FEATURE

Nondestructive Evaluation of Wood

Our forests are an extremely valuable resource. In addition to their value for aesthetics and recreation, the forest serves as a renewable source of raw material for an ever-increasing list of wood and fiber products.

by
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Nature's engineering of wood through genetics, wind, and weather creates a wide variability in wood as a material. Consequently, manufacture and users of wood products are frequently frustrated in dealing with the forest resource. Manufacturers sometimes argue that wood is difficult to consistently process into quality products because of the wide range of properties that exist in this raw material. Users of wood products can be equally frustrated with the performance variability found in finished products.

Nondestructive evaluation (NDE) technologies have contributed significantly toward eliminating the cause of these frustrations. NDE technologies have been developed and are currently used in lumber and veneer grading programs that result in engineered materials that have consistent well-defined performance characteristics. Through the development and use of NDE technologies. advances have been made in the grading of a variety of wood-based materials and products that are used in many structural and nonstructural applications. These technologies are also integral parts of scanning systems used in the forest products industry to identify and locate defects in wood-based materials. Advances have also been made in the development of NDE technologies for use in the inspection of wood members in structures.

WHAT IS NONDESTRUCTIVE EVALUATION?

By definition, nondestructive materials evaluation is the science of identifying the physical and mechanical properties of a piece of material without altering Its end-use capabilities and using this information to make decisions regarding appropriate applications. Such evaluations rely upon nondestructive testing (NDT) technologies to provide accurate information pertaining to the properties, performance, or condition of the material in question.

Many tests or techniques can be categorized as nondestructive (Fig. 1). A wide variety of tests can be performed on a material or product, with the selection of an appropriate one dictated by the particular performance or Quality characteristic of interest.

Visual assessment of the quality of a piece of lumber is probably one of the most widely used nondestructive techniques

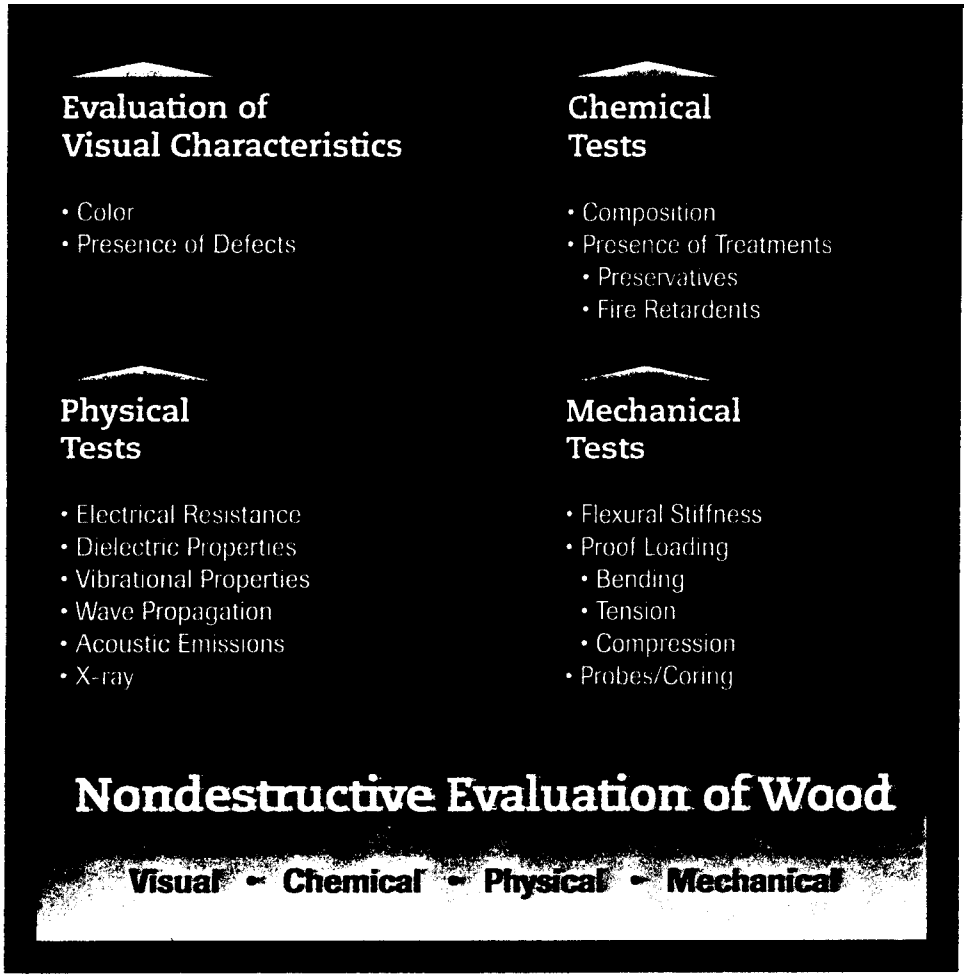

FIGURE 1

Various tests can nondestructively evaluate wood and wood products. Adapted from Galligan (4)

in the forest products industry. Characteristics such as the size, number, and location of knots are common visual characteristics considered when grading both structural and nonstructural lumber.

Various chemical tests have been examined as potential ways to assess the residual performance characteristics of wood products. For example, wood strength loss that results from attack by brown-rot fungi is closely associated with degradation of hemicellulose components in Douglas-fir heatwood (14). Although at the present time such tests are not used extensively to predict residual load-carrying capacity, they do provide valuable information on the causes or mechanisms of deterioration.

SOLID RESEARCH BASE

An exceptionally strong research base pertaining to the nondestructive evaluation of wood has evolved over time. Numerous publications are available that document these efforts. A summary and review of them has been completed and is available from the USDA Forest Products Laboratory (11). Nearly 300 published technical reports, representing more than 40 years of research are application efforts from throughout the world, are cited in that report.

One of the most thoroughly researched areas of NDE has focused on the development and use of technologies for property assessment of structural products. These particular efforts, conducted at various universities and research centers, have resulted in grading processes for both lumber and veneer. These pioneering research efforts were significantly different from NDE research being conducted with other materials at the time. For homogeneous, isotropic materials such as steel, plastics, and ceramics, whose mechanical properties are known and tightly controlled by manufacturing processes, NDE researchers focused on developing technologies to detect the presence of discontinuities, voids, or inclusions. In wood, irregularities of this type occur naturally and may be further induced by the environment. Therefore, researchers working on NDE of wood focused on developing technologies that measure how naturally and environmentally induced irregularities interact in a wood member to determine its performance.

Research and development activities by public agencies, universities, and equipment manufacturers have also addressed the use of NDE to identify defects in hardwood lumber as a means to optimize yield and lumber grade, improve quality control. and provide detailed information about the lumber resource.

CURRENT USES IN THE FOREST PRODUCTS INDUSTRY

As previously mentioned. a wide variety of tests can be classified as nondestructive; the following examples were chosen to highlight just a few of the current applications of NDE in the wood industry.

MACHINE GRADING STRUCTURAL LUMBER

Two of the most widely known machine-graded products are machine-stress-rated (MSR) lumber and machine-evaluated lumber (MEL).

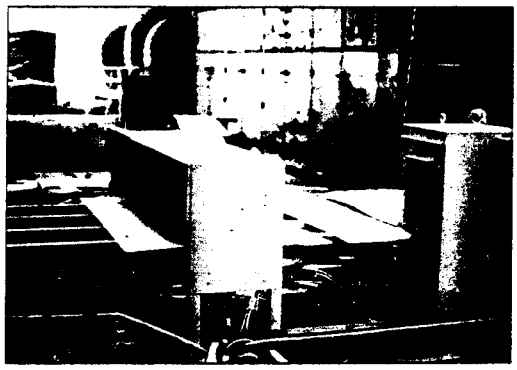

FIGURE 2

An excellent example of the industrial use of NDE, ultrasonic veneer graders provide valuable information on the quality of veneer used in laminated veneer lumber production. (Photo courtesy of Metriguard, Inc., Pullman, Wash.)

The MSR evaluation process, as currently practiced in North America, couples visual sorting criteria with nondestructive measurements of the modulus of elasticity (MOE) of a piece of lumber to assign it to an established grade. Annually, nearly 900 million board feet (BF) of softwood lumber is graded in this manner, with most of it being sold for use in engineered components and structures.

A typical in-plant MSR installation consists of 1) a high-speed machine that nondestructively determines the MOE of individual pieces of lumber by measuring the resistance to deflection of each piece; and 2) off-line quality control testing equipment. In a typical installation, the lumber is fed endwise through a machine that measures its flexural stiffness. The lumber is then marked based on its MOE and is visually inspected for strength-reducing defects, such as edge knots. It is then assigned a grade. In order to verify assigned strength values, samples from each day's production are tested by proofloading, i.e., the samples are loaded in a testing machine and stressed in bending, compression, or tension (depending upon intended end use) to a predetermined level, to insure performance.

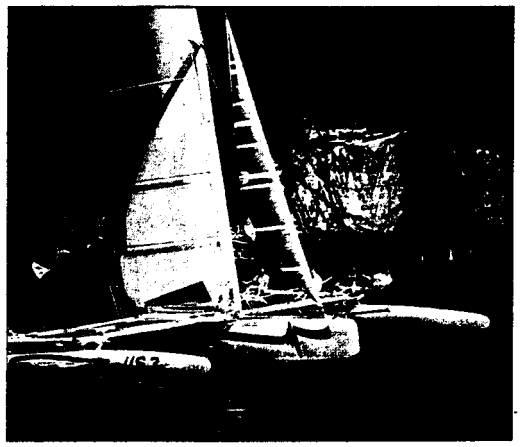

FIGURE 3

The design of this tri-hulled racing boat required ultrasonically graded Douglas-fir veneer. (Photo courtesy of Gougeon Brothers, Inc., Bay City, Mich.)

From 1990 to 1995, annual production of MSR lumber grew from 691.9 to 922.2 million BF (12). Most of this material was used in the manufacture of engineered components, such as trusses, I-joists, and glued-laminated timbers.

MEL is the most recent commercially available product that utilizes machine-grading concepts. In contrast to MSR lumber. MEL relies upon in-line measurements of the density of each piece of lumber as a primary sorting tool. These measurements are followed by visual inspection and rigorous quality control testing on samples of production.

Excellent reviews are available for both MSR and MEL products (2,5,15,17). These reviews provide in-depth discussions of the manufacture and properties of these products.

USE OF ULTRASONIC NDE IN WOOD COMPOSITES PRODUCTION

The development and growth of the laminated veneer lumber (LVL) industry has been a direct result of the application of ultrasonic N DE methods for assessing the properties of wood veneer. A typical in-plant installation that highlights use of these methods is shown in Figure 2. Individual veneer sheets are fed through opposing ultrasonic rolling transducers that send and receive a wave that travels through the veneer along its length. Using previously determined empirical relationships that relate wave velocity and strength, each sheet of veneer is assigned to a strength category based on the velocity at which the stress wave traveled through it. These relationships were derived from fundamental research studies in which samples of veneer were tested to determine the velocity at which a wave traveled through them and then destructively tested to determine their strength. Knowledge of the properties of each sheet of veneer enables manufacturers to design and produce engineered composites that have products with predictable performance characteristics. These composites can be used in highly engineered structures and products (Fig. 3).

North American LVL production has significantly increased during the past decade, to a point where approximately 450 million BF was manufactured in 1994, with production projected to surpass 1.2 billion BF by the year 2005 (7).

Another use of ultrasonic NDE methods in the manufacture of wood composites is for detecting and locating delaminated areas in LVL or blows and blisters in particleboard, medium density fiberboard, oriented strandboard, or plywood. In a typical in-plant installation, multiple sensors are spaced across the width of the panel. An ultrasonic pulse is sent through the thickness of the panel at each sensor point. The ratio of the transmitted to the received signal magnitude is then used to determine whether or not a delamination exists.

SCANNING SYSTEMS FOR HARDWOOO LUMBER DEFECT DETECTION

The primary use of NDE for hardwood dimension lumber and components has been to identify characteristics that affect the value of the material. Emphasis has been placed on locating surface defects including splits, knots, holes, discoloration from stains or decay, and checks. Many commercial scanning systems have been coupled with cutting tools so that cross-cutting, rip-sawing, grading, and sorting can be optimized.

Machine vision technology uses high-speed color cameras to acquire surface characteristics of lumber. The image of the lumber surface is then processed and analyzed. These vision systems can be combined with sorting and cutting machinery and successfully used to sort lumber by color and to cut defects out of dimension lumber.

Laser inspection and x-ray-based systems have been developed and are beginning to be employed for use in locating knots, mineral stain, compression wood, and wane. The laser systems scan both lumber surfaces, process the image, and when combined with cutting machinery, optimize yield by cutting out defects deemed unacceptable by the manufacturer.

INSPECTION OF WOOD STRUCTURES

A wide variety of NDE techniques are used to assess wood in structures. Visual evaluation, which emphasizes examination for signs of exposure to moisture and evidence of attack by biological agents, is frequently coupled with mechanical tests to assess the condition of wood in service. The mechanical tests are used to assess the relative amount of sound material in a wood member, and they can range from simple pick- or probing-type tests to mechanical boring equipment

Advances have been made in the development and use of a variety of stress-wave-based technologies for inspection purposes. Some inspection professionals utilize commercially available adaptations of these technologies to aid in their inspection work. Coupled with a thorough visual examination, these technologies can add significantly to the quality of an inspector's evaluation by providing information on the internal condition of members and the residual load-carrying capacity (Fig. 4).

FIGURE 4

A variety of stress-wave-based NDT techniques are used to aid in the inspection of wood structures. (Photo courtesy of EDM, Inc., Fort Collins, Colo.)

INSPECTION OF THE USS CONSIITUTION

The *USS Constitution,* often called *Old Ironsides* is the oldest commissioned ship in the U.S. Navy. This wood ship was built between 1794 and 1796 under orders from President George Washington. As a historic treasure, it attracts more than 1.5 million national and international visitors each year. In preparing the ship for its 200th anniversary, the Navy and various cooperators conducted a thorough investigation of the ship. Ultrasonic NDE tests were performed on the copper pins used to fasten the ship's large timber members together to determine their structural integrity (16). An ultrasonic pulse was transmitted via a transducer into the end of individual pins. If the pin was free of defects or deterioration, the pulse reflected off the other end of the pin. In partially deteriorated pins, secondary pulses were observed. Pin defects, such as fractures and deep pits, characteristically yielded well-defined secondary pulses and spikes in the received signals. Copper alloy pins often fail from the effects of various forms of corrosion and this condition was readily identified in distinctive scatter characteristics of the ultrasonic pulse.

Stress-wave tests were conducted on various wood members in the ship to locate areas of deterioration. All deck beams (four decks of approximately 32 beams each), various knees, the stern post, the stem keelson, and the keel were examined. Several members were found to have significant deterioration and were replaced.

An excellent review of the entire inspection and rehabilitation effort was recently published in *National Geographic* (9).

RECENT RESEARCH AND DEVELOPMENT ACTIVITIES

MACHINE GRADING HARDWOOD STRUCTURAL LUMBER

A series of research and application efforts aimed at using machine-grading principles to grade hardwood lumber for structural applications has been completed (6). These efforts revealed that MSR procedures currently utilized for various softwood species can be successfully applied to hardwood lumber. More importantly, use of these procedures significantly increases the allowable design values for hardwoods. MSR grading of hardwood structural lumber is now available for use by the industry (Fig. 5).

FIGURE 5

Bending proof load test being conducted on hardwood MSR lumber. (Photo courtesy of USDA Forest Products Laboratory.)

MACHINE GRADING WOOD COMPOSITE PANELS

Technology has been developed to monitor the stiffness and strength of wood-based composite panels in-line during production. Research and development efforts have focused on using this technology to grade oriented strandboard, plywood, and particleboard. It is expected that this technology will be commercialized within the next several years.

ULTRASONIC NDE OF GREEN MATERIALS

Laboratory investigations of the use of ultrasonic-based NDE methods for assessing the quality of green (moisture content aoove the fiber-saturation point) veneer has yielded promising results (1). Strong relationships were found to exist between green and dry N DE assessments. This research effort indicates that it may be possible to sort green veneer prior to drying, which could result in significant savings for manufacturers of LVL materials.

In addition to veneer, efforts have focused on evaluating other green materials, including logs, timbers, and lumber. The use of NDE before drying may result in improved and more efticient processing of these materials.

INSPECTION OF WOOD STRUCTURES

Excellent progress is being made in the development of technologies for assessing the residual performance of wood in structures. For example, Lemaster et al. (8) have shown through a series of laboratory studies that acoustic emission NDT techniques can be used to detect the presence of termites in wood members. DeGroot et al. (3) have explored the relationships between fundamental wave propagation characteristics and various deterioration agents. These and other fundamental efforts, coupled with advances being made in the evaluation of connections (10) and structural systems, show promise for providing a new generation of NDE for wood structures.

LOG SCANNING TECHNOLOGIES

X-ray based evaluation systems are being developed and implemented to provide internal views of a log. These systems provide images that are used to detect and locate internal defects that affect value and yield. Use of these systems in the future may result in improved cutting patterns and an optimized yield for each log.

NONDESTRUCTIVE TESTING OF WOOD SYMPOSIUM

Since the early 1960s, researchers and others interested in furthering the development and use of NDE technologies for use with wood products have gathered at a series of symposiums. Jointly initiated by the USDA Forest Service, Forest Products Laboratory and Washington State University, these meetings have attracted individuals from throughout the world who are interested in the N DE of wood. These meetings have been held at several sites and the most recent was in Lausanne, Switzerland. The 1998 symposium will be held in Madison, Wis.. September 9-11. The proceedings from these meetings are an excellent source of information for those interested in pursuing the use of NDE with wood (13).

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