RESEARCH NEEDS IN WOOD PHYSICS: A BROAD OVERVIEW

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ABSTRACT

The international community of forest products scientists perceives research needs in wood physics in a broad range of subjects. The research needs compiled here are organized into several areas of wood physics and technology, for the purpose of helping individual scientists formulate research projects and programs that are consistent with widely recognized needs.

Keywords: Wood physics, research needs.

INTRODUCTION

Background

Interest in the physics of wood began in response to practical considerations of wood use. Artisans recognized that the utility of wood depended greatly on its density and also that wood changed size with varying humidity. They also saw that particular species were preferable for particular uses.

Hardly more than 100 years ago, folklore began to give way to systematic wood science, with studies of density and its relationship to other wood properties. Studies of the effect of moisture content (MC) and ways of drying wood followed. Modern kiln-drying technology began early in the present century, when the great diversity of wood physics and related technology also began to emerge.

Until recently, the predominant thrust of research in wood physics has been to compile design data and to solve technological problems. But, now, wood scientists seem to be increasingly aware of the value of understanding the actual physical processes behind observable behavior of wood. Old, mundane problems such as efficient drying of lumber or measuring and controlling MC are still with us to a remarkable degree; but wood technologists are now looking more to fundamental physical principles for solutions to these problems. This philosophy is evident in the research needs listed in the following section where, in many cases, the materials science approach is expressed or implied.

The purpose of the compilation is to help individual scientists to formulate research projects and programs responsive to recognized needs in wood physics. It may serve also as a vehicle for cooperative research projects between individuals or between institutions.

I have attempted to obtain and summarize the perceptions of research needs in wood physics expressed by the international community of wood technology.

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The material covers a very broad spectrum of physical science and demonstrates that substantial research effort in wood physics will be justified for many years to come.

Scope and organization

Physics is the study of the interaction of matter with energy. The basic forms of energy are heat, light, sound, electricity, and magnetism. Physics also includes the broad area of mechanics, which is the study of the interaction of matter with force. Often it must include as special cases such forms of energy as kinetic energy (energy of motion), gravitational energy, nuclear and electromagnetic radiation (other than light), and the latent heat of vaporization embodied in atmospheric humidity.

These basic interactions of matter and energy translate into several areas of wood physics:

- Wood-liquid relations, including such phenomena as diffusion, shrinkage and swelling, absorption-desorption, and the interaction of these phenomena with other physical and mechanical properties and as affected by various forms of energy
- Thermal properties, including conductance, diffusion, and thermal activation of other physical processes
- Electric and dielectric properties
- Acoustic properties, including internal friction, dynamic elastic constants, and physical effects of sound
- Optical properties, including reflectance, transmission, and physical effects of light and other radiation
- Static and dynamic mechanical properties
- Properties as predictable from microscopic and submicroscopic structure (materials science)

Finally, from these areas of wood physics come several corresponding areas of wood technology. For example:

- Drying technology
- Measurement and control of MC
- Nondestructive testing, stress grading, defect evaluation
- Effects of process variables on final properties and performance
- Effect of environmental factors on performance
- Strength and elastic properties and related factors
- Miscellaneous topics related to materials science
- Miscellaneous topics in wood physics

To help wood technologists identify research needs in the broad area of wood physics, therefore, I consider these needs and as far as possible identify desirable studies for each of the above areas of wood technology. Within the major areas of wood technology, I attempt to organize the research needs according to economic and technological priority.

In ordering these priorities, I have been helped greatly by a large number of colleagues who responded to my request for information. The diversity of their responses underscores the broad range of interest and research needs in wood physics. The priorities I adopt are based largely on the frequency with which the various study areas were mentioned.

In many of the technological areas of interest here, the research needs are outlined only in a general way because the attempt to define and list specific problems or studies would become overwhelming. I believe that readers will find the broad objectives outlined helpful, as they develop individual studies according to their immediate needs, interests, and resources.

In most areas of study listed, selected key references are given for background. The selection process was somewhat arbitrary, and many excellent references are excluded for lack of space. In other areas, no pertinent publications were found.

RESEARCH NEEDS

Drying technology

1. To study moisture migration in abnormal wood such as reaction wood and wood infected with bacteria (Schroeder and Kozlik 1972; Ward and Groom 1983; Ward and Zeikus 1980).

The abnormalities cause affected wood to dry at rates much different from those of normal wood, causing problems of overdrying and underdrying and excessive drying degrade when abnormal and normal wood are intermixed in the kiln or in a given piece of wood. Research in this area should consider microscopic factors. The goal would be to establish drying schedules or other techniques that would minimize the difference in migration rates through normal and abnormal wood.

2. To develop methods for rapidly detecting abnormal wood (see above) (Kozlik and Ward 1981; Shortle 1982; Ward and Shedd 1981). (See also topic 1 in section on nondestructive testing (NDT).)

If studies of moisture migration through abnormal wood succeed in showing better ways to dry it, use of this new technology and possibly other technology will require a means of segregating abnormal wood from normal wood. Fast methods adaptable to automatic scanning are needed.

3. To expand high-temperature drying (HTD) technology, especially to include hardwoods (Boone 1984).

Some problems of excessive degrade with HTD of hardwoods may fade if temperatures are set even higher because of greater plasticizing of the wood. Kiln control for this procedure would be very exacting, and critical research is needed to define the parameters.

4. To establish a reliable and well-founded basis for high-technology drying methods and show where these methods may best be employed (Green 1980; Harris and Taras 1984; Olson and Arganbright 1983).

Considerable promise for rapid drying with acceptable degrade has been shown by advanced drying procedures, such as those that combine dielectric heating with other techniques. The promises need to be realized at a practical level and the limits of application clearly defined by research covering a broad range of the pertinent variables such as species, end-use requirements, and costs versus value added.

5. To study drying characteristics of dead, fast-grown, whole-tree, and other new classes of raw material.

Wood and wood-based products will be increasingly made from salvaged dead timber and rapid- and plantation-grown trees. These and other new classes of wood may pose new challenges to kiln drying.

6. To study the basics of wood-water bonding, mass transfer concepts of both bound and free water movement, and the details of non-isothermal moisture movement (Bramhall 1976; Chudinov 1978; Haishi 1980; Hart 1964; Nelson 1983; Siau 1980).

These data should enable technologists to predict drying performance without a large number of trial-and-error kiln runs as well as help them understand anomalous behavior or observations.

7. To evaluate gross density (wood plus water) as a measure of total drying burden for kiln charge segregation.

Many kiln-drying problems arise because of wide variation in the drying burden (MC and permeability) of individual pieces. Presorting the lumber into more homogeneous loads would ease these problems.

8. To study energy consumption in kiln drying, related to operating parameters and alternate energy sources (Chen et al. 1982; Kent et al. 1981; Little 1981; Miller 1977; Morton 1976; Schneider 1984).

Dry kiln schedules have been compiled primarily to maximize drying rate while minimizing lumber degrade. The energy efficiency of the process has not been a major concern. Variables in the kiln schedule, such as fan speed, duty cycles, and venting schedules, however, could probably be adjusted for minimum energy consumption without significant change in the effectiveness of the kiln schedule. Even the principal variables, time, temperature, and humidity, could be adjusted in many schedules to reduce total energy costs without seriously compromising schedule effectiveness.

Further studies are needed to establish what adjustments, if any, are necessary in order to use alternate energy sources (most obviously solar and waste-wood fuel) for kiln drying. These energy sources have been studied and are in fact being used, but problems persist in achieving efficiency, flexibility, and economy.

9. To study radiofrequency-vacuum drying of lumber (Harris and Taras 1984).

Drying lumber using radiofrequency dielectric heat in vacuum chambers has been shown to be feasible and advantageous, but the technique has not been developed enough to permit economic industrial use. The operating parameters and equipment design need to be studied more extensively to perfect the method for practice. Some of the potential advantages of the method have not been explored or exploited: for example, a vacuum chamber could be designed with an extensible top so that air pressure supplies top loading on the kiln charge for warp control.

Measurement and control of MC

1. To study local thermal diffusivity as an indicator of MC (Hirai 1980).

The rate of temperature decay in the vicinity of a thermal pulse may show a usable correlation with local MC.

2. To study dielectric properties of wood at millimeter wavelengths (Busker 1968; Hazlewood 1973; James and Hamill 1965; Purslow 1971).

The dielectric properties of wood at frequencies near 25 GHz may correlate well with MC, particularly when liquid water is present, because water vapor shows strong absorption at 25 GHz. Liquid water, however, may not absorb at this frequency, so data on liquid water are needed. At these extremely high frequencies, it may also be possible to increase the effective depth of penetration of the electric field, thereby easing the troublesome surface bias of present dielectric moisture meters.

3. To refine use of speed of sound to monitor dry kilns (James et al. 1982).

The use of the speed of sound to monitor kiln drying has been shown to be feasible. Experience is needed over a broader range of species, sizes, and kiln designs in order to establish the method in practice.

4. To refine use of nuclear magnetic resonance (NMR) and nuclear radiation methods for measuring wood MC (Gibson and Rusten 1964; Nanassy 1976, 1978; Olson et al. 1982; Onedera 1966; Riggins 1979).

These methods of measuring MC have been shown to be feasible, but probably for laboratory procedures only. The NMR method could be more precise than oven-drying, and nuclear methods would be faster than oven-drying and have an advantage over electric methods by being able to determine MCs greater than fiber saturation.

5. To extend understanding of thermodynamics of wood-water relations (Bramhall 1976; Chudinov 1978; Haishi 1980; Hart 1964; Nelson 1983; Siau 1980; Skaar and Babiak 1982).

The details of absorption-desorption phenomena at the molecular level are not well understood nor is the process of diffusion of water (either adsorbed or liquid). Scientists do not agree on whether moisture migrates under a concentration gradient or a vapor pressure gradient, or if in fact the two are really different. The involvement of heat of vaporization and of wetting in the activation energy of diffusion has not been investigated thoroughly. Because these concepts are not well understood, drying technology and the measurement and control of MC are forced to be empirical instead of developing logically from a comprehensive data base.

6. To develop calibration procedures for dielectric moisture meters that reflect the influence of moisture gradients (Dennis and Beall 1977; James et al. 1984; Kondratev 1975; Sharma et al. 1979; Skaar 1964).

Presently available dielectric-type moisture meters have the advantages of being easy to use and usable at very low MC, but their accuracy is seriously degraded by moisture gradients. Assuming that the gradient is known, a calibration based on that particular gradient should be possible. Typical gradients in recently dried softwood dimension lumber have been determined, so calibration for this material should be possible. Typical gradients in other classes of lumber have yet to be determined, and practical procedures for adjusting calibrations or actual data for the influence of known gradients have yet to be developed.

NDT, stress grading, defect evaluation

1. To study physical properties of decayed wood to discover measurable indicators of early decay (Boyd 1952; Kaiserlik 1978; Konarski 1977; Shortle 1982).

Early decay is difficult to detect and reduces strength properties substantially. Inspection for strength-reducing decay of load-bearing members in place is a particular challenge. Effects of decay or thermal, acoustic, dielectric, and optical properties should be investigated because these variables, in various combinations, may be useful indicators of early decay.

2. To develop a rapid method for measuring density (Phillips 1960).

Density is commonly considered to be the single most important parameter for quality of natural wood, but no reliable, convenient, non-destructive method exists for its estimation. Measurable parameters that vary with density are recognized, but none is free of serious confounding with other factors such as MC. No doubt two or more parameters must be measured simultaneously in order to infer density accurately. The research goal is to determine these parameters.

3. To study ways to predict porosity and other factors that affect formaldehyde emission from particleboard (Berge and Mellegaard 1979; Myers and Nagaoka 1981).

Formaldehyde emission from particleboard is recognized as a serious problem. Research should be carried out to control and measure the process factors and broad parameters that determine formaldehyde emission.

4. To study methods of defect detection, to refine existing technology and seek superior technology (Burmester 1967; Gerhards 1982b; James 1975; McGinnes and Shigo 1975; McLauchlan et al. 1973; Miller and Tardiff 1967; Sumiya 1965; Szymani and McDonald 1981).

Ultrasonic, optical, and X-ray methods exist for evaluating defects in lumber, veneer, and logs; but none have been refined to where they can be used routinely in lumber production. Reliability, speed, and economy need to be improved, either by improving existing technology or developing new technology. For example, discontinuities in dielectric properties associated with natural defects are possible indicators of these defects. Thus, the anisotropy of the dielectric constant of wood provides the basis of operations for a slope-of-grain detector. In like manner, discontinuities in dielectric or electrical properties associated with defects are potentially useful for automatic detection and evaluation of the effect of these defects on strength. At present, defects are evaluated visually or in terms of their effect on stiffness of individual pieces. Ultrasonic or X-ray methods are too slow for production use at this time.

Effect of physical process variables on properties and performance

1. To study effects of time and temperature on physical and mechanical properties of lumber, especially as interacting with chemical impregnants and MC (Kollmann 1982; Lin 1969; Price and Koch 1980; Sawabe 1970, 1971).

The efficiency of HTD will stimulate its use for increasing numbers of lumber products. Further, lumber treated with waterborne chemicals will be a candidate for HTD with increasing frequency. The effect of the process on mechanical properties is of crucial interest whenever lumber so processed is used in critical load-bearing applications. Data are not presently available to predict performance of treated, high-temperature-dried lumber or to design structures using such lumber, nor even to determine if HTD is appropriate for treated lumber.

2. To study details of hot-pressing parameters on performance of products.

Hot pressing is done usually for two purposes: to dry relatively thin pieces of solid wood or to form and cure the resin binder of particleboards. The time and temperature cycle is chosen to achieve the immediate purpose, with little regard for the effect of the heating cycle on ultimate properties of the product. The effect of the heating cycles on all properties needs to be determined so the best compromise of time and temperature may be established.

3. To study possible ways to enhance certain properties of wood by heat treatment. Anecdotal evidence exists that some properties of wood may be modified substantially by well-defined time-temperature treatments. For example, dimensional stability may be improved by brief exposure to temperatures near 400 F. The full potential of this technology has not been explored.

4. To study modification of physical and mechanical properties by chemical treatments (see item 1, this section) (Knezevic and Lin 1975; Mackay 1978; Rowell 1977).

Investigation of HTD of treated wood (mentioned earlier) should be extended to study the effect of chemical treatments on all physical and mechanical properties of wood. The large number of chemical treatments used commercially and the equally large number of physical and mechanical properties that are of engineering importance suggest a great many studies. This question, therefore, should be approached from basics rather than empirically, to establish broad principles that are applicable to a variety of treatments and property combinations.

In this area, information is needed on the effect of chemical treatments on the response of wood to environmental factors. Response factors include such wood properties as equilibrium moisture content (EMC), vapor and liquid permeability, thermal conductivity, electric and dielectric properties, mechanical properties, internal friction and speed of sound, and shrinkage coefficients.

Effect of environmental factors on performance

1. To study defect and failure generation by alternating shrink and swell environments.

When wood is subjected to cyclic humidity so as to suffer repeated shrink-swell stress, the material is gradually degraded by developing defects and failures. The actual mechanisms of this degradation are not well understood; if they were, it might be possible to prevent the degradation.

2. To study the basic nature of shrinkage, looking at variability, types of stress, effects of treatments, and measurement of stress.

The design and construction of successful wooden artifacts require control of shrinkage. In addition to control of MC, this requires ability to predict shrinkage from a knowledge of the expected use environment and a design that allows properly for shrinkage. It follows, if the design is to be ideal, that the factors that affect shrinkage and the overall mechanical effects of shrinkage must be known.

3. To study and develop procedures for restoring and protecting wood subjected to adverse environments.

Many valuable structures and other wooden artifacts throughout the world have been damaged by atmospheric pollution, and many more are at risk. Procedures for restoring and protecting these objects are needed, particularly by using surface treatments.

4. To study moisture migration in wood-based materials and structures under various environments (American Society of Heating, Refrigerating, and Air-Conditioning Engineers 1981; Sherwood and TenWolde 1981, 1982; TenWolde 1983).

Control of moisture in wood and in structures is often crucial to their durability and efficiency of performance. The migration and accumulation of moisture in walls is complex. Although it has been studied extensively, the recent emphasis on super energy-efficient houses has expanded the range of needed investigations. Research clearly should be expanded to match.

5. To study the details of creep acceleration under cyclic humidity (Humphries and Schniewind 1982; Kingston 1962; Raczkowski 1969; Schaffer 1972).

The mechanism of creep in wood under sustained load is not well understood, and specifically the question is not answered why cyclic ambient humidity hastens creep. Predicting and controlling creep would be facilitated by knowledge of the basic mechanisms and their interaction with MC and temperature. Creep phenomena should be studied at the microscopic level, including stress-strain studies of individual fibers and theoretical studies at the molecular level.

6. To study how to design outside doors to minimize distortion caused by temperature gradients (Kisseloff 1969).

The interactions of temperature and MC on the shrink-swell coefficients of wood need to be clarified to enable design of doors that do not warp under large temperature gradients.

7. To study thermal expansion of wood (Abe 1973; Christoph 1977; Yokota and Tarkow 1962).

Change in the dimensions of wood with changing temperature is confounded with the change in MC when the wood is at a different temperature than ambient. For both design and theoretical purposes these confounded phenomena should be studied from a fundamental standpoint, so the independent influence of each may be defined.

8. To study the optical reflectance of wood and its modification by environmental factors such as heat, light, etc. (Hon and Ifju 1978; Leary 1967; McGinnes et al. 1984; Nordman 1965; Schneider 1966; Wengert 1966).

The color of wood is obviously an important characteristic for some applications, and occasionally wood technologists need details of the reflectance spectra of various species. Actual data on reflectance spectra are rather meager, as is the understanding of the basic mechanisms for color changes in response to environmental factors. A data base of reflectance spectra needs to be compiled and the source of color changes identified so the color of wood can be stabilized in actual use.

9. To study degradation of wood by nuclear radiation (Loos 1962; Shuler et al. 1975).

General empirical data exist on the loss of strength of wood caused by large doses of gamma radiation. These data should be supplemented to cover other properties, such as electrical and thermal conductance and also other forms of radiation, particularly neutrons, to provide design data for use of wood in high-exposure situations. To facilitate the prediction of effects, the study should include seeking an understanding of the basic mechanisms of degradation, such as physical-chemical modification of cellulose and lignin, destruction of lignin-cellulose bonds, and modification of the crystalline structure of the cellulose.

10. To study degradation of wood by repeated alternation of soaking and drying (see also topic 1, this section).

Alternate soaking and drying causes rapid degradation of wood, but the mechanisms are not perfectly understood. A major use of wood is for pallets, which commonly suffer such exposure and degradation. If the exact mechanisms were known, prevention might be possible, giving the pallets an extended service life.

11. To study environmental performance of solid log walls, especially their heat transfer and fire performance (Allard and Troxell 1980; Burch et al. 1984; Courville and Bales 1983; Woods 1984).

The growing interest in solid log houses has increased the need for pertinent design data. Claims that this type of construction has superior energy (thermal) performance need to be confirmed and analyzed to identify optimal design. Specific fire performance data are also needed, as well as data on humidity and air infiltration control.

Strength and elastic properties and related factors

1. To study the effects of time and temperature on mechanical and other related properties (see item 1, section "Effect of physical process variables on properties and performance") (Chudinov 1971; Gerhards 1982a; Gerhards and McMillen 1976; MacLean 1954).

Heat treatment of wood may degrade or enhance wood properties depending on the conditions and the desired effect. Data exist that suggest that proper heat treatments may improve dimensional stability, reduce hygroscopicity, and relieve warp-producing stresses. These procedures should be studied to establish optimal enhancement of wood quality while minimizing detrimental effects.

2. To study the mechanical properties of the "new resource"—rapidly grown, genetically improved, whole-tree, plantation-managed, etc. timber (Pearson and Gilmore 1980).

Present efforts to augment the timber resource by breeding superior trees, optimizing growing conditions through intensive site management, and using parts of the tree that previously were discarded, have resulted in a timber resource that is not properly represented statistically by existing design data. This new resource should be carefully sampled, and mechanical design data should be compiled.

3. To study failure mechanisms, in relation to other pertinent factors (Côté and Hanna 1983; Green 1980; Kollmann 1963).

The fundamental modes or mechanisms of failure in wood should be established for various types of loading (tension, compression, shear) and related to details of the wood such as grain direction and structure, chemical proportions in wood substance, and MC. Temperature, load duration, and other variables are also likely to be pertinent. These relationships should be studied to provide engineering design data for use of wood in unusual conditions.

4. To study friction of wood (Attack 1958; Guan et al. 1983; McKenzie and Karpvich 1968; McMillin et al. 1970; Murase 1980).

Friction of wood has been studied extensively, but because the subject is very complex, the available data are inadequate. Also, data from different studies often conflict. For design and research purposes, wood technologists and engineers need a reliable data base of coefficients of friction for a variety of species, grain direction, MC, temperatures, chemical treatments, and other factors.

5. To study superplasticizing of wood (Davidson and Baumgardt 1970).

Wood may be made superplastic by treatment with ammonia, but the process is cumbersome and costly because of the nature of the chemical. A means of superplasticizing wood is needed that permits easy mechanical forming into products and does not require complex equipment or noxious reagents. The study should begin by establishing the mechanism of plasticizing to enable the logical selection of promising reagents and to minimize the effect of plasticizing on wood properties.

6. To study acoustic emission (AE) from stressed wood, including that stressed for long duration (Becker 1982; Lemaster et al. 1982; Morgner et al. 1980; Sato 1983; Skaar et al. 1980).

Acoustic emission from stressed wood has been studied to some extent, principally in the search for test methods. Acoustic emission could be a useful research tool and should be studied from the point of view of microstructure of the wood. Combining AE methods with creep studies, for example, under cyclic humidity, should provide deeper insights into the mechanisms of creep and failure. Acoustic emission may also be useful in stress grading.

7. To study possible means for predicting or measuring drying stress (James 1984; Lessard et al. 1982).

Research has shown that electric or dielectric measurements are not feasible methods of measuring drying stresses, but useful methods may yet exist. Usable correlations of drying stresses should be sought with such measurable quantities as speed of sound, internal friction, thermal conductance, and acoustic emission; or, alternatively, with independent measurements of quantities such as MC gradient and temperature gradients.

8. To study strength and elastic properties of wood at high loading speeds, as related to microscopic properties of the wood (James 1962, 1967; Krech 1960; Miyakawa and Mori 1977, 1978; Partl and Strässler 1977).

The most practically interesting time-related mechanical effects are long-duration load effects on strength and stability. For some applications, however, wood is subjected to impact or other short-duration loads, or perhaps rapidly cycling loads. The response of wood to high-speed shock loading has been explored only superficially; most data on rapid loading are for loading times greater than 50 ms. Strength properties and mode of failure for load times of 1 ms or less are unknown. These data should be obtained for design purposes and for expanding understanding of fracture modes in wood.

9. To study appearance (color) change of finished wood resulting from mechanical abrasion.

Abraded surfaces such as wood floors or furniture may suffer severe degrade in appearance long before significant mechanical wear occurs. The basic cause and prevention of the discoloration should be established.

Miscellaneous topics related to materials science

1. To study permeability of wood to fluids, as related to microstructure and compounded with physical/chemical reaction between the fluid and wood (see topic 6, section "Drying technology").

The processes of impregnating wood with chemicals, drying, finishing, and the use of wood in conjunction with fluids, for example in barrels or cooling tower slats, all are dependent on the degree of permeability of the wood to the fluids involved. Many of the data used in controlling these processes or in designing applications involving interaction of wood with fluids are empirical and not easily generalized or applied to new situations. At the microscopic level, basic data are needed from which behavior can be predicted for wood in interaction with fluids at any given condition.

2. To study the nature of bonding between wood substance and coatings, adhesives, and impregnants, at the microscopic level, considering interactions with temperature and MC (Jahns and Nguyen 1977; Murmanis et al. 1983a, b; Nissan and Sternstein 1964; Rowell et al. 1984; Young et al. 1982).

This is a broad and complex subject in which many studies might be undertaken. Research in this area would involve physical chemistry primarily and require elegant apparatus and techniques. The basic understanding that might be gained of bonding mechanisms, however, could be very valuable in explaining why protective coatings fail, why protective chemical treatments are unstable, and why adhesive bonds perform poorly. On the positive side, better understanding of these basic mechanisms would certainly help in finding improved treatments and better adhesives.

3. To study relationships between measurable properties or characteristics of fibers, microfibrils, lignin, and other fundamental elements and the gross physical and mechanical properties of lumber and wood composites (Armstrong et al. 1977; Beery et al. 1983; Burmester 1965; Duncken and Nordman 1968; Hamilton and Clark 1970; James 1973; Myers 1983; Norimoto and Yamada 1973; Woodward 1980).

Here, again, is a major research program encompassing many individual studies. The need for information on these relationships results from the wide diversity of timber resources, especially when the characteristics of a resource are changing; the results of research in this area will be valuable for predicting performance of any given structural or other element in either normal or adverse environments without the need for extensive testing of each particular element. At the other end of the spectrum, knowing how microscopic and submicroscopic properties translate into gross properties should be valuable in breeding and managing the forest for optimal property development.

4. To study product performance from a theoretical standpoint, particularly expanding statistical (probability) theories, and combining materials science and fracture mechanics (Ifju 1983; Johnson 1980).

This area of endeavor would complement the experimental studies in areas 2 and 3 above. A well-developed theory provides the means of generalization, by which to transfer experimental data from the conditions of the experiment to hypothetical conditions and to predict performance of untested configurations.

5. To study acoustic properties of wood from a microstructure basis (Alper 1984; Aoki and Yamada 1973; Holz 1973; James 1961; Kitahara and Kitamura 1972; Kollmann 1983; Nakao et al. 1983; Niedzielska 1972; Norimoto 1982).

One of the most challenging problems in wood science and technology is the preparation of wood for high-quality musical instruments and their subsequent fabrication. The design and construction of violins, for example, has been studied from many angles by many workers, but no one has yet matched the standards established by the classic Cremona craftsmen. Recent experiments suggest that chemical modification of the wood may play a critical role. It appears that the problem will be solved only when the microstructure of the wood can be manipulated in a controlled way to produce the characteristics desired. Research is needed to determine what these desired microscopic characteristics are, in relation to the gross characteristics of the instrument, and how to achieve these micro-characteristics.

Miscellaneous topics in wood physics

1. To compile a handbook of physical and mechanical data of wood for laboratory and design purposes.

2. To study the basic physical and mechanical properties of the new, genetically improved, plantation-grown woods.

3. To study the basic physical and mechanical properties of chemically treated and otherwise modified wood (Weatherwax and Stamm 1956).

4. To study the basic physical and mechanical properties of wood-based composites.

5. To study dielectric properties of wood moistened with swelling liquids other than water.

The mechanisms of electric conduction and polarization in wood are complex and not well understood. The modification of these phenomena by adsorption of various fluids, as they interact with frequency and temperature, would provide valuable insights to the nature of the conduction and polarization processes. These insights in turn would help solve problems in wood-liquid technology such as moisture measurement and use of wood in environments of electric stress.

6. To study the piezoelectric properties of wood (Bazhenov 1961; Fukada 1968; Hirai and Yamaguchi 1979; Smetana and Kelso 1971).

The piezoelectric response of wood is of both academic and practical interest; for example, piezoelectric data can clarify the crystalline structure of a material and can contribute to some techniques of NDT. It has been studied to a considerable extent, but its full potential as a source of understanding of the crystalline nature of wood has not been developed. Further, the use of piezoelectric properties for NDT has not been carried to completion.

7. To study dynamic thermal properties of wood, as affected by MC, from a molecular or microscopic viewpoint (Abe 1973; Christoph 1977; Chudinov 1971, 1978; Dunlap 1912; Hearmon and Burcham 1955; Hirai 1980; Kelsey and Clark 1955; Kisseloff 1969; McMillin 1970; Ratcliffe 1964a, b; Shida and Okuma 1980; Yokota and Tarkow 1962).

The thermal conductance, heat capacity, and thermal diffusivity of wood have been studied extensively, but the effect of MC on these properties has not been explored completely. Much of the available data are for dry wood. Also, most present data were obtained in steady-state conditions. Practical application to present problems requires a knowledge of the dynamics of thermal response (non-steady-state) as confounded with MC; considerable energy transfer can be associated with moisture migration. Data on these processes are needed for reliable design of energy efficient structures, especially with solid (log) walls.

Understanding of the complex interaction of wood and water in the transfer of thermal energy will be well served by studying the phenomenon at the microscopic level. Further, this type of information should ease the problem of predicting the effects of treatments, growth anomolies, permanent thermal effects, and related variables.

SUMMARY

Recognized research needs in wood physics now cover a wide range of topics. These I have organized above under major areas of wood technology: drying technology, measurement and control of moisture content, nondestructive testing, stress grading and defect evaluation, effects of process variables on final properties and performance, effect of environmental factors on performance, strength and elastic properties and related factors, miscellaneous topics related to materials science, and miscellaneous topics in wood physics.

With the aim of helping individual scientists to formulate research projects responsive to the need, I have considered each of these areas separately, identified particular needs as nearly as possible, and given references to existing work on these topics.

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