ANATOMICAL STUDIES OF CCA PENETRATION ASSOCIATED WITH CONVENTIONAL (TOOTH) AND WITH MICRO (NEEDLE) INCISING

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ABSTRACT

Individual tooth and needle incisions were made on radial and tangential surfaces of white spruce and jack pine heartwood test samples. The samples were pressure-treated with CCA preservative and then dissected in various planes to examine patterns of preservative penetration. Lateral movement of preservative from incisions was generally greater in the radial than in the tangential direction (average R/T ratio about 1.5). Longitudinal movement was in the range of 15 to 20 times that of lateral movement. Ray tissue facilitates movement in the radial plane, but difficulty is encountered in traversing latewood bands. An individual tooth incision resulted in a larger zone of treated wood but also in a greater amount of wood tissue damage than a needle incision. When compared as ratios of treated wood area to damaged wood area at a depth of 9 mm beneath the original treated surface, needle incisions were decidedly superior. For an equivalent degree of preservative treatment, conventional incising teeth damaged about ten times the amount of wood tissue as did incising needles.

Keywords: CCA penetration, tooth incision, needle incision, wood anatomy, white spruce, jack pine.

INTRODUCTION

Heartwood of many species of conifers is difficult to penetrate with preservative chemicals so that treated lumber and timbers from these species may not be adequately protected against decay. Incising is one of the techniques that can be effective in improving penetration in these refractory timbers (Perrin 1978).

Incising with conventional oyster-knife teeth, however, is a fairly brutal process suitable mainly for large timbers (railway ties, etc.) where appearance is not a major concern. In smaller material, such as dimension lumber for decking, patios, fences and related uses, both the appearance factor and potential strength reductions become significant. Under these circumstances, it is important that incision type, depth, frequency, etc., are carefully established to provide the minimum amount of damage necessary to achieve adequate preservative treatment. In order to achieve this objective, basic information is required on the three-dimensional movement of preservative in wood of different species related to different types of incisions and treatment variables. The present investigations were carried out with a view to derive some of this basic information.

A recent development of considerable interest with respect to the preservative treatment of softwood lumber is the process of needle incising that originated in West Germany. Incisions made by steel needles are much smaller than conventional tooth incisions and are virtually invisible on the surface of treated lumber. Some preliminary information on the application of this process to Canadian softwood species has been provided by Forintek Canada Corp. (1985, 1986) and in more detail by Ruddick (1985, 1986).

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FIG. 1. Modified oyster-knife tooth and #16 steel needle mounted in holders for experimental incising.

As with other types of incisions, a reasonable approach to the problem of establishing optimum spacing of the incisions, both laterally and longitudinally, would appear to be basic investigations on the spread of preservative solution around individual incisions in relation to the three-dimensional structure of wood. Wood anatomy considerations are of fundamental importance in wood preservation as they are responsible for wood's anisotropic permeability characteristics and have an important influence on the limits of preservative penetration in different directions.

Anisotropic behavior of wood with respect to its permeability characteristics is a well-established phenomenon. Ratios of longitudinal to transverse permeability as high as 10^6 have been reported in some species (Comstock 1970), although values of less than 100 are much more common. For wood of European spruce, Hackbarth and Liese (1975) reported values of 34 for sapwood and 18 for heartwood. With the exception of results reported by Courtois (1964) for European spruce, the transverse permeability of softwoods is generally considered to be somewhat greater in the radial than in the tangential direction (Banks 1970). This is supported by Comstock (1970), who cites reports by several investigators that show ratios of radial to tangential permeability extending from 5 to 37 for pines and from 0.04 to 10 for spruces.

Anisotropy in permeability derives from anatomical characteristics of the cell elements involved in the transport of preservative chemicals in the different directions. Longitudinal and tangential movements involve chiefly the longitudinal tracheids and intertracheid bordered pits (Wardrop and Davies 1961; Bailey and Preston 1969; Banks 1970). Pit aspiration is, therefore, a major factor contributing to poor penetration of liquids in wood of gymnosperms. Movement in the radial direction is facilitated by the rays (Wardrop and Davies 1961; Liese and Bauch 1967; Behr et al. 1969; Banks 1970). The relative effectiveness of the ray tracheids compared with the ray parenchyma seems to differ somewhat between species (Wardrop and Davies 1961; Behr et al. 1969).

Few investigators have made comparative observations on the permeability of earlywood versus latewood in softwoods. Wardrop and Davies (1961) and Behr et al. (1969) have indicated that latewood appears to be more easily penetrated than earlywood. Preferential penetration of latewood was reported by Cooper (1973) for Douglas-fir and some other species. In amabilis fir, however, the earlywood was penetrated much better than the latewood. In European spruce, Courtois (1964) observed that axial penetration was greater in earlywood than in latewood.

The present investigation was carried out to examine the new needle-incising technique and to obtain comparative information on preservative movement and wood tissue damage in this and in conventional tooth-incising. We were also interested in gathering information on the relation between preservative penetration and specific anatomical characteristics of wood and on how penetration may be influenced by moisture content (green vs. air-dry) at the time of incising and preservative treatment.

MATERIALS AND METHODS

Sample preparation

A total of 160 specimens of white spruce [*Picea glauca* (Moench) Voss] and jack pine (*Pinus banksiana* Lamb.) were prepared from selected heartwood portions of 50-mm × 100-mm green boards originating from eastern Canada. After about half of the samples were air-dried, they were all machined to expose accurately aligned radial and tangential surfaces, and they varied slightly in size around target dimensions of 38 mm × 38 mm × 400 mm long. One surface of each sample, selected for accurate alignment in either a radial or tangential plane, was designated for incising. Both end surfaces of each sample were sealed with two coats of resorcinol resin to prevent end penetration during preservative treatment.

Incisions were made with a commercial incising tooth (modified oyster knife design) and with a #16 steel needle (diameter approximately 0.68 mm) to a uniform depth of 9.5 mm (Fig. 1). Full penetration of the tooth resulted in an incision about 17 mm long on the treatment surface. Several tooth and several needle incisions were made on each designated surface, allowing a generous space between incisions and avoiding areas of significant grain distortion.

Preservative treatment

A 2.4% oxide solution of chromated copper arsenate (CCA) was applied in a full cell process. A preliminary vacuum (710 mm) was applied for 30 min before

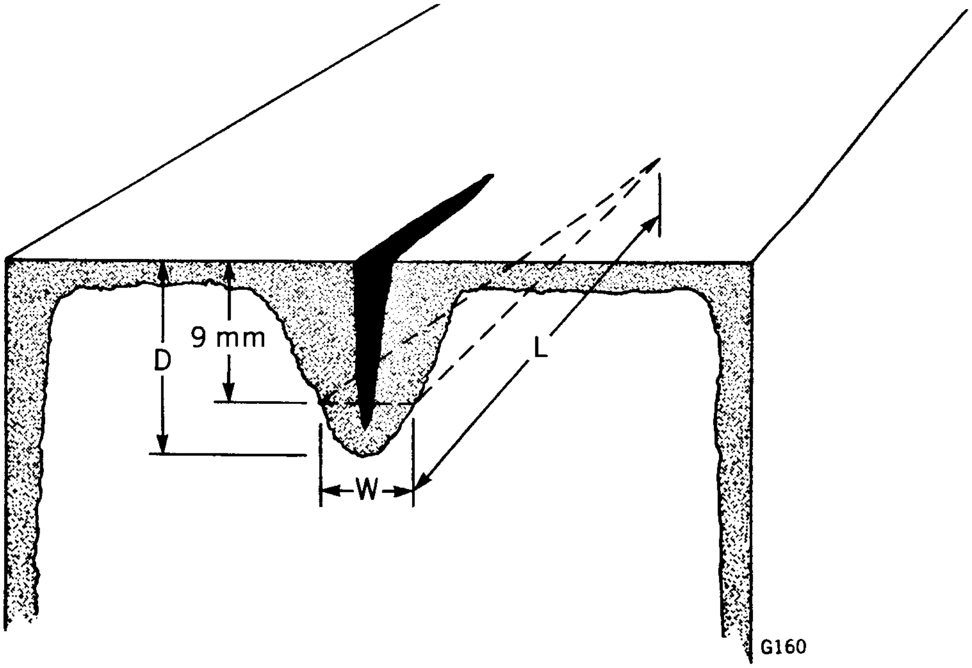


FIG. 2. Penetration characteristics D, W, and L measured on test specimens.

introducing the solution into the retort. The pressure period (22 C and 1,030 KPa) was 3 h. A 30-min final vacuum terminated the process.

Assessment of the extent of preservative movement associated with incisions

Following a 6-week drying and fixation period indoors, five samples of each type were cross-cut through the center of each incision, stained with a 0.5% solution of chrome azurol S, and examined with a stereomicroscope equipped with a micrometer eyepiece. Measurements were made of the maximum depth of preservative penetration and also the lateral spread of preservative (radial or tangential as the case may be) at a depth of 9 mm beneath the treated surface (Fig. 2).

For samples incised on tangential surfaces, the needle incisions were also used to obtain data on lateral movement in earlywood compared to that in latewood. This was accomplished by recording whether the lateral penetration measurement

TABLE 1. *Depth penetration of CCA preservative achieved with 9.5 mm-long needle and tooth incisors.*

Species	Moisture condition	Penetration (mm) associated with: Needle incisions	Penetration (mm) associated with: Tooth incisions
Spruce	Green	10.2 (0.61)	10.8 (0.58)
Spruce	Air-dry	10.4 (0.79)	10.8 (0.83)
J. Pine	Green	10.0 (0.60)	11.0 (1.14)
J. Pine	Air-dry	10.0 (0.56)	11.7 (1.22)

Std. deviations in parentheses.

TABLE 2. *Lateral breadth* of CCA-treated zone at 9 mm beneath the treated surface.*

		Breadth (mm) of treated zone associated with	
Species	Moisture condition	Needle incisions	Tooth incisions
Spruce	Green	1.75 (0.77)	3.69 (2.24)
Spruce	Air-dry	2.52 (1.17)	3.23 (1.03)
J. Pine	Green	1.65 (0.55)	2.38 (0.65)
J. Pine	Air-dry	2.07 (1.37)	4.63 (2.16)

* Ave. for both radial and tangential directions.
Std. deviations in parentheses.

(W in Fig. 2) at the arbitrary depth of 9 mm happened to fall in earlywood or in latewood tissue and then obtaining a corresponding measurement in the opposite tissue layer adjacent in the direction toward the incised surface.

Longitudinal penetration associated with incisions was measured on samples cut longitudinally to expose a surface 9 mm below the original incised surface. Measurements were made in one direction along the grain from the center of the incision to the extreme point of preservative movement.

Anatomical observations on the penetration of preservatives and the assessment of wood tissue damage associated with incisions

Selected areas adjacent to incisions were sectioned and prepared for microscopic study. Both transverse and longitudinal sections were examined during the course of the investigation and extensive use was made of the histochemical indicator stain dithiooxamide (Bedford et al. 1959; Yata et al. 1979) to reveal the location of the preservative chemicals in the wood structure and help identify the pathways of and the obstacles to preservative movement.

The type and extent of damage to the wood tissue caused by the two kinds of incisions were also subjects of microscopic study and photographic recording at several levels of magnification. Samples exhibiting typical areas of incision damage were mounted on metal stubs, coated with a layer of gold and examined with a scanning electron microscope (SEM).

Finally, an attempt was made to develop a method to compare the efficiency of the two different methods of incising based on the ratio of the amount of penetrated tissue to the amount of damaged tissue.

RESULTS AND DISCUSSION

Depth of penetration

Measurements of the maximum depth of penetration of CCA preservative associated with the two types of incisions are summarized in Table 1. Significantly deeper preservative penetration was obtained with tooth incisions than with needle incisions. We presume that this is related to the difference in wood tissue damage associated with the two types of incisions. Compare Figs. 6 and 12 (needle incisions) with Fig. 13 (tooth incision). Differences between species and between green vs. air-dry treatments were generally small and not significant.

Preservative penetration was generally greater for incising on a tangential as compared with a radial surface. The reason for this, as will be discussed in greater detail later, is that the preservative solution is able to move in the wood more readily in the radial than in the tangential direction.

TABLE 3. *Lateral spread of CCA preservative at needle incisions.*

Species	Moisture condition	Radial direction (mm)	Tangential direction (mm)		
			Earlywood	Latewood	Ave.
Spruce	Green	2.31 (0.90)	1.47 (0.44)	1.39 (0.51)	1.43
Spruce	Air-dry	3.04 (1.31)	2.41 (0.94)	2.05 (1.05)	2.23
J. Pine	Green	2.41 (1.13)	1.73 (0.55)	1.73 (0.55)	1.73
J. Pine	Air-dry	3.57 (1.15)	1.23 (0.24)	1.23 (0.25)	1.23

Std. deviations in parentheses.

Lateral breadth of preservative—Treated zone

Measurements of the lateral breadth (W in Fig. 2) of the preservative-treated zone resulting from the two different types of incisions at a depth of 9 mm below the treated surface are shown in Table 2. Tooth incisions always resulted in a broader treated zone than needle incisions. Differences between tooth incisions and needle incisions, using Student's t-test, were significant for all categories of material. This is at least partly attributable to the greater thickness of the incising tooth as compared with the diameter of the needle. Differences associated with species or with moisture condition occasionally showed significance, but these were not consistent.

Lateral spread of preservative from both tooth and needle incisions was better in the radial than in the tangential plane. Calculated R/T ratios were above unity for all categories of material and ranged from 1.02 to 2.93. Movement in the radial plane is facilitated by the ray tissue system, while tangential movement appears to depend largely on the bordered pit openings for cell to cell transfer (Wardrop and Davies 1961: Banks 1970). Unfortunately, the bordered pit system in the heartwood of these species is prone to such problems as incrustation of membranes and/or torus aspiration, which can seriously reduce permeability.

Differences in the tangential penetration of preservative solution in earlywood as compared to latewood were not consistent or significant (Table 3). In pine, preservative movement was significantly better in green than in air-dry samples. Spruce, on the other hand, showed significantly better movement in the air-dry material. Differences between radial and tangential movement in these samples were highly significant in favor of radial movement. In all cases, the significance of differences between means was tested using Student's t-test.

Longitudinal spread of preservative solution

Data on longitudinal movement of preservative measured at a depth of 9 mm beneath the treated surface are shown for the sample material in Table 4. The measurements were made in one direction along the grain starting from the center of the incision (dimension L in Fig. 2).

As might be expected, on the basis of the larger dimension of the incising tooth, the longitudinal extent of the treated wood zone was greater for tooth incisions than for needle incisions. The highest values for both species occurred in air-dry tooth-incised samples. In every treatment group, the mean values for jack pine samples showed greater longitudinal movement of preservative than their spruce counterparts. In statistical "t" tests, however, the differences between the various treatment means were almost entirely nonsignificant. These tests were applied to

TABLE 4. *Longitudinal movement of CCA preservative (single direction) associated with needle and tooth incisions.*

Species	Moisture condition	Penetration (mm) associated with	
		Needle incisions	Tooth incisions
Spruce	Green	14.5 (2.38)	16.75 (1.32)
Spruce	Air-dry	14.1 (5.24)	17.38 (4.08)
J. Pine	Green	19.2 (5.25)	20.41 (6.20)
J. Pine	Air-dry	19.4 (11.29)	26.38 (7.02)

Std. deviations in parentheses.

examine the differences between sample's means for species, moisture condition, and incision type.

Influence of wood structure and incision characteristics on preservative penetration

Radial Movement of Preservative:

(i) *White spruce*

The cross section of a test sample immediately adjacent to a tooth incision (Fig. 3) illustrates good radial movement of CCA preservative laterally from incisions in earlywood tissue. The earlywood tracheid walls are densely stained with the copper indicator dithiooxamide. Note that the compound middle lamella is also deeply stained.

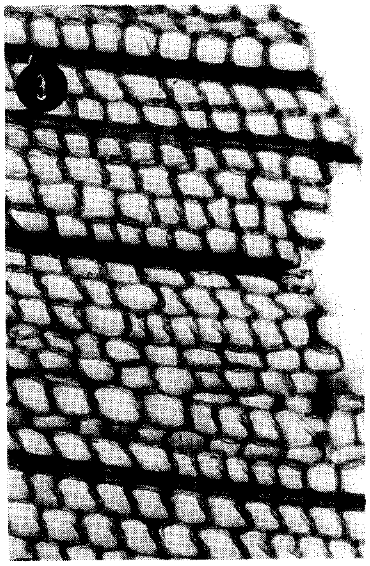
As reported widely in the literature (Wardrop and Davies 1961; Liese and Bauch 1967; Behr et al. 1969; Banks 1970), we also noted that ray tissues played an important role in the radial transport of preservtive, and both ray tracheids and ray parenchyma cells tended to be uniformly stained. The horizontal resin canals in fusiform rays also participate in preservative movement (Fig. 10, arrows) even if they are not very numerous.

Radial movement of CCA was definitely restricted in the latewood. Penetration from the surface or lateral spread from incisions often stopped abruptly at the earlywood-latewood boundary (Fig. 4). Poor radial transport of preservative through the latewood bands sometimes resulted in abrupt changes in the shape of the treated areas associated with incisions (Fig. 5). Even preservative transport in the rays was often halted at a latewood band (Fig. 6).

Latewood cells were often unevenly stained and some contained deposits of preservative in their lumina, while adjacent cells remained relatively unstained. Accumulations of preservative in the cell lumina were often observed at latewood bands where preservative penetration was terminated (Fig. 6, arrow).

(ii) *Jack pine*

Radial movement of CCA in jack pine heartwood was usually more erratic than in spruce. As in spruce, the preservative generally moved readily through the earlywood tissue but often appeared to be restricted at the latewood boundary (Fig. 7). Such latewood restrictions were observed less frequently in the green-treated samples. Latewood tracheids of jack pine often showed large concentrations of preservative in their lumina, while their cell walls and those of adjacent tracheids were virtually unstained (Fig. 8).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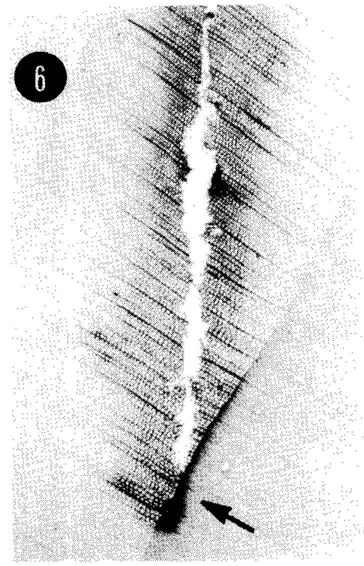
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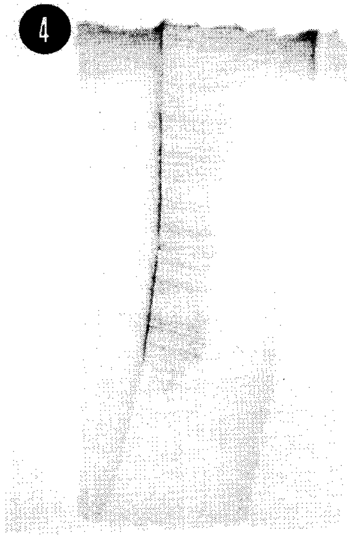
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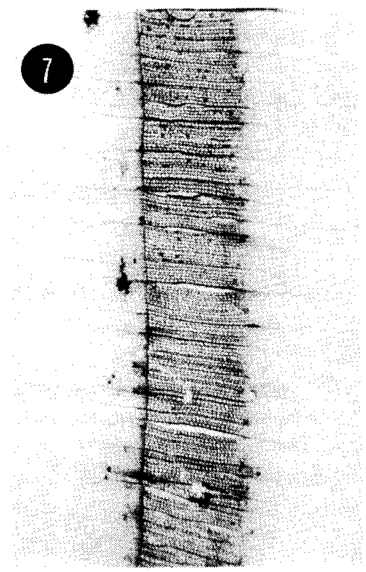
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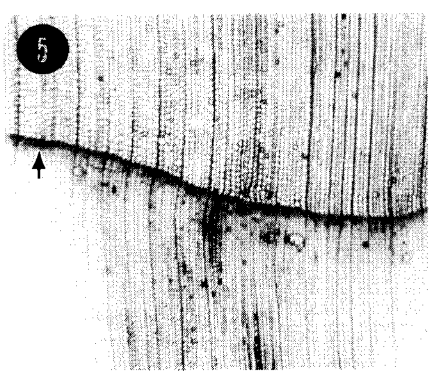
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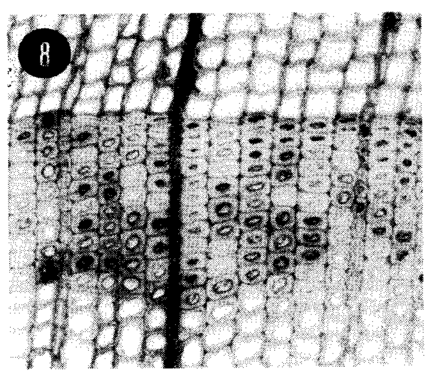
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As in spruce, rays and horizontal resin ducts appeared to contribute to radial movement of preservative. The ray tracheids in pine, however, often appeared to be less effective in this process than the ray parenchyma (Fig. 9).

Tangential Movement of Preservative:

The extent of tangential movement was usually somewhat less than that of radial movement. Differences in preservative transport between earlywood and latewood were much less prominent in tangential than in radial movement (Fig. 5). In both pine and spruce, however, we did see some examples of exceptional tangential movement of preservative in latewood bands. Preferential tangential penetration in latewood bands has been reported by several investigators (Wardrop and Davies 1961; Behr et al. 1969). Cooper (1973) found this to be particularly common in Douglas-fir but not in amabilis fir, which generally showed superior preservative penetration in earlywood.

As observed in connection with radial penetration, tangential penetration was more erratic in pine than in spruce. Examples of very good and/or of very poor penetration in pine could readily be found. In well-penetrated areas of both pine and spruce, the cell walls and compound middle lamellae stained deeply with the dithiooxamide. Dark staining of the bordered pit pairs was common and confirms the importance of these structures in preservative transport.

Longitudinal Movement of Preservative:

Since longitudinal penetration values are greatly in excess of tracheid lengths in these species, transfer of preservative solution via bordered pit pairs is also involved. There are, however, a great deal fewer pit transfers associated with longitudinal than with tangential movement. In both species, we saw evidence indicating that vertical resin ducts assist longitudinal movement of preservative to and from longitudinal tracheids and rays (Fig. 10).

Tissue damage and spread of preservative solution

A technique that we found useful in assessing the relationship between tissue damage and preservative spread was to make a saw cut and/or a planer cut to expose a new surface at a given depth (e.g. 9 mm) beneath the original treated surface. Application of the chrome azural indicator stain to the new surface revealed the patterns of preservative spread at this depth and clearly showed the

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FIG. 3. Spruce-tooth incised on a radial surface showing good radial movement of CCA preservative in earlywood tissue. Mag. 160×.

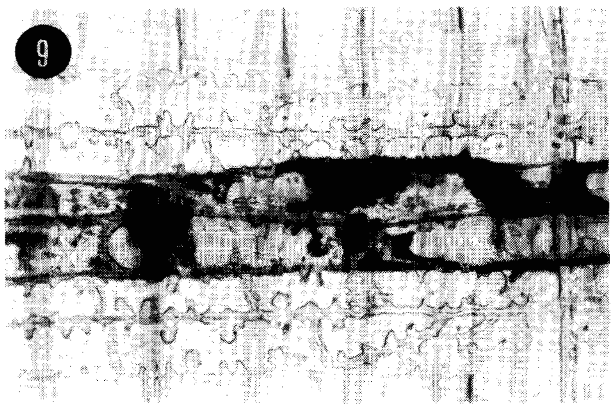
FIG. 4. Latewood bands obstruct radial movement of preservative. Spruce sample adjacent to a tooth incision applied on a radial surface. Mag. 5×.

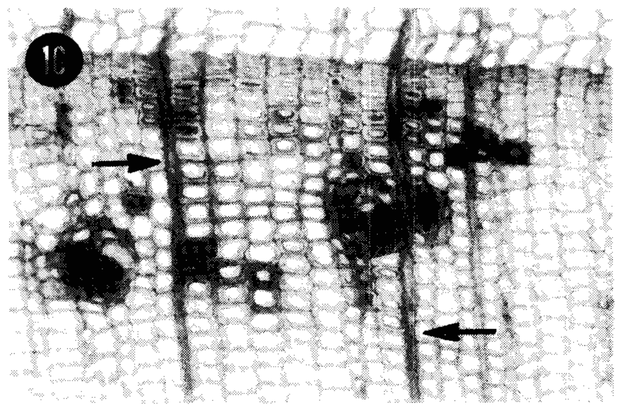
FIG. 5. As in Fig. 4, except adjacent to a tooth incision applied on a tangential surface. Mag. 20×.

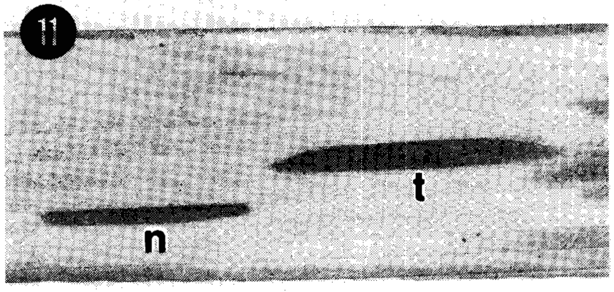
FIG. 6. Spruce, oblique needle incision shows radial penetration terminating at a latewood band and accumulation of preservative at that point. Mag. 15×.

FIG. 7. Effective radial penetration in earlywood is halted at the latewood boundary. Pine sample adjacent to a needle incision applied on a radial surface. Mag. 12×.

FIG. 8. Uneven penetration of latewood cell walls and deposits of preservative in cell lumina. Pine sample adjacent to a tooth incision applied on a tangential surface. Mag. 125×.







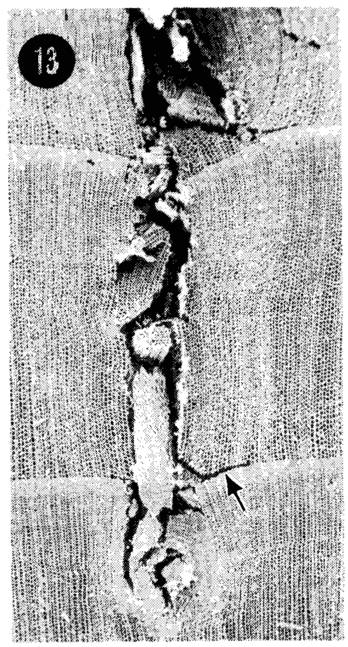


FIG. 9. Ray tracheids in pine may be less effective in preservative transport than ray parenchyma. Mag. 320×.

FIG. 10. Both horizontal (arrows) as well as vertical resin ducts appear to be involved in lateral and longitudinal movement of preservative. Spruce, Mag. 125×.

FIG. 11. Patterns of preservative spread resulting from a needle (n) and a tooth (t) incision on a radial surface 9 mm beneath the original incised surface. Spruce, Mag. 0.75×.

FIG. 12. SEM view of a needle incision penetrating from the tangential surface of a spruce test specimen. Mag. 20×.

FIG. 13. SEM view of a tooth incision penetrating from the tangential surface of a spruce test specimen. Mag. 20×.

differences in both lateral and longitdinal spread of preservative associated with the two types of incisions (Fig. 11).

A good deal of our sample material appeared to originate from relatively young fast-growing trees. The broad bands of earlywood tissue present in such material facilitate lateral movement of preservative in the radial direction with relatively fewer obstructing bands of latewood than would be found in narrower-ringed stock. Hackbarth and Liese (1975) reported similar observations with wood of European spruce.

Needle Incisions:

Because of their small size and sharply-pointed ends, needles offer a means of improving preservative penetration at a minimum cost in terms of tissue damage. An SEM view of a test sample cut through a needle incision (Fig. 12) shows the minor extent of crushing of soft earlywood tissue and a minimum of tangential separation at the annual ring boundaries.

The extent of wood tissue damage associated with needle incisions appeared to be basically similar in both species and for material incised in either green or air-dry conditions.

Tooth Incisions:

Tooth incisions resulted in a noticeably greater degree of wood tissue damage than needle incisions. A cross section through this type of incision (Fig. 13) reveals that the penetration of the incising tooth resulted in a compaction of the earlywood tissue along both sides of the incision. A zone of compacted earlywood has also developed at the base of the incision.

Another characteristic feature of tooth incisions penetrating from a tangential wood surface noted in the SEM was the development of tangential separations between earlywood and latewood at the annual ring boundaries (Fig. 13). These types of damage were fairly typical of both species and both moisture content conditions.

Amount of Wood Treated Versus Amount Damaged:

Our observations on the lateral and longitudinal movement of preservative clearly showed that a greater amount of treated wood resulted from an individual tooth incision than from a needle incision. On the other hand, the tooth incision caused a greater amount of tissue damage. The relationship between the amount of wood treated and the amount of wood damaged appeared to us to offer a reasonable basis for comparing the relative efficiency of the two types of incisions.

Areas of treated and of damaged wood calculated from measurements made on surfaces exposed at a depth of 9 mm were used to calculate ratios of treated wood to damaged wood areas. On the basis of these ratios, needle incisions were shown to be superior by a factor of about ten times. This means that the complete treatment of wood products to a depth of 9 mm could be accomplished with needle incising at about one-tenth the amount of wood tissue damage that would be necessary to achieve the same degree of treatment by using conventional tooth incising.

In actual practice, the relative disadvantage of tooth incising is even greater than that indicated above. Since the tooth is wedge-shaped, the damage at a depth of 9 mm in the wood is minimal compared to the damage that occurs closer to the treated surface. This does not apply to the incising needle.

The combination of superior treatment efficiency and desirable appearance characteristics makes the needle incising process hold a great deal of promise for the wood treating industry.

CONCLUSIONS

Movement of CCA preservative laterally from individual incisions was generally greater in the radial than in the tangential direction. Ray tissue facilitates movement in the radial plane, but difficulty appears to be encountered in traversing latewood bands.

A larger zone of treated wood results from a conventional tooth incision than from an experimental needle incision based on lateral and longitudinal measurements of preservative spread. Needle incisions, on the other hand, resulted in much less wood tissue damage than tooth incisions, giving them an overall superior efficiency rating based on the ratio of treated wood area to damaged wood area.

Differences between spruce and pine and between samples treated green versus air-dry were generally not large and not consistent.

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