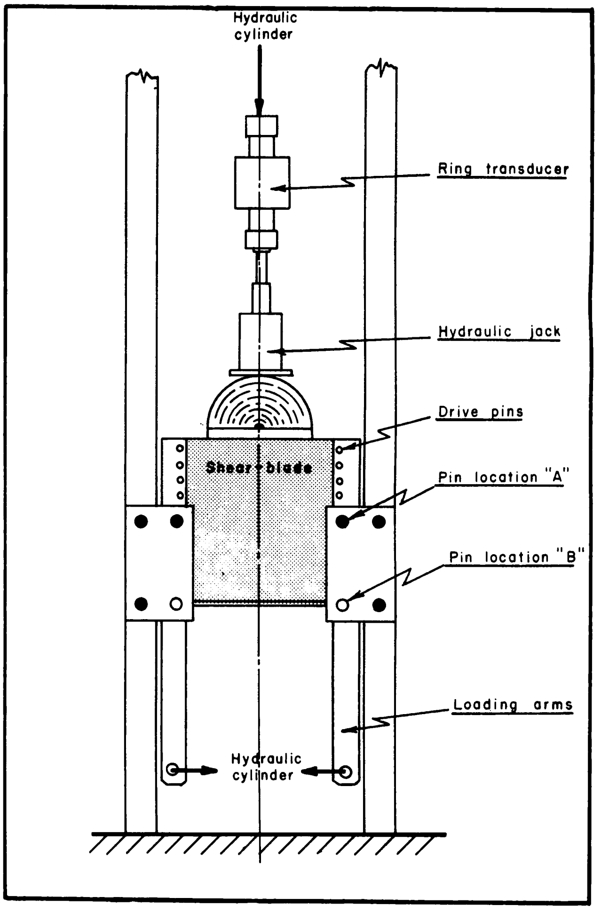


Figure 16. — *Test arrangement for conducting pretensioning and photoelastic analysis of thin shear blades.*

(shear blades) used *do not* behave as thick, deep beams. The objective of the photoelastic study was to determine how the shear blades vary from thick, deep beams, and to provide insight into establishing more exacting theoretical approaches for predicting the performance of thin shear blades. The results of the photoelastic analysis are too extensive for inclusion in this paper; however, several comments are in order concerning the actual shearing tests that were conducted with thin shear blades.

Unfrozen basswood bolts with maximum diameters of about 8 and 9 inches were sheared with the ⅛- and 3/16-inch shear blades, respectively. The maximum diameters for unfrozen hard maple were 6.0 and 7.3 inches for the same two blades. When the thin blades were pretensioned, inelastic stability problems were not encountered under the following conditions: with pin location A and the ⅛-inch blade (prestress moment applied was approximately 19,000 inch-pounds); with the same pin location and the 3/16-inch blade (three prestress moments were applied —

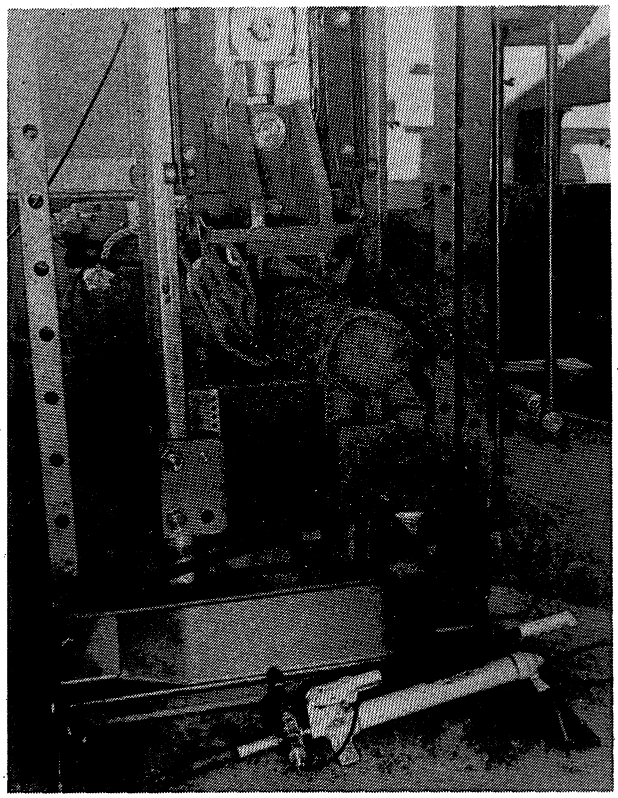


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Figure 17. — *Assembly for conducting crosscut shearing tests with pretensioned, thin shear blades.*

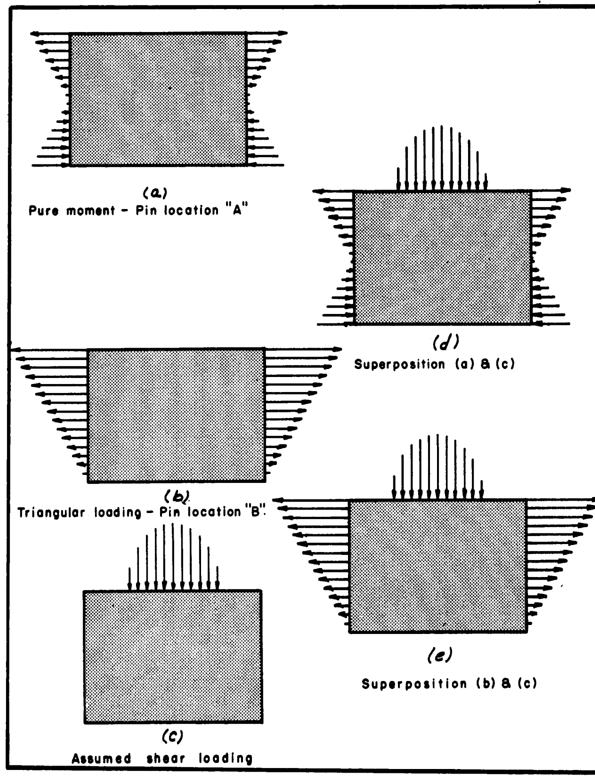

Figure 18. — *Load and prestress configurations studies for pretensioning of thin shear blades.*

approximately 38,000 inch-pounds, 57,000 inch-pounds, and 76,000 inch-pounds); with pin location B and the 3/16-inch blade pretensioned with a 3,800-pound cylinder force at a 10-inch lever arm from the pin connection. It was not hypothesized that the pretensioning results in less shear force, but rather that the pretensioning permits the use of thinner shear blades because of increased elastic stability. Figures 11 and 12 clearly indicate the benefit of thin blades for reducing shear force requirements and splitting damage.

As a final test with the 3/16-inch pretensioned blade, a *frozen* 7.5-inch diameter hard maple bolt was sheared resulting in complete blade failure (fig. 19a). This blade failure prompted the testing of several basswood samples (low density) with the ⅛-inch blade without pretensioning. Extremely smooth cuts were obtained without blade failure. The same thin shear was then tested without pretensioning on a 6-inch diameter oak bolt (high density) — blade failure resulted (fig. 19b).

In summary, the pretensioning methods appeared to increase the stability of the shear blade to a lim-

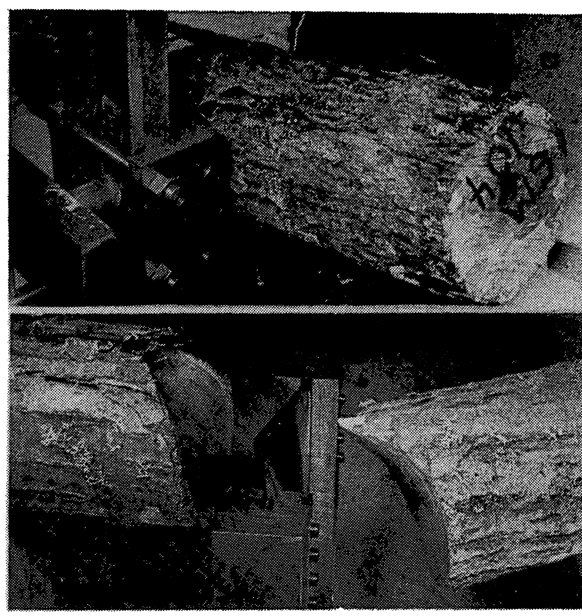

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Figure 19. — *Thin shear blade failures. (a) Pretensioned blade, 3/16-inch, 30° bevel angle; 7.5-inch diameter hard maple (frozen). (b) Shear blade without pretensioning, ⅛-inch, 30° bevel angle; 6.0-inch diameter oak (unfrozen).*

ited extent, but not to complete satisfaction, as is obvious from the pretensioned blade failure with frozen maple. Further work needs to be done in the area of pretensioning. Perhaps a better approach would be to subject the shear blade to a uniform tensile stress throughout its depth.

The mechanical arrangement of the test assembly did not permit investigating pure tensioning without major modifications. Pure tensioning is suggested because of the difficulty encountered in pretensioning the very thin shears by the methods used in this study. Almost as soon as the pretensioning loads were applied, (with either pin arrangement A or B, fig. 15) elastic buckling occurred (opposite of what happens during shearing).

Another problem associated with the performance of thin shear blades, whether pretensioned or not, is preventing the cutting edge from drifting along the direction of the fiber lines in the denser species. In other words, once the thin shear blade starts cutting at even the slightest angular variation to orthogonal cutting (perpendicular to the fibers), the edge of the blade tends to follow the path of least resistance — along the fiber lines. Structural failure of the shear blade may be the final result. Thus the equipment designer contemplating the use of thin shear blades must consider the elastic stability of the shear blade and localized buckling.

Dulling

Unfrozen aspen, spruce, and yellow birch bolts were sheared to evaluate the effect of blade dulling on shear force requirements and splitting damage (fig. 20). Two shear blades, a plain and a guillotine, were machined to two arbitrary levels of dulling — flats of 1/32 and 1/64 inch were ground along the cutting edge and were classified as dull and half-dull, respectively. Blade dulling was not found to influence shear force requirements as much as in the earlier study by Erickson (1968a). Erickson found dulling to a 1/32-inch at to increase shear force for a 3/8-inch blade having a 30° bevel by 34, 44, and 27 percent in spruce, aspen, and birch, respectively. In this study, for the same level of dulling and same species, the percentage increases were only 6, 19, and 5 for a 1/2-inch shear blade having a 30° bevel. The differences between the results in the two studies may be attributed to variation in the classification "full sharp," and in wood samples (roundwood bolts vs. 2 by 4 sections). Erickson's "full sharp" shear blades were maintained in a honed condition, whereas mine were machine-ground only.

The dull guillotine blade appeared to increase shear force slightly more than the plain shear blade. Full dulling of the guillotine blade increased shear force approximatey 31, 13, and 15 percent for spruce, aspen, and birch, respectively.

Both levels of dulling produced greater splitting damage than the sharp condition; however, no consistent trend was apparent (table 4). Visually examining the cut face of spruce sheared with dull blades was found to be misleading, because it appeared that splitting penetration was extensive (fig. 21). However, maximum splits detected for the two dull shear blades were only 4 to 4.5 inches (table 4). This is attributed in part to the characteristic concentric-

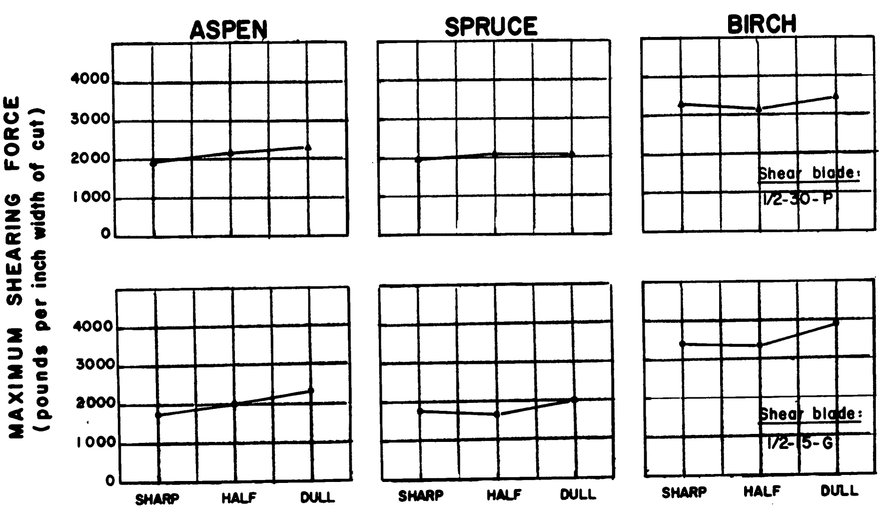

Figure 20. — *Effect of blade dulling on shear force requirements.*

Table 4. — *Mean[1] splitting damage with dull shear blades*

Shear blade type and species	Maximum split length (inches)		
	Sharp	Half-dull (1/64-inch flat)	Dull (1/32-inch flat)
½ inch, 30°, plain			
Aspen	4.3	7.4	5.2
Spruce	2.0	2.3	3.9
Birch	6.5	6.9	8.8
½ inch, 15°, guillotine			
Aspen	4.7	10.3	9.4
Spruce	--	3.1	4.4
Birch	--	9.8	7.8

1/ Average of six shear cuts at each treatment level.

ring type failure in spruce rather than laminar splitting.

Coated Shear Blades

To find out if the effect of friction on the sides of the shear blade could be reduced, two ⅜-inch blades were completely coated with different low-friction materials. A blade having a 40° bevel was coated with "Teflon-S"[1]. The second shear blade having a 20° bevel was coated with a different low-friction material.

Consistent reductions in shearing force with both coatings were observed with all species (table 5).

Table 5. — *Crosscut shearing force (pounds per inch width of cut) for coated and uncoated shear blades*

Species	Uncoated blades 1/	Teflon-S 2/		New material 3/	
	Mean force	Mean force	Reduction (percent)	Mean force	Reduction (percent)
Basswood	1,548	898	42	882	43
Aspen	1,709	1,218	29	1,299	24
Spruce	2,026	1,141	44	1,203	41
Birch	3,164	2,232	29	2,021	36
Maple	3,812	3,100	19	3,286	14
Average	--	--	33	--	32

1/ Average of six shear cuts at each bevel angle (20°, 30°, 40°, and 50°); i.e., average of 24 bolts.
2/ Applied to blade code 3/8 inch, 40°, plain (six shear cuts).
3/ Applied to blade code 3/8 inch, 20°, plain (six shear cuts).

The most significant force reductions — more than 40 percent — were with basswood and spruce. Hard maple, the densest species tested, resulted in the least force reduction. Pooling all species, both coatings yielded roughly a 30-percent reduction in shearing force. These results indicate significant benefits of low-friction coatings and point out the need for further investigations. No consistent differences in splitting damage were noted between the coated shear blades and the uncoated blades tested earlier. After approximately 50 cuts with each shear blade the coating in the bevel area showed signs of excessive wear.

Other researchers have estimated the effect of the friction forces between the blade and wood during the shearing operation. Both Kempe (1964) and Johnston (1968d), using coefficients of friction of 0.20 and 0.23, respectively, estimated the friction force to contribute up to a third of the total energy required to effect the cut in spruce. Grease on the blade surface was unsuccessful in reducing the shearing force. Through the use of metal inserts impregnated with a low-friction polytetraflourethylene, Wiklund (1967) reduced the maximum shearing force by approximately 10 percent.

Temperature

The effects of wood temperatures ranging from 0° to 60°F. were evaluated for several blades when shearing aspen, white spruce, and hard maple (the shear blades were not cooled to corresponding temperatures). Although much scatter resulted in mean shear-force values for the random temperature levels (fig. 22), the approximate linear trends shown for the ½-inch, 30°, plain shear blade can be used for discussion. For hard maple a force increase of approximately 17 percent was noted when temperature was decreased from 50° to 5° F. For aspen and spruce, the median force increase was about 55 percent for the same drop in temperature.

Aspen, spruce, and hard maple bolts were also sheared with five different blades at several internal wood temperatures below 32° F. The mean values of shearing force and splitting damage for these tests were summarized along with the data for the corresponding blades at temperatures above freezing (tables 6, 7, and 8). Compared with unfrozen wood, increases in force required to cut frozen wood at the lowest temperatures in each test level fell within the following ranges: aspen, 51 to 80 percent; spruce, 56 to 72 percent; and maple, 13 to 37 percent. Another measure illustrating the effect of decreasing temperature on shear force is an approximate unit increase of 20 (pounds/inch width cut)/°F. for aspen, 23 (pounds/inch width cut)/°F. for spruce and 13 (pounds/inch width cut)/°F. for hard maple. A pooled value for all three species of 20 (pounds/inch width cut)/°F. can be used for estimating purposes.

In general, splitting damage increased with de-

[1] *Dupont, 958-200 Series, Stratified Non-Stick and Self-Lubricating Finish. The names of manufacturers and models of equipment are mentioned in this paper for identification only, and no endorsement by the USDA Forest Service is implied.*

Shear blade ½ inch, 30° plain		Shear blade ½ inch, 30°, guillotine	
Half-dull (1/64 inch flat)	Dull (1/32 inch flat)	Half-dull (1/64 inch flat)	Dull (1/32 inch flat)

Aspen

Yellow Birch

White Spruce

Figure 21. — *Cut faces of unfrozen roundwood bolts sheared with dull shear blades (anvil E, 1.5-inch gap).*

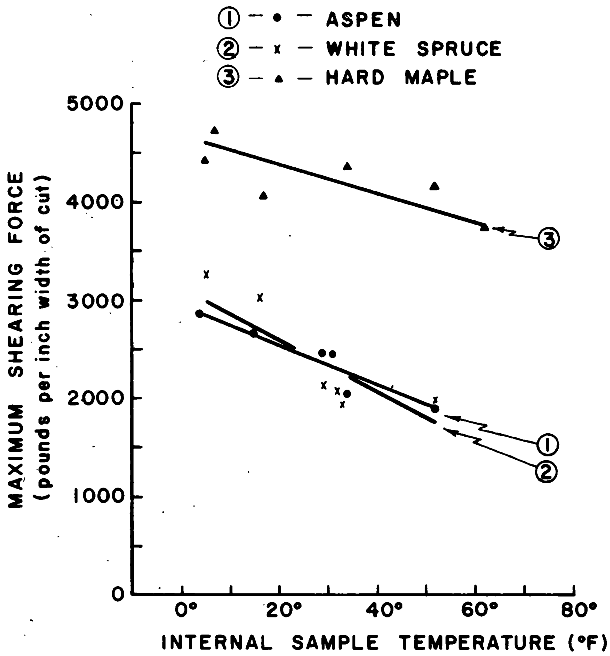

Figure 22. — *Effect of temperature on shearing force (shear blade: ½-inch, 30°, plain).*

creasing temperature. With frozen maple at the lower temperatures, many of the bolts split the entire length, or about 2 feet. These completely split bolts were not included in calculating the mean value of splitting damage because it is not known whether the splits would have been longer or shorter had the bolts been longer to begin with. This is also the case in table 8, where forces are recorded but splitting damage has been omitted. With frozen spruce, extreme fracturing of the cut-face area was frequently noted at the lower temperatures; however, the splits did not extend as far into the bolts as with aspen and maple. In addition, occasional complete tearout of wood chunks was noted in spruce near the last one-quarter of the cut, and the remainder of the cut face was characterized by macro-tearouts of the fibers.

Cutting Speed

Cutting speeds varying between 2 inches per second and 12 inches per second did not affect shear force requirements with either coated or uncoated shear blades. However, power is a function of cutting speed. The instantaneous maximum power which corresponds to the maximum force required to effect the cut is defined as follows:

$$P_{max} = F_{piwc} \times D \times V$$

where

P_{max} = maximum power in inch-pounds per second

F_{piwc} = maximum force required to effect the cut in pounds per maximum inch width of cut

V = cutting speed in inches per second, and

D = log diameter (or maximum width of cut) in inches.

Table 6. — *Mean crosscut shearing force and splitting damage for unfrozen and frozen aspen sheared with different blade designs*

Shear blade design	Temperature	Shearing force	Increase		Maximum split	Average split
	°F.	Lbs./in. width cut	Percent	Lbs./in. width cut/°F.	Inches	Inches
3/8", 30°, Plain	59	1,584			2.3	1.0
	27	2,299			5.4	1.3
	15	2,374			9.1	3.3
	0	2.608	65	17.4	9.3	1.8
1/2", 30°, Plain	52	1,888			4.3	1.7
	15	2,668			13.7	4.0
	4	2,855	51	20.1	1/ 14.2	1/ 4.0
1/2", 30°, Guillotine	67	1,591			6.1	2.7
	9	2,349			11.7	4.2
	2	2,864	80	19.5	2/ 14.2	2/ 5.1
1/2", 30°, Positive Taper	67	2,074			6.6	2.1
	30	2,960			7.9	1.8
	7	3,041			10.3	4.2
	4	3,463	67	22.1	10.8	3.8
1/2", 30°, Negative Taper	67	1,815			4.7	1.8
	30	2,328			7.0	2.0
	9	3,110			2/ 9.4	2/ 3.1
	0	3,177	75	20.3	2/ 10.9	2/ 3.3
Average				19.5		

1/ Average of four bolts.
2/ Average of three bolts.

A conclusion based on calculations from shear cuts made during the entire study revealed the ratio between average force and the actual maximum required force to effect the cut to be generally 0.65 to 0.75. Thus, the *average* power required to shear a log of a given diameter can be approximated by the following formula using 0.75 for the above ratio:

$$P_{avg} = \tfrac{3}{4} P_{max.}$$

To convert either maximum or average power to the standard unit of measurement of horsepower the following conversion is used:

$$1\ \text{HP} = 6600\ \text{in.-lb./sec.}$$

No relationships could be established between splitting damage and cutting speed.

Table 7. — *Mean crosscut shearing force and splitting damage for unfrozen and frozen spruce sheared with different blade designs*

Shear blade design	Temperature	Shearing force	Increase		Maximum split	Average split
	°F.	Lbs./in. width cut	Percent	Lbs./in. width cut/°F.	Inches	Inches
3/8", 30°, Plain	45	1,962			2.4	1.0
	30	1,902			3.5	1/ 1.2
	16	2,585			3.3	1/ 1.3
	-1	3,347	71	32.3	6.4	1/ 1.4
1/2", 30°, Plain	52	1,978			2.0	1.0
	16	3,016			1/ 6.8	1/ 2.4
	5	3,291	66	27.9	1/ 5.2	2/ 1.4
1/2", 30°, Guillotine	68	1,534			4.3	2/ 1.5
	11	2,631	72	19.2	1/ 6.6	1/ 1.7
1/2", 30°, Positive Taper	65	2,353			4.6	1.0
	32	2,463			1/ 3.6	1/ 1.5
	12	2/ 3,651			3/ 10.0	3/ 1.4
	-3	2/ 3,673	56	19.4	2/ 7.2	2/ 1.1
1/2", 30°, Negative Taper	67	2,158			2.3	1.0
	29	2,123			4.6	1.7
	10	1/ 3,053			1/ 6.3	1/ 0.9
	-2	1/ 3,457	60	18.9	3/ 3.8	3/ 1.0
Average				23.4		

1/ Average of five bolts.
2/ Average of four bolts.
3/ Average of three bolts.

Table 8. — *Mean crosscut shearing force and splitting damage for unfrozen and frozen hard maple sheared with different blade designs*

Shear blade design	Temperature	Shearing force	Increase		Maximum split	Average split
	°F.	Lbs./in. width cut	Percent	Lbs./in. width cut/°F.	Inches	Inches
3/8", 30°, Plain	64	3,511			7.5	3.3
	16	4,308			1/ 10.6	1/ 7.2
	2	4,296	22	12.7	3/ 6.0	--
1/2", 30°, Plain	52	4.174			11.0	--
	17	4,065			2/ 13.7	1/ 11.2
	7	4,708	13	11.8	--	--
1/2", 30°, Guillotine	69	3,611			10.8	2/ 8.8
	9	4,306			3/ 17.6	3/ 16.2
	0	2/ 4,414	22	11.6	--	--
1/2", 30°, Positive Taper	65	4,187			9.7	6.0
	10	4,743			--	--
	6	4,784	14	10.1	3/ 20.9	3/ 15.1
1/2", 30°, Negative Taper	69	3,673			11.7	7.8
	10	4,823			3/ 16.4	--
	0	5,022	37	19.6	--	--
Average				13.2		

1/ Average of five bolts.
2/ Average of four bolts.
3/ Average of three bolts.

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ABOUT THE FOREST SERVICE . . .

As our Nation grows, people expect and need more from their forests — more wood; more water, fish, and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

- Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.
- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

Traditionally, Forest Service people have been active members of the communities and towns in which they live and work. They strive to secure for all, continuous benefits from the Country's forest resources.

For more than 60 years, the Forest Service has been serving the Nation as a leading natural resource conservation agency.