NEW WORLD EVALUATION OF WOOD DEGRADED BY OLD CULTURES
"Evaluation of Residual Strength Characteristics in Micro-organically Degraded Wood"

by
James A. Wermuth

The contemplation of things as they are
Without error or confusion
Without substitution or imposture
Is in itself a nobler thing
Than a whole harvest of invention
-Francis Bacon

Evaluation of micro-organically degraded wood is difficult. Seen in the context of historic fabric, the material is both inherently valuable and easily degraded. Wood is a producer in the food chain; subject, therefore, to ecosystem consumers. In all but a "perfect" environment, it is often in the process of reverting to topsoil. Accurate measurement of the degree of reversion (through residual strength) is critical to conservation efforts.

Data acquisition is difficult and at times impossible. The structure of wood does not support most non-destructive test methods and the first indication of degradation is often associated with material failure. Timely data acquisition is made more critical in light of the occurrence of wood. As the most adaptable raw material available to man, it is used for a wider range of purposes than any other substance (Eames, 1980).

This paper provides one approach to the problem. In any work of this sort it is necessary to assume that the reader has a working knowledge of conservation principles and the material. A brief review follows for those who do not evaluate wood on a routine basis. Readers who desire greater detail are referred the references listed at the end of this paper.

Wood is primarily a matrix of hollow closed tubes. Under low power, it resembles the inner grain of an orange. The strength of wood is derived from this skeletal structure that makes up 70% to 99% of its dry mass. All components of the skeletal tissue are polymers which are 60% to 80% carbohydrates and the remaining network, phenolic polymers (Berndt, 1987).

Its primary chemical components are cellulose, hemicellulose, and lignin. Extractives, extraneous materials and minerals average 1%. Table 1 illustrates proportional relationships of the major constituents in both hard and soft woods.

Cellulose is a common organic chemical with an estimated 265 billion metric tons in plant matter (Fengel and Wegener, 1984). It is a linear polymer of anhydro-D-glucopyranose units linked by glycosidic bonds. It is organized into distinct layers of fibrils (S1, S2, and S3) that provide axial strength characteristics (see figure 1). Diminution of cellulose reduces the axial strength of wood making it brittle.

TABLE 1
Percentages of Major Components in Wood of Representative Angiosperms and Gymnosperms {74}
(values expressed as % of total weight of wood)

	Angiosperms			Gymnosperms		
	Betula Papyrifera	Fagus grandifolia	Ulmus americana	Picea glauca	Pinus strobus	Tsuga canadensis
Cellulose	42	45	51	41	41	41
Lignin	19	22	24	27	29	33
Polyoses	38	29	23	31	27	23
Total*	99	96	98	99	97	97

* The difference between these totals and 100% is made up of pectin, starch, minerals, and extraneous materials. Data from Syracuse Wood Science Series #5 vol. I

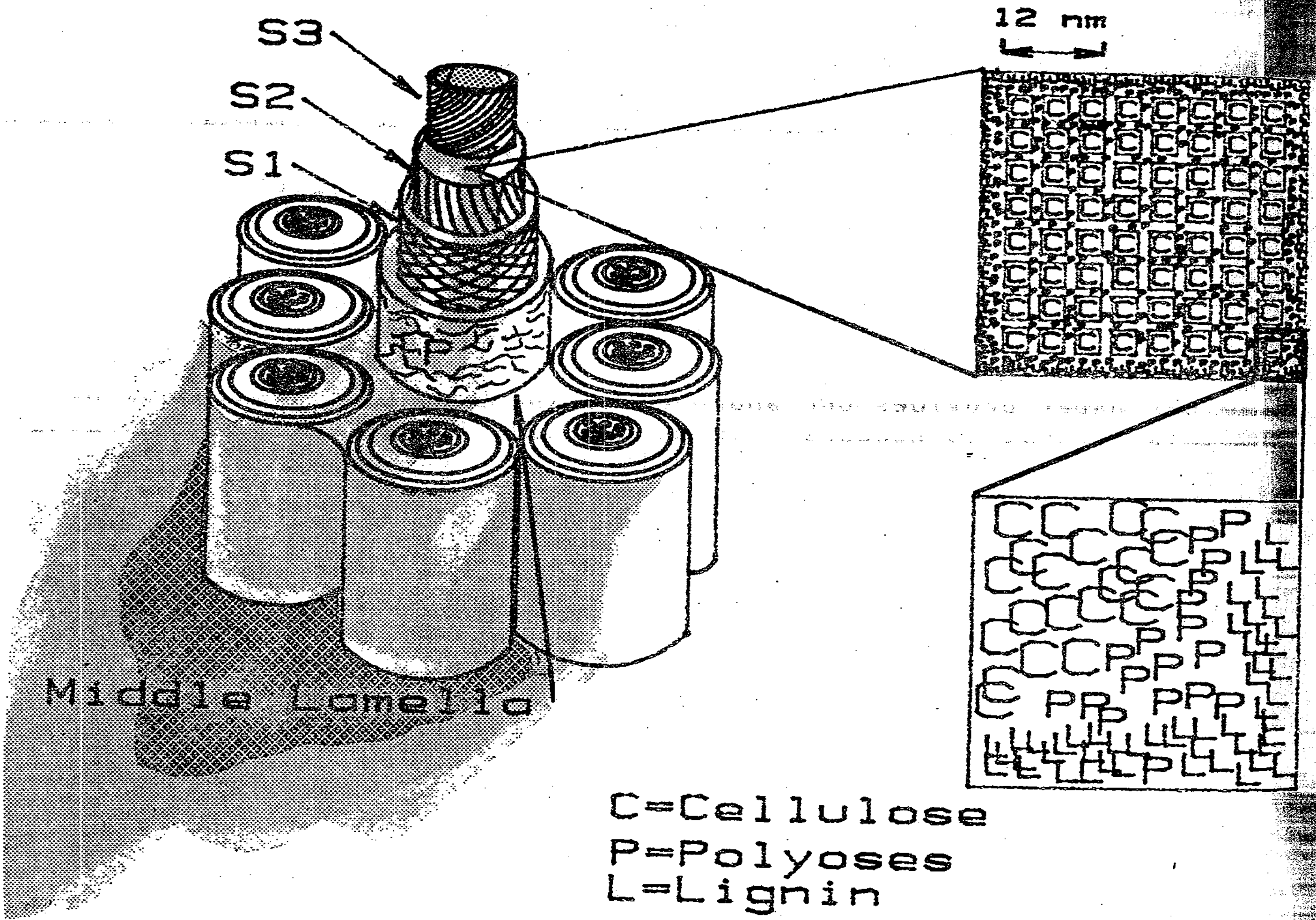

Fig. 1: The relationship of cellulose, polyoses, and lignin are illustrated in a simplified cell structure; P: primary wall with S1: outer layer, S2: middle layer of secondary, and S3: inner layer of secondary with fibril orientation and the middle lamella. (Journal of Wood Conservation 1987)

Hemicellulose (polyoses) is interfacing material between cellulose and lignin. Branched or two dimensional polymers, are anhydrosugar units linked by glycosidic hemiacetal bonds (polysaccharides). Most polyoses are located in the cell wall. Lignin is a large three dimensional amorphic polymer. It is comprised of oxyphenulpropane units derived from three substituted cinnamyl alcohols. Proportions differ widely between various species. It is the main component of the middle lamella. Diminution seriously reduces the stiffness of wood.

Strength characteristics can be divided into two components; normative and degraded. Normative strength and wood orientation determine reserve strength; the agent and degree of degradation determine the diminution of normative strength. A member with little reserve is likely to fail quickly if it is degraded.

NORMATIVE CHARACTERISTICS

Within a single species, tree, and even a single cell, there are large variations of normative strength. The orientation of microfibrals determines strength axis within the cell. Cellulose polymers are held together with strong primary bonds. Lateral connections are united by weaker secondary bonds. S2, the thickest layer, dominates cell behavior. Oriented in a steep helix, it provides maximum strength parallel to the cell orientation {see fig. 1} (Schniewind, 1987). S1 and S3 layers have shallow angles creating a differential between layers; the composite strength is fairly uniform. Environmental conditions during cell development determine actual thickness of the cell wall components within genetic parameters.

Section (branch wood, limb, trunk, etc...), direction of cut (radial, tangential, or axial), anomalies, and moisture content also affect normative strength. Radical strength variations occur with grain orientation. Wood splits easily parallel to the grain but great effort is required to cut wood across the grain. Artifacts that are contoured so that dead loading occurs parallel to the grain leave little reserve in the event of decay. The presence of an anomalie or thin cell walls further reduces the reserve.

Specific gravity is directly proportional to wood properties. The specific gravity of cell wall tissue can be considered constant for all species at approximately 1.5 (Schniewind 1987). Gross measurement of specific gravity determines cell wall thickness; an indication of strength, hygroscopicity, and porosity. Although the greatest variation of specific gravity occurs between species (Balsa has a MOR of 2,800 psi; some high density exotics are in excess of 24,000 psi) intraspecies variation can also be large. The MOR range of yellow birch varies between 8,300 psi and 16,600 psi (Forest Products Laboratory, Madison Wis. 1972). High specific gravity wood has a propensity to split and warp, a critical evaluation factor. Simple identification of wood is, therefore, not an indication of its reserve. It is better to measure specific gravity, and to evaluate grain orientation and homogeniousness of the section.

DEGRADATION CHARACTERISTICS

There are four categories for degrading agents: mechanical, physical, chemical, and biological. Although all degrading agents take on an increased importance when they affect cultural properties, biological agents are considered to be most serious. It is practical to recognize five kinds of micro-organisms: decay or rot, soft rot, mold, stain, and bacterial agents. Brown rot, soft rot, and white rot account for most damage.
Fungi require moderate temperatures and a MC in excess of fiber saturation point to flourish and colonize (Ambugury 1972). Strength diminution is caused by enzymes that are polymer specific. Hyphae create bore holes in the cell walls and progress by assimilating materials they can depolymerize and assimilate. Detection during incipient stages is difficult. At the first sign of infection (weight loss) as much as a 30% to 50% of the normative strength is lost (Scheffer 1973). Reduction of toughness, rigidity and compressive strength occurs quickly.

Each organism assimilates a different component of the cell structure diminishing cell strength in different ways. White rot fungi typically assimilates all major components. Different species vary, however; polyporus berkelyi attacks lignin faster than the carbohydrate structures reducing stiffness. Polyporus versicolor removes all cell components simultaneously.

Brown rots depolymerize cellulose and hemicellulose and are thought to be small enough to effectively penetrate all portions of the cellulose structure. Lignin is not assimilated leaving an amorphic tissue that has no strength orientation; cube-like checking occurs with severe loss of strength. Poria incressata is one of the most destructive of the brown rot fungi.

Also known as a pocket rot, P incressata is thought to produce its own moisture through metabolic processes. It grows moisture conducting rizomorphs to saturate unaffected areas as far as 30 feet and three stories away (Ebling 1978). The infection pockets in the middle of the section where it is difficult to detect. It is limited by its ability to retain moisture; as the infection progresses towards an outer surface, desorption occurs more rapidly than replenishment.

Soft rot fungi primarily attack the polysacharide component and reduce the weight of a section rapidly. They progress much like white rots but do not assimilate lignin. Mold and stain fungi use wood as a habitat deriving nutrition from nutrients stored in the wood. Actual decomposition of the skeletal structure is thought to stop at the production of minute bore holes (Wilcox 1972), although some mold fungi are capable of producing typical soft rot in oak (Duncan 1960).

EVALUATION METHODS

Competency determinations of wood are difficult. Most reliable tests for wood quality have been developed by industry and are destructive in that they measure load at the point of failure.

The following is a systematic procedure for evaluating wood components with least damage. It depends, in great part, on the experience and competency of the surveyor.

1. Determine the reserve strength.
   A To evaluate reserve strength, the anticipated load must be known as a reference. Take into account stressing from environmental cycles, loading, or use.
   B Determine the approximate normative strength of the material. Identify the species and measure the specific gravity.
   C Evaluate the construction detail and how are loads applied.
   D Examine the surface for anomalies and evaluate the effective reduction of crossection of load bearing sections.
   E Determine the potential for degradation, particularly if moisture is present.
   F Compare the calculated load and normative strength to determine reserve strength. If the reserve is low and there is degradation or potential for degradation, proceed.

2. Determine the degree and nature of degradation.
   A If there is a high MC lift a sample for analysis. If infection is detected, mechanical testing is advised.
   B If there is evidence of failure with no apparent cause, insert long MC meter probes in the center of the section to detect pocket rot. An incremental bore sample can take remote specimens for microscopy. If one area of decay is found, it can generally be assumed that several areas are involved with the infection. Mechanical testing is advised.
   C Altered surface texture and fruiting bodies indicate serious infection. Specimens should be identified and proceed with mechanical testing.
   D Define specific level and location data. It is convenient to recognize four levels of decay:
      1 Incipient decay; bore holes present but little diminution of cell tissue. Strength reduction is less than 10%.
      2 Hyphae present throughout the structure, but no measurable weight loss. The strength reduction is less than 30%.
      3 Widespread hyphae and serious diminution of cell tissue. Strength reduction is less than 90%.
      4 There is no appreciable strength; the cell structure is no longer recognizable and complete failure has occurred.
3. Determine the degree of residual strength. Infection type will indicate the type of failure to be expected. The following conservative methods are useful to obtain general readings.
   A The Schniewind test; developed by A. Schniewind Phd., U.C. Berkeley Forest Products Lab.. An instron fitted with a reduced span reads MOR from a series of samples. The test provides accurate readings from small samples.
   B An evolution of this test is to take samples from representative sections, correlate the data with intact crossection, and subject test beams to a set load deflection test Develop a curve to establish intact cross section for unsampled sections. There are draw backs: members may be restricted and have to be measured under load.

C Surface rot can be evaluated by mechanical penetration from the outer surface of the section. An simple, effective measurement is achieved by inserting a series of fine uniform pins into the decayed area with equal force. The resulting profile created by the tops of the pins indicates the extent of Level 3 and level 4 degradation.
The Pilodyn is an impact density or shock-resistant test instrument that operates by firing a blunt pin with a known surface area with a constant force spring device. Degree of penetration is recorded as an indication of degradation (Clark and Squirrell 1985).

D Pocket rots can not be detected or measured by external penetration tests. The CTG laboratory is developing a device to measure the force required to insert a standard pin through an entire section. Although the device has been used with some success in selected architectural evaluations, mechanical refinements, testing, and weight reduction is necessary before the instrument will be released for field use. The desired result is a field instrument that will provide point MOR analysis. It will be "discreetly destructive" leaving only a small hole.

4. Develop a competency factor by evaluating the collected data. The complex anatomical structure of wood necessarily limits the accuracy of measurements; experience, and in particular, the establishment of baseline data provides an accurate reference if alterations occur.

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ABSTRACT

Evaluation of micro-organically degraded wood, is difficult when seen in the context of historic fabric; it is both inherently valuable and easily degraded (often found in the process of reverting to topsoil). Accurate measurement of the degree of reversion (through residual strength) is critical to conservation efforts in that it provides an indication of the ability of the material to tolerate the environment and provides baseline information.

Because of the information contained by cultural surfaces and the complex anatomical structure of wood, data acquisition is often difficult if not impossible. Destructive tests are not acceptable and most non-destructive test methods do not provide effective criteria for evaluation. The result is that often the first indication of degradation is material failure.

This paper provides one approach to the problem through a systematic process. It begins with a brief review of wood structure and anatomy for professionals who do not work with wood evaluation on a routine basis. The review is followed by a more detailed analysis of the role ultrastructure components and gross features play in determining normative strength characteristics and an analysis of micro-organic degrading agents.

Chemical composition and orientation are discussed as the foundation of mechanical properties. Cell structure is examined with attention to microfiber orientation and bonding. Specific gravity is discussed as a critical measurement in determining the strength, porosity, and hygroscopicity of a wood section.

An evaluation evaluation system is then presented to examine normative, reserve, and degraded strength characteristics. This evaluation is followed by a review of several conservative test methods. Finally, the evaluation of a competency factor relating to the ability of wood to function in an anticipated environment is discussed. Even though the complex anatomical structure of wood necessarily limits the accuracy of measurements, the establishment of baseline data provides an accurate reference if alterations occur.