DISCOLOURATION IN THE WOOD OF LIVING AND CUT TREES

by

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Summary

The various kinds of discolourations in the wood of living and cut trees described in the literature are reviewed and I attempt to classify the different processes involved as physiological, biochemical, and chemical reactions. In a living tree, discolourations are initiated predominantly through wounds and dying branches and roots, where all three types of reactions may be involved. In some species, chemical reactions as e.g. between tannins and metals occur. Discolourations that develop after cutting of a tree are interpreted mostly as oxidative reactions; however, bacteria may also be involved. Chemical reactions of accessory compounds in contact with metals during wood processing are also discussed.

Introduction

The various kinds of discolourations along with wood decay cause the severest impairments to wood quality. They can develop in the wood of all living and cut trees. In recent decades, discolourations in wood have increased due to mechanised harvesting of trees and other anthropogenous influences that cause many wounds on living trees. Harvesting throughout the year, and modern drying procedures for lumber and veneer may, additionally, induce discolourations.

A vast amount of the valuable biomass wood could be used for higher quality products, if more knowledge existed on the development and characteristics of discolourations. The causes for many types of discolourations are not clearly understood and the methods for prevention are not known.

The various kinds of discolourations described in the literature are reviewed and additional information on some individual case studies is given. Discolourations are classified in two groups: those in living trees and those in cut trees. On the basis of this review, it may be possible to better understand basic patterns of discolourations and the different reaction mechanisms involved. Blue stain and wood decay are not included in this review.

Discolourations in living trees

Initiation by wounds, dying branches and roots

Shigo and Hillis (1973), Hillis (1977), Bauch (1980) discuss in reviews numerous studies which demonstrate that wounds in living trees initiate the formation of discoloured wood.

Major injuries to the tree — broken branches, severe logging damages — may cause discolouration of the entire core of the tree (Fig. 1). This kind of discolouration is of increasing importance due to improper pruning procedures — cuts flush with the joining stem — in plantations as has been demonstrated by Shigo et al. (1979) for Juglans nigra, and other species (Shigo, 1983).

Compared with true heartwood, the most common and typical pattern of discoloured wood is an irregular column of dark-coloured wood extending up and down the trunk (Shigo & Sharon, 1970; Bauch et al., 1982). Typical taxa with the potential of forming only discoloured wood, but no heartwood are the genera Acer, Betula, Carpinus, Fagus, Fraxinus and numerous tropical wood species, whereas other genera such as Juglans, Quercus and Abies form both types of alterations (Bauch et al., 1975; Shigo & Shortle, 1979; Phelps & McGinnes, 1980; Kuroda & Shimaji, 1983).

Minor injuries such as those made by insects, sapsuckers, small animals, etc. can also lead to serious wood defects as shown in Entandrophragma utile (Gottwald & Willeitner, 1976) and in Juglans nigra (Höster, 1966). Although the defects do not cause serious injury to the tree they do cause serious economic loss for veneer production. Experiments with artificial wounding has helped to clarify the wound response in general and the individual response of the tree species studied. Softwoods (Kucéra, 1973; Von Aufsess, 1975) and hardwoods (Bauch et al., 1980; Rademacher et al., 1984) have specific differences. Tissues formed after wounding and tissues formed before wounding that are altered must be considered separately.

According to several authors (Wardell & Hart, 1970; Rier & Shigo, 1972; McGinnes et
al., 1977) the earliest response to wounding occurs at the cambium and adjacent tissues external to the time of wounding. After wounding the still living cambium begins to form a ‘barrier zone’ which, according to Shigo’s CODIT model (Shigo & Marx, 1977) is the strongest boundary for compartmentalisation of infected wood.

To estimate the effects of wounds upon the extent of discoloration and decay, Shigo (1975) developed a concept that helps to explain a tree’s response to wounding and infection. After wounding there are three major stages in the processes that may lead to discoloured and decayed wood:

- stage 1 includes all those processes associated with host response to wounding. At this phase, physiological, biochemical and chemical reactions of the tissue occur. This stage may last a very short time.

- stage 2 comprises those events that occur when microorganisms invade the xylem and interact with the tree. These pioneer invaders are in most cases – but not always – bacteria and non-hymenomycetous fungi. The discoloured wood that forms may be more or less protective than the contiguous wood. As some discoloured wood changes further, wetwood forms.

- at stage 3 wood decaying microorganisms may invade the discoloured wood.

In recent years investigations have shown that discolorations in some species develop in the absence of bacteria and other microorganisms. The tree itself may respond to wounds with reactions that lead to discoloured wood (e.g. Torelli, 1978). In other species, pioneer bacteria may contribute to wood discoloration (Shigo & Sharon, 1970; Shortle & Cowling, 1978; Shortle et al., 1978; Ward & Zeikus, 1980). Wetwood formation is always important. Tiedemann et al. (1977), Brill et al. (1981), Schink et al. (1981), isolated several strains of aerobic and anaerobic bacteria from wetwood in soft- and hardwood species and characterised their physiological ability to cause discoloured wood.

In softwoods, the acidity increases due to the bacterial activity, which in turn stimulates extended reactions in the living woody tissue (Bauch et al., 1975). However, Worrall & Parmeter (1982) believe that in white fir, wetwood formation is the result of host response to parenchyma death.

Wetwood is a serious problem in trees affected by pollution. In fir (Abies alba) for instance, the wetwood spreads out into the less vital sapwood (Fig. 3). This kind of discoloration fades out almost completely during the drying of the sawn wood. The strength properties of the wood are not affected (Frühwald et al., 1981).

In hardwoods, the pH value in wetwood shifts to alkaline (Tiedemann et al., 1977), which means that the microorganisms will obey other rules than in softwoods (Schink et al., 1981; Schmidt et al., unpubl.).

Reactions of tannins with metals

In contrast to the restricted knowledge on discoloration after wounding, the chemical reactions of some accessory compounds such as tannins with metals have been described in detail. According to the relevant literature, tannins can react in living wood tissue when, for instance, an iron nail is driven into it (Fig. 4). But occasionally in injured systems, metals like iron or manganese penetrate into the tissue and lead to extensive reactions.

Discolourations initiated after felling

Oxydative reactions

In the classical forest products literature, the discolorations in round wood after felling or in sawn logs or boards after drying were frequently described as oxydative reactions. Indeed, in many cases this explanation is adequate. But usually it was not shown whether there were chemical reactions of accessory organic compounds associated with enzymes after oxygen penetrated the tissues.

For instance, in 1911 Neger already described the orange discoloration of freshly cut Almus wood as an oxydative reaction. Recently Hruttiord and Luthi (1981) identified the oregonin (a diaryl heptanoid xylanosoide) as the original compound, which was oxidised by chemical and enzymatic means to the orange colour. Oxygen and polyphenol oxidase were responsible for the discoloration. Similar reactions may occur in other species.

The brown stain of lumber of pine species (Oldham & Wilcox, 1982) and Douglas fir (Miller et al., 1983) is a serious problem that begins during storage in moist conditions. The stain is a result of an enzymatic reaction involving peroxidases on tannins and phlobaphenes. The intensity of the stain is dependent on the moisture content of the wood, the length of time the wood is exposed to air, and the temperature during drying (Millett, 1952, Stutz, 1959). Ward and Pong (1980) indicated that brown stain developed in lumber of sugar pine when wetwood was present in the wood (Fig. 5). Bacterial wetwood can predispose the wood to oxydative brown stain during drying. This predisposition depends upon the composition of the microbial population.
Fig. 1. Discolouration in *Terminalia superba* Engl. & Diels originating from a broken branch. — Fig. 2. Spots of discolouration in *Entandrophragma utile* Sprague initiated at the cambium, which contain hyphae. — Fig. 3. Wetwood in diseased trees of *Abies alba* Mill. spreading out in peripheral sapwood to black water transport. — Fig. 4. Reaction of tannins of *Quercus robur* L. with the iron of a nail.

Fig. 5. Kiln-dried sugar pine shows chemical brown stain in centre board that contained wetwood (W) but not in boards with sapwood (S) or normal heartwood (H). End sections (bottom) were cross cut from rough, dry boards and planed (Ward & Pong, 1980). — Fig. 6. Reaction of accessory compounds in wetwood boards with the metal band. The sapwood board remains bright (see arrow). Ward, unpubl. — Fig. 7. Discolouration in *Pycnanthus angolensis* Exell starting after felling at the fresh cross cut and extending in the fibre direction.
Reaction of accessory compounds with metals

Chemical reactions will take place in wood when metals come in contact with tannins or other accessory compounds. Wood in many species with a high tannin content will discolor, when metal tools contact the wood, provided that the wood is wet. In wet lumber, the chemical reaction is the same as that in the living tree (Fig. 4).

Figure 6 shows a serious problem of discoloration in green lumber of Western Hemlock for overseas shipment. The lumber was bound by steel bands with an epoxy-powdered zinc coating. It was striking that the two boards with wetwood of pH 4.3 reacted in contact with metal, but the sapwood board remained bright (Ward, unpubl.).

Reactions associated with bacteria

Some discolorations in several species are associated with bacteria (cf. Zimmermann, 1974). The question is, whether the enzymes from the bacteria are directly involved in the development of discoloration or whether the metabolic products of bacteria — acids or ammonia — indirectly initiate discoloration by starting chemical reactions with accessory compounds in the wood.

The reactions leading to the discoloration in the light coloured tropical wood, Pycnanthus angolensis (Ilomba) (Fig. 7) were recently identified (Starck et al., 1984). After felling, bacteria grow on the freshly cut ends of the timber and penetrate longitudinally into the vessels, increasing the pH from 5.5 up to 7.5. Several strains of bacteria were isolated from the discoloured wood, and their physiological activities were characterised. Bauch et al. (1984) showed that some of the strains caused a reddish-brown discoloration when incubated on dried wood of Ilomba that was resaturated with water. The pH reached 8 at the brown zone. Corresponding experiments with milled wood lead to the same result. This kind of discoloration can also be obtained when ammonia or sodium hydroxide are added to green or rehumidified wood.

Yazaki et al. (1984) proved that the components responsible for the discoloration are extractable with hot methanol. A bioassay test with bacteria and the separated compounds showed that three different types of components were involved in the discoloration. They were (-)-epicatechin and (+)-epicatechin type of components, an intensively redcoloured compound, and a water soluble component. A reaction with oxygen is not likely, because light green wood of Ilomba discolors although no reduction of moisture content occurs. Furthermore, there is no indication that physiological or biochemical processes of the woody tissue itself are involved. The increase of pH caused by protein metabolism of bacteria in the light coloured sapwood, initiates chemical reactions of some accessory compounds. In this context, it should be emphasised that discolorations in the wood of numerous species react in a way similar to Ilomba.

Zimmermann (1974) showed similar discolorations ('Einlauf') in maple where bacteria were involved. He added bacteria to sawdust agar of sapwood of maple and showed that leucoanthocyanidins played a role in the formation of brown discolorations.

On the other hand, there are discolorations similar in appearance to those in Ilomba and maple, but associated with different reaction mechanisms. This may be true for the oak species. Many oaks in the northern hemisphere contain valuable wood. Ward and Pong (1980) showed serious discolorations during drying of red and white oaks. Presently emphasis is given to identify these specific mechanisms for discolorations in oak and to find methods to prevent them. In particular in oak species, discolorations can affect the veneer quality considerably.

Conclusions

After reviewing the literature on discolorations the following conclusions can be drawn:

1. In many respects the reactions that lead to discolorations in wood of living trees may also apply to the discolorations in the wood of cut trees.
2. Therefore it is necessary to differentiate between — physiological processes, environmentally initiated — biochemical processes and — chemical reactions that may take place both in wood of living and cut trees. They can either occur separately or in combination.
3. Changes in moisture content and temperature that favour growth of microorganisms or the development of chemical and biochemical reactions are preconditions for all kinds of discolorations.
4. Discolorations of similar appearance in different species may be caused by different reactions. It is of major importance to know the chemical characteristics and the accessory compounds of different species.
5. It is of major economic importance to really reduce or prevent defects in wood due to discolorations in trees and lumber. In this respect it is a considerable task to prevent
logging damage to roots, trunks and branches and to reduce animal wounds (e.g. deer). The quick move of wood from forest to product, especially in summer, is also an important contribution to preserve the quality of wood.

References


