Springer Series in Wood Science

Nondestructive Characterization and Imaging of Wood

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1. Auflage 2003. Buch. xiv, 354 S. Hardcover
ISBN 978 3 540 43840 3
Format (B x L): 15,5 x 23,5 cm
Gewicht: 787 g

1 Introduction

1.1 Brief Historical Review of Nondestructive Evaluation of Wood and Aim of the Book

Nondestructive evaluation of the physical properties of wood has its origin in the need to solve practical problems without destruction of the integrity of the object under inspection. It is generally accepted that the terms "nondestructive evaluation of wood properties" and "nondestructive testing of wood properties" can be used interchangeably. Beall (1996), Ross and Pellerin (1991) and Bodig (1994) selected the term "nondestructive evaluation" as more attractive since "it represents the process by which selected physical properties of a material is being assessed without damage or alteration to its end-use capabilities."

The earliest nondestructive evaluation of wood was visual inspection, largely used for the selection of timber used as load-bearing members for specific applications. Even today, this method is extensively used for the grading of wood products for lumber, poles, plywood, etc. and for the detection of biological degradation of these products.

The development of scientific nondestructive methods became possible in the early 20th century with the development of the theory of elasticity and of the instrumentation for the measurement of wood properties. The interest of scientists was initially focused on the determination of the modulus of elasticity by static methods (Hörig 1935; Kollmann 1951). Later, the use of acoustic vibrations for dynamic methods to determine elastic constants of wood were published in Europe (Barducci and Pasqualini 1948; Hearmon 1948, Kollmann and Krech 1960) in North America (Jayne 1955; James 1959), and in Japan (Fukada et al. 1956).

The enthusiasm for the development of X-ray techniques for evaluation of the internal structure of wood in the 1960s had a beneficial influence on the development of microdensitometry in different laboratories all over the world (Polge 1978). The X-ray diffraction technique was developed in Japan for the study of the crystallinity of cellulose in wood (Fukada 1965; Fukada et al. 1956).

Pioneering results of dynamic tests using vibrational methods were reported in the early 1960s by Hoyle (1961), Senft et al. (1962), and Pellerin (1965) for the nondestructive testing of structural lumber. The development of ultrasonic techniques for elastic characterization of wood was promoted in the

United Kingdom by Hearmon (1965). Since the late 1970s, the activity of laboratories all over the world on nondestructive testing of wood has been stimulated by symposia organized in the USA at Washington State University by Pellerin and coworkers in collaboration with the Forest Products Laboratory, Madison (Ross and Pellerin 1991, 1994) and since 1996 alternatively in Europe and in the USA.

Since 1970, reference books have been published in the field of mechanical characterization of wood (Jayne 1972; Bodig and Jayne 1982), dielectric properties of wood (Torgovnikov 1993), and acoustical properties of wood (Bucur 1995). Schniewind (1981) was the editor of the first encyclopedia of wood science. The publication of an especially important series of books in the *Springer Series in Wood Science* was initiated in 1983. The last 20 years of the 20th century have been characterized by an extraordinary development of different methodologies for nondestructive evaluation of wood products, which has succeeded in the imaging of the internal structure of wood at both the macroscopic and microscopic levels.

Due to the extensive literature on this subject, this book will provide an overview of wood structure imaging techniques and the corresponding basic concepts related to the nondestructive characterization of this material that permitted the development of the modern imaging procedures. These outstanding modern wood structure imaging techniques are a logical extension of existing nondestructive methods developed previously and has benefited from their breadth.

1.2 General Concepts of Nondestructive Testing of Wood

To promote the efficient use of wood materials in the future, three major areas need to be addressed:

- development of nondestructive techniques for the evaluation of different properties such as: physical, mechanical, chemical, aesthetic, etc.,
- improvement of natural qualities of wood through the modification of properties with different treatments, and
- creating new products using wood as a major raw material, corresponding to the requirements of a modern society.

The development of nondestructive techniques has as it principal purpose to reduce the uncertainty of wood products characteristics as influenced by wood's biological nature. Despite the great attention given to quality control in the development of manufacturing processes for glue laminated timber, laminated veneer lumber or plywood, for particleboard and other wood-based composites, interfaces are still the weakest link in the performance of these products. To ensure interfacial integrity it is important to develop methods for nondestructive inspection of wood-based composites and their components (solid wood and adhesives).

The interfacial discontinuities, delaminations, cracks, porosity or density variations may be detected by nondestructive techniques such as acoustic, microwave, thermal, radiographic, or classical static methods. These methods can help in the understanding of material behavior under different environmental conditions, but difficulties still remain for detection and for quantitative description of structural discontinuities and defects. It is important to relate the nondestructive measurements to the mechanical properties of wood and wood-based composites. The basis of such relations is the dependence of the interfacial strength, on one or more mechanical characteristics related to the nature and morphology of defects. There is also a need for the development of nondestructive techniques in industry. The development of these techniques will lead to intelligent manufacturing processes for wood products, resulting in processes that will identify defects without characterizing "good material" as defective.

The second approach is the quality assessment of improved wood products from different chemical or mechanical treatments, which requires the development of nondestructive techniques appropriate to each material. Analytical assessment techniques will be used to gain an understanding of failure mechanisms in wood composites. The combination of physical testing and modeling should then yield an improved understanding of the factors that determine the quality of products.

The third approach is to create new products using wood as a major raw material, corresponding to the requirements of modern society. The market for wood-based composites is a growing one worldwide, with new production plants coming on line. Probably "biomimetics" will be a source of inspiration for designing new composites. Progress can be expected from a "better microarchitecture and from the mastering of smaller and smaller scales for the basic constituents, and their spatial arrangement" (Roux 1998). In many applications, the nonlinear behavior of solid wood and of its composites must be considered. The sensitivity of new nondestructive evaluation techniques to defects provides an opportunity to control the statistical properties of structures.

Given the hierarchical structure of wood it is obvious that one should seek multiscale characterization tools. The use of multiscale approaches and the prediction of the behavior of very complex systems through probabilistic approaches and small-scale measurements must be emphasized. The problem of selecting the most relevant scale for the study of the properties of the equivalent medium has to be addressed for all applications.

The importance of the microstructure must be underlined because of its basic role in nondestructive evaluation of the properties of materials. New materials are currently "designed with a view towards developing microstructural conditions that more effectively allow the material to meet application specific structural requirements" (Frantziskonis and Blodgett 1998). The mechanics of heterogeneous media require the definition of the representative elementary volume (Bourbié et al. 1987; Chelidze et al. 1998). This volume must be larger than the size of the elementary heterogeneity and, in the case of wood, larger than the width of the annual ring, fiber length, etc (Fig. 1.1). Under this assumption at different scales, the sample can be considered quasi-homogeneous. This approach can be applied to any physical property and the principle of physical analogies can be used. However, experimental studies as well as theories have confirmed the dependence of the properties of heterogeneous media on the scale of observation and size of the system. It is reasonable to expect that in the near future the new approach to the mechanics of heterogeneous materials will be that of fractal mechanics (Sahimi and Arbabi 1993). It is also generally accepted that the control of mechanical properties of new wood-based composites such as glued laminated timber and oriented strandboard, can be performed using probabilistic design (Castera 1998). At times, the deterministic approach may be better than the probabilistic one, because it is difficult to find a general correlation between micro- and macro-scale behavior of wood-based composites. A possible explanation of this can be found in the multiplicity of the factors influencing the phenomena studied.

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. In the future, it will be important to develop new nondestructive techniques and devices for quality control of new wood composites produced with a more diverse raw material supply. As noted by Youngquist and Hamilton (1999), this is the challenge for the 21st century.

1.3 Classification of Nondestructive Techniques for Wood Quality Assessment

The characterization of wood properties is critical for the understanding of material behavior and performance under operating conditions. Tailoring the properties of new wood-based composites is essential for advanced product design. The composites of the future will have to be made from such new resources as underutilized species, recycled wood, and municipal waste, which will be a mixture of wood, paper, plastic, and agricultural residues (Maloney 1992; Peterson 1993; Greaves 1998; Bowyer 2000).

The need to characterize wood-based composites for a myriad of applications has spurred the development of many new methods and instruments. An ideal characterization tool would provide data about the properties that are related to micro and macro structure without destructive sectioning. Such data can only be obtained using nondestructive methodologies. Nondestructive evaluation of wood and wood-based composites enables the determination of

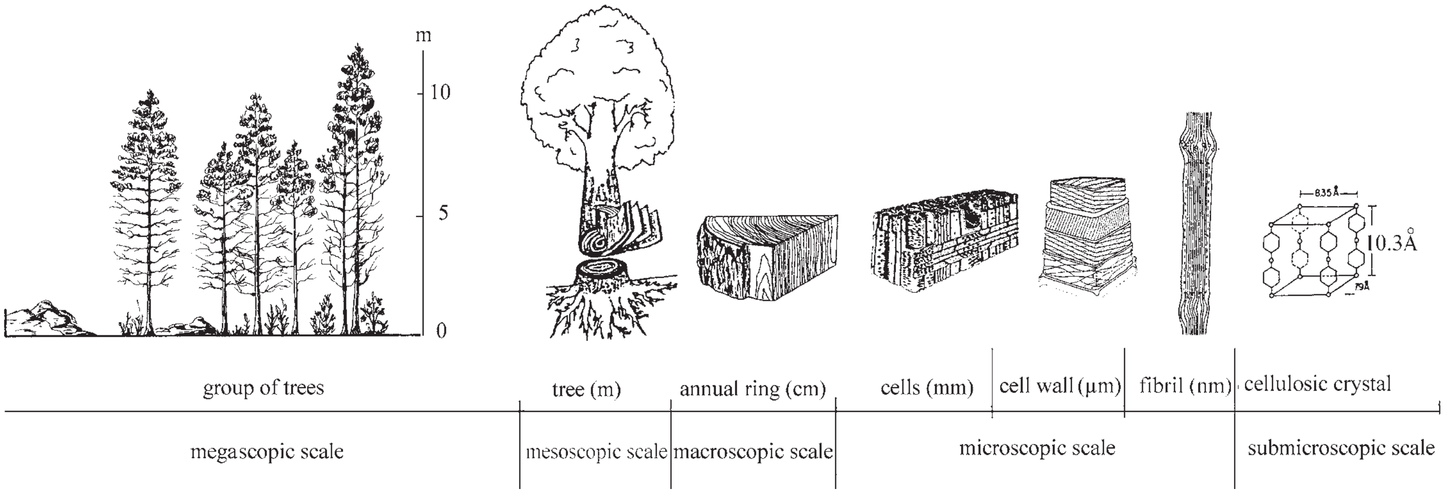

Fig. 1.1. Hierarchical structure of wood. (Data from Bucur 1995, with permission)