

A CHEMICAL AND MICROSCOPIC STUDY OF DECAYED EARLYWOOD AND LATEWOOD OF LOBLOLLY PINE KILLED BY THE SOUTHERN PINE BEETLE¹

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ABSTRACT

Chemical and anatomical changes in the wood of loblolly pines (*Pinus taeda* L.) killed by southern pine beetles (*Dendroctonus frontalis* Zimm) were examined. The trees had been dead for approximately 20 months, and were harvested near Jacksonville, North Carolina. Decay occurred in both earlywood and latewood although the rate of deterioration was greater in the earlywood. The dominant patterns of decay in earlywood were dissolution of the secondary walls from the lumen outward toward the middle lamella, and finally a total destruction of cell-wall structure. Decay in latewood was characterized by localized dissolution of the secondary walls, and the formation of "soft-rot" type cavities in the S₂ layer of the secondary walls. Chemical analysis showed little or no difference in proportions of holocellulose and lignin in earlywood and latewood of sound and beetle-killed wood. One percent NaOH solubility of both earlywood and latewood was significantly greater in beetle-killed wood than in sound wood. These characteristics suggest that the primary fungus responsible for decay may be *Peniophora* sp., a fungus commonly found in stored southern pine logs. The results indicate that the beetle-killed wood could be used successfully as a furnish for pulp and reconstituted board products.

Keywords: Decay, chemical analysis, microscopy, loblolly pine, southern pine beetle, earlywood, latewood.

INTRODUCTION

An important cause of mortality in southern pine is the southern pine beetle *Dendroctonus frontalis* Zimm (Levi and Dietrich 1976). Severe epidemics occur frequently, and average annual losses in the southeastern United States are estimated to exceed 100 million cubic feet of growing stock (Bennett 1966).

Differences in the resistance of earlywood and latewood to fungal attack have been reported by several investigators. Levi and Dietrich (1976) noted that decay of beetle-killed timber appears to be concentrated in the earlywood portion of each growth ring; similar observations have been made by Lindgren (1951) for the decay of southern pine pulpwood caused by *Peniophora gigantea* Fr. He noted that in the early stages, there is moderate softening in earlywood; later stages are characterized by a pronounced softening of the earlywood and some attack of the latewood, without the formation of pockets or cracks in the wood.

Differences in the resistance of earlywood and latewood may be related to their chemical composition. The latewood of loblolly pine contains a higher percentage of cellulose and a lower percentage of nitrogen than the earlywood (Savory 1954).

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FIG. 1. Beetle-killed trees with no needles and few or no twigs. (Dead for approximately 20 months.)

Conversely, there is more lignin in the earlywood than in the latewood (Necesity and Cetlova 1963; Savory 1954). Differences of about 2% (29% in earlywood, 27% in latewood) in Klason lignin of extracted wood are typical for loblolly pine.

The objective of this study was to characterize the changes induced by decay fungi in beetle-killed southern pine wood. This was achieved by chemical and microscope studies of earlywood and latewood. The results will assist in the development of technical guidelines for the utilization of beetle-killed wood in pulp and board products.

MATERIALS AND METHODS

Five loblolly pines (*Pinus taeda* L.) killed by the southern pine beetle (*Dendroctonus frontalis* Zimm) were selected for the microscope and chemical studies (Fig. 1). The ages of the trees ranged from 35 to 40 years and their dbh ranged from 20 to 25 cm. They had been dead for approximately 20 months. The trees were in an advanced stage of deterioration with no needles, and many branches were missing. Bark was loose and decay had superseded blue stain in most sapwood areas. Two healthy loblolly pines of similar age and diameter to the beetle-killed pines were selected as controls. All trees were harvested at Camp LeJeune, Jacksonville, North Carolina.

Microscope studies

Cross-sectional discs were cut from each tree 1.3 m from the base. Five blocks (15 mm × 15 mm on the transverse face) were taken from each disc at highly decayed points on the circumference of the discs. The procedures used for embedding, sectioning, and staining wood blocks were based on those of Wilcox (1964).

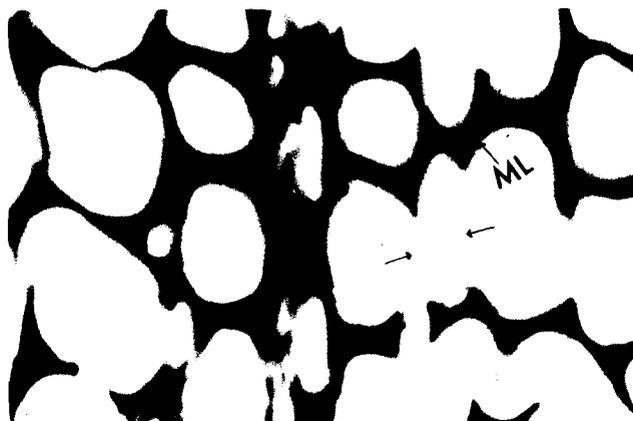


FIG. 2. Cross sections of springwood in beetle-killed loblolly pine wood. Shows almost total removal of secondary wall of tracheids and removal of some regions of compound middle lamella (\rightarrow). Note also thickened region of compound middle lamella at cell corners remained longer than other regions (ML). Magnification 290 \times .

Chemical studies

Similarly, samples from the sapwood fractions of highly decayed beetle-killed and sound loblolly pines were prepared from cross-sectional discs. A sharp wood chisel and razor blade were used to carefully separate the earlywood and latewood of each growth ring. Samples from replicate trees were combined to provide bulk samples of beetle-killed earlywood, beetle-killed latewood, sound earlywood, and sound latewood. These were ground separately in a standard model No. 3 Wiley mill to pass through a 20-mesh screen. Moisture contents on 0.5-g subsamples were then determined. Byrd's procedure using delignification with sodium hydroxide and acetic acid (1964) was used for the determination of holocellulose, Kirk's method using 72% sulphuric acid (1964) was used to determine Klason lignin content. One percent sodium hydroxide solubles were determined using TAPPI Standard T4M-59 (1959a), and ethanol-benzene extractives were removed according to TAPPI Standard T12M-59 (1959b).

RESULTS

Microscope studies

The most conspicuous change in structure of the earlywood cell walls of beetle-killed wood was dissolution of the secondary walls from the lumen outward toward the middle lamella and almost total destruction of cell walls in some areas (Fig. 2). Another feature of decay was a greatly increased tendency for the cell walls to separate into various layers. This was detected using polarized light; cell-wall separation occurred predominately between the S_1 layer and the compound middle lamella (Fig. 3).

In the latewood, decay was more localized than in the earlywood. In some instances, the pattern of decay was similar to that in earlywood: there was dissolution of the secondary wall from the lumen outward toward the middle lamella and cell-wall separation between the S_1 layer and compound middle lamella. The

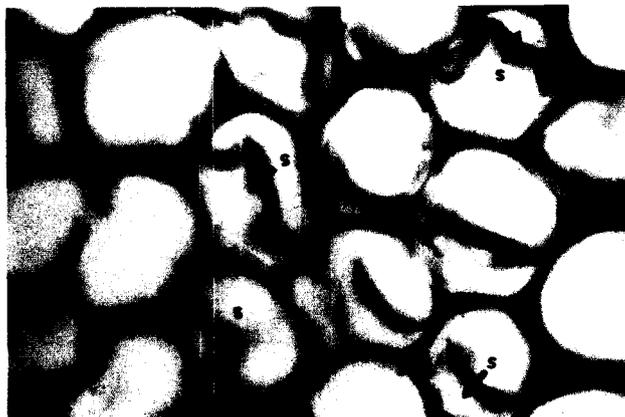


FIG. 3. Cross section of springwood in beetle-killed loblolly pine wood; polarized light photomicrographs show extensive cell separation (S), which is predominantly between S_1 layer and compound middle lamella. Magnification $260\times$.

major difference between earlywood and latewood was the formation of cavities within the secondary cell walls (the S_2 layer) of latewood tracheids. Almost complete dissolution of the S_2 layer had occurred in some areas (Fig. 4).

Differences in rates of decay of earlywood and latewood were clearly observed, the rate being greater in the earlywood.

Chemical studies

The results of chemical studies are summarized in Table 1. Holocellulose content of the latewood of sound pine was significantly higher ($P = 0.05$) whereas lignin content, 1% NaOH solubles and ethanol-benzene extractives were consistently and significantly lower ($P = 0.05$) than in earlywood.

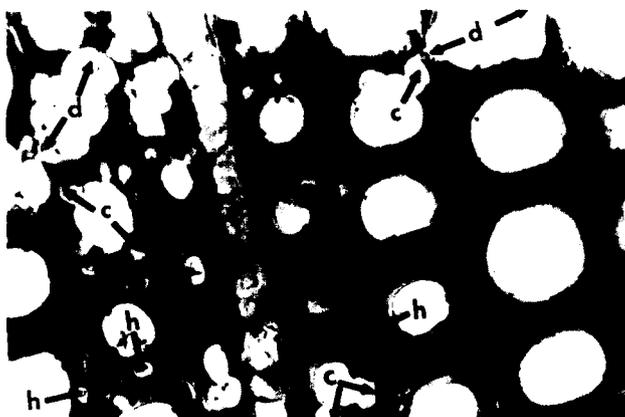


FIG. 4. Cross section of summerwood in beetle-killed loblolly pine wood; formation of cavities within cell walls (c), dark circles are fungal hyphae cut transversely (h) and dissolution of the secondary wall has been almost completed (d). Magnification $290\times$.

TABLE 1. Chemical composition¹ of springwood and summerwood of sound and beetle-killed Loblolly pine.

Chemical constituent	Springwood		Summerwood	
	Sound (%)	Beetle-killed (%)	Sound (%)	Beetle-killed (%)
Holocellulose	72.5	70.6	75.1	72.1
Lignin	28.6	27.6	26.8	27.3
1% NaOH solubles	14.4	24.9	12.3	22.5
Ethanol-benzene extractives	6.1	3.1	3.1	1.7

¹ All results are averages of three replicates.

There was no significant difference ($P = 0.05$) in holocellulose, lignin, 1% NaOH solubles and ethanol-benzene extractives in earlywood and latewood of beetle-killed loblolly pine.

Comparison between earlywood of sound and beetle-killed loblolly pine showed that the holocellulose and lignin contents were not significantly different ($P = 0.05$). There was a significant increase ($P = 0.05$) in 1% NaOH solubles and a significant decrease in ethanol-benzene extractives as deterioration occurred. Similar results were found in the comparison between latewood of sound and beetle-killed loblolly pine.

DISCUSSION

The chemical and microscopic changes caused by the fungal system responsible for deterioration of these beetle-killed trees are quite complex. There are similarities in the patterns of attack in earlywood and latewood, for example dissolution of the secondary wall and cell-wall separation. There were also differences, particularly in cell-wall cavity formation. The deterioration has characteristics of white-, brown-, and soft-rot.

The microscope studies of the earlywood of beetle-killed trees indicated several characteristics of white-rotted wood. These included progressive thinning of the cell walls (Cowling 1961; Liese and Schmid 1962; Meier 1955; Wilcox 1968), and cell separation (Necesany and Cetlova 1963; Wilcox 1968).

In the latewood, decay patterns such as localized thinning, bore hole formation, and cell separation were less common in comparison with the earlywood fraction. The predominant phenomenon of decay in latewood was the formation of cavities in the S_2 layer. Such cavities usually are associated with soft-rot fungi. However, cavities have also been found in the walls of both white-rotted and brown-rotted wood by Duncan (1960), Liese (1963) and Liese and Schmid (1962). Observation of cavities only in the latewood agrees with the findings of Duncan (1960) and Savory (1954), who indicated that soft-rot cavities are more conspicuous in latewood than in earlywood, especially in softwoods.

Peniophora incarnata (Pres.) Cooke has been shown to cause progressive thinning as well as the formation of cavities in the secondary-wall of Scots pine (*Pinus sylvestris* L.) (Ravilly 1971). In addition, *Peniophora gigantea* is the fungus found most commonly in stored southern pine pulpwood where it causes softening of the springwood and some attack of the latewood (Lindgren 1951). Efforts to isolate

decay fungi from the beetle-killed trees were unsuccessful. However, the similarity between patterns of attack observed in this experiment and those caused by *Peniophora* and the prevalence of this fungus in stored pine pulpwood suggests that *Peniophora* may also be the primary fungus responsible for decay in beetle-killed trees.

The results of the chemical studies indicating little changes in holocellulose and lignin content suggest that decay was of the white-rot type. Cowling (1961) and Kirk and Lundquist (1970) found that the amount and form of polysaccharides and lignin remaining in white-rotted wood at various stages of decay are not very different from those in sound wood. Lindgren (1951) showed that in southern pine pulpwood decayed by *Peniophora gigantea* both cellulose and lignin were attacked, causing little change in the chemical composition of the wood.

The solubility of wood in 1% NaOH is an indication of the type of decay that has taken place. As the wood decays, the percentage of the alkali-soluble materials increases in brown-rot attack (1961). A significant increase ($P = 0.05$) in 1% NaOH solubles of earlywood and latewood in beetle-killed wood in comparison with sound wood again confirms the mixed characteristics of the fungi attacking these beetle-killed trees.

The small changes in ethanol-benzene extractives suggest that only a small part of the polymers are attacked and that the affected portions are completely degraded and assimilated before other parts of the polymers are significantly affected. This is a characteristic of white-rotted wood (Cowling 1961). The results of chemical analyses support the earlier conclusion based on microscopic studies that both earlywood and latewood of beetle-killed trees were deteriorated. They also support the inference that *Peniophora* may be involved in the decay process.

An important implication of this research for the use of beetle-killed wood is that because of the high residual holocellulose content of the beetle-killed wood, it should be suitable for use in pulp and reconstituted board products. This has been confirmed recently in other studies (Ifju et al. 1979; Kelly et al. 1982).

CONCLUSIONS

This chemical and microscope study of decayed loblolly pine killed by the southern pine beetle has shown that deterioration occurs in both the earlywood and latewood although it is more rapid in the earlywood. The fungal system responsible for decay created microscopic characteristics of white- and soft-rot fungi. Chemical characteristics resembled those of both brown- and white-rot fungi. These effects are similar to those caused by *Peniophora* sp., a fungus commonly found in stored southern pine logs. The lignin and holocellulose contents of sound and decayed wood were similar, suggesting that the beetle-killed wood could be used as a furnish for pulp and reconstituted board products.

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