

BIOGRAPHIES & ABSTRACTS

WOOD ADHESIVES 2005

November 2-4, 2005
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San Diego, California, USA

Sponsored by the USDA Forest Service, Forest Products Laboratory
in cooperation with the Forest Products Society, Adhesion Society,
International Union of Forestry Research Organizations (IUFRO),
Japan Wood Research Society, The Adhesive and Sealant Council,
Inc. (ASC), and *Adhesives & Sealants Industry Magazine*.

PLANNING COMMITTEE

Symposium Chair

Charles R. Frihart
Project Leader, Wood Adhesives Science & Technology
USDA Forest Service
Forest Products Laboratory
Madison, Wisconsin, USA

Dr. Charles Frihart is Project Leader of Wood Adhesives Science & Technology at the USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. He received a B.S. degree in Organic Chemistry from the University of Wisconsin-Madison in 1969. He received a M.S. degree in 1971 and Ph.D. in 1973 from the University of Illinois-Urbana/Champaign with a major in Bio-Organic Chemistry. He worked in industry for 25 years developing new products and processes for a variety of markets, before joining the Forest Products Laboratory. He currently leads a group of chemists and engineers examining adhesive interactions with wood, bond durability for bonded wood, and methods for determining bond formation and failure. He also helps direct research programs with outside organizations. He is active in ASTM International, Adhesion Society, and Forest Products Society. He obtained 29 patents, published 40 articles, delivered 17 presentations, and has received several honors and awards.

Planning Committee Members and Session Moderators

Arthur B. Brauner
Executive Vice President
Forest Products Society
Madison, Wisconsin, USA

Art Brauner received B.S. and M.S. degrees in Wood Science & Technology from the University of Michigan. He has been Executive Vice President of the Forest Products Society since 1976. He came to the Society in 1968 as Editor of Publications and Director of the Society's computerized information retrieval system. Previously, he was on the staff of West Virginia University's School of Forestry as a Research Assistant and Assistant Professor.

Alfred W. Christiansen
Retired Chemical Engineer
USDA Forest Service
Forest Products Laboratory
Madison, Wisconsin, USA

Dr. Alfred Christiansen is a Retired Chemical Engineer, USDA Forest Products Laboratory (FPL), Madison, Wisconsin. He received a B.S. in Chemical Engineering from the University of Illinois, a M.S. in Engineering from Case Institute of Technology (Cleveland, Ohio), and a Ph.D. in Macromolecular Science from Case Western Reserve University (Cleveland, Ohio). As a Post-Doctoral Research Fellow at the University of Liverpool (U.K.), he studied fracture processes in fiberglass composites. After his post-doctoral, he developed adhesives for the Exxon Chemical Company, Plastics Division, from polyolefin copolymers for 2 years. In 1975, he joined FPL as a Chemical Engineer.

Manfred Dunky
Application Manager, Europe PB&MDF + OSB
Dynea Austria GmbH
Krems, Austria

Dr. Manfred Dunky is Application Manager, Europe PB&MDF + OSB at Dynea Austria GmbH in Krems, Austria. Previously, he was Technical Service (including European responsibility) for panelboard resins and partly sales, Dynea Austria (formerly Krems Chemie), Krems, Austria; Applied Development, PCD, Schwechat, Austria; Technical Service, Krems Chemie, Krems, Austria; and Assistant, University of Leoben, Leoben, Austria. He received a

Universitaetsdozent degree from the University of Natural Resources & Applied Life Sciences, and Dr. mont. and a Dipl.-Ing. degrees from the University of Leoben.

Charles E. Frazier
Professor and Director,
Wood-Based Composites Center
Department of Wood Science & Forest Products
Virginia Tech
Blacksburg, Virginia, USA

Dr. Charles Frazier is a Professor in the Department of Wood Science & Forest Products and Director of the Wood-Based Composites Center (WBC) at Virginia Tech, Blacksburg, Virginia. He received a B.S. in Forest Products from Virginia Tech in 1985, along with a minor in chemistry with emphasis in polymer science. He subsequently moved to Seattle, Washington and studied the chemistry and biochemistry of wood extractives while earning a M.S. at the University of Washington. He returned to Virginia Tech and received a Ph.D. in Wood Science and Forest Products. He accepted a faculty position at Virginia Tech in October 1992. Dr. Frazier works in the area of adhesion and polymer science with an emphasis on wood-based composite materials. He is active in the WBC, the Sustainable Engineered Materials Institute, the Center for Adhesive and Sealant Science, and the Polymer Materials and Interfaces Laboratory. His areas of expertise include wood adhesion, characterization of the wood/adhesive interface, wood rheology, thermoplastic and thermosetting adhesives for wood, and fracture testing of bonded wood.

Douglas J. Gardner
Professor of Wood Science
Department of Forest Management
Advanced Engineered Wood Composites Center
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Dr. Douglas Gardner is Professor of Wood Science in the Department of Forest Management and the Advanced Engineered Wood Composites Center at the University of Maine, Orono, Maine. Prior to coming to Maine, he was Interim Director of the Institute of Wood Research (1997-1998) and Associate Professor at Michigan Technological University (1995-1998). He served on the Faculty of Wood Science at West Virginia University (WVU) from 1988-1994, and was Post-Doctoral Research Associate at Auburn University (1986-1988). Dr. Gardner's research, teaching, and service activities focus on polymer and interfacial science aspects of wood-polymer hybrid composite materials. He is also involved in research in the areas of adhesion and surface science, extruded wood plastic composites, and the analysis of volatile organic compound emissions from wood composite processing. He has coauthored over 95 technical publications and 90 research presentations. Dr. Gardner is a member of the Forest Products Society, Adhesion Society, American Chemical Society, and Vice President of the Society of Wood Science & Technology. He serves on the editorial advisory board of the *Journal of Adhesion Science & Technology*. He has been recognized for his work by receiving the 1992 Cahn Award and appears in the *4th Edition of Who's Who in Science & Engineering*. He is an Honorary Member of the Union of Wood Processing Manufacturers of the Slovak Republic. He received a B.S. and Certificate of Advanced Study from the University of Maine, and a Ph.D. from Mississippi State University.

Leslie H. Groom
Project Leader
USDA Forest Service
Southern Research Station
Pineville, Louisiana, USA

Dr. Leslie Groom is a Project Leader at the USDA Forest Service, Southern Research Station in Pineville, Louisiana. As Project Leader of Utilization of Southern Forest Resources, his responsibilities include planning research for himself and four other scientists focusing on the efficient use of raw materials removed from southern forests. The research deals primarily with composites and material characterization. He received a B.S. in Wood Science from Colorado State University, and a M.S. and Ph.D. from Oregon State University.

Chung-Yun Hse
Research Forest Products Technologist
USDA Forest Service
Southern Research Station
Pineville, Louisiana, USA

Dr. Chung-Yun Hse is a Research Forest Products Technologist in the Utilization of Southern Forest Resources Unit at the USDA Forest Service, Southern Research Station, Pineville, Louisiana. His responsibilities include research in the application of resin and composite technology to advance the use of wood fiber resources into high performance composite products. He received a B.S. in Forestry from National Chung-Hsing University (Taichung, Taiwan), a M.S. from Louisiana State University, and a Ph.D. in Wood Science & Technology from the University of Washington.

Fred A. Kamke
JELD-WEN Professor of Wood-Based Composite Science
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Corvallis, Oregon, USA

Dr. Fred Kamke is a JELD-WEN Professor of Wood-Based Composite Science in the Department of Wood Science & Engineering at Oregon State University, Corvallis, Oregon. His responsibilities include research and teaching. Previously, he was Director, Sustainable Engineered Materials Institute, Virginia Tech; Director, Wood-Based Composites Center, Virginia Tech; and Professor, Virginia Tech. He received a B.S. from the University of Minnesota, and a Ph.D. from Oregon State University.

Marie-Pierre G. Laborie
Assistant Professor
Wood Materials & Engineering Laboratory
Washington State University
Pullman, Washington, USA

Dr. Marie-Pierre Laborie is an Assistant Professor of Civil & Environmental Engineering in the Wood Materials & Engineering Laboratory at Washington State University, Pullman, Washington. She received an Engineering degree from the University of Nancy I, and a Ph.D. in Wood Science & Forest Products from Virginia Tech. Her research interests include: Wood adhesion; polymer viscoelasticity; morphology and properties of wood/polymer interphases; and bio-based polymers. Her teaching areas include: Advanced topics - polymer and adhesion science; and solid state NMR characterization of polymers. Previously, she was Graduate Research Assistant, Wood Adhesion Laboratory, Virginia Tech; Visiting Scientist, Swedish Research Institute for Pulp & Paper; and Quality Assurance Engineer, Menuiseries Lapeyre.

Robert J. Moon
Materials Research Engineer
USDA Forest Service
Forest Products Laboratory
Madison, Wisconsin, USA

Dr. Robert Moon is a Materials Research Engineer at the USDA Forest Service, Forest Products Laboratory in Madison, Wisconsin. His responsibilities include directing fundamental research on the mechanical behavior of wood adhesive systems subjected to environmental changes and in-service loading conditions and linking this to the durability of the bond assembly; and directing fundamental research on the mechanical behavior of localized wood properties along the bond-line and interphase regions on the resulting strength and fracture behavior of bonded assemblies. Previously, he was a Visiting Researcher, University of New South Wales; Australian Research Council Post-Doctoral Fellow, University of New South Wales; and Post-Doctoral Research Associate, University of New South Wales. He received a B.S. in Metallurgical Engineering from the University of Wisconsin-Madison; and a M.S. in Metallurgical Engineering and Ph.D. by Research in Materials Engineering from Purdue University.

Douglas R. Rammer
Research Engineer
USDA Forest Service
Forest Products Laboratory
Madison, Wisconsin, USA

Doug Rammer is a Research Engineer at the USDA Forest Service, Forest Products Laboratory (FPL) in Madison, Wisconsin. Mr. Rammer began working at FPL in 1991 with responsibility for research and development efforts aimed at enhancing the engineering uses of wood-based materials. During his tenure, he has made outstanding contributions to the field of wood engineering in the following areas: 1) connection design, 2) strength of notched beams, 3) column design, and 4) shear strength of beams. By focusing his work on challenging issues in wood engineering, his research has significantly influenced development of the *National Design Specification® for Wood Construction (NDS®)* and *AF&PA/ASCE 16 Standard for Load and Resistance Factor Design (LRFD) for Engineered Wood Construction*. He has also been an active participant in Committees responsible for development of the *NDS, AF&PA/ASCE 16*, and *ASTM* standards for wood. Mr. Rammer is the recipient of the Forest Products Society 2005 Wood Engineering Achievement Award for outstanding young engineer. The Young Engineer Award honors an individual who has provided a valuable contribution to the field of wood engineering.

Richard M. Rammon
Group Leader and Technology Manager
Georgia-Pacific Resins, Inc.
Decatur, Georgia, USA

Dr. Richard Rammon is Group Leader and Technology Manager at Georgia-Pacific Resins, Inc. in Decatur, Georgia. He is responsible for technical and administrative management of R&D activities for wood adhesives; administrative oversight for wood adhesives R&D staff; specific technical management of UF resin product development efforts and support of new product development in engineered wood and wood composites. Previously, he was Senior Research Scientist, Georgia-Pacific Resins, Inc.; Development Chemist, Georgia-Pacific Resins, Inc.; and Chemist, Chembond (Neste). He received B.S. and M.S. degrees from the University of Wisconsin, and a Ph.D. from Washington State University.

Timothy G. Rials
Professor and Director
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University of Tennessee
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Dr. Timothy Rials is Professor and Director of the Forest Products Center, University of Tennessee, Knoxville, Tennessee. Dr. Rials became an Assistant Professor in the Forest Products Laboratory at University of California in 1986. He joined the USDA Forest Service, Southern Research Station as a Research Physical Scientist in 1988 and was promoted to Project Leader/Research Scientist in 1996. He then joined the Department of Forestry, Wildlife and Fisheries at the University of Tennessee, and became the Director of the Tennessee Forest Products Center in 2001. His research interests include structure and properties of wood/polymer interfaces, raw material assessment and process monitoring using spectroscopy, and cure analysis of thermosetting polymers. He received a B.S. in Forestry & Forest Biology from Mississippi State University, and a M.S. and Ph.D. in Wood Science & Technology (polymer chemistry emphasis) from Virginia Tech.

Rob Schmidt
Senior Vice President, Market Applications
Dynea North America
Mississauga, Ontario, Canada

Dr. Rob Schmidt is Senior Vice President of Market Applications, Dynea North America, Mississauga, Ontario, Canada. He is responsible for short and long range business and research planning at Dynea North America, a subsidiary of the world's largest producer of formaldehyde resins. He received his Ph.D. degree in 1998.

Ken A. Van Langenberg
Team Leader, Adhesives & Composites
Ensis - The joint forces of CSIRO and Scion
Clayton South, Victoria, Australia

Dr. Ken Van Langenberg is Team Leader, Adhesives & Composites at Ensis - The joint forces of CSIRO and Scion, Clayton South, Victoria, Australia. As Team Leader, he oversees a number of different research projects within his team. His main areas of interest include new phenolic technologies for engineered wood products and composite panel applications; improvements in performance of ultra-low formaldehyde emitting binder systems; new composite product development and determining the durability of new adhesive systems for Australian conditions and wood species. As well as in-house research for Ensis, his team is also involved in commercial work for the industry. Some of the work they have recently undertaken has included studying the efficacy of preservative treatments for EWP and composite panels (in collaboration with the Ensis Preservation group) and studying MDF processing conditions utilizing the two Ensis MDF pilot plant facilities. Previously, he was Senior Research Scientist, Value-Added Wood Products Group, CSIRO Division of Forestry & Forest Products; and Development Chemist, Orica Adhesives & Resins. He received a B.S. and Ph.D. in Chemistry from Monash University, Melbourne, Victoria, Australia.

Magnus E.P. Wälinder
Head, Material Science & Product Development
SP Trätekt, Swedish National Testing & Research
Institute, Wood Technology, Stockholm, Sweden
Assistant Professor, Biofibre Materials Centre
KTH-Royal Institute of Technology
Stockholm, Sweden

Dr. Magnus Wälinder is Head of Material Science & Product Development, SP Trätekt, Swedish National Testing & Research Institute, Wood Technology, Stockholm, Sweden, and Assistant Professor, Biofibre Materials Centre, KTH-Royal Institute of Technology, Stockholm, Sweden. Previously, he was a Research Scientist, Trätekt, Swedish Institute for Wood Technology Research; Post-Doctoral Research Associate, Advanced Engineered Wood Composites Center, University of Maine; and Research Associate, Teaching Assistant/Graduate Student, and Research Engineer, Division of Wood Technology & Processing, KTH-Royal Institute of Technology. He received a M.S. in Mechanical Engineering, Licentiate of Engineering degree, and Ph.D. from KTH-Royal Institute of Technology.

Michael P. Wolcott
Louisiana-Pacific Professor and Research Director
Wood Materials & Engineering Laboratory
Washington State University
Pullman, Washington, USA

Dr. Michael Wolcott is a Louisiana-Pacific Professor and Research Director of the Wood Materials & Engineering Laboratory at Washington State University (WSU), Pullman, Washington. He received a Ph.D. in Materials Engineering Science from Virginia Tech in 1989. Before coming to WSU, Dr. Wolcott was an Associate Professor of Wood Science at West Virginia University. His research emphases include wood composites design, wood-plastic composites, wood-polymer interaction, viscoelasticity, and adhesion. Dr. Wolcott has received numerous honors including two George Marra Awards for excellence in wood research, Wood Award for excellence in graduate research, and the Cahn Award for research in dynamic contact angle analysis. He has served on the Board of Directors for the Forest Product Society and the Society of Wood Science & Technology, Chair of the National Planning Committee for Forest Products Research, and Program Manager for the USDA National Research Initiative. Dr. Wolcott's research is published in over 85 manuscripts appearing in journals, books, and proceedings, and he regularly presents his work internationally. He has served as principal investigator on over 40 academic research projects totaling more than \$16.5 million USD. He has managed over 75 industrial product research and development projects with more than 30 companies. In addition to research, Dr. Wolcott teaches undergraduate and graduate courses in

the Department of Civil & Environmental Engineering. These courses include wood composites design and production, dynamics, remedial and advanced mechanics of materials.

SESSION SPEAKERS AND POSTER PRESENTERS

Eka Mulya Alamsyah
Ph.D. Student
Faculty of Agriculture
Shizuoka University
Shizuoka City, Japan

Eka Mulya Alamsyah is a Ph.D. Student in the Faculty of Agriculture, Shizuoka University, Shizuoka City, Japan. He is currently studying the bondability of tropical fast-growing tree species; especially focused on collecting data of the bondability of wood species from Indonesia. Previously, he was a Lecturer in the Department of Forest Products Technology, Faculty of Forestry, Winaya Mukti University, Sumedang, Indonesia. He received a B.S. from Bogor Agricultural University, Bogor City, Indonesia; and a M.S. from Shizuoka University, Shizuoka City, Japan.

Marina A. Alipon
Scientist I
Forest Products Research & Development Institute
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Dr. Marina Alipon is a Scientist at the Forest Products Research & Development Institute in Laguna, Philippines. Her responsibilities include conducting independent/original research on wood science and technology and writing reports; render technical assistance and consultancy to various clientele (timber industry sector); and attend to relevant meeting, conferences, and seminars. She received a B.S. in Forestry from Gregorio Araneta University, Manila, Philippines; and a M.S. in Forestry (Wood Science) and Ph.D. in Forestry from the University of the Philippine, Laguna Philippines.

James F. Beecher
Group Leader
USDA Forest Service
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Dr. James Beecher is a Group Leader at the USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. As Group Leader, his responsibilities include working administrator for the Analytical Chemistry & Microscopy department. Previously, he was Visiting Associate Professor, Miami University; Staff Chemist, International Paper Company; Staff Scientist, GenCorp Research; and Senior Research Associate, Northwestern University. He received a B.S. in Chemical Engineering from Christian Brothers University (Memphis, Tennessee), and a Ph.D. in Physical Chemistry from the University of Notre Dame (South Bend, Indiana).

Ronny Bredesen
Research Scientist, Wood & Specialty Adhesives
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Ronny Bredesen is a Research Scientist, Wood & Specialty Adhesives at Dynea ASA in Lillestrøm, Norway. He is responsible for the application testing laboratory, Engineered Wood Solutions, Dynea ASA Europe. He received a M.S. in Wood Technology from Norwegian University of Life Sciences, Aas, Norway.

Robert A. Breyer
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Dr. Robert Breyer is Senior Technology Manager, Wood Adhesives at Georgia-Pacific Resins, Inc. in Decatur, Georgia. His responsibilities include senior technology resource for wood adhesives group and technology manager for OSB. Previously, he was Technology Manager, UF Wood Adhesives and Technology Manager, Plywood at Georgia-Pacific Resins, Inc. He received a B.S. in Chemistry from Bowling Green State University, and a Ph.D. in Organic Chemistry from the University of New Orleans.

Bruce M. Broline
Research Manager, North America
Dynea USA
Springfield, Oregon, USA

Dr. Bruce Broline is Research Manager, North America at Dynea USA in Springfield, Oregon. He received a B.S. in Chemistry and M.S. in Organic Chemistry from California State University, and a Ph.D. in Physical Organic Chemistry from the University of Oregon. Previously, he was R&D Manager, Panelboard Resins, Dynea; Analytical Group Leader, Neste Resins; Senior Research Chemist, Neste Resins; Senior Chemist, Boeing Military Airplane Company; and Propulsion Analyst, Boeing Aerospace Company.

Nicole R. Brown
Assistant Professor of Wood Chemistry
School of Forest Resources
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Dr. Nicole Brown is an Assistant Professor of Wood Chemistry in the School of Forest Resources at Pennsylvania State University, University Park, Pennsylvania. She received a B.S. in Forestry & Wildlife and Ph.D. in Forest Products from Virginia Tech. Her research interests include: wood adhesives, coatings, and finishes; physical and mechanical behavior of wood and wood composites; chemical treatments for wood; polymer impregnation of wood; and wood fiber polymer composites. She has authored or coauthored seven peer-reviewed proceedings in the area of wood adhesives and has given numerous presentations at technical meetings. She is a member of the Adhesion Society, American Chemical Society, Forest Products Society, and Society of Wood Science & Technology. She received the Forest Products Society 2004 Wood Award for outstanding research in the field of forest products.

Gang-Fung Chen
Development Fellow
Ashland Specialty Chemical Company
Columbus, Ohio, USA

Dr. Gang-Fung Chen is a Development Fellow at Ashland Specialty Chemical Company in Columbus, Ohio. He is responsible for developing wood adhesives for a variety of applications. He received a B.S. in Chemistry from the National Taiwan University, and a M.S. in Polymers & Coatings and Ph.D. in Chemistry from North Dakota State University.

Liheng Chen
Research Scientist, Forest Products
Alberta Research Council
Edmonton, Alberta, Canada

Dr. Liheng Chen is a Research Scientist in the Forest Products Business Unit of the Alberta Research Council specializing in wood adhesion and adhesives, with specific expertise in ultrasound monitoring of resin cure, resin performance, non-destructive evaluation of adhesive bond, polymer science and surface chemistry, and wood science and technology. Previously, he was a Graduate Research Assistant at the Forest Products Laboratory, University of California at

Berkeley. He received a B.S. in Forestry and M.S. in Forest Products from the National Taiwan University, and a Ph.D. in Wood Science & Technology from the University of California at Berkeley.

Richard A. Cook
President
National Casein
Santa Ana, California, USA

Richard Cook is President of National Casein in Santa Ana, California. As President, he oversees the research and development of adhesives and oversees the Technical Service Division as it applies to customer service and manages the International Division as well as travel and visit prospects and customers outside the U.S. He also manages National Casein of California. He is National Casein's representative to ASTM, where he is Chairman of D14 Adhesives and Subcommittee Chairman for ASTM D 14.30 on Wood Adhesives. He was recently accepted by ANSI to formulate the U.S. position on adhesives as they relate to ISO standards for adhesives. Previously, he was Vice President and Technical Service Representative, National Casein of California, Santa Ana, California; and Technical Service Representative and Production Planning/Chemist, National Casein Company, Chicago, Illinois. He received a B.A. in Chemistry from Tarkio College, Tarkio, Missouri.

Pierre-Louis Cyr
Ph.D. Candidate
Department of Wood & Forest Sciences
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Pierre-Louis Cyr is a Ph.D. Candidate in the Department of Wood & Forest Sciences at the Université Laval, Québec City, Québec, Canada. He began his studies in 1995 at Université Laval's Faculty of Chemical Engineering. In May 2000, he joined Jolan Chemicals, a producer of formaldehyde scavenger for the PB/MDF industry. His first objective was to develop a way to improve production without any major investment. He graduated from Université Laval in December 2000 with a specialty in biochemical engineering. After graduation, he rejoined Jolan's team in order to work as a R&D Engineer and later, as the Plant Director. After 1 year with Jolan, he decided to further his studies. At the end of 2001, he went back to the Université Laval and earned a M.S. in Wood Science. He is currently working towards a Ph.D. degree.

Joseph Gabriel
Technical Director
Purbond AG
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Dr. Joseph Gabriel is Technical Director of Purbond AG in Sempach-Station, Switzerland. He is Head of R&D, where he is responsible for toll production and product quality. He received a Diploma in Chemistry and Ph.D. in Chemistry from the Federal Institute of Technology, Zurich, Switzerland.

Michael M. Goerger
Senior Research Chemist
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Dr. Michael Goerger is Senior Research Chemist at Dynea USA, Springfield, Oregon. His responsibilities include product development of amino resins, specializing in resins used in structural applications and in the furniture and flooring industries. Previously, he was R&D Manager, Wood & Specialty Adhesives, North America, Dynea; Assistant Laboratory Manager, Neste; Group Leader, Neste; Senior Research Chemist, Neste; and Research Chemist, Chembond. He received a B.S. from the University of California, and a Ph.D. from the University of Oregon.

Warren J. Grigsby
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Dr. Warren Grigsby is a Senior Scientist at Scion in Rotorua, New Zealand. He is a scientist leader within the Biomaterials Engineering Group, a transformational science platform in Scion (formerly Forest Research). He has been employed by this organization since 1997. His research interests span synthetic and polymer chemistry applications of biopolymer systems and the understanding of natural fiber-polymer interactions in wood and wood-plastic composites. He also has interests in the synthesis and development of natural and synthetic resin and adhesive formulations for use in engineered wood products and high performance composites. His current research activities include: the novel extraction, functionalization and synthetic utility of bark tannins and polyphenolics in a range of applications; evaluation of interfacial behavior of polymers on natural fibers; and evaluation of adhesives and polymers in composite wood-fiber products. He received a B.S., M.S. in Chemistry, and Ph.D. from the University of Waikato.

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Kristin Grøstad is Chief Research Scientist, Product Development Europe at Dynea ASA in Lillestrøm, Norway. She is a R&D Specialist within wood adhesive systems for production of beams and multilayer boards in Europe. This covers both formaldehyde-based and nonformaldehyde-based adhesives. She is responsible for developing new adhesive systems, for introduction and follow-up of new adhesive systems in production and to the customer, and for progress in the development of projects. Previously, she was Senior Research Scientist, Dyno ASA - Dynea ASA; Senior Research Scientist, Borealis A/S; and Research Scientist, Norsk Hydro A/S. She received a M.S. from the University of Trondheim, Norwegian Institute of Technology, Trondheim, Norway.

George A. Grozdits
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Dr. George Grozdits is a Research Associate in the School of Forestry at Louisiana Tech University, Ruston, Louisiana. He received a B.S. in Forest Engineering from the University of British Columbia, and a M.S. in Wood Technology and Ph.D. in Wood Science from Virginia Tech. He has 26 years of experience in the forest products industry and 19 years of experience in research and teaching at major U.S. universities. He has served as an affiliate member of the graduate faculty at Louisiana State University in Baton Rouge. His international experience includes consulting in South America, Europe, Canada, and the U.S. Dr. Grozdits serves as a consultant on wood in-service, wood adhesives, and plant equipment and process modifications. His expertise includes adhesives, basic wood products manufacturing (including veneer, plywood, fiberboard, and oak flooring), wood chemistry, and bagasse utilization. He has been with the Louisiana Forest Products Development Center in the School of Forestry at Louisiana Tech University since 1993.

Timothy M. Gruver
Graduate Research Assistant
School of Forest Resources
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Timothy Gruver is a Graduate Research Assistant in the School of Forest Resources at Pennsylvania State University, University Park, Pennsylvania. His current tasks include researching wood species and moisture relations of pMDI wood binders. Other tasks include providing teaching assistance, assistance in undergraduate research projects,

and assistance in the thermal analysis laboratory. He received a B.S. in Wood Products Processing & Manufacturing and a M.S. in Forest Resources from Pennsylvania State University.

Yasunori Hatano
Head, Composite Products Laboratory
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Dr. Yasunori Hatano is Head of Composite Products Laboratory, Department of Wood-Based Materials, Forestry & Forest Products Research Institute (FFPRI), Tsukuba, Ibaraki, Japan. His responsibilities include research and leading in the fields of wood composites, boards, adhesives, and wood adhesion. Previously, he was Head of Composite Products Laboratory, Wood Chemistry Division, FFPRI, FFPRI, Ministry of Agriculture, Forestry & Fisheries (MAFF); Head of Adhesion Laboratory, Wood Chemistry Division, FFPRI, MAFF; Senior Researcher of Adhesion Laboratory, Wood Chemistry Division, FFPRI, MAFF; and Assistant Professor, Faculty of Agriculture, University of Tokyo. He received a B.S. and M.S. from Shizuoka University, and a Ph.D. from the University of Tokyo.

Naruhito Hori
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Naruhito Hori is an Assistant Professor in the Laboratory of Polymeric Materials, Department of Biomaterial Sciences, Graduate School of Agricultural & Life Sciences, University of Tokyo, Tokyo, Japan. His responsibilities include teaching both undergraduate and graduate students. He received Bachelor and Master of Agriculture degrees from the University of Tokyo.

Philip E. Humphrey
Founder
Adhesive Evaluation Systems, Inc.
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Dr. Philip Humphrey is the Founder of Adhesive Evaluation Systems, Inc. and an Affiliate Professor in the Department of Wood Science & Engineering, Oregon State University. He specializes in analysis and modeling of composite pressing processes and develops instrumentation for evaluating furnish properties.

Akio Inoue
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Dr. Akio Inoue is Head of Adhesion & Glue Laminating Laboratory, Forestry & Forest Products Research Institute (FFPRI), Tsukuba, Ibaraki, Japan. His responsibilities include research on bond durability; formaldehyde emission from wood-based materials; and Japanese Agricultural Standard (JAS) Test Methods. Previously, he was Head of Adhesion Laboratory, FFPRI, FFPRI, Ministry of Agriculture, Forestry & Fisheries (MAFF); and Researcher of Adhesion Laboratory, FFPRI, MAFF. He received a B.S. from the Tokyo University of Agriculture & Technology, and Ph.D. from the University of Tokyo.

Björn A. Källander
R&D Manager
SP Trätekt, Swedish National Testing & Research
Institute, Wood Technology
Boras, Sweden

Björn Källander is R&D Manager at SP Trätekt, Swedish National Testing & Research Institute, Wood Technology in Boras, Sweden. His responsibilities include research and technical evaluation regarding wood adhesives. He is a specialist in technical evaluation of glued timber components such as glulam, windows, and doors. He is a Swedish representative in European standardization CEN/TC193/SC1 Wood Adhesives and a convenor in two standardization groups: CEN/TC193/SC1/WG4 test methods, classification and performance requirements for adhesives other than phenolic and aminoplastic for load bearing timber structures, and WG6 Adhesives for glued in rods in timber structures. He is a representative of Sweden in the management committee of COST Action E34 Wood Bonding and Chairman of E34 working group WG2 green/wet gluing of wood. He is a specialist in wood drying in water vapor under superheated conditions, high temperature drying, and vacuum drying. He works with combined drying and wood processing: bonding/drying such as green gluing, and curing/drying such as in chemical modification of wood properties. He received a M.S. in Mechanical Engineering, Wood Technology and a Licentiate of Engineering in Wood Physics from KTH-Royal Institute of Technology.

Naryuki Kamo
Researcher
J-Chemical, Inc.
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Dr. Naryuki Kamo is a Researcher in the Technical Development Department at J-Chemical, Inc. in Tokyo, Japan. He received a B.S., M.S., and Ph.D. from Kyushu University, Fukuoka, Japan.

Herbert J. Kennedy
Mid-Continent Sales Manager, Wood Adhesives
Georgia-Pacific Resins, Inc.
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Herbert Kennedy is the Mid-Continent Sales Manager, Wood Adhesives at Georgia-Pacific Resins, Inc., Decatur, Georgia. Mr. Kennedy has 30 years experience in the wood panel products industry including: Sales Management in Wood Adhesives with Georgia-Pacific Resins (2001-2005); Technical Service Manager in Wood Adhesives with Georgia-Pacific Resins (1992-2001); Technical Sales of Wood Adhesives with Georgia-Pacific Resins (1986-1992); Industrial Adhesives Sales with Borden Chemical (1981-1986); and Technical Manager in Particleboard Manufacturing with Temple-Inland (1975-1981). He received a B.S. in Wood Technology from Auburn University.

Moon G. Kim
Professor
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Mississippi State, Mississippi, USA

Dr. Moon Kim is a Professor in the Department of Forest Products at Mississippi State University, Mississippi State, Mississippi. His research interests include thermosetting wood adhesive resins; wood composites; steam injection pressing of wood composites; tool wear of wood composites; curing chemistry of thermosetting resins and polymers; and molecular structure determination of resins and polymers. His teaching areas include wood adhesives and finishes. He received a B.S. in Chemistry from Kyung Hee University, and a Ph.D. in Organic Chemistry from Kansas State University.

Sumin Kim
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Laboratory of Adhesion & Bio-Composites
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Seoul, South Korea

Sumin Kim is a Ph.D. Candidate in the Laboratory of Adhesion & Bio-Composites at Seoul National University, Seoul, South Korea. His major is in Environmental Materials Engineering. Previously, he was a Research Engineer, R&D Center, Dongwha Enterprise Co. Ltd. (2002-2004); and Assistant for Researcher, Laboratory of Wood-Based Materials, Korea Forest Research Institute (1996, 1998). He received a B.S. from Kookmin University, and a M.S. from Seoul National University.

Masayuki Kiyabu
Graduate Student
Graduate School of Life & Environmental Science
University of Tsukuba
Ibaraki-ken, Japan

Masayuki Kiyabu is a Graduate Student in the Graduate School of Life & Environmental Science at the University of Tsukuba, Ibaraki-ken, Japan. His responsibilities include the study on application of liquefied wood by using ϵ -caprolactone under the supervisor of Professor Bunichiro Tomita. He received a Bachelor (Agriculture) degree from the University of Tsukuba.

Masahiko Kobayashi
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Forestry & Forest Products Research Institute
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Dr. Masahiko Kobayashi is a JSPS (Japan Society for the Promotion of Science) Research Fellow in the Department of Wood-Based Materials, Composite Products Laboratory, Forestry & Forest Products Research Institute, Tsukuba, Ibaraki, Japan. Previously, he was a Researcher, Research Institute for Sustainable Humanosphere, University of Kyoto; Researcher, Institute of Agricultural & Forest Engineering, University of Tsukuba; and JSPS Research Fellow, Institute of Agricultural & Forest Engineering, University of Tsukuba. He received a Bachelor of Engineering from Tokyo University of Agriculture & Technology, and a Master of Environmental Sciences and a Doctor of Agriculture from the University of Tsukuba.

Albert G. Landers
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Dr. Albert Landers is Vice President of Technology & Business Process Improvement at Huber Engineered Woods, LLC, Commerce, Georgia. His responsibilities include identifying and developing key technologies that will provide the major platforms for new products and continuing improvement of current process and products to provide sustainable growth; align with major universities to identify key programs supporting the business; and develop key technical competencies in the three major initiatives identified in their 2008 strategic plan. Previously, he was Vice President of R&D at Huber Engineered Woods, LLC; Director of Innovation & Technology and Director of R&D at J.M. Huber Engineered Woods; Technology Manager, Specialty Additives Group at J.M. Huber Chemicals Division; and Senior Research Scientist, Building Product Operations, Senior Research Scientist (Group Leader), Exploratory Research Group, and Research Scientist, Basic Chemistry Research at Armstrong World Industries. He received a B.A. in Chemistry from the State University of New York at Plattsburgh, and a M.S. and Ph.D. in Chemistry from the University of Delaware.

Jong N. Lee
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Dr. Jong Lee is a Research Scientist in the Sustainable Engineered Materials Institute at Virginia Tech, Blacksburg, Virginia. Dr. Lee earned a B.S. from Seoul National University in 1988. He worked for Dongwha and ChungDam Enterprise as a managing staff in the Department of MDF and HardBoard Production from 1987 to 1989. Dr. Lee moved to the U.S. in 1990, where he earned a M.S. from North Carolina State University in 1993. In 1999, he completed the requirements to earn a Ph.D. from Auburn University in the major of Mechanics of Wood Composites/Wood Mechanics. His areas of expertise include computer simulation of mathematical models developed in the field of wood composites manufacturing/wood engineering.

Kaichang Li
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Dr. Kaichang Li is an Associate Professor in the Department of Wood Science & Engineering at Oregon State University, Corvallis, Oregon. His research interests include the development of formaldehyde-free wood adhesives from renewable natural resources; investigation of interfacial chemistry of wood-plastic composites; development of new paper additives from renewable natural resources with biological methods; mechanistic studies of lignin biodegradation; development of an environmentally benign pulp bleaching technique; enzymatic deinking of recycled paper; modification of cellulose and lignin for a high-value added product; pulping and pulp bleaching chemistry. Previously, he was an Assistant Research Biochemist, Department of Biochemistry & Molecular Biology, University of Georgia; Post-Doctoral Research Associate, Department of Biochemistry & Molecular Biology, University of Georgia; Graduate Research Assistant, Department of Wood Science & Forest Products, Virginia Tech; Research Associate and Instructor, South China University of Technology; and Graduate Research Assistant, South China University of Technology. He received a B.S. and M.S. from South China University of Technology, and a Ph.D. from Virginia Tech.

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Nan Ling is a Ph.D. Student in the Laboratory of Polymeric Materials, Department of Biomaterial Sciences, Graduate School of Agricultural & Life Sciences, University of Tokyo, Tokyo, Japan. Previously, he was Editor, Shanghai Furniture Research Institute. He received a Bachelor and M.S. degree from Northeast Forestry University, Harbin, P.R. China.

Linda Lorenz
Chemist
USDA Forest Service
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Madison, Wisconsin, USA

Linda Lorenz is a Chemist at the USDA Forest Service, Forest Products Laboratory (FPL) in Madison, Wisconsin. She has worked at FPL on hydrolysis of wood to analyze the components for wood adhesives from renewable resources, conversion of wood furfural to isocyanates for bonding, modification of urea resin adhesives with soy protein isolates, and kinetics of phenolic monomers reacting with formaldehyde. She has characterized resins and other adhesive chemicals by various types of chromatography (TLC, HPLC, SEC/GPC), spectroscopy (IR, UV, NMR), and thermal analysis. She received a B.S. in Molecular Biology from the University of Wisconsin-Madison.

Richard Magill
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Richard Magill is the Director of Research & Development at Signature Control Systems, the world's leading provider of industrial dielectric control solutions. Mr. Magill has directed numerous plant trials, designed experiments, and production startups using dielectric control methodologies in various production applications. He has authored numerous technical papers on this topic, and has also presented a coauthored paper with Borden specific to particleboard cure monitoring. Previously, he was Project Engineer, Signature Control Systems; Project Engineer, U.S. Department of Energy; and Naval Officer, U.S. Navy. He received a B.S. in Electrical Engineering from the University of Wyoming.

Kohta Miyamoto
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Dr. Kohta Miyamoto is a Researcher in the Adhesion & Glue Laminating Laboratory at the Forestry & Forest Products Research Institute in Tsukuba, Ibaraki, Japan. His responsibilities include research on formaldehyde and VOC emission from wood-based materials. He received a B.S. and M.S. from Shizuoka University, and a Ph.D. from Gifu University.

Ellen V. Nagy
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Dr. Ellen Nagy is a Scientist at Georgia-Pacific Resins, Inc. in Decatur, Georgia. As an Analytical Chemist, she is responsible for infrared spectroscopy, near infrared spectroscopy, thermogravimetric analysis with infrared detection and microscopy in support of R&D. Previously, she was a Senior Research Chemist, Georgia-Pacific Resins, Inc.; and Research Chemist, DuPont. She received a B.A. from West Georgia College, and a Ph.D. from the University of Georgia.

Jianwen (Jim) Ni
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Dr. Jianwen Ni is a Senior Development Chemist, Wood Adhesives R&D at Georgia-Pacific Resins, Inc. in Decatur, Georgia. He received a B.S. from Shanghai Jiao Tong University (Shanghai, P.R. China), M.S. from John Carroll University (Cleveland, Ohio), and Ph.D. from Virginia Tech.

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Dr. Jan Jaap Nusselder is Manager, Product & Application Research at DSM Melamine in Geleen, The Netherlands. His responsibilities include program manager for application development; program manager for product quality and applicability; knowledge management on melamine applications; and program manager for business redesign. Previously, he was Project Leader, DSM Research. He received a Ph.D. from the University of Groningen, The Netherlands.

Tadashi Okamoto
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Dr. Tadashi Okamoto is a Professor in the Department of Applied Bioscience, Graduate School of Agriculture, Kinki University, Nakamachi, Nara, Japan. His responsibilities include teaching, research, and consulting. Previously, he was Department Manager, Ibaraki Research Laboratory, Hitachi Chemical Company; Assistant Professor, Institute of Chemical Research, Kyoto University; and Research Associate, Department of Chemistry, University of Chicago. He received a Bachelor of Engineering from Kobe University, and a M.S. in Chemistry and Ph.D. from Kyoto University.

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Hui Pan is a Graduate Research Assistant in the School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, Louisiana. Her responsibilities include research on wood adhesives from liquified wood. She received a B.S. and M.S. from the Northeast Forestry University in Harbin, P.R. China.

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Dr. Byung-Dae Park is a Research Scientist in the Department of Forest Products at the Korea Forest Research Institute in Seoul, South Korea. His responsibilities include fundamental research on wood adhesives' curing and adhesion; developing low emission amino resin adhesives; and research on VOCs of wood adhesives. Previously, he was a Research Scientist, Forintek Canada Corporation. He received a B.S. from Chonnam National University, M.S. from the University of Toronto, and Ph.D. from the Université Laval.

Charles W. Paul
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Dr. Charles Paul is a NSC Fellow at the National Starch & Chemical Company in Bridgewater, New Jersey. His responsibilities include Group Leader of New Adhesives Technology, where he explores new technologies for water-borne, solution, and hot-melt adhesive applications. Previously, he was a Scientist, Honeywell; and Visiting Scientist, IBM San Jose. He received a B.S. in Chemical Engineering from Cornell University, and a Ph.D. in Chemical Engineering from the University of California.

Astrid Pedersen
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Dr. Astrid Pedersen is Chief Research Scientist, Product Development Europe at Dynea ASA, Lillestrøm, Norway. Her responsibilities include the development of adhesive solutions for the woodworking industry in Europe with main focus on adhesive solutions for production of furniture, flooring, doors, and windows; development projects in the above areas; development projects in cooperation with customers in the above areas; and transfer of products used with Dynea's plants in Europe. Previously, she was Senior Research Scientist and Laboratory Manager, Dyno ASA. She received a M.S. from the University of Trondheim, Norwegian Institute of Technology, and a Doctor Scientiarum (Ph.D.) from the University of Oslo.

Amy Philbrook
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Canberra, Australia

Amy Philbrook is a Ph.D. Candidate in the Research School of Chemistry, Australian National University, Canberra, Australia. She is co-supervised by Professor Chris Easton from the Australian National University and Dr. Noel Dunlop from Orica Australia Pty. Ltd. Previously, she was a Process Control Engineer, The Foxboro Company. She received a B.S. in Chemical Engineering from the University of Maine.

Milena Properzi
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School of Architecture, Civil & Wood Engineering
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Dr. Milena Properzi is a Research Scientist in the School of Architecture, Civil & Wood Engineering, HSB University of Applied Science, Biel-Bienne, Switzerland. Her specialty is material sciences. She focuses her research activities on the development of environmentally-friendly wood adhesives and assembling technologies. Previously, she was Project Manager and Teaching Assistant, HSB University of Applied Science; and Junior Lecturer, University of Florence. She received a M.S. in Forestry Sciences and Ph.D. in Wood Sciences from the University of Florence, and a Ph.D. in Industrial Sciences & Technologies from ENSTIB-LERMAB, University of Nancy 1.

Gary M. Raftery
Ph.D. Student
Department of Civil Engineering
National University of Ireland
Galway, Ireland

Gary Raftery is a Ph.D. Student in the Department of Civil Engineering, National University of Ireland (NUI), Galway, Ireland. The position he currently holds is as a result of an award of a prestigious EMBARK scholarship by IRCSET (Irish Research Council for Science, Engineering & Technology) to undertake research involving fiber-reinforced plastic Irish Grown Sitka Spruce. The project is jointly funded by Coillte (the Irish Forestry Board), Coford (National Council for Forestry Research & Development), and the NUI, Galway Millennium Fund. Mr. Raftery is continuing his studies after obtaining a first class honors in the undergraduate B.E. degree at the Department of Civil Engineering, NUI, Galway and is pursuing his studies with this topic in order to obtain a Doctor of Philosophy degree in Structural Engineering. As a further responsibility, he participates with undergraduate students in the demonstration of laboratory experiments and also in providing direction for degree projects that contribute to the award of the B.E. degree at NUI, Galway.

Jouni Rainio
R&D Manager
Hexion Specialty Chemicals Oy
Puuhos, Finland

Jouni Rainio is R&D Manager at Hexion Specialty Chemicals Oy in Puuhos, Finland. Previously, he was R&D Manager, Bakelite Oy; Product Development Manager, Dynoresin Oy; Deputy R&D Manager, Dynoresin Oy; Product Development Manager, Dynoresin Oy; and Laboratory Manager, Dynoresin Oy. He received a M.S. in Wood & Polymer Chemistry from Helsinki University.

Klaus Richter
Head, Wood Laboratory
Empa, Swiss Federal Laboratory for
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Dr. Klaus Richter is Head of Wood Laboratory at Empa, Swiss Federal Laboratory for Materials Testing & Research in Duebendorf, Switzerland. The Wood Laboratory pursues research and development as well as ambitious services to promote the sustainable use of wood specifically in capital goods. The activities focus on wood derived materials and their utilization in products, processes, and systems within the forestry-wood production chain, with special emphasis on application in building and construction. Their team consists of approximately 24 qualified and skilled specialists, who solve the given questions mainly with inter- and transdisciplinarily structured cooperations, thus using available competence and infrastructure of other disciplines and laboratories. Their current research program focuses on three main activities: 1) material modification for new wood-based applications; 2) durability of wood and wood-based products; and 3) materials and systems for timber engineering. He is also responsible for personally performing and supervising R&D and knowledge transfer activities in the fields of wood technology and wood products application in building and construction, wood adhesion, surface treatment, timber modification, LCA of building materials, sustainability in building and construction. He received a Dipl. Holzwirt degree and Ph.D. in Wood Biology from the University of Hamburg.

Milan Sernek
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Dr. Milan Sernek is an Assistant Professor in the Department of Wood Science & Technology, University of Ljubljana, Ljubljana, Slovenia. His lectures include the following courses: wood-based composites manufacture, wood adhesives, and designing of technological processes in wood industry. His research work includes several projects: dielectric properties of wood and adhesives, wettability and penetration of adhesives, fracture testing of adhesive bond, and adhesive cure kinetics. Previously, he was a Graduate Student, Virginia Tech; and Young Researcher, Department of Wood Science & Technology, University of Ljubljana. He received B.S. and M.S. degrees from the University of Ljubljana, and a Ph.D. from Virginia Tech.

John G. Sharp
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Dr. John Sharp is a Consultant of Resins & Panel Process Technology (United Kingdom and Brazil) in Stirling, United Kingdom. Previously, he was Production & Technical Manager, Caberboard Ltd., Scotland; Manager, Chemical Division, Placas do Paraná, Curitiba, Brazil; and Senior Chemist, Borden Chemicals, United Kingdom. He received a B.S. and Ph.D. in Chemistry from the University of London.

Jeanne N. Shera
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Jeanne Shera is a Ph.D. Student in the Thames-Rawlins Research Group, School of Polymers & High Performance Materials, University of Southern Mississippi in Hattiesburg, Mississippi. Her responsibilities include conducting research on soy protein adhesives for utilization in formaldehyde-free wood composites. Previously, she was a Graduate Student, Guymon Research Group, University of Southern Mississippi. She received a B.A. degree from Ripon College (Ripon, Wisconsin), and a M.S. degree from the University of Southern Mississippi.

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Dr. Sheldon Shi is an Assistant Professor in the Department of Forest Products, Mississippi State University, Mississippi State, Mississippi. Within the Faculty of Wood-Based Composites/Engineered Wood Products, his research areas include: 1) design and processing of wood composites/engineered wood products; 2) adhesion, interface/interphase; and 3) durability and wood-plastic composites. Previously, he was an Associate and Staff Scientist, APA - The Engineered Wood Association; Research Scientist, University of Maine; Post-Doctoral Fellow, Michigan Technological University; Research and Teaching Assistant, Michigan Technological University; and Research Staff and Instructor, Northeast Forestry University. He received a B.S. in Wood Engineering and M.S. in Wood Science from Northeast Forestry University, and a Ph.D. in Wood Science from Michigan Technological University.

Turid Sigvartsen
Product Development Manager
Dynea ASA
Lillestrøm, Norway

Turid Sigvartsen is Product Development Manager at Dynea ASA in Lillestrøm, Norway. She is responsible for product development in Dynea Europe within the following applications: Composite Board, Engineered Wood Solutions, and Interior Wood Solutions. Previously, he was Global R&D Manager, Wood & Specialty Adhesives, Dynea; Global R&D Manager, Wood & Specialty Adhesives, Dyno; Laboratory Manager, Wood & Specialty Adhesives, Dyno; and Research Chemist, Dyno. She received a Cand. Scient in Organic Chemistry degree from the University of Oslo.

Magdalena Sterley
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SP Trätekt, Swedish National Testing & Research
Institute, Wood Technology
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Magdalena Sterley is a Research Engineer, Building Technology and Mechanics and Wood Technology, SP Trätekt, Swedish National Testing & Research Institute, Wood Technology, Stockholm, Sweden. She is responsible for research and development within gluing of wood, durability, and wood coatings. Previously, she was a Researcher of gluing of wood, testing of wood, and wood-based panels, and Quality Manager of Accredited Laboratories, AB Trätekt, Swedish Institute for Wood Technology Research; Researcher of development of glued and impregnated railway sleepers, Research & Development Institute of Polish Railways, Warsaw, Poland; and Researcher of development of hot-melt adhesives, Institute of Industrial Chemistry, Warsaw, Poland. She received a M.S. in Mechanical Wood Technology from the Agricultural University, Warsaw, Poland; and a Licentiate of Technology from KTH-Royal Institute of Technology.

Wu Suen
Senior Associate
National Starch & Chemical Company
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Dr. Wu Suen is a Senior Associate at the National Starch & Chemical Company in Bridgewater, New Jersey. His current responsibilities include using different polymerization approaches to improve emulsion and solution polymer properties for adhesive applications, and also mechanism studies on reactive hot-melt adhesives. Previously, he was an Associate, National Starch & Chemical Company; and Post-Doctoral Fellow, University of Massachusetts-Amherst. He received a B.S. from the University of Science & Technology, HeFei, Anhui, P.R. China; and a Ph.D. from Princeton University, Princeton, New Jersey.

Shin-ichiro Tohmura
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Dr. Shin-ichiro Tohmura is a Senior Researcher at the Forestry & Forest Products Research Institute (FFPRI) in Tsukuba, Ibaraki, Japan. His responsibilities include research on wood adhesion and adhesives; wood composite materials; VOCs from wood-based materials; development of new bio-materials from waste wood; and utilization of biomass resources. Previously, he was a Visiting Scientist, McGill University, PAPRICAN; Researcher, FFPRI; Post-Doctoral Fellow, USDA Forest Service, Southern Research Station; and JSPS Fellow, Kyushu University. He received B.S., M.S., and Ph.D. degrees from Kyushu University.

Kenji Umemura
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Dr. Kenji Umemura is an Assistant Professor in the Laboratory of Sustainable Materials, Research Institute for Sustainable Humanosphere, Kyoto University, Uji, Kyoto, Japan. Previously, he was an Assistant Professor, Wood Research Institute, Kyoto University; Research Fellow, Institute of Wood Technology, Akita Prefectural University; Domestic Research Fellow, Japan Society for the Promotion of Science; and JSPS Research Fellow, Japan Society for the Promotion of Science. He received Bachelor and Master of Agriculture degrees from Kinki University, and a Doctor of Agriculture degree from Kyoto University.

James M. Wescott
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Dr. James Wescott is Chief Technology Officer of Heartland Resource Technologies, a start-up wood adhesive/additive company that specializes in soy-based and formaldehyde free technology. He is responsible for all R&D and commercialization efforts. Previously, he was Technical Manager of Operations, Eastman Chemical; Composite Polymer Technical Manager and Site Laboratory Manager, Eastman Chemical (formerly McWhorter Technologies); and Senior Development Chemist, Arizona Chemical (International Paper). He received a B.S. in Polymer Chemistry from Rochester Institute of Technology, and a Ph.D. in Chemistry from Virginia Tech.

Stefanie Wieland
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Stefanie Wieland is a Research Scientist in the School of Architecture, Civil & Wood Engineering, HSB University of Applied Sciences, Biel-Bienne, Switzerland. She is responsible for the development of new assembling technologies and processes; development of new environmental friendly wood adhesives; development of new drying technologies for lacquer and varnishes; services; and assistance in surface treatment lessons for the engineer students. Previously, she was Project Manager, Construction Department, Hohenloher Spezial-Möbelwerke, Germany; Graduand (Dissertation Work), Fraunhofer-Institute for Wood Research (WKI), Braunschweig, Germany; Trainee (Internship), Sonae Industria, Tafisa, Solsona, Spain; and Trainee (Internship), Michael Weinig AG, Tauberbischofsheim, Germany. She received a Completion of Apprenticeship Certificate as Cabinetmaker from Chamber of Trade Stuttgart, Stuttgart, Germany; a Wood Engineering degree from University of Applied Science, Rosenheim, Germany; and an M.S. in Wood Science and is in the process of completing her Ph.D. in Wood Science from ENSTIB-LERMAB, University of Nancy 1, Nancy, France.

Jack G. Winterowd
Senior Scientific Specialist, Corporate R&D
Weyerhaeuser Company
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Dr. Jack Winterowd is a Senior Scientific Specialist, Corporate R&D at Weyerhaeuser Company in Federal Way, Washington. His responsibilities include: manager of a company-wide wood adhesive research program for Weyerhaeuser; development and commercialization of specialty adhesives, sealants, coatings, and additives for wood products (12 issued patents and nine published pending applications); modeling of dimensional stability, mass transport of compounds in composite-wood products, and kinetics of pollution formation in OSB mills; and technical advisor to company procurement department for adhesives and resins. Previously, he was a chemistry teacher at the University of Washington. He received a B.S. in General Chemistry from Boise State University, and a M.S. and Ph.D. in Polymer Chemistry from the University of Washington.

Ning Yan
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Faculty of Forestry
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Dr. Ning Yan is an Assistant Professor in the Faculty of Forestry, cross appointed to the Department of Chemical Engineering & Applied Chemistry, and an Associate Director of the Pulp & Paper Centre. She obtained her Ph.D. in Chemical Engineering from the University of Toronto in 1997. Before joining the University of Toronto as a faculty member, she worked as a Research Scientist for various companies, including the Pulp & Paper Research Institute of Canada, Trojan Technologies Inc., and Xerox Corporation. She has broad expertise in cellulosic materials, composites and adhesives, surface science, and conventional and digital printing technologies. Her research interests are in the areas of wood/natural fiber composites, pulp and paper, and printing.

Han-Seung Yang
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Dr. Han-Seung Yang is a Post-Doctoral Research Associate in the Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington. His research interests include lignocellulosic material-thermoplastic polymer composites; wood and non-wood-based bio-composites; biodegradable polymer composites; and composites made of agricultural wastes and recycled waste materials. Previously, he was a Post-Doctoral Research Associate, Seoul National University; and Lecturer, Division of Forest Science, College of Agriculture, Chonbuk National University. He received a B.S. in Forest Products, and M.S. and a Ph.D. in Adhesion & Bio-Composites from Seoul National University.

Borjen Yeh
Director, Technical Services Division
APA - The Engineered Wood Association
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Dr. Borjen Yeh is Director, Technical Services Division, APA - The Engineered Wood Association, Tacoma, Washington. His responsibilities include directing the Technical Services Division on technical activities associated with code and standards, research and development, and product evaluation. Previously, he was Manager, R&D, Senior Engineer, and Associate Engineer at APA - The Engineered Wood Association. He received a M.S. from Iowa State University, and a Ph.D. from the University of California.

ABSTRACTS

WEDNESDAY MORNING, NOVEMBER 2

PLENARY SESSION - TECHNOLOGY

Future Technology and Product Development in Wood Adhesives: A Customer's Perspective

Albert G. Landers, Vice President, Technology & Business Process Improvement, and *Terry Liles*, Director, Adhesive Technology, Huber Engineered Woods, LLC, Commerce, Georgia, USA

The volume of wood adhesives used in North America has grown significantly over the past 10 years and is currently in excess of 7.5 billion pounds annually. Over 95% of these adhesives are based on formaldehyde-based materials. The environmental, product, and cost parameters of these adhesive types have all shifted in a negative direction from a users perspective. New research and technology development is needed to be able to shift from these product types especially in regards to specialty and high-performance wood composite materials. The technology development efforts should include an increase in investigating new adhesive chemistries, novel processing technologies, use of additives, and conduct of basic research in bonding.

Cost Trends Associated with the Production and Delivery of Wood-Based Composites in North America

Jack G. Winterowd, Senior Scientific Specialist, Corporate R&D, Weyerhaeuser Company, Federal Way, Washington, USA

Costs associated with adhesive, wax, wood, labor, energy, pollution control, and transportation constitute much of the total cost to manufacture and deliver wood-based composite products. Recent costs for emulsified wax, softwood logs, Douglas-fir veneer, labor, and electricity are only slightly greater than their respective costs in 2000. In contrast, recent costs for urea-formaldehyde (UF), phenol-formaldehyde (PF), pMDI, neat slack wax, hardwood logs, natural gas, pollution control, and transportation have increased substantially since the year 2000. During this period, the cost of most of the raw materials used to synthesize key wood adhesives has also increased dramatically. The actual total cost associated with the purchase, operation, and maintenance of air-borne pollution control devices (regenerative thermal oxidizers, regenerative catalytic oxidizers, wet electrostatic precipitators, and biofilters) is estimated to be about \$0.5-3.0 million/yr. for each U.S.-based OSB, particleboard, and MDF plant and about \$0.3-1.5 million/yr. for each U.S.-based plywood and veneer plant. Many wood-based composite mills will be required to utilize these devices as a result of a recent, more restrictive, EPA regulation (40 CFR, Part 63, Subpart DDDD; 9 69 FR 45944). Transportation cost increases are largely attributed to increased driver compensation rates, increased diesel fuel costs, and the new Hours-of-Service regulations (49 CFR, Part 395).

European Industry - Academic Cooperation

Björn A. Källander, R&D Manager, SP Trätekt, Swedish National Testing & Research Institute, Wood Technology, Borås, Sweden; and *Magnus E.P. Wälinder*, Head, Material Science & Product Development, SP Trätekt, Swedish National Testing & Research Institute, Wood Technology, Stockholm, Sweden, and Assistant Professor, Biofibre Materials Centre, KTH-Royal Institute of Technology, Stockholm, Sweden

The European Union strongly supports cooperation between industry and academic institutions in order to strengthen the scientific and technological bases of the industry and encourage its international competitiveness, while promoting research activities in support of other EU policies. Close industrial - academic cooperation is encouraged by means of instruments directly aimed at promoting such cooperation, as well as by means of requirements formulated in the guidelines for programs aimed at scientific and technical development. This paper will provide a general overview of the European system of coordinated research activities within Framework Programs in addition to a more detailed description of two examples of instruments aimed at cooperation between industry and academic institutions, "COST" and "CRAFT."

New Adhesive Development to Meet the Challenges of Tomorrow

Turid Sigvartsen, Product Development Manager, Dynea ASA, Lillestrøm, Norway; and *Manfred Dunky*, Application Manager, Europe PB&MDF + OSB, Dynea Austria GmbH, Krems, Austria

Progress in development within the wood adhesive industry has shown many successes during the last decades, with driving forces like "cheaper," "quicker," and "more complex." In addition to the wood species, the wood surface, the working conditions, and the process parameters, the type and quality of the applied adhesive has an important influence on bond quality. The adhesives must perform according to a wide variety of requirements. They must withstand the stresses in the glued product, tolerate the climate exposure, be environmentally friendly and easy to use, be cost-efficient, and fulfill the requirements of various standards. So, in practice, most market requirements are linked to the use of new or special adhesive systems in order to provide suitable solutions. The demand for higher production capacity with higher quality gluebond performance, improved hygroscopic behavior of boards (lower thickness swelling, higher resistance against the influence of humidity and water, and better outdoor performance) and at the same time the focus on more environmentally friendly products, makes the development of new adhesive systems very challenging.

WEDNESDAY AFTERNOON, NOVEMBER 2

PLENARY SESSION - BUSINESS

The Who, What, Why, Where, and How of Test Methods and Specifications for Adhesives

Richard A. Cook, President, National Casein, Santa Ana, California, USA

Adhesive manufacturers make adhesives to meet specific quality standards that have been developed over the course of many years. Some of these were developed in-house, but many were developed by national or international standards organizations such as ASTM and ISO. These allow the adhesive manufacturer to offer a quality product on a consistent basis. On the opposite side of this issue are the users of these adhesives. They need adhesives to meet certain quality issues that pertain to how the finished piece may be used or where it might be placed. Some of these issues might be as follows: outside exposure to weather, stress due to carrying a vertical or horizontal load, use in a low humidity or very high humidity environment, or even full immersion in water for an extended period of time. Some of the quality and use issues that face the adhesive manufacturer or the adhesive user are addressed in a multitude of test methods or specifications that are available locally or internationally for many countries or organizations, but it can be daunting to find the proper one. Conversely, some quality and use issues might not be found after extensive research because the need has never been expressed. What can the adhesive manufacturer or user do in this instance? This paper will give you the tools and sources to search out the answers to your questions. It will also show how academics, standards organizations such as ASTM and ISO, as well as industry can work together for improvement and development of new or existing test methods or specifications.

The North American Wood Adhesives Market

Herbert J. Kennedy, Mid-Continent Sales Manager, Wood Adhesives, Georgia-Pacific Resins, Inc., Decatur, Georgia, USA

The forests of North America are one of its most valuable natural resources. The industries based on this resource play a major economic role in the United States and Canada. Wood composites are an ever-increasing portion of the wood-products industry and are expected to continue to grow. The health and vitality of the wood adhesives industry is crucial to the health and future of the wood composites market. The wood adhesives industry, in partnership with the composite panel industry, continues to adjust to a changing market place in North America. Reductions in demand in some areas are being replaced by increased demand in other segments. An overview of past and current adhesive use patterns as well as projections for the future is presented. Demand for some segments of wood adhesives is expected to grow significantly in North America in the short term. The recent highly

competitive wood adhesive market has limited reinvestment in wood adhesive manufacturing capabilities. Implications of this minimal reinvestment combined with the impending expansion of the North American composite panel industry are examined.

European Market for Adhesives for Panel Board Products: Current State and Challenges for the Future

Joni Lukkaroinen, Senior Vice President, Europe North, Dynea Oy, Helsinki, Finland; and *Manfred Dunky*, Application Manager, Europe PB&MDF + OSB, Dynea Austria GmbH, Krems, Austria

The market for adhesives is closely related to the market and production of panel board products. New requirements in the production of boards usually are linked to progress in development within the wood adhesive industry. For Europe, including European Russia, approximately 25 new plants are estimated to go into operation in 2005 - 2010, which will mean an additional resin consumption of 700,000 t/y. The trends in the board industry, which will have an impact on the adhesive industry are: 1) Increased share of specialty products with an increased demand in resin performance (e.g. water or fire resistant boards). The adhesive industry needs to serve the board industry with tailor-made solutions, while producing on the other hand an additional margin for adhesive producers. 2) Solutions for lower emissions, in cases such as Japanese "F****" quality or for German pre-fabricated houses, and also brought to the forefront by the reclassification of formaldehyde. 3) Reduction of production costs (e.g. by reducing board press times by the use of resin systems with higher reactivity, or by improved production technologies, such as better resin distribution). 4) The realistic threat of a decrease in emission limits in production plants. 5) High pressure on resin prices based on resin overcapacity. A threat for the adhesive industry is that big board producers might increase their captive resin production and even enter into the open market. The adhesive industry is also experiencing a trend towards globalization and a concentration into a few large companies.

Wood Adhesive Trends in Asia

Bunichiro Tomita, Professor, Graduate School of Life & Environmental Science, University of Tsukuba, Ibaraki-ken, Japan (Presented by *Chung-Yun Hse*, Research Forest Products Technologist, USDA Forest Service, Southern Research Station, Pineville, Louisiana, USA)

The production amounts and trends of wood adhesive usage in East Asia, especially in China and Japan, are presented in relationship to the production trends of wood-based composite products. The trends in these regions and countries are also compared with those of the United States (U.S.) and Europe (EU). This paper includes statistical data mainly for Japan and China. Reliable statistical data on China and Asia could not be obtained because of great discrepancies among the sources of information and difficulty in the classification of adhesives such as identification between UF and MUF resins. However, generally speaking in China, the demand of wood adhesives is increasing dramatically in accord with the increasing production of wood composites. This trend is estimated to continue in the near future. In Japan, wood adhesive demand is still decreasing slightly due to the economic conditions. The utilization of domestic softwoods is an urgent problem. Therefore, the demand of PF resin can be estimated to increase. The demand of API (aqueous vinyl polymer solution-isocyanate adhesives) will be expected to increase with increasing use of structural laminated woods. The trends of wood adhesive usage in other Asian countries has not changed greatly in the past 5 years.

THURSDAY MORNING, NOVEMBER 3

CONCURRENT SESSIONS

SESSION 1A: Analytical Techniques

The Wood-Resin Interphase: Characterization by Nanoindentation and Chemical Imaging

Williams T.Y. Tze, Research Associate, and *Timothy G. Rials*, Professor and Director, Forest Products Center, University of Tennessee, Knoxville, Tennessee, USA; *Steve Kelley*, Principal Scientist, National Renewable Energy Laboratory, Golden, Colorado, USA; *Siqun Wang*, Assistant Professor, Forest Products Center, University of Tennessee, Knoxville, Tennessee, USA; and *George M. Pharr*, Professor, Department of Material Science & Engineering, University of Tennessee, Knoxville, Tennessee, USA

The significance of the interphase on properties of wood-adhesive bondlines continues to be the focus of intense research interest. In par-

ticular, questions remain regarding the structure of the composite system established by resin interaction with cell wall polymers, and the role it plays in determining bond performance. To address this question, laminate composites of southern pine veneer were bonded with two different commercial adhesives: a phenol-formaldehyde and an isocyanate resin. A PerkinElmer FTIR chemical imaging system was used to determine the extent of penetration and cure state throughout the interphase region. Nanoindentation experiments were targeted on the resin and selected increments moving away from the pure adhesive. Surprisingly, very little variation in stiffness was observed throughout the interphase region. Similar observations were made for modulus measurements, which remained relatively constant from the pure resin to the pure wood elements. Constant strain, or creep, experiments on the same materials did reveal dramatic differences in the time-dependent response at different locations in the interphase. This paper will discuss the implications of these and other observations provided by nanoindentation.

T_g as an Index of Chemical Conversion for Isocyanate Impregnated Yellow-Poplar

Darren Riedlinger, Graduate Research Assistant, Department of Macromolecular Science & Engineering, and *Nanjian Sun*, Post-Doctoral Research Associate, and *Charles E. Frazier*, Professor and Director, Wood-Based Composites Center, Department of Wood Science & Forest Products, Virginia Tech, Blacksburg, Virginia, USA

In the classic work by Gilham and coworkers, it has been established that the glass transition temperature (T_g) is a very sensitive measure of the degree of cure in many thermosetting adhesives. As cure advances, network mobility declines and the T_g rises in a systematic fashion. We were curious to see if such a relationship existed for polymeric isocyanate (pMDI) adhesives cured in the presence of wood. Yellow-poplar samples were treated with neat pMDI and then isothermally heated for various periods in two different differential scanning calorimeters. After this isothermal cure period, the samples were cooled and scanned to detect the T_g of the uncured resin, in addition to the residual heat of cure. The degree of resin cure varied significantly under identical isothermal curing conditions; nevertheless a strong relationship was found between the degree of resin cure and the associated T_g. The general technique will be discussed and comparisons made between the results from two different calorimeters.

Near Infrared Monitoring of Resin Loading Prior to Assembly of Engineered Wood Products

Bruce M. Broline, Research Manager, North America, and *Reginald A. Mbachu*, Senior Research Chemist and Group Leader, Analytical Services, North America, Dynea USA, Springfield, Oregon, USA; and *Tyler G. Congleton*, Composite Products Technical Manager, Jeld-Wen Inc., Chillicothe, Ohio, USA

The determination of resin loading during assembly of engineered wood products has been attempted by a variety of methods with little success. Simple near infrared (NIR) methods employing the monitoring of fixed wavelengths provide results that are unsatisfactory for the applications we have investigated. We have developed methods employing NIR spectroscopy and multivariate analytical techniques to provide real-time values of resin loading during the assembly of engineered wood products. The technique is quite robust over a wide range of resin loading and the accuracy is not significantly affected by substrate moisture or particle size. A laboratory method of calibration was also developed to simplify implementation on a production line. Laboratory and mill data have shown this method to offer a convenient and practical on-line technique to monitor resin loading during the production of OSB, plywood, particleboard, and MDF.

Hydroxymethylated Resorcinol Coupling Agent: Stress Relaxation Analysis

Nanjian Sun, Research Associate, and *Charles E. Frazier*, Professor and Director, Wood-Based Composites Center, Department of Wood Science & Forest Products, Virginia Tech, Blacksburg, Virginia, USA

Isothermal stress relaxation was used to investigate the influence of hydroxymethylated resorcinol (HMR) coupling agent on dry yellow-poplar wood. It was found that the relaxation modulus of HMR-treated and untreated wood fit nicely to the Kohlrausch-Williams-Watts relationship. This provided insight into the HMR mechanism and how HMR alters wood relaxation in the dry state. It was found that HMR significantly stiffened wood against stress relaxation and that this effect was not attributed to simple wood bulking. This suggests that HMR actually crosslinks the wood cell wall and that the coupling

mechanism may involve wood stabilization against swelling and other mechanical stresses.

Characterizing Resin Distribution and Penetration of MDF Wood Fibers

Leslie H. Groom, Project Leader, *Chi-Leung So*, Post-Doctoral Scientist, and *Thomas Elder*, Research Scientist, USDA Forest Service, Southern Research Station, Pineville, Louisiana, USA; *Thomas Pesacreta*, Director, Microscopy Center, University of Louisiana, Lafayette, Louisiana, USA; and *Timothy G. Rials*, Professor and Director, Forest Products Center, University of Tennessee, Knoxville, Tennessee, USA

One of the primary factors governing the structural performance of medium density fiberboard (MDF) is the interaction of fiber and resin and the subsequent distribution of resin on the fiber surface and penetration into the cell wall. This study undertakes a microscopic investigation to develop a mechanistic definition of fiber-to-fiber stress transfer in MDF. Chips from wood sources defined as juvenile, juvenile-transition, mature-transition, and mature were refined at various pressures and blended with urea-formaldehyde resin of various molecular weights (low, standard, high). Both blowline and drum blending were investigated. MDF furnish and corresponding panels were sampled for resin distribution on the fiber surfaces and penetration into the cell wall lumen. Resin distribution and penetration patterns for low MW resin were distinctly different from high MW resins as investigated on the fiber furnish samples. Pressed panels show that these differences are minimized when subjected to pressure and temperature. Qualitative analyses show that resin penetration into cell wall lumens is much greater in blowline blending as compared to corresponding drum blending.

Dielectric Characterization of Phenol-Formaldehyde Adhesive Cure

Fred A. Kamke, JELD-WEN Professor of Wood-Based Composite Science, Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA

Dielectric spectroscopy has been used with mixed success to monitor the polymerization of thermoset adhesives. This technique is sensitive to the motion of polar groups within the polymer network that dissipate the energy within the applied electric field. Waterborne adhesives, such as phenol-formaldehyde and urea-formaldehyde, pose a special problem because of interference by the polar water molecule. This paper discusses the application of fringe-field and parallel-plate dielectric spectroscopy to the cure of phenol-formaldehyde adhesive bondlines in wood. The use of multiple frequencies permits a certain degree of specificity, thus minimizing the signal influence induced by the movement of water. Two phenol-formaldehyde adhesives were used for this study. The difference between these resins was only the degree of advancement of the polymerization during the resin cook. Both the fringe-field and parallel-plate methods detected differences between these resins in the rate of change of permittivity and loss-factor during cure. The parallel-plate method is influenced by all molecular components with dielectric behavior that reside within the electric field, and therefore, the dielectric measures are less distinct.

Use of X-Ray Photoelectron Spectroscopy for Characterization of Wood Surfaces in Adhesion Studies

James F. Beecher, Group Leader, and *Charles R. Frihart*, Project Leader, Wood Adhesives Science & Technology, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA

An understanding of wood adhesion has been limited by the ability to fully characterize the bonding surfaces. X-ray photoelectron spectroscopy (XPS or ESCA) is one of a set of tools that have been used in characterizing wood surfaces. XPS has provided chemical information about failure surfaces and chemically modified wood surfaces. Among the advantages of XPS are: surface sensitivity, identification of nearly all elements and, frequently, discrimination of bonding states. Some care needs to be taken to ensure correct analysis of the high-resolution spectra. Examples of XPS use for a specific adhesion study are given, including the analysis of acetylation of cellulose and wood. The procedures and use of trifluoroacetic anhydride for analysis of reactive hydroxyl groups are also described.

SESSION 1B: Bond Durability

A Proposed Mechanism for Adhesive Bonding Using Hydroxy Methyl Resorcinol (HMR)

Douglas J. Gardner, Professor of Wood Science, Department of Forest Management and Advanced Engineered Wood Composites Center, University of Maine, Orono, Maine, USA; *Charles E. Frazier*, Professor and Director, Wood-Based Composites Center, Department of Wood Science & Forest Products, Virginia Tech, Blacksburg, Virginia, USA; and *Alfred W. Christiansen*, Retired Chemical Engineer, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA

A recent collaborative effort among the USDA Forest Products Laboratory, Virginia Tech, and University of Maine has explored the possible bonding mechanisms contributing to durable wood adhesive bonding using hydroxymethyl resorcinol (HMR) surface treatment. Current adhesive bonding mechanisms include: mechanical interlocking, electronic or electrostatic theory, adsorption, (thermodynamic) or wetting theory, diffusion theory, chemical (covalent) bonding theory, theory of weak boundary layers and interphases. In this paper, the findings of the research project will be presented and categorized relative to current adhesion bonding mechanism theories. In addition, consideration will be given to HMR's impact on adhesion bonding relative to interactions across different length scales from molecular to macroscopic. HMR has been shown to diffuse into the wood cell wall on the molecular scale, and appears to associate with lignin based on similar solubility behavior. Within the cell wall, HMR chemically cross-links contributing both to an increased stiffness of the wood material and improved dimensional stabilization on a macroscopic scale.

Assessment of Increased Wet-Wood Strength for Epoxy Bonded Samples Using a Melamine-Urea-Formaldehyde Priming Agent

Jermal G. Chandler, Chemist, and *Charles R. Frihart*, Project Leader, Wood Adhesives Science & Technology, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA

Is the hydroxymethylated resorcinol primer unique or can a melamine-based primer also increase the wet-wood strength of epoxy bonds? Although the exact mechanism for poor durability with some wood adhesives is not known, a hydroxymethylated resorcinol (HMR) priming agent was found to facilitate durable bonds in most cases tested. The model of cell wall stabilization for the role of the HMR primer led to the consideration of melamine-based primers. Previous studies have shown that melamine resins can increase the hardness of the cell walls of wood and lower the modified wood's volumetric swelling in water. Primer formulations of melamine-urea-formaldehyde have yielded higher wood failure and shear strengths bonded with an FPL-1A epoxy using ASTM D-905 block shear samples under wet conditions than did unprimed bonded samples. The primer was most effective at high dilutions and dropped off at concentrations of 5% solid or greater. Hexamethylolmelamine methyl ether and a commercial melamine-formaldehyde adhesive were also effective in improving epoxy bonded wood assemblies. Thus, the properties of HMR are not unique and may be related to modification of wood cell walls near the surface.

Influence of RF Cure Time on the Performance of Poly(vinyl acetate) Latex Adhesives

Austin E. Graybill, Former Student, and *Nicole R. Brown*, Assistant Professor of Wood Chemistry, School of Forest Resources, Pennsylvania State University, University Park, Pennsylvania, USA

This project explores the effect of four different RF cycle times on the bonding performance of a latex adhesive. In particular, edge glued panels made from yellow-poplar (*Liriodendron tulipifera*), were bonded with a crosslinking poly(vinyl acetate) latex adhesive. The four different cycle times include 60, 80, 100, and 120 seconds. All edge-glued panels were prepared in a commercial manufacturing facility in southeastern Pennsylvania. Performance of the samples was examined through the use of compression shear block tests. Samples were exposed to a given accelerated aging condition prior to testing. Dynamic mechanical analyses (DMA) were also conducted on samples extracted from the edge glued panels. Like the compression shear block samples, these specimens will be exposed to accelerated aging conditions prior to analysis. DMA samples were examined in both shear and cantilever testing modes. The effect of accelerated aging treatments and RF cycle times will be discussed in detail.

The Effects of Chemically Modified Wood on Bond Durability

Rishawn L. Brandon, Chemical Engineer, Rebecca E. Ibach, Research Chemist, and Charles R. Frihart, Project Leader, Wood Adhesives Science & Technology, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA

Chemical modification of wood improves its dimensional stability and biodegradability, and creates a new surface for bonding. Acetylation, results in the loss of hydroxyl groups that makes the wood hydrophobic and can reduce hydrogen bonding with the adhesive. Reacting wood with butylene oxide and propylene oxide not only modifies the wood hydroxyls, but also generates another hydroxyl group for each one reacted, which should result in better bonds due to hydrogen bonding with the adhesive. The effectiveness of adhesion was evaluated by measuring the dry and wet shear strength and percent wood failure. The unmodified and modified wood specimens were bonded with four adhesives: epoxy, emulsion polymer isocyanate, melamine formaldehyde, and resorcinol formaldehyde. The ability of butylene oxide and propylene oxide to give better bonds could not be fully determined because even though the modifications enhanced wood failure percentages, they made the wood substantially weaker. Except for the emulsion polymer isocyanate, all adhesives gave stronger bonds with the acetylated wood than the untreated wood especially under water-saturated conditions.

Evaluation of Wood Adhesives for a Glue-Laminated Softwood

Gary M. Raftery, Ph.D. Student, and Annette M. Harte, Senior Lecturer, Department of Civil Engineering, National University of Ireland, Galway, Ireland

Structural glue laminating is a successful technique for eliminating or controlling naturally occurring strength reducing defects that regularly appear in larger size low-grade wood members. Despite a wide range of adhesives currently available for laminating softwood, little comparison has been made between their performance for both bond strength and durability. The notched shear block test was utilized in this study where six adhesives were examined to determine the ultimate shear strength obtained when bonding parallel to grain specimens of Irish grown Sitka spruce. Adhesives examined included a melamine urea-formaldehyde, a polyurethane, an emulsion polymer isocyanate, a polyvinyl acetate, and two phenol resorcinol formaldehydes. Testing of specimens was carried out for both ambient and accelerated aging conditions, which involved vacuum-pressure soak cycling. Parameters varied, depending on the adhesive being studied, included clamping time, clamping pressure, adhesive spread rate, single or double face application and quarter sawn or plain sawn grain arrangement. Bond shear strength values were compared to clear solid wood specimens sheared in the tangential, radial, and cross-grain directions. The failure modes varied between large percentages of solid wood failure in the shear plane, failure along annular ring, adhesion failure, or cohesive failure. Adhesive type proved significant in the bond integrity for both ambient and accelerated-aging tests. In general, specimens subjected to accelerated aging conditions failed at lower shear strengths than those tested at ambient conditions. Furthermore, the combination of parameters selected during the test program was influential on the effectiveness of the bond strength.

Penetration and Performance of pMDI Resin on Selected Wood Species

Timothy M. Gruver, Graduate Research Assistant, and Nicole R. Brown, Assistant Professor of Wood Chemistry, School of Forest Resources, Pennsylvania State University, University Park, Pennsylvania, USA

Methylene diphenyl-di-isocyanate (pMDI) has proven itself as a strong, durable thermosetting resin for structural wood composites. The underlying reasons for the outstanding performance of pMDI have been researched in some detail. Recent research by Malmberg and Frazier has suggested that adhesive performance exhibits a dependency on the species of the wood substrates. Das and Frazier are further exploring this result through solid state NMR and DMA studies. However, other important issues have yet to be studied. The goal of this research is to further explore the species dependent performance of pMDI. Specifically, the effect of anatomical differences among species will be studied, as this could impact adhesive penetration. In addition, different moisture contents of each wood species will also be tested to determine if it also affects performance of the pMDI/Wood bondline. Aspen (*Populus grandidentata*), yellow-poplar

(*Liriodendron tulipifera*), and southern yellow pine (*Pinus spp.*) wood species were chosen for initial studies due to their commercial importance and their anatomical and chemical features. Preliminary data will be acquired by testing and comparing adhesively bonded compression shear blocks, as described in ASTM D-905. The species exclusive shear blocks will reveal bondline strengths and the percentage of wood failure. Adhesive penetration in the compression shear block samples will also be quantitatively assessed with fluorescence microscopy. These findings will provide more detail regarding the species dependent performance of isocyanate resins.

Rheological and Fracture Cleavage Analysis of the Effects of Phenolic Additives on the Durability of PVAc Latex Adhesives

Francisco Lopez-Suevos, MECD/Fulbright Post-Doctoral Visiting Scholar, and Charles E. Frazier, Professor and Director, Wood-Based Composites Center, Department of Wood Science & Forest Products, Virginia Tech, Blacksburg, Virginia, USA

Resol type phenol-formaldehyde (PF) resins are common additives employed to promote greater crosslinking and durability of poly(vinyl acetate) latex adhesives. The objective of this work is to evaluate how a commercial PF additive influences the viscoelastic properties of PVAc films and of wood/PVAc composites, and if detected effects correlate with performance. Time-temperature transformations were conducted by parallel-plate dynamic mechanical analysis to evaluate relaxations associated with the PVAc glass transition. This novel analysis compares the rheological properties of freestanding films with films bonded directly to wood, using completely dry samples in both cases. Adhesive performance was evaluated through Mode-I fracture testing. Correlations between fracture testing and rheological analyses are discussed.

THURSDAY AFTERNOON, NOVEMBER 3

CONCURRENT SESSIONS

SESSION 2A: Resin Synthesis and Analysis

Static and Dynamic Mechanical Methods for Evaluating Wood/Adhesive Interactions

Sudipto Das, Graduate Research Assistant, and Charles E. Frazier, Professor and Director, Wood-Based Composites Center, Department of Wood Science & Forest Products, Virginia Tech, Blacksburg, Virginia, USA

In the past, mechanical measurements have revealed insight about the *in situ* nature and ordering of structural wood polymers. In recent years, instrumental sensitivity has improved such that mechanical measurements of wood relaxations might now be described as mechanical spectroscopy. In other words, progressive developments in thermomechanical analysis have improved our ability to apply the principle of time/temperature equivalence for purposes of mapping wood relaxations. The temperature dependence of wood relaxations can reveal relatively minor cell wall perturbations that are caused by chemical treatments, as, for example, from thermosetting adhesives. Two approaches are useful, dynamic and static, respectively as in isothermal frequency sweeps or isothermal creep experiments. The master curves resulting from each approach have certain advantages and disadvantages, as will be discussed; and while these techniques are improving, the complexity of the wood cell wall still prevents an unambiguous interpretation of wood relaxations.

UMF Resin Diffusion into MDF Wood Fibers

Pierre-Louis Cyr, Ph.D. Candidate, and Bernard Riedl, Senior Professor, Department of Wood & Forest Sciences, Université Laval, Québec City, Québec, Canada; Xiang-Ming Wang, Research Scientist and Group Leader, Forintek Canada Corporation, Sainte-Foy, Québec, Canada; and Stephen M. Shaler, Professor and Assistant Director, Advanced Engineered Wood Composites Center, University of Maine, Orono, Maine, USA

Resin efficiency is a major concern for the fiberboard industry. Some recent publications showed that board internal bond strength is strongly affected by resin distribution on the wood fibers. It has also been demonstrated that resin pre-cure and resin diffusion into wood fibers may negatively affect board properties. This study, based on some of the most recent techniques of fiber and adhesive visualization, describes the mechanisms of adhesion of urea-based resin on fibers. MDF fiber samples were analyzed with an atomic force microscope

(AFM) and a confocal laser scanning microscope (CLSM) to study the resin and fiber interactions. Diffusion of urea-melamine-formaldehyde (UMF) resin into wood fibers is different than its diffusion into solid wood. Instead of progressing along fibers, resin droplets, when sprayed on the fiber, tend to stay where they land. Because of the small size of the droplets, diffusion is not affected by gravity. Penetration of the resin toward the lumen occurs as soon as the resin makes contact with the fibers. A resin diffusion model, based on capillary forces and the resin's rheological properties, has been developed. Predictions from this model showed that diffusion only occurs when the resin's viscosity is under 1000 cps. The highest diffusion rate is reached at the beginning of the curing process, when resin's viscosity is the lowest. The final depth of penetration of catalyzed UMF resin into dry spruce fibers can be as low as 1 μ m when mixed in a drum blender at room temperature for a short period of time.

Demonstration of Co-polymerization in Melamine-Urea-Formaldehyde and Cellulose-Urea-Formaldehyde Reactions Using ^{15}N NMR Correlation Spectroscopy

Amy Philbrook, Ph.D. Candidate, Research School of Chemistry, Australian National University, Canberra, Australia; *Noel Dunlop*, Senior Technologist, Orica Australia Pty. Ltd., Deer Park, Victoria, Australia; and *Christopher J. Easton*, Professor of Organic Chemistry, and *Max A. Keniry*, Research Fellow, Research School of Chemistry, Australian National University, Canberra, Australia

Melamine-urea-formaldehyde (MUF) resins are used in the manufacturing of water-resistant particleboards, papers and laminates. The three resin components react in a two-step process to form polymers. By using ^{15}N -labeled melamine and urea in ^1H - ^{15}N HMQC NMR experiments we have developed a tool that identifies co-polymer cross-peaks in MUF reactions. In order to distinguish between methylene and ether-bridges between melamine and urea moieties a doubly selective ^1H - ^{15}N - ^{13}C CP-INEPT NMR experiment was developed which correlates the ^1H - ^{15}N resonance pairs with the directly-bonded ^{13}C s. This technique has been further developed to investigate co-polymerization in other resin systems. Wood fiber contains between 30-60% cellulose depending on the species. The hydroxymethyl group in the C6 position in the cellulose unit could react with hydroxymethylurea forming a dimethylene-ether linked species. A mono-glucose unit, methyl- β -D-glucopyranoside was used as the cellulose model compound. The NMR techniques developed to establish co-polymerization in MUF resins were applied to determine that UF resins form dimethylene-ether bridges with a cellulose model compound.

Various Synthesis and Storage Parameters of Urea-Formaldehyde Resins and Particleboard Bonding and Formaldehyde Emission Performance

Moon G. Kim, Professor, Department of Forest Products, Mississippi State University, Mississippi State, Mississippi, USA

Results of investigations on various synthesis and room temperature storage parameters of urea-formaldehyde resins were studied, including: formaldehyde/first urea mole ratios, extents of polymerization, addition methods of second urea, storage temperatures and times, and low levels of melamine added. The parameters were examined by ^{13}C NMR and other characterization methods and a selected series of resins was evaluated by bonding particleboard and testing for physical properties and formaldehyde emission. Various ways of optimizing and improving urea-formaldehyde resins for better bonding and lower formaldehyde emission are suggested.

Characterization of Adhesive Behavior Under High Temperature for Engineered Wood Products

Sheldon O. Shi, Assistant Professor, Department of Forest Products, Mississippi State University, Mississippi State, Mississippi, USA

In the recent years, the market share of engineered wood products (EWPs) in building constructions has been increased significantly. These EWPs utilize small-diameter trees or residues as raw materials and reassemble the lumber and panel products with adhesives. Therefore, the adhesive bonding strength and the bond durability are very critical to the EWPs. In residential and commercial building codes, durability during a fire is one of the increasingly important performance concerns for glued structural components. In a structure fire, the structural components in the building should ideally maintain their structural integrity for some time after fire initiation. Questions are being asked whether the adhesives used in the EWPs can hold up the wood components when the temperature rises to a certain degree. The objective of this research work is to investigate the effect of elevated temperature on the adhesive bondline of EWPs. In this research, three

commonly-used engineering adhesives will be evaluated: phenol-resorcinol-formaldehyde (PRF), melamine-formaldehyde (MF), and isocyanate-based adhesive. The cured resin films will be carefully prepared simulating the actual curing process during application to a wood component. Micro/nano indentation technique will be used to characterize the resin films at different temperatures (75°C to 400°C). The indentation technique involves applying a vertical load through an indenter to the carefully prepared resin film samples. The indenter tip with a known geometry is driven into a specific site of the resin films to be tested by applying an increased normal load. When reaching a preset maximum value, the normal load is reduced until partial or complete relaxation. During the testing, the position of the indenter relative to the sample surface is precisely monitored with a differential capacitive sensor. The resulting load-displacement curves provide data specific to the mechanical nature of the resin film under examination. These micro-mechanical properties of the adhesive resin films will help to develop a better understanding of the fire performance of EWPs.

Characterizing Local Curing of Liquid Phenol-Formaldehyde Resin on Wood Surfaces Using Micro-Thermal Analysis

Anbu Clemensis Johnson, Post-Doctoral Fellow, and *Ning Yan*, Assistant Professor and Associate Director, Pulp & Paper Centre, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada

It is well known that wood has a marked influence on the cure mechanism of phenolic resins. It has been shown using micro-thermal analysis (μ -TATM) that curing behavior of liquid phenol-formaldehyde resin is significantly affected by the substrates. μ -TA is a hybrid which combines the principles of atomic force microscopy (AFM) with that of thermal analysis. It can perform a local thermal analysis on a spot of 1 micron in size. Essential thermal parameters such as glass transition temperature and cure onset were detected. It was found that certain wood species, such as pine and oak, accelerated the curing rate while other substrates, such as birch and glass substrate retarded the resin curing. The exothermic event associated with the phenol-formaldehyde curing was also detected for wood substrates and was almost absent in the case of glass substrate. This seems to suggest wood has certain catalytic effect on the curing of the phenol-formaldehyde resin.

SESSION 2B: Properties of Engineered Products

Experience in Engineered Wood Applications with Moisture Curing One-Component Polyurethane Adhesives in Europe

Joseph Gabriel, Technical Director, Purbond AG, Sempach-Station, Switzerland

The use of one-component moisture curing, 100% solid polyurethane (1K PUR) adhesives for bonding wood started about 40 years ago. Due to strict regulations in most European countries, these types of adhesives were not initially accepted for the production of load bearing elements like beams. The laws in Switzerland, however, are different. Only the load bearing elements themselves have to comply with the Swiss building code, not the adhesives for bonding them. About 20 years ago, a few glulam producers did pioneering work and began producing structural beams with 1K-Polyurethane adhesives. Based on their positive experience, adhesive manufacturers then tried to get approvals for their adhesives from the leading certification body in Europe, the German 'Otto-Graf-Institut' (FMPE). These efforts were successful in the early 90s, when the first 1K PUR-adhesives received a German certification. The products were the first 'not water- and formaldehyde-based' adhesives to get the approval for load-bearing applications in Europe. In subsequent years, other countries followed and more types of 1K PUR-adhesives entered the market. The first commercially successful 1K-PUR adhesive with an approval - PUR-BOND HB 110 - has now been in use for engineered wood for more than 10 years. This long history of use now allows assessing the long-run behavior of PUR's in practice. In recent years, substantial research has been conducted at various laboratories and institutes to investigate the benefits and drawbacks of 1K-PURs versus conventional water-based adhesives for structural wood applications. This paper summarizes the most important aspects of the results of these studies, and also field experience gathered in Europe over the last 20 years with 1K-PURs.

Melamine-Formaldehyde Adhesives as Structural Laminating Resins

Michael M. Goerger, Senior Research Chemist, Dynea USA, Springfield, Oregon, USA

Melamine-formaldehyde (MF) resins have been used for years in the construction of structural wood items, primarily to “fingerjoint” lumber together. There has been increasing interest in using MF resin as the main adhesive on the faces of laminate lumber to form multiply beams, known typically as glulam beams or laminated beams. A few reasons for this increased interest are that they produce a clear glue line and provide the possibility of increased cure speed, leading to higher throughput. There is debate within the industry as to what testing is required to certify that a “new adhesive” is acceptable for external structural beams. One criterion lists ASTM-D3434 as a necessary test. There is little published data on the performance of MF resins using this test. This paper will compare results of different MF resin types tested by ASTM-D3434. It will also briefly compare some of these results with ASTM-D2559, an industry standard for existing structural adhesives. A brief look at the effect of hardener choice on results will also be presented.

Melamine and Melamine-Urea Adhesives for the European Glulam Market

Kristin Grøstad, Chief Research Scientist, and *Egil B. Ormstad*, Senior Technical Manager, Product Development Europe, Dynea ASA, Lillestrøm, Norway

The laminated timber industry in Europe has been through a tremendous change during the recent years. The number of producers has been reduced, but the production volume has increased, resulting in larger production units and more specialized production processes with higher efficiency. The main application areas are standard beams, glulam for special projects (order production), and posts for Japan. The adhesive types vary from PRF to MUF/MF and EPI and even PUR for a few applications. Due to this development, the adhesive manufacturer is now an even more important partner for further improvement and optimization of glulam production. The first modern MUF adhesive was introduced into the European market in 1987 with great success. The market required a cold setting, water resistant, and light-colored glue line. Since then new MUF/MF adhesives for glulam have been developed, and press time has been reduced from 10-13 hours down to 2-3 hours at 20°C. The after-cure time is now in the range of 1-3 days at 20°C, in other words at the same level as for PRF adhesives. Some systems in the market are very flexible with respect to application units and may be used both in a separate application and mix-in equipment. By changing the resin-to-hardener ratio, the pot life, the assembly time, and the press time may be varied. This gives glulam producers the possibility of using only one adhesive system for both glulam production and fingerjoints. The systems are flexible and can be cured with all the common curing techniques such as cold cure, hot cure, and radio-frequency (RF) cure.

Adhesive Performance at Elevated Temperatures for Engineered Wood Products

Borjen Yeh, Director, Technical Services Division, and *Benjamin Herzog*, Staff Scientist, APA - The Engineered Wood Association, Tacoma, Washington, USA; and *Parry Ipsen*, New Product Engineer, and *Rob Brooks*, Raw Material Technical Manager, Trus Joist - A Weyerhaeuser Business, Boise, Idaho, USA

Phenolic-based adhesives have traditionally been used in the manufacture of engineered wood products, such as I-joists and laminated veneer lumber (LVL), in North America. In the last few years, however, an unprecedented number of non-phenolic-based adhesive systems, such as polyurethane-based and isocyanate-based adhesives, have been introduced to the engineered wood products industry. While these relatively new adhesives have demonstrated their compliance with most international adhesive standards, concerns have been raised by the fire services and others on the performance of these adhesives at an elevated temperature, such as just below the ignition temperature of wood. While full-scale fire assembly tests, such as ASTM E119, CAN/ULC S101, or ISO 834, address the fire performance of wood assemblies, no international adhesive standards exist in testing the adhesive, as a critical component of engineered wood products, to such an elevated temperature. A task committee was formed in June 2004 by the engineered products industry in North America to address this issue with input from key adhesive suppliers to the industry. Through coordinated efforts, an industry standard, APA/WIJMA AC1000-05, was developed and adopted by the engineered wood products industry in March 2005.

This paper presents the background information and test data used to develop the industry standard.

Thermal Stability of Structural 1 P PUR Adhesives

Klaus Richter, Head, Wood Laboratory, and *Michel Barbezat*, Research Scientist, Laboratory of Materials & Engineering, Empa, Swiss Federal Laboratory for Materials Testing & Research, Duebendorf, Switzerland; *Antonio Pizzi*, Professor of Industrial Chemistry, ENSTIB, and Deputy Director, LERMAB, Integrated Research Unit INRA/ENGREF, University Henri Poincaré-Nancy 1, Epinal, France; and *Aurelien Despres*, Ph.D. Student, ENSTIB, University Henri Poincaré-Nancy 1, Epinal, France

The mechanical performance of seven one-part polyurethane (1 P PUR) adhesive systems under increased temperatures was analyzed and compared with their adhesive formulation characteristics. Dynamic thermo mechanical analysis (DTMA) was applied to evaluate the viscoelastic nature of bonded joints, and static load resistance of lap-shear samples was determined under increasing temperature. All adhesives were analyzed with liquid ¹³C-NMR in order to assess their formulation and polymerization characteristics. Mechanical and TMA tests revealed that some adhesives systems studied perform sufficiently well and do not show noticeable creep at increasing temperatures, whereas others tend to creep at temperatures above 40°C especially when the bondlines of 0.5mm thickness were evaluated. Post-curing of the bondline at 80°C for 4h reduced the creep effects slightly. Relative proportions of PMDI to TDI and the degree of polymerization in the different adhesives systems were related to the temperature creep behavior of the bonded adhesives. Recommendations for the formulation of safe and low-temperature creep 1 P PUR adhesives are proposed.

Strength Properties of Wood Adhesives After Exposure to Fire

Björn A. Källander, R&D Manager, SP Trätekt, Swedish National Testing & Research Institute, Wood Technology, Borås, Sweden; and *Per Lind*, Utilization & Durability, NTI Norwegian Institute for Wood Technology Research, Oslo, Norway

A comparative study of the properties of five different adhesives before and after exposure to fire was conducted. The adhesives used ranged from D4 PVA to Type I PRF. Unloaded glulam beams of dimensions 138 x 240 x 1100mm were exposed to standard fire exposure conditions and internal wood temperatures were determined. Charring rate and open glue lines were determined. Shear strength and resistance to delamination were determined prior to and after fire exposure. Results of the study were compared to results of creep rupture tests at elevated temperatures of adhesives in the study. A theoretical study of internal temperatures in smaller and dryer beams was carried out to evaluate the need for further tests. The results show small differences in charring rate or open glue lines between beams glued with different adhesives. Shear strength was reduced after fire exposure while resistance to delamination was improved for all adhesives. The results indicate that a larger glulam beam produced with adhesives that have passed a creep rupture test at elevated temperatures also will perform well under exposure to fire. However, a study of smaller beams indicates that further research is needed in order to study the performance of small cross-sections exposed to high temperatures.

Shear Fracture Properties of Green-Glued Polyurethane Adhesive Bonds

Magdalena Sterley, Research Engineer, SP Trätekt, Swedish National Testing & Research Institute, Wood Technology, Stockholm, Sweden; and *P.J. Gustafsson*, Professor, Division of Structural Mechanics, Lund Institute of Technology, Lund, Sweden

The shear fracture properties of green-glued polyurethane wood adhesive bonds subjected to kiln drying were investigated. The local shear strength and fracture energy of the wood adhesive bonds were determined from experimentally recorded complete shear stress versus deformation curves of the bondline. A stable test set-up and small specimens that were anti-symmetrically loaded were used in order to get a uniform and pure state of shear stress. Different moisture contents (MCs) and pressing times were investigated. The fracture properties of conventionally dry-glued polyurethane wood adhesive bonds were used as reference. The results show that the fracture energy of green-glued bonds with PUR adhesive is dependent on the MC of wood and on press time. The same fracture energy and strength can be obtained by green gluing as by dry gluing, but there seems to exist a maximum MC of sapwood, in the range between 78% and 160%, and a minimum press time, in the range between 3h and 48h, for which it can be achieved.

Utility of Horioka's and Marra's Models for Adhesive Failure

Charles R. Frihart, Project Leader, Wood Adhesives Science & Technology, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA

Failure of wood bonds is often done using the general classification of wood failure or adhesive failure. However, to clearly understand performance more detail failure analysis is needed. Horioka and Marra have proposed models that define failure zones for wood bonds. These types of models can have utility for thinking about the weak links in bonds and for classification of the failure types. Models can also be used to relate bond formation issues to adhesive failure. However, it is important to realize that mechanical properties from the bulk adhesive to the bulk wood are not divided into discrete domains, but are a continuum of change. Additionally, the complex forces upon a bondline are not easy to understand by the link analogy. The suitability of these models is evaluated and the Marra model is extended to relate bond formation problems to specific types of failures.

Moving Beyond Commodity Composite Products - Into a New Realm

Philip E. Humphrey, Founder, Adhesive Evaluation Systems, Inc., and Affiliate Professor, Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA

Most present day wood-based composites have properties which are standardized to satisfy quite diverse service demands. Compromise in performance and efficiency is an inevitable consequence. With innovations in materials science, miniaturization, and process control, the automated mass production of new strong and light bio-based objects which are highly and uniquely tailored to specific end-use demands may be possible. The envisioned array of products entails the manipulation of both external shape and the spatial distribution of internal micro-structure. Such objects could challenge substantial markets presently dominated by non-ferrous alloys, forged steel, polymers, and ceramics in a diversity of applications - from household items to aircraft structures. The vision has grown from our fundamental analysis and modeling of material behavior during the production of conventional panel products, where heat and gas movement, adhesion and consolidation mechanisms interact to profoundly effect product structure and properties. Technologies for rapidly forming highly tailored molded objects with orientation of specially selected fibers, and process-induced property gradients, are being conceptualized. The potential impact of such a development philosophy on engineering design, aesthetics, and the environment could be far reaching. This discussion will explore these ideas.

Are Epoxy-Wood Bonds Durable Enough?

Charles R. Frihart, Project Leader, Wood Adhesives Science & Technology, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA

An important aspect of any adhesive bond is that the bond maintains its integrity under use. Epoxies generally form very durable bonds with most substrates, but are usually not considered to form completely durable bonds with wood. However, epoxies are sold for boat construction, and other data has indicated the sufficient durability for some epoxies. This raises the questions on the appropriateness of the durability test methods. Several models are considered for their ability to explain the inconsistency of durability observations with epoxies. The results of bond failure analysis, ability to bond acetylated wood, and bond durability to wood primed with hydroxymethylated resorcinol or melamine-based primers have helped to limit the number of models that explain epoxy bond durability.

CONCURRENT SESSIONS

SESSION 3A: Bio-Based Adhesives

Investigation of Green Wood Adhesives from Soy Protein

Yuan Liu, Ph.D. Student, and *Kaichang Li*, Associate Professor, Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA

Formaldehyde is a human carcinogen. However, formaldehyde-based synthetic resins such as urea-formaldehyde resins are commonly used for production of wood composites. To cope with waves, mussels stick to rock or other substances through secreting a proteinaceous adhesive. The mussel adhesive protein is an environmentally friendly, strong, and water-resistant adhesive, but is expensive and not readily available. The protein contains a high amount of phenolic hydroxyl groups, amino groups, and disulfide linkages. We have previously demonstrated that increasing the amount of a phenolic hydroxyl group or a mercapto group in soy protein, converted soy protein to a strong and water-resistant wood adhesive. In this study, we explored various methods to increase the amount of free amino groups in soy protein and demonstrated that increasing the amount of free amino groups in soy protein greatly improved the adhesive properties of the modified soy protein. The adhesion mechanisms of this new adhesive will be discussed in detail.

Application of Liquefied Wood Prepared by Ozone Treated Wood: Synthesis and Properties of Liquefied Wood/Epoxy Resins Having a High Wood Content

Masahiko Kobayashi, JSPS Research Fellow, Department of Wood-Based Materials, Composite Products Laboratory, Forestry & Forest Products Research Institute, Tsukuba, Ibaraki, Japan; *Toshiyuki Asano*, Principal Researcher, Ibaraki Industrial Technology Center, Ibaraki, Japan; and *Bunichiro Tomita*, Professor, and *Mikio Kajiyama*, Associate Professor, Graduate School of Life & Environmental Science, University of Tsukuba, Ibaraki-ken, Japan

Liquefied wood having a high wood-to-polyhydric alcohol ratio (W/P ratio) can be prepared by using ozone treated wood. In this study, a liquefied wood/epoxy resin was prepared by mixing the liquefied wood and two types of epoxy compounds; one is a water soluble epoxy compound (ethylene glycol diglycidyl ether: EGDGE) and the other is an oily epoxy compound (diglycidyl ether of bisphenol A: DGEBA). The resins were cured by triethylenetetramine (TETA) or citric acid, and their mechanical properties were measured. By using liquefied wood prepared with a W/P ratio of 2/1 as a raw material, the wood content of the blending resin could be increased to a maximum of 53%. The results from dynamic mechanical measurements indicated that the resins cured by citric acid had higher glass transition temperature than those cured by TETA for each epoxy compound. It was also found that liquefied wood/DGEBA resins cured by citric acid had almost the same level of tensile strength as commercial phenol- or melamine-formaldehyde resins.

Mechanical and Physical Properties of Bio-Composites from Wood Fiber and Liquefied Wood/Phenol/Formaldehyde Co-Condensation Resin

Hui Pan, Graduate Research Assistant, and *Todd F. Shupe*, Associate Professor, School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, Louisiana, USA; and *Chung-Yun Hse*, Research Forest Products Technologist, USDA Forest Service, Southern Research Station, Pineville, Louisiana, USA

Compression molded composites were made from wood fiber and a liquefied wood/phenol/formaldehyde co-condensation resin. The preparation of the liquefied wood/phenol/formaldehyde co-condensation resin consisted of two steps: 1) preparation of liquefied wood, and 2) preparation of liquefied wood/phenol/formaldehyde co-condensation resin. For step one, different ratios of wood powder and phenol (P/W=1/1, 2/1, 3/1) were mixed and reacted at 160°C for 120 minutes. The whole mixture from step one was mixed with different molar ratios of formaldehyde (F/P=0.6/1, 0.7/1, 0.8/1) and reacted at 105°C for 80 minutes. The three experimental variables selected were: 1) phenol to wood ratio (P/W) in the liquefaction reaction, 2) formaldehyde to phenol ratio (F/P) in the co-condensation reaction, and 3) oxalic acid (as a catalyst) content in the co-condensation reaction. Panels were tested in static bending for modulus of rupture (MOR) and modulus of elasticity (MOE). Dimensional stability properties were also measured. The results of the flexural test indicated that P/W

ratio had a significant effect on both MOR and MOE of the composites. Oxalic acid content had a significant effect on MOR, but not MOE. The F/P ratio had no effect on either MOR or MOE. Water soaking (24h) and boiling (2h) tests both showed similar trends on dimensional stabilities of the composites. Both P/W ratio and F/P ratio had significant effects on thickness swelling of the composites. Oxalic acid content showed no influence on the dimensional stabilities of the composites.

Durable Soy-Based Adhesive Dispersions

James M. Wescott, Chief Technology Officer, and *Amy Traska*, Technologist, Heartland Resource Technologies, Waunakee, Wisconsin, USA; and *Charles R. Frihart*, Project Leader, Wood Adhesives Science & Technology, and *Linda Lorenz*, Chemist, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA

Acidic soybean flour/phenol-formaldehyde dispersions have been found to be more versatile and cost-effective than similar formulations at basic pHs, despite recent improvements in the technology. Soybean flour-based adhesive dispersions have been prepared by the acidification of alkaline-denatured, formaldehyde-modified soybean/phenol-formaldehyde co-resin systems. The resultant dispersions contain from 40-70% soybean flour and demonstrate room temperature viscosity stabilities in excess of 100 days with no observed separation or settling. The pH of these adhesives ranges from 4-6 with typical viscosity values from 200-800 cps. Randomly oriented strandboard panels were prepared from the dispersions. These panels demonstrated excellent durability comparable to a commercial phenol-formaldehyde control resin. Also, the low pH of these resin system also allows for lighter colored gluelines in the finished product with as much as 77% reduction in total phenol. The cost savings of these resin systems is estimated to be 40-50% when compared to commercial phenol-formaldehyde resins currently being employed.

Liquefaction of Wood with ϵ -Caprolactone and Application to Wood Adhesion *in situ*

Masayuki Kiyabu, *Hiroko Yamada*, and *Shunsuke Abe*, Graduate Students, *Bunichiro Tomita*, Professor, and *Mikio Kajiyama*, Associate Professor, Graduate School of Life & Environmental Science, University of Tsukuba, Ibaraki-ken, Japan

The liquefaction of wood was performed by using a mixture of ϵ -caprolactone and ethylene glycol or glycerol as solvents and sulfuric acid as catalyst. Its progress was investigated by determining the solubility to dimethyl formamide and changing the solvent ratio and reaction temperature. It was found that liquefaction produces a long reaction time after the reaction once attains the maximum liquefaction point. The temperature dependence of viscoelastic properties, ultimate strength, and chemical properties of the cured solid materials were investigated, and the application of liquefied wood to wood adhesive was attempted. Further, the liquefaction procedures were applied directly to wood adhesion, wood adhesion *in situ*. Namely, the mixtures of solvents including ϵ -caprolactone, polyethylene glycol, or glycerol and sulfuric acid were spread on the surface of veneers to produce plywood and the liquefaction was performed directly in the adhesive layers. The results showed that the wood adhesion *in situ* could produce good bond strengths for plywoods.

Bonding Properties of Konjac Glucomannan and Chitosan Composites

Kenji Umemura, Assistant Professor, Laboratory of Sustainable Materials, Research Institute for Sustainable Humansphere, Kyoto University, Uji, Kyoto, Japan; *Akio Inoue*, Head, Adhesion & Glue Laminating Laboratory, Forestry & Forest Products Research Institute, Tsukuba, Ibaraki, Japan; and *Shuichi Kawai*, Professor, Laboratory of Sustainable Materials, Research Institute for Sustainable Humansphere, Kyoto University, Uji, Kyoto, Japan

To develop new safe natural adhesives, bonding properties of konjac glucomannan (KG) and chitosan composites were investigated by changing the ratio of KG and chitosan. Preparing 3-ply plywood glued with these adhesives, the dry- and wet-bond strengths of the plywood were evaluated. The bond strength of soybean glue was also studied for comparison. In the case of KG alone, the maximum dry bond strength was 1.41 MPa under the solid-based spread rate of 8 g/m². The average wood failure of the samples glued with KG was observed to be less than 30%. When the water immersion test was performed, delamination occurred in all of the samples. In the case of chitosan alone, the maximum dry bond strength was 2.22 MPa in the solid-based spread rate of 32 g/m². The average wood failure of the samples glued with chitosan was observed to be less than 20%. After water

immersion treatment, the maximum wet-bond strength was 1.74 MPa in the solid-based spread rate of 32 g/m². When KG and chitosan were combined, the maximum dry bond strengths were 2.23 MPa in the condition of 8 g/m² of KG and 8 g/m² of chitosan. Wood failure was improved remarkably and a maximum average value of 70% was observed. The maximum wet-bond strength after water immersion treatment exceeded 1.2 MPa. The bonding properties of the composites were superior to that of soybean glue.

Secondary Structural Changes During Adhesive Processing of Soy Protein Isolate via ATR-IR

Jeanne N. Shera, Ph.D. Student, Thames-Rawlins Research Group, *J.W. Rawlins*, Assistant Professor, and *S.F. Thames*, University President and Distinguished University Research Professor, School of Polymers & High Performance Materials, University of Southern Mississippi, Hattiesburg, Mississippi, USA

In recent years, wood composites have grown in popularity due to limited lumber resources. Current industrial composite manufacturing methods employ formaldehyde-based resins such as urea-formaldehyde (UF) as the adhesive. Formaldehyde emissions from such materials are a health concern, as formaldehyde is listed as a known carcinogen by the World Health Organization. The Thames-Rawlins Research Group has demonstrated that soybean protein-based adhesives can be used to manufacture wood composites. The adhesives are made almost entirely from natural products and are completely formaldehyde-free. Composites fabricated with soybean protein-based adhesives demonstrate physical properties comparable to commercial particleboards manufactured with UF resin. In order to understand the interactions within these adhesives, a soybean protein study has been conducted using attenuated total reflectance infrared spectroscopy (ATR-IR). Soy protein isolate (SPI) was adjusted to varying pH levels, ranging from 7.1 to 11.5. In the amide I regions (1590 cm⁻¹ to 1720 cm⁻¹) of the treated SPI, ATR-IR spectra were deconvoluted to reveal peaks that can be attributed to protein secondary structure. As the pH of the SPI mixtures increased, peaks that can be attributed to β -sheets (1635 cm⁻¹) and β -turns (1670 cm⁻¹) were significantly less prominent. Peaks consistent with random coils (1650 cm⁻¹) and interactions between β -sheets of different protein chains remained (1620 cm⁻¹ and 1695 cm⁻¹). The shift of the protein secondary structure with increasing alkalinity will be also investigated.

SESSION 3B: Composite Products

Changes in Studies as OSB Grows-Up

Robert A. Breyer, Senior Technology Manager, *P.S. Baxter* and *J.H. Knight*, Senior Development Chemists, *J.D. Cothran*, Associate Chemist, *D.L. Atkinson* and *C.E. Vest*, Technologists, and *D.W. Price*, Development Chemist, Wood Adhesives, Georgia-Pacific Resins, Inc., Decatur, Georgia, USA

As the OSB industry has made advancements in their production lines they have required faster curing adhesives. Phenolic adhesive suppliers have traditionally focused on technologies that resulted in faster cure development. This meant the studies to evaluate the phenolic resins were focused on evaluating cure speed of the resin. This could simply be done by testing the resins ability to bond the wood as the press time is reduced. This provides a very one-dimensional evaluation of the resin. We have now moved into a new stage of development in resins. Cure speed is still important, but equally important is the operating window of the resin. The operating window of the resin is the range of conditions that the resin can still perform acceptably in the mill. These conditions include, but are not limited to changes in moisture content of the wafers and the density of the mat. A resin that is better able to handle variation will allow the mill to run at high speeds even during some upset conditions, thus improving overall output of the mill. The old one-dimensional studies were not able to evaluate the resins operating window so new designs have to be developed. This talk focuses on one approach using statistically designed experiments to compare resin performance under a wide array of conditions. This design was then validated by using resins that are similar in formulation, but manufactured differently and have been shown to have operating windows in OSB mills. The results showed the expected differences in the resins and the design was able to highlight the fine differences between the resins. The design, results, and the statistical approaches for this methodology will be discussed.

Comparison of Formaldehyde Emission from Building Finishing Materials at Various Temperatures in an Under-Floor Heating System: ONDOL

Sumin Kim, Ph.D. Candidate, and *Hyun-Joong Kim*, Associate Professor, Laboratory of Adhesion & Bio-Composites, Seoul National University, Seoul, South Korea

The objective of this research was to investigate the effect of various temperatures, 37°C and 50°C, on formaldehyde emission from floor materials, such as laminate and plywood floorings, and furniture materials, such as MDF and particleboard veneered with decorative paper foil, by desiccator method. The temperature conditions were set up by measuring the temperature in a Korean under-floor heating system. To maintain an indoor air temperature of 20°C, the temperature of the flooring surface was about 37°C and the temperature of the cement mortar was 50°C. The initial formaldehyde emission of the laminate flooring and plywood flooring was 1.44 mg/l and 0.63 mg/l, and for MDF and particleboard it was 4.73 mg/l and 4.95 mg/l, respectively. Floor materials were under E1 grade while furniture materials were under E2 grade in terms of formaldehyde emission. Because of the under-floor heating system, the flooring materials were exposed to 37°C and 50°C, while the furniture materials mostly existed at room temperature. At 37°C and 50°C, the formaldehyde emission level of the flooring materials was already under 0.3 ppm (F**** level by JIS A 1460, application possibility without area limit) after 10 days and the emission had decreased further (0.03 ~ 0.10 mg/l) after 28 days. These levels are not injurious to the human body and will not cause sick house syndrome (SHS). The problem, however, is the furniture materials such as MDF and particleboard. As these materials are not exposed to high temperature (50°C in this experiment) in living conditions, E2 grade of formaldehyde emission levels at room temperature remained even after 28 days. Although there will be variations with the volume of furniture materials and the indoor conditions, furniture materials are the principal cause of indoor air quality pollution in Korean with the under heating system.

Toward an Understanding of Fiber-Adhesive Interactions in MDF Manufacture: Mill-Scale Trial

Warren J. Grigsby, Senior Scientist, and *Armin Thumm* and *Peter Burrell*, Scientists, Biomaterials Engineering Group, Scion, Rotorua, New Zealand

In composite panel manufacture, resin distribution plays an integral role in panel performance. An MDF mill trial was undertaken to investigate processing parameters which may impact resin distribution and their relationship, if any, to panel properties. Using resin visualization technology, the location and distribution of resin on fiber was determined through the entire MDF process, characterizing both the coverage of resin, but also the extent of any movement within the wood fiber cellwall. The results have lead to a greater understanding of the MDF process at a fundamental level. Using fluorescently labeled resin and confocal microscopy, the effects of several common processing conditions such as resin nozzle pressure, production rate, and blowline velocity were evaluated. Resin distribution of blowline-sampled fiber showed relatively high resin coverage rates, dominated by the very large resin features, attributable to resin smearing processes in the blowline. However on passing through the dryer and upon pressing, significant changes were observed in resin coverage. Variations in distributions and coverage between process conditions were also evident. This movement of resin on fiber through the MDF process suggested by resin distribution analysis was also reflected by the resin profiles in the fiber cellwall with correlations evident at differing process points of MDF manufacture.

Temperature and Reactant Injection Effects on the Bonding Kinetics of Thermosetting Adhesives

Philip E. Humphrey, Founder, Adhesive Evaluation Systems, Inc., and Affiliate Professor, Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA

The rate at which adhesives within bio-composite materials develop strength during hot-pressing critically effects production efficiency and product properties. Tailoring the reactivity of adhesives to industrial pressing processes requires specific information on the responsiveness of adhesives to thermal and chemical environments that occur at bonding sites during pressing. The ABES (Automated Bonding Evaluation System) technique has been used to characterize such effects for miniature test bonds. The results of a range of investigations relevant to adhesion in the formation of present and future bio-composite products are reported. These include: 1) the effect of temperature on the

isothermal strength development rate of PF-to-wood bonds; 2) the strength enhancement that results from rapidly cooling partially cured PF bonds below their transient T_g prior to their being tested; 3) the thermal damage of UF adhesive-to-wood bonds as a function of temperature; and 4) the influence of the sequential application of reactive chemicals (ammonia for cellwall softening and methyl formate as a catalyst) on the strength development of PF bonds. The implications of bonding kinetics data for present and future industrial pressing operations will be explored with the aid of simulation models of the hot-pressing process; spatial predictions of bond strength, along with temperature, sorbed moisture, gas pressure, density, and residual stress will be included.

Low Temperature Fast Curing Coatings for the Surface Treatment of Wood Composite Panels

Jianwen (Jim) Ni, Senior Development Chemist, Wood Adhesives R&D, *Anna Eley*, Technologist, Wood Adhesives R&D, *Brett Neumann*, Senior Development Chemist, Pine Chemicals R&D, *Phillip W. Hurd*, Research Scientist, Pine Chemicals R&D, and *Pablo Dopico*, Group Leader, Wood Adhesives R&D, Georgia-Pacific Resins, Inc., Decatur, Georgia, USA

In the hardboard industry, it is a common practice to temper the panel surface with drying oils, such as linseed oil, to improve surface hardness. This technology requires the panels to be heat-treated in a high-temperature oven after the tempering oil is applied. The high temperature process has energy cost and emission regulation implications. A novel and proprietary coating compound has been developed that allows tempering of the panels without the need for a high-temperature oven to cure the coating.

The New Way for Plywood Foam Gluing

Jouni Rainio, R&D Manager, Hexion Specialty Chemicals Oy, Puhos, Finland

Cost-effective plywood foam gluing still has some limitations - some technical and some from the adhesives being used. We have developed a new type of foam glue together with a new type of foam gluing system. Our target has been to develop a suitable foam system for both phenol and amino resins, including: foaming agent on-line charging, foaming agent easy handling and mixing, foam gluing system suitability for different types of plywood production, and the right cost structure. All the adhesive compounds have an effect on foaming properties as well as the gluing results. We have developed a good basic resin for different foam applications that has optimized resin properties and manufacturing conditions together with development of other glue compounds to determine the best possible gluing results. A standard blood system gives good foaming properties for phenol plywood adhesives, however it has an effect on adhesive color and it is not totally soluble in the phenol resin. Tested liquid colorless resin soluble foaming agents can be charged into the adhesive batch together with extenders or just before foamer, if needed. Foam properties can easily be adjusted as needed by on-line changes in the amount of foaming agent. We have developed suitable foaming agents for amino resins as well as for phenol resins by testing foam properties together with gluing properties. Other factors studied were foam effect on formaldehyde emission from amino resin glued panels; effect of foaming agent type on foam quality and adhesive flow on the veneer surface; possibilities for stopping foam outflow from extruder head when there is no veneer under the extruder head; and the effect of the amount and type of circulated foam on the mash roll-prepress system.

Use of In-Mold Dielectric Analysis in Particleboard Production

Richard Magill, R&D Director, Signature Control Systems, Lakewood, Colorado, USA

Setting and maintaining optimal cure times in the particleboard manufacturing environment is often a difficult proposition. A variety of factors can adversely affect the rate and quality of cure, including platen temperature, moisture content, pH of the furnish, and numerous other environmental factors. Additionally, there is often little or no indication of the adverse condition to warn production operators of the problem. In many cases, the first indication of a detrimental process shift may be from a blow or delamination of the product. One method of particleboard cure monitoring that is gaining increasing acceptance is the use of in-mold dielectric measurement. This method has now been implemented in a major North American particleboard production facility since September of 2004. The system has monitored and recorded tens of thousands of cures in this facility, operating 24 hours a day, 7 days a week. The data is being successfully used to reduce

cycle times, troubleshoot problems, and to recognize abnormal processing conditions. This paper describes the dielectric control methodology, including the theory, background, and results from the field. Data from actual production applications is included and analyzed.

FRIDAY AFTERNOON, NOVEMBER 4

CONCURRENT SESSIONS

SESSION 4A: Resin Chemistry

Structure and Properties of Radiation-Curable Resins for Bonding Wood

Timothy G. Rials, Professor and Director, *G.F. Dorsey*, Research Chemist, and *Ting Song*, Graduate Research Assistant, Forest Products Center, University of Tennessee, Knoxville, Tennessee, USA; *Steve Kelley*, Principal Scientist, National Renewable Energy Laboratory, Golden, Colorado, USA; *William W. Moschler*, Research Associate, Forest Products Center, University of Tennessee, Knoxville, Tennessee, USA; and *B. Griffith*, Program Leader, Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA

Development of rapid, low-temperature electron beam-curable resin systems offers tremendous energy savings potential to the wood composites industry, as well as unique opportunities to develop novel products and processes. This research has screened a wide range of resin systems that vary in base polymer structure. Focusing on the urethane family of resins, the influence of dose on network structure and properties was explored using dynamic mechanic thermal analysis. Although some dependence on functionality (i.e., acrylate or diacrylate) was observed, complete consumption of reactive groups occurred at approximately 40 kGy. Higher levels of radiation resulted in considerable structural rearrangement, and altered properties. FTIR and pyrolysis-molecular beam mass spectrometry helped elucidate the relationships between structure and resin properties. Bond quality was assessed using conventional shear tests and boil tests. The results highlight the significance of resin viscosity on structure development in the wood-resin interphase, and ultimately performance characteristics of the adhesive bond.

Effect of Molecular Weight on Bonding Performance for Liquid Phenolic Resins

Guangbo He, Post-Doctoral Fellow, and *Ning Yan*, Assistant Professor and Associate Director, Pulp & Paper Centre, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada

In this study, several wood species and liquid PF resins and resin mixtures with different molecular weights were chosen to investigate the curing process and bonding properties. Dynamic mechanical analysis (DMA), the lap-shear test, and other mechanical tests were used to characterize the curing kinetics and the final mechanical properties of the products. The results indicated that molecular weight significantly influenced the curing process. The resin with high molecular weight cured much faster than the resin with low molecular weight. There was little difference in the curing rate for different wood species. Bond strength as determined by the lap shear and DMA tests was found to depend on the wood species. An optimized resin should contain both low molecular weight and high molecular weight portions for the best bonding properties, especially at a low resin-loading rate. The optimum molecular weight combination for different wood species varies.

A Honeymoon-Type Adhesive for Wood Products Based on Acetoacetylated Poly(vinyl alcohol) and Diamines: Effect of Diamines and Degree of Acetoacetylation

Atsushi Mori, Research Associate, *Masaaki Morita*, Student, *Kazuhiisa Tashiro*, Graduate Student, *Masahiro Takatani*, Associate Professor, and *Tadashi Okamoto*, Professor, Department of Applied Bioscience, Graduate School of Agriculture, Kinki University, Nakamachi, Nara, Japan

A honeymoon-type adhesive for wood products based on acetoacetylated poly(vinyl alcohol) (AAPVA) was investigated focusing on the effect of acetoacetylation on performance, and that of amino compounds as a crosslinking agent. Acetoacetylated poly(vinyl alcohol) with different degrees of acetoacetylation were synthesized by the addition reaction of diketene in dimethylsulfoxide. Adhesive tests were carried out using aqueous solutions of acetoacetylated poly(vinyl alcohol) and six kinds of amino compounds, spread separately on test pieces of red meranti selected as the adherend. The mechanical strength of the bonded test pieces was then analyzed. It was found that

the adhesive strength increased together with the degree of acetoacetylation up to at least 3 hours after the application of the adhesives. The degree of acetoacetylation had little effect on water resistance within the range 3.3 to 37.1%. As a crosslinking agent, diamines containing primary amino groups were effective, but secondary amines and polyethyleneimine were not. It is assumed that the chemical structure of the amine influenced the crosslinking reaction at the adhesion interface. The use of this reaction on the acrylate emulsion surface was also studied.

Resins for Ultra-Low Formaldehyde Emission According to Japanese F**** Quality

Manfred Dunky, Application Manager, Europe PB&MDF + OSB, Dynea Austria GmbH, Krems, Austria

This presentation summarizes studies of wood-based panels exhibiting ultra-low formaldehyde emission according to the Japanese F**** (Super E Zero) quality. Emission was tested according to the Japanese Industry Standard JIS A 1460 (Desiccator Test). The limit itself is described in JIS A 5908 for particleboards and in JIS A 5905 for MDF and is 0.3 mg/l for both board types. There is no official limit expressed as European perforator value or as steady state concentration in a climate chamber. Correlations usually reported are perforator values of approximately 1.5 mg/100 g for absolutely dry board and a steady state concentration of less than 0.03 ppm. Such low emissions can be reached using aminoplastic adhesive resins as well as phenolic resins. Aminoplastic bonded boards show formaldehyde emission mainly determined by the molar ratio of the resin and the resin mix and evoked by residual formaldehyde present in the boards and by the hydrolysis of weakly bonded formaldehyde in the hardened resin. To fulfill the F**** requirements, the molar ratios need to be distinctly below 1.0; to overcome the weak network formation in the hardened resin, usually modified or melamine fortified urea-formaldehyde resins are used. Contrary to this for phenolic resins the amount of emittable formaldehyde always is more or less zero based on the good hydrolytical resistance of the resins.

Moisture Curing, Liquid Polyurethane Adhesive for Structural Wood Bonding Applications

Wu Suen, Senior Associate, and *Charles W. Paul*, NSC Fellow, National Starch & Chemical Company, Bridgewater, New Jersey, USA

One-component, moisture curing liquid polyurethane adhesives have found applications in engineering wood products due to their many advantages (ambient cure, curable at high moisture content, formaldehyde free, etc.). Most of this success has been in Switzerland and Germany. Several experimental liquid polyurethane adhesives were developed and tested against standards for North America and Europe for structural and non-structural use in exterior wet-use environments. Results indicate that European standards (WATT 91 and EN204 D4) are relatively easy to pass. The North American structural standard (ASTM D2559) is not difficult for softwoods, but hardwoods are more challenging. However, the non-structural test (D5572) is more difficult to pass, due to the requirement for a certain degree of wood failure, even while bond strength requirement is vastly exceeded. Microscopy was used to evaluate bondlines and interpret failure mechanisms. IR was used to assess degree of cure under ambient conditions. Shelf life studies of these 1-part formulas indicated that as the storage time increased, the amount of urea product increased as a result of moisture ingress. Allophanate by-product is also formed, but relatively slowly. A model for allophanate conversion versus time and temperature was developed using accelerated aging and NMR characterization.

pMDI Co-Binder for Oriented Strandboard

Gang-Fung Chen, Development Fellow, and *Tom Bidwell*, Statistician, Ashland Specialty Chemical Company, Columbus, Ohio, USA

Oriented strandboard (OSB) is an important wood product used for a variety of construction structural wood applications such as wall panels, flooring, siding, and I-joist webs. Presently, polymeric MDI (pMDI) is an important class of adhesives for bonding OSB because it offers good physical and mechanical properties in the finished product. As the global demand for pMDI continues to exceed global capacity, escalating cost and limited supply will be an issue for pMDI users. The added pressure of being a petroleum distillate adds to this complexity. To address these issues, it is desirable to develop a co-binder that can be used to replace a portion of pMDI for the manufacture of OSB, thus lowering overall binder cost and increasing binder options. This paper describes the development of a pMDI co-binder, which is derived from naturally occurring renewable resources. Different methods of evaluation were performed which provided information for the

concept of successful co-binder development. This includes the viscosity characterizations of pMDI/co-binder mix under high shear rates, the crosslink density relationship with the performance of face lamination and fingerjoints, and a statistical approach to analyze the OSB properties. Our results demonstrated that up to 33% of pMDI may be replaced with co-binder to give an equal or better OSB performance compared to a pure pMDI binder system.

The Solution for Low Emission Panels - A Highly Efficient and Extremely Consistent Resin - ART Resin Technology

John G. Sharp, Consultant, Resins & Panel Process Technology (United Kingdom and Brazil), Stirling, United Kingdom

Economic and competitive production of low- and ultra-low formaldehyde emission MDF and particleboard using resins which are formaldehyde-based patently requires that such formaldehyde is efficiently and intimately incorporated into the resin-wood matrix while still permitting fast press speeds and low resin consumption. Operation at fast press speeds, furthermore, requires not only a fast reacting resin, but one of extremely consistent quality to enable press operators to fine-tune their production working close to the limits. The majority of traditional and operator-controlled resin products cannot guarantee such a performance. The ART (Advanced Resin Technology) process, on the other hand, is based on a radically different philosophy whereby, in addition to utilizing a distinctly different chemical route to confer high efficiency, uses fully-automated and computer-controlled conditions to produce resins with a precision and consistency on a par with a pharmaceutical product - a process which is truly 'State of the ART.'

SESSION 4B: General Topics

Wood Bonding by Vibrational and Rotational Friction Welding

Antonio Pizzi, Professor of Industrial Chemistry, ENSTIB, and Deputy Director, LERMAB, Integrated Research Unit INRA/ENGREF, University Henri Poincaré-Nancy 1, Epinal, France; and *Milena Properzi*, Research Scientist, and *Frédéric Pichelin*, Head, R&D Panel Products, School of Architecture, Civil & Wood Engineering, HSB University of Applied Sciences, Biel-Bienne, Switzerland

Mechanically-induced wood welding, without any adhesive, yields wood joints satisfying the relevant requirements for structural applications. The mechanism of mechanically-induced vibrational wood fusion welding is due mostly to the melting and flowing of amorphous, cell-interconnecting polymer material in the structure of wood - mainly lignin, but also hemicelluloses. This causes partial detachment (the "ungluing") of long wood cells, wood fibers, and the formation of a fiber-entanglement network in the matrix of molten material which then solidifies. Thus, a wood cell/fiber-entanglement network composite having a molten lignin polymer matrix is formed. Cross-linking chemical reactions also occur. These reactions have been identified, but are relatively minor contributors during the very short welding period. Their contribution increases after welding has finished, explaining why long holding times under pressure after the end of welding contribute strongly to obtaining a good bond. Equally, high speed rotation-induced wood dowel welding, without any adhesive, yields wood joints of considerable strength. The mechanism is similar to that observed in vibration welding. Wood species, relative diameter differences between the dowel and the receiving hole, and pressing time are parameters yielding significant strength differences; while relative orientation of the fiber grain of the dowel in relation to the fiber grain of the substrate, relative rate of rotation within a limited range, and the use of rough or smooth dowels did not have any significant influence. The welded contact area is sufficient to yield strength results comparable to or even slightly higher than those obtained by PVAc adhesive bonding. The use of dry dowels inserted hot in the substrate after preheating them at high temperature (100°C) yielded consistently better results than that obtained with PVAc gluing.

LWVT - An Innovative Wood Bonding Technique

Milena Properzi and *Stefanie Wieland*, Research Scientists, *Frédéric Pichelin*, Head, R&D Panel Products, and *Balz Gfeller*, School of Architecture, Civil & Wood Engineering, HSB University of Applied Sciences, Biel-Bienne, Switzerland

In the years 2001-2004, the authors conducted an investigation to find an alternative to traditional gluing techniques. The aim of the project was the development of an innovative gluing technique that would be applicable both economically and qualitatively in industrial produc-

tion. This research work led to the discovery that Linear Vibration Welding Technology (LVWT), a technique widely used in the plastic and car industries, can also be used to induce the thermal activation of duroplastic adhesives and thus can be applied to the manufacture of high-quality wood joints. According to the positive outcomes of this study, the innovation was patented and the first contacts with potential customers were taken. The authors report on the latest progress made in both research and industrial implementation of the developed technique.

Wood Adhesion Mechanisms: Prediction of Wood-Thermoplastic-Water Interactions

Magnus E.P. Wälinder, Head, Material Science & Product Development, SP Trätek, Swedish National Testing & Research Institute, Wood Technology, Stockholm, Sweden, and Assistant Professor, Biofibre Materials Centre, KTH-Royal Institute of Technology, Stockholm, Sweden; and *Kristoffer Segerholm* and *Lars-Elof Bryne*, Ph.D. Students, Division of Building Materials, KTH-Royal Institute of Technology, Stockholm, Sweden

This paper discusses adhesion mechanisms relevant for wood bonding in general and wood-thermoplastic composites in particular. The wetting (or adsorption) mechanism including the so-called acid-base theory is examined in more detail, especially related to "preferential" wetting of wood by water sorption. A new concept is presented for the prediction of wood-polymer-water interactions which could be a valuable tool for tailoring new durable outdoor wood-adhesive or wood-thermoplastic systems. Effects of different wood modification routes on wood-polymer-water interactions are predicted for some wood-thermoplastic composites (WPCs). These predictions are also related to the moisture sorption behavior and interface morphology of the composites. Wood modifications of interest are based on acetylation, furfurylation, and heat treatment.

High Class Adhesive Systems for Production of Sandwich Parquet

Astrid Pedersen, Chief Research Scientist, Product Development Europe, Dynea ASA, Lillestrøm, Norway

Parquet is manufactured as a solid wood product or as different glued constructions, like wood veneer floor covering, hardwood flooring, engineered flooring, or laminated parquet. The laminated (glued) parquet can consist of two, three, or five layers. The three-layer system, called sandwich parquet (also known as long strip parquet), is the market leader in Europe. The annual growth rate in world-wide production of sandwich parquet is approximately 10%. Different adhesive systems are required for different production lines. Generally, mix-in systems are used for hot-press lines, while sequential separate application of hardener and adhesive is used for RF lines. Traditionally, separate application systems have been inferior to mix-in systems, giving brittle gluelines and low penetration into the wood, resulting in glue bonds of lower quality. Dynea's R&D laboratory has developed a glue system for separate application combining the fast setting properties of separate application systems with the bond quality of mix-in systems. Additionally, the RF curing time is reduced by 25 to 50% compared to traditional separate application systems. In spite of the very fast setting times, the glue mixture is able to penetrate deep into the wood surface. This ensures flexible, high-quality gluelines, resulting in high-quality parquet. This paper will provide details and further information on the above points in addition to recent developments with the aim to further improve both bond quality and speed for both mix-in and separate application systems.

Bondability of Tropical Fast-Growing Tree Species

Eka Mulya Alamsyah, Ph.D. Student, *Masaaki Yamada*, Assistant Professor, *Kinji Taki*, Professor, and *Hiroaki Yoshida*, Professor Emeritus, Faculty of Agriculture, Shizuoka University, Shizuoka, Japan; and *Atsunori Inai*, Technical Development Manager, Koshii & Company, Ltd., Osaka, Japan

To estimate potential bonding performance of bonded wood products from tropical fast-growing tree species, a study of the bondability of *Acacia mangium*, *Paraserianthes falcataria*, and *Pinus merkusii* from Indonesia and *Shorea* sp., *Acacia hybrid*, and *Acacia mangium* from Malaysia have been done. Two-ply laminations were produced using PVAc, UF, RF, and API. In order to determine the bonding performance, the shear block test was applied according to JAS-SE (2000) under normal conditions and after accelerated-aging treatments. To support this study, curing behavior of some resin adhesives and contact-angle of each wood species were also investigated. The results show that among the wood species used, for Indonesian woods, the

bonding performance of *P. falcata* and *P. merkusii* was better than that of *A. mangium*, while for Malaysian woods, the bonding performance of *Shorea* sp. was better than that of *A. hybrid* and *A. mangium*. In addition, the bonding performance of *A. mangium* from Indonesia and *A. mangium* and *A. hybrid* from Malaysia was almost similar. This different bonding performance was clarified by the results of contact angle measurement; namely, small contact angles and good wettability in *P. falcata*, *P. merkusii*, and *Shorea* sp. led to good adhesive spread and intimate adhesive contact with their surfaces.

Bonding Strength Evaluation of Modified Commercial Adhesives on Bamboo and Bamboo-Wood Combinations

Marina A. Alipon, Scientist I, *Mildred M. Fidel*, Supervising Science Research Specialist, and *Elvina O. Bondad*, Science Research Specialist II, Department of Science & Technology, Forest Products Research & Development Institute, College, Laguna, Philippines

The performance of different adhesives on bamboo and bamboo-wood combinations for construction purposes was studied. Two bamboo species namely, Kauayan tinik (*Bambusa blumeana*) and Giant Bamboo (*Dendrocalamus asper*) and one industrial tree plantation species, yemane (*Gmelina arborea*) were used as experimental materials for the study. The materials were glued using the following adhesives: Glue I - urea-formaldehyde (UF), 60% resin solids, wheat flour, water, and ammonium chloride (NH₄Cl); Glue II - polyvinyl acetate (PVAC); Glue III - UF, 60% resin solids, and NH₄Cl; and Glue IV - UF, 60% resin solids, NH₄Cl plus isocyanate. A bamboo strip 50mm long x 25mm wide x 8.5mm thick was glued to another similar bamboo strip using the above mentioned adhesives and used as samples for shear testing along the glue line. The same procedure for the preparation of samples was applied to the bamboo-wood combinations except that each bamboo strip was glued to yemane of similar dimensions. Bamboo laminates produced significantly higher wet shear strength than bamboo-wood laminates. All samples were found to have 100% wood failure. However, all the values did not pass the Japanese Standard for laminated timber except in cold pressed bamboo-bamboo laminates of botong with Glue III and Glue IV. The bonding strengths of Glue I and Glue II were lower than Glue III and Glue IV. On the other hand, Glue IV performed better than Glue III.

Acetaldehyde Emission from Glued-Laminated Timber Using Phenol-Resorcinol-Formaldehyde Resin Adhesives with the Addition of Ethanol

Shin-ichiro Tohmura, Senior Researcher, *Kohta Miyamoto*, Researcher, and *Akio Inoue*, Head, Adhesion & Glue Laminating Laboratory, Forestry & Forest Products Research Institute, Tsukuba, Ibaraki, Japan

Volatile organic compounds (VOC) from wood-based materials have been a great concern as one of the causes of sick building syndromes for decades. Recently, there have been multiple reports in which an extraordinary amount of acetaldehyde emission (600~1500 µg/m²h) from glued-laminated timbers and laminated veneer lumber bonded with phenol-resorcinol-formaldehyde (PRF) resin adhesives was measured using small chamber methods. These values are much higher than the natural acetaldehyde emission from wood. In this study, the effect of PRF type, press condition, and wood species on acetaldehyde emission from glued-laminated timbers was investigated using the small chamber method. Extraordinary amounts of acetaldehyde, i.e. 800-1000 µg/m²h (Sugi) and 200-500 µg/m²h (Douglas-fir), were observed after one day in the case of the glued-laminated timber using ethanol-PRF resin. These phenomena were noticeably independent of the species and press condition. In addition, the interaction between ethanol and various materials such as wood, filter paper, and glass was investigated. We found that a large amount of acetaldehyde is produced when ethanol is added to the surface of wood, but not other materials. Therefore, we conclude that the source of the extraordinary acetaldehyde emission from glued-laminated timbers bonded with PRF resin adhesive is ethanol contained in the PRF resin. The production of acetaldehyde appears to be caused by a certain interaction (possibly oxidation) between the ethanol and the wood. Further experiments to elucidate the mechanisms of the acetaldehyde production from ethanol and wood is now under study.

POSTER PRESENTATIONS

POSTER 1

Gluing of Green Norway Spruce Sapwood

Edil B. Ormstad and *Ronny Bredeesen*, Research Scientists, Wood & Specialty Adhesives, Dynea ASA, Lillestrøm, Norway

The gluing of green lumber is a new technique in bonding of wood and is a tool for a better utilization of the wood raw material. The problem normally raised in attempts to glue green lumber is the formation of starved gluebonds due to over-penetration of the water-based adhesive into the wet wood. These gluebonds will have insufficient strength to hold the glued assembly together. One way to overcome this problem is by using a one-component polyurethane adhesive (PUR) in the gluing process, as this adhesive reacts with the water in the wet wood during the curing reaction and is not diluted by the water. Another possible solution to the over-penetration problem is to use a very fast-setting modified water-based adhesive system, for instance the Greenweld process. Gluing experiments in the lab showed that it was possible to establish a good gluebond with PUR-adhesives at all wood MCs. Based on these results, a full-scale trial at a sawmill with PUR-adhesive was carried out. The results clearly show that the use of PUR adhesives in gluing green sideboards from Norway spruce will create a gluebond of high quality with low delamination and high shear strength.

POSTER 2

Same Specs, Same Raw Materials, But Not the Same Resin by NMR: Specs Are Not the Total Picture

Robert A. Breyer, Senior Technology Manager, *D. Valdez*, Senior Research Scientist, *P.S. Baxter* and *J.H. Knight*, Senior Development Chemists, *J.D. Cothran*, Associate Chemist, *D.L. Atkinson* and *C.E. Vest*, Technologists, and *D.W. Price*, Development Chemist, Wood Adhesives, Georgia-Pacific Resins, Inc., Decatur, Georgia, USA

Many times people look at the specifications for resins, see that they are similar, and therefore believe that the resins will perform the same, but specifications are only part of the story. Other people will look at the raw material balance that goes into a resin and if they are the same, believe that the resins are the same, but again this is only part of the story. To get the full story, one must look at the raw material balance, the specifications, and how the resin was manufactured, to get the full picture of the resin and to be able to predict its performance. In the study described by in this work, several batches of resins were made using two different synthetic approaches. All of the resins had the same raw material balance and same final specifications such as % caustic, % solids, and viscosity. Several batches of each type of resin were made so that the intra-batch (resins made by the same approach) variation could be determined and also the inter-batch (resins made by the two different approaches) could be examined. The resins were examined by NMR and it was found that there were minimal differences in the intra-batch, but significant variation in the inter-batch. The two different style resins were then examined in a board study and differences seen in the NMR were reflected in the board study.

POSTER 3

Application of Near Infrared Spectroscopy to Resin/Wax Adhesive Systems

Ellen V. Nagy, *Jeff Balogh*, and *Robert Meacham*, Scientists, Georgia-Pacific Resins, Inc., Decatur, Georgia, USA

The scientists of Georgia-Pacific Resins, Inc. (GPRI) have developed a near infrared (NIR) method to determine the percentages of wax, resin, and water in GPRI's patented single-component resin/wax wood adhesive system used in the production of engineered wood products. A specific ratio of resin to wax must be used in the adhesive system in order to obtain desired properties for the finished wood products. The analytical method currently used for determining wax concentration in adhesives is a tedious wet chemistry extraction method that is subject to error and is not conducive to an efficient adhesive manufacturing process. NIR is a faster and more accurate method for verifying that the optimum wax-to-resin ratio is consistently maintained throughout the process. The NIR method, developed from a test set of 25 samples with varying wax and resin concentrations, provided good results with correlation coefficients (R²) of greater than 0.9 for each of the analyzed constituents. The ability to perform the wax-to-resin ratio analysis by NIR will be a valuable tool in ensuring consistency of the adhesives and consequently, of the finished engineered wood products.

POSTER 4

Thermokinetic Simulation of a Hot-Press Cycle in the Production of Particleboards

Christian Heinemann, Senior Scientist, Wood Kplus, Competence Center for Wood Composites & Wood Chemistry, Linz, Austria; and *Manfred Dunky*, Application Manager, Europe PB&MDF + OSB, Dynea Austria GmbH, Krems, Austria

The speed of the curing reaction and the development of bond strength when using aminoplastic adhesive systems highly depends on the temperature conditions in the wood furnish mat being hot-pressed. An approach was introduced to assess the degree of cure of adhesive systems by using "Thermokinetic simulation." Using the Virtual Hot-Press (VHP) software, the temperature development within different particle mats was simulated, and the chemical cure of two adhesives was monitored with DSC. A reaction model (multivariate non-linear regression) was fitted to the obtained data of the exothermic energy values at different heating rates. Hence, the partial area as evidence of the progress of the curing reaction was determined within well-defined positions of wood furnish mats during the hot-pressing cycle taking into account the real given temperature at these positions during hot-pressing. Differences between face and core layer could be clearly evaluated with this method.

POSTER 5

Preparation of Tannin-Based Cold Set Adhesives for Structural Wood Gluing

Warren J. Grigsby, Senior Scientist, and *Charles McIntosh, Ross Anderson*, and *Jeremy Warnes*, Scientists, Biomaterials Engineering Group, Scion, Rotorua, New Zealand

Many have recognized the potential of tannins, such as those extracted from bark, as a substitute for more expensive petrochemical components in adhesives for wood gluing applications. The adhesive application which tannins can be used in is dictated by the inherent tannin chemistry. Recent work has determined that the extracts of radiata pine bark, which primarily consist of phloroglucinolic tannins, can successfully be incorporated in cold set adhesives by substituting much of the resorcinol component in phenol resorcinol formaldehyde adhesives. It was found that the method of formulation of such pine bark tannin-based resins is critical in ensuring sufficient adhesive strength development and durability of the structural glue bond. Moreover, the adhesive system formulated with up to 70% tannin has a long shelf life, suitable application viscosity, and can be added through an in-line glue mixer head as a conventional two pot adhesive formulation.

POSTER 6

A Novel Technique for Recycling of Particleboard and Fiberboard - Hydrolysis of the Adhesives and Spring Back of Board Elements by Steaming

Yasunori Hatano, Head, Composite Products Laboratory, Department of Wood-Based Materials, Forestry & Forest Products Research Institute, Tsukuba, Ibaraki, Japan; *T.L. Alpár*, Associate Professor, Department of Wood-Composites, University of West Hungary, Sopron, Hungary; and *T. Shibusawa*, Senior Researcher, Department of Wood-Based Materials, Composite Products Laboratory, Forestry & Forest Products Research Institute, Tsukuba, Ibaraki, Japan

Recycling of wood waste is very important for the improvement of the environment, because it leads to a reduction of CO₂ in the atmosphere. In Japan, the law requires that 95% of waste materials (wood products, concrete, and asphalt) from demolished houses must be recycled after 2010. Wood wastes like pillars, lumber, pallets, and plywood are already recycled to produce particleboard. But, particleboard and fiberboard are seldom recycled because it is difficult to obtain good quality elements from these boards. When the boards are produced, the elements are set with large deformation by hot-pressing at about 3-4 MPa. By hammer milling, only small elements or small lumps of fine elements bonded with adhesives are obtained from used or waste particleboard or fiberboard. Also, it is difficult to use a ring-flaker or a disc refiner in order to obtain the elements from boards because they include such alien substances as metals, concrete, stone, plastics, etc. A novel technique was applied in order to produce particle elements or fiber elements from used or waste particleboard or fiberboard. The technique is based on hydrolysis of the adhesives, which were used to bond the board elements together, by means of steaming. The boards were crushed to 10-20 cm square sizes and then steamed under several

conditions (100~180°C, 10~20 min.). The adhesives (urea-formaldehyde resin or urea/melamine-formaldehyde resin), which were used to bond the elements, were hydrolyzed and then the elements were separated. At the same time, the compressive deformation of the elements was sprung back by the steaming. Finally, a hammer mill was used to separate the elements of the boards completely. The elements were separated very easily by weak impacts. The separation energy was small because the adhesives were hydrolyzed. Even the elements of fiberboard (MDF) could be separated by a hammer mill without any problem, provided that this technique was applied. It was not necessary to use a ring-flaker or a disk refiner. The separated elements did not contain any small lumps of fine elements bonded with adhesives. As a result, the volume of the bulk elements, that is, the height of the formed mat increased by steaming, and the increment was larger at higher temperatures and at longer steaming times. If the densities of boards are the same, the mechanical properties of the board made from low-density elements are generally higher than those of the board made from high-density elements, because the elements contact with each other better in the former than in the latter. MOR increased and the thickness swelling decreased at higher temperatures and at longer steaming treatment times. This technique, hydrolysis of the adhesives by means of steaming, is very effective for the recycling of used or waste boards.

POSTER 7

A New Prediction Method of Bond Durability of Plywood

Akio Inoue, Head, Adhesion & Glue Laminating Laboratory, Forestry & Forest Products Research Institute, Tsukuba, Ibaraki, Japan

In this study, a new theory for predicting bond durability is proposed. The theory shows that a kind of acceleration factor (the relationship between the cycle of accelerated aging treatment and the period of use in service which cause the same degree of deterioration) can be obtained by exposing bonded joints to service conditions for only 1 year following the accelerated aging treatment, if the superposition principle exists between the accelerated aging treatment and the exposure to service conditions. Then the long-term bond durability of the bonded joints in service can be predicted by using the acceleration factor. The theory was applied to outdoor exposure tests of 3-ply plywood bonded with three types of adhesives (phenol-formaldehyde resin, melamine-urea-formaldehyde resin, and melamine-phenol resin adhesives) and 2-ply birch specimens bonded with three kinds of adhesives (resorcinol resin, polyurethane, and water-based polymer-isocyanate adhesives) and the validity of the theory was investigated. The predicted bond strength for outdoor exposure tests conformed well to the experimental results for all adhesives. The theory was also applied to predict the bond durability of 5-ply plywood under several conditions including simulated service conditions (outdoor, under eaves, and in a humid room at 90% RH).

POSTER 8

Measurement of VOC Emissions from Particleboard and MDF Products by the JIS Small Chamber Method

Kohta Miyamoto, Researcher, *Shin-ichiro Tohmura*, Senior Researcher, and *Akio Inoue*, Head, Adhesion & Glue Laminating Laboratory, Forestry & Forest Products Research Institute, Tsukuba, Ibaraki, Japan

Emissions of aldehydes and volatile organic compounds (VOCs) from wood-based products have become a serious problem in Japan. However, there are few data of VOC emissions from various wood-based products. Thus, it is necessary to investigate and evaluate the characteristics of aldehydes and VOC emissions of wood-based products experimentally. In this study, aldehydes and VOC emissions from commercial particleboard and medium density fiberboard (MDF) products were measured using the small chamber method according to Japanese Industrial Standard A 1901. The emission factors of formaldehyde for all the samples gradually decreased during 21 days in the chamber. After 21 days, the formaldehyde emissions from all the particleboard samples decreased to about 60% of their initial values. Emissions of VOCs other than formaldehyde also decreased with increasing time. The main components emitted from the particleboard samples were hexanal and terpenes. MDF products made from softwood and hardwood were different in predominant VOCs. Aldehydes such as hexanal were found in the emission from softwood MDF samples, while the predominant VOC emitted from hardwood MDF samples was acetic acid. It was found that VOC emissions determined by the JIS small chamber method strongly depend on the wood species and the type of products.

POSTER 9

Reducing Undesirable Foaming in a Water-Based Polymer-Isocyanate Adhesive for Wood

Naruhito Hori, Assistant Professor, *Akio Takemura*, Associate Professor, and *Hirokuni Ono*, Professor, Laboratory of Polymeric Materials, Department of Biomaterial Sciences, Graduate School of Agricultural & Life Sciences, University of Tokyo, Tokyo, Japan

Japanese Industrial Standards (JIS) defines water-based polymer-isocyanate adhesives for wood as two component systems of a water-based glue and an isocyanate (NCO) crosslinker. Generally in commercial products, the water-based glue is a mixture of poly vinyl alcohol (PVA) solution, emulsions of styrene-butadiene-co-polymer (SBR) and ethylene-vinylacetate-co-polymer (EVA), and calcium carbonate; the crosslinker is a crude of polymeric methylene bis (phenyl isocyanate) (pMDI). It is known that EVA is more effective than SBR for improving initial bond strengths; however, the addition of EVA sometimes causes undesirable foaming during mixing of the NCO crosslinker with the water-based glue. This foaming results from a release of carbon dioxide from the reaction between NCO groups and water. In this study, we aimed to decrease the gas emission by examining two factors of the constituents: the particle diameter of calcium carbonate and the E/VA molar composition of EVA. Water-based glue used in this study was prepared by mixing 25 parts of PVA 15% solution, 45 parts of EVA emulsion, and 30 parts of calcium carbonate, where three of calcium carbonates with different diameter and three of EVA emulsions were examined. EVA emulsions were different in their ethylene / vinylacetate molar composition, though equal in other properties such as solid content (c.a. 50%), viscosity, pH (at neutral), and both amount and chemical of surfactant; they were specially prepared by Denki Kagaku Kogyo (JAPAN). The NCO crosslinker was a commercial pMDI. The base glue and the crosslinker were mixed in the weight ratio of 100 / 15 by an agitator for 3 min., and cast onto a Teflon sheet. This sheet was immediately placed in a sealed container connected to a gas burette charged with copper sulfate solution. Arising gas from the adhesive was measured by the volume of gas collected into the burette. The film with commercial EVA released about 20 times as much gas as that with commercial SBR: this provides evidence for the undesirable foaming of the adhesive with EVA. All the samples emitted most of their gas within 3 hours, after 24 hours they stopped emitting gas. The volume of emitted gas decreased with an increase of vinylacetate (VA) molar ratio of EVA. It is considered that high VA ratio EVA has an effect on delaying the reaction of NCO in this adhesive system. This was confirmed by FT-IR measurement. As a function of the particle diameter of calcium carbonate, its small diameter resulted in less gas emission and in more unreacted NCO.

POSTER 10

Effect of Residual NCO on the Dynamic Viscoelastic Behavior of a Water-Based Polymer-Isocyanate Resin Adhesive for Wood

Nan Ling, Ph.D. Student, *Naruhito Hori*, Assistant Professor, *Akio Takemura*, Associate Professor, and *Hirokuni Ono*, Professor, Laboratory of Polymeric Materials, Department of Biomaterial Sciences, Graduate School of Agricultural & Life Sciences, University of Tokyo, Tokyo, Japan

In order to understand the effect of the residual isocyanate group (NCO) on the dynamic viscoelastic behavior of water-based polymer-isocyanate adhesives for wood, we investigated the reaction between polyvinyl alcohol (PVA) solution and polymeric diphenylmethane diisocyanate (pMDI) as the most simplified model of the adhesive. One result is that heat treatment of the prepared film increases its storage modulus at the rubbery plateau region from 100 to 200°C, suggesting that heat treatment could promote the reaction of NCO with PVA. Samples were prepared by mixing PVA solution (15 weight%, $M_w = 1,000,000$, degree of deacetylation = 99%) and pMDI (containing mainly 4, 4'-pMDI) at weight ratios of 2:1, 3:1, and 8:1. The mixture was cast onto a Teflon sheet, and then conditioned at 23°C and 50% RH for 4 days. After conditioning, the film was heated at various temperatures between 60 and 220°C for 2 hours. DMA and FT-IR measurements of the samples were carried out. As a reference, a simplified API adhesive sample was prepared by the same procedure, where the base resin was the mixture of SBR and PVA (50 / 50 in wt), and 15 parts of pMDI was added to the base resin. The sample films prepared from the mixture of PVA and pMDI without heat treatment had an obvious E' transition at 50°C, corresponding to the glass transition of PVA. Around 170°C; a sharp drop was observed for the films with

weight ratios of 2:1 and 3:1, and the drop was not observed in the case of a weight ratio of 8:1. This phenomenon suggests that residual pMDI reacts with PVA during DMA measurement. In the sample with a weight ratio of 8:1, the drop around 170°C disappeared, which suggests that the NCO reaction did not occur because of the few NCO groups remaining. After heat treatment at 180°C for 2 hours, the glass transition of PVA around 50°C became unclear, the change of E' around 170°C disappeared, and the magnitude of E' at high temperature range from 100 to 200°C increased compared to the unheated sample. These phenomena could be attributed to the continuous reaction of residue NCO by heat treatment, resulting in increased crosslinking. This idea was confirmed by FT-IR measurement focused on the reaction of residual NCO and the production of its derivatives such as urea and urethane. After the heat treatment, the peak at 2270 cm^{-1} due to NCO anti-symmetric stretching decreased and the bands around 1730 - 1640 cm^{-1} due to urea and urethane C=O stretching increased. This suggests that the heat treatment can promote the reaction of residual NCO with PVA, resulting in a more crosslinked structure.

POSTER 11

Concentration Dependence of the Reaction Mechanism of Hydroxymethylphenols in Alkaline Medium

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To elucidate the curing mechanism of phenol-formaldehyde resins, we studied the condensation of 2,4,6-trihydroxymethylphenol (THMP) as a model compound. Kinetic analyses on the self-condensations of THMP clarified that both unimolecular and bimolecular reactions occurred as the rate-determining steps during the self-condensation of THMP with the concentrations less than 1.0 mol l^{-1} , and that nothing but bimolecular reactions occurred as the rate-determining steps during the self-condensation of THMP with the concentrations higher than 1.5 mol l^{-1} . The state of molecular association THMP was assumed to contribute to the change of reaction mechanism depending on the concentration. In this work, therefore, the dependence of molecular association of THMP on the concentration was studied. ^{13}C nuclear magnetic resonance (NMR) spin-lattice relaxation time (T_1) measurements indicated that molecular interaction tended to be influenced by the concentration of THMP. In addition, the change was discontinuous at a border zone of concentration of around 1.2 mol l^{-1} . Molecular orbital calculations of THMP molecules implied the following features of molecular interaction: in the low concentration region, THMP existed as a single molecule and then each molecule started to self-associate with an increase in concentration. In a higher concentration region, almost all of THMP molecules were bimolecularly associated and enhanced formation of larger association occurred with an increase in concentration. Based on the above results, we propose a reaction pathway of the self-condensation of THMP, in which the dependence of the molecular interaction of THMP on the concentration may play an important role in the rate-determining step.

POSTER 12

Effect of Miscibility and Initial Adhesion Properties in Blending of Melamine-Formaldehyde Resin and Poly(vinyl acetate) on Adhesion in Engineered Flooring

Sumin Kim, Ph.D. Candidate, and *Hyun-Joong Kim*, Associate Professor, Laboratory of Adhesion & Bio-Composites, Seoul National University, Seoul, South Korea

The objective of this research was to investigate the effect of miscibility and initial adhesion properties of melamine-formaldehyde (MF) resin and poly(vinyl acetate) (PVAc) blends, on the adhesion of MF resin for decorative veneers and plywood in engineered flooring. We controlled the hot-press temperature, time, and pressure to determine bonding strength and formaldehyde emission. Blends of various MF resin/PVAc compositions were prepared. To determine and compare the effect of PVAc content, 0, 30, 50, 70, and 100% PVAc floorings, by weight of MF resin, were used. Twenty-five percent of wheat flour by weight of adhesive was added to increase the quantity of resin. The miscibility of melamine-formaldehyde resin and poly(vinyl acetate) (PVAc) blends was investigated by differential scanning calorimeter (DSC), Fourier transform infrared spectroscopy (FT-IR), and Dynamic Mechanical Thermal Analyzer (DMTA). This blend displayed single

glass transition temperature (T_g) over entire compositions indicating that the blend system is miscible in the amorphous phase due to the formation of hydrogen bonding between hydroxyl groups of MF resin and carbonyl groups of PVAc. Tack test for early adhesion properties was conducted using a Texture Analyzer with a polished stainless steel cylinder probe with a diameter of 5 mm. The tack strength of the MF resin and PVAc blends was affected by the addition rate of PVAc and wheat flour.

POSTER 13

The Effects of Various Edge-Sealing Treatments in Wood-Based Composites on the Measurement of Formaldehyde Emission by the Desiccator Method

Sumin Kim, Ph.D. Candidate, and *Hyun-Joong Kim*, Associate Professor, Laboratory of Adhesion & Bio-Composites, Seoul National University, Seoul, South Korea

The objective of this research was to investigate the effect of various edge-sealing treatments - para film, aluminum foil, and polyethylene wax - on formaldehyde emission from 8mm floor materials, such as laminate and 15mm plywood floorings, and furniture materials, such as MDF and particleboard (PB), by the desiccator method (JIS A 1460). Compared with non sealed-samples at the same exposure dimension (1800mm²), formaldehyde emission levels were decreased by edge-sealing treatments; the difference in formaldehyde emission in the case of PB was quite higher than other cases, presumably due to openings between wood particles in the core. When we compared PB with MDF, there were large openings in core of PB where free formaldehyde could easily emit. Furthermore, the adhesion layer surrounding wood particles in PB was thicker than that around wood fibers in MDF. We investigated this result by Confocal Laser Scanning Microscope (CLSM). For CLSM test, we manufactured PB and MDF using a urea-formaldehyde resin with an incorporated fluorescent pigment.

POSTER 14

Effect of Different Compatibilizing Agents on Lignocellulosic Material Filled-Polyethylene Bio-Composites

Han-Seung Yang, Post-Doctoral Research Associate, and *Michael P. Wolcott*, Louisiana-Pacific Professor and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA; and *Hee-Soo Kim*, Ph.D. Student, and *Hyun-Joong Kim*, Associate Professor, Laboratory of Adhesion & Bio-Composites, Seoul National University, Seoul, South Korea

The tensile strength and modulus of the lignocellulosic filled-polyethylene composites dramatically improved with the incorporation of maleated polyethylene (MAPE) compared with maleated polypropylene (MAPP), because maleic anhydride grafted polyethylene is the same type of material as polyethylene, the matrix polymer. The Izod impact strength of the composites slightly decreased or stayed almost the same with the incorporation of MAPP, but increased with the incorporation of MAPE. The incorporation of MAPE had a toughening effect on the impact strength. The composites made with two different compatibilizing agents showed some different morphological characteristics. Some pulled-out traces and fractured filler particles were seen in the SEM micrographs of the MAPP incorporated composites, while no pulled-out traces and many fractured filler particles were seen in the MAPE incorporated composites. The use of MAPE is recommended in the polyethylene composite system due to its better compatibility than MAPP.

POSTER 15

Comparison of Cure Kinetics Models for Cure Prediction of Phenol-Formaldehyde Resins

Marie-Pierre G. Laborie, Assistant Professor, *Jinwu Wang*, Ph.D. Candidate, and *Michael P. Wolcott*, Louisiana-Pacific Professor and Research Director, Wood Materials & Engineering Laboratory, Washington State University, Pullman, Washington, USA

Phenol-formaldehyde (PF) resins have been the subject of many cure kinetic studies utilizing both model-fitting and model-free kinetics; however, a highly method for predicting PF-cure behavior has not been established. The objective of this research was to determine the best kinetic method for predicting the cure development of PF resins. To that end the most common model fitting kinetics and model free

kinetics were evaluated on PF resins. These are the n^{th} - Borchard-Daniels, ASTM E698, and autocatalytic methods for model fitting kinetics, and the Friedman, Vyazovkin, and Kissinger-Akahira-Sunose algorithms for model-free kinetics. The accuracy of the methods for predicting isothermal and dynamic cure of two PF resins was compared and the most accurate methods are proposed.

POSTER 16

Development of a Finite Element Model for the Interfacial Bond Strength of Bio-Based Composites

Jong N. Lee, Research Scientist, Sustainable Engineered Materials Institute, Virginia Tech, Blacksburg, Virginia, USA; and *Fred A. Kamke*, JELD-WEN Professor of Wood-Based Composite Science, Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA

This study proposes a unique approach to the mechanical analyses of the nature and the magnitude of stresses in adhesive joints formed between furnish in bio-based composites by using modern engineering techniques. We will develop scientific models based on the investigation of the effect of resin penetration on the mechanical properties of the interphase region. Also, the effect of resin distribution parameters on the stress distribution at the bonded surface will be investigated by developing an analytical model. The statistical distributions of resin droplet parameters will be characterized and incorporated into the mathematical model. A numerical analysis of adhesive bond performance at the interphase region will be performed to quantify the reinforcement of the wood cell walls by resin penetration within the micro-anatomical structure. The proposed research will expand the crucial part of our understanding on blending and binding technologies for bio-based composites through an engineering and scientific approach. The success of the proposed study will provide manufacturers and scientists an opportunity for technology breakthrough necessary to achieve the enhancement of the interfacial bonding strength of OSB and other particulate composites, and ultimately to attain better profitability. The goal of this research is to improve the performance of adhesive joints in bio-based composites. This is to be accomplished with an engineering analysis of the adhesive bond strength between strands in a bio-based composite by incorporating the resin penetration characteristics and the microstructure of wood into a finite element (FE) model. The objectives are: 1) Perform a numerical analysis of the effect of resin penetration into the cellwall on the adhesive bond performance; and 2) Analyze the stress distributions around the area of a discontinuous adhesive bond, by establishing the theoretical model as a function of principal parameters in the blending process of a bio-based composite.

POSTER 17

The Wood-Based Composites Center: Universities Meeting the Education and Research Needs of the Wood-Based Composites Industry

Charles E. Frazier, Professor and Director, *Linda C. Caudill*, Managing Director, and *Will Pfeil*, Graphic Artist, Wood-Based Composites Center, Department of Wood Science & Forest Products, Virginia Tech, Blacksburg, Virginia, USA

The partner universities of the Wood-Based Composites Center (WBC) cooperate to achieve the common mission of providing relevant and effective education and training, research, and technology transfer to service the North American wood and fiber based composites, and related industries. The Center is housed in the Department of Wood Science and Forest Products at Virginia Tech in Blacksburg, Virginia. Participating universities include Mississippi State, Oregon State, the University of Minnesota, and Virginia Tech. The Center is supported by 14 member companies that manufacture composites or that supply wood adhesives. Funding is shared among Center universities to provide undergraduate scholarships, graduate fellowships, tuition waivers, and general support of composites-related research. The Center's research agenda is created and maintained by industry participants. Since its inception in 1999, the Center has been instrumental in the successful placement of multiple graduates in employment with the composites industry. Through its unique cooperative efforts, the WBC works to strengthen communication and collaboration among academic institutions and between industry professionals and academia. Students benefit through available funding and specialized education and experience.

POSTER 18

Analysis of Soy Flour/Phenol-Formaldehyde Adhesives for Bonding Wood

Linda Lorenz, Chemist, and *Charles R. Frihart*, Project Leader, Wood Adhesives Science & Technology, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA; and *James M. Wescott*, Chief Technology Officer, Heartland Resource Technologies, Waunakee, Wisconsin, USA

The desire to make more environmentally friendly and lower-cost products has led to an interest in replacing some of the phenol-formaldehyde with soybean flour-based adhesives. Because end-use performance depends upon many process variables, it is important to develop tests that relate resin production variables to the properties of the resin before and after wood bonding. To use soybean flour effectively in a water-resistant adhesive, the denaturation conditions are important. The protein needs to be denatured, with minimal hydrolysis. A gel permeation chromatography (GPC) method was used to determine conditions that selectively break down the high molecular weight fragments that contribute to high viscosities. The best conditions for denaturation were to keep the temperature below 100°C. GPC and high-pressure liquid chromatography (HPLC) were also used to analyze the reaction of the denatured soy flour with formaldehyde and phenol. This analytical information together with extraction data was used to develop improved face adhesives for OSB (oriented strand-board) production that are more environmentally friendly.

POSTER 19

Melamine-Based Adhesives for OSB: There is a Competitive Melamine-Based Resin for Every OSB Type!

Jan Jaap Nusselder, Manager, Product & Application Research, and *Bert Stijnen*, Technical Service Manager, DSM Melamine, Geleen, The Netherlands; and *Liheng Chen*, Research Scientist, Forest Products, and *Robert W. Wellwood*, Manager, Forest Products, Alberta Research Council, Edmonton, Alberta, Canada

The demand for OSB panels still exhibits healthy growth both in the America's and Europe. Traditional resin technology for OSB is rather different on both sides of the ocean. The North American preferred adhesive system was PF adhesive both in core and face or isocyanate adhesives in core and PF in face. In contrast, the preferred European system was isocyanate in core and MUF in face. Also a premium grade OSB exists, which is fully isocyanate based. Recently, adhesive systems are changing. MUF resin technology intrinsically offers large freedoms of design, by varying the levels of melamine and urea. This freedom has been used to develop specific tailored resins for different types of OSB in the last couple of years. Combined with DSM's breakthrough knowledge on efficient melamine use, we are now ready to "cross the ocean" with highly competitive melamine-based adhesives. In this presentation we will discuss two new types of melamine-based adhesives, MFu and UFM adhesives, and compare those with the traditional adhesive systems for OSB. The MFu resin is characterized by high melamine loadings and was developed and introduced in mills for the face and core of European OSB 3 and 4. The UFM resin was designed for the face of Exposure 1 panels and is a low-cost resin. Both resin panel properties will be reviewed and benchmarked with the economical performance of traditional adhesives systems.

POSTER 20

Formaldehyde Scavenging of Urea-Formaldehyde Resin for Particleboard

Byung-Dae Park, Research Scientist, *Eun Chang Kang*, Post-Doctoral Researcher, *Jong Young Park*, Head, Wood Processing Division, and *Sang-Bum Park*, Research Scientist, Department of Forest Products, Korea Forest Research Institute, Seoul, South Korea

This study was conducted to lower formaldehyde emission (FE) of particleboard using urea-formaldehyde (UF) resin modified with an addition of urea solution (US) and urea-formaldehyde prepolymer (UFP) synthesized in the laboratory for a partial replacement of the resin. As the US and UFP concentration in UF resin increased, the gel time, on-set temperature, and peak temperature increased, while the E_a decreased. The reactivity of UF resin was better for the UFP addition than the US, which could be attributed to the presence of methylol groups in the UFP. The modified UF resins were used for preparation of the core layer of particleboard. Also, various hardeners and their combinations were used to speed up the cure of the modified UF

resins. The results showed that the core UF resin of low molar ratio was more effective than the counterpart in formaldehyde scavenging of particleboard. Various hardeners showed different gel times, indicating that the cure rate of UF resin depended on the types of hardeners used. In general, faster hardener provided a greater FE in particleboard. The addition of about 20% UFP in the core UF resin lowered the FE of particleboard to around E₁ grade.

POSTER 21

Water Soluble Larch Extractives: Impact on 1 P PUR Wood Bonds

Tina Künniger, Research Scientist, *Anja Fischer*, Research Assistant, *Esther Strub*, Research Chemist, and *Klaus Richter*, Head, Wood Laboratory, Empa, Swiss Federal Laboratory for Materials Testing & Research, Dübendorf, Switzerland

Recent research aiming to evaluate the compatibility of one-part polyurethane adhesives with three softwood species (spruce, larch, and Douglas-fir) identified specific wet bonding problems of larch wood (*Larix decidua*). Arabinogalactan (AG), a water-soluble extractive specific for larch heartwood, is assumed to interfere the setting of the adhesive. In order to better understand the mechanisms we simulated the effect of AG on spruce wood, while applying artificially certain concentrations before bonding. Dynamic contact angle measurements revealed that the extractive positively influences adhesive wetting, while on the other hand adhesive penetration into the wood surface is impeded. As in larch wood, wet strength of AG-treated spruce was reduced. Results of ongoing studies will be presented, aiming to identify the critical concentration of AG, the effect of AG on other adhesive types, and the chemical reactions that cause the incompatibility.

POSTER 22

Acid-Base Interactions in Wood-Plastic Composites

Bernard Riedl, Senior Professor, and *Xiaolin Cai*, Ph.D. Candidate, Department of Wood & Forest Sciences, Université Laval, Québec City, Québec, Canada (Presented by *Pierre-Louis Cyr*, Ph.D. Candidate, Department of Wood & Forest Sciences, Université Laval, Québec City, Québec, Canada)

Cellulose fiber/thermoplastic composites with ionic interphase were prepared from modified cellulose fibers and poly(ethylene-co-methacrylic acid) (PE-co-MA). The cellulose fiber was treated by using a coupling agent or sodium hydroxide followed by introduction of ionic quaternary ammonium groups on the fiber surface, which was then compounded with the polymer having anionic groups. The effect of the ionic interface on the composite physical and thermal dynamic properties was investigated. An obvious improvement in mechanical strength of the ionic-interface composites was observed due to acid-base interactions. The improved adhesion could be ascribed to the interaction between cationic grafted groups at the cellulose fiber surface and the anionic groups in the PE-co-MA.

POSTER 23

The Influence of Storage pH on the Stability of Melamine-Formaldehyde Resins

Mary Reilly, Technical Officer, and *Ken A. Van Langenberg*, Team Leader, Adhesives & Composites, Ensis - The joint forces of CSIRO and Scion, Clayton South, Victoria, Australia

Melamine-formaldehyde resins are used in the impregnation of décor paper for the lamination of particleboard and medium density fiberboard (MDF) with low-pressure laminates (LPL) and for the production of high-pressure laminates (HPL). These value-adding processes are an important component in the use of composite panels. Like most amino-formaldehyde resins, these resin solutions have a finite shelf-life which can limit their industrial application. There has been a recent resurgence in interest in the chemistry of these resins, particularly the mechanism of storage instability and the ability to manipulate the production of these resins to control the shelf-life of the resin. Some of the factors that have been previously investigated include the storage temperature, mole ratio of formaldehyde to melamine, and various reaction conditions. Recently, we have begun investigating various methodologies for maximizing the usable shelf-life of melamine-formaldehyde resins. One such approach that has not received much attention is the effect of the storage pH on the shelf-life. This poster will present some of our initial findings into the influence of the storage pH on the shelf-life of melamine-formaldehyde resins.

POSTER 24

Studies of UF/Isocyanate Hybrid Adhesives

Stefanie Wieland, Research Scientist, School of Architecture, Civil & Wood Engineering, HSB University of Applied Sciences, Biel-Bienne, Switzerland; *Antonio Pizzi*, Professor of Industrial Chemistry, ENSTIB, and Deputy Director, LERMAB, Integrated Research Unit INRA/ENGREF, University Henri Poincaré-Nancy 1, Epinal, France; *Warren J. Grigsby*, Senior Scientist, and *Jeremy Warnes*, Scientist, Biomaterials Engineering Group, Scion, Rotorua, New Zealand; and *Frédéric Pichelin*, Head, R&D Panel Products, School of Architecture, Civil & Wood Engineering, HSB University of Applied Sciences, Biel-Bienne, Switzerland

Most adhesives used for the production of wood-based panels are based on the use of formaldehyde as a cross-linking agent. Due to the recent reclassification of formaldehyde as “carcinogenic to humans,” the already existing market demand for products with low or no formaldehyde emissions has increased. Urea-formaldehyde (UF) resins, the most widely employed adhesives for wood products in the range of formaldehyde-based wood adhesives, and polymeric diphenylmethane diisocyanates (pMDI), are commonly used thermosetting adhesives in the wood panels industry. Combinations of these two adhesives are of interest in order to benefit from their positive attributes while compensating for some of the negative ones, and also considering the market demand for low formaldehyde wood-based composites. Although combination systems have been reportedly used in some industrial cases, a fundamental understanding is still lacking and further research work has to be done to understand better the behavior and performance of such hybrids. This research work serves that purpose and deals with the investigation of some of the important characteristics of hybrid systems and their influence on final panel properties. Mixed resins containing different proportions of UF resin and pMDI, were investigated with standard characterization tests such as determination of gel time. The gel times obtained for all glue mixes were sufficiently short to be of industrial significance. The gelled/hardened resins obtained by the gel tests were ground for Solid-State ^{13}C Nuclear Magnetic Resonance (NMR) Spectroscopy. The CP MAS ^{13}C NMR spectra of the hardened resins showed that urethane bridges derived by the reaction of the isocyanate group with the hydroxymethyl group of urea do form, even at fast curing times, comparable to adhesives commonly used in the wood-based panels industry, but they appear to form in lower portions than what has already been shown to occur at much longer curing times. The same proportions of glue mixes were used to produce thin high-density fiber boards. The panel properties were investigated by measuring the density profile and determining internal bond strength. Using the same resin load, the internal bond increased with higher proportions of pMDI in the glue mix. After testing the panels were ground for NMR analysis. The direct NMR tests on hardboards bonded under fast pressing conditions confirmed that cross-linking due to polyureas and biurets formation are predominant in the cross-linking of pMDI when alone and in UF/pMDI resin systems. The results confirmed that residual, unreacted isocyanate groups are present in the finished panel. Their proportion increased as the proportion of pMDI in the system increased. The presence or absence of urethanes could not be confirmed since the relevant peaks were masked by the wood carbohydrate signal of wood cellulose and hemicelluloses. An investigation of density profiles showed that the core density of the panels decreased up to a blend of 50/50 UF/pMDI blend, and then increased. The shape of the density profile changed with an increasing proportion of pMDI in the system, and started to reach its target density profile as defined in the press program when using the 25/75 UF/pMDI blend. More detailed studies were performed by different microscopic methods to allow a correlation of the colloidal appearance of the UF/pMDI blends with the panel properties, but further investigations have to be done in order to interpret the results. This research on fundamental information regarding the behavior and the influence on the panel properties of UF/pMDI hybrid adhesives suggests that it may be possible to improve the potential use of UF/pMDI blends for wood-based panels.

POSTER 25

On the Durability of the University of California Forest Products Laboratory Nonconventional Bonding System - Properties of 26-Year-Old Flakeboards

George A. Grozdits, Research Associate, and *Mark D. Gibson*, Professor and Associate Director, School of Forestry, Louisiana Tech University, Ruston, Louisiana, USA

The patented “non-conventional bonding” - NCB system developed at the University of California Forest Products Laboratory was based on surface activation of wood flakes and spray addition of a cross-linking agent. The surface activation was done by concentrated HNO_3 spray and the cross-linking agent (CLA) was ammonium lignosulfonate: furfuryl alcohol: maleic anhydride at a 4.2 : 1.8 : 1.0 wt. ratio. The inception of this surface activation bonding system was in the late 1970's and the system was patented. The late 1970's coincided with the 1973 and 1978 phenol shortages (crude oil shortages). An alternate or possible replacement of the traditional exterior phenol-formaldehyde wood bonding system was a concern for the forest products industry. The importance of the exterior wood panel bonding system was further enhanced by the fact that the wafer-, flake- and oriented strandboard industries were emerging in the late 1970's. At the University of California Forest Products Laboratory, the UC-NCB project was sponsored by an industry consortium. Most major wood panel producers and chemical suppliers participated over a decade-long project. The project reached plant trial stage, and in 1979, during the first plant trials, 27' 4' x 4' and 4' x 8' panels were produced. These panels were tested at industry specifications and met industry standards. However, there were two concerns: 1) The application of HNO_3 spray for flake activation that would have required stainless steel spray-blender equipment and surface-activated flake holding tanks; and 2) The continued oxidation of wood due to HNO_3 activation. This poster reports on the actual aging of the NCB-bonded flakeboards. The properties of the original 4' x 8' flake boards from the first pilot plant trials were compared to those of boards aged for 26 years. The average original MOR and MOE for flake boards were 1,796 psi and 462,000 psi, respectively. The aged samples from the same boards after 26 years had an average MOR of 1,211 psi and MOE of 641,000 psi. The MOR retention was 69% and the MOE increased by 25%. Other board parameters, such as changes in board thickness and internal board strength, were also measured. The concentrated HNO_3 acid activated and lignin-based, cross-linking-agent-bonded boards after aging for 26 years in humid and hot southern environmental conditions did not deteriorate as was predicted by the 2 hour boil-wet test, which predicted a 66% wet strength loss (34% strength retention) in 1979. The wood's extremely high buffering capacity arrested the HNO_3 oxidations and the NCB bonded panels would have performed without detrimental early aging. However, the use of stainless steel equipment still remains a question, but after 20 plus years, stainless steel equipment is preferred due to reduced wear and corrosion resistance, and its cost is not really prohibitive.

POSTER 26

Evaluation of Adhesive Cure Kinetics by Dielectric Analysis

Milan Sernek, Assistant Professor, Department of Wood Science & Technology, University of Ljubljana, Ljubljana, Slovenia; *Fred A. Kamke*, JELD-WEN Professor of Wood-Based Composite Science, Department of Wood Science & Engineering, Oregon State University, Corvallis, Oregon, USA; and *Matej Jost*, Graduate Student, and *Mirko Kariz*, Undergraduate Student, Department of Wood Science & Technology, University of Ljubljana, Ljubljana, Slovenia

Monitoring the rate and extent of adhesive cure during hot-pressing of wood-based composites would be useful information for selecting the appropriate processing conditions and adhesive formulation. A continuous *in situ* technique is desirable, in contrast to off-line batch analysis of cure under idealized laboratory conditions (e.g. DSC, DMA, DMTA, NMR, etc.). A promising continuous *in situ* technique for in-process measurements is dielectric analysis (DEA). A remote probe configuration permits DEA measurement of changes in the dielectric properties of an adhesive during cure of a composite in a hot-press. The changes in dielectric properties relate to the changes in viscosity and polymer mobility of the adhesive. Experiments may be conducted at several press temperatures and press times. An empirical equation describing the cure kinetics is derived from DEA measurements. The objective of this presentation is to demonstrate utilization of DEA for characterization of the cure process of different thermosetting adhesives, and to determine the parameters for the Arrhenius type of a cure

equation with respect to the adhesive. The relationship among the degree of cure, press temperature, and press time for the each of the studied adhesives can be further used for modeling and simulation of wood-based composite manufacturing.

POSTER 27

Effects of Swelling Forces on the Durability of Wood Adhesive Bonds

Robert J. Moon, Materials Research Engineer, *Rishawn L. Brandon*, Chemical Engineer, and *Charles R. Frihart*, Project Leader, Wood Adhesives Science & Technology, USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin, USA; and *Blake M. Hofferber*, Graduate Student, and *Edward Kolodka*, Assistant Professor, Department of Chemical Engineering, University of North Dakota, Grand Forks, North Dakota, USA

Wood is a hygroscopic material, and the moisture content (MC) of wood can change considerably with fluctuations in relative humidity and temperature. These variations in MC result in appreciable dimensional changes, adding to the complexity of producing durable bonds to wood substrates. The anisotropic nature of the wood structure results in non-symmetric mechanical property and swelling/shrinking behavior in the three distinctive directions: longitudinal, radial, and tangential. Wood-adhesive bonds can be adversely affected by the strain differential between the adhesive, adherent, and interphase region, which produce stress distributions that act along the bondline region. These stress distributions, combined with localized stress concentration, may modify the long-term mechanical and fracture properties of the bondline region. Chemical modifications to wood can increase the dimensional stability of wood exposed to moisture, which may reduce the stress distributions along the bondline regions, and result in stronger more durable bonds. The results from an on-going study investigating the effects of chemical modification (by either bulk acetic anhydride treatment or hydroxymethyl resorcinol primer) on the anisotropic swelling strains of yellow-poplar, and its effect on the resulting bondline stress and fracture properties of epoxy adhesives will be discussed. Swelling in the three distinct directions were measured using strain gauges mounted on the sample surface. The effect of swelling on the bondline stresses were estimated by using pressure sensitive films and the fracture properties were studied using compression shear tests. The chemical modification of wood was found to modify the swelling behavior, the bondline stress, and the fracture properties. The contribution of the wood swelling on the resulting fracture properties will be discussed.

POSTER 28

Strandboard Made from Soy-Based Adhesive with High Soy Content

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A novel green adhesive with high soy content has been recently developed (Wescott and Frihart 2004). The new resin system is based on a three-step process that includes denaturation of soy flour, modification of resulting protein with formaldehyde, and co-polymerization with suitable phenolic cross-linking agents. Comparing with certain mechanical and physical performances of commercial oriented strand board (OSB), the new soy-based resin system showed a promising future in improving the panel performances and lowering the costs. As an initial study in a series of the extensive investigations, four variables (face resin content, face furnish moisture content (MC), density of the panels, and press time) were selected to explore their effects on the panel performances with this new soy-based resin system and to identify possible interactions with each other. The results indicated that increasing the face resin content and the density would improve the mechanical bending performance. This soy-based PF also somewhat reduced the thickness swelling and water soak absorption. Face furnish MC had no effect on tested properties, but it significantly enhanced heat transfer (i.e., core temperature and internal steam pressure) during the press process. Under a press temperature of 215°C, a closed press time of 150 seconds was not sufficient to fully cure the new soy-PF face resin and further investigation is recommended to optimize the press process (press time and face furnish MC) and to optimize resin performance.



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