History of the Wood Materials and Engineering Laboratory

1949-1999

College of Engineering and Architecture
Washington State University
Pullman, Washington

Written by
Thomas M. Maloney, WMEL Director Emeritus

April 1999

Golden Anniversary Edition

The Old Laboratory at WSU

This document presents the history of the Wood Materials and Engineering Laboratory (WMEL) but does not include the names of all those who have contributed to the great success of this Laboratory over the years. Unfortunately, space limitations make it impossible to list all of the more than 100 individuals who have worked in the Laboratory over the last 50 years. This document was prepared, however, to recognize the great contribution of all these individuals as well as to record their great scientific, technical, and engineering achievements.

Any errors made in presenting the research of the WMEL in this document are mine alone. Any errors are in no way intended to demean the work of anyone who was a part of the great team with whom I was fortunate to work and call my friends and colleagues over the 40 years I was a part of this great Laboratory, College, and University.

Thomas M. Maloney

Acknowledgements

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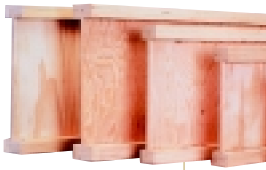
The collage on the cover was done by Donna Maloney who is as much an endearing part of the legacy of the Laboratory as her husband, Tom, the author.

Editing, design, and layout of this publication were the collaboration of Linda Miklosko of the WMEL, and John Sutherland and Diana Whaley of WSU Publications and Printing with a special thank you to Denise Pressnall.

The graphics on the back cover are courtesy of Washington State University. The framed print of the Cougar is displayed on the second floor of the WSU Lewis Alumni Centre.


Marty Lentz, 1967 and 1984.

Marty Lentz and Glen Cambron, 1991 (below) and 1994 (right).



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Preface

The Wood Materials and Engineering Laboratory (WMEL) at Washington State University has an international reputation for research and development among industry, university, and governmental laboratories. This reputation was forged by dedicated faculty, staff, and students, and nurtured for over a half century by George Marra and Thomas Maloney. George Marra led the organization for 22 years after which he served as Associate Dean of Engineering at WSU and later as Deputy Director of the U.S. Forest Products Laboratory. Thomas Maloney led the Laboratory for the next 22 years, expanding its programs into the international arena. One of Tom's most significant accomplishments was the establishment of the International Particleboard/Composite Materials Symposium held annually at WSU since 1967.

Today, Tom is retired, but he and his wife, Donna have graciously agreed to prepare this special anniversary edition of a more extensive history Tom has compiled on the laboratory, and for which we are most grateful.

The current faculty, staff, and graduate students at the WMEL are committed to building on the tradition of excellence founded by George Marra and Tom Maloney. The WMEL has long recognized the need for more effective utilization of forest resources and responded with a program of basic and applied research, technology transfer, and a strong graduate program to develop future leaders of the industry. Research at the laboratory today includes the development of new building materials from a myriad of recycled and virgin wood resources. It is also developing innovative structural systems to effectively utilize these new materials while maintaining economic viability and public safety. Other areas of emphasis are on the development of:

- An improved fundamental understanding of wood-based materials, adhesive systems, and processes to enhancing material behavior.
- A solid scientific basis to guide development of hybrid composites that combine wood with synthetic materials to meet a range of performance requirements.
- Techniques for rapid assessment of material durability to optimize composite materials and processes.
- Nondestructive evaluation techniques to monitor product quality for process control, and to assess damage and residual strength of existing wood structures.
- Performance-based methodologies to provide a rational basis for structural design and to guide product improvement research.
- High performance building systems to combine complementary characteristics of various construction materials, and to enhance efficiency, reliability, and economy.

In this brief history, we hope you will discover something new about the WMEL. We invite you to visit the Laboratory located at the WSU Research and Technology Park anytime, or tour our website at www.wmel.wsu.edu to learn more about our programs.

Donald A. Bender
Director and Professor
Wood Materials & Engineering Laboratory

Gil Anderson, Roy Pellerin, and Gary Gunning, 1970.

Introduction

The Wood Materials and Engineering Laboratory (WMEL) in the College of Engineering and Architecture at Washington State University has a long and illustrious career in the world of forest products. Research, Teaching, and Education programs have ranged from conserving our valuable forests, developing products that efficiently use the harvested forest including raw materials that for centuries were considered waste, adding value to products, aiding the establishment of new production lines, helping develop new processes, reducing energy consumption, recycling materials, assisting with gaining code and consumer acceptance of the new products and, in general, providing society with up-to-date science and technology and technology transfer in the field of forest products.

When founded in 1949, the Laboratory was ahead of its time in many ways. The vision and need for such a facility was there, and time has proven the value of such a laboratory. Now, there has been 50 years of success and leadership in the world of forest products. This success has been the result of the dedication and work of many individuals in the Laboratory, the support from the state of Washington, Washington State University, and the College of Engineering and Architecture. Moreover, and very importantly, the support of many companies and individuals worldwide has been invaluable to the Laboratory, both morally and financially.

All of the accomplishments of the Laboratory over the last 50 years and the support developed throughout the world has set the stage for even greater accomplishments by the Laboratory, its staff, and supporters in the next 50 years.

This History has been written for the 50-year anniversary, the Golden Anniversary celebration of the Laboratory, for the use of present and future scholars of the Laboratory, and of scholars throughout the world. This History is also designed to celebrate the work of the many individuals who have worked in the Laboratory over the past 50 years whose research, teaching, and public service have contributed greatly to the field of wood science and forest products. Their work has made it possible to more efficiently use that great resource—the forest. Wood is still the most widely used industrial raw material in the United States and in the world, and will remain so far into the future.

As will be noted later, the self developed mission of the Laboratory, as established during the 1970's, was to assist in developing the means to get four times as much product from the harvested forest as had been possible previously. Much of this goal has now been accomplished. Production in the U.S. alone in 1998 is at about 5 billion square feet of particleboard (3/4 in. basis), 1.5 billion square feet of MDF (medium density fiberboard) (3/4 in. basis), and 40 million cubic feet of LVL (laminated veneer lumber). In North America, production is about 17 billion square feet of OSB (oriented strand board) (3/8 in. basis). Almost all of the wood raw materials used for these products were either previously waste or wood species not suitable for use in standard lumber and panel products.

In addition, far more efficient use of lumber and panels has taken place through the use of nondestructive testing. For example, the stress-wave system for nondestructive testing based on the research of the Laboratory is used in industry for selecting the veneer for LVL. This high quality engineered lumber product can not be made without a system for ensuring that the proper strength veneer is placed in the LVL in the correct locations, such as the tension and compression laminations. LVL is used in most of the I-joists now made and the I-joist now claims about 30 percent of the market for floor supports in single-family homes.

Incidentally, research and development in the Laboratory during the 1960's also helped develop the I-joist material. Twelve demonstration houses were built in the Pullman area using this concept. Other highlights in the history of the Laboratory include:

- Assisting in the development of new composite wood building products, i.e., particleboard, medium density fiberboard, oriented strand board using waste wood or low value logs, agricultural materials (wheat straw and bagasse, which is sugar cane), plastics, and improved adhesives.
- Recycling wood and plastic materials into new composite materials.
- Development of a method — a new mat former — to electrically align particles, fibers, flakes, and strands or admixtures of these particles in the mat former thereby providing products with much greater bending strength and stiffness in the aligned or oriented direction.
- Provided basic research findings on the use of isocyanate binder for composite materials helping bring this binder into use in the composites industry.
- Conducted basic research on the use of dead standing timber as raw material for composite products. Also evaluated nondestructively, lumber cut from dead standing timber showing that the quality of the lumber could be successfully measured by this method. This research lead to including dead standing timber as part of Forest Service timber sales, a policy not previously followed.
- Partner in a massive research project re-evaluating certain strength properties of Douglas fir throughout the western U.S.
- Invented the stored heat system for rapidly curing glue lines in laminated and fingerjointed materials.
- Invented the impression fingerjointed system for both dry and green lumber.
- Performed the research on high speed pressing of laminated veneer lumber using high frequency, thus dramatically reducing the length of the press cycle. New plants were built with this advance in pressing.
- Pioneered nondestructive testing of the integrity of wood structures.
- Developed the tension proof-loading concept now used in evaluating fingerjointed stock and for lams in the beam laminating industry.
- Developed prototypes, standards, and technological guidelines to build wood houses and structures for economically depressed governments and countries.
- Awarded more than 27 patents that included electro-static fiber alignment, particleboard blending; impression finger-joints; Nondestructive Testing (NDT) devices for timbers; veneers; and composites; wood I-beams; and wood foundation systems.
- Assisted in the establishment of businesses including Metriguard Inc. of Pullman, Washington, now a world leader supplying nondestructive testing and measuring equipment to the forest products industry.
- Invented the low-profile wood floor system.
- Performed research on elastomer adhesives for use in construction, which lead to the development of the ASTM standard governing the use of such adhesives in the construction of mobile homes.
- Provides information and technology transfer to the world wood product community through the WMEL's International Particleboard/Composite Materials Symposium and published Proceedings, now in its 33rd year.
- Assisted in developing North American house building systems in China, South Korea, and Taiwan sponsored by WSU's International Marketing Program for Agricultural Commodities and Trade (IMPACT).

- Since 1975, provided over 50 students with an invaluable research facility for pursuing Master and Ph.D. degrees to in turn assume leadership roles in the wood industry, government agencies, and at other universities.
- In the fall of 1997, the Laboratory began work on a collaborative effort with industry and other universities to develop a fiber reinforced engineered thermoplastic/wood materials that will meet the Navy's requirement for a strong, cost-effective, and environmentally benign alternative to treated wood.
- Based on Laboratory research, a handbook on new NDE inspection and detection techniques for evaluating the strength of timber bridges is being developed for bridge inspections.
- Presently working on the evaluation of structural insulated panels — modules of oriented strand board laminated to polystyrene foam cores. Prefabricated SIPs have already proven more energy efficient than traditional wood-frame construction and to reduce job-site waste.

- The WMEL and TriDiamond Sports, Inc. of Spokane are working together to develop a fiber reinforced, laminated wooden baseball bat that if successful, will be a more durable and economic alternative to aluminum bats used at the collegiate level and thus provide a more realistic training experience during pre-professional play.

The Laboratory has provided leadership in all of these areas and others to be mentioned later. One can say that the Laboratory has indeed contributed tremendously to the industry and to society throughout the world.

Some of the research successes of the Wood Materials and Engineering Laboratory are presented in Part I of this document. Other achievements are highlighted in greater detail in Part II of this publication.

Tom Maloney working in the Laboratory, 1959.

Part I

Development of the Laboratory

The Wood Materials and Engineering Laboratory at Washington State University is a development unlike most university operations. It began as an exclusive research laboratory as part of the Washington State Institute of Technology in 1949. Upon the abolition of the Institute, it became a part of the Department of Material Science and Engineering in 1972, and then in 1985, it was established as an independent laboratory within the College of Engineering and Architecture.

During the 1940's, the state legislature established at Washington State College (now Washington State University), the Washington State Institute of Technology. The original organizational concept of the Institute was identical to that of many colleges of agriculture in which education, research, and extension are carried out in separate administrative units. In the case of the new Institute of Technology, these units were the College of Engineering, the Division of Industrial Research, and the Division of Industrial Services. Faculty and staff of the Research Division were primarily involved in research and development. Some of them taught courses in their area of expertise when qualified faculty were not available on the regular teaching faculty.

The primary emphasis of the program at first was to assist in the technical and economic development of the state of Washington. However, the economic development of this, as with any other state, functions as a highly interdependent entity within a much larger sphere. Thus, this research and development program almost from the start provided services on a national and international scale and gained a worldwide reputation in the scientific disciplines involved. In general, about half of the funding for the Division was to come from the state of Washington and the other half from outside grant and contract research projects.

A high percentage of the services rendered have been for industry, with the balance from various federal, state, and municipal government agencies. As a consequence of this close association, the scientists and engineers involved have been able to develop and maintain a strong sense of relevance to current problems.

The strength of the research and development program has been its ability to call upon many disciplines for solving a particular problem. Major departments in the College are Mechanical and Materials Engineering (until 1985, they were two separate departments), Electrical Engineering and Computer Science, The School of Architecture, Civil and Environmental Engineering, Chemical Engineering, and Biological Systems Engineering (previously primarily agricultural engineering). In the old Industrial Research Division, there were many research sections of which Wood Technology was one. The other sections relating to the forest products industry included: metallurgy, polymers, air pollution (now atmospheric sciences), radioisotopes, materials chemistry, structures, electronics, and design. Most of these sections were incorporated into the departments upon the elimination of the Division in 1973.

As would be expected on any university campus, other departments such as forestry (now natural resource sciences), political science, economics, sociology, computer science, and business administration can be and have been, involved in various research projects of the Laboratory.

The Wood Technology Section, today the Wood Materials and Engineering Laboratory (WMEL), was formed in 1949. The initial request for its establishment occurred about 1946. The first Section Head, Earl G.

Hallonquist, stayed for only a short time. His thrust was to develop the Wood Technology Section into a pulp and paper research facility. George G. Marra became the next Section Head in 1950. He quickly realized that the tremendous cost of developing a high level pulp and paper facility was something that would not be funded, particularly since the University of Washington in Seattle already was recognized as a world leader in this field. He also recognized that the major focus of the forest products industry would have to be more efficient use of forest resources.

During these early years, the Wood Technology Section developed areas of specialization for more efficient use of the forest, namely, in particleboard, fiberboard, waferboard, oriented strand board, and medium density fiberboard technology. Broadening its expertise, the section became known for its work with adhesives and adhesion, nondestructive testing, wood design engineering, and mechanical and physical properties of wood. It was calculated that with success in these areas of research and development, four times as much product could be manufactured out of the forest base as was being done in the 1960s, which was the overall goal of the wood technology staff.

As time went on, the laboratory expertise expanded to all types of wood composite materials, including those made of other lignocellulosic materials such as bagasse and straws. The expertise quickly became internationally recognized, as Pullman became a gathering place for the world community involved in wood and lignocellulosic composites, particularly at the annual International Washington State University Particleboard/Composite Materials Symposium. This Symposium, begun by Tom Maloney in 1967, now draws about 500 people to Pullman each spring. As many as 30 countries have been represented at one time.

When the Division of Industrial Research was abolished, the various research sections, where possible, became part of existing departments. Wood Technology joined materials chemistry, polymers, and metallurgy in a new Department of Materials Science and Engineering. The intermarrying of these research groups resulted in a department continuing their high level of research activities. However, of great importance, the polymers and wood technology faculty was now able to start a graduate program that included a number of widely different materials in one curriculum. Emphasis was placed on establishing a common base within the department for all materials.

Recognized was a need to organize such a curriculum according to broad aspects rather than being based on narrow disciplines, as had been done many times previously. What developed was a coherent, all-embracing materials philosophy extending from the resource to processing, properties, environmental impacts, energy, consumption, recycling, and disposal. In other words, the entire picture was looked at from an engineering viewpoint rather than small individual segments. Such an approach was felt to be the only one possible in this modern age when all of the foregoing factors are recognized by the world as important to survival. Materials have to be consumed judiciously and must be conserved and used only where appropriate. This instructional program has proven very successful with about fifty graduates now holding important positions in universities, government laboratories, and industry.

An interesting sidelight is that one former undergraduate student working in the Laboratory in the 1960s, John Fabian, did not pursue a career in the industry after all, but instead went on to become one of the country's top astronauts and space explorers.

In 1972, Thomas M. Maloney became Section Head after having been the Laboratory 's manager and financial manager since 1958 and also head of the wood composite research. In the early 1980's, WSU established a new Research and Technology Park located away from the colleges, but still on campus. The university asked the Wood Technology group to move to this new location

because of its prominent research profile. The move meant that the Section would have a new laboratory built for its research activities. The new laboratory was to be a highlight of the new Research and Technology Park, illustrating the university's commitment to its development.

As a note, the university had chosen the Wood Technology Section in 1966 for a new large building located near the college headquarters, Dana Hall. Tom Maloney was in charge of planning. An architectural firm, which constructed a model of the new building, designed a building and approximately one million dollars were allocated for construction. The remaining costs to complete construction and purchase equipment were expected to come from federal resources, however, these funds were not realized in lieu of the Vietnam War still ongoing, thus the building was never constructed. Instead the mining experiment station that had previous been closed was given to the section. This facility was then remodeled for office space, conditioning rooms, nondestructive, and physical testing research.

The faculty and staff accepted this new challenge, and the Laboratory was constructed. The new Laboratory was occupied over a two-year period from 1987-88, and dedicated in 1988 during the 22nd Particleboard/Composite Materials Symposium. President of the WSU Board of Regents, Mac Crowe, christened the Laboratory by smashing a bottle of wine, held on a rack made of OSB, with a "bottle' made of particleboard. Note: *a full account of the dedication can be found in the Proceedings of the 22nd Symposium.*

In 1985, the Laboratory was established separately within the College and Tom Maloney's title changed from Section Head to Director, a position he held until is retirement in 1995. The faculty associated within the Laboratory who had been reporting to the Section Head became responsible to the Department Chairs of their respective disciplines. The Laboratory remained the research home of the students specializing in wood materials.

The advanced degrees awarded up until this time were primarily Master's Degrees in Material Science and Engineering, and Doctorates, which are a college-wide degree, in Engineering Science. A few students in Civil and Environmental Engineering were also doing their research work in the Laboratory. In 1996, the degree granting process was changed so that most degrees would be granted through Civil and Environmental Engineering. However, the emphasis on materials science and engineering remains an important part of the educational program.

Philosophy and Purpose as of 1991

The mission of the Laboratory developed in the early 1970s was updated in 1991 with the assistance of the Advisory Board. The result of this effort was a philosophy and purpose statement embracing the goals of the Laboratory and embellishing upon them. The following is that statement:

> The Washington State University Wood Materials and Engineering Laboratory is an established Laboratory for enhancing the utilization of wood and other materials' resources through improvements in processing, properties, environmental impact, energy consumption, recycling, and final disposal. This is an all-encompassing engineering philosophy rather than a collection of isolated elements. Materials must be conserved and used judiciously, a philosophy that has had a long tradition at Washington State University.

The Wood Materials and Engineering Laboratory supports the forest ecology of the Pacific Northwest (PNW) region and the economic benefits derived from wood and wood products. An abundance of renewable wood resources in the PNW supplies over one-half of the structural wood products, as well as much of the aesthetically pleasing wood, consumed in North America. The forest products industry is the second leading industry in the state of Washington in gross business income and significantly impacts the regional economy. World-wide ecological challenges emphasize the need for research and development to increase wood utilization efficiency.

The Wood Materials and Engineering Laboratory's mission is to provide an integrated program of research, education, and the transfer of technology to the forest products industry both domestically and internationally. All three of these elements are directed toward areas of primary emphasis: composite products, adhesives and polymers, physical and nondestructive testing and innovative methods for using wood in construction. Liaison activities found in the College of Engineering and Architecture and in the College of Agriculture and Home Economics that support the Wood Materials and Engineering Laboratory mission include structural engineering, housing design, machining, drying, environmental considerations, manufacturing, and economics and marketing.

An Advisory Board Assists the Wood Materials and Engineering Laboratory. Major activities of this Board are to advise on the research program, to advise on the graduate education program, to act as liaison to industry and government, to represent industry and government with the university community, and to serve as contacts in the recruitment of students. The Board membership encompasses large international forest products and machinery firms, lumber and panel manufacturers, producers of engineered wood products, suppliers of chemicals, the U.S. Forest Products Laboratory, and other universities.

The Wood Materials and Engineering Laboratory with the assistance of the Advisory Board also further established the following areas of primary emphasis in research, education, and technology transfer:

1. Composite product development, performance modeling, and optimization;
2. Development of more efficient and innovative uses of adhesives, polymers, and treatments in wood products;
3. Development of more advanced methods in the nondestructive testing of wood with a focus on product structural properties performance;
4. Further development of innovative uses of wood in buildings, including construction methods, design, and structural components; and
5. Performance evaluations of wood products and buildings both by destructive and nondestructive methods.

Within each of these areas of primary emphasis, the following critical economic factors shall be considered:

1. The minimization of waste;
2. Affordable building construction;
3. Proper environmental control of air and water;
4. Restrictions on world-wide timber supplies;
5. Responses to world-wide timber demands;
6. The changing quality of timber supplies; and
7. Utilization of recyclable materials.

The Wood Materials and Engineering Laboratory of Washington State University already is recognized internationally. The Laboratory direction is to continue strengthening its international programs, and to continue developing new liaisons with appropriate university, institutional, and international individuals and bodies to access interdisciplinary skills appropriate for maintaining the health of the forest products economy. Such liaisons are also critical to the health of society not only within the state of Washington, but also nationally and internationally.

The Laboratory's Goal and Description of Research in 1997

In 1997, based on expansion of the research effort and the addition of new faculty with their expertise, the goal of the Laboratory and the description of the research were expanded upon as follows:

The Goal

To provide novel structural and materials solutions to meet the nation's need for infrastructure renewal. The WMEL responds to this challenge by developing new building materials from a myriad of recycled and virgin resources. We also develop innovative structural systems to effectively utilize these new materials while maintaining economic viability and public safety.

Description of Research

- *Wood composite materials development and process modeling.* Developing a fundamental understanding of materials, adhesive systems, and processes is key to enhancing material behavior. A critical feature of this work is our collaboration with over 100 industrial clientele.
- *Interactions of wood with synthetics.* Hybrid composites are a new class of materials, which combine wood with synthetic materials to meet a range of performance constraints. Our aim is to develop a solid scientific basis to guide product development.
- *Performance evaluation and optimization.* Durability is a key aspect of infrastructure development to resist degradation from environmental attack and extreme load events. Evaluation techniques are being developed for rapid performance assessment to optimize composite materials and processes.
- *Advanced methods for nondestructive evaluation (NDE).* NDE techniques are being developed to monitor product quality for process control. Techniques also are being developed for *in situ* damage assessment and residual strength determination for wood members and connections.
- *Performance-based design methodologies.* Current prescriptive codes and standards can impede material and process innovations. Performance-based methodologies are being developed to provide a rational basis for structural design and to guide product improvement research.
- *Novel building systems.* High performance building systems are being developed to combine complementary characteristics of various construction materials. Structural behavior, durability, and environmental issues at material interfaces are being addressed.

The People of the WMEL

Leadership

The first Section Head, Earl G. Hallonquist, as previously mentioned, stayed for a short time when the Wood Technology Section was formed in the late 1940's. George G. Marra was the Section Head from 1950 to1972. He was also the Assistant Director of the Division of Industrial Research from the early 1960's until 1972 when he became first the Assistant and then the Associate Dean in 1980, for Research in the College. He was "on loan" from the university to the U.S. Forest Products Laboratory from 1980 to 1984 where he was the Deputy Director. He then retired and, unfortunately, passed away not long after.

Thomas M. Maloney was the Laboratory Manager, Fiscal Manager, and leader of the composite research from 1958 until 1972 when he became the Section Head. The new responsibilities as Section Head were in addition to his previous duties, which he also continued fulfilling. When the Laboratory was made a separate entity in 1985, Tom Maloney became its first Director until his retirement in 1995 when he was succeeded by Roy F. Pellerin who served as Director until his own retirement in 1996. At that time, Michael P. Wolcott became Interim Director until the current Director, Professor Donald A. Bender, came on board in 1997.

Faculty

The core group of faculty who worked in the Laboratory for many years and was responsible for its long-term success included George G. Marra, Thomas M. Maloney, Roy F. Pellerin, John W. Talbott, M. D. Strickler, William E. Johns, and Robert J. Hoyle, Jr. Faculty associated with the Laboratory when it became an independent unit were R. V. Subramanian, Keith Blatner, David McLean, and Rafik Itani. Other faculty members associated with the Laboratory have been J.W. Wilson, Dale Ziegler, Claude Douty, James Brumbaugh, William L. Galligan, E. Max Huffaker, Arthur F. Noskowiak, Cham Brar, Forrest Milton, Murray Carroll, Harry Browne, Benjamin Jayne, Orville Lee, Duane Lyon, James Logan, Peter Gaudert, William Johns, Renganathan Govindarajoo, Larry Olsen, Robert W. Meyer, and William Cofer. In 1992, alumnus, Robert J. Tichy was added to the faculty of the Laboratory as a Research Engineer.

After 1993, David Pollock, Kenneth Fridley, Lloyd Smith, Michael Wolcott, Michael Symans, Donald Bender, John Hermanson, Tim Adcock, and Suzanne Peyer became a part of the Laboratory faculty. Stanley Suddarth, William Lehmann, Timothy Rials, and Jay Johnson are among the adjunct faculty of the Laboratory.

Visiting Scientists

Scholars from the international community have continued to be an important part of the Laboratory's history representing China, Korea, Hungary, Ghana, and Norway. Visiting scientists who have worked at the Laboratory have been Zhen Yuan Sun, Cao Zhi Qiang, Cao Jiqiang, Jin Heon Kwon, Hwy Hyong Lee, Li Xiaoming, Heon Park, Jun Jae Lee, Shi Bozhang, Divos Ferenc, Peter Takats, Augustas Addae Mensah, Boss Lanius, Peter Aune. Working today at the WMEL on wood composite materials is Zushou Yin from the Nanjing University in Nanjing, China.

Staff

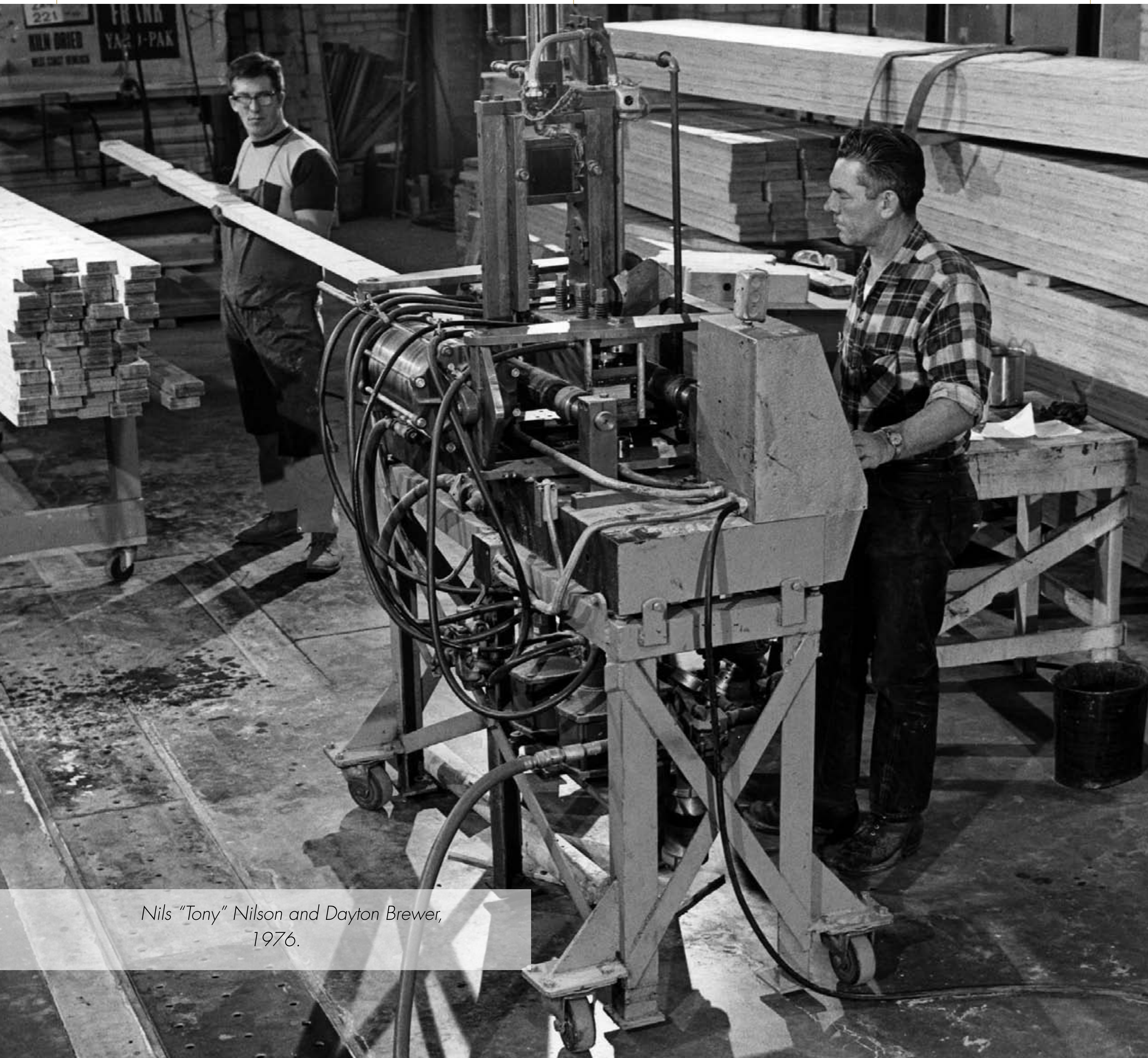
Long time staff members critical to the success of the Laboratory were Martin T. Lentz, Nils Antone "Tony" Nilson, Gilbert Anderson, Dayton Brewer, John Saunders, Patricia Baga, Linda Villett, Christina Rockett, Lucille Leonhardy, and Stephanie Hetrick.

Marty Lentz is still working at the Laboratory, however, Tony Nilson recently retired on January 31, 1999 after 28 years of service and dedication.

Other staff members through the years have included Rochelle Troyano, Carol Lawton, Linda Johnson, Charles Mohr, Gary Glaze, James Kasper, Kathleen Johnson, Tony

Seitz, Roland Besel, David Little, Andrew Porter, Maxine Andrews, Charles McGogney, Clint Glover, Jackie Collins, Carol Still, Arna Zook, Linda Benefiel, Edward Richards, Stephanie Longmire, Gail Spurgeon, Claudia Mays, Margit Carder, Christine Calderone, Sue Vickerman, Phil Westover, John Bremmer, Stanley Bauer, Idelle Winer, Daphne Gustafson, Sally Lefler, Kathleen Gill, Esther Caprez, John Kirkwood, Leslie Perri, Elizabeth Hiroaki, Tammy Otway, Dede Hilliard, Lyle Amsden, Jack Rucker, Patricia Gibson, Don Backus, Maria Henry Roberts, Kristin Mullally, Renee Tobias, John Porter, and Danielle Walker.

Today, the staff at the Laboratory are Engineering Technicians Martin Lentz, who oversees Composite Manufacture, and Glen Cambron, who works with Composite Manufacture and Nondestructive Evaluation. Dave Dostal recently replaced retired Engineering



Nils "Tony" Nilson and Dayton Brewer, 1976.

Technician, Nils "Tony" Nilson, and is working with structures. Jane Lawford is the Administrative Assistant. Linda Miklosko is the Information Specialist and Associate Editor of the annual *Particleboard/Composite Materials Symposium Proceedings*.

Alumni

Following graduation, several Alumni who called the Laboratory their research home, developed significant careers and some of their accomplishments include:

- The team lead by Dr. Jonathan W. Martin of the National Bureau of Standards in 1988 was awarded one of *Research and Development Journal's* 100 most significant new technical products of the previous year. The IR-100 award was for their development of an automated technique using thermography to measure the roughness of surfaces and find defects. The procedure is faster and more versatile than current methods and is important for quality control in such industries as electronics, automotive, ceramics, and construction.
- Dr. W. Ernest Hsu received the 1989 Canada Award in the invention category for Business Excellence. The Government of Canada created the Canada Awards to recognize outstanding business achievers. His award was for the invention of edge-sealing steam pressing technology for wood and composite panels.
- Dr. Robert Ross of the U.S. Forest Products Laboratory, as part of a team with Susan LeVan and Jerrold Winandy, received the U.S. Forest Service's Honor Award for 1992. The work was in resolving concerns about fire retardant wood properties and the use of such treated wood, which was a major problem. This team also received Honorable Mention in the form of the U.S. Forest Service's Chief's Technology Transfer Award.
- In 1993, Dr. Ross received one of the Federal Laboratory Consortium's awards for Excellence in Technology Transfer.
- In 1998, Julia Hsu received two Technology and Quality Innovation Recognition Awards from Louisiana Pacific. The awards recognized Ms. Hsu's work on the Nail-Head-Pull-Through Test and her development of the L-P Corner Strength Impact Tester.

Former Graduate Student of the Laboratory, Brian Brashaw, shown here pressing a particleboard, is today a WMEL Advisory Board Member.

Graduates with Major Research Experience at the WMEL

1955			
	Ericson, Elvin	Paper Mill Waste as a Stabilizing Agent for Clay	MSCE
1960			
	Zeeben, Joe	Thermal Conductivity and Diffusivity of Flakeboards	MSCE
1961			
	Doutriaux, J. P.	Matrix Solution of a Rigid Frame Using a Digital Computer	MSCE
1966			
	Bertolf, Larry	Longitudinal Elastic Wave Propagation in Cylinderical Bars	Ph.D.
	Iyengar, Sampath	Deflection Curves for Columns Bending about the Weak Axis	MSCE
	Meyn, David	Comparison of Stressed Skin Design with Present Standard Construction	MS
1967			
	Courteau, Richard	Propagation and Attenuation of Elastic Waves in Wood	MSME
	Mohr, Charles	An Experimental Determination of the Dynamic Physical Constants of Wood	MSME
1968			
	Garner, John	Computer Analysis of Plane Frames with Application to Gabled Frames	MSCE
	Godfrey, Daniel	Matrix Analysis of Plane Frames with an Application to Wind Force Analysis	MSCE
1971			
	Farhad, Afagh	Buckling of a Cylindrical Shell under the Action of Uniform Axial Pressure	MSCE
1972			
	Huber, Dean	Sorption of Water by Structural Wood Components from Grand Fir [Abies Grandis (Doug L.) at 130° C]	MS (UI)
	Al Hasni, Abdul	Photoelastic and Analytical Stress Analysis of Curved Beams	MS
1973			
	Sharma, Sukhdev	A Study of the Effect of Internal Friction on Rupture Modulus of Wood	MSME

	Mohr, Charles	Non-Linear Stress Analysis of Indeterminate Structural Elements Subjected to Bi-axial Stress States using the Finite Element Technique	Ph.D.
	Genry, Carl Allen	Plate Analysis Using the Finite Element Method	MSCE
1974			
	Krisnabamrung, W.	Strength and Dimensional Stability of Electrically Oriented Particleboard from Western Red Cedar Mill Waste	MS (UI)
1975			
	Shantz, Roger	Aligning Torque and its Frequency Response Related to Wood Particles in an Alternating Electric Field	MSMSE
	Kaiserlik, Joseph	Attenuation of Longitudinal Stress Waves as an Indicator of Lumber Strength	MSMSE
	Anderson, Mark	Behavior of Wood Beams Bonded with an Elastomeric Adhesive	MSCE
	Lee, Gordon	Effects of Joint Fixity on Dynamic Stresses and Deflections	MSCE
1976			
	Kern, James	Non-thesis Option Graduate	MSMSE
	Mir, Muhammad	Hyperbolic Paraboloid Stresses	MSCE
1977			
	Fyie, Joseph	Sandwich Panel with Vertically Aligned Fiber Core	MSMSE
	Bessette, Allan	An Evaluation of Elastomeric Adhesive Bonded Structural Design Theory, and the Effect of Panel Gaps in T-Beams	MSMSE
	Brito, Francisco	Investigation of the Elastomeric Adhesive Bonded Wood T-Beam Having Gaps in the Flange	MSCE
	Hesner, Ed	Wind Load Analysis for Buildings and Other Structures	MSCE
1978			
	Hsu, Wu Hsiung (Ernest)	Analysis of Elastic Behavior of Orthotropic Wood Composite Plates	Ph.D.
	Hsu, Julia	Non-thesis Option Graduate	MSMSE
	Eriksen, Knut	Influence of Flange Gaps on Wood Floor Systems Bonded with an Elastomeric Adhesive	MSCE
	Hiremath, Girish	*Analysis of Composite Action in Lumber Diaphragms*	*MSCE*

1979			
	Dong, Chung Ching	The Mechanical Properties of Flakeboards Related to Flake Orientation	Ph.D.
	Martin, Jonathan	The Statistical Analysis of Life Data for Wood in the Bending Mode	Ph.D.
	Spaun, Frank	Reinforcement of the Tensile Strength and Bending Stiffness of Wood with Fiberglass	MSMSE
	Carll, Charles	The Effect of Platen Temperature on the Pressing Time and Properties of Dialectically Cured Particleboards	MS (UI)
	Filho, M. S.	The Influence of Wood Furnish Type on the Properties of Oriented Strand Panels	Ph.D. (UI)
	Abullah, Sule	Non-thesis Option Graduate	MSMSE
1980			
	Bulleit, William	Behavior of Fiberglass Reinforced Particleboard Beams and Plates in Flexure	Ph.D.
	Mahoney, Robert	Physical Changes in Wood Particles Induced by the Particleboard Hot-Pressing Operation	MSMSE
	Duran, Juan	An Investigation of Creep Buckling in Wood Columns	MSCE
	Williams, Russell	Synthesis, Structure and Properties of Organometallic Monomers and Polymers	Ph.D.
	Naizi, Khan	Non-thesis Option Graduate	MSME
	Robledo, F.	Linear/Nonlinear Material, finite Element Analysis of Wall/Panel Frame Systems	Ph.D.
	Younis, Naim	Creep Buckling of Wood Columns	MSCE
1981			
	Tichy, Robert	Stochastic Concepts in the Design of Wood Structures: The Concomitant Problem	Ph.D.
	Adams, Roy	Analysis of Glued Wood Fingerjoint Connections Using the Finite Element Technique	Ph.D.
	Cheung, C.	Effect of Axial Loads on Radial Stress in Curved Beams	MSCE
	Elliott, Randall	Racking-Resistance of Light Framed Walls	MSCE
	Gianni, Lawrence	A Computer Program for the Design of Articulated Glued-Laminated Roof Framing	MSCE

1982			
	Plagemann, Walter	The Response of Hardwood Flakes and Flakeboard to High Temperature Drying	MSMSE
	Latibari, Ahmad	The Response of Aspen Flakes and Flakeboard to Flake Surface Modifications	Ph.D.
	Aguilar, Sergio	Non-Linear Racking Analysis of Nailed Walls	MSCE
	Gorrie, Thomas	Lateral Buckling of Parallel Chord Trusses	MSCE
1983			
	Terbilcox, Thomas	Formaldehyde Modified Lignosulfaonate Extenders for Furan Systems	MSMSE
	Fung, Thomas	Force to Restrain Lateral Buckling of Parallel Chord Trusses	MSCE
	Griffith, Michael	Creep Buckling of Timber Columns	MSCE
1984			
	Gosse, Jonathan	Probe Withdrawal Load as an Indicator of the Presence of Decay in Structural Wood Members	MSMSE
	Wospakrik, Frans	Evaluation of Modulus of Elasticity and Strength of Structural Lumber using a New Modulus of Elasticity Measuring Device	MSMSE
	Ross, Robert	Stress Wave Speed and Attenuation as Predictors of the Tensile and Flexural Properties of Wood-Based Particle Composites	Ph.D.
	Wospakrik, Judya	Non-thesis Option Graduate	MSMSE
	Akhtar, Mohammad	Damping of Composite Beams	MSCE
	Cheung, C.	Dynamic Response of Wood Diaphragms in Low-Rise Wood-Framed Buildings	Ph.D.
	Eckard, James	Creep of Douglas Fir Beams Due to Cyclic Humidity	MSCE
	Little, Roger	Use of Finger Joints as Rigid Corner Joints	MSCE
	Sun, Shao Kii	Finite Element Analysis of Storage Bins Subjected to Flow Grain and Wind Loads	MSCE
	Tessem, John	Earthquake Analysis of Low Rise Multistory Buildings	MSCE
	Van Halm, T.	Analysis and Testing of a Curved Glued-Laminated Beam	MSCE

1985			
	Rammon, Richard	The Influence of Synthesis Parameters on the Structure of Urea-Formaldehyde Resins	Ph.D.
	Vogt, James	Evaluation of the Tensile and Flexural Properties and Internal Bond of Medium Density Fiberboard Using Stress Wave Speed and Attenuation	MSMSE
	Plagemann, Walter	Wood Isocyanate Interactions: Chemical Implications	Ph.D.
	Anderson, Jill	The Effect of Moisture Cycling on the Creep of Glulam Beams	MSCE
	Ghosh, Ashok	Buckling of Cantilever Cylindrical Shells Subjected to Unsymmetrical Lateral Pressure	MSCE
	Patel, Anil	Large Deflection Analysis of Laterally Loaded Stiffened Plates	MSCE
1986			
	Petit, Marie Helene	Flexural Properties of Full Size Wood Composite Panels Evaluated by Stress Wave Speed and Attenuation	MSMSE
	Martin, Cynthia	Effects of Dispersion and Distribution of Polymeric Diisocyanate Binder on Waferboard and Particleboard Properties	MSMSE
	Falk, Robert	Experimental and Theoretical Study of the Behavior of Wood Diaphragms	Ph.D.
	Maganga, Joe	Nondestructive Testing of Wood	MSCE
1987			
	Radcliffe, Scott	Nondestructive Evaluation of Damage Caused by Cyclic Stress	MSMSE
	Rutherford, Paul	Nondestructive Stress Wave Measurement of Incipient Decay in Douglas Fir	MSCE
	Collons, Bryan	Investigation of the Load-Sharing Capabilities of Bridging	MSCE
	Kuruvilla, Santosh	A Study of Building Coefficients Used in Earthquake Resistant Design	MSCE
1988			
	Janowiak, John	Impact Dynamics of Reconstituted Wood Plates	Ph.D.
	Vogt, James	Characterizing the Effect of Moisture Content on the Flexural Properties of Sugar Pine and Black Spruce Dimension Lumber	MSCE

1989			
	Ma, Dawn	The Effect of Donor/Acceptor Interactions on Mechanical Properties of Wood	MSMSE
	Jackson, Julia	Gravity Load Effects on Lateral Load Resistance of Diaphragms	MSCE
1990			
	Lindfors, Bryan	A Full Tension Capacity Connector for 2 x 4 Lumber	MSCE
	Matt, Thomas	Full Member Capacity Nailed Tension Connections	MSCE
	Motter, William	The Formation of the Colloidal Phase in Low Mole Ratio Urea-Formaldehyde Resins	Ph.D.
	LaFave, Kelly	Experimental and Analytical Study of Load Sharing in Wood Truss Roof Systems	MSCE
	Phillips, Timothy	Load Sharing Characteristics of Three Dimensional Wood Diaphragms	MSCE
1991			
	Brashaw, Brian	Evaluation and Comparison of the Creep Performance Of Douglas Fir Laminated Veneer Lumber and Douglas Fir Dimension Lumber	MSMSE
	Park, Joung Man	Interfacial Aspects of Mineral Fiber Reinforced Wood Composites	Ph.D.
	Hutnik, Mark	Concomitant Properties of Lumber	MSMSE
	Wasniewske, John	Evaluation of Juvenile Wood and its Effect on Douglas Fir Structural Composite Panels	MSMSE
	Emerick, Shannon	Developing Wood Housing in the Peoples Republic of China	MSCE
	Ayoub, Ihab	Redundancy and Reliability of Bridge Structures	MSCE
1992			
	Bodenheimer, Todd	Production of Laminated Veneer Lumber Using High Frequency Heating in the Pressing Operation	MSMSE
	Farrell, Patrick	Effects of Processing Parameters on the Performance Of Flakeboard made from Douglas Fir Juvenile Wood	MSMSE
	Chin, Carolyn	The Reliability Analysis of Wood Diaphragms Under Wind Loading	Ph.D.

1993

Akesson, Kevin	Analysis of Finger Joint Quality Using Non-Destructive Evaluation	MSCE
Akesson, Kevin	Analysis of Finger Joint Quality Using Nondestructive Evaluation	MSCE
Gianotti, C.	Structural Response to Long-Duration Earthquakes	MSCE

1994

Gai, Chunxu	Reliability Analysis of Glulam Beams Under Dynamic Loads	Ph.D.
Cheng, Jian	A Computer Simulation and Analysis of Strength and Failure for Glue Laminated Beams	Ph.D.
Olsen, Jeffrey	Feasibility of the Utilization of Northwest Hardwoods in Oriented Strand Lumber	MSCE

1995

Sauter, Steven	Developing High Quality Composites from Urban Waste Wood and Wheat Straw using Urea-Formaldehyde Resin	MSMSE
Peterson, Jason	Shear Strength of Southern Pine Lumber with Natural and Artificial Defects	MSCE
Lavinder, Jeff	Nondestructive Evaluation of Timber Bridges	MSCE
Asselin, Steven	Effects of Member Size on the Shear Strength Of Sawn Lumber	MSCE
Emerson, Robert	Resistance of Metal Plate Connections to Cyclic Loading	MSCE
Nagele, Trent	Dynamic Embedment of Metal Plate Connections in Timber	MSCE

1996

Olson, Brent	Developing Wood Composites Using Small Diameter Timber Resources from Dense, Stagnant Strands	MS
Shi, Wen	Use of NDT Techniques for Prediction of Tensile Properties in 2 x 4's from Douglas Fir Peeler Cores	MSCE
Tucker, Brian	Partial Composite Action and Lateral Distribution Effects On Wood-Joist Floor Systems with Various Construction Techniques	MSCE
Burt, Cornell	Nondestructive Evaluation of Douglas Fir Peeler Cores	MSCE
Laura Brantley	Damage Accumulation in Structural Lumber Due to Dynamic Loads	MSCE

Proctor, Frank Jr.	Finite Element Analysis of Shear Strength in Timber Beams	MSCE
Sanders, C.	the Effects of Testing Conditions on the Measured Shear Strength of Wood Beams	MSCE
Voorhees, Bradley	Building Code Comparison of U.S. and Japanese Light Frame Timber Design	MSCE

1997

Al Foqaha, Arshad	Design Criterion for Wood Floor Vibrations via Finite Element and Reliability Analyses	Ph.D.
Wongprasert, Nat	Parametric Study of Wood Floor Vibration due to Occupant Activities	MSCE
Earnest, Diane	Vibration of Wood Joist Floors Due to Occupant Loading	MSCE
Hua, Wenhua	Creep Mechanisms in Oriented Strand Board	MSCE

1998

Harper, David	The Evaluation of 4-4" Diphenylmethante Diisocyanate Cure in a Saturated Steam Environment	MSCE
Stephen Carstens	Static and Dynamic Dowel Bearing of Wood Products and Species	MSCE
Monique Paynter	Design of Composite Waterfront Structures	MSCE
Judsen Williams	Strength Reduction of Timber	MSCE

Faculty Recognition

Faculty members in the Laboratory have held many offices in various technical and professional societies. Hoyle, Maloney, and Marra were all President of the International Society of Wood Science and Technology. Marra and Maloney were Presidents of the International Forest Products Research Society (now Forest Products Society). Marra and Maloney were also Fellows in the International Academy of Wood Science.

Marra was selected to give an Invited Address to the university in 1961, entitled *Pathways to Technological Progress*. In 1989, he received the Borden Chemical Company Award given through the International Forest Products Research Society for outstanding research.

Maloney received the first Washington State University Faculty Excellence Award for Public Service in 1983. The Award read:

> Thomas M. Maloney has received international acclaim for his innovative work in wood product technology during the past twenty-eight years. As Head of the Wood Technology Section, he is a respected leader of the profession, bringing results from the laboratory to government, industry, and the general public. His accomplishments have promoted the economic welfare of the Pacific Northwest. Election to the presidency of international professional associations and service to United Nations' agencies indicate the range and diversity of his professional influence. As a faithful servant of the public welfare, he continues to advance the stature of Washington State University.

In 1988, he was honored with the *Forest Industries* annual award given for leadership in developing excellence in the forest products industry. The National Particleboard Association in 1993 recognized him for Dedicated Service to the Particleboard and Medium Density Fiberboard Industries. In 1994, he was awarded the Faculty Service Award of the National University Continuing Education Association Division of Conferences and Institutes for founding and conducting for 28 years, the International Washington State University Particleboard/Composite Materials Symposium.

George Marra and Tom Maloney were both elected to the International Academy of Wood Scientists. Roy F. Pellerin and M.D. Strickler received the 1972 L. J. Markwardt Wood Engineering Research Award given through the International Forest Products Research Society.

Roy Pellerin was given the Woodworking and Furniture Digest Award in 1975 for his research on nondestructive testing, also awarded through the International Forest Products Research Society. John W. Talbott received the Borden Chemical Company Award for outstanding research in 1980.

In 1997, Robert J. Hoyle, Jr. was given the Wood Engineering Achievement Award. This award is given through the International Forest Products Society and is sponsored by the American Wood Council of the American Forest and Paper Association. He wrote the comprehensive book, *Wood Technology in the Design of Structures,* which was published in 1973. This book is now in its fifth edition and is used throughout the world.

Kenneth Fridley, Associate Professor in Civil and Environmental Engineering since 1994, received the Marian E. Smith Faculty Achievement Award for 1997-98.

Robert "Bob" Hoyle, Jr.

The award recognizes significant and meritorious achievement in teaching and Fridley has shown extraordinary commitment to students, adventuresome teaching methodology, mastery of the latest knowledge in the field of structures through prolific research, publications, and community service.

Tom Maloney is the author of, *Modern Particleboard and Dry-Process Fiberboard Manufacturing,* which is also used throughout the world and continues to be requested for purchase from the Laboratory. The Proceedings of the annual International Particleboard/Composite Materials Symposium, the first 29 volumes edited by Maloney, with subsequent volumes edited by Don Bender, Robert Tichy, and Michael Wolcott are often referred to today as the "Bible" in this sector of the forest products industry.

Laboratory Recognition

Composite Materials

In the 1950's, there were a few small particleboard plants operating in the U.S. and indeed in the world. Starting in the late 1950's, there were a tremendous number of new plants constructed. Today there is about five billion square feet (3/4-in. basis) of particleboard produced in the United States. The Laboratory was instrumental in providing the fundamental information to companies entering the particleboard field enabling them to build board plants. Most of the companies starting new plants through their own operation, or through consulting engineering firms, had the Laboratory research the materials they planned to use to determine if they could be used for particleboard manufacture. The staff in the Laboratory performed much in-house research on particle geometry, wood species, wax additives, resin application, resin distribution, and pressing parameters that enabled them to assist the developing industry. This information was not available elsewhere.

As the composites industry developed and began introducing medium density fiberboard (MDF), waferboard, oriented strand board (OSB), laminated veneer lumber (LVL), dry-process hardboard, oriented strand lumber, and composites of agricultural straws, the Laboratory continued its leadership role in the industry. Today there is about 1.5 billion square feet (3/4-in. basis) of MDF produced in the U.S. annually. North American OSB production is about 17 billion square feet (3/8-in. basis) and LVL production is about 40 million cubic feet. In total, the production of wood composites over the past 50 years is an amazing record and the Wood Materials and Engineering Laboratory was an important part of developing this huge new industry.

In a 1985, the University of Minnesota recognized this leadership in a published study, noting that the Laboratory and the U.S. Forest Products Laboratory stood out in providing leadership and direction over a long period of time in the structural particleboard industry. As stated in the study, "These two organizations consistently maintained close contact with the industry and carried out research ranging from basic to immediately applicable studies. Washington State University (Pullman, Wash.) has been a leader in particleboard research and in technology transfer efforts since 1960. The Laboratory sponsored an annual symposium starting in 1967, which brought together researchers, equipment suppliers, and industry representatives from around the world. These symposia have focused on new structural panels as well as particleboard."

In 1994, Peter Locke, Manager of Agcor, an Australian integrated agribusiness development operation, traveled in Germany, Denmark, the United States, and Canada visiting research centers, both private and institutional/university, investigating the international composites industry. He had also visited the research centers in his home country and was most interested in using cereal straw for composites. He said, "I can state that I have not seen a composite board Research and Development Centre that compares with the Wood Materials and Engineering Laboratory at Washington State University.

The variety of resin blending apparatus, the many pressing machines, the depth of calibration and methods of pressing is greater than in any R & D center I have visited, coupled to a most sophisticated product testing facility that I would be surprised is repeated in any other university. Not only is the center world class with years of experience within its personnel being positioned in Whitman county, the largest wheat growing county in the USA, it is well placed to lead the world in cereal straw board technology in the future."

Nondestructive Testing

The Wood Materials and Engineering Laboratory has nondestructive testing of wood and wood products as one of its major research areas. Significant funding for this program has been provided over the years through the federal McIntire-Stennis Act, which was signed into law in

Tom Maloney and Dayton Brewer, 1967.

1961. At the 25th celebration of this significant program, four and only four projects were recognized for excellence over this 25-year period. One of these projects was the nondestructive research in the Laboratory directed by Roy Pellerin. At the time of the recognition, about $162 million had been awarded to various universities. The Laboratory had received about $227,000 for its research so it was a great honor to be recognized as one of the four best projects funded over the previous 25 years.

The NDT research was also selected as one of the most outstanding research efforts of the College of Engineering and School of Architecture over the first 100 years of the university. It was recognized at the university's Centennial Celebration.

The long-time leader of the research in this area, Roy F. Pellerin, along with coworker James Logan and industrial leader Ed DeKoning, formed Metriguard, Inc. in 1973 to commercialize the research from the Laboratory particularly in the nondestructive testing area. Today, Metriguard, is the world leader in supplying many types of nondestructive testing and other equipment to the forest products industry.

Symposia

The internationally acclaimed Particleboard/Composite Materials Symposium was mentioned above. The Symposium was founded by Tom Maloney and brings together the leading people in the industry from throughout the world. Attendees include scientists; engineers; technologists; product manufacturers; equipment manufacturers; suppliers of resins, waxes, and chemicals; government agency representatives; and product users. A critical element to the overall success of the Symposium has been publishing its *Proceedings.* Great efforts have been made to edit publish all the papers from all of the Symposia.

The mailing of the first Symposium Announcement is an interesting piece of this history. Although prepared by the Laboratory staff and mailed on time, no one received their information, not even the chairman whose name was on the mailing list. The university mailroom assured the Laboratory that indeed the mailing had been sent out. Tom Maloney insisted that the mailroom be rechecked. Begrudgingly, the mailroom personnel took another look around and found the mailing in several boxes behind a freight door. The mailing was made and 175 people showed up for the first Symposium. Without this checking of the mail, the Laboratory probably would still be wondering why no one came to the meeting. And further, this valuable and important series of Symposia would not have gotten off the ground.

An interesting sidelight on the Symposium occurred at one of the huge Ligna industrial fairs in Hanover, Germany in the early 1990's. It was the year that a very large new exhibition hall was opened for displaying machinery, instruments, and chemicals for the composites industry. Tom Maloney was standing on a catwalk observing the magnificent displays of modern advancements for the industry. A leading European industrialist came upon him and much to his surprise, the industrialist said that the Laboratory had to take much of the credit for getting this part of the show at Ligna started. He stated that Pullman showed the world that people interested in composites would indeed gather together to learn of the latest advances in the industry. He felt that the Symposium helped inspire the development of the Ligna show, which indeed began after the founding of the Symposium.

The Laboratory has held two other important Symposia. The Nondestructive Testing Symposium series was started in 1963 at the U.S. Forest Products Laboratory in Madison, Wisconsin. The Second one held in 1964 with William L. Galligan and George Marra as Co-Directors was the one where WSU took the lead and it was also the first one to publish proceedings. Robert Hoyle directed the Third Symposium but since then the lead person at Washington State University has been Roy Pellerin. This important series has not been held annually but more or less on a biannual basis. Recently, the Symposium has been co-hosted by the U.S. Forest Products Laboratory. A total of eleven meetings have now been held with Proceedings published for all but the first one.

The Laboratory sponsored four International Symposia on Adhesion and Adhesives for Structural Materials during the 1980's under the direction of William Johns. The papers presented were published in the refereed, *Journal of Adhesion*.

The Northwest Wood Products Clinic was the forerunner of the Forest Products Research Society. Established in Spokane in 1946, this important meeting brought together the academic, government, and industrial leadership throughout the Pacific Northwest and western Canada. The Engineering Extension Service from 1955 through 1983 managed the Clinic. The leaders in sequence throughout this time period were Eri Parker, William Knight, and Bruce Shelton. Bruce Shelton retired in 1983 and Tom Maloney then took over the leadership position from Washington State University until his retirement in 1995.

As a service to the industry and the public, the Laboratory and the Engineering Extension Service published the *Wood Industry Abstracts* from 1971 to 1984. The Abstracts (numbering about 200 per issue) were published in six issues per year. The Abstracts covered summaries of current technical literature on wood procurement, treatment, processes, and products. In the latter years of its publication, the abstracts were prepared by the Forest Products Research Society but the actual publication remained at Washington State University. The Abstracts ceased publication with the advent of the electronic library search engines.

Distinguished Professorships

The international acclaim developed by the Laboratory lead to two Distinguished Endowed Professorships established for faculty performing their forest products related research there. The first was the Weyerhaeuser Distinguished Professorship set up in 1994. Thomas M. Maloney was the first Distinguished Weyerhaeuser Professor and was followed in 1997 by Donald Bender.

The Louisiana Pacific Corporation established the second Distinguished Professorship in 1996. This Professorship recognized the career contributions of Thomas M. Maloney. The first Distinguished Professor was Michael Wolcott.

Graduate Student Research Recognition

The International Forest Products Society (until 1994, the Forest Products Research Society) annually recognizes outstanding graduate research with the Wood Award. This is a prestigious award and past winners have risen to leadership positions in government, academia, and industry. A first and second place award is given and the competition for these awards is fierce. Students with their research home in the Laboratory who have won the Wood Award are Jonathan W. Martin, second place, 1978; Robert J. Ross, first place, 1985; John J. Janowiak, second place, 1989; and William K. Motter, first place, 1991.

Scholarships

In recognition of the outstanding work of the Laboratory, a number of scholarships have been established for the graduate students working in the Laboratory,

Marty Lentz and Bob Tichy in China, 1992.

- Weyerhaeuser Graduate Scholarship
- William H. Cooke Memorial Scholarship
- Theodore E. Jenks Memorial Scholarship
- Steven K. Nicholls Memorial Scholarship
- Helmut G. Moeltner Memorial Scholarship
- John W. Talbott Memorial Scholarship
- J. R. and Lois L. Stillinger Scholarship

Laboratory Enhancement Fund Drive

Because of its international stature, the Laboratory was a natural for further support from industry to enhance the facilities, staff, and graduate program. A proposal was prepared in 1985 and over a three-year period, 25 companies and foundations contributed approximately $1.2 million dollars. An important grant of $330,000 was provided by the M. J. Murdock Charitable Trust challenging the industry to support long-term research critical to its continued competitiveness in today's global economy.

Contributors to the Laboratory Enhancement Fund Drive were: Acrowood Corp.; Bison Werke; Boise Cascade Corp.; Borden Chemical Co.; Borden Foundation; Carbocol Inc.; Carl Schenk AG; Casco Nobel; Coe Manufacturing Co.; Frank Lumber Co. Inc.; ICI Americas Inc.; Kimwood Corp.; Kusters Maschinenfabrik GmbH; Plum Creek Timber Co. (Burlington Northern Foundation); The Robertson Corp.; G. Siempelkamp GmbH; Simpson Timber Co.; Sunds Defibrator AB; Trus Joist Corp.; Ultrasonic Arrays Inc.; Westralia Forest Industries Ltd. (now Westfi); Weyerhaeuser Co.; and Willamette Industries Inc.

Laboratory Advisory Board

The successful fund raising drive lead to the establishment of a 15 member Advisory Board to assist the Laboratory in its operation for the benefit of society, industry, and education. The membership consists of people from large international forest products and equipment suppliers, lumber and panel manufacturers, producers of engineered wood products, chemical suppliers, a faculty member from the University of Washington, and the Director of the U. S. Forest Products Laboratory. Later, a member representing alumni of the Laboratory was added.

Some of the Advisory Board members over the years have been Fred W. Fields, Coe Manufacturing Co.; John Galbraith, ICI Polyurethanes; William L. Galligan, Frank Lumber Co., Inc.; Peter Weicke and Joel Goranson, Sunds Defibrator, Inc.; Jim Eisses and Warren Easley, Louisiana-Pacific Corp.; Jay Johnson, University of Washington; Dick Just, Boise Cascade Corp.; John Kerns, Weyerhaeuser Co.; Douglas McVey, Willamette Industries, Inc.; Charles Grenier, Dwight O'Donnell, and Dennis Robinson of Plum Creek Timber Mfg. L.P.; George D. Waters Borden; Rick Wentworth, Bison-Werke; and Alumnus, Brian K. Brashaw, University of Minnesota Duluth.

Wood Composites Hall Of Fame

In 1977, the Wood Materials & Engineering Laboratory inaugurated a program of recognizing internationally known pioneers of the wood composites industry (including agrofiber) in the United States and the world. In one way or another almost all of these individuals have had a positive interactions with the Laboratory. The Wood Materials and Engineering Laboratory considers all of these people as an extension of the Laboratory. They are friends and colleagues who have left a great legacy in the world of wood composites.

Wood Composites Materials Hall of Fame Inductees

1998

Dennis Cullity	WESFI, Australia
Kieth Morley	Reichhold, Keith Morley Assoc. Ltd., Canada

1997

Lucille H. Leonhardy	Washington State University
Murray G. Sturgeon	Nelson Pine Industries, New Zealand
Alfred H. Schenkmann	Schenkmann & Piel, Germany
Otto Suchsland	Michigan State University

1996

S. Hunter W. Brooks	Miller Hofft Inc.; Brooks Assoc. Ltd.
Alan L. Lambuth	Monsanto Co.; Boise Cascade Corp.
Harold "Hank" N. Spurlock	Spurlock Adhesives, Inc.

1995

Günter Bücking	Bison Werke, Germany
Owen F. Haylock	Canterbury Timber Productions Ltd.; Owen Haylock Consultants Ltd., New Zealand
Robert J. Kolp	Georgia Pacific Corp.

1994

Robert Carter	Boise Cascade Corp.
John W. Churchill	U.S. Plywood Co.; Georgia Pacific Corp.
William A. McCredie	National Particleboard Assoc.

1993

Ted J. Bauer	Medite Corp.
Tom Buglione	U.S. Plywood Co.; DuraFlake/Williamette Industries Inc.
James L. Graves	Washington Iron Works; Merillat Industries
Werner W. Westphal	Temple-Inland, Inc.
Glenn Sprouse	Washington State University

1992

Fred W. Fields	Coe Manufacturing Co.
Larry L. Hammock	Medite Corp.
Keith M. Horner	Roseburg Forest Products
Herbert H. Krichel	Bison-Werke, Germany
E. Birger Sundin	Casco Nobel Industrial Resins AB, Sweden

1991

James Eisses	Louisiana-Pacific Corp.
George Waters	Borden Adhesives & Resins

1990

William F. Lehmann	Weyerhaeuser Co.
Douglas T. McVey	Williamette Industries Inc.
Larry G. Chambers	Georgia Pacific Corp.

1989

Gene E. Tower	Gene Tower Consultant
Elmer Van Schoick	Louisiana-Pacific Corp.

1988

K. Gordon Borchgrevink	Weyerhaeuser Co.; Medite Corp.
Robert J. Crawford	Roseburg Forest Products
Wilhelm Pallmann	Pallmann Maschinenfabrik GmbH, Germany
Peter H. Wiecke	Columbia Engineering International Ltd.; Sunds Defibrator, Canada

1987

Norman J. Briggs	Weyerhaeuser, Georgia Pacific Corp.
Lawrence E. Legas	Monsanto Co.
Edward F. Steck	Berthelsen Co.; Wilco Machines;
Siempelkamp Corp.	

1986

Thomas M. Maloney	Washington State University
Ernst Greten	Bison-Werke, Germany
H. John Knapp	Grenco, Inc.
H. Dale Turner	U.S. Forest Products Laboratory; Masonite Corp.; Dierks Forests; Weyerhaeuser Co.

1985

Donald E. Lengel	Columbia Engineering Co.;
	International Systems Engineering Corp.
John W. Talbott	Washington State University
Duncan R. Young	Rexwood Products DYHM, Canada

1984

George G. Marra	Washington State University; U.S. Forest Products Laboratory
John W. Maxwell	Borden International
J. R. Stillinger	Oregon Forest Products Research Center; Cascades Plywood;
	Roseburg Forests Products; Wynnewood Products Co.;
	American Liberty Oil Co.; Bison-Werke, Caberboard Ltd.,
	Scotland

1983

Peter Vajda	Columbia Engineering International Ltd.
Irv Wentworth	Pack River Lumber Co.; Potlatch
Forests, Inc.; Duraflake Co.	
Ronald G. Frashour	Oregon Forest Products Laboratory;
	Forrest Industries, Fiber Processes, Inc.;
	Coe Manufacturing Co.
Helmut G. Moeltner	De Mets, Belgium, DYHM

1982

Fred Fahrni	Fahrni Institute
Wilhelm H. Klauditz	National Institute for Wood Research;
	Institute for Wood Research, Germany
Clark C. Heritage	U.S. Forest Products Laboratory;
	Weyerhaeuser Co.
Charles R. Morschauser	Timber Engineering Co. (TECO),
	West Vaco; National Particleboard Assoc.
Hobert O. McQueary	Williamette Fiber & Chipboard, Inc.;
	Inter-Pacific Resins, Inc.; Ellingson Lumber Co.

1981

James F. Hamilton	Souhegan Mills; Michigan Technological Institute
Theodore E. Jenks	Allied Chemical Corp.; Miller Hofft, Inc.

1980

Burton F. Swain, Jr.	National Veneer & Lumber Co.; Swain Industries
Arthur L. Mottet	Long-Bell Co.; International Paper Co.
Harry A. Raddin	Miller Hofft Inc.

1979

L.A. (Pat) Patronsky	University of Michigan; Wabash Screen Door Co.; Pack River Lumber Co.; Timber Engineering Co. (TECO)
Warren C. Smith	Wonder Wood Corp.; U.S. Plywood Co.

1978

Armin Elmendorf	Elmendorf Research, Inc.
H. C. L. Miller	Miller Hofft, Inc.
William M. McNeil	U.S. Gypsum Co.; Bauer Brothers Co.

1977

James D'A. Clark	Bowaters Paper Mills; Mead Corp., Pack River Lumber Co., Consultant
Armin A. Wehrle	Plywood Research Foundation; Coos Bay Lumber Co.; Georgia Pacific Corp.
William H. Cooke	Oregon Forest Products Laboratory; Pacific Plywood Co.; Weyerhaeuser Co.

Research Successes

Since 1950, there has been a revolution in the forest products industry. The major product line was lumber with softwood plywood just coming into its own. Hardboard, insulation board, and cement-bonded products were invented early in the century and there were a number of these plants in operation. Particleboard was developed in the 1930's, but significant production was yet to take place. Since 1950, numerous "Wonders of the Wood World" have been developed. A number of these wonders are listed below and the Wood Materials and Engineering Laboratory has had a significant impact on many of these developments:

- particleboard
- medium density fiberboard (MDF)
- oriented strand board (OSB)
- laminated veneer lumber (LVL)
- oriented strand lumber (OSL)
- COM-PLY (panels and lumber)
- molded door skins
- molded wood fiber/plastic fiber automobile panels
- the development of the southern pine plywood industry
- fingerjointing of structural lumber and millwork
- the development of process lines for plywood and all of the composite products listed above including:
    - new plywood lathers, clippers, dryers, composers, pre-presses, hot presses, cutup equipment, and sanders
    - composite processing equipment such as flakers, strand makers, hammermills, pressure refiners, screens, dryers, blenders, formers, pre-presses, hot presses (monster sizes up to 8 by 176 feet in size), continuous presses , cutup equipment, sanders

- computer controls for all of the processes
- complete log utilization
- use of recycled wood and recycled fiber in composites
- I-joists (now making up 30 percent of the market for floor structural members)
- trusses using metal plates for connections (computer designed and delivered complete to the job site). Almost all buildings are now built with such trusses, in 1975 only about 5% of homes were built with trusses as they had to be constructed on the job, thus conventional rafters were easier to use
- nondestructive testing for lumber, panels, veneers, engineered wood products and structures
- proof loading of structural materials
- development of performance standards
- many new developments in wood construction

Part II

Basic Research on Particleboard

Little was known in the late 1950s about the basics of manufacturing particleboard. The Laboratory performed several basic research projects and the results of this work was used by engineering firms in the design of the many plants built at this time. Some of this research was published and some was not. Papers by Brumbaugh on flake dimensions, and by Strickler on pressing are presented later. Research done on resin distribution, species density, and planer shavings particle geometry by Maloney; on resin particle size by Brumbaugh, and the effect of wax on board properties by Talbott, were performed as basic work for industry and was not published at the time.

In research included in Tom Maloney's book, *Modern Particleboard and Dry-Process Fiberboard Manufacturing,* it was found that very small resin droplets distributed evenly over the particle surfaces yielded boards with the best properties when dealing with homogenous boards. Varying levels of resin over different particle sizes in graded boards were later found to be the best, but fine resin droplets was still the premier way resin was applied.

Talbott's wax research was the first to show that wax inhibited the absorption of water by boards but did not prevent water absorption. Contrary to the conception of the time, wax did not inhibit the pickup of moisture from the air by boards. Also, in his work, it was determined that wax levels as high as two percent did not cause problems with the bonding of the resins in the boards. Further, the wax could be applied before, with, or after resin application with urea formaldehyde resins.

It is well known that the density of the species influences the properties of boards made from the species. Higher density species make poor medium or low-density boards. A certain amount of pressure is needed to "clamp" the particles together while they are being pressed into a board in the hot press. Maloney's research dealt with softwood species on the west coast that were approximately the same in density. The initial research showed some differences in particleboard properties between the species being investigated but the differences could not be explained by species density alone. Further research showed that the particle geometry of the planer shavings from each species had a profound effect on board properties. In this work, species such as Douglas fir and lodge pole pine had blocky particles of planer shavings, Ponderosa pine had a preponderance of fine particles, and Engelmann spruce had mostly flaky planer shaving particles. This particle geometry, for the most part, remained the same no matter what particle size was evaluated (within the range of sizes used for board). For example, in species with blocky particles the boards had high internal bonds and lower bending properties while boards of the flaky particles had superior bending properties but lower internal bond properties.

Electrical Orientation of Fibers and Particles

Particles, fibers, flakes, and strands can be aligned to provide panel of lumber-type products with much greater bending strength and stiffness in the oriented or aligned direction. Such orientation interacts with most of the major parameters involved in producing composite materials, and manipulation can change the level of strength through orientation.

Two ratios should be understood when considering orientation. One, the slenderness ratio that is the particle length divided by the thickness. Any particle with a ratio over one will be longer than it is thickness and thus will be amenable to orientation. The second ratio is the aspect ratio, which is important when considering flakes or strands. It is calculated by dividing the flake or strand length by its width. A ratio of one means a square particle, which is one that cannot be oriented. A ratio of at least three appears to provide good orientation.

In recent years, mechanical orientating has been developed but they can only work with longer strands, say as much as three to five inches long. In the 1970s, an electrical method for orienting was developed in the Wood Materials and Engineering Laboratory by John W. Talbott and James Logan. This method can orient any particle, fiber, flake, or strand that has a good aspect ratio. Particles are dropped through an electrical field formed between two oppositely charged plates, and the electric field aligns the particles. This device using little energy is incorporated as part of a former. It has the particular advantage of being able to orient small particles or fiber or admixtures of various particle or fiber sizes, something not possible with mechanical formers.

This invention franchised to Morrison-Knudsen Forest Products Company. Morrison-Knudsen accomplished considerable commercial development, and pilot plant formers were built for fiber, flakes, and strands. The flake former was used for a long pilot plant run at the Potlatch research pilot plant in Lewiston, Idaho making oriented flake board for the U.S. Forest Service project on Com-Ply.

For numerous reasons not associated with technical feasibility, Morrison-Knudsen was not able to place any electrical formers in commercial facilities. About five years ago, Coe Manufacturing took over the rights to this process and it is available for sale through Coe.

Bonding Problems with Tropical Species

The commonly used species for particleboard and MDF can be bonded with urea formaldehyde (UF) resin and usually are because this is the lowest cost adhesive system. However, there are many species where the pH and the buffering capacity of the species makes it impossible or economically impossible to bond these species using UF resins. In a project performed for a Philippine Company in the 1970s, 26 low value species were evaluated for use in making particleboard. These species were low value because they could not be converted into lumber or plywood. The company wanted to use these species intermixed, as that is how they would be harvested.

These species were evaluated for ease of converting into ring-cut flakes, and for pH and buffering capacity. The raw material was ring-flaked in a commercial pilot plant, measured for pH and buffering capacity and was then made into particleboards. The experimental boards were evaluated for various properties.

It was found that most of the species could be used successfully for manufacturing particleboard. However, there were a few species that had pH levels over 7.0 and had very high buffering capacities. It was not possible to use these species for particleboard using UF resin. Thus, for the company to proceed with using these species in a new plant, a different resin system had to be used (which for them was impossible because of higher cost) or that the impossible to use species had to be separated out of the harvest.

This research showed conclusively that great care has to be taken when trying to use a number of species mixed together for any composite bonded with UF resin. In particular, tropical countries with a great number of species growing on a single hectare have to be very aware of how these species are used. In the time since this research was performed many plants have been built in tropical countries, however, the raw materials are from single species such as rubberwood or other plantations emphasizing the importance of species pH and buffering capacity.

End-Use Standards

The Laboratory almost from its inception has been involved in developing standards and specifications for composite products. The phrase used in the early days was "End-use Standards" with respect to the properties of the different new materials. The thrust was to use scientific and engineering information to design materials to perform given tasks. Lumber and plywood panels had design numbers assigned to various grades but these numbers were generally after the fact. These materials were used successfully based on experience and later had design numbers developed for various applications. With the new composite products, the approach taken was to determine how the new material had to perform in the field and then to use science, technology, and engineering to develop the new products.

The American Plywood Association (APA) later took this approach to successfully develop "Performance Standards" for the different panels being manufactured commercially, then and for those yet to be produced. The Wood Materials and Engineering Laboratory produced more than four hundred experimental 4 by 4-feet composite panels of varying particle configurations, resin types, and resin levels for APA to use in their extensive testing and development program leading to the establishment of the Performance Standards.

Composite Boards of Agricultural Fibers

For the most part, the composite industry has used wood as its raw material throughout the years. However, it is often overlooked that agricultural fibers have actually been used, not only recently with the new plants using wheat straw as furnish but also for many years.

The early insulating board plants of the 1920s used corn stalk for furnish. A very old insulating board plant, believed to be still operating in Louisiana, uses bagasse (sugar cane stalk) for furnish. Bagasse has been used in many plants throughout the world. In the 1950s, plants were built in Venezuela and Cuba, and more recently, an MDF plant was built in Thailand. For a long time, flax was used for particleboard furnish in plants in Belgium and Eastern Europe.

Considerable research has been conducted on agricultural fibers over the years but plants based on waste wood have usually been much more economical to operate. In countries or locations where wood was not available, economics favored the use of agricultural fiber.

The Laboratory has performed research on hemp and wheat straw showing the possibilities of economically using these raw materials for composites. The most interesting has been the use of wheat straw as furnish for MDF. Work of Steve Sauter and Martin Lentz gave indications that the pressure refining of the wheat straw made it possible to use conventional urea formaldehyde resins, or variations thereof, for producing board. Many of the newer wheat straw plants are using expensive isocyanate binders.

The Laboratory performed extensive research in the 1960s on bagasse for particleboard. The work was done for a large industrial firm and was quite successful. A plant was built in Jamaica for manufacturing board of bagasse based on this research. From all accounts, this plant later failed due to non-technical related factors.

Composite Structural Panels of Red Alder

Alder was analyzed in 1984 as a raw material for structural panels. Red alder (*Alnus rubra*) is an abundant, low-density hardwood species readily available in western Washington and Oregon. It has a great potential for use in composition board types of structural panels.

This research explored the potential of structural panels by evaluating appropriate particle production and by producing experimental panels assessing bonding, bending properties, durability, dimensional stability, and the effect of particle size, thickness, and orientation.

It was found that of the particle types evaluated, good wafers, ring-cut flakes from pulp chips and 1-1/8 and 2 inch strands could be easily produced. No bonding problems were found with conventional powder and liquid phenolic resins.

As would be expected, orienting the ring-cut flakes and the strands dramatically improved bending properties and linear expansion in the oriented directions. Orientation incorporated into panels to form cross-lapped layers analogous to plywood could possibly reduce board density markedly while still maintaining suitable board properties.

According to the durability evaluation conducted, a two-hour boil, the alder panels were generally good. Particle thickness at the two higher levels of 0.020 and 0.030-inch had little effect on internal bond in boards of ring-cut flakes and 1-1/8 and 2-inch long strands. A small difference was observed in waferboard with the boards of 0.020-inch wafers the best. In all boards, the thinnest particle of 0.010-inch yielded boards with the lowest internal bonds, but minimum property levels were easily met.

Flake thickness did not affect modulus of rupture (MOR) and modulus of elasticity (MOE) in boards of wafer or ring-cut flakes. The thinner 0.010-inch flake, however, in the two strand boards resulted in the higher MOR and MOE values. In both the linear expansion in a high humidity atmosphere, and after drying and soaking, all of the different types of board had the lowest and, therefore, the best value when made with the 0.010-inch particles.

As the particle thickness decreased, the surface area of the particles in a given board increased tremendously, approximately 50 percent when going from 0.030-inch to 0.020-inch particles and 300 percent when the particle thickness was 0.010 inch. Nevertheless, board properties were relatively constant no matter which three thicknesses were used, although resin levels were held constant by weight. Evidently, better commingling of the thin particles made more efficient use of the applied resin, which showed that consideration of flake thickness solely as a measure of resin coverage and, therefore, resin efficiency, is not appropriate.

The oriented boards showed promise as construction grade lumber because they exceeded the design values for fiber stress in bending and approximated the modulus of elasticity values for several softwood species.

Isocyanate Binder for Composites

The studies on isocyanate binders lead by William E. Johns starting in 1981, were undertaken to investigate the effects and interactions of moisture content, press temperature, press time, and post-cure on the physical properties of isocyanate-bonded aspen flake board. A three-percent isocyanate was used. The moisture contents used were 4, 10, and 18 percent at temperatures of 300∞, 350∞, and 400∞F, and press times selected were near optimum, under cure, and over cure.

It was found that the single most important process variable was the effect of mat moisture content. In almost all cases, boards with moisture content of 18 percent were weaker than boards with either the 4 or 10 percent moisture content. The 4 percent moisture content boards were of marginally greater strength than boards with 10 percent, but the differences between the boards with 4 and 10 percent moisture content were not statistically significant.

Isocyanate-bonded aspen flake board can be made at press temperatures as low as 300∞F, given adequate press time. The difference between an under cured and an adequately cured board can be as little as 15 seconds of press time, and appears to be a function of press temperature and moisture content. Interestingly, the temperature rise of the panel core is not, by itself, a good

indicator of rate of bond development. Post-cure treatments of high temperature pressing for extended times had little effect on board quality. This research in the United States was some of the first to lead to the greater use of isocyanate in North America and lead to research on the use of isocyanate in MDF.

In this work, medium density fiberboard (MDF) was prepared with 4-4-feet Diphenylmethane Diisocyanate (MDI). Commercially prepared fiber was blended with either 3 or 6 percent MDI, and formed into 0.75-inch thick boards at 0.70 g/cc. Experimental factors are resin type (neat, emulsifying), closing rate (45 sec., 120 sec.), press time (5 to 8 min.), press temperature (300∞F, 330∞F, 360∞F), and moisture content (4 and 10 percent). Results showed no difference between neat and emulsifying resin. At 10 percent moisture content, 330∞F, 3 percent resin, and press times in excess of 4.5 minutes, panel performance did not significantly improve.

Previous work with flake board has shown that moisture contents in excess of 10 percent were detrimental to board performance. Typically, 4 percent moisture content was indicated as being marginally better than 10 percent. With MDF, 4 percent moisture content levels were found to be significantly lower than 10 percent. Also of interest was the effect of press closing rate. Invariably, the faster closing rate yielded boards with higher bending and internal bond values. Density profile studies did not show significant differences between panels prepared with the fast or slow closing rate, or with the 4 or 10 percent moisture content levels. It is speculated that this unusual behavior is related to the relationship between the chemical reactivity of the resin, the mat moisture, and the surface areas of furnish.

Composition Board from Standing Dead White Pine and Dead Lodgepole Pine

In work sponsored by the U.S. Forest Service, and lead by Tom Maloney, John Talbott, M.D. Strickler, and Martin T. Lentz, dead trees of western white pine (Pinus monticola) and lodgepole pine (Pinus contorta) were studied. Generally considered unacceptable for plywood and with limited acceptance for lumber, these resources constitute an important potential resource for wood construction materials in the form of dry-process composition boards. It was demonstrated that, even after standing dead many years, the wood of such trees changed very little from that of live trees in characteristics important to composition board manufacture. A wide spectrum of desirable particles, ranging from flakes to fiber, can be produced. Compatibility with commercial composition board resin appears to be retained, as determined by chemical tests of the wood and internal-bond strength tests.

It was concluded that the dead material of both white pine and lodgepole pine could be used effectively in various types of composition board. Some minor refinements of board producing parameters are needed to optimize commercial board technology. Suitable properties were found in almost all cases studied. Lodgepole pine composition boards had relatively poor linear expansion, exceeding commercial standards, except in flake boards. It appeared that this was due to a species effect.

Of the particles studied, hammermilled, ring-cut flakes, atmospheric and pressure-refined fiber appeared to be best. Drum-cut flakes were difficult to glue because of apparent surface quality damage due to flaking dry wood.

As part of the Forest Service program, dimension lumber from dead lodgepole and western white pine was evaluated nondestructively using the WMEL developed E-computer. Test results showed no marked differences between lumber cut from dead trees and lumber cut from live or green trees.

Prior to this composite research and research using NDT to evaluate lumber quality, dead timber was not considered useful. At times, the purchaser of federal timber would be paid to remove the dead timber when harvesting the green timber. Thus, they were getting raw material of a negative value. Upon the completion of the WMEL research and research at other laboratories, dead timber in a sale is now sold the same as green timber.

Stored Heat System for Gluing

In the 1950s, the stored heat system for rapid curing of glue joints was developed in the Laboratory. In this system, heat is applied to wood that is about to be glued together for a few seconds. The heat level is in the range of 450∞ F and is applied for a few seconds, and because wood is a good insulator, it holds the heat once it has been applied. Glue is then applied and the pieces are clamped and held for a few more seconds. During the clamping period, the heat stored in the wood cures out the glue. Thus, the gluing operation is reduced, from what typically took hours with structural glues such as phenolic, to seconds.

The invention, Patented by G. Marra, was assigned to the Potlatch Corp. in the 1950s. Potlatch developed a continuous pressing system to manufacture a 2 by 6-inch (actual thickness 2-1/4 inch) tongue, and groove-decking material they trade named "Lockdeck". Infrared heaters applied heat to a nominal 1 by 6-inch lumber passing through the continuous system. Once the heat was applied, glue was spread on the wood surfaces, and the 1 by 6-inch pieces passed through a continuous press to complete the process.

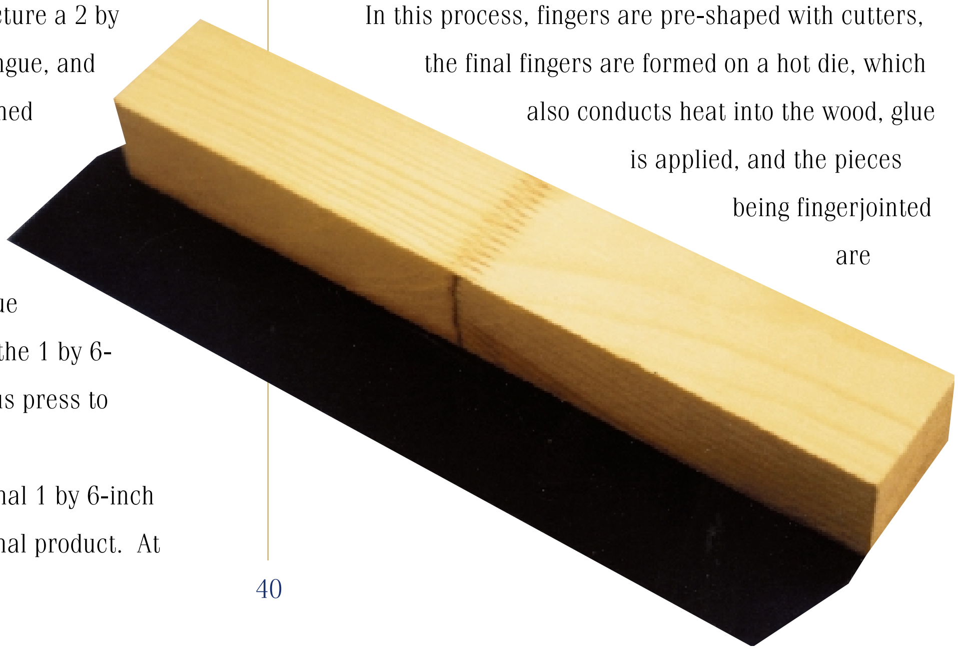
In this system, three pieces of nominal 1 by 6-inch lumber were glued into a very stable final product. At that time, there wasn't a great market for the 1 by 6-inch lumber that resulted from normal sawmill operations, thus the laminating process upgraded it r into a higher quality final lumber product. To make such a product out of solid wood, about 13 percent of the wood is lost when milling the tongue and groove. However, the laminated product was made by offsetting the inner 1 by 6 to make the tongue and groove. Thus, only a small amount of cleanup milling was needed to finish the tongue and groove.

This Potlatch plant operated in Lewiston, Idaho for about 35 years. The plant was sold recently to Shelton Structures in Chehalis, Washington where it is in operation today. Considering the savings on material alone, 13 percent from eliminating the milling of the tongue and groove, the process was a great financial success. Weyerhaeuser Company adopted this process for producing a similar product for a number of years.

Impression Fingerjointing

Impression finger jointing invented by M.D. Strickler is a method of end gluing lumber that employs a heated die to form joint ends. The die-forming operation develops densified fingers with parallel-grain surfaces. Furthermore, fingers are very short and a minimum of wood waste, and fingertips are thinner than conventional, machined finger joints.

In this process, fingers are pre-shaped with cutters, the final fingers are formed on a hot die, which also conducts heat into the wood, glue is applied, and the pieces being fingerjointed are



clamped together. The stored heat in the fingers quickly cures the glue. The whole process could be completed in less than 15 seconds on a production line. Several pieces can be made at one time by stacking pieces to be fingerjointed.

Pilot scale research demonstrated the feasibility of impression finger jointing with a pre-shaping operation for producing uniform high strength end joints in Douglas fir and western larch. Such joints meet the most stringent code requirements for strength of structural end joints. In addition, satisfactory end joints may be produced without pre-shaping in low-density softwoods for applications in which maximum joint strength is not required. This development was used extensively in commercial plants for a number of years.

End gluing of green lumber in the sawmill offers several distinct advantages for mill operation, including elimination of sorting to length before drying salvage of green shorts and reduction of green trim waste. Gluing of lumber while it is green, however, is not practical with present wood adhesives and conventional gluing systems.

In research led by M.D. Strickler during the 1970s, it was found that the impression finger jointing process is suitable for end gluing of green lumber. This process, as noted, employs a hot die to form the finger configuration in the ends of boards to be joined. The heat from the die dries the mating wood surfaces momentarily and accelerates the initial bonding action of the adhesive. The strength of experimental joints in Douglas fir, larch, grand fir and cedar, after the wood had dried, was equal to high-quality structural end joints now being used, for example, in laminated beams. These joints would therefore be acceptable for any structural application. Durability tests further indicated that such joints would withstand severe wet-use conditions.

In research in the 1990s, considerable laboratory and simulated mill experimentation was conducted on green inland Douglas fir, lodgepole pine, coast Douglas fir and hem-fir. Three different glues, phenol-resorcinol formaldehyde (PRF), which is commonly used in structural applications, melamine, and polyvinyl acetate (PVA) were used. Final processing was conducted using a temperature of 500^0 F (the die temperature) and a holding time on the die of five seconds.

The results of this research project on impression fingerjointing of green lumber were very encouraging. Traditionally, PRF is considered the best glue for fingerjointing and lamination. In this work, it proved again to be the best. Melamine glue also performed well in the laboratory work. Statistical analysis showed no problems with gluing of material at varying moisture contents when using the PRF and melamine glues. The PVA glue did not work as well but showed some promise. All of these glues can be "fine tuned" by the adhesive companies to the optimum level for a particular mill and the species cut by the mill.

Glued-Laminated Douglas Fir Beams from E-Rated and Tension Proof Loaded Lumber

Tension proof loading represents an improved method of material selection for timber laminating. In a project lead by M. D. Strickler and R. F. Pellerin, 78 large laminated beams were evaluated. The material was E-rated and the critical tensile laminations proof loaded in tension parallel to grain prior to beam glue bonding. The experimental variables consisted of beam E, proof load level, and the number of lamination proof loaded.

The results were a 2400 F design stress with 1.9E beams when three laminations representing 18.75 percent of beam depth are proof loaded at 2640 psi. Three laminations should be proof loaded in high stress beams (2400 F or higher), 24 inches deep consisting of 16 laminations. Lower F values, comparable to beams made from visually graded material, could be developed with 1.9E beams by proof loading fewer laminations.

With 2.1E beams, design stresses of 2600 F and 2800 F can be obtained by proof loading three tension laminations at 3120 and 3640 psi, respectively. With 2.3 E beams, 2800 F and probably 3000 F are possible by proof loading at 3640 and 3920 psi, respectively. Consequently, significant improvements in allowable design properties result from proof loading and E-rating in comparison with conventional visual grading methods.

Material saving on the order of 10 percent was possible through higher stiffness and F values compared with those used at the time of the research. A proof load breakage loss of 0.5 to one percent of beam material occurs with this method. This research led to a patented system for tensile E-rating, tensile proof loading, and visual grading combined into one fairly simple operation. This development became an important part of the industry.

A Bending Proof-Load for Quality Assurance of Finger Joints

Finger-jointed structural lumber is widely used in the production of laminated beams. The laminations located in the tension zone of the beam are crucial to the integrity of the final beam and therefore, it is of utmost importance that joints contained in these laminations are known to be of adequate quality.

In order to insure that the joints located in the tension zone of a beam are of adequate quality, proof loading of these joints prior to being laid-up in the beam has been proposed.

The concept of proof-loading end joints in tension has been successfully demonstrated in research jointly sponsored by the National Science Foundation, the American Institute of Timber Construction, and Washington State University. The results of these research projects, published by Strickler and Pellerin, showed that significant improvements in allowable design properties could be reliably obtained from tensile proof loading and E-rating.

Also, an additional study sponsored by the American Institute of Timber Construction and reported by Pellerin showed that a bending proof of 6000 psi on fully cured joints could be used without lowering the original tensile strength of either the end-joints or the material within which the end-joints are contained.

The research was sponsored by the American Institute of Timber Construction, AITC, with cooperation from Mann-Woodlam Inc. and was designed to study the feasibility of a bending proof load applied to partially cured joints for assuring the integrity of finger joints in laminating lumber.

Evaluation of the Structural Integrity of Wooden Structures

Wood structures are subject to degradation of their structural integrity due to decay. Therefore, periodic inspection of wood structures is necessary to ensure continued performance. A method that has been successfully used for the inspection of wood structures is the inducement of a stress wave in a structural member followed by measurement of attenuation and the time required for the stress to propagate through the member. If decay is present in the member, the attenuation and propagation time of the stress wave passing through the member is increased. This increase in time in decayed wood may be as great as 10 times the propagation time for solid wood.

The stress wave concept first induces a stress wave by an impactor striking the specimen, which can be a hammer or an acoustical shock. Then accelerometers, which are coupled to the specimen, respond to the leading edge of the propagating stress wave and send a signal to a timer. A signal from the accelerometer, which is located nearest the impactor, starts the timer and subsequently, a signal from the second accelerometer

stops the timer. Thus the elapsed time for the stress wave to propagate between the accelerometers is displayed on the timer. In general terms, the faster the stress wave propagates through a specimen with the least attenuation, the better structural properties of the specimen. The device used based on the Wood Materials and Engineering Laboratory research was the Metriguard 239A Stress Wave Timer.

The Washington State University Football Stadium

Part of the WSU stadium grandstand built in the 1930s using heavy timbers was suspected to have significant decay although an engineering report stated that the grandstand was structurally sound. Significant decay was found after evaluating the grandstand with the stress wave equipment. The university was ultimately convinced that there indeed was a decay problem, which was eventually confirmed when the grandstand was dismantled. Of the original heavy timbers, only thin shells of sound wood remained and once the grandstand seats that had been acting as a stress skin were removed, the grandstand fell of its own weight. There would have been serious bodily injury if the grandstand had collapsed when several thousand people were in the stands during a football game.

Rathdrum School Gymnasium

The Rathdrum Idaho School Gymnasium was constructed with laminated timber barrel arches. Each end of the laminated arches were exposed to the weather and rested in metal stirrups fastened to a concrete pier foundation. The metal stirrups pooled water at the arch ends, and a non-breathing paint was used on the exposed part of the arches. The structure presented an ideal condition for decay, which ultimately occurred. The stress wave system was used to determine the extent of the decay in the arches and the decayed parts were removed and replaced with structurally sound material.

The TRESTLE

The TRESTLE is the largest known glued laminated structure in the world. It is located at Kirkland Air Force Base in New Mexico, USA. It was built as a test stand for aircraft weighing 550,000 pounds. It has a 50 by 394-feet access ramp and a 200 by 200-feet test platform with its top surface 118 feet above ground. The TRESTLE was built in the 1970s. In the early 1980s, the US Air Force wanted to test larger aircraft than it had before. They requested a structural evaluation of the structure and conventional means of conducting it were impossible. Therefore, the stress wave concept was used to evaluate 484 glulam members of the structure (about 5% of the total in the structure). It was found that the main framework was still sound and the exposed deck system was about 18 percent degraded. Measurements were conducted onsite and with minimum disturbance to the structure. Based on this work, the Air Force went on to expand the TRESTLE.

Piers

The stress wave method has been used to inspect the structural integrity of several piers, and is limited at present to evaluating above-water sections of piers. One example of the value of this NDT method is the evaluation of a Coast Guard pier suspected of having decay requiring repairs projected to cost several million dollars. After the pier was evaluated with the stress wave system, the repairs were completed for about $250,000 as opposed to several million dollars.

Bridges

In 1987, twelve bridges in the state of Washington were evaluated with the stress wave system. All were suspected of having significant decay; however, it was determined that only one actually had signs of decay. It is recommended to use the stress wave system to evaluate wooden bridges every three years. Further, a new wooden bridge should be evaluated upon construction to give a base line of information for future evaluations.

I-Beams

The Wood Materials and Engineering Laboratory was engaged by an industrial firm in the 1960s to develop a long span truss type system for it to manufacture. They were interested in spans ranging over 50 feet in length. Research by John Talbott resulted in the Laboratory's development of the I-Beam (now known as *I-joists* in the industry). However, the I-Beams, with a reasonable depth, could not span the distances desired by the industrial firm.

Talbott continued with his work developing many versions of the I-Beam using machine stressed lumber and lumber evaluated by the Laboratory's stress wave system for NDT. He used plywood for the webs in the I-Beams. He also developed a patented system for gluing the webs into the lumber flanges.

Approximately twelve homes were built in the Pullman community using the I-Beam concept, and one was the Maloney home in Pullman. In this home are floor joists (some spanning 28 feet); two web headers over doors and windows, a center two-web girder holding up the first floor, and roof beams used in the garage were all versions of the I-Beam. In the construction of the Kirkwood home in neighboring Moscow, Idaho, the I-Beam was used for floors and for the roof (the roof I-Beams had a slight camber so water would not pond on the roof). Finger-jointed 2 by 4's, 56 feet long were used for wall sills and plates in this home to cantilever the second floor about 12 feet out beyond the first floor.

Talbott then worked with Trus Joist in their industrial development of the I-joist as well as their system for producing laminated veneer lumber. Talbott was literally farmed out by the Laboratory to the Trus Joist operation in Boise, Idaho where he participated in this important industrial development which now claims about 30% of the house floor support market.

I-Joists

Low-Profile Wood Floor Systems

For some years, the American lumber industry was concerned about the growing use of concrete for ground floor construction in homes as noted in 1963. Wood has long been the accepted and traditional material for residential floor construction in the U.S., and the present trend towards concrete floors has resulted in a loss of market for wood estimated at two billion board feet per year.

Use of concrete floors in houses began in the South about 1940 and after the war, gradually spread farther north as improved methods of perimeter heating, edge insulation, and moisture protection were developed. Today, concrete slab constructed houses are being built in all parts of the country and account for possibly as much as half of the new housing.

In 1960, a preliminary study was sponsored by Timber Engineering Company at Washington State University to determine the reasons for this trend toward the use of slabs, and to find or develop wood floor systems that could better compete, both in performance and cost.

In 1961, the National Lumber Manufacturers Association (now the American Forest and Paper Association), through its National Wood Promotion Program, sponsored the floor study program. The program was extended to include full-scale testing of the systems developed during the preliminary study and the proving of their total performance in northern climates. This work was lead by John Talbott and the low-profile wood floor system was the result of his research.

A test house was constructed at Washington State University employing all the new design features. The normal crawl space beneath the floor was made into a plenum. A plastic ground cover was laid over the ground to prevent the entrance of moisture and to also eliminate any odor from the ground. The ground was treated with soil poison to keep out termites and other insects. This system eliminates the sheet metal ducts used in most heating and cooling systems.

Heating and cooling units can be installed in the center of the house on the main floor (only a heating unit was installed in this test house). The hot or cool air from these units is driven into the plenum under the floor. The floor is uniformly warm of cool depending on the time of year. Also, the occupant has the advantage of a resilient floor comfortable to the feet of the people in the house.

Openings are cut in the floor in appropriate places for the warm or cool air to circulate throughout the house. In many test measurements, it was found that uniform temperatures were easy to maintain throughout the house.

This work lead to promotion of this floor system by the American Plywood Association, the Western Wood Products Association, the American Wood Preservers Institute, and the Southern Forest Products Association, and the construction of many thousands of homes using it. Known as the Plen-Wood System, the NAHB Research Foundation developed a manual for constructing this revolutionary floor/heating/cooling system.

Performance of Experimental Houses Embodying Some New Concepts in Floors, Foundations, and Heating Systems

Following completion of the work on the Low-Profile Wood Floor System, further work sponsored by Potlatch Inc. was done. The foundation and flooring-system concepts previously developed promised important improvements in function and economy in comparison to current practice. With this project lead by John Talbott, WSU attempted to further demonstrate these concepts in two residences built as a part of a FHA-insured housing development. It consisted of about 120 houses of several standard plans was modified to include two combinations of the experimental features that were to be tested. The presence of adjacent houses, which are identical except for the specific experimental features, afforded more valid comparisons with conventional construction.

The overall objective of this work was to determine the practicality of combinations of several new concepts in home constructions that appear to offer the homeowner advantages in lower costs and greater comfort and convenience. The concepts evaluated and proven were:

1. Reduction of the usual “crawl space” under a wood-floored house to a non-access space with a height appropriate to its use as an air circulation plenum.
2. Total elimination of outside venting of this space.
3. Use of this space as an air circulation plenum without under-floor ducts of any kind.
4. Elimination, in houses so constructed, of the requirement for the footing depth to be below frost depth.

5. Provision of interior floor support on a system of shallow blocks set to grade in mortar on top of a continuous moisture barrier over compacted earth.
6. Construction of a foundation wall and footing of preservative-treated wood.
7. Use of prefabricated stressed-skin floor components of novel configuration developed for the sponsor by WSU.

Elastomeric Adhesives in Construction

Research lead by Robert J. Hoyle, Jr. in the 1970s analyzed the use of elastomeric adhesives in building construction. This important research by Bob Hoyle and his colleagues lead to the development of the ASTM standard governing the use of such adhesives in the construction of mobile homes. Much of the text of the standard was based on this work.

This research was conducted because elastomeric adhesives had attracted the interest of the home-building industry in field and factory applications. Their use lends versatility, strength, and economy to house structures. At the time of the research, applications for these adhesives in housing developed only a portion of the true potential of elastomers, due to a lack of information on the relation of design load stress to the basic properties of the adhesive.

The primary object of this project was to develop a design procedure that related both the elastomeric and the adhesive properties of these bonding agents to the desired performance of structural elements in various applications. Such a method would permit designs to be produced on paper and then executed in the shop or field with a high degree of reliability and confidence. Developing this procedure greatly expanded the utilization of this type of structural technology and contributed to material and labor economies in the important area of housing.

An important secondary outcome of the research was a clear definition of the properties required in elastomeric adhesives in order to function properly in different structural applications, which aided both the selection of available adhesives and in the development of new adhesives in the future.

International Trade Activities

In 1985, a legislative act led to the establishment of the International Marketing Program for Agricultural Commodities and Trade (IMPACT) at Washington State University. The Laboratory was an important part of the proposal that went from the university to the legislature and thus was part of IMPACT right at the start. At the beginning, the Laboratory drew up its role in assisting with trade in wood products. This role follows:

1. Develop professional, technical, and industrial contacts in trading countries.
2. Explore the market needs for wood products from the viewpoint of science and technology.
3. Assess the potential for exporting U.S. wood technology.
4. Assess the trading countries' culture and how this culture can be served by newer and better wood products.
5. Consider the trading countries" building codes and how wood materials must be manufactured or constructions fabricated to meet these codes.
6. Analyze the trading countries' quality concerns.
7. Develop a network of scientists, wood technologists, engineers, manufacturers, and others

Developing Wood Housing in the People's Republic of China

Photo taken by Engineering Technician, Martin T. Lentz, Construction Supervisor on this project in Bejing, China.

interested in wood products in the trading countries and in the state of Washington who are willing to work together for advancements in the use of wood materials.

Since the inception of the IMPACT program, Tom Maloney, Roy Pellerin, and Robert Tichy have visited and given presentations in Japan, Korea, China, and Taiwan as part of the Laboratory's research effort. Roy Pellerin spent time in Japan working with Japanese leaders in the use of wood in construction. Japanese, Chinese, and Korean experts have spent time at the Wood Materials and Engineering Laboratory as part of the IMPACT program.

Two major programs for developing wood housing in China and Korea have been completed. Recently, Robert Tichy has been working in these two countries assisting them in developing building codes appropriate for wood construction.

The Laboratory is also member of the Evergreen Partnership in Washington, which is a non-profit state organization formed to help members succeed in international trade. Tom Maloney has participated as part of international missions to Japan on behalf of the Partnerships effort. Also, numerous groups from other countries have visited the Laboratory, or Faculty from the Laboratory has made presentations to such groups in the Seattle and Tacoma area.

Bob Tichy in China, 1993.

Effect of Locality of Growth on Certain Strength Properties of Douglas fir

The western forest products industry, through the Western Pine Association, sponsored a massive research project on certain strength properties of Douglas fir. By the late 1950s, the industry was well into cutting the second growth forest and there was some question as to whether the strength properties found originally in the lumber from the virgin forest logs, was the same or greater than in the lumber from second growth logs. Douglas fir was categorized for strength at the time as coast, intermediate, and Rocky Mountain types. The coast fir had the highest strength values and the Rocky Mountain type had the lowest values.

The research was conducted jointly by the Wood Technology Section at Washington State University (under Arthur F. Noskowiak), and the Forest Research Laboratory at Oregon State University (under James D. Snodgrass). The purpose of this research was to determine the strength properties of the "new" Douglas fir lumber being produced by about 1600 sawmills.

Major strength properties and specific gravity were determined and compared for clear, unseasoned wood of Douglas fir grown in the Coast and Inland regions. Together, these regions comprise the commercial range of this species in 10 far-western states of the United States, excluding Alaska. The range includes trees of the typical variety of Douglas fir, Pseudotsuga menziesii var. menziesii and the Rocky Mountain variety, P. menziesii var. glauca (Beissn) Franco.

Specimens for testing were obtained from sawmills by using techniques of probability sampling, which was a departure from the usual standard procedure of gathering bolts from trees in the forest for determining average strength of a species of timber.

Methods for picking specimens at each sawmill resulted in random selection of one piece from a log, and probably only one from a tree. Efficiency and precision were achieved by stratifying the commercial range of Douglas fir into 19 more or less homogeneous areas for sampling. The Coastal region included 10 such areas and the Inland region had nine. The number of samples (sawmills) allocated to each area in a region was proportionate to estimated volume of Douglas fir lumber produced in the area, relative to estimated total production in the region. Allocation within areas was proportionate to lumber production by mills in six classes delineated according to mill production capacity. A total of 405 sawmills were sampled in this study. These were selected according to a predetermined plan from the 1600 mills known to be cutting this species, such that a random assignment occurred in each area-mill-size stratum.

Standard testing procedures were followed as much as possible. Estimates of means and measures of dispersion were obtained for specific gravity, moduli of elasticity, and rupture in static bending, and crushing and shearing strengths parallel-to-grain. Estimated mean values of specific gravity and major strength properties were greater for Coastal Douglas fir than for Inland fir, except in shearing strength. Differences between means for the two regions were statistically significant for all properties as determined by appropriate analysis.

The critical question of whether observed differences were sufficiently large enough to be of practical importance relative to specification and use of Douglas fir wood were decided by agencies concerned with such matters.

Performance Modeling and Reliability Based Analyses of Horizontally Laminated Timber Beams

An important contribution to the glulam beam industry was the development of a stochastic model (STOCHLAM) for simulating the structural performance of horizontally laminated timber beams. The algorithms for the model were developed at two levels: at the laminating lumber level and at the beam level. At the laminating lumber level, seven random variables were needed for describing the material properties. These variables were: the joint location; the localized modulus of elasticity; the localized clear-wood strength; the knot location; the knot size; the joint modulus of elasticity; and the joint strength. The correlation of these properties was given important consideration. The beam level algorithms required a total of five random variables that were derived from the lumber level random variables.

An important aspect of the STOCHLAM model is that it incorporates the principles of the deterministic IK/IG model within a probabilistic context. Failure models incorporated delamination of the outer tension laminations through application of progressive failures within a probabilistic context. The STOCHLAM model was incorporated within two computer programs, one of which uses the transformed section method of structural analysis and the other, the finite element method of structural analysis. The STOCHLAM model has been validated with respect to a set of 98 glulam beams made of Douglas fir and southern pine species. The beams varied in sizes an din material grades. The simulated strength and stiffness data were found to be in good agreement with the test data. The validated STOCHLAM model was subsequently used in a series of simulation studies. Simulated data were then used in performing reliability analysis under both static and dynamic loading.

Laminated Beam under Test

Composite Reinforcement of Wood Baseball Bats

This is a collaborative project between the WSU Wood Materials and Engineering Laboratory and TriDiamond Sports, Inc. that is targeted at improving the durability of wood baseball bats. Metal bats were approved for collegiate competition primarily for economic reasons associated with wood bat replacement. Traditional wood bats tend to suffer damage due to off center hits, i.e., near the handle or tip. Broken bats, in turn, represent a hazard to players and an expense to teams. Metal bats respond differently than wood, however, imparting greater ball velocity, which skews the competitive advantage toward the batter, increases the risk to infield players, and forces the batter to relearn batting skills as they transition from amateur to professional play.

The goal of the project is to develop a reinforced laminated wood bat that conforms to Major League Baseball regulations and exhibits superior strength and durability over solid wood bats. We will utilize finite element modeling to study the failure mechanisms in bats under static and dynamic loading, and to identify promising fiber reinforcement technologies. Prototype bat designs will be fabricated and tested at WSU, and compared with finite element predictions. Automated fiber and matrix processing systems will be evaluated for eventual deployment in TSI's manufacturing operations. Finally, optimal reinforced bat designs will be evaluated and submitted for MLB approval.

Engineered Wood Composites for Naval Waterfront Facilities

In 1997, the Office of Naval Research awarded $2.5 million of a three-year $7.5 million contract to the multidisciplinary team of Washington State University's Wood Materials and Engineering Laboratory, the University of Maine, the New Mexico Institute of Mining and Technology, Michigan Technological University, Amoco

Polymers, Inc. of Georgia, and Naval Facilities Engineering Service Center (NFESC) in California. The team will use the funds to develop high performance wood-based composites for Navy shore facilities. While approaching this goal, the broad objectives are:

1. Develop cost effective processing techniques to diversify existing wood/thermoplastic composites and integrate carbon-fiber reinforcement.
2. Optimize the structural systems to guide design of the structural components.
3. Investigate recycling methods to clean and utilize creosote treated piles.
4. Demonstrate applications of commercial wood/thermoplastic composites as a replacement for current shore facility components.

The engineered pier components made of thermoplastic wood may supplant the need for creosote or pesticide-treated timber. They will be used for pilings, wales, chocks and camels for a new generation of concrete pier fendering systems to replace decaying wood in the majority of the U.S. Navy's waterfront facilities. As many as 8,000 tons of timber could be removed each year as the Navy transitions these timbers that have been treated with creosote, pesticides, preservatives or other environmentally compromising substances. As much as $1 billion in structural deficiencies affect current Navy shore facilities, most of which were established in the 1940s.

With success, the results of this research will be cleaner harbors and more durable piers that can handle increased loads, be longer lasting, and require less maintenance. WSU will use $1 million of the initial funding for project startup and testing. The thermoplastic wood composite is essentially comprised of ground up plastic and sawdust reinforced with carbon fiber for strength. The objectives are to create cost-effective, stiff and strong yet flexible, long lasting and environmentally safe timbers approximately 3 to 4 feet in diameter, which

also can hold nails and have minimal water absorption and swelling.

Similar engineered materials are emerging on the commercial market in such applications as doors and windows, and siding, flooring, and decking. This scientific research and technology transfer will take the material to a major load-bearing application, which is expected to be patented. Testing will include economic feasibility studies, optimizing shapes for particular functions, and the feasibility of recycling the old chemically treated timbers back into the product.

The technology transfer is expected to result in additional industrial uses for carbon fiber. Amoco Polymers, Inc., the largest producer of carbon fibers in the U.S., and a leading polymer producer in the world, will contribute carbon fibers (manufactured at its South Carolina plant), polypropylene and some extrusion equipment for the project. The company will help develop and test the materials both in Alpharetta, Georgia, and at a temporary site at Pullman's Research and Technology Park.

NFESC, at Port Hueneme just north of Los Angeles, will play a key role in transferring the technology to Naval waterfront sites. It will define Navy performance requirements, determine loading characteristics, model structural performance, and provide a demonstration model of the fendering system at its advanced waterfront technology test site.

Michigan Tech researchers specialize in the bioremediation of creosote-treated woods, and will focus on the recycling component to reuse creosote-treated wood removed in the project. The chemistry faculty at New Mexico Tech will apply thermoplastic grafting of wood fibers and use a coupling agent to recycle and form construction materials for the waterfront structures. The technology developed for grafting wood or making tit compatible with other materials can be used by the Navy to convert its old structures. Strandex Corp. of Wisconsin developed the product experimentally using extrusion and holds its patent.

Legislators sponsored this joint effort that has combined the top researchers, industry practitioners, and Navy operations in this field in the country. Principal political sponsors were Washington's George Nethercutt, Adam Smith, Doc Hastings, Norm Dicks, Slade Gorton, and Patty Murray; and South Carolina's Strom Thurmond and John Spratt. Nethercutt said the developing composite "has significant promise for marine applications, allowing the Navy to replace decaying pilings with strong, water-resistant material free of creosote, which will improve the water quality in our harbors."

Evaluation of Timber Bridges Using Stress Wave Technology

The focus of this research was to develop stress wave nondestructive evaluation (NDE) techniques for determination of the in-place properties and strength of timber bridge components. Current inspection procedures for timber bridges is often an art involving visual assessments of the degree of decay and mechanical damage and of the extent to which the deterioration has penetrated into hidden regions of the structure. NDE techniques utilizing stress waves has successfully been used to improve the assessment of the integrity of wood structures.

Marty Lentz examining a thermoplastic composite emerging from the extruder, 1999.

The research results show improved stress wave velocity methods that more accurately quantify the residual strength of wood members and the timber bridges themselves. These improved methods have been applied to wood bridges and piles that had been targeted for replacement. Stress wave evaluations were performed on bridges in-place, followed by destructive testing of elements of the bridges and piles after demolition to verify the NDE conclusions. While the application of the stress wave methods in this study is for softwood timber bridges, the methods are applicable to all timber bridges.

Based on this successful research, a comprehensive handbook for bridge inspectors, providing guidelines on the use, application, and interpretation of stress wave methodology for locating and defining areas of deterioration in timber bridges is now under development.

Closing

The first 50 years of the Laboratory's operation have passed quickly. However, this 50-year period in the history of the forest products industry has been momentous. Almost all of the development of the various composites has occurred in this time period. Millions of tons of product have been made from what was previously wasted. New methods of gluing and the development of non-destructive means of evaluating the strength and quality of forest products have greatly benefited the industry. Newly engineered building components and building systems have further advanced the forest products industry. The Wood Materials and Engineering Laboratory has been a significant player in all of these developments. Further, graduates have been educated to become significant leaders in the industry, universities, and government laboratories. Also, scientific and technical information has been provided through the work in the Laboratory and by means of sponsoring significant meetings, conferences, and symposia for the betterment of the industry and society as a whole.

Moreover, all of the people involved in the Laboratory over the past 50 years have worked well together providing the research information noted above. They can be proud of their work and their significant contributions.

And lastly, everyone, past and present in the Laboratory, recognizes that they could not have made these contributions without the support of their many colleagues throughout the worldwide forest products industry. These colleagues can also be proud of their contributions to the success of the Washington State University Wood Materials and Engineering Laboratory.

Tom Maloney, Charles Morschauser, and George Marra, reviewing the Proceedings of the Second Particleboard Symposium, *1969.*

Gil Anderson operating Drum Flaker

Medium Density
Fiberboard
(MDF)

Composite
Panels