FOREST PRODUCTS JOURNAL VOL. 21 NO. 3 MARCH 1971

Force and Work to Shear Green Southern Pine Logs At Slow Speed

Peter Koch

Abstract

When logs of three diameter classes and two specific gravity classes were sheared with a 3/8-inch-thick knife travelling at 2 inches per minute, shearing force and work averaged greatest for dense 13.6-inch logs cut with a knife having a 45° sharpness angle (73,517 pounds; 49,838 foot-pounds). Force and work averaged least for 5.1-inch bolts of low density when cut with a knife having 22-1/2° sharpness angle (9,975 pounds; 2,885 foot-pounds). Values for 9.7-inch bolts were intermediate. Shear force reached a maximum about three-fourths the way through the log; it then dropped rapidly as the knife travelled the remaining distance. Momentary peaks of force commonly occurred near the three-quarter point. The greatest observed force to shear was 92,000 pounds required for a 13.6-inch log of 0.51 specific gravity (ovendry weight and green volume) when cut with a knife having 45° sharpness angle. When sheared logs were viewed in radial section, each annual ring showed a check at the earlywood-latewood boundary. Checks were least severe in small logs sheared with the 22-1/2° knife, where they averaged 0.8 inch deep; they were most severe in large logs of low density sheared with the 45° knife, where they averaged 1.4 inches deep. Each sheared log generally also had one to several rather lengthy checks that formed just prior to emergence of the knife. Regression expressions were developed to predict force and work to shear as well as average and maximum check depth—all in terms of sharpness angle, wood specific gravity, and log diameter.

The author is Chief Wood Scientist, Southern Forest Experiment Station, USDA Forest Service, Pineville, La. This paper was presented at Session 10 — Mechanical Conversion — of the 24th Annual Meeting of the Forest Products Research Society, June 30, 1970, in Miami Beach, Fla. It was received for publication in September 1970.

THE WORK REPORTED HERE is an extension of a general study of orthogonal cutting of southern pine wood (12).

When a knife is arranged to cut across the grain against an anvil or opposing knife, and the chip and the workpiece are of about equal thickness (visualize rose stems cut with pruning shears), the process is described as shearing (Fig. 1). Shears to fell trees or reduce long logs to pulpwood lengths are in common use. Published research is chiefly on species other than southern pine, but it defines principles that probably are widely applicable (1, 3, 4, 5, 6, 7, 8, 10, 11).

In general, shear forces are less in warm than in frozen wood, less in clear than in knotty wood, less in heartwood than in sapwood, less in low-density than in dense wood, and less where the shearing direction is perpendicular rather than parallel to the annual rings. Above the fiber saturation point, moisture content apparently makes little difference in the force required to shear.

The friction coefficient between a steel knife and green wood is approximately 0.2. Greasing the knife does not reduce shearing forces greatly; Teflon surfaces on the cutter are more effective. Axial loads (simulating the weight of a standing tree) do not appreciably increase shearing forces. Lateral vibration of the cutter reduces shear forces required, as does tapering the cutter plate (Fig. 2A) to give clearance between the plate and the wood. In a review of Russian work, Kubler (9) reported that vibration in the feed direction also reduces shear forces required.

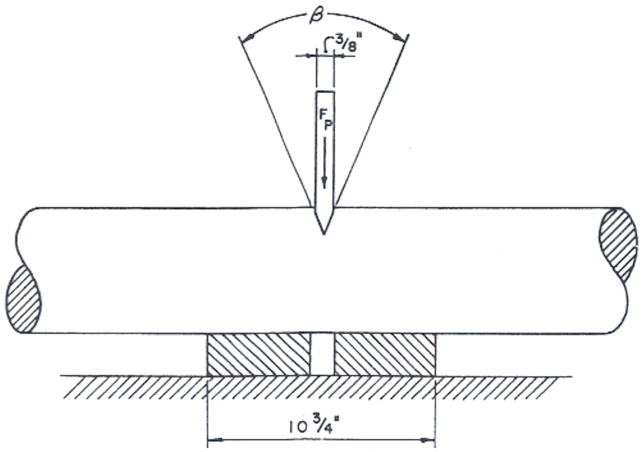

Figure 1. — Shearing. β is the sharpness angle, and F_p is the shearing force.

For parallel-sided cutters (Fig. 2B), thin blades shear with less force than thick blades. Blades tapered so that the plate near the cutting edge is thin and the root thick (Fig. 2C) require forces intermediate to thin and thick plates without taper. Sharp blades shear with less force than dull blades. In comparison with a straight edge, an edge in the shape of an open V does not appreciably lessen forces. Shear force is least when the specimen is cut between opposing knives; if cutting is by a single knife against an anvil, a narrow anvil requires less force than a wide one.

The quality of sheared ends is impaired—*i.e.*, knife-induced splits tend to be deep—if the wood is frozen, the knife dull, or the blade thick. McIntosh and Kerbes (10) found that lumber losses from splitting were less than 1 percent when lodgepole pine (*Pinus contorta* Dougl.) and white spruce (*Picea glauca* var. *glauca*) trees less than 14 inches in diameter were sheared at 45°F. with a knife 1½ inches thick.

In trials (unpublished) of industrial shears with two ½-inch thick blades (45° sharpness angle) converging at the center of the tree, lumber loss from splitting in southern pine butt logs was more severe than indicated by McIntosh and Kerbes. In the test, 202 sheared butt logs scaling 7,280 board feet (Scribner standard rule) yielded 8,064 board feet of lumber when sawed. From production records, the mill estimated that, if the trees had been felled with a chainsaw, the butt logs would have yielded 8,820 board feet of lumber; *i.e.*, the sheared logs produced 10.7 percent overrun as compared to the usual overrun of 20.1 percent.

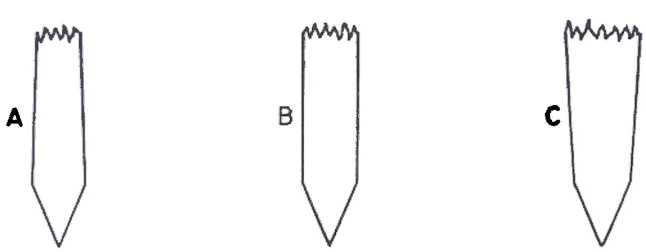

Figure 2. — Styles of shearing knives. (A) Tapered knife with thin root. (B) Parallel-sided knife. (C) Tapered knife with thick root.

Table 1 RELATION BETWEEN STUMP DIAMETER AND LENGTH OF SHEAR-CAUSED SPLITS IN PLANED BOARDS.

Stump Diameter	Split Length		Logs Cut	Boards Measured
	Maximum	Average		
Inches	- - - -Inches- - - -		- - -Number- - -	
12	14	8.1	6	36
14	25	10.3	12	70
16	31	11.6	8	44
18	22	8.7	2	21
20	50	20.6	2	21

The same mill (located in South Carolina) observed what appeared to be even more severe splitting when 30 longleaf pines were sheared with a single blade closing against a fixed anvil. The sheared butt logs were conventionally converted to lumber, dried, and planed—except that the butt ends of the boards were not trimmed. Length of shear-caused splits in the planed boards was positively correlated with stump diameter (Table 1).

Mill management concluded that butt logs from sheared trees 16 inches and less in diameter would have to be cut back 24 inches before conversion to lumber; larger butt logs would require a 48-inch trim to eliminate most splits in the lumber. Such a trimming practice, although resulting in lumber loss, has some virtue; Hallock (2) has reported that the portion of loblolly pine trees immediately adjacent to the ground yields lumber that frequently warps excessively when dried.

As the fundamentals of shearing appear well established, and since southern pine is seldom cut at temperatures below freezing, the study here reported was confined to measurement of force and work to shear and of magnitude of knife-induced splits as affected by log diameter, wood specific gravity, and knife sharpness angle. Because of equipment limitations, cutting speed was 2 inches per minute. The literature indicates that cutting velocity apparently has little effect on shearing force, but there are no published comparisons of fast and very slow cutting speeds.

Procedure

A stratified random sample of green southern pine bolts, 8-1/2 feet long, was obtained in central Louisiana. Factors in the experiment were:

1) Diameter class: 5.1, 9.7, and 13.6 inches inside bark at midlength
2) Specific gravity (green volume and ovendry weight): 0.40-0.46 and 0.47-0.52 as determined by averaging the values of disks sawn from both ends of each bolt
3) Sharpness angle: 22-1/2 and 45°
4) Replications: three

Thus, the experiment required 36 bolts: (three diameters) (two specific gravities) (two sharpness angles) (three replications). Each log was sheared at midlength regardless of knot locations, with bark in place, and at wood temperatures in the range 60 to 80°F. Prior to shearing, the green logs had been stored for several months under a water spray; moisture contents were determined immediately after each log was sheared. As has been noted, cutting velocity was 2 inches

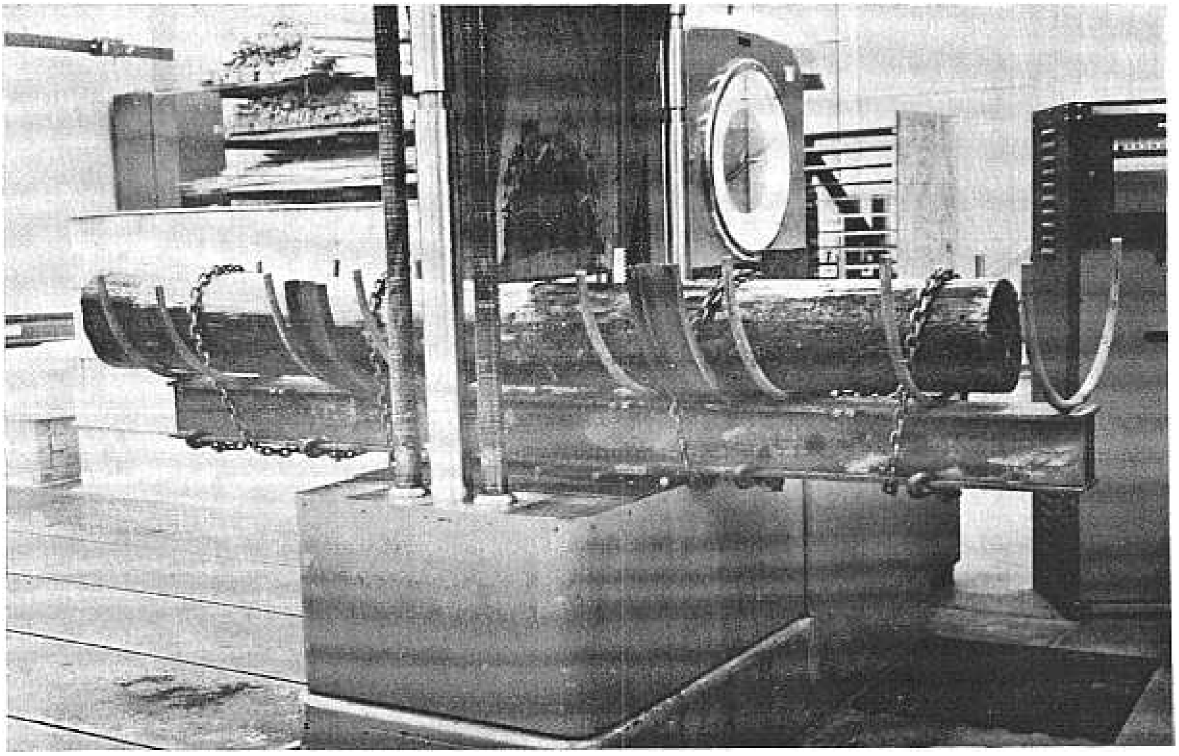

Figure 3. — Setup to shear logs 5 to 15 inches in diameter with 120,000-pound universal testing machine. Anvil width was 10-3/4 inches, cutting speed 2 inches per minute, and knife thickness 3/8-inch.

per minute. The mild-steel knife was 3/8-inch thick with parallel sides; anvil width was 10-3/4 inches (Figs. 1, 3). The knife was sharpened by grinding to 22-1/2° at the beginning of the experiment and became progressively duller as half the logs were sheared; it was then resharpened to 45°, and the remaining logs were sheared.

Cutting force was continuously graphed in relation to knife position as the knife passed through each log. After each log had been sheared, the two pieces were split on a diameter line parallel to the knife travel, and the sheared end stained to reveal checks and splits caused by the knife. Average and maximum check depths were determined.

Table 2. — MAXIMUM SHEAR FORCE, WORK, AND AVERAGE CHECK DEPTH WHEN BARK-COVERED, ROUND, GREEN, SOUTHERN PINE LOGS WERE SHEARED WITH A 3/8-INCH-THICK KNIFE CLOSING AGAINST A FLAT ANVIL.[a]

Average Log Diameter Inside Bark and Specific Gravity[b]	22-1/2° Sharpness Angle			45° Sharpness Angle		
	Force (pounds)	Work (foot-pounds)	Check Depth (inch)	Force (pounds)	Work (foot-pounds)	Check Depth (inch)
	9,975	2,885	0.8	12,466	4,191	1.4
	12,533	4,506	.8	15,300	4,339	1.1
	22,900	13,618	1.0	32,100	18,120	1.4
	36,300	20,637	1.0	41,183	22,001	1.3
0.40 - 0.46	55,933[c]	37,822[c]	.9	51,933	33,016	1.4
.47 - .52	47,967	36,983	1.1	73,517	49,838	1.3

[a]Cutting velocity 2 inches per minute. Each value is an average of three replications.

[b]Based on green volume and ovendry weight.

[c]Values are high because these three low-gravity logs averaged 15.1 inches in diameter, whereas the three high-gravity logs cut with the 22-1/2° knife averaged only 13.3 inches in diameter.

Results

Data for logs of the three diameters and two specific gravity classes are shown for each sharpness angle in Table 2. In Table 3 the effects of primary variables are tabulated. Values found significantly different (0.05 level) by analysis of variance appear below an asterisk. The values in Table 3 are derived from the data in Table 2; *i.e.*, under the heading *Diameter of bolt*, each value is a 12-log average; those under the headings of *Specific gravity* and *Sharpness angle* are 18-log averages.

Check depth was unaffected by log diameter, but interacted with specific gravity and sharpness angle. Thus with the 22½° knife, specific gravity of the wood had little effect on check depth (Table 2); with the 45° knife, check depth was significantly greater in low-gravity wood (1.4 inches) than in high-gravity wood (1.2 inches).

Table 3. — TABULATION OF THE EFFECTS OF PRIMARY VARIABLES (FROM TABLE 2).

Factor	Maximum Force (pounds)	Work to Shear (foot-pounds)	Average Check Depth (inches)
	*	*	
	12,569	3,980	1.1
	33,121	18,594	1.2
	57,338	39,415	1.2
	*	*	
	30,885	18,275	1.2
	37,800	23,051	1.1
	*	*	*
	30,935	19,409	0.9
	37,750	21,918	1.3

Shearing force and work to shear averaged greatest for dense 13.6-inch logs cut with a knife having a 45° sharpness angle (73,517 pounds, 49,838 foot-pounds), and were least for low-density, 5.1-inch bolts cut with a knife having 22-1/2° sharpness angle (9,975 pounds, 2,885 foot-pounds). Shear force built to a maximum about three-fourths the way through the log; it then dropped rapidly as the knife travelled the remaining distance. A momentary peak of force commonly occurred near the three-quarter point (Fig. 4, top).

At a cutting velocity of 2 inches per minute and with cutter thickness constant at 3/8-inch, shearing force (F_p, pounds) of green southern pine at 60 to 80°F. can be expressed in terms of bolt diameter inside bark (inches), sharpness angle (β, degrees), and wood specific gravity (ovendry weight and green volume).

For green southern pine logs sheared with bark in place, shearing force is:

$$F_p = -76{,}268 + 5{,}173\ (diameter) + 104{,}485\ (specific\ gravity) + 373\ (sharpness\ angle) \quad [1]$$

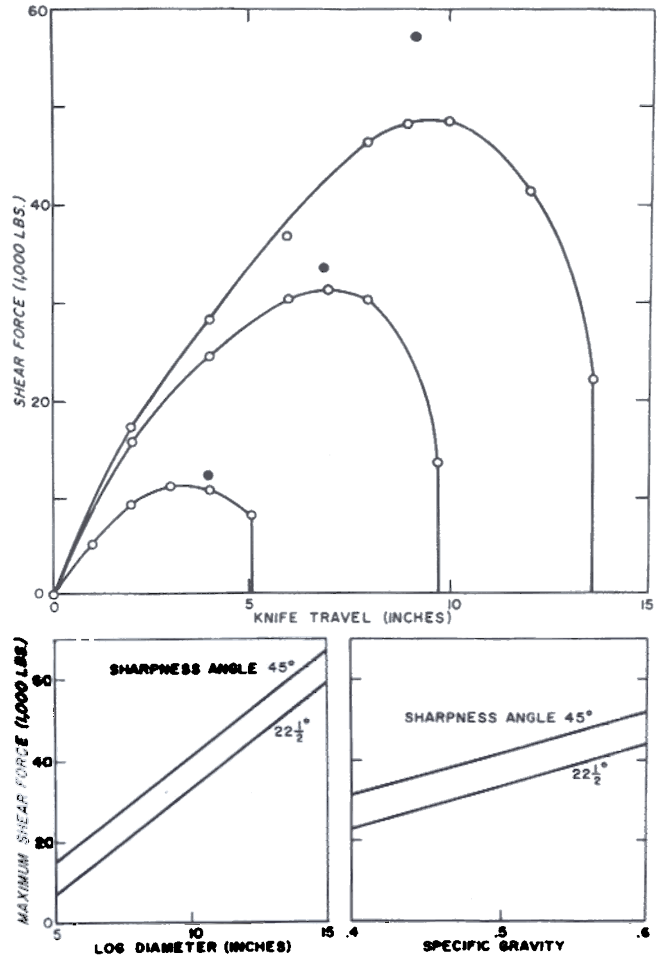

Figure 4. — Force to shear green southern pine logs. (Top) Force related to knife travel when shearing green southern pine logs in three diameter classes (5.1, 9.7, and 13.6 inches). Circles defining curves each represent information from 12 logs; i.e., data from both high- and low-gravity logs and from both 22-1/2 and 45° knife angles were pooled. The solid point above each curve shows the average (and position of occurrence) of maximum peak forces that lasted only momentarily; the peaks tended to occur when the knife was about three-quarters through each log. (Bottom) Relationships between maximum shearing force and factors of log diameter, specific gravity (basis of green volume and ovendry weight), and sharpness angle. Curves were plotted from regression equation 1 by holding all factors but the one of interest at average value. Average log diameter was 9.51 inches; average specific gravity was 0.467.

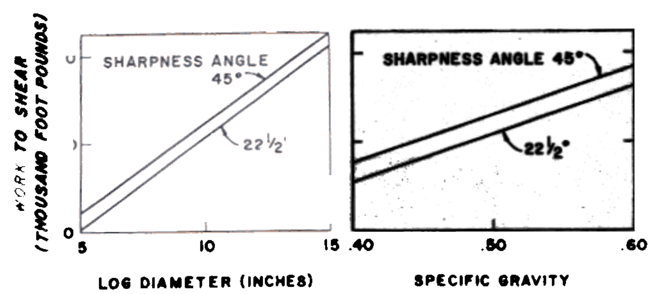

Figure 5. — Relationships between work to shear and factors of log diameter, specific gravity (basis of green volume and ovendry weight), and sharpness angle. Graphs were plotted from regression Equation [2] by holding all factors but the one of interest at average value. Average log diameter was 9.51 inches, and average specific gravity was 0.467.

This equation is graphed in Figure 4 (bottom). Within the range of the factors tested (sharpness angles 22-1/2 to 45°, bolt diameters 5 to 15 inches, and specific gravity on ovendry weight and green volume basis 0.40 to 0.52), Equation [1] accounted for 81 percent of the variation. Standard error of the estimate was 9,680 pounds.

Work to shear (foot-pounds) is expressed:

$$Work = -71{,}538 + 4{,}048\ (diameter) + 102{,}589\ (specific\ gravity) + 171\ (sharpness\ angle) \quad [2]$$

Within the range of the study, Equation [2] accounted for 93 percent of the variation. Standard error of the estimate was 4,500. The equation is graphed in Figure 5.

Because machine builders must design for the maximum shear force expected, it is of interest that, with a knife having 45° sharpness angle, one 13.6-inch-diameter log of 0.51 specific gravity required 92,000 pounds to shear through a knot cluster. To shear 20-inch southern pine logs of high density with this—or a thicker—knife, it is likely that forces in excess of 100,000 pounds would occasionally be required.

When sheared logs were viewed in radial section, each annual ring showed a check at an earlywood-latewood boundary (Fig. 6B). Checks were least severe in the smallest logs sheared with the 22-1/2° knife, where they averaged 0.8 inch deep; they were most severe in the larger logs of low density sheared with the 45° knife, where they averaged 1.4 inches deep.

In addition to the shallow checks shown in Figure 6B, one to several rather lengthy checks (Fig. 6C) generally formed in each sheared log just prior to emergence of the knife.

At a cutting velocity of 2 inches per minute, with cutter thickness constant at 3/8-inch, average check depth (inches) of green southern pine sheared at 60 to 80°F. can be expressed in terms of bolt diameter inside bark (inches) and sharpness angle (β, degrees). Wood specific gravity proved to be not significant.

$$Average\ check\ depth = 0.411 + 0.0147\ (diameter) + 0.0172\ (sharpness\ angle) \quad [3]$$

Within the range of factors tested, Equation [3] accounted for 55 percent of the variation with standard error of the estimate of 0.19 inch.

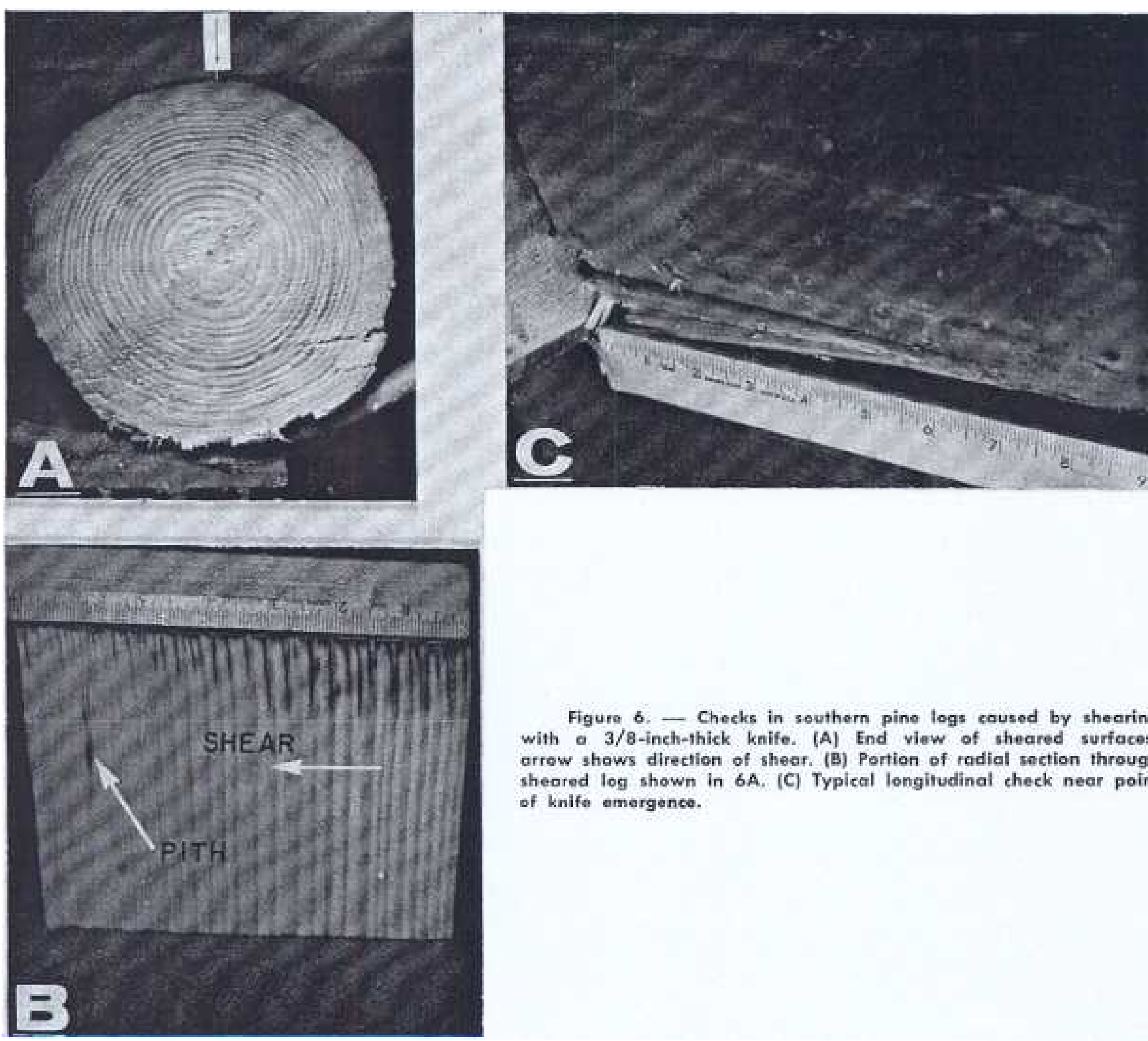

Figure 6. — Checks in southern pine logs caused by shearing with a 3/8-inch-thick knife. (A) End view of sheared surfaces; arrow shows direction of shear. (B) Portion of radial section through sheared log shown in 6A. (C) Typical longitudinal check near point of knife emergence.

In an equation for maximum check depth in inches (ignoring the large splits occurring near knife emergence), only sharpness angle was significant:

$$\textit{Maximum check depth} = 0.0944 + 0.0588\ (\textit{sharpness angle}) \qquad [4]$$

Equation [4] accounted for 39 percent of the variation with standard error of the estimate of 0.85 inch.

Equations [3] and [4] describe checks illustrated in Figure 6B; the check (or checks) found near knife emergence were much longer, as illustrated in Figure 6C.

Literature Cited

1. ERICKSON, J. R. 1967. Crosscut shearing of wood. IUFRO Congr. Proc. 1967, Vol. 8, Munich.
2. HALLOCK, H. 1965. Sawing to reduce warp of loblolly pine studs. USDA Forest Serv. Res. Pap. FPL 51, 52 pp. Forest Prod. Lab., Madison, Wis.
3. JOHNSTON, J. S. 1967. Investigation of some variables in the crosscutting of small logs by shear blades. IUFRO Congr. Proc. 1967, Vol. 8, Munich.
4. ———. 1968a. An experiment in shear-blade cutting of small logs. Pulp Pap. Mag. Can. 69(3):77-82.
5. ———. 1968b. Crosscutting trees and logs by shear blades. Can. Forest Ind. 88(6):34-37.
6. ———. 1968c. Experimental crosscut shearing of frozen wood. Proc., Forest Eng. Conf. Amer. Soc. Agr. Eng., ASAE Pub. PROC-368, pp. 47-49, 55. East Lansing, Mich.
7. ———. 1968d. Experiments in cross-cutting with shear blades. Forest Prod. J. 18(3):85-89.
8. KEMPE, C. 1967. Forces and damage involved in the hydraulic shearing of wood. Stud. Forest. Suecica 55, 38 pp.
9. KUBLER, H. 1960. [Cutting timber with vibrating knives.] Holz Zentralblatt 86(115):1605-1606.
10. McINTOSH, J. A., and E. L. KERBES. 1969. Lumber losses in tree shear felling. Brit. Columbia Lumberman 53 (10):43-46.
11. WIKLUND, M. 1967. Forces and damages in felling and bucking with knife and shear type tools. Forsk. Skogsarbeten Rep. 9, 39 pp.
12. WOODSON, G. E., and P. KOCH. 1970. Tool forces and chip formation in orthogonal cutting of loblolly pine. USDA Forest Serv. Res. Pap. SO-52, 25 pp. South. Forest Exp. Sta., New Orleans, La.