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PROCEEDINGS OF THE

SYMPOSIUM ON NONDESTRUCTIVE TESTING OF WOOD

MARCH 1964

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Sponsored jointly by
National Lumber Manufacturers Association
and the Forest Products Laboratory

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PROCEEDINGS OF SYMPOSIUM ON NONDESTRUCTIVE TESTING OF WOODS[1]

Summary

This report summarizes the main points considered and the conclusions reached during the Symposium on Nondestructive Testing, October 7 to 9, 1963, at the Forest Products Laboratory.

The purpose of this symposium was to bring research and industry leaders together to examine what is being done in nondestructive testing and discuss its applications to the wood products industries.

Some 100 scientists, engineers, and industry leaders heard and discussed the possibilities of a wide range of scientific means for testing wood nondestructively--that is, without impairing the usefulness of the piece tested. The program included experts in nondestructive testing as developed for other industries and specialists in nuclear radiation, sonic and vibration methods of testing, electrical devices, and mechanical methods. The discussions served to provide a better understanding of the current status of nondestructive testing methods and to emphasize their many potentialities in the forest products field.

The Forest Products Laboratory would like to be kept informed of all new developments as they occur and will be glad to assist wherever possible in expediting such developments.

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[1]Presented in cooperation with the National Lumber Manufacturers Association.

The assistance of the Society for Nondestructive Testing in planning and conducting the Symposium is acknowledged.

Program for Symposium on

NONDESTRUCTIVE TESTING OF WOOD

Held at

U.S. Forest Products Laboratory, Madison, Wis.
October 7–9, 1963

October 7, 1963––Session I - Introduction

Chairman--R.L. Youngs, U.S. Forest Products Laboratory

Welcome--E.G. Locke, Director, U.S. Forest Products Laboratory

Introduction––R: L. Youngs, U.S. Forest Products Laboratory

Keynote Address––"Objectives and Need for Nondestructive Testing of Forest Products"––A. S. Gregory, Weyerhaeuser Company

"A Survey of the Status of Nondestructive Testing"––R, C. McMaster, Ohio State University

"The Structure and Physics of Wood as a Material to be Tested Nondestructively" ––C. H. de Zeeuw, State University of New York, College of Forestry

"The Status of Nondestructive Testing of Wood"––W. L. Galligan, Washington State University

Discussion

October 7, 1963––Session II - Nuclear Radiation Methods

Chairman––Harold Tarkow, U.S. Fbrest Products Laboratory

"The Interaction of Nuclear Radiation With Matter"––G. L. Gyorey, University of Michigan

"Radiography as a Tool of Nondestructive Testing"––Harold Berger, Argonne National Laboratory

"Simultaneous Determination of Moisture Content and Density by Radiation Methods" ––J . Crump, Nuclear-Chicago Corporation

"Determination of Moisture Content and Density of Wood by Radiation Methods" --W. E. Loos, North Carolina State College

"Detection of Decay and Voids in Wood by Radiation Methods"--R. E. Byrne and F. P. Drew, Association of American Railroads

Discussion

October 8, 1963—Session III - Electrical Methods

Chairman--A. J. Stamm, North Carolina State College

"The Electrical Properties of Wood as a Material to be Tested Nondestructively" --C. Skaar, State University of New York, College of Forestry

"Measuring Moisture Content of Wood by Electrical Resistance and Capacitance Methods"--W. J. Delmhorst, Delmhorst Instrument Company

"Applications of Microwaves in Nondestructive Testing"--C. W. E. Walker, Beloit Corporation

"The Piezoelectric Effect in Wood"--L. D. Bertholf, Washington State University

"Applications of Nuclear Magnetic Resonance in Nondestructive Testing"-- Harold Tarkow, U.S. Forest Products Laboratory

Discussion

October 8, 1963--Session IV - Vibration Methods

Chairman--R. E. Pentoney, State University of New York, College of Forestry

"Stress Waves in Solids"--B. A. Jayne, North Carolina State College

"Factors Affecting Vibration Characteristics of Wood"--W, L. James, U.S. Forest Products Laboratory

"The Concept of Selection Efficiency and Tolerance in Nondestructive Testing of Wood"--D. G. Miller, Forest Products Research Branch, Canada Department of Forestry, Ottawa Laboratory

"A Vibration Grading System for Structural Lumber"––R. F. Pellerin, Washington State University

"Ultrasonic Nondestructive Testing of Wood and Other Materials"––A. S. Birks, Sperry Products Division, Automation Industries Inc.

Discuss ion

October 9, 1963––Session V - Mechanical Methods

Chairman––L. W. Wood, U.S. Forest Products Laboratory

"Stress Rating of Lumber by Flexure Tests"––S. K. Suddarth, Purdue University

"The Potlatch System of Stress Rating"––H. B. McKean and R. J. Hoyle, Jr., Potlatch Forests, Inc.

"The Stress–O–Matic Stress Rating System"––S. D. Pelster, Western Pine Association

Discussion

October 9, 1963––Session VI - Summary

Chairman––A. D. Freas, U.S. Forest Products Laboratory

Review of Conclusions, Possibilities, and Research Recommendations

Review Committee––R. C. Platow, U.S. Plywood Corporation, Chairman
J. G. Shope, NLMA
G. G. Marra, Washington State University
W. L. James, U.S. Forest Products Laboratory
P. S. Johnson, Society for Nondestructive Testing
A. D. Freas, U.S. Forest Products Laboratory (Ex officio)

General Discussion

Symposium Committee––R. L. Youngs, Chairman
H. Tarkow
D. Kutscha

NLMA Representative--J.G. Shope

SESSION VI--SYMPOSIUM SUMMARY

Chairman--A. D. Freas, U.S. Forest Products Laboratory

Impressions of the Meeting--G.G. Marra, Washington State University

The Symposium has reviewed possibilities for nondestructively evaluating the moisture content, density, and strength of wood. Also pointed out were the applicable chemistry, physics, and mathematics and means by which they should be considered. Wood is an engineering material and, as such, must meet certain stringent specifications. It is important that the various test methods that may be employed agree in their evaluation of the same property. We need to develop low-cost nondestructive test methods and means for comparing them, In so doing, we should not necessarily fall back on the usual destructive tests as a basis for comparison. (A comprehensive account of this summary is given in the Appendix.)

Current Uses of Nondestructive Testing--P.S. Johnson, Society for Nondestructive Testing

There is a conflict between the technical man, the trade, and management in development and application of nondestructive testing. There are about 26 methods of nondestructive testing, of which about 7 have been mentioned as of possible use in the lumber industry, including those involving particularly penetrating radiation, sonics, and vibration. It is important that the parameters to be evaluated be defined more explicitly, There is likely to be danger in simply passing along proprietary methods and in correlating nondestructive testing with results of the usual destructive testing.

A Look at the Future--W.L. James, U.S. Forest Products Laboratory

It is significant that a number of different technologies have been brought to bear on the problem of developing effective approaches to nondestructive testing. Perhaps additional attention might be given to such other unusual approaches as, for example, the significance of the characteristic noises developed in proof loading. In order for nondestructive testing to be applied successfully in the forest products industries it is necessary that further thought and study be given to such still unanswered questions as: (1) How may various methods be used commercially? (2) What are the parameters that should be measured? (3) At what stage in processing could the various approaches be applied most effectively?

Recommendations of the Review Committee--R. C. Platow, U.S. Plywood Corporation, Chairman

1. There have been significant technological developments in nondestructive testing. Thorough search and study should now be made to determine how this information can be applied to the nondestructive testing of wood and wood–base products.

2. Such an effort requires the team concept in drawing together the potential contributions of various disciplines such as wood technology, physics, electrical and mechanical engineering, chemistry, etc.

3. Research programs for the immediate future should define parameters that fit present use requirements and relate such currently understood properties as modulus of elasticity and modulus of rupture. Future programs should define parameters related to such characteristics as those of creep and combinations of properties such as moduli of elasticity and of shear that may be more useful than properties commonly considered at present.

4. A follow–up meeting should be held in approximately 1 year. The papers to be presented should be identified and grouped as (1) pure research, (2) applied research, and (3) product or commercial development.

5. A meeting should be held at the U.S. Forest Products Laboratory in about 6 months for the purpose of having proper representatives from the lumber, plywood, particle board, and hardboard industries meet to discuss their needs for nondestructive testing and organize specific problems to be presented at the follow–up meeting recommended in (4).

Discussion

Mr. W. L. Gallimn––Washington State University

From a research man’s point of view, the problems themselves have not been defined, as Bill James suggests. Objectives should be noted, if research is to help the industry. Lines of communication should be improved between industry and research people.

Mr. Freas

The committee supports this and recommends the objectives be written down.

Mr. F. J. Hanrahan--American Institute of Timber Construction

There is a lack of communication with management. We need educational programs for management and nontechnicians.

Mr. Steele Barnett--Boise Cascade Corporation

Investment demands a profit. We are customers for nondestructive testing machines. We are satisfied that the investment can be justified for our plant. Machine manufacturers must be made to realize that certain standards of quality must be met. We need a system established to guarantee the NDT system will meet certain high standards. The lumber industry wants the customer to be protected.

Mr. P. D. Johnson

In answer to Mr. Hanrahan, where the problem is, the answer lies. In the military services, or very large companies, if you want to sell an idea to your superiors, it must be stated in black and white, and in terms the boss understands. This man works by the dollar sign. The researcher must be able to communicate without confusion. He must concentrate on public speaking and on articulation. Make it simple.

Mr. Platow

I disagree. I don't feel the wood industry has enough research and development. But some high positions are held by technically trained men. I think we're on the right track, after attending this meeting. I've never found inability to get money if the needs are known.

Mr. S. K. Suddarth--Purdue University

There are three parts to our problem (1) Material and its strength, (2) structures and their design, and (3) loads on the structure. No. (3) is poorly established and we therefore are forced to over design. No. (2) is complex and we are indefinite on it.

Mr. J. G. Shope--NLMA

Wood is not an engineering material on the job site. It is not efficiently used. Much more accurate selection of lumber must be made, and the designer or user informed of this.

Mr. W. E. Loos--North Carolina State College

With regard to research expenditures, the chemical industry spends 6 percent of the sales dollar on research. The wood industry spends something like 0.2 per cent.

Mr. Platow

I don't think the statistic is accurate. We checked this out in another industry and, of the 5 percent of the sales dollar spent on research and development, 85 percent goes to product development and 15 percent to fundamental research. If one considers all the various wood–using industries, I think it's more.

Mr. W, H. Sanders--U.S. Naval Research Laboratory

Lockheed uses plywood in a missile. Here is a case where a design study shows wood superior to other materials. The value of the construction makes some testing feasible.

OBJECTIVES AND NEED FOR NONDESTRUCTIVE TESTING OF FOREST PRODUCTS

A. S. Gregory
Weyerhaeuser Company

The implications to the forest products industry of nondestructive testing are substantial. Since many variables are involved in visual grading of lumber for structural properties, conservative safety factors are used in design specifications. Consequently, a high percentage of wood is applied below its strength capability. Exacting nondestructive testing could permit precision grading and 100 percent inspection of product quality. It could also provide the tools to gain a better definition of the consumer's needs and to develop designs which put more strength in place with less weight in those uses where strength is the limiting factor. Broadly developed, nondestructive testing could measure other properties required to meet the end use requirements of each market to be served not only by lumber but all forest products.

In manufacturing, the ability to make measurements rapidly, continuously, and dependably would facilitate efficient use of raw materials and improvements in process design and control. Also, research and development programs would be significantly aided by more precisely defined market and processing needs and increased ability to measure properties of experimental products.

The full potential of nondestructive testing cannot be realized unless accompanying changes are accomplished in the market place and in the manufacturing plants. A great deal of lumber is now, and will continue to be, purchased on the basis of appearance. The main lumber uses in home construction do not require significantly higher strength ratings than are now achieved, and will not require more unless and until home construction specifications are redesigned. As soon as we can demonstrate that the higher strength grades and guaranteed performance grades can be used in new designs at lower costs, these and other markets should develop.

Scientists and engineers working on new nondestructive testing procedures must thoroughly establish the precision and reliability of their methods before recommending commercial use. A variety of techniques will be needed for the different properties, products, and conditions of manufacture.

There is a real potential in our industry for nondestructive testing but it is going to take time for it to reach its proper place and the development will be evolutionary rather than revolutionary.

A SURVEY OF THE STATUS OF NONDESTRUCTIVE TESTING

Robert C. McMaster
Ohio State University

The present status of nondestructive test methods in industrial use is surveyed in this paper. Basic methods such as visual inspection, liquid penetrant and magnetic particle testing, filtered particle and electrified particle testing, penetrating radiation tests, electromagnetic induction and eddy current tests, sonic and ultrasonic tests, strain-sensitive tests, and thermal nondestructive tests are described. However, at present, such test methods are generally designed for and applicable only to metallic materials, ceramics, and other relatively homogeneous materials. They find most frequent application in detection of discontinuities, although material property tests are presently being given priority development.

Few nondestructive tests have yet been developed for application to wood or wood products, or to other structural and civil engineering materials such as soils, concrete, and other natural or nonhomogeneous materials. Tests for wood have, in general, been of the type of penetrating radiation tests, ultrasonic or sonic tests, electrical conductivity tests, and others with limited applications.

The state of the art is most primitive with respect to tests for inhomogeneous, anisotropic, and nonmetallic materials. With respect to most nonmetallic civil engineering materials, concrete, earth structures, wood and wood products, the needs for nondestructive tests have been as yet inadequately defined. In addition, the serviceability of such materials must be related to specific material properties and the correlation between these properties or their discontinuities established reliably, to provide a sound basis for development of future nondestructive tests. Since most nondestructive tests involve indirect measurements (of properties other than the material characteristics that directly influence serviceability), such related properties must be discovered and evaluated. When this type of information becomes available, and when civil engineering and wood producing and utilizing industries are prepared to support the needed research and development, it is probable that the art of nondestructive testing in these areas can be rapidly advanced. If such developments permitted more effective and economical use of these structural materials, reducing the present excessive factors of safety based upon lack of assurance of material strength and quality, the true benefits of nondestructive testing could be attained.

THE STRUCTURE AND PHYSICS OF WOOD AS A MATERIAL TO BE TESTED NONDESTRUCTIVELY

Carl de Zeeuw
College of Forestry
State University of New York

The elastic behavior of wood can be described in terms of an orthotropic system related to the three major axes of symmetry in wood. The longitudinal (L) elasticity is primarily a reflection of the principal orientation of the highly elastic cellulose chain molecules in this direction. The lateral elasticity (R and T planes) in wood exhibits much smaller values than the longitudinal. Low bond strength laterally between the cellulose chains and the ease of lateral deformation of the tubular cells account for much of this difference. Variations in density and arrangement of cells between the radial and tangential planes appears to cause the discrepancies in elasticity between these two lateral axes.

Wood exhibits a plastic deformation which occurs under load simultaneously with the elastic deformation. The flow characteristic appears to be the result of bond rearrangement along the length of the cellulose chains with additional deformation arising from flow in the lignin-rich regions of the cell wall,

Water and other polar liquids are strongly attracted to wood. They are believed to bond to hydroxyl groups preferentially at sites which are related to the regions between the crystalline zones in the cell wall. The polymer network of the cell wall changes dimensions depending upon the number and size of the polar molecules present. The principal dimensional change occurs normal to the direction of the carbohydrate chains and explains the large transverse changes in size which occur in wood as a result of moisture fluctuations and the small longitudinal changes. The presence of polar liquids also explains the major variations in density, electrical properties, thermal characteristics, and strength properties which are encountered in wood.

THE STATUS OF NONDESTRUCTIVE TESTING OF WOOD

W. L. Galligan
Washington State University

Significant accomplishment in the nondestructive testing of wood is exemplified by the commercial machines recently developed for the rapid measurement of E and the estimation of R for structural lumber. These machines utilize mechanical deflection and correlation between E and R, although the machine design principles differ in the several versions now available. There is evidence also that the commercial potentials of nondestructive testing techniques generally are being understood more fully, as evidenced by such applications as the underwater testing of pilings by ultrasound. As success in each application is demonstrated, research in new applications of NDT is stimulated.

An evident need remains for tests to evaluate many product properties. As examples, dimensional stability in particle board and local bond strength in glue joints and fastenings are virtually untouched by nondestructive testing procedures. It is suspected that our broadest gap maybe between the nondestructive research man and the applications engineer in the wood industry. The reports of specific laboratory research on wood testing, while not numerous, might be contrasted with the minimal published information on systems research for commercial usage.

As a scoreboard of progress, NDT in wood is best categorized by product requirements, such as E, R, moisture, etc. While not without fault, this method (a) points up areas needing research emphasis, (b) permits ready comparison of test methods aimed at the same goal (for example: subsonic, sonic, ultrasonic, and mechanical methods for rapid evaluation of elasticity) and, (c) follows product requirements through the evolution of the product. The overall view of testing that is provided by this method illustrates the desirability of moving NDT upstream, as it were, as far as possible toward the tree.

DISCUSSION

Q. What is the order of magnitude of the voltage generated by the piezoelectric effect in wood?

A. Millivolts.

Q. Can cooperation from industry be expected in developing new testing procedures?

A. Yes.

THE INTERACTION OF NUCLEAR RADIATION WITH MATTER

Geza L. Gyorey
The University of Michigan

If one directs a beam of radiation onto a slab of material, the radiation will interact with the material and will thereby be attenuated, that is, the intensity of the beam emerging on the far side will be less than that of the incident beam. The manner of interaction will depend on both the type of radiation and the type of material one is considering. The magnitude of the attentuation will depend also on the density and the thickness of the material, usually in such a way that the product of these two quantities, that is, the total mass traversed by the beam, is the important factor. The accompanying table lists the more common types of radiations.

Alpha and beta rays are fast moving charged particles. In their passage through matter, which, of course, also consists of electrically charged particles: the positive nuclei and the negative electrons around them, alpha and beta rays will interact through the repulsive and the attractive forces which exist between charged particles. Thus they interact and lose speed in a more or less continuous manner, eventually coming to rest. Alpha particles are completely stopped by a mil or two of solid material, the range of betas in solids is, at most, a few tenths of an inch. These particles are of interest, therefore, only in measurements on very thin sheets or very low density materials.

Gamma rays (and X–rays) and neutrons are uncharged, and may travel long distances in a material without interacting at all. On the other hand, they may lose a large fraction of their energy, or be completely absorbed, in a single interaction. For these radiations we cannot specify a maximum range; no matter how thick the material in their path, some of them will get through. We can characterize the attenuation in this case by specifying the half value thickness of the material: the thickness necessary to reduce the radiation beam intensity by a factor of two. The half thickness of water is about 2 inches for fast (highly penetrating) neutrons; it is about 4 inches for penetrating (high energy) gammas, and decreases to a few tenths of an inch or even less for soft (low energy) gamma or X–radiation.

Type of radiation	Nature	Electrical charge (relative)	Rest mass, in atomic mass units
Alpha	Fast moving Helium nucleus	+2	4
Beta	Fast moving elecrton	-1	1/1840
Gamma or X	Electromagnetic radiation	None	None
Neutron	---------------	None	1

RADIOGRAPHY AS A TOOL OF NONDESTRUCTIVE TESTING[2]

Harold Berger
Argonne National Laboratory

Radiography, that is the imaging of a radiation beam that has passed through an object under study, is a widely used inspection method. Images of the transmitted radiation are of value because resolution and contrast capabilities are high and because the production of an image greatly simplifies the interpretation of the test result. Radiations which have been used for radiographic purposes include gamma radiation, electrons, alpha particles, thermal neutrons and X-rays. This discussion will concern itself primarily with the latter two radiations.

The type of radiography one obtains is dependent on many factors, among them being the type of radiation used and the absorption of that radiation by the various materials and thicknesses in the inspection object. The absorption of materials for X-radiation generally increases with increasing atomic number. The absorption pattern for thermal neutrons, on the other hand, is essentially reversed from that of X-radiation in that many light materials, notably hydrogen, lithium and boron have very high absorption for thermal neutrons while most heavy materials transmit thermal neutrons to a high degree. Therefore, these two radiographic methods complement each other, and appreciably broaden the usefulness of radiography when used together.

In homogeneous material$, radiographic techniques are generally capable of detecting thickness changes which are in the order of 1 to 2 percent of the base material thickness. Under ideal conditions one can improve on these figures by about an order of magnitude. In addition, of course, radiographic techniques are capable of detecting density variations which produce changes in radiation absorption equivalent to this change in thickness.

Possible uses for radiographic methods in the wood products field include the detection of internal discontinuities, grain direction, gross density variations and moisture content. Examples demonstrating several of these will be given.

[2]Work performed under the auspices of the U.S. Atomic Energy Commission.

SIMULTANEOUS DETERMINATION OF MOISTURE CONTACT AND DENSITY BY RADIATION METHODS

J. O. Crump
Nuclear–Chicago Corporation

Moisture and density of wood can be measured using nuclear methods. Moisture determination on a weight basis requires the use of density correction. A radiation source of fast neutrons is used to measure the concentration of hydrogen in the moisture laden wood. Gamma radiation determines product density. The ratio between these measurements is calibrated in percent moisture. The primary advantages of the nuclear method are the noncontracting form of the measurement, high accuracy continuous in depth moisture analysis, and temperature wood species independence. Limitations on use of this system are primarily related to cost and to the necessity of providing a reproductable measurement geometry.

DETERMINATION OF MOISTURE CONTENT AND DENSITY OF WOOD BY RADIATION METHODS

W. E. Loos
North Carolina State College

The discussion of nondestructive measurement of wood moisture content and density by radiation methods is analyzed in the classical manner by source type, considering alpha, beta, gamma, and neutron radiation. A critical review of a few key papers serves to indicate the feasibility, advantages, and limitations of each of these types of radiation for wood moisture content and density measurements. The unpublished work of the author is included in this review. The presentation concludes with a few projections as to the future usefulness of the more promising radiation sources and techniques.

Specifically the presentation includes the following:

1. Alpha radiation has virtually no use in the measurement of wood moisture content or density because of its limited range.

2. Beta radiation has obtained the most attention of any type or radiation to date, there being probably half a dozen key papers on the use of this type of radiation. The first of these published was by Cameron who showed the feasibility of the beta transmission technique for measuring increment core density variations. Noack and Kleuters, Keyluerth and Keuter and Kleuter have carried beta–ray increment core moisture content and density measurement to a fine point of perfection. Ecklund used beta rays to determine the fiber saturation point of wood.

3. Gamma radiation has been used mostly to measure wood density of large cross section specimens, for example, utility poles. Parrish measured the attenuation of gamma rays by wood in an attempt to detect internal decay in poles. Others have done similar work in Australia, Japan, Russia, and in this country. The author has worked out the relationship between wood density and moisture content and gamma–ray attentuation, as well as the use of the gamma–ray backscatter technique to detect internal decay in utility poles.

From preliminary calculations the moderation of neutrons for the measurement of hydrogen–water does not show too much promise. Too large a specimen would be required.

In conclusion the author indicates which radiation methods show the most promise for wood moisture content and density measurements and possible sophistications of present techniques and their combination with other methods to obtain much greater effectiveness.

DETECTION OF DECAY AND VOIDS IN WOOD BY RADIATION METHODS

Robert Byrne and Freeman P. Drew
Association of American Railroads

Part I: Instrumentation

The Association of American Railroads is interested in detecting decay of timbers using rapid and accurate procedures. The use of radioactive materials for determining the structural soundness of timbers seemed an attractive avenue of approach. Investigations in the laboratory and in the field have been carried out to evaluate the feasibility of radiation methods for predicting soundness of timber.

Gamma and neutron sources have been used in these studies. The measurement of gamma radiation has been made by backscatter and transmission techniques. The backscatter intensity has been found to depend upon the distance of a void from the source. The transmission measurement technique is not as satisfactory at low hydrogen densities of wood as at high hydrogen densities.

Measurement of radiation produced by neutron sources was made on back-scattered thermalized neutrons. As the distance of the void increased from the source, the neutron backscatter value approaches a limit which is the same as the value for a sound timber.

Commercial instruments which have been utilized to some extent on railroads include a low energy gamma source which is used with a transmission type detector. This instrument has been used on bridge timbers where accessibility to each side of the timber was no problem.

Another commercial instrument was designed especially for determining the soundness of railroad ties. This instrument measures backscatter gamma radiation and its limitations are those associated with such techniques.

Part II: Laboratory and Field Investigations With Railroad Trestle Timber

The American railroads have 1,800 miles of timber bridges. Extensive use is also made of timber for track ties and for telegraph poles. Decay and voids reduce its serviceability and all of this timber must be periodically inspected. It would be to the railroad industry's advantage to have a method whereby timber could be more readily and more completely inspected than by methods presently used. A nuclear source offers some promise to accomplish this and the AAR working with AREA Committee 7, Wood Bridges and Trestles, has conducted laboratory and field investigations with such a device and a description of these investigations will be given.

Trestle timber was obtained from a railroad. This timber was in various states of decay and consisted of 14 inch by 14 inch caps and short lengths of piling of varying diameters up to about 16 inches. Some stringers were also used which were 18 inches deep.

The procedure was to obtain an indication with the instrument as to the percentage of decay or void and then to cut the specimen at that point to verify the instrument reading.

The results of this investigation will be discussed as well as the apparent limitations of such a device.

A description of the use of this instrument on a railroad trestle will be given and problems relating to field use will be discussed.

DISCUSSION

Nothing reported.

THE ELECTRICAL PROPERTIES OF WOOD AS A MATERIAL TO BE TESTED NONDESTRUCTIVELY

Christen Skaar
College of Forestry
State University of New York

The electrical properties of wood are useful as parameters for indicating wood moisture contents. It is convenient to consider separately the D.C. conductivity and the A.C. properties such as dielectric constant and loss factor.

The D.C. conductivity K varies with moisture content, temperature, kind of wood and grain direction. Over the range useful for wood moisture meters, from 5 or 6 percent to the fiber-saturationpoint, the effects of moisture content M and temperature T (Kelvin degrees) can be represented by the equation, log K = A log M + B/T + C, where A and C are constants for a given wood and B is a function of moisture content, different in general for each wood, Time-dependent polarization causes reduction in K with time, particularly at higher moisture contents. The Evershed or voltage effect also becomes noticeable at voltages below about 20 volts.

At moisture contents below 5 of 6 percent, K is too low for good measurements except at high temperatures. At moisture contents near fiber-saturation and above, K varies only slightly with moisture content and therefore does not give reliable moisture content indications. In spite of the variations in K between different woods and even within a given species, these variations are small compared with the large effect of moisture content and temperature, and for industrial use measurement of K gives a good indication of wood moisture content.

The A.C. properties of wood useful for indicating moisture content are the dielectric constant D and the loss factor F. Both D and F vary with wood moisture content, density, temperature, grain direction and frequency.

The loss factor F varies with wood moisture content, temperature and frequency in a complicated manner, A broad region of anomalous dispersion occurs at radio frequencies presumably due to dipole orientations. The frequency of this dispersion region increases with increasing wood temperature and moisture content. Another dispersion region is believed to exist in the low power or audio frequencies due to ionic or interfacial polarizations.

The dielectric constant D increases with increasing wood density, moisture content and temperature. It decreases with increasing frequency, particularly in the regions of anomalous dispersion.

MEASURING MOISTURE CONTENT OF WOOD BY ELECTRICAL RESISTANCE AND CAPACITIVE METHODS

W. J. Delmhorst
Delmhorst Instrument Company

The moisture content of wood can be readily measured with instruments based on the measurement of electrical resistance or of the dielectric constant of the wood. They are not suitable for measuring the entire range of moisture content as the relationship between the electrical properties and moisture content is subject to considerable variation when the wood is over fiber saturation point.

The electrical resistance type meter was the first commercial moisture meter and has been on the market since the early 30's. It is suitable for measuring moisture from 6 percent to the fiber saturation point. Although relationship between electric resistance and moisture content below 6 percent is quite definite, the electric resistance increases to extremely high values so that it is impractical to measure it with other than elaborate laboratory equipment. The standard deviation is between 3 and 5 percent when testing 1 inch lumber over the above mentioned range of 6 percent to fiber saturation point. Somewhat greater variation can be expected when testing thicker stock due to the more uneven distribution of moisture that frequently occurs in wood of greater thickness. Different electrodes are available for testing lumber, veneer, or heavy timber. Some are especially designed to detect the distribution of moisture or its gradient. Contact with the wood is usually made by driving contact pins into the wood so that tests cannot be made on finished surfaces without some damage to them.

Other types of moisture meter are based on applying an alternating current to the wood by means of surface electrodes. These meters measure the dielectric properties of wood such as capacitance, impedance, or power loss as a function of moisture content. Portable meters usually operate at a frequency of approximately 10 megacycles and are extremely simple to operate as the condenser plates are applied directly to the surface of the wood and the meter dial may be calibrated directly in moisture content. However, as they are sensitive to total moisture, the readings are subject to variations in the density of wood. Therefore, a piece of wood of which the density is lower than the average for the species will show a reading lower than the actual moisture content. Because density for various species differs considerably, separate calibrations are required for each species, The dielectric meters tend to measure the average moisture content of the material that is within the dielectric field and cannot be used for measuring gradient without cutting the wood. Readings show standard deviations from 5 to 20 percent with an average of 10 percent of the mean.

The dielectric principle is also utilized in the so-called continuous meters. Here the alternating current, usually at rather low frequencies, is applied through a plate type electrode as wood passes under it. Because the electrodes can be arranged so that 100 percent of the wood can be inspected, the accuracy is good because of the large sample size.

Measuring the moisture content of wood is not a simple matter because there is always the problem of uneven moisture distribution in each piece and in between the various pieces in a quantity of lumber. Careful sampling is of primary importance.

APPLICATIONS OF MICROWAVES IN NONDESTRUCTIVE TESTING

Charles W. E. Walker
Beloit Corporation

The use of microwaves in industrial measurement and testing is very new and the only applications so far have been to the measurement of moisture using the water resonance at 22 Gc/s, in which application it can be used virtually over the whole range from 0 to 100 percent H_2O. Microwave spectroscopy is a well-developed science and resonances for many other substances are known in the accessible microwave region. The technology is also being pushed into the millimeter region where many more resonances exist.

In the measurement of moisture in most natural organic material including wood, grains, and other food products a major basic cause of uncertainty and inaccuracy in the readings has been the association or binding which occurs between some of the water and the organic molecules. This binding is not yet fully understood but appears to occur in several different ways due to several different mechanisms. In the case of both cellulose and starch the first molecular layer of the order of 5 percent water appears to be quite strongly bound to active hydroxyl groups in the organic molecules. The next and successive molecular layers are more loosely bound but some form of interaction still exists at least to 50 percent moisture and the water does not behave as bulk water as shown by specific heat, electrical conductivity, dielectric constant, and several other properties.

Since the proportion of the water in these various degrees of association does not remain constant even in a given sample, any method of measuring the moisture content which uses specific heat, dielectrical conductivity, dielectric constant, and so on is liable to inaccuracies.

Microwave absorption is in a different category because there is no gradual change over from bound to free water. If the water molecule is bound sufficiently strongly so that it is not free to rotate as a water molecule, there is no absorption. If it is free to rotate, there is the full absorption as for free water, Measurements on paper have indicated that only the first layer of water molecules is bound so far as microwave absorption is concerned and that the proportion of the water in this layer remains constant over a wide range of conditions such as relative humidity and temperature and is independent of the past history of the paper sample. Furthermore, the microwave absorption varies to only a small extent between widely different types of paper indicating that the proportion of water in the first molecular layer is not greatly affected by fiber composition and treatment. Whether this will also be found to be true of starch in grains remains to be determined.

THE PIEZOELECTRIC EFFECT IN WOOD

Larry D. Bertholf
Washington State University

Piezoelectricity is the property of a material which causes a voltage to be developed when the material is subjected to a strain; and conversely, when a voltage is impressed across a piezoelectric material, strain is induced.

The study of this property in wood at Washington State University has been dual in nature. Both effects, one concerned with the direct effect of piezoelectricity, and the other with the use of the indirect effect of piezoelectricity as a voltage-strain transducer, have been utilized in the research.

The apparatus used for introducing a stress wave in Douglas-fir specimens (3/4 by 3/4 by 28 inches) consisted of a small air hammer for dynamic loading of the specimen parallel to the grain, a support for the specimen, a trigger-circuit for reference to the time of impact, a voltage sensitive measuring device, and an oscilloscope for time and amplitude indication.

In the use of the direct effect of piezoelectricity in wood, the amplitude of the signal was measured and a selected parameter of this signal was compared to some of the wood characteristics (bulk density, percent summerwood, growth rate, and local grain slopes), plus two mechanical properties, modulus of rupture, and Young's modulus. A correlation coefficient of 0.68 was found between the signal parameter and the modulus of rupture.

Photographs of oscilloscope traces show proportionality in the wave form during the initial portion of two signals, one of which was obtained from an SR-4 strain gage bridge circuit and the other from the piezoelectric signal. The similarity of these signals allowed the use of the indirect effect of piezoelectricity to indicate strain. From this indication of strain the velocity of stress wave propagation in the wood was calculated and by using the approximate equation $v = \sqrt{\frac{E}{\rho}}$ where v is the propagation velocity, E is the dynamic Young's modulus and r is the bulk density, an indication of E is readily obtained. The data collected on selected specimens indicate probable adaption of this method to nondestructive testing of dimension lumber. A correlation coefficient of 0.95 was found between the dynamic Young's modulus and the static Young's modulus in bending.

APPLICATION OF NUCLEAR MAGNETIC RESONANCE IN NONDESTRUCTIVE TESTING

Harold Tarkow
U.S. Forest Products Laboratory

Nuclear magnetic resonance is a form of spectroscopy. In a homogeneous magnetic field, hydrogen-containing compounds absorb certain radio frequency radiations. The shape of the absorption curve is sensitive to molecular motion. The width of the curve due to hydrogen in wood substance is considerably greater than that due to hydrogen in adsorbed water. Thus, the two components in moisture equilibrated wood can be recognized. The areas under the curves are proportional to the amounts of wood substance, and adsorbed moisture and their relative amounts can be computed. Since the difference in degree of molecular motion of adsorbed water below and above the fiber saturation point is much smaller than the difference in molecular motion between wood substance and adsorbed water, the method is theoretically applicable from appreciably below the fiber saturation point (5 percent) to any value above. There is, however, one extremely serious limitation. Because of the requirement that the specimen be in a homogeneous magnetic field, it is essential that no dimension of the specimen exceed 2 to 3 centimeters. The method, therefore, is nondestructive only in the sense that the sample is not disturbed or altered. It is destructive in the sense that the sample must be subdivided as in chips or pulp. Other uses of nuclear magnetic resonance are discussed.

DISCUSSION

Q. What contact materials were used for resistance measurements?

A. Silver paint. An inert material is necessary to avoid change with time. Perhaps platinum. Two factors are involved in the change in resistance with time--change of electrode-wood contact resistance and change in resistivity of the wood itself. The change in resistance with time is due to the relaxation of fibers around the electrode pin. Silver paint gives readings constant with time.

Q. How do you account for the dependence of activation energy for electrical conductance on the grain angle?

A. There is no clear answer. It may be an artifact, or it may be related to special properties of the rays. The activation energy increases with decreasing moisture content.

Q. Has anyone investigated the resistance-potential shrinkage relationship and, if so, is the relationship better than the resistance-moisture content relationship?

A. Shrinkage is not the only reason for measuring moisture content. Painting, gluing, decay, etc., are also dependent on moisture content. The most realistic relationship is that between resistance and equilibrium relative humidity. A resistance-shrinkage relationship will be clouded by collapse.

Q. With microwave absorption, how wide is the water resonance line?

A. The peak is sharp for water vapor. It is broad in paper at 12 percent moisture or higher.

Q. Surface moisture may form on exposed siding, etc., that may or may not be painted. Could a microwave device measure this?

A. Yes.

Q. How much energy is dissipated as heat in the absorbing material?

A. The source has an output of only 100-200 milliwatts, of which 10 percent is applied to the specimen. This is too small to do much heating.

Q. Is there any speed limitation?

A. Practically none.

Q. Can microwave absorption detect flaws?

A. No.

Q. Is the moisture content at which the water monolayer is complete based on wood weight? Is it a measure of internal surface?

A. The monolayer moisture content is related only to the number of unsatisfied hydroxyl groups.

Q. It is interesting that there can be "free" water below the fiber saturation point. Are there other data confirming this?

A. No. Actually this depends on the definition of "free" and "bound" water, although there is some evidence that water above 6 percent can act as a solvent and thus in a sense is "free." Whether water is "free" or "bound" simply depends on the energy required to make it (H_2O) interact with the microwave field.

Q. In the piezoelectric work, was the interference between the direct and reflected stress wave a problem?

A. It was a minor problem, but was ignored.

Q. Was the double peak (piezovoltage) due to springwood–summerwood interface?

A. It is not known. Knots and other discontinuities have big effects on piezo properties.

Q. Where is the ground reference of the detector?

A. The reference is in capacitance between specimen and grounded frame of machine.

Q. Is there any apparent difference in piezoeffect between cellulose and lignin?

A. No evidence that there is.

Q. Where does the piezoelectric effect fit into the evaluation of glue joints?

A. Such techniques are still in the hopeful stage.

Q. What is the general order of magnitude of piezocoefficients?

A. About $3x10^{-6}$ per millivolt.

Q. If voltage was sensed at each end, would it be greater?

A. Don't know.

Q. Will a forced twist of the specimen produce a voltage?

A. Yes.

Q. Why is there only one proton absorption bond in the NMR spectrum for dry cellulose?

A. In dry cellulose, the hydrogens are attached to a rigid lattice.

Q. Wouldn't some difference be expected between protons in different parts of the cellulose molecule?

A. Perhaps. But a high resolution would be necessary.

Q. Has any NMR technique been successful using a skewed magnetic field?

A. In conventional NMR work, a uniform magnetic field is essential.

A. With spin-echo technique, the field need not be highly uniform.

STRESS WAVES IN SOLIDS

B. A. Jayne
North Carolina State College

Using the methods of classical elastic theory it can be shown that two types of stress waves can be propogated in an unbounded elastic media; waves of dilatation and waves of distortion. In bounded media when a wave of either type impinges on a free surface both types of waves are generated. In addition to these two types of waves, elastic waves known commonly as Rayleigh waves can be propogated along the surface of a solid.

Under the assumption of ideal elastic behavior two constants can be used to characterize the elastic nature of a bounded isotropic solid. These two constants and the density are used in formulating partial differential equations of motion of the elastic solid. Solutions of these equations, which yield displacements as functions of time and the constants, are available only for a few relatively simple boundary conditions. A few specific cases are discussed.

A description of the elastic nature of wood requires in the simplest case the specification of nine independent elastic coefficients. Furthermore, it is recognized that wood is imperfectly elastic. Consequently, the equations of motion must include dissipative forces as well as forces due to elastic deformation. Due to the number of elastic constants and the presence of dissipative mechanisms several simplifying assumptions are necessary in order to arrive at solutions of the equations of motion. A few simple cases are reviewed.

FACTORS AFFECTING THE VIBRATION PROPERTIES OF WOOD

W. L. James
U.S. Forest Products Laboratory

The vibration properties of a material may provide measures of other properties that are otherwise difficult to measure,

Vibration testing requires fairly simple equipment and techniques and is capable of highly accurate measurement. Inference of basic information from vibration data, however, may involve rather complex theoretical problems.

Vibration measurements on wood have been attractive not only to provide new insight and understanding of basic wood structure, but also as a possible non-destructive estimate of wood strength.

Vibration properties that usually are measured directly are the damping capacity or internal friction, and the speed of sound. The internal friction is commonly expressed by the log decrement, d, and measured either by noting the rate of decay of free vibration or the amplitude of driven vibration as the frequency of the driving force varies in the neighborhood of the resonant frequency of the specimen. The speed of sound is obtained from the resonant frequency and dimensions of the specimen.

The vibration properties of wood are affected by such factors as moisture content, temperature, grain direction, species, and the frequency and amplitude of vibration. A number of studies have been made of the effect of such factors on the vibration properties of wood.

Early studies indicated that the internal friction of wood was independent of frequency, but later work contradicted this. A recent study in Germany showed that the internal friction in uniform wood bars increased as the bars were shortened to give higher frequency, but this increase disappeared when the lateral dimensions were reduced in proportion to the length. The effect of frequency is still not well known.

The internal friction in wood is strongly affected by moisture content. At room temperature, the internal friction is minimum at 6 to 8 percent moisture. At higher temperatures, the minimum internal friction is less and occurs at a lower moisture content; at lower temperatures the converse is true.

At certain temperatures the internal friction is minimum, the temperature of the minimums increasing as the moisture content approaches zero.

The internal friction in wood is about two to five times greater when the stress is perpendicular to the grain than when parallel to the grain and about three to four times greater for shear stress than for direct stress parallel to the grain.

The speed of sound in wood decreases with increasing temperature or moisture content and increasing grain angle. The speed of sound may be reduced by as much as tenfold as the direction changes from parallel to perpendicular to the grain.

The internal friction in wood has not been generally useful in predicting strength values, but correlations between elastic modulus, determined either in static or dynamic tests, have been good enough to permit estimates of strength values to be made from nondestructive determinations of the elastic modulus.

The limited data presently available suggest that if the coefficients of correlation relating the strength values to the elastic modulus have been properly determined, no more than 1 percent of the estimated values will differ from the true value by more than about 15 percent of the true value.

THE CONCEPT OF SELECTION EFFICIENCY AND TOLERANCE IN THE NONDESTRUCTIVE TESTING OF WOOD

D. G. Miller
Forest Products Research Branch
Canada Department of Forestry

A nondestructive strength test of wood must be based on a known relationship between its strength and some other property which can be evaluated without damaging the wood. Scatter about the regression line of such a relationship reduces the accuracy of the nondestructive test causing it to reject some acceptable wood and to pass some low strength wood. The selection efficiency of a nondestructive test is defined as the percentage of acceptable material which is actually passed by the test. The tolerance of a nondestructive test is defined as the percentage of the material passed which is actually below acceptable strength. The permissible tolerance depends mainly on the system of loading and the consequences of a failure in service, For some uses of wood an infallible nondestructive test having no tolerance may be necessary. The selection efficiences of an infallible vibrational test of the bending strength of clear maple wood were found to range from about 10 percent at high acceptable strength levels to about 70 percent at low acceptable strength levels. Permitting a small tolerance in the nondestructive testing of clear maple wood results in large increases in selection efficiencies.

Application of the concept of selection efficiency and tolerance to the non-destructive testing of cross-arms was investigated. The vibrational properties of 50 cross-arms 10 feet long were measured using pulses of compressed air as the driving force. The cross-arms were later tested to destruction in static bending. A proposed nondestructive test is based on a relationship between maximum load and vibrational index (resonant frequency squared times weight). Ideally each cross-arm should have a strength equal to the maximum load in service. However, an infallible nondestructive test of cross-arms has very low selection efficiencies causing high wastage of acceptable cross-arms. The cost of this wastage must be weighed against the cost of replacing the cross-arms which fail in service. A large increase in selection efficiency resulting from allowing small tolerance appears to justify the risk involved in allowing a small percentage of the cross-arms passed to be below ideal strength level. In the nondestructive testing of wood a compromise must be reached between selection efficiency and tolerance. Tolerance should be made as great as the likelihood and the consequences of failure will permit in order to achieve a selection efficiency which is economically acceptable.

A VIBRATION GRADING SYSTEM FOR STRUCTURAL LUMBER

R. F. Pellerin
Washington State University

The development of a grading system for structural lumber was undertaken using the hypothesis that energy loss and energy storage parameters are related to the mechanical properties of wood.

The feasibility of such a grading system was established by measuring the energy loss and energy storage parameters by vibrational methods and correlating these to the static bending properties of the lumber.

The key to finding a useful correlation between vibrational parameters and mechanical properties of structural lumber appeared to be in the selection of the proper mode of vibration and mode of support. Another key factor was the proper characteristics of the monitoring system.

Preliminary tests, using a particular mode of vibration and mode of support, resulted in a correlation coefficient between static "E" and dynamic "E" of 0.96. A correlation coefficient of 0.91 was achieved between modulus of rupture and a certain combination of vibrational parameters. Coefficients of this magnitude are considered to be adequate for the prediction of the strength properties of structural lumber for the most demanding applications.

ULTRASONIC NONDESTRUCTIVE TESTING OF WOOD AND OTHER MATERIALS

A. S. Birks
Sperry Products Division
Automation Industries Incorporated

This presentation will begin with an explanation of the phenomena of ultrasound as compared to everyday audible sounds. A detailed explanation will be made of physical and electronic functions of the Sperry Reflectoscopes and operating techniques. A UM-700 Reflectoscope will be demonstrated along with search units (transducers) to give the conferees a feel of the physical appearance and operations of industrial ultrasonic equipment.

Use of couplants or materials used to match acoustical impedance characteristics of search unit materials and the inspected media, will be explained. Several couplants used in current inspection applications on wood, plastics and metals will be discussed.

Choice of size of search unit and frequency of ultrasonic equipment will be compared with actual applications. In this phase of the talk, penetration of materials and sensitivity of detection with ultrasound waves will be compared to actual results now obtained with commercial equipment. Hints on producing artificial defects will also be covered.

In conclusion, actual ultrasonic inspection applications of wood products will be discussed. The goal of each application and testing techniques chosen will be reviewed along with results and possible practical applications.

DISCUSSION

Comment: When testing wood in compression parallel to the grain, the maximum load is reached when the rate of creep equals the head speed. Thus the head speed, damping capacity, and strength are interdependent.

Q. Is there evidence that the viscosity coefficient in wood is constant or does it depend on the stress level?

A. It seems to be constant except at extreme stress levels.

Comment: The values of viscosity inferred from creep data seem to be functions of temperature.

Q. Why should E (modulus of elasticity) correlate with modulus of rupture?

A. No basic reason. E reflects amount of material present, but also tells a little more than density alone about interfiber bonds.

Q. Has the selection efficiency of visual grading ever been studied?

A. No, but cross–arms used in vibration tests were visually graded. In one study, 25 pieces that passed visual grading limits had same strength as 25 pieces that failed to pass the visual grading requirement.

Q. Shouldn't tolerance limits be placed at extremes of range?

A. Strictly yes, but probably not necessary if a uniform variance is assumed.

Comment: It would be ideal if the selection efficiency were constant at any stress level. The lower efficiency at high stress is probably due to natural distribution of strength values.

Comment: Kitazawa found it possible to detect some voids in wood using high frequencies, but as the frequencies increased, the scattering also increased.

Comment: We need a better explanation of the fracture behavior of wood. This would aid us greatly in our correlation with nondestructive testing methods. Some preliminary studies have shown that acoustic emission occurs in wood at stress levels as low as 5 percent of strength. This means that crack extension from defects is occurring. With clear specimens, the level is higher, but all structural material contains defects.

Q. In vibration grading, were static M of R values obtained with flat or edge loading? Is there a difference?

A. Flat loading. Difference is not known.

Q. Is it necessary to determine the density for strength prediction by vibration method?

A. No, but it helps.

Comment: These results show the best vibration-strength correlation to date.

Comment: It might improve correlations if the specimen was cut into three parts to get a better average.

Q. In the vibration technique, do you feel you test the whole board?

A. Don't know.

STRESS RATING OF LUMBER BY FLEXURE TESTS

Stanley K. Suddarth
Purdue University

Automated production line equipment for stress grading of lumber using measured physical properties is now a reality. Accuracy apparently exceeds that for the established visual system and higher stress ratings are possible. My laboratory has been and continues to be interested in the practical and scientific aspects of this process of statistical prediction.

Two hundred pieces of material from five visual stress grades were tested to destruction in bending and both multiple linear and multiple joint prediction equations were evaluated from the data. Modulus of rupture was predicted using modulus of elasticity, density, moisture content, and slope of grain as independent variables. The dominance of modulus of elasticity as a predictor overshadowed the other variables in the multiple linear system. The multiple joint equations tried did not yield improvement in predictive powers but this is still considered to be a fertile area for further study. A final choice for an initial grading system was a two variable linear equation using modulus of elasticity and density to predict modulus of rupture with density being a weak contributor and retained more for academic reasons. The resulting grading system displayed clear advantages over the established visual system in both accuracy and the identification of material that can be assigned working stresses up to 3,000 pounds per square inch (p.s.i.). The highest rating assigned to this same lumber by visual grading was 2,150 p.s.i.

There is room for improvement: our best statistical efforts now explain about half of the observed variation in modulus of rupture. Past work with clear wood has yielded nonlinear relationships of strength with such properties as moisture content and density while statistical findings with full-scale members have found simple linear models to be adequate. These considerations provide evidence of the existence of undiscovered parameters and equations that can greatly increase predictive power. Our future research program is directed toward this target.

An increase in predictive power will bring increased interest in proof testing as the margins of ignorance are melted away. It then will become desirable to put a catch-basket under the statistical system to identify those few pieces that will slip through. The key problem here appears to be the need for an accurate instrumental method for the detection of compression failures. The solution might take the form of physical equipment or a further statistical system applied to the results of a sequence of quickly repeated and reverse flexure tests.

THE POTLATCH SYSTEM OF STRESS RATING

I. ECONOMIC ASPECTS

H. B. McKean
Potlatch Forests, Incorporated

Modulus of elasticity is the only structural property that can be accurately measured without breaking the piece. A vast majority, perhaps 75 percent or more, of all 2-inch dimension lumber is used for joists and rafters--uses where modulus of elasticity is generally the controlling factor. The Potlatch machine grader accurately measures this property. Having accurate measurements of moduli of elasticity correlated with working stresses in bending, span tables based on moduli of elasticity have been developed. Since E controls in about 99 out of 100 cases of machine graded lumber, span tables are the same for all species when machine graded and sorted by E classes. So a single set of tables replaces the 40 or so pages of span tables now used by Federal Housing Authority for visually graded lumber.

Commercial runs with two Idaho species provided the following yields:

Grade	Percent of Total: White Fir[1]	Percent of Total: Inland Douglas-fir[2]
E 2.2, f 2700	5	28
E 1.8, f 2100	39	40
E 1.4, f 1500	48	27
E 1.0, f 900 and lower	8	5

An important economic benefit for both manufacturer and user is the use of smaller sizes to provide a given performance. For example, with a 40 pound per square foot load on a 13 foot 6 inch span (normal span for a 14 foot joist), a Douglas-fir 2 by 10 is required under visual grading, but a 2 by 8 (any species) in E 2.2 machine grade is adequate.

[1] White fir was mostly *Abies grandis;* 800 M bf provided these data.

[2] Represents values from about 60 M bf.

Machine graded 2 by 4’s will permit longer trusses. In one set of conditions, a 28 foot truss is the longest possible with visually graded 2 by 4’s. With machine graded stock of any western pine species, certified for machine grading, 2 by 4’s can be used up to 32 foot spans using E 1.8 grade.

The more important advantages of the system are:

1. High strength wood can be positively identified and made readily available.

2. Accurately measured E ratings are provided,

3. There is much greater uniformity of structural properties within grades.

4. Savings result for the user through the use of smaller but stronger pieces.

II. EQUIPMENT AND PROCEDURES

R. J. Hoyle, Jr.
Potlatch Forests, Incorporated

Relationships between several mechanical properties of wood which are important to the designer, are the basis for lumber grading by nondestructive tests, The property that is measured nondestructively is modulus of elasticity. Properties which are well correlated with elasticity are extreme fiber in bending, compression–parallel–to–the–grain, and tension parallel–to–the–grain. Properties which are lees well correlated, but not altogether unrelated are compression–perpendicular-to-the-grain and shear parallel–to–the–grain.

Quantitative measurements of these relationships have been made. They are in reports, some already presented and others available for presentation in the future. Portions of this evidence are the work of different investigators working independently and obtaining similar results.

The influence of strength reducing growth characteristics has traditionally been stated as a modification of the basic strength of clear wood, The growth characteristics themselves modify the gross cross–section of members by reducing the effective working area, altering the direction of fiber axis, and influencing density of the wood composing the residual working area. It has been more convenient to represent these effects as a series of modified strength properties, than as a modified cross–sectional property,

Effective stiffness is a product of modulus of elasticity and moment of inertia. Rather than evaluate a complex modification of moment of inertia, it is convenient to adjust the modulus of elasticity for design, In this way the influence of defects may be regarded as a reduction in the modulus of elasticity of the clear wood.

Scientific investigations have established rather conclusively that a direct relationship exists between suitable design values for modulus of elasticity and for the other principle useful strength properties.

It is emphasized that the interrelationship of properties are characteristics of wood, and not of nondestructive grade classifying machines. The two commercially available grading machines are designed merely to measure and classify. They differ in their speed, efficiency, and practical operating characteristics.

Elements of variability exist in these newly exposed relationships. This variability has been measured, and while it is substantial, the classification of structural lumber according to stiffness permits identification of several grades more clearly than has been possible by older grading methods. Substantial quantities of lumber having a higher order of strength can be identified and made available for use.

To accomplish this classification the machine developed by the authors' organization continuously integrates the reaction of a tested piece to a standard deflection applied along its length. This produces a measure of average stiff-ness. To qualify for any particular stiffness grade the piece must display a specific minimum average stiffness. In addition the piece must exhibit a second specified minimum, minimum stiffness. This offers insurance against pieces with areas of localized extreme weakness without rejection of pieces with more frequent but less weakening defects. The strength properties are sensitive to the weakest area in each piece. The stiffness property is also essential to good design. In most structural members the stiffness and strength conform to a pattern. There are pieces which depart from the pattern, due to a high average quality with a weak link, so to speak, of low quality. These relatively infrequent pieces can be identified and rated safely, although their average stiffness property will be underestimated.

Grade rules for nondestructively tested and stress-rated lumber, based on an expanded knowledge of wood properties, have been provided by three of the principal softwood grading associations.

THE STRESS–O–MATIC STRESS RATING SYSTEM

Stanley D. Pelster
Western Pine Association

The Stress–0–Matic system evolved from early efforts of the W.P.A. Laboratory in nondestructive testing finger joints by rapid loading in mechanical bending. This has been extended to stress–rate dimension lumber in current production. Of primary interest is how and why this machine rapidly and accurately performs the function of stress–rating.

The operating principle and actual function of the machine may be visualized by analogy with a static bending test, Recording only the load held by the test piece flatwise at its weakest point without deflecting past a preset deflection limit, we have an indication of the strength and stiffness of this piece when used on edge. The correlations of lumber's strength versus stiffness both flat and on edge have been well established by thousands of static tests so that an indication of either strength property flatwise gives good indication of these properties for use on edge.

A more detailed analysis will give some insight as to why and how the machine performs its function of stress–rating. This has consisted of assumptions, calculations, trial runs, and final proof of results by standard static bending tests. When one considers the nature of the problem, first in a machine rapidly loading the piece at four points and supporting at four points, and finally the infinite variations in the product being rated, theory and calculation gives only a sound basis. The final loads and deflection used results from actual static test results from lumber rated under several different load and deflection combinations. The combination used results in a minimum reliability of 95 percent on the f value assigned and a tolerance of 100,000 pounds per square inch on average MOE for groups of stress–rated lumber.

DISCUSSION

Q. With stress rating by flexure, are slope of grain and moisture content eliminated as important variables?

A. Yes. That is indicated by these data. The partial correlation coefficients are very low. All possible interactions were not explored, however.

Q. Was the mathematical model constructed after the data were collected?

A. Several models were selected for consideration prior to data collection. The final selection depended on how well the data supported these models.

Q. Were moisture contents stratified at three levels?

A. Yes, but with some spread.

Comment: Then the relationships are confounded by moisture content.

Q. Is slope of grain the general slope or that of deviation around knots?

A. Slope of grain is an estimated value intended to represent the general slope rather than localized grain direction.

Comment: Perhaps, until we can define and measure slope of grain more accurately, there is no need for high sophistication.

Q. In using the Potlatch system, what is the value of $\underline{r^2}$?

A. For the relationship between MOR and MOE, about 0.68 to 0.73.

Q. On the minimum threshold value, does this represent an individual for the piece or an average between two directions?

A. The minimum level of voltage put out by the transducers is an average.

Comment: In pieces shorter than 12 feet, the graders will ascertain if defects on the ends are less significant than those in the middle. To this extent, grading is visual.

Q. Do the data on sales of machine stressed–rated lumber apply to the lower grades?

A. We had few orders for the grade called E 1.0. Fortunately, we do not get much E 1.0.

Q. Can you elaborate on the location of knots?

A. Consider the location of the knot with respect to the neutral axis. The knot is perpendicular to the broad face, usually. On this assumption, effect of this knot on strength depends on position with respect to the neutral axis. In testing flat, it depends less on position. We thought that pieces tested on edge would display more variation than when tested flat, but there is little difference in r. There is a difference in level.

Q. If material which is rejected in machine stress rating is subsequently visually graded, won't it be substandard in quality?

A. Visual grade rules define the minimum requirements of a grade. Professor Suddarth's previous talk has demonstrated that the minimum strength of visual graded material is seldom below the allowable strength for the grade. The user expects a certain strength capability. Visually graded material which is rejected by machine grading is unlikely to be uprated dangerously. There just won't be as much "cream" in the visual grade as there used to be. I have referred here to strength. As far as stiffness is concerned, I expect that visually graded reject from M.S.R. lumber will be slightly lower in average stiffness than the same visual grade would be if none of the lumber was being machine rated. Remember that most visually graded lumber in the lower grades is currently overrated for stiffness. Despite this overrating, it seems to be performing satisfactorily on the basis of the span tables of questionable accuracy that have been in use.

Based on observations of the operation of Potlatch's machine grading operation, material rejected by grading machines is not going to be upgraded to any extent by a further visual grading treatment. If it was, machine grading would not be a very successful practice.

Q. The E value now used is an average. When we test a panel or assembly, as a check we find the E of the assembly is close to the individual pieces. With the range of E's you get in machine grading, is it possible that higher E's could be used to raise lower E's to the average? If so, should the 9 or 11 classes be reassembled to some extent as in visual grading?

A. Of the 9 or 11 levels in existence, no one species from any mill will be sold at all levels. We now sell three levels. If we assume a price difference between levels, the substitution of smaller pieces will give a monetary advantage. In certain residential buildings live load criteria change for various rooms, but all the builders want the same depth of member. Here the builder may be able to use different grades to advantage.

Q. How many Western Pine Stress–0–Matics are in use?

A. In the Western Pine region, two Stress–0–Matics and two Continuous Lumber Testers. West Coast is installing one at Junction City.

Q. What is the potential number?

A. There are many western pine mills.

Q. What is the $\underline{r^2}$?

A. With 2 by 4's, we got results to substantiate the 80 percent value.

Comment: In the Potlatch, we get 0.9 to 0.92, in compression.

Q. What accuracy do you have on the "Stress–O–Matic"?

A. With Douglas–fir, the machine is set to 0.420±0.005 inch. We can set it down to 0.002 inch.

APPENDIX

General Impressions of the Symposium on Nondestructive Testing of Wood

G. G. Marra
Washington State University

The discussions of this symposium dealt primarily with determination of moisture content, density, and strength properties of wood by nondestructive means. The background sciences for nondestructive testing, as represented by chemistry, physics, and mathematics, were also covered insofar as they were pertinent to the subject at this stage of development. Finally, a number of examples of specialized equipment now in use for wood and other materials were discussed,

These discussions were all aimed at making a long-standing dream of wood technologists come true--a dream that wood would some day become, in every sense of the word, an engineering material with easier acceptance by architects, engineers, and builders alike. For some of the more ardent wood enthusiasts, the futurity implied in this statement may be unacceptable in view of the centuries of successful application of wood in engineered or nonengineered structures. Nevertheless, we must admit that an objective retrospective view of wood use would always expose the fact that past successes have been attributable more to high factors of safety, compounded with factors of ignorance, than to engineering acuity. Hence, efficiency in the use of materials, as a basic tenet of engineering, has not really been susceptible of practice in regard to wood.

One notable exception in regard to efficiency might be the early aircraft industry. However, in this case the factor of ignorance, operating ruthlessly under the goading of a heavy weight of responsibility throughout the selection of material, made possible a low factor of safety in the design. The large amount of unrecognized good material rejected with the bad would again support the charge of poor efficiency in the use of materials.

The promise of nondestructive testing, therefore, addresses, itself primarily to the problem of efficiency in the use of wood in engineered structures. Since roughly two-thirds of all wood is used in construction, much of it in load-carrying situations, the potential for tangible benefits from widespread practice of nondestructive testing is tremendous.

It is interesting that the expectation of this great promise has surged to the fore from practically an unknown term in the wood industry only 5 years ago. This symposium is the realization of the urgency with whch the industry now regards its present need for reliable methods of testing wood. We might well ponder the reason for the delay in attacking chronic wood problems through this route. After all, the Society of Nondestructive Testing has been existence for 27 years, and electrical moisture meters, an outstanding example of non-destructive testing applied to wood, have been in use for 30 years.

I would like to pursue this point further to make another point. Dr. Ben Jayne, a wood technologist (North Carolina State College), is largely responsible for introducing the concept of nondestructive testing to the wood industry. It was not, and could not be, the equipment manufacturers. First of all, the problems of wood are entirely different from those for which the term was originally developed, namely, metallic materials. Secondly, the equipment manufacturers had no way of being aware of problems in the wood industry. Consequently, the required initial concepts have to originate with people who know <u>wood</u> and who know the <u>wood industry</u>,

The important point, therefore, is the following. The wood industry and associated research people must be alert to the developing technologies in related areas and must constantly recognize and spell their own particular needs. The equipment manufacturers then have a chance to be helpful in solving the problems. The initattive, I beg to repeat, remains on the wood industry side of the fence. The necessary alertness, in regard to nondestructive testing, has now been well demonstrated, but spelling out needs has only just begun and must be accelerated.

Perhaps with this point thus emphasized at the outset, the highlights of the symposium may best be summarized as a series of statements.

1. Most applications of nondestructive testing heretofore have been in the detection of flaws in the material, for example, voids or foreign objects, and various manufacturing faults. In contrast, one of the important goals for nondestructive testing of wood is the strength property itself, and not simply the detection of flaws (for example, knots) and other factors which influence strength. Consequently, it is reasonable to expect a good deal of modification of existing equipment and techniques in adapting them to the problems of wood.

2. In regard to the concept of wood as an engineering material, John Shope (NLMA) in committee discussions pointed out that to take its place along with steel, concrete, and other recognized engineering materials, wood will have

to meet specifications of comparable stringency. Data for such specifications, in his opinion, are now lacking; many thousands of tests will be needed to establish reliable correlations which will be convincing to code authorities and to specification–issuing agencies.

3. Mr. Shope also emphasize that if the industry comes up with a variety of test methods all claiming to do the same thing, they must all agree in regard to the end result. Otherwise, great confusion will ensue to the detriment of the entire development.

4. The foregoing observation brings forth the problem of a method of comparing test methods, Don Miller (Canada Department of Forestry) has already started thinking about this problem with his concept of selection efficiency. Dr. Suddarth (Purdue U.) has also presented a helpful statistical analysis of the conventional parameters relating to strength properties of wood.

5. Dr. Gregory (Weyerhaeuser) in his keynote address, pointed out that more high–strength lumber is available today than high–strength uses.

   This can be taken either as a discouraging note or as a challenge. Perhaps more consideration needs to be given to the quality of the guarantee asso–ciated with the labels on high–strength lumber. In any case, it seems axiomatic that as quality of a product goes up, use potentials also go up, provided, of course, that price remains in line. However, this is not automatic, and much work needs to be done before we can hope to harness the full power of NDT. In addition to uses, there are serious implications in regard to manufacturing and sales. Developing the maximum potential in sales may call for a more concerted effort than has been characteristic of the industry in the past.

6. Dr. McMaster (Ohio State University) introduced a further complication by his warning that cheap materials cannot bear the cost of expensive NDT.

   This would indicate that wood must either become an expensive material or low cost methods for NDT must be developed. Present indications, as revealed by the existing stress rating machines, are that the cost per thousand board feet for this type of test is reasonable and the rate of testing adequate. Future improvements are likely to bring forth increased speeds. Moisture detectors, both manual and automatic, have also proved to be low in cost of operation.

7. Both Potlatch Forests, Incorporated, Lewiston, Idaho, and Western Pine Association, Portland, Oregon, have developed commercial stress–rating machines for lumber. Both machines employ the principle of continuous end–wise travel of the board in the machine while subjecting it to load–deflection action and measurement. These measurements involve calculations dealing with modulus of elasticity and make possible the use of correlative proce–dures for determining allowable working stress. Although sequence and mathematical manipulation differ in the two machines, the end result in both cases is a board stamped with a modulus of elasticity class and a stress rating. These machines are known as mechanical stress rating machines, a name which will serve to distinguish them from other approaches to the same problem.

8. It is relevant to keep in mind that NDT in its present course of progress could very well be the route to important properties of wood heretofore inaccessible by any other test method. For example, creep and its relation–ship to long–term loading may someday be approached as a direct measure–ment, instead of by assumptions and approximations. According to Dr. Ben Jayne, future developments could bring forth properties of engineering value now not suspected. The piezoelectric effect in wood, as reported by Larry Bertholf and W. L. Galligan (Washington State University), for example, holds forth such a promise. The vibration approaches to NDT as reported by Don Miller (Canada Department of Forestry), William James (Forest Products Laboratory), and R. F. Pellerin (Washington State University) could also lead to new parameters for engineering purposes.

9. Because of the possibility that NDT may develop new parameters representing the critical engineering properties of wood, it is apparent that some of the present strength parameters based on destructive tests may become obsolete. This could well be the case, for example, with modulus of rupture, a measure that has long been used as a practical basis for engineering design, but which has little theoretical validity.

10. In addition to the situation projected above, it should be recognized that the use of standard destructive tests may not always be appropriate for verifica–tion and correlation purposes. For example, the usual bending tests subject the midlength of the piece to greater outer fiber stresses than the ends. Defects in this central portion of the length, therefore, affect the observed “strength” of the piece more than the same defects near the ends. Nondestruc–tive testing by vibrational methods also operates with a nonuniform stress distribution pattern, but, as presently understood, seems to measure the effect of defects irrespective of location in the piece. Consequently, indis–criminate correlation with bending test results will tend to develop an

inaccurate assessment of the accuracy of vibration methods. On the other hand, future developments in wood–use concepts may place greater emphasis on the strength of the piece as a whole, in which case values reliably predicted by vibration methods would gain intrinsic validity.

11. When wood in lumber form is tested for strength by nondestructive methods, part of the potential advantage of NDT is lost. The maximum dimensions are irretrievably committed and the fate of the piece rests largely on the properties displayed at that point. If wood quality could be determined in the log, then a further chance would exist for selecting dimensions to match quality and thus enhance the potential returns from the material.

    Backing up one step further in this fantasy of desire, if quality of wood could be determined in the tree, still another opportunity would be provided for selection and judgment before committing it to length, or even to harvest. The tree, therefore, seems to be the ultimate in the application of NDT to selection of wood, although a geneticist may wish to argue the point back to the seed.

    In the opposite direction, NDT will find wide application to manufactured wood products and to composite wood–nonwood products. These products are all characterized by adhesives as a critical linkage, and their performance depends upon both wood quality and bond quality. Plywood, particle board, laminated beams, sandwich construction, and stressed–skin panels are examples of these products for which reliable test methods are lacking. The application of NDT to such products could greatly enhance the potential for utilization through providing means of controlling quality.

    There were no references to testing products of this type during the symposium, a fact which reflects the present status of the interest and effort. However, in spite of the extreme complexity of the problems, a limited amount of work is in progress in various laboratories.

12. Many potential applications of NDT to wood will involve properties other than strength. As pointed out by W. L. Galligan (Washington State University) surface characteristics, both chemical and physical, are subject to measurement by NDT. Methods for measuring moisture content, density, and dimensions are already realities in this field. Tests for permeability may also be possible as progress is made in understanding wood–liquid relationships.

Conclusion

The general conclusion that emerges from this symposium is that the application of nondestructive testing to wood has made an auspicious start. As a term generally unknown to the wood industry a few years ago, nondestructive testing now is starting to command first ranking as a desirable area of research. Commercial machines for predicting strength properties of structural lumber are now a reality and are forcing consideration of the impact of such developments on the marketing of lumber. It is apparent that success in this area will create a demand for more precise measurements and for an expansion of this highly useful concept to other properties and to other products in various stages of manufacture.

It is apparent furthermore, that maximum benefits from the applications of nondestructive testing to wood will occur as it is moved closer to the raw material itself. This will permit judgment to be applied in regard to end products before cuts are made which tend to foredoom the material to specific uses regardless of its inherent properties.

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