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EUROPEAN WOOD NDT&NDE RESEARCH AND PRACTICAL APPLICATIONS

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Abstract

The pioneering studies on non-destructive testing (NDT) and evaluation (NDE) of wood have been introduced in early 20th century in Europe as it is in North America. Several improvements were recorded since then in NDT&NDE technologies with parallel to the development in wood industry. A wide range of NDT technologies are currently being used successfully for evaluating wood and wood based materials in many areas from the inspection of artifacts to on-line production control in plants all over the world. Today, research and technology transfer efforts are underway throughout the world to further the development and use of nondestructive methods to address the many challenges that arise with using forest resources. This study aims to review the NDT/NDE research efforts and their practical applications being conducted in Europe that is significant contributors to the international research and development activities.

Keywords: European wood NDT research, Wood structures, Urban trees, Industrial applications.

Özet

Avrupa'da ahşabın tahribatsız test ve muayenesi alanındaki öncü araştırmalar, Kuzey Amerika'da olduğu gibi 20. yy. başlarında görülmeye başlanmıştır. İlerleyen yıllarda odun işleyen endüstrilerdeki gelişmelere paralel olarak tahribatsız test ve muayene alanında birçok önemli gelişmeler kaydedilmiştir. Günümüzde ahşap ve ahşap esaslı malzemelerin değerlendirilmesinde çok sayıda tahribatsız test teknolojisi, arkeolojik eserlerin incelenmesinden fabrikalarda üretimin on-line kontrolüne kadar oldukça geniş bir yelpazede başarılı bir şekilde kullanım alanı bulmaktadır. Bugün orman kaynaklarının kullanımındaki artıştan kaynaklanan birtakım problemlerin üstesinden gelmek için tahribatsız muayene yöntemlerinin geliştirilmesi ve kullanılmasının sağlanması amacıyla bu alanda yapılan araştırmalar ve teknolojik ilerlemeler bütün dünya ölçeğinde paylaşılmaktadır. Bu çalışmada ağaç malzemenin tahribatsız muayene ve değerlendirilmesi alanında Avrupa'da yapılan çalışmalar gözden geçirilmiş ve bu çalışmaların pratik uygulamaları hakkında bilgiler verilmeye çalışılmıştır.

Anahtar kelimeler: Tahribatsız muayene, Avrupa'daki araştırmalar, ahşap yapılar, şehir ağaçları, endüstriyel uygulamalar.

INTRODUCTION

It is assumed that the first concepts of forest science, included wood utilization, were developed in the middle of the 19th century in Europe. During the 20th century, especially during the last 60 years, the utilization of wood advanced through unprecedented and exciting industrial evolution and expansion in many fields. All these improvements in forest industry brought out the need of quality assurance concepts. During the last 20 years, globalization has changed the marketplace. The importance of quality assurance for wood products and their manufacturing is increasing with the increase in world trade (Resch 2008). However, biological nature of trees through genetics and environmental factors causes great variability in wood as a material. Consequently manufacturers and users of wood products are frequently frustrated in dealing with the wood quality. Nondestructive evaluation (NDE) technologies have contributed significantly toward eliminating the cause of these frustrations (Pellerin and Ross 2002).

Since the publishing of initial scientific researches in early 20th century (Hörig 1935, Hearmon 1948, Bell et al. 1950, Kollmann 1951, Jayne 1955, Fukada et al. 1956), the field of nondestructive testing (NDT) and nondestructive evaluation (NDE) of wood materials is constantly evolving (Brashaw et al. 2009). Through the development and use of NDE technologies, advances have been made in the grading of a variety of wood-based materials and products used in both structural and nonstructural applications (Pellerin and Ross 2002). So that a wide range of NDT technologies are currently being used successfully for evaluating wood and wood based materials in many areas from the inspection of artifacts to on-line production control in plants (Brashaw et al. 2009; Bucur 2003).

The original impetus of the development of nondestructive evaluation techniques was the need to reduce the uncertainity of wood material characteristics as influenced by its biological nature so that to make more accurate decisions about proper use (Pellerin and Ross 2002, Bucur 2003, Brashaw et al. 2009). This remains the major driving force for NDT/NDE wood research, with two significant additional challenges. First, there is an increased emphasis around the world to address forest and ecosystem health issues. Utilization of woody biomass from widely varying growing conditions will play a key role in providing economical options for managing the health of these forests and ecosystems. Second, the marketplace has become increasingly global in nature. Shipments of raw materials and products between countries on different continents is now commonplace. Both of these challenges require accurate, cost-effective NDT/NDE technologies (Brashaw et al. 2009).

The international forest products research community is responding to these driving forces by conducting NDT/NDE research to provide the technologies needed to address these challenges. Continuing nondestructive evaluation research holds promise for wider and more efficient utilization of wood in an increasing number of applications. If our forests are managed wisely, and if we continue to build our knowledge base in nondestructive evaluation to meet the challenges of evolving human needs and changing wood characteristics, this amazing material that is wood will serve the public well for years to come (Ross and Wang 2012).

NDT/NDE of wood research in Europe dates back over 60 years with some of the first reported work on the establishment of fundamental relationships between various nondestructive test parameters and mechanical properties. Currently, the European Union's policy is to promote harmonization of research efforts across Europe, with much of the work being conducted at universities and research institutes (Brashaw et al. 2009). This paper presents a samples of the on-going NDT/NDE research efforts and their practical applications in major categories being conducted in Europe.

WOODEN STRUCTURE EVALUATION

Traditional methods for assessing the condition of timber are generally nondestructive, but may require probing or removal of small samples for species identification. Nondestructive techniques are useful for rapid screening of timber for potential problem areas or implying internal conditions, but typically are not particularly reliable for identifying material properties. Semi-destructive techniques require extraction of a small specimen for subsequent testing to determine elastic and strength parameters while preserving the integrity of the structural member. Both nondestructive and semi-destructive techniques are powerful aids to building conservation decisions (Kasal 2004). Resistograph drilling, developed in Germany is widely accepted in historical timbers structure evaluation not only in Europe, but other continents as well (Rinn 1996). Technical university of Madrid, Spain is a center for wood structure engineering and structural evaluation. A team lead by Dr. Francisco Arriaga Martitegui have published several papers (Íñiguez 2007, Bobadilla 2007, Esteban 2007). Institute of Theoretical and Applied Mechanics is a center for semi-destructive method developments (Kasal 2003).

URBAN TREE SAFETY

Condestructive methods give tremendous help in determining the stability of urban trees. There are several methods available for evaluating urban trees: pulling test, acoustic tomography, impedance tomography, acoustic root detection. Pulling methods are widely accepted in Germany, Czech Republic and Austria. Details of the pulling test are given by Wessoly (2012). This technology is applicable to evaluate uprooting safety and stem stability. Acoustic tomography is supported by several companies in Europe (Argus electronics, Fakopp and Rinntech). Acoustic tomography is widely used by horticulturists and foresters all over the world. The spreading of acoustic tomography methods is a success story of European wood

NDT research and development (Divos 2000, Rust 2000, Rinn 2003).

APPLICATIONS OF NDE&NDT TECHNOLOGIES IN EUROPEAN WOOD INDUSTRY

NDT is needed as an integral part of manufacturing for the optimization of volume and quality of output from each tree. Many NDE systems have been developed and implemented for the NDE of wood products in a myriad of applications before, during, and after processing from logs to finished wood products. The major materials properties groups would include basic properties, mechanical properties, defects and bonding quality. Basic properties include moisture content, density, and grain orientation. Moisture content and density measurement technologies could be considered mature, with many available commercial devices. Defects can include natural (from wood growth) or from exposure in growth or manufacturing. Some of these are confounding, such as decay or grain separations that can occur in virtually any stage. Bonding quality relates to both the adhesive curing process and quality of adhesion (Beall 2007).

Despite the great attention given to quality control in the development of manufacturing process for glue laminated timber, laminated veneer lumber or plywood, for particleboard and other wood-based composites, interfaces are still weakest link in the performance of these products. There is a growing need for the development of nondestructive techniques in industry due to the necessity to create new products using wood as a major raw material corresponding to the requirements of modern society. The development of these techniques will lead to intelligent manufacturing processes for wood products (Bucur 2003).

Basic material properties

Moisture content (MC) recognition as part of quality control is vital in all branches of the forest products industry. Improved, more rapid methods for determining MC are desired for a number of production stages, but especially in conjunction with stress rating and rating of lumber and veneer (Resch 2005). By far, the widest used technology for non-intrusive MC sensing has been electromagnetic. The typical radio frequency (RF) meter electrodes always have a component of the electric field along all three major axes of wood, therefore, the influence of grain angle on electrical properties must be considered. Two types of RF moisture meters are commercially available. Power loss meters react primarily to resistance and capacitance (or admittance) meters are more sensitive to dielectric constant. Both types of meters have arbitrary readout scales because of the effects of density and species. A dual-frequency moisture gauge (10 kHz, 312.5 Hz) was developed to measure lumber moisture content on line, with the two frequencies used to compensate for distance to the single-sided sensing heads (Beall 2007).

In-line moisture meters are used extensively in the softwood lumber industry to detect wet lumber. They are usually installed in the package breakdown area, often immediately behind the planer. These meters measure every piece of lumber without contacting it. With softwood lumber destined primarily for construction, these meters are used principally to detect wet lumber which would be off grade. The resistance and dielectric technologies used in portable meters has been applied in the development of in-line moisture meters.

Near infrared spectroscopy (NIR) is most common method used in wood-based panel industry for in-line control of MC. This method consists of a lamp that illuminates a material with light. Light wave-lengths used are from 850 to 2500 nm. Some of the light is absorbed by the material and some is reflected. A lens collects the reflected wavelengths, and a detector gathers the data producing the NIR spectra.

Microwave, nuclear magnetic resonance, x-ray, and noncontact laser technology are the other methods which have the potential for in-line measurement of moisture content of wood materials.

Radiation (gamma or X-ray) has been used for density measurements in internal defect scanning of logs, weigh scales for composite product panels, and density determination of lumber in mechanical grading. In measurements of the combination of wood and moisture, the mass attenuation coefficients of each must be considered (Olson and Arganbright 1981, Laufenberg 1986, Winistorfer et al 1986, Karsulovic et al 1999). Density of wood-based composites can also be measured using microwave technology by obtaining attenuation and phase change to measure moisture content and density (King and Basuel 1992). A relatively new measurement system based on innovative non-contact ultrasonic sensors for density measurement and knots location has been discussed by Marchetti et al. (2004). The method is based on piezo-electric noncontact ultrasonic probes, which allow having a complete nonintrusive inspection of the sample during production processes.

Grading of logs, lumbers, veneers

One of the most thoroughly researched areas of NDE has been in development and use of technologies for property assessment of structural products. These particular researches, conducted at various universities and research centers, resulted in grading processes for both lumber and veneer (Pellerin and Ross, 2002). Mechanical devices to enhance the grading process were introduced commercially to North America in 1963. These initial devices evaluated the stiffness of lumber basis as part of a combined visual and mechanical process that evolved as machine stress rated (MSR) lumber (Galligan and McDonald 2000). In 1965, the first in a series of international symposia was sponsored by Washington States University. One of the main topics of this symposium was the development of the mechanical grading technology. The participants of this symposium from Europe were Professor F. Kollmann (Germany) and RFS Hearmon (England) (Pellerin and Ross 2002, Ross and Wang 2012). The machine controlled grading system was developed in Europe around 1969 (EN 519 1995).

Transverse vibrational techniques have been used to assess the material properties of wood members in bending (Pellerin 1965) and have led to the development of commercially available grading devices. Followed efforts have been directed towards a better understanding of the time and frequency domain characteristics of longitudinally induced acoustic signals (Falk et al. 1990). The determination of wood material properties using acoustic wave propagation has also attracted considerable research effort. The ultrasonic velocity method and stress wave method are effective tools for grading structural lumber, round wood, and logs in industry. Early contribution to the development of ultrasonic methods for grading structural lumber in Europe was made by establishing relationships between the ultrasonic velocity and the overall mechanical parameters of lumber (Elvery and Nwokoye 1970). Ultrasonic transmission technique as a powerful tool for grading logs, lumber and glue-lam in industry has been discussed by Sandoz (1989, 1991,1994) and Steiger (1991) in Europe. In 1990s, several companies in Europe such as Brookhuis (Holland), CBS-CBT (Switzerland), Dynalyse (Sweden), Microtec (Italy), Weinig (Germany) developed their own in-line log and lumber grading technology based on the measurement of dynamic modulus of elasticity of timbers or logs.

Modern scanning technology is very important as the industry strives to utilize timber to sell into the highest value markets maintaining a high product quality output throughout. Scanning technology have been used in sawmills and veneer plants in Europe to choose the best sawing pattern, to maximize volumetric yield, to detect the usable area, and eliminate wane in edging of boards (Resch 2005). In softwood logs, the knots are the most common grade reducing characteristic. Hardwood logs are more complex because of the structural complexity and heterogeneity as well as the biological variability of their internal structure, both among and within species. The first decision in a sawmill is made for the processing of logs sorted as veneer logs or as high-quality saw logs (Bucur 2003). Advanced scanning technology provides knowledge of the internal quality of logs and lumber before conversion in terms of the extent of knots, grain direction, growth rate, and density.

It has been shown that the sawing process can be considerably improved by the utilization of software based on X-ray scanning data deduced from the softwood saw logs in Sweden (Gröndlund et al. 1994). For a complete strength grading of structural timber, strength grading machines must always be complemented with a visual override inspection, done either by a human or a machine vision system. Kliger et al. (1995) demonstrated that the density and the knot area ratio can be used to explain the variations in strength and stiffness of Norway spruce beams. Many of industrial scanning devices that utilize x-rays, laser, microwave, optical cameras have been used in Europe since 1990s to evaluate and grade logs and lumbers according to internal and appearance properties such as dimensions, knots, holes, wanes, splits, shakes, slope of grain, stains, warp etc. Thermal imaging technique which is relatively new field for wood NDE has a good potential to detect internal quality of logs and lumbers in grading process.

In Europe, the requirements for assessing and operating machine strength grading system were standardized method by the adoption of EN 519 in 1995. Timbers graded according to this standard were accepted for use in several countries such as Finland, Norway, the Netherlands, Sweden and the UK. EN 519 was developed in its final form in 2005 as EN 14081(1-2-3).

Industrial non-destructive grading is a fundamental topic today in Europe. The importance of strength grading of sawn timber will increase in the future. In Europe, the gradual application of the CE-marking of sawn timber for structural purposes requires that an increasing amount of timber will go through strength grading. On the other hand, much of the potential of structural timber is nowadays unused in what comes to strength. A large portion of the timber reaches much higher strength level than its present design strength value. With more accurate strength grading systems, this potential could be exploited. The effectiveness of a grading system depends on the prediction capability of the grade indicating properties and the accuracy by which they can be measured. Thus, the problem with stress grading focuses on these two key questions: (1) how to predict the strength of timber pieces by measuring other properties with the best possible reliability and (2) how to measure the predictor parameters with the best possible accuracy (Hanhijärvi and Ranta-Maunus 2008).

Control of lumber drying

For wood quality control during drying, several nondestructive methods have been developed. Acoustic emission related to the drying of lumber and associated acoustic events and shrinkage, and, on the other hand, swelling and internal fractures induced by drying stresses have been studied since 1980s. Acoustic emission systems “listen” to material by amplifying, filtering, recording, and analyzing signals emitted by wood during drying. Commonly, the measured parameters are: count rate, amplitude distribution of signals, energy levels, and frequency spectra. These parameters are studied as a function of drying rate or moisture loss (Bucur 2003). Establishing relationships between emission rate, wood moisture content, and drying conditions has been the main aim of many authors. As an example let us consider the results reported by Becker (1982) for drying pine lumber with a variable proportion of sapwood under severe conditions of relative humidity. More acoustic events were generated by specimens containing 20−25% sapwood. This demonstrates the potential for the development of automatic drying control systems, involving acoustic emission monitoring in commercial kilns (Kitayama et al. 1985; Noguchi et al. 1987).

Despite nuclear magnetic resonance and neutron imaging techniques have a great potetial for monitoring wood drying process, a serious limitation of these techniques is the large expense of the apparatus required.

Laminates

For a glulam beam the NDE for mechanical grading of the final product is not feasible. In these cases the component, i.e. the laminae, are graded by NDE prior to lamination and the lay-up organized in such a way that the expected behavior of the finished product can be established. An in-line NDE methodology is needed to accept or reject each finger joint in laminates as it is manufactured. Because the location of the evaluation needs to focus on the finger joint itself, the ultrasonic range of stress wave is judged to be the most suitable method for the NDE method (Bodig 2000).

Ultrasonic is an effective method to detect delaminated areas in laminates (Bodig 2000). In one of the first studies on wood laminate bond quality (Reis et al 1990a), single-paired laminates were made with various adhesive bond defects, tested in through-transmission. The ultrasonic parameters (RMS area and peak amplitude) showed high correlations with shear failure before and after conditioning. A subsequent study on finger-jointed material gave similar correlations (Reis et al 1990b). This ultrasonic technique was also used by Anthony and Phillips (1992) in developing a process control system to evaluate the quality of finger joints in tension members of wood. Methods for statically and dynamically measuring laminate bonding quality have been developed (Biernacki and Beall 1993, Beall and Biernacki 1994).

There have been a number of studies to evaluate the curing process of adhesives. Several adhesives were studied using wood adherents with an RMS output to quantify the development of modulus, and therefore the curing of the bonds (Beall 1987, 1989). This work was continued using full-size laminating material (Beall and Biernacki 1992; Biernacki and Beall 1996a, 1996b).

Wood based composites

The wood based panel industry is a key stone of the wood industry. Following the development of these products, there has been a growing need for NDE methods for grading and quality assurance. Today, the technologies for wood-based composites are based on quality control with nondestructive evaluation techniques, which play an increasing, important role in adapting the market to the change of timber resources.

Different acoustic techniques have been used with varying degrees of success in predicting the quality of wood-based composites. Ultrasonics are most effective for manufacturing quality control to detect blows and blisters in plywood and particle composites. This is due to the ability of ultrasonic waves to be concentrated in a small area (Bodig 2000). French scientists Roux et al. (1980) proposed that industrial continuous control of particleboard using the ultrasonic velocity method could be possible. An ultrasonic device was implemented after the press. Measurements can be taken through the thickness of the board, at the current speed of fabrication. Conical transducers were placed in direct contact with the surface of the board, without a coupling medium, on cool boards. The first such reported use of ultrasonics for panel evaluation was to determine the effect of additives on the quality of hardboard (Reis and McFarland 1986). Studies run on specially-prepared particleboard having low and high density, and low and high resin content, provided a range of internal bond strengths that correlated well with ultrasonic outputs (Green 1988). Subsequently, a number of studies were done on larger and increased numbers of panels, which led to a patent (Shearer et al. 1988) for an online system. GreCon (Germany), EWS (Germany), and Siempelkamp (Germany) are some of the European suppliers of in-line production and quality control system such as delamination detecting, density profile measurements, surface measurements, and moisture measurements for wood panel industry.

Attenuation measurements combined with velocity measurements can improve the detection of discontinuities in wood-based composites. Wave attenuation is sensitive to bonding characteristic and is a valuable NDE parameter that contributes significantly to the prediction of tensile and flexural mechanical behavior of wood based composites (Ross 1984, Ross and Pellerin 1988).

To produce an LVL with the required mechanical properties it is necessary to determine the mechanical properties of each sheet, in green and dry conditions. Ultrasonic veneer grading has been developed for mechanical grading of veneer sheets.

Acoustic emission (AE) has been used with wood-based materials since the 1960s. Acousto ultrasonic (AU), which was developed in the late 1970s, was applied to wood in the mid-1980s (Beall 2002). For the detection of poor bonding in the plywood production line, Sato et al. (1995) proposed a prototype of a testing machine for real-size plywood plates (910×1,820 mm and 8−15 mm thick). The acoustic emission activity was stimulated with three points bending the loading of boards and detected with a roller sensor (296 mm diameter, 1,200 mm long, at feed speed of 90 m/min). The evaluation of the defect distribution in the transverse direction was possible, as well as the measurement of Young's modulus, longitudinally, every 100 mm by two load cells set at the axis of the roller.

CONCLUSIONS

The non-destructive testing and evaluation has been introduced in forestry and the forest products industry several decades ago. Since then, radical changes have occurred and many new experimental techniques have been developed. Due to the improvement of computerization, data acquisitions and processing increased extremely in speed and volume as well.

The purpose of this paper and presentations was to draw the attention of the audience to the European universities, institutions, testing facilities and researchers. Unfortunately, not all the significant personnel and workshops could be recognized. Our apology is due to the not mentioned researchers, institutions, companies and research facilities.

As one may notice that in Europe, wood researchers are working hard to develop new NDT methods and technologies. Furthermore, the transfer of these novel evaluation techniques into practice is underway or has already been established. The next step should be the incorporation of NDT techniques into the unified European standards EUROCODE. These efforts, accompanied by the new measuring techniques, contribute to the sustainable forest management and to the effective and environmental friendly wood utilization. Additionally, in certain fields of NDT, Europeans are significant contributors to the international research and development activities.

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