DECAY DETECTION IN SITU

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INTRODUCTION

During my past 25 years as a wood products pathologist, perhaps the most common and practically important question that I have been repeatedly asked has been, "How much strength has been lost in this decayed wooden commodity or structure?" Since the decay of wood in service in North America alone results in annual losses of billions of dollars, it is hardly surprising that the strength loss of a commodity is such a common question raised by engineers, architects, utilities and builders across Canada. The question is asked for practical reasons, with two obvious implications. If the strucutre or commodity is too weakened, then it must be replaced, or if there is some useable strength remaining, it may be possible to apply remedial treatments to arrest the process of decay, thereby prolonging its service life. Both of these alternatives have an economic cost which must be balanced in coming to a decision regarding future action. As an example, a recent study by Munro and Mann in 1982 (1) of some 250,000 pine poles treated with creosote about 30 years ago revealed that an alarming 11 to 28% of these poles were actively decaying. The use of selective, remedial groundline treatments could prevent much of this decay and could save considerable costs, both in manpower and pole value. The same study showed that the possible savings in 1982 dollars to be achieved by selective groundline treatments for the 250,000 poles would be in excess of $33 million.

Before an answer can be given to this frequent question, it is important to elaborate on the background which created the question. The losses in strength properties of wood are caused by the activities in wood-destroying fungi, and the resulting effect we recognize and describe as decay. A piece of decayed wood may be infested by living, wood-destroying fungi, or their activities could have ceased and they may even be dead. In other words, it is important to recognize the fact that decay is the result of the activity of wood-destroying fungi, but decayed wood, when examined in service, may or may not contain living fungi. This fact is important as we consider methods to answer the questions of strength loss in decayed wood, for the mere presence of wood-destroying fungi implies that some structural strength loss occurred. Some guidance to strength loss in a commodity, therefore, can be provided through a measure of the activity and distribution of wood-destroying fungi in that commodity. The effects of early stages of decay on wood strength was well reviewed by Wayne Wilcox (2) in 1978, who concluded that when wood weight losses reached only 5 to 10%, toughness and impact bending could be reduced by 60 to 80%. Also, at the same weight losses, bending strength, modulus of rupture, and modulus of elasticity could all be reduced by 50 to 70%. At these low weight losses, we may be unable to visually describe the wood as decayed and this condition is normally called "incipient decay".

Returning now to my original question of strength loss in a decayed structure or commodity. There are a variety of techniques available to measure either the presence of decayed wood, or the presence of wood-destroying fungi. With the foregoing decision in mind, I will now consider these techniques and their usefulness in situ. However, please remember that no personal preference for specific methods are implied in this paper, since individual circumstances, finances or convenience frequently dictate the methods best used by the investigator.

METHODS

1. PICKING

Picking involves the use of a sharp instrument to pry up the wood surface, which, if decayed, breaks off as a brash fracture (3, 4, 5). This is a simply, cheap, and commonly used method. Unfortunately, it is subjective and hard to apply on a boring taken from the inside of a pole. Wilcox (5) has recently shown that this method can be used to detect the early or incipient stages of decay of Ponderosa pine by the fungi Gloeophyllum trabeum and Poria placenta.

2. VISUAL EVIDENCE

Decayed wood frequently is discolored or shows some abnormal shrinkage patterns (3, 6). Some fungi discolor wood in the early stages of decay; for example, Poria carbonica can discolor the heartwood of Douglas-fir a purple color. However, many wood-destroying fungi, called brown-rot fungi, discolor the wood bark brown, particularly in the advanced stages of decay. Decayed wood also shrinks severely when dried, resulting in a typical cross-cracked appearance. Such observations are very subjective and confounded by variations in the natural wood color. Frequently, there is no apparent change in wood during the early stages of decay, thereby limiting this method of detection. The visual identification of decayed wood is best done by trained people.

Included in this method would be the visual identification of superficial growths of wood-destroying fungi on the surface of wood, which indicates decaying within the wood. The use of a medical endoscope for detection of decay in wooden beam ceilings has been described by Petermann (7). This method is useful to observe decay within hollow wooden structures, in the same way as it is used to observe the unborn baby within a pregnant woman.

3. DRILLING

Decayed wood is soft in the advanced stages and drilling with brace and bit can easily be used to detect internal pockets of decay (3). This method gives little guidance for the presence of incipient decay and, therefore, is only a useful indicator when considerable strength loss of the product has occurred.

4. TORQUE-METER

The development of torque measurements while drilling a pole or tree has been investigated, but shows little promise for evaluating incipient decay (3, 8). Such measurements are correlated with the density of the wood, which varies considerably between and within tree species.

5. SOUNDING

The resonant sound produced when a pole is struck with a hammer is commonly used as an indicator of internal decay (3, 4, 6). This is a useful method for detecting advanced decay, but again very subjective. Eslyn (6) looked at utility-line poles in the U.S.A. using sounding and was 84% correct in detecting external decay, 73% correct in detecting internal decay, but 31% of the sound poles indicated decay using this method.

6. COLOR REACTIONS

The detection of metabolic acids produced during the growth of fungi on wood has been advocated by Eslyn (9) as a means of detecting decay in poles. He recently examined 53 chemicals on southern pine stubs and nine of these chemicals, or combinations of chemicals, showed promise in detecting some of the tested fungi. The combination of Butter yellow plus methylene blue, followed by bromcresol green plus methyl orange, clearly identified the presence of all nine wood-destroying fungi tested on southern yellow pine. Similar studies on lodgepole pine were positive, but results from ponderosa pine were less effective.

Peek et al. (10) in 1980 described the successful use of bromophenol blue and bromocresol green to detect incipient white and brown-rot in several species of softwoods and hardwoods. However, they indicated that these indicators were ineffective on acidic woods, such as Douglas-fir. These methods are simple, inexpensive, and show considerable promise; however, they are subjective and some of the color changes are rather subtle. More research needs to be done before applying this technology to the Canadian wood situation, where both wood species and the fungi will be different from those tested in the U.S.A. and Germany.

7. MOISTURE CONTENT

When fungi attack wood the cellulose and lignin is converted to carbon dioxide and water. The presence of a high moisture content in wood has been suggested as a method for estimating the presence of wood-destroying fungi (6). There is also evidence to indicate that decayed wood will absorb moisture more rapidly than sound wood (11). The development of increased moisture content in wood during decay will also depend on the specific fungus (12), some fungi generating more moisture than others. An analysis of this method by Bell Telephone Company many years ago concluded that most decayed poles had a moisture content value in excess of 31%, but unfortunately many poles showing no decay also had moisture content above 31%. They concluded that this method had little merit as a diagnostic tool for decay detection.

More recently, Graham and Mothershead (13) published data on 49 decaying and sound Douglas-fir poles, which clearly indicated a steep moisture content gradient for decayed wood at and below the groundline, moving from the pole surface to 2.5 inches in depth. Moisture contents of about 60% were measured for advanced decay at 2.5 inches, while sound wood values were about 25%.

I would conclude that a high moisture content in some commodities could indicate the presence of decay, but that the method must be used with some caution and it could not be relied on without other supplemental tests.

8. PILODYN

This simple instrument, developed in Switzerland, is a strength tester, measuring the resistance of wood to impact by a blunt pin (14, 15). The pin is spring loaded and when fired into a wood pole its depth of penetration can be measured off the instrument. The apparatus comes either as a 6 or 12 joule model, the extra energy of the 12 joule being required for denser wood. The pilodyn has shown great value in measuring the presence of surface decay caused by soft-rot fungi (14). It is largely independent of the effects of moisture content at values above fiber saturation, a condition normally found in poles at the groundline.

It is effected by wood density and has been extensively tested for use in tree improvement programs, where breeding for denser wood is desired. Density values for sound wood can be developed for each pole species and these values used as baseline values when testing for possible decay.

The Pilodyn was used by J.B. Wilson (16) to identify potentially weak pine utility poles for the Pacific Gas and Electric Company of California. Some failures of CCA treated western pine poles, both prior to and in service, had promoted the development of this study. A meaningful correlation was found between Pilodyn readings and static bending strength. He concluded that the Pilodyn could be used to identify potentially harzardous pine poles.

Setliff et al. in 1983 (17) used the Pilodyn to assist in decay evaluations of Douglas-fir pulp storage stave tanks in British Columbia. The wood staves in this situation had a thick, sound inner zone, a thin outer sound skin, and considerable brown-rot between these two zones. The Pilodyn proved effective in penetrating the outer shell of sound wood and identifying the presence of decayed wood underneath. An excellent correlation was obtained between Pilodyn readings and the remaining thickness of sound wood on the inner side of the staves.

One great advantage of the Pilodyn is its simplicity and ease of operation by unskilled workers. It is used routinely in Sweden and Denmark by utility companies to determine whether poles are safe enough to be climbed, or should be replaced. It is also proving most effective in Australia for the evaluation of soft rot in hardwood poles, where soft rot is proving to be a serious problem.

9. SHIGOMETER

The Shigometer generates a pulsed audio frequency current which passes between two contact surfaces on the tip of an electrode that is inserted into a hole drilled into a pole (18). Provided the moisture content of the wood is above fiber saturation, the instrument should detect changes in conductivity caused by microbial activity between the two contact points in the wood. It has been shown by Shortle (19), during laboratory decay studies, that brown-rot fungi cause a general increase in the hydrogen-ion concentration and white-rot fungi cause an increase in potassium ions. These changes result in an increased conductivity in the wood and low Shigometer readings. There have been many studies done using this instrument for decay detection (18, 19, 20, 21, 22, 23, 24, 25). Shortle et al. (21) looked at 174 poles of seven wood species and with five preservative treatments for the presence of decay. They concluded that a decrease in one or more Shigometer readings by 75% of the highest reading taken on the pole generally indicated decayed wood. Errors that occurred resulted in some sound wood being called decayed. Shigo (17) considers the "patterns of reading" to be most important. It is the rapid change in conductivity values across the pole diameter that signifies decayed wood. Thornton et al. in Australia (24) have evaluated the Shigometer on creosoted Eucalyptus poles and clearly shown its value. Shigometer readings taken from three radial holes per pole were required to overcome

the variability in decay patterns within the poles. They also found the Shigometer was unable to detect the presence of external soft rot, probably due to the hot climatic conditions.

Wilkes and Heather (25), also in Australia, have used the Shigometer to study decay in tallowwood. They concluded that, because of the extreme natural variation in pulsed-current resistance with this wood species, even advanced decay could not be reliably detected. Piirto and Wilcox have critically evaluated the Shigometer for detecting decay in sequoia heartwood and white fir sapwood (20). They found a large variability in readings, particularly for sound wood from the same general location in one tree. This is considered a shortcoming for a species like sequoia where the difference in Shigometer readings between sound and decayed wood was small. However, under laboratory conditions, as decay progressed over a 12 week period, a trend to lower Shigometer readings developed. Smith (11) used three fungi and four species of posts to study decay using the Shigometer and other methods. Average data for all wood species showed monthly decreases in Shigometer readings of about 10 kilohms for Lentinus lepideus and Poria incrassata over a 12 month period. However, rapid changes in Shigometer values were not observed when readings were taken radially across the posts.

Clearly, the Shigometer responds to the presence of some wood-destroying fungi in poles and provides a non-destructive method for decay detection. However, because it only functions in wood where the moisture content is above the fiber saturation point, this can limit its usefulness. Methods are suggested for wetting the wood before evaluations are made, but this is not always achievable. The Shigometer should be used in conjunction with other methods for decay evaluation before economic decisions are made regarding the commodity under inspection.

A similar instrument to the Shigometer has recently been produced in Germany and is called the Conditiometer AS 1. Since its mode of operation is identical to the Shigometer, my previous comments would apply equally to this instrument.

10. ACOUSTIC SYSTEMS

A. Acoustic Velocity

The sonic testing device (Pol-tek), developed by Detroit Edison Company (3), measures acoustic velocity diametrically across poles. The success of this instrument relies on the presence of gross defects in the poles, such as large decay pockets or tunneling caused by termite attack. Unfortunately, acoustic velocity may be greatly affected by the moisture content of the wood and the S2 fibril angle in the wood cell walls (26). Another serious operational variable is the frequent inability to obtain a reproducible acoustic bond for the transducers to the wood surface. Since the pole surface at the groundline frequently is softened and decayed, this later operational problem with the Pol-tek renders it unreliable as a routine inspection tool.

B. Acoustic Damping

Measurements of longitudinal acoustic dampening in poles have been developed by J.J. Dunlop (26). This method of sonic detection appears to be little affected by wood moisture content, pole dimensions, or surface softening of the pole. However, it is sensitive to decay, possibly in the incipient stages. Because it is used over the length of the pole, a "signature" for each pole can be obtained. Changes in this signature will reflect the development of decay or other deterioration.

Initial studies in Australia have shown great promise for its usefulness. However, recent work at Forintek Canada Corp. (27) suggests that ground-coupling in wet soils could seriously affect the pole "signature", thereby negating its usefulness as a diagnostic tool for decay detection.

C. Acoustic Amplitude

Recent studies by McCracken and Vann (28) have utilized a magnetic vibrator at 100 Hz and 1 KHz to evaluate decay in cottonwood, green ash, and willow oak. They found a strong relationship betweent diameter of internal decay and increased signal amplitude. No studies of incipient decay were presented and it would seem probably that this method is only suited for the evaluation of large voids created by the decay. However, the methodology would seem worthy of further evaluation.

11. ELECTROMAGNETIC RADIATION

The use of electromagnetic radiation, either X-rays or gamma rays, is a feasible way to measure decayed wood in a commodity like a utility pole. The passage of this radiation through wood will be attenuated and the degree of attenuation will be determined by the wood thickness and the coefficient of absorption of the wood. If the wood is dense, the coefficient of absorption is high and if the wood has a low density, or has been decayed, the coefficient of absorption is low.

The use of X-ray techniques for evaluating the presence of decay in wood (13, 29) has been looked at by several workers and companies, such as the Detroit Edison Company in the U.S.A. (30). X-ray fluoroscopy was used by Miller (29) to evaluate decay in unseasoned western hemlock lumber three inches in thickness. Voids, due to decay, or the other causes, could be detected in the unseasoned lumber and decay was clearly visible in the dry wood.

At the Siberian Technological Institute, Skiba and Mysin in 1976 developed a gamma radiation technique using radioactive selenium to examine 200 logs of spruce and fir for internal defects (31). By making measurements at 10 cm increments along a log, they built up a series of graphs depicting the internal decay. By measuring the moisture content and coefficients of absorption of typical stages of the decayed wood, they were able to interpret the measurements made on the logs. They were 100% and 85% successful in detecting advanced decay and incipient decay resectively.

In spite of the apparent success of the radiation technique developed to evaluate decay in poles, logs and trees, these methods have never received widespread acceptance as viable and economical methods for field use. However, a recent development, called computerized tomographic analysis, has provided a dramatic advance in radiation analysis. Before this development, all X-ray analyses suffered from the same problem: that the energy absorption occurring through a body of varying thickness (i.e., a pole) was accumulative and was projected as a two dimensional image on the X-ray photographic plate. Consequently, areas of light and dark were partially caused by thickness of the subject and not necessarily by variation in density (i.e., decay) within the subject.

Computerized tomography can now be used to provide the following steps in analyzing a defect which may have occurred in wooden structures:

A. Coefficients of absorption are measured sequentially throughout the wooden structure.

B. A mathematical reconstruction is provided to calculate the picture matrix of the coefficient of absorption, using a computer.

C. A two dimensional display is adapted to the specific requirements of the analysis and the needs of the users.

Both X-ray (32) and gamma radiation (33, 34) systems have recently been used to evaluate deterioration in poles and trees, respectively. Each system consists of a radiation source, detectors, a device for determining the location of the subject, microprocessor units for detection output, and memory of projection data. Data can be stored in the field and transposed for computer analysis in the laboratory.

Studies in 1984 by the Japanese I.E.R.E. Council (32), using a portable X-ray computerized tomographic analysis, clearly diagnosed decay in wooden electric power distribution poles. Images produced from decayed poles were related to sections subsequently cut from these poles and close agreement was observed for the patterns of internal rot. Also a qualitative measure of the extent of decay was possible.

Similar tomographic studies in West Germany by D. Habermehl (33, 34), using a gamma radiation source, have successfully demonstrated internal trunk rot in spruce trees. In an examination of 40 trees, 11 healthy, 19 infected with heartwood rot, and 10 infected with wound rot, the tomographic analyses only failed in two cases to correctly identify the decayed or healthy state of the trees.

Despite the fact that variations in moisture content still present a major problem in radiation analysis of wood, the method of computerized tomography clearly has taken us closer to the goal of non-destructive measurement of decay _in situ_.

However, the methods described are still very slow and expensive and would not be suitable for routine field use.

12. CARBON DIOXIDE DETECTION

The measurement of changes in carbon dioxide or oxygen levels as an index of the rate of decay of wood has been used by several workers in Canada (35), Australia (36), and the U.S.A. (37). Recently, at Forintek Canada Corp. in Vancouver, B.C., the measurement of carbon dioxide levels at the groundline in spruce poles has been related to internal decay by specific wood-destroying fungi. The method, although still in the experimental stages, does show promise as a viable and inexpensive, non-destructive test for measuring decay caused by wood-destroying fungi in poles.

13. SNIFFER DOGS

Following the successful use of trained dogs to detect the presence of drugs and explosives, the Swedish Dog Training Center at Solleftea has trained dogs to detect decay fungi in poles and wooden structures (38). A demonstration of this technique was recently reported from the 15th Annual Meeting of the International Research Group Wood Preservation at Ronneby Brun, Sweden, 1984. Further work is now underway to determine whether dogs can be used to detect decay in creosote-treated poles.

CONCLUSIONS

No single system or method can be reliably used for decay detection in situ unless the decay is advanced enough to create voids in the subject. The problem of measuring incipient decay in situ, therefore, remains largely unsolved. It is probable that different methods will have to be used for different wood species and for different wood commodities and structures. The variation in moisture content, which can occur within a commodity, remains a major weakness in the application of many decay detection methods.

Finally, if I return to answer the question described in my introduction, I would say that a reliable measurement of the strength lost in a wooden commodity, due to decay, is not yet possible. The various methods described in this paper for use in situ will assist in obtaining only a very crude measure of strength loss. However, many methods will indicate the presence of active wood-destroying fungi, which may be sufficient knowledge to support the development of a remedial program to save the structure, or commodity, from total destruction.

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