SURFACE AND SUBSURFACE CHARACTERISTICS RELATED TO ABRASIVE-PLANING CONDITIONS

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ABSTRACT

The goal of this study was to examine the quality of abrasively planed wood surfaces when variable grit sizes, feed speeds, and depths of cut are used. Our observations show that grit size and wood structure and density seem to have larger effects on the depth and type of damage than feed speed and depth of cut. Coarser grit sizes seem to cause greater damage than finer grit sizes.

Surface damage in Douglas-fir occurs at every grit size, feed rate, and depth of cut combination; the earlywood shows more severe damage than the latewood. Surface damage is more variable in hard maple and yellow-poplar than in Douglas-fir. This variability may be due to different cell types present at the surface and the angle of intersection between the surface and the rays. Similar machining conditions do not always have similar effects on the surface quality even in the same wood species. Other factors, such as moisture content, between and within species density variations or belt conditions, might also contribute to the surface quality variability, but these were not explored.

Keywords: Abrasive planing, grit size, feed speed, depth of cut, surface quality, Douglas-fir, hard maple, yellow poplar.

INTRODUCTION

Abrasive planing, like all grinding processes, removes material by a combination of rubbing, cutting, and plowing. Consequently, many shear and cleavage failures as well as significant compression forces crumple wood or crush cells on the surface or in the subsurface layers (Marra 1943; Stewart and Crist 1982; Murmanis et al. 1983). Damaged surface and subsurface layers have been linked to inferior adhesive-bonded joint performance (River and Miniutti 1975; Jokerst and Stewart 1976; River et al. 1981). The goal of the present study was to find out if there are abrasive-planing conditions that minimize significant surface or subsurface damage.

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Stewart (1976, 1978) observed that as stock removal rate increases:

abrasive belt loading increases to a point but then decreases,
power consumption increases, and
belt life decreases to a point but then increases.

On the basis of these observations, Stewart hypothesizes that stresses developing within the workpiece also vary in some nonlinear fashion with the stock removal rate. If this is true, then possibly there exists some combination of belt speed, feed speed, and depth of cut (the elements of stock removal rate) that minimize crushing and cell-wall cracking. Previously we examined wood surfaces prepared with 36 grit at rates similar to Stewart's 1976 and 1978 studies (5 to 86 $in.^3$ of wood per inch of width per minute) without discovering nondamaging conditions (River et al. 1981). In the present study we examined 36 and finer grit sizes and lower rates of stock removal for nondamaging conditions. Using microscopy, we examined the abrasively planed wood for damage, which we could relate to inferior bond performance based on our previous work.

MATERIALS AND METHODS

The woods of Douglas-fir (*Pseudotsuga menziesii*, specific gravity 0.60), yellow-poplar (*Liriodendron tulipifera*, specific gravity 0.53), and hard maple (*Acer saccharum*, specific gravity 0.69) were examined. Nominal 4/4 lumber of these species was cut to 3¾ by 60 inches for abrasive planing and conditioned to 8% equilibrium moisture content.

Abrasive belts of 36, 80, 100, 120, or 150 grit size were mounted in turn on a multiple-head abrasive planer. Each belt was predulled to stable working sharpness before planing the test material. The machine feed speeds and depths of cut in the earlier study were:

45 and 90 feet per minute,
0.010, 0.040, and 0.080 inch;

and in the present study:

35, 45, 55, 60, and 65 feet per minute,
0.002, 0.003, 0.005, 0.010, and 0.020 inch.

In all, thirty-four combinations of feed speed and depth of cut have been studied. In subsequent discussion, these combinations are often referred to in terms of the resulting stock removal rate (stock removal rate = feed speed × 12 × depth of cut). The machining conditions and resulting stock removal rates are set out in Table 1 (treatment parameter). In machining all the material, the machining conditions progressed from the mildest to the most severe to minimize belt damage and subsequent effects on the results. In machining a given board, sufficient material was removed in successive passes to ensure that the surfaces represented the machining conditions to be examined.

After machining, a small block, approximately ¼ by ½ by ½ inch, was cut from the larger piece for microscopy. The abraded surface of the block was dipped in a diluted epoxy resin to protect it during microtoming; then 25-μm transverse sections were microtomed in order to view the surface and subsurface cell layers in reflected near-ultraviolet light with a transmission peak at 365 nm. For photomicrographs Kodak Plus-X pan 35-mm film was used.

RESULTS

The broad range of abrasive-planing conditions examined is shown in Table 1. Table 1 shows the overlap of planing conditions between our two studies. It shows also that the maximum removal rate is not achieved at fine grit sizes and high wood density.

Douglas-fir

Surface and subsurface damage is found at every set of planing conditions. In severe cases earlywood cells are crushed to a depth of 10 to 12 cells with the upper layers forming a compact mat (as shown in Fig. 1, when 36 grit was used). In the latewood the damage is less severe—only two to three cells deep. However, the compressive forces crumple earlywood cells below the surface (Fig. 2).

The finer grit sizes appear to cause less damage, as complete crushing of earlywood cells extends only three to six cells deep (Fig. 3). In latewood the surface damage is minimal, but the earlywood cells beneath the surface still are crumpled (Fig. 4).

Feed speed and depth of cut make no appreciable difference in the damage caused at any one grit size. For example, compare Fig. 5 (stock removal rate 1.26 in.^{3}/in./min) with Fig. 6 (6.6 in.^{3}/in./min) and Fig. 7 (16 in.^{3}/in./min) in which all three samples are machined with 80 grit.

Hard maple

Surface and subsurface damage is not as severe as in Douglas-fir but is still found at every set of planing conditions. In maple the fibers are more likely to be torn away or compressed into vessel lumina than to be crushed flat. Ray cells are often left protruding above the surface when the fibers are torn away. When crushing occurs, it extends only five or six cells deep. The severity of damage is variable but cannot be positively linked either to feed speed or depth of cut. For example, a piece machined with 36 grit at 35 ft/min and 0.010-inch depth of cut shows severe damage (Fig. 8), but a piece machined with a higher stock removal rate (36 grit at 45 ft/min and 0.020-in. depth of cut) shows virtually no damage (Fig 9). This observation supports our hypothesis that at some rate of stock removal (not necessarily the lowest) the compression force on the wood may be reduced to a level minimizing the damage. Similar types of, and variability in, the amount of damage occur with 80 and smaller grits, but the patterns of variability at these grit sizes do not support our hypothesis. For example, pieces of wood machined with 80 grit at 45 ft/min, 0.020-in. depth of cut or at 35 ft/min and 0.010-in. depth of cut show equal damage (compare Figs. 10 and 11 with Figs. 8 and 9). Although the severity of damage is not linked to feed speed or depth of cut, at machining levels within the range of stock removal rates applied, the damage seems less when 120 and 150 grit are used (Fig. 12).

Yellow-poplar

Surface and subsurface damage is found at every set of planing conditions. The amount and severity of damage appear intermediate between the damage in Doug-

TABLE 1. *Experimental design relating feed speed, depth of cut, stock removal rate, species, and grit size.*

Treatment parameter			Species														
Feed speed	Depth of cut	Stock removal rate	Douglas-fir					Yellow-poplar					Hard maple				
ft/min	*1/1,000 in.*	*in.³/(in. of board width)/min*	grit size														
35	2	0.84	—	—	—	—	150[1]	—	—	—	—	150	—	—	—	—	150
45	2	1.08	—	—	—	—	150	—	—	—	—	150	—	—	—	—	150
35	3	1.26	36	80	100	120	150	36	80	100	120	150	36	80	100	120	150
60	2	1.44	—	—	—	—	150	—	—	—	—	150	—	—	—	—	150
45	3	1.62	—	—	—	—	150	36	80	100	120	150	36	80	100	120	150
75	2	1.80	36	80	100	120	150	—	—	—	—	150	—	—	—	—	150
55	3	1.98	36	80	100	120	—	36	80	100	120	—	36	80	100	120	—
35	5	2.10	36	80	100	120	150	36	80	100	120	150	36	80	100	120	150
60	3	2.16	—	—	—	—	150	—	—	—	—	150	—	—	—	—	150
90	2	2.16	—	—	—	—	150	—	—	—	—	150	—	—	—	—	—
65	3	2.34	36	80	100	—	—	36	80	100	—	—	36	80	100	—	—
45	5	2.70	36	80	100	120	150	36	80	100	—	150	36	80	100	—	150
75	3	2.70	36	80	100	120	150	36	80	100	120	150	36	80	100	120	150
90	3	3.24	—	—	—	—	150	—	—	—	—	150	—	—	—	—	—
55	5	3.30	36	80	100	120	—	36	80	100	120	—	36	80	100	120	—
60	5	3.60	—	—	—	—	150	—	—	—	—	150	—	—	—	—	—
65	5	3.90	36	80	100	—	—	36	80	100	—	—	36	80	100	—	—

TABLE 1. *Continued.*

Treatment parameter			Species														
Feed speed	Depth of cut	Stock removal rate	Douglas-fir					Yellow-poplar					Hard maple				
ft/min	*1/1,000 in.*	*in.³/(in. of board width)/min*	*grit size*														
35	10	4.20	36	80	100	120	—	36	80	100	120	—	36	—	100	—	—
75	5	4.50		80	—	—	150	—	80	—	—	150	—	80	—	—	—
45	10	5.4	36*	80*	100*	120*	—	36*	80*	100*	120*	—	36	80	100	—	—
90	5	5.4	—	—	—	—	150	—	—	—	—	150	—	—	—	—	—
55	10	6.6	36	80	100	120	—	36	80	100	120	—	36	80	100	—	—
65	10	7.8	36	80	100	—	—	36	80	100	—	—	36	80	100	—	—
35	20	8.4	36	80	100	120	—	36	80	100	—	—	36	80	100	—	—
75	10	9.0	—	80	—	—	—	—	80	—	—	—	36	80	—	—	—
45	20	11	36	80	100	120	—	36	80	100	—	—	—	80	100	—	—
90	10	11	36**	—	—	—	—	36**	—	—	—	—	—	—	—	—	—
55	20	13	36	80	100	120	—	36	80	100	—	—	36	80	100	—	—
65	20	16	36	80	100	—	—	36	80	100	—	—	36	—	—	—	—
75	20	18	—	80	—	—	—	36	80	—	—	—	—	—	—	—	—
45	40	22	36**	—	—	—	—	36**	—	—	—	—	—	—	—	—	—
45	80	43	36**	—	—	—	—	36**	—	—	—	—	—	—	—	—	—
90	40	43	36**	—	—	—	—	36**	—	—	—	—	—	—	—	—	—
90	80	86	36**	—	—	—	—	36**	—	—	—	—	—	—	—	—	—

[1] Most data are from the present study; * indicates data from both Murmanis et al. (1983) and the present study; ** indicates data from Murmanis et al. (1983).

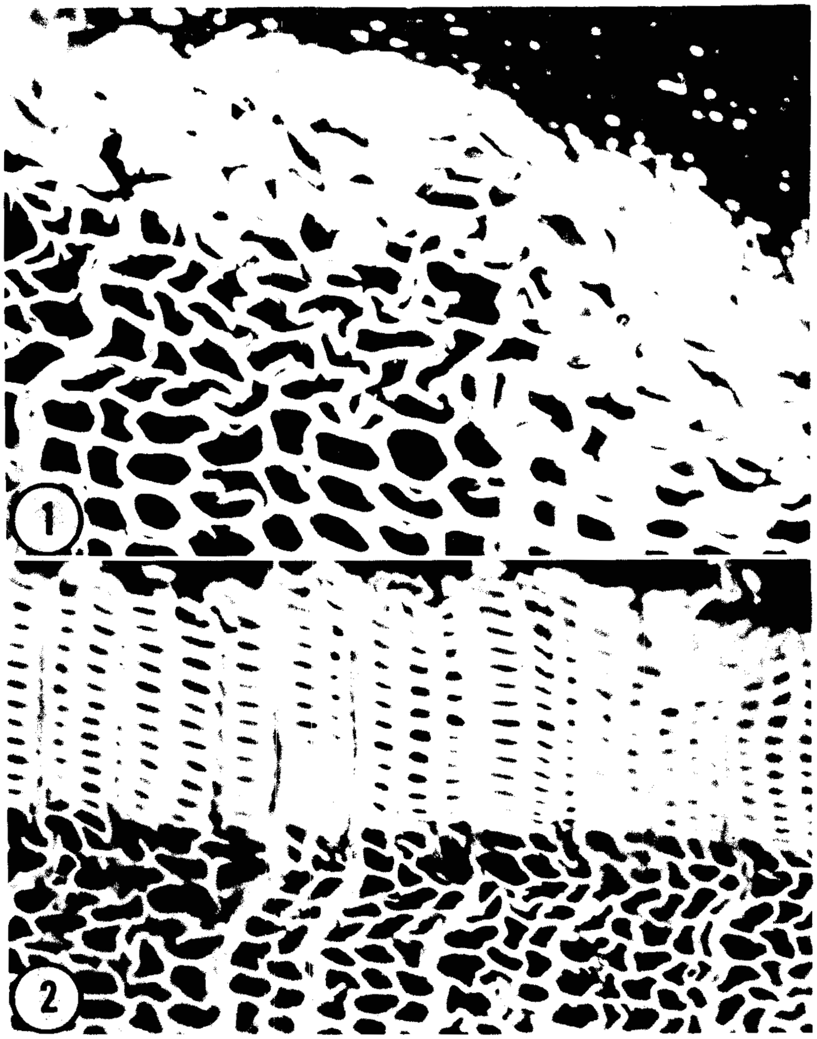

FIG. 1. Douglas-fir (36 grit, 35 ft/min, 0.003 in.). Earlywood compacted to a depth of about six cells, crumpled and broken to an additional depth of five to six cells. ×162.

FIG. 2. Douglas-fir (36 grit, 35 ft/min, 0.003 in.). Latewood surface with damage one to two cells deep but underlying earlywood cells crumpled and some broken. ×125.

las-fir and hard maple. Fibers are crushed to a depth of five or six cells as in maple, but they are more likely to be pressed into vessel lumina since there are a greater number of vessels than in maple (Fig. 13). As in Douglas-fir latewood, and in maple, there are areas of the yellow-poplar pieces where damage is minimal (Figs. 14 and 15). In contrast to maple, yellow-poplar ray cells do not protrude above the surface after abrasion probably because the rays are narrower and weaker. In yellow-poplar there also seems to be some trend toward lesser damage with finer grit sizes, and as with the other two species examined, the effects of feed speed and depth of cut are negligible.

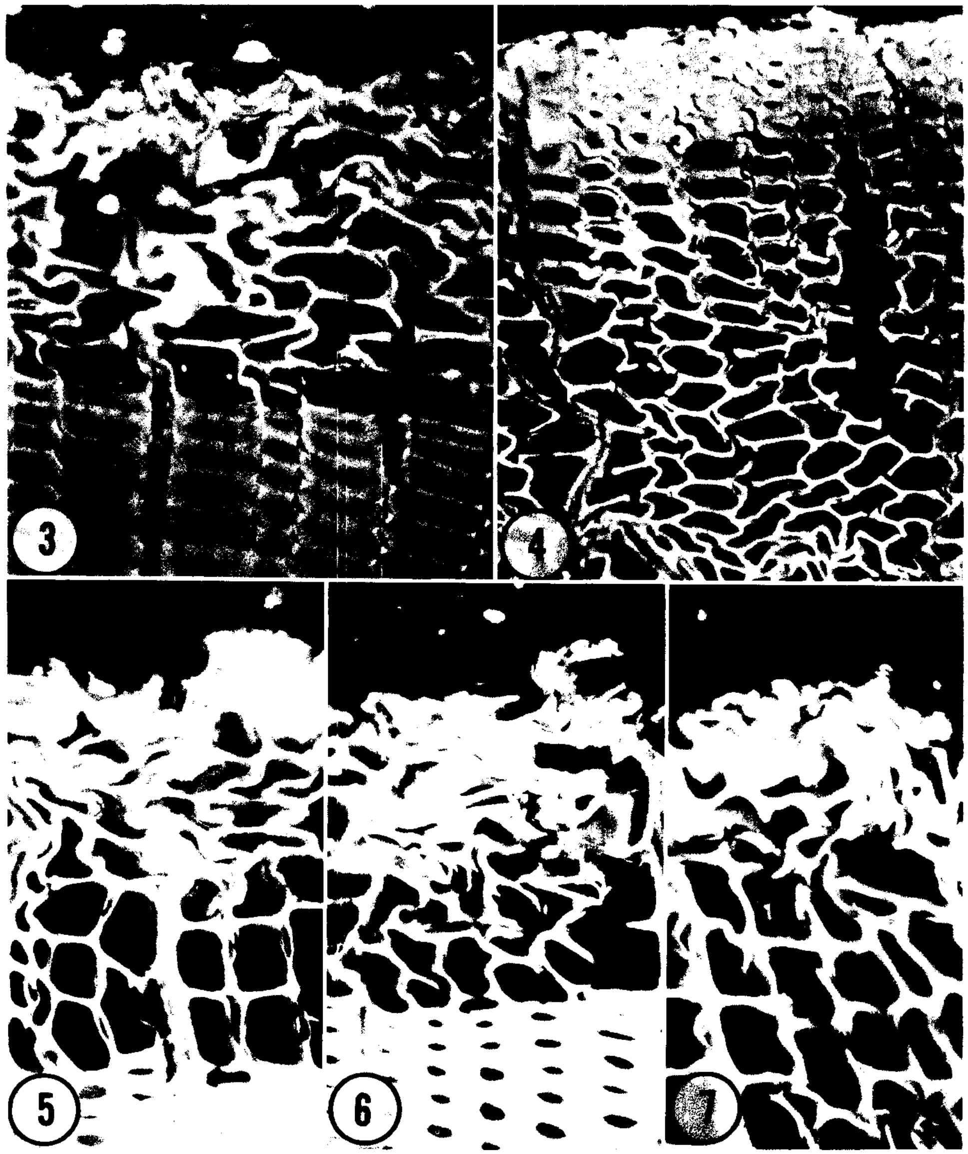

FIG. 3. Douglas-fir (120 grit, 55 ft/min, 0.010 in.). Earlywood compacted to a depth of three to six cells and crumpled an additional four to five cells deep; latewood with some cracking between rows of cells. ×170.

FIG. 4. Douglas-fir (120 grit, 35 ft/min, 0.003 in.). Latewood surface relatively sound except for cracking between rows of cells; underlying earlywood crumpled to a depth of 14 to 15 cells, with some cracking evident. ×98.

FIGS. 5–7. 5.—Douglas-fir (80 grit, 35 ft/min, 0.003 in.). 6.—Douglas-fir (80 grit, 55 ft/min, 0.010 in.). 7.—Douglas-fir (80 grit, 65 ft/min, 0.020 in.). All samples show similar damage when the same grit but different feed speeds and cuts of depth were used. ×170.

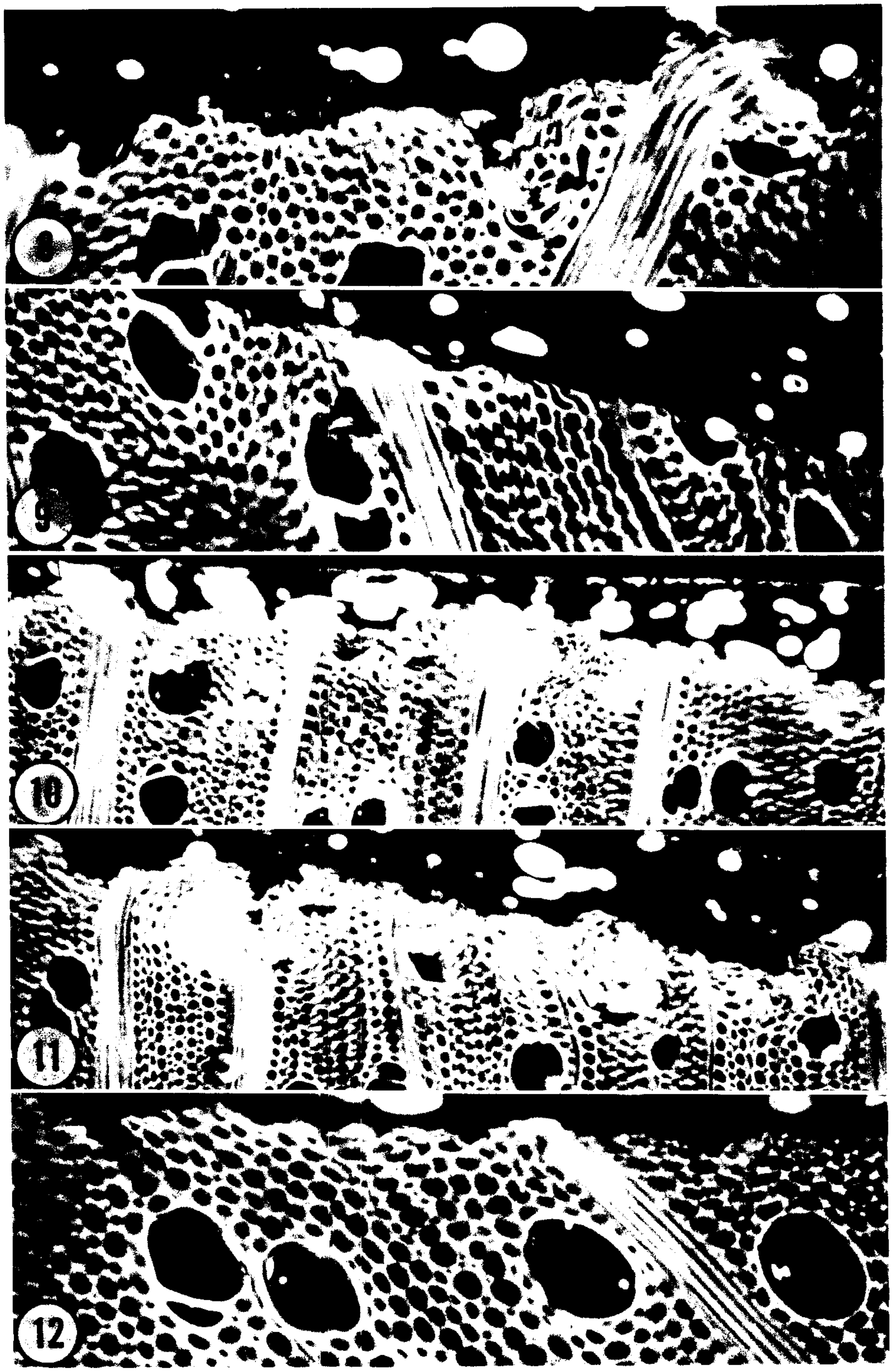

FIG. 8. Hard maple (36 grit, 35 ft/min, 0.010 in.). Surface severely damaged; fibers in some regions flattened to a depth of two to three cells or pressed into vessel lumina; ray protrudes above the surface and pressed into vessel lumen. ×170.

FIG. 9. Hard maple (36 grit, 45 ft/min, 0.020 in.). Almost no surface damage present. ×170.

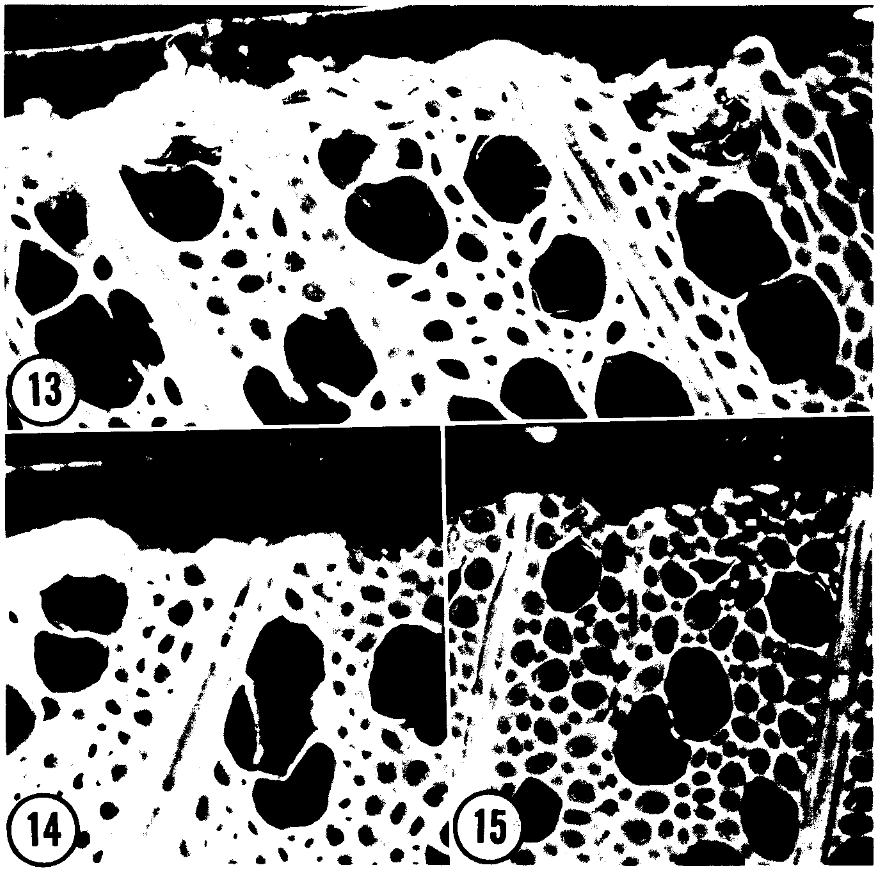

FIG. 13. Yellow-poplar (36 grit, 55 ft/min, 0.020 in.). Some fibers flattened or pressed into vessel lumina. ×162.

FIGS. 14, 15. Yellow-poplar. 14.—(80 grit, 55 ft/min, 0.010 in.). 15.—(80 grit, 65 ft/min, 0.003 in.). Both surfaces show minimal damage. ×162.

DISCUSSION AND CONCLUSIONS

This study provides additional information about the problems of abrasive-planing damage. The trends observed in the course of this and the previous study may be of future use.

Grit size, wood density, and wood structure seem to have larger effects than feed speed and depth of cut on the depth and type of damage that occurs at least within the conditions of our studies. Damage seems greater with coarser grit sizes. Larger particles plow deeper furrows. Many layers of cells are compacted at the bottom of these deep furrows, with less severe crushing between them. Crushing is usually more severe in earlywood tracheids and in vessels than in latewood tracheids and fibers. Thick-walled cells are more likely to be fractured and torn

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FIGS. 10, 11. Hard maple. 10.—(80 grit, 35 ft/min, 0.010 in.). 11.—(80 grit, 45 ft/min, 0.020 in.). Both samples show severe surface damage. ×98.

FIG. 12. Hard maple (120 grit, 35 ft/min, 0.003 in.). Fairly sound surface; fibers flattened or slightly crumbled only to a depth of one to three cells. ×170.